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Project Oberon

The Design of an
Operating System
and Compiler

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Preface

This book presents the results of Project Oberon, namely an entire software environment for a modern workstation. The project was undertaken by the authors in the years 1986-89, and its primary goal was to design and implement an entire system from scratch, and to structure it in such a way that it can be described, explained, and understood as a whole. In order to become confronted with all aspects, problems, design decisions and details, the authors not only conceived but also programmed the entire system described in this book, and more.

Although there exist numerous books explaining principles and structures of operating systems, there is a lack of descriptions of systems actually implemented and used. We wished not only to give advice on how a system might be built, but to demonstrate how one was built. Program listings therefore play a key role in this text, because they alone contain the ultimate explanations. The choice of a suitable formalism therefore assumed great importance, and we designed the language Oberon as not only an effective vehicle for implementation, but also as a publication medium for algorithms in the spirit in which Algol 60 had been created three decades ago. Because of its structure, the language Oberon is equally well suited to exhibit global, modular structures of programmed systems.

In spite of the small number of man-years spent on realizing the Oberon System, and in spite of its compactness letting its description fit a single book, it is not an academic toy, but rather a versatile workstation system that has found many satisfied and even enthusiastic users in academia and industry. The core system described here, consisting of storage, file, display, text, and viewer managers, of program loader and device drivers, draws its major power from a suitably chosen, flexible set of basic facilities and, most importantly, of their effective extensibility in many directions and for many applications. The extensibility is particularly enhanced by the language Oberon on the one, and by the efficiency of the basic core on the other hand. It is rooted in the application of the object-oriented paradigm which is employed wherever extensibility appears advantageous.

In addition to the core system, we describe in full detail the compiler for the language Oberon and a graphics system, which both may be regarded as applications. The former reveals how a compact compiler is designed to achieve both fast compilation and efficient, dense code. The latter stands as an example of extensible design based on object-oriented techniques, and it shows how a proper integration with an existing text system is possible. Another addition to the core system is a network module allowing many workstations to be interconnected. We also show how the Oberon System serves conveniently as the basis for a multi-server station, accommodating a file distribution, a printing, and an electronic-mail facility.

Compactness and regular structure, and due attention to efficient implementation of important details appear to be the key to economical software engineering. With the Oberon System, we wish to refute Reiser's Law, which has been confirmed by virtually all recent releases of operating systems: In spite of great leaps forward, hardware is becoming faster more slowly than software is becoming slower. The Oberon System has required a tiny fraction of the manpower demanded for the construction of widely-used commercial operating systems, and a small fraction of their demands on computing power and storage capacity, while providing equal power and flexibility to the user, albeit without certain bells and whistles. The reader is invited to study how this was possible.

But most importantly, we hope to present a worth-while case study of a substantial piece of programming in the large for the benefit of all those who are eager to learn from the experiences of others.

We wish to thank the many anonymous contributors of suggestions, advice, and encouragement. In particular we wish to thank our colleagues H. Mössenböck and B. Sanders and our associates at the Institut für Computersysteme for reading all or parts of the draft of this book. We are grateful to M. Brandis, R. Crelier, A. Disteli, M. Franz, and J. Templ for their work in porting the Oberon System successfully to various commercially available computers, and thus making the study of this book more

worth-while for many readers. And we gratefully acknowledge the contribution of our school, ETH, for providing the environment and support which made it possible for us to pursue and complete this project.

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N.W. and J.G.

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N. Wirth and J. Gutknecht

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1. Historical Background and Motivation

How could anyone diligently concentrate on his work on an afternoon with such warmth, splendid sunshine, and blue sky. This rhetorical question I asked many times while spending a sabbatical leave in California in 1985. Back home everyone would feel compelled to profit from the sunny spells to enjoy life at leisure in the country-side, wandering or engaging in one's favourite sport. But here, every day was like that, and giving in to such temptations would have meant the end of all work. And, had I not chosen this location in the world because of its inviting, enjoyable climate?

Fortunately, my work was also enticing, making it easier to buckle down. I had the privilege of sitting in front of the most advanced and powerful workstation anywhere, learning the secrets of perhaps the newest fad in our fast developing trade, pushing colored rectangles from one place of the screen to another. This all had to happen under strict observance of rules imposed by physical laws and by the newest technology. Fortunately, the advanced computer would complain immediately if such a rule was violated, it was a rule checker and acted like your big brother, preventing you from making steps towards disaster. And it did what would have been impossible for oneself, keeping track of thousands of constraints among the thousands of rectangles laid out. This was called computer-aided design. "Aided" is rather a euphemism, but the computer did not complain about the degradation of its role.

While my eyes were glued to the colorful display, and while I was confronted with the evidence of my latest inadequacy, in through the always open door stepped my colleague. He also happened to spend a leave from duties at home at the same laboratory, yet his face did not exactly express happiness, but rather frustration. The chocolate bar in his hand did for him what the coffee cup or the pipe does for others, providing temporary relaxation and distraction. It was not the first time he appeared in this mood, and without words I guessed its cause. And the episode would reoccur many times.

His days were not filled with the great fun of rectangle-pushing; he had an assignment. He was charged with the design of a compiler for the same advanced computer. Therefore, he was forced to deal much more closely, if not intimately, with the underlying software system. Its rather frequent failures had to be understood in his case, for he was programming, whereas I was only using it through an application; in short, I was an end-user! These failures had to be understood not for purposes of correction, but in order to find ways to avoid them. How was the necessary insight to be obtained? I realized at this moment that I had so far avoided this question; I had limited familiarization with this novel system to the bare necessities which sufficed for the task on my mind.

It soon became clear that a study of the system was nearly impossible. Its dimensions were simply awesome, and documentation accordingly sparse. Answers to questions that were momentarily pressing could best be obtained by interviewing the system's designers, who all were in-house. In doing so, we made the shocking discovery that often we could not understand their language. Explanations were fraught with jargon and references to other parts of the system which had remained equally enigmatic to us.

So, our frustration-triggered breaks from compiler construction and chip design became devoted to attempts to identify the essence, the foundations of the system's novel aspects. What made it different from conventional operating systems? Which of these concepts were essential, which ones could be improved, simplified, or even discarded? And where were they rooted? Could the system's essence be distilled and extracted, like in a chemical process?

During the ensuing discussions, the idea emerged slowly to undertake our own design. And suddenly it had become concrete. "Crazy" was my first reaction, and "impossible". The sheer amount of work appeared as overwhelming. After all, we both had to carry our share of teaching duties back home. But the thought was implanted and continued to occupy our minds.

Sometime thereafter, events back home suggested that I should take over the important course about System Software. As it was the unwritten rule that it should primarily deal with operating system principles, I hesitated. My scruples were easily justified: After all I had never designed such a system nor a part of it. And how can one teach an engineering subject without first-hand experience!

Impossible? Had we not designed compilers, operating systems, and document editors in small teams? And had I not repeatedly experienced that an inadequate and frustrating program could be programmed from scratch in a fraction of source code used by the original design? Our brain-storming continued, with many intermissions, over several weeks, and certain shapes of a system structure slowly emerged through the haze. After some time, the preposterous decision was made: we would embark on the design of an operating system for our workstation (which happened to be much less powerful than the one used for my rectangle-pushing) from scratch.

The primary goal, to personally obtain first-hand experience, and to reach full understanding of every detail, inherently determined our manpower: two part-time programmers. We tentatively set our time-limit for completion to three years. As it later turned out, this had been a good estimate; programming was begun in early 1986, and a first version of the system was released in the fall of 1988.

Although the search for an appropriate name for a project is usually a minor problem and often left to chance and whim of the designers, this may be the place to recount how Oberon entered the picture in our case. It happened that around the time of the beginning of our effort, the space probe Voyager made headlines with a series of spectacular pictures taken of the planet Uranus and of its moons, the largest of which is named Oberon. Since its launch I had considered the Voyager project as a singularly well-planned and successful endeavor, and as a small tribute to it I picked the name of its latest object of investigation. There are indeed very few engineering projects whose products perform way beyond expectations and beyond their anticipated lifetime; mostly they fail much earlier, particularly in the domain of software. And, last but not least, we recall that Oberon is famous as the king of elfs.

The consciously planned shortage of manpower enforced a single, but healthy guideline: Concentrate on essential functions and omit embellishments that merely cater to established conventions and passing tastes. Of course, the essential core had first to be recognized and crystallized. But the basis had been laid. The ground rule became even more crucial, when we decided that the result should be able to be used as teaching material. I remembered C.A.R. Hoare's plea that books should be written presenting actually operational systems rather than half-baked, abstract principles. He had complained in the early 70s that in our field engineers were told to constantly create new artifacts without being given the chance to study previous works that had proven their worth in the field. How right was he, even to the present day!

The emerging goal to publish the result with all its details let the choice of programming language appear in a new light: it became crucial. Modula-2 which we had planned to use, appeared as not quite satisfactory. Firstly, because it lacked a facility to express extensibility in an adequate way. And we had put extensibility among the principal properties of the new system. By "adequate" we include machine-independence. Our programs should be expressed in a manner that makes no reference to machine peculiarities and low-level programming facilities, perhaps with the exception of device interfaces, where dependence is inherent.

Hence, Modula-2 was extended with a feature that is now known as type extension. We also recognized that Modula-2 contained several facilities that we would not need, that do not genuinely contribute to its power of expression, but at the same time increase the complexity of the compiler. But the compiler would not only have to be implemented, but also to be described, studied, and understood. This led to the decision to start from a clean slate also in the domain of language design, and to apply the same principle to it: concentrate on the essential, purge the rest. The new language, which still bears much resemblance to Modula-2, was given the same name as the system: Oberon [1, 2]. In contrast to its ancestor it is terser and, above all, a significant step towards expressing programs on a high level of abstraction without reference to machine-specific features.

We started designing the system in late fall 1985, and programming in early 1986. As a vehicle we used our workstation Lilith and its language Modula-2. First, a cross-compiler was developed, then followed the modules of the inner core together with the necessary testing and down-loading facilities. The development of the display and the text system proceeded simultaneously, without the possibility of testing, of course. We learned how the absence of a debugger, and even more so the absence of a compiler, can contribute to careful programming.

Thereafter followed the translation of the compiler into Oberon. This was swiftly done, because the original had been written with anticipation of the later translation. After its availability on the target computer Ceres, together with the operability of the text editing facility, the umbilical cord to Lilith could be cut off. The Oberon System had become real, at least its draft version. This happened around mid 1987; its description was published thereafter [3].

The system's completion took another year and concentrated on connecting the workstations in a network for file transfer [4], on a central printing facility, and on maintenance tools. The goal of completing the system within three years had been met. The system was introduced in mid 1988 to a wider user community, and work on applications could start. A service for electronic mail was developed, a graphics system was added, and various efforts for general document preparation systems proceeded. The display facility was extended to accommodate two screens, including color. At the same time, feedback from experience in its use was incorporated by improving existing parts. Since 1989, Oberon has replaced Modula-2 in our introductory programming courses.

At this point, a word about the underlying hardware is perhaps in order. The Ceres workstation had also been developed at the Institute for Computer Systems of ETH, and it provided an ideal platform for implanting the Oberon System on a bare machine. It offered the immensely valuable opportunity to design without regard to established constraints and to avoid compromises enforced by an incompatible environment.

Ceres-1 was built around a National Semiconductor 32032 microprocessor, which was in 1985 the first commercially available processor using a 32 bit wide bus. It appeared as particularly attractive to the compiler builder because of its regular instruction set. The computer was equipped with 2 MBytes of main memory, a 40 MByte disk, a diskette, a 1024*800 pixel display, and of course with keyboard and mouse. These resources were more than adequate for the Oberon System.

Ceres-2 was introduced in 1988 and replaced the processor by its faster version, the NS 32532, which increased its computing power by a factor of at least 5 over its predecessor. Memory was extended to 4 - 8 MByte and the disk to 80 MByte. In order to install the software, "only" a few modules had to be adapted, the kernel because of different page structure, and device drivers because of different device addresses.

In 1990, a low-cost version, Ceres-3 was designed, and 100 computers were built and installed in laboratories. This single-board computer is based on the NS 32GX32 processor without virtual addressing unit, and includes a 4-8 MByte memory. The distinctive feature is that the file system is implemented in one (protected) half of memory instead of a disk, increasing operating speed dramatically. Ceres-3 is free from mechanically moving parts (no fan) and therefore is completely noiseless. It is primarily used in laboratories for students. The usefulness of a central server for system file distribution is evident.

Because of its success and flexibility in use, a project was started in 1989 to transport the System to a number of commercially available workstations. The plan to install it on bare machines, like on Ceres, was quickly discarded; nobody would even give it a try, if one had to buy another computer or even only to exchange ROMs in order to experiment with Oberon. The drawback of building on top of an existing system had to be accepted; it implies the cost of some rarely used software occupying part of memory, sometimes even occupying a sizeable part. At the time of this writing, implementations exist on Apple's Macintosh II, Sun Microsystem's Sparc Station, DEC's DECStation 3100 and 5000, and IBM's RS/6000. These implementations each took about half a man-year of effort. The solution to build on top of an existing system carries the invaluable advantage that applications designed under the base system are accessible from Oberon. All these systems comply with their published description in a user manual [Reiser, 1991], all have exactly the same user interface, and every program operating on one of these computers can be executed on any of the others without change. Evidently, this is an important advantage that can only be gained by programming at a higher level of abstraction, such as in the language Oberon.

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2. Basic Concepts and Structure of the System

2.1 Introduction

In order to warrant the sizeable effort of designing and constructing an entire operating system from scratch, a number of basic concepts need to be novel. We start this chapter with a discussion of the principal concepts underlying the Oberon System and of the dominant design decisions. On this basis, a presentation of the system's structure follows. It will be restricted to its coarsest level, namely the composition and interdependence of the largest building blocks, the modules. The chapter ends with an overview of the remainder of the book. It should help the reader to understand the role, place, and significance of the parts described in the individual chapters.

The fundamental objective of an operating system is to present the computer to the user and to the programmer at a certain level of abstraction. For example, the store is presented in terms of requestable pieces or variables of a specified data type, the disk is presented in terms of sequences of characters (or bytes) called files, the display is presented as rectangular areas called viewers, the keyboard is presented as an input stream of characters, and the mouse appears as a pair of coordinates and a set of key states. Every abstraction is characterized by certain properties and governed by a set of operations. It is the task of the system to implement these operations and to manage them, constrained by the available resources of the underlying computer. This is commonly called resource management.

Every abstraction inherently hides details, namely those from which it abstracts. Hiding may occur at different levels. For example, the computer may allow certain parts of the store, or certain devices to be made inaccessible according to its mode of operation (user/supervisor mode), or the programming language may make certain parts inaccessible through a hiding facility inherent in its visibility rules. The latter is of course much more flexible and powerful, and the former indeed plays an almost negligible role in our system. Hiding is important because it allows maintenance of certain properties (called invariants) of an abstraction to be guaranteed. Abstraction is indeed the key of any modularization, and without modularization every hope of being able to guarantee reliability and correctness vanishes. Clearly, the Oberon System was designed with the goal of establishing a modular structure on the basis of purpose-oriented abstractions. The availability of an appropriate programming language is an indispensible prerequisite, and the importance of its choice cannot be over-emphasized.

2.2. Concepts

2.2.1. Viewers

Whereas the abstractions of individual variables representing parts of the primary store, and of files representing parts of the disk store are well established notions and have significance in every computer system, abstractions regarding input and output devices became important with the advent of high interactivity between user and computer. High interactivity requires high bandwidth, and the only channel of human users with high bandwidth is the eye. Consequently, the computer's visual output unit must be properly matched with the human eye. This occurred with the advent of the high-resolution display in the mid 1970s, which in turn had become feasible due to faster and cheaper electronic memory components. The high-resolution display marked one of the few very significant break-throughs in the history of computer development. The typical bandwidth of a modern display is in the order of 100 MHz. Primarily the high-resolution display made visual output a subject of abstraction and resource management. In the Oberon System, the display is partitioned into viewers, also called windows, or more precisely, into frames, rectangular areas of the screen(s). A viewer typically consists of two frames, a title bar containing a subject name and a menu of commands, and a main frame containing some text, graphic, picture, or other object. A viewer itself is a frame; frames can be nested, in principle to any depth.

The System provides routines for generating a frame (viewer), for moving and for closing it. It allocates a new viewer at a specified place, and upon request delivers hints as to where it might best be placed. It keeps track of the set of opened viewers. This is what is called viewer management, in contrast to the handling of their displayed contents.

But high interactivity requires not only a high bandwidth for visual output, it demands also flexibility of input. Surely, there is no need for an equally large bandwidth, but a keyboard limited by the speed of typing to about 100 Hz is not good enough. The break-through on this front was achieved by the so-called mouse, a pointing device which appeared roughly at the same time as the high-resolution display.

This was by no means just a lucky coincidence. The mouse comes to fruition only through appropriate software and the high-resolution display. It is itself a conceptually very simple device delivering signals when moved on the table. These signals allow the computer to update the position of a mark - the cursor - on the display. Since feedback occurs through the human eye, no great precision is required from the mouse. For example, when the user wishes to identify a certain object on the screen, such as a letter, he moves the mouse as long as required until the mapped cursor reaches the object. This stands in marked contrast to a digitizer which is supposed to deliver exact coordinates. The Oberon System relies very much on the availability of a mouse.

Perhaps the cleverest idea was to equip mice with buttons. By being able to signal a request with the same hand that determines the cursor position, the user obtains the direct impression of issuing position-dependent requests. Position-dependence is realized in software by delegating interpretation of the signal to a procedure - a so-called handler or interpreter -which is local to the viewer in whose area the cursor momentarily appears. A surprising flexibility of command activation can be achieved in this manner by appropriate software. Various techniques have emerged in this connection, e.g. pop-up menus, pull-down-menus, etc. which are powerful even under the presence of a single button only. For many applications, a mouse with several keys is far superior, and the Oberon System basically assumes three buttons to be available. The assignment of different functions to the keys may of course easily lead to confusion when every application prescribes different key assignment. This is, however, easily avoided by the adherence to certain "global" conventions. In the Oberon System, the left button is primarily used for marking a position (setting a caret), the middle button for issuing general commands (see below), and the right button for selecting displayed objects.

Recently, it has become fashionable to use overlapping windows mirroring documents being piled up on one's desk. We have found this metaphor not entirely convincing. Partially hidden windows are typically brought to the top and made fully visible before any operation is appiled to their contents. In contrast to the insignificant advantage stands the substantial effort necessary to implement this scheme. It is a good example of a case where the benefit of a complication is incommensurate with its cost. Therefore, we have chosen a solution that is much simpler to realize, yet has no genuine disadvantages compared to overlapping windows: tiled viewers as shown in Fig. 2.1.

Fig. 2.1. Oberon Display with tiled Viewers

2.2.2. Commands

Position-dependent commands with fixed meaning (fixed for each type of viewer) must be supplemented by general commands. Conventionally, such commands are issued through the keyboard by typing the program's name that is to be executed into a special command text. In this respect, the Oberon System offers a novel and much more flexible solution which is presented in the following paragraphs.

First of all we remark that a program in the common sense of a text compiled as a unit is mostly a far too large unit of action to serve as a command. Compare it, for example, with the insertion of a piece of text through a mouse command. In Oberon, the notion of a unit of action is separated from the notion of unit of compilation. The former is a command represented by a (exported) procedure, the latter is a module. Hence, a module may, and typically does, define several, even many commands. Such a (general) command may be invoked at any time by pointing at its name in any text visible in any viewer on the display, and by clicking the middle mouse button. The command name has the form M.P, where P is the procedure's identifier and M that of the module in which P is declared. As a consequence, any command click may cause the loading of one or several modules, if M is not already present in main store. The next invocation of M.P occurs instataneously, since M is already loaded. A further consequence is that modules are never (automatically) removed, because a next command may well refer to the same module.

Every command has the purpose to alter the state of some operands. Typically, they are denoted by text following the command identification, and Oberon follows this convention. Strictly speaking, commands are denoted as parameterless procedures; but the system provides a way for the procedure to identify the text position of its origin, and hence to read and interpret the text following the command, i.e. the actual parameters. Both reading and interpretation must, however, be programmed explicitly.

The parameter text must refer to objects that exist before command execution starts and are quite likely the result of a previous command interpretation. In most operating systems, these objects are files registered in the directory, and they act as interfaces between commands. The Oberon System broadens this notion; the links between consecutive commands are not restricted to files, but can be any global variable, because modules do not disappear from storage after command termination, as mentioned above.

This tremendous flexibility seems to open Pandora's box, and indeed it does when misused. The reason is that global variables' states may completely determine and alter the effect of a command. The variables represent hidden states, hidden in the sense that the user is in general unaware of them and has no easy way to determine their value. The positive aspect of using global variables as interfaces between commands is that some of them may well be visible on the display. All viewers - and with them also their contents - are organized in a data structure that is rooted in a global variable (in module Viewers). Parts of this variable therefore constitute visible states, and it is highly appropriate to refer to them as command parameters.

One of the rules of what may be called the Oberon Programming Style is therefore to avoid hidden states, and to reduce the introduction of global variables. We do not, however, raise this rule to the rank of a dogma. There exist genuinely useful exceptions, even if the variables have no visible parts.

There remains the question of how to denote visible objects as command parameters. An obvious case is the use of the most recent selection as parameter. A procedure for locating that selection is provided by module Oberon. (It is restricted to text selections). Another possibility is the use of the caret position in a text. This is used in the case of inserting new text; the pressing of a key on the keyboard is also considered to be a command, and it causes the character's insertion at the caret position.

A special facility is introduced for designating viewers as operands: the star marker. It is placed at the cursor position when the keyboard's mark key (SETUP) is pressed. The procedure Oberon.MarkedViewer identifies the viewer in whose area the star lies. Commands which take it as their parameter are typically followed by an asterisk in the text. Whether the text contained in a text viewer, or a graph contained in a graphic viewer, or any other part of the marked viewer is taken as the actual parameter depends on how the command procedure is programmed.

Finally, a most welcome property of the system should not remain unmentioned. It is a direct consequence of the persistent nature of global variables and becomes manifest when a command fails. Detected failures result in a trap. Such a trap should be regarded as an abnormal command termination. In the worst case, global data may be left in an inconsistent state, but they are not lost, and a next command can be initiated based on their current state. A trap opens a small viewer and lists the sequence of invoked procedures with their local variables and current values. This information helps a programmer to identify the cause of the trap.

2.2.3. Tasks

From the presentations above it follows that the Oberon System is distinguished by a highly flexible scheme of command activation. The notion of a command extends from the insertion of a single character and the setting of a marker to computations that may take hours or days. It is moreover distinguished by a highly flexible notion of operand selection not restricted to registered, named files. And most importantly, by the virtual absence of hidden states. The state of the system is practically determined by what is visible to the user.

This makes it unnecessary to remember a long history of previously activated commands, started programs, entered modes, etc. Modes are in our view the hallmark of user-unfriendly systems. It should at this point have become obvious that the system allows a user to pursue several different tasks concurrently. They are manifest in the form of viewers containing texts, graphics, or other displayable objects. The user switches between tasks implicitly when choosing a different viewer as operand for the next command. The characteristic of this concept is that task switching is under explicit control of the user, and the atomic units of action are the commands.

At the same time, we classify Oberon as a single-process (or single-thread) system. How is this apparent paradox to be understood? Perhaps it is best explained by considering the basic mode of operation. Unless engaged in the interpretation of a command, the processor is engaged in a loop continuously polling event sources. This loop is called the central loop; it is contained in module Oberon which may be regarded as the system's heart. The two fixed event sources are the mouse and the keyboard. If a keyboard event is sensed, control is dispatched to the handler installed in the so-called focus viewer, designated as the one holding the caret. If a mouse event (key) is sensed, control is dispatched to the handler in which the cursor currently lies. This is all possible under the paradigm of a single, uninterruptible process.

The notion of a single process implies non-interruptability, and therefore also that commands cannot interact with the user. Interaction is confined to the selection of commands before their execution. Hence, there exists no input statement in typical Oberon programs. Inputs are given by parameters supplied and designated before command invocation.

This scheme at first appears as gravely restrictive. In practice it is not, if one considers single-user operation. It is this single user who carries out a dialog with the computer. A human might be capable of engaging in simultaneous dialogs with several processes only if the commands issued are very time-consuming. We suggest that execution of time-consuming computations might better be delegated to loosely coupled compute-servers in a distributed system.

The primary advantage of a system dealing with a single process is that task switches occur at user-defined points only, where no local process state has to be preserved until resumption. Furthermore, because the switches are user-chosen, the tasks cannot interfere in unexpected and uncontrollable ways by accessing common variables. The system designer can therefore omit all kinds of protection mechanisms that exclude such interference. This is a significant simplification.

The essential difference between Oberon and multiprocess-systems is that in the former task switches occur between commands only, whereas in the latter a switch may be invoked after any single instruction. Evidently, the difference is one of granularity of action. Oberon's granularity is coarse, which is entirely acceptable for a single-user system.

The system offers the possibility to insert further polling commands in the central loop. This is necessary if additional event sources are to be introduced. The prominent example is a network, where commands may be sent from other workstations. The central loop scans a list of so-called task descriptors. Each descriptor refers to a command procedure. The two standard events are selected only if their guard permits, i.e. if either keyboard input is present, or if a mouse event occurs. Inserted tasks must provide their own guard in the beginning of the installed procedure.

The example of a network inserting commands, called requests, raises a question: what happens if the processor is engaged in the execution of another command when the request arrives? Evidently, the request would be lost unless measures are taken. The problem is easily remedied by buffering the input. This is done in every driver of an input device, in the keyboard driver as well as the network driver. The incoming signal triggers an interrupt, and the invoked interrupt handler accepts the input and buffers it. We emphasize that such interrupt handling is confined to drivers, system components at the lowest level. An interrupt does not evoke a task selection and a task switch. Control simply returns to the point of interruption, and the interrupt remains unnoticeable to programs. There exists, as with every rule, an exception: an interrupt due to keyboard input of the abort character returns control to the central loop.

2.2.4. Tool Texts as Configurable Menus

Certainly, the concepts of viewers specifying their own interpretation of mouse clicks, of commands invokable from any text on the display, of any displayed object being selectable as an interface between commands, and of commands being dialog-free, uninterruptible units of action, have considerable influence on the style of programming in Oberon, and they thoroughly change the style of using the computer. The ease and flexibility in the way pieces of text can be selected, moved, copied, and designated as command and as command parameters, drastically reduces the need for typing. The mouse becomes the dominant input device: the keyboard merely serves to input textual data. This is accentuated by the use of so-called tool texts, compositions of frequently used commands, which are typically displayed in the narrower system track of viewers. One simply doesn't type commands! They are usually visible somewhere already. Typically, the user composes a tool text for every project pursued. Tool texts can be regarded as individually configurable private menus.

The rarity of issuing commands by typing them has the most agreeable benefit that their names can be meaningful words. For example, the copy operation is denoted by Copy instead of cp, rename by Rename instead of rn, the call for a file directory excerpt is named Directory instead of ls. The need for memorizing an infinite list of cryptic abbreviations, which is another hallmark of user-unfriendly systems, vanishes.

But the influence of the Oberon concept is not restricted to the style in which the computer is used. It extends also to the way programs are designed to communicate with the environment. The definition of the abstract type Text in the system's core suggests the replacement of files by texts as carrier of input and output data in very many cases. The advantage to be gained lies in the text's immediate editability. For example, the output of the command System.Directory produces the desired excerpt of the file directory in the form of a (displayed) text. Parts of it or the whole may be selected and copied into other texts by regular editing commands (mouse clicks). Or, the compiler accepts texts as input. It is therefore possible to compile a text, execute the program, and to recompile the re-edited text without storing it on disk between compilations and tests. The ubiquiteous editability of text together with the persistence of global data (in particular viewers) allows many steps that do not contribute to the progress of the task actually pursued to be avoided.

2.2.5. Extensibility

An important objective in the design of the Oberon System was extensibility. It should be easy to extend the system with new facilities by adding modules that make use of the already existing resources. Equally important, it should also reduce the system to those facilities that are currently and actually used. For example, a document editor processing documents free of graphics should not require the loading of an extensive graphics editor, a workstation operating as a stand-alone system should not require the loading of extensive network software, and a system used for clerical purposes need include neither compiler nor assembler. Also, a system introducing a new kind of display frame should not include procedures for managing viewers containing such frames. Instead, it should make use of existing viewer management. The staggering consumption of memory space by many widely used systems is due to violation of such fundamental rules of engineering. The requirement of many megabytes of store for an operating system is, albeit commonly tolerated, absurd and another hallmark of user-unfriedliness, or perhaps manufacturer friendliness. Its reason is none other than inadequate extensibility.

We do not restrict this notion to procedural extensibility, which is easy to realize. The important point is that extensions may not only add further procedures and functions, but introduce their own data types built on the basis of those provided by the system: data extensibility. For example, a graphics system should be able to define its graphics frames based on frames provided by the basic display module and by extending them with attributes appropriate for graphics.

This requires an adequate language feature. The language Oberon provides precisely this facility in the form of type extensions. The language was designed for this reason; Modula-2 would have been the choice, had it not been for the lack of a type extension feature. Its influence on system structure was profound, and the results have been most encouraging. In the meantime, many additions have been created with surprising ease. One of them is described at the end of this book. The basic system is nevertheless quite modest in its resource requirements (see Table at the end of Section 2.3).

2.2.6. Dynamic Loading

Activation of commands residing in modules that are not present in the store implies the loading of the modules and, of course, all their imports. Invoking the loader is, however, not restricted to command activation; it may also occur through programmed procedure calls. This facility is indispensible for a successful realization of genuine extensibility. Modules must be loadable on demand. For example, a document editor loads a graphics package when a graphic element appears in the processed document, but not otherwise.

The Oberon System features no separate linker. A module is linked with its imports when it is loaded, and never before. As a consequence, every module is present only once, in main store (linked) as well as on backing store (unlinked, as file). Avoiding the generation of multiple copies in different, linked object files is the key to storage economy. Prelinked mega-files do not occur in the Oberon System, and every module is freely reusable.

2.3 The System's Structure

The largest identifiable units of the system are its modules. It is therefore most appropriate to describe a system's structure in terms of its modules. As their interfaces are explicitly declared, it is also easy to exhibit their interdependence in the form of a directed graph. The edges indicate imports.

The module graph of a system programmed in Oberon is hierarchical, i.e. has no cycles. The lowest members of the hierarchy effectively import hardware only. We refer here to modules which contain device drivers. But module Kernel also belongs to this class; it "imports memory" and includes the disk driver. The modules on the top of the hierarchy effectively export to the user. As the user has direct access to command procedures, we call these top members command modules or tool modules.

The hierarchy of the basic system is shown in Fig. 2.1. The picture is simplified by omitting direct import edges if an indirect path also leads from the source to the destination. For example, Files imports Kernel; the direct import is not shown, because a path form Kernel leads to Files via FileDir. Module names in the plural form typically indicate the definition of an abstract data type in the module. The type is exported together with the pertinent operations. Examples are Files, Modules, Fonts, Texts,Viewers, MenuViewers, and TextFrames. (The exception is Reals which is an auxiliary module to Texts containing conversion operations for floating-point numbers programmed in assembler code). Modules whose names are in singular form typically denote a resource that the module manages, be it a global variable or a device. The variable or the device is itself hidden (not exported) and becomes accessible through the module's exported procedures. Examples are all device drivers, Input for keyboard and mouse, Kernel for the store and disk, Display, and SCC (communication controller). Exceptions are the command modules whose name is mostly chosen according to the activity they primarily represent, like Edit and Backup.

Module Oberon is, as already mentioned, the heart of the system containing the central loop to which control returns after each command interpretation, independent of whether it terminates normally or abnormally. Oberon exports several procedures of auxiliary nature, but primarily also the one allowing the invocation of commands (Call) and access to the command's parameter text through variable Oberon.Par. Furthermore, it contains the log text and exports this variable. The log text typically serves to issue prompts and short failure reports of commands. The text is displayed in a log viewer that is automatically opened when module System is initialized. Module Oberon furthermore contains the two markers used globally on the display, the cursor and the mark. It exports procedures to draw and to erase them, and allows the installation of different patterns for them.

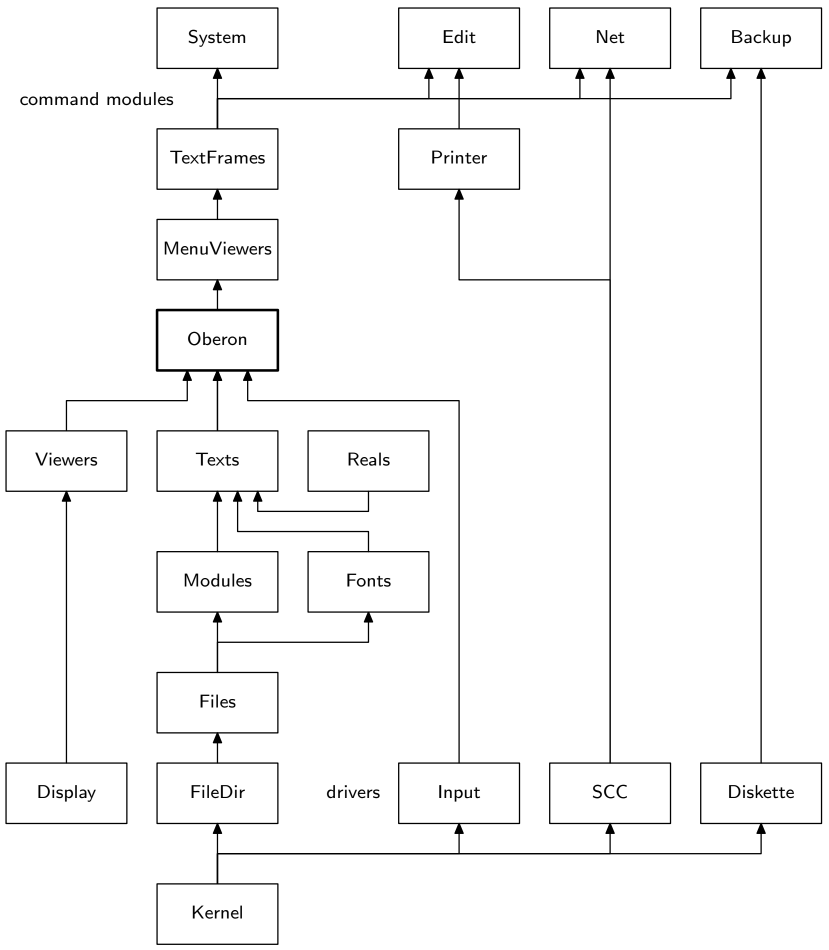


Fig. 2.2. Structure of the Oberon core

The system shown in Fig. 2.1. basically contains facilities for generating and editing texts, and for storing them in the file system and for backing them up on diskettes. All other functions are performed by modules that must be added in the usual way by module loading on demand. This includes, notably, the compiler, network communication, document editors, and all sorts of programs designed by users. The high priority given in the system's conception to modularity, to avoiding unnecessary frills, and to concentrate on the indispensible in the core, has resulted in a system of remarkable compactness. Although this property may be regarded as of little importance in this era of falling costs of large memories, we consider it to be highly essential. We merely should like to draw the reader's attention to the correlation between a systems' size and its reliability. Also, we do not consider it as good engineering practice to consume a resource lavishly just because it happens to be cheap. The following table lists the core's modules and the major application modules, and it indicates the number of bytes used for their code, their constants, and their static variables and, lastly, the number of source code lines.

module name	code (bytes)	constants	variables	source lines
Kernel	1896	144	108	*
FileDir	4324	56	0	368
Files	3640	24	4	450
Modules	2356	32	48	229
Input	452	4	48	73
Display	2284	392	52	*
Fonts	1204	44	8	117
Viewers	1836	12	20	248

Reals	484	104	0	*
Texts	9388	176	8	666
Oberon	3836	48	120	495
MenuViewers	2776	8	4	226
TextFrames	10148	152	112	868
System	6820	688	76	617
	51444	1884	608	4357
SCC	1144	8	2056	161
V24	340	4	516	71
Diskette	2812	40	1504	382
Printer	1512	36	1072	175
Edit	4668	240	596	458
Backup	1428	280	48	147
Net	5868	548	88	610
	17772	1156	5880	2004
Compiler	8988	144	84	967
OCS	3600	448	944	314
OCT	5000	504	260	583
OCC	6252	140	22540	611
OCE	12212	320	48	972
OCH	5804	48	36	553
	41856	1604	23912	4000
Graphics	7124	232	116	728
GraphicFrames	5648	60	60	566
Draw	2876	268	44	265
Rectangles	1508	16	8	128
Curves	3572	12	4	229
	20728	588	232	1916
total	131800	5232	30632	12277

* written in assembler code

2.4. A Tour through the Chapters

Implementation of a system proceeds bottom-up. Naturally, because modules on higher levels are clients of those on the lower levels and cannot function without the availability of their imports. Description of a system, on the other hand, is better ordered in the top-down direction. This is because a system is designed with its expected applications and functions in mind. Decomposition into a hierarchy of modules is justified by the use of auxiliary functions and abstractions and by postponing their more detailed explanation to a later time when their need has been fully motivated. For this reason, we will proceed essentially in the top-down direction.

Chapters 3 - 5 describe the outer core of the system. Chapter 3 focusses on the dynamic aspects. In particular, this Chapter introduces the fundamental operational units of task and command. Oberon's tasking model distinguishes the categories of interactive tasks and background tasks. Interactive tasks are represented on the display screen by rectangular areas, so-called viewers. Background tasks need not be connected with any displayed object. They are scheduled with low priority when interactions are absent. A good example of a background task is the memory garbage collector. Both interactive tasks and background tasks are mapped to a single process by the task scheduler. Commands in Oberon are explicit atomic units of interactive operations. They are realized in the form of exported parameterless procedures and replace the heavier-weight notion of program known from more conventional operating systems. The Chapter continues with a definition of a software toolbox as a logically connected collection of commands. It terminates with an outline of the system control toolbox.

Chapter 4 explains Oberon's display system. It starts with a discussion of our choice of a hierarchical tiling strategy for the allocation of viewers. A detailed study of the exact role of Oberon viewers follows. Type Viewer is presented as an object class with an open message interface providing a conceptual basis for far-reaching extensibility. Viewers are then recognized as just a special case of so-called frames that may be nested. A category of standard viewers containing a menu frame and a frame of contents is investigated. The next topic is cursor handling. A cursor in Oberon is a marked path. Both viewer manager and cursor handler operate on an abstract logical display area rather than on individual physical monitors. This allows a unified handling of display requests, independent of number and types of monitors assigned. For example, smooth transitions of the cursor across screen boundaries are conceptually guaranteed. The Chapter continues with the presentation of a concise and complete set of raster operations that is used to place textual and graphical elements in the display area. An overview of the system display toolbox concludes the Chapter.

Chapter 5 introduces text. Oberon distinguishes itself by treating Text as an abstract data type that is integrated in the central system. Numerous fundamental consequences are discussed. For example, a text can be produced by one command, edited by a user, and then consumed by a next command. Commands themselves can be represented textually in the form M.P, followed by a textual parameter list. Consequently, any command can be called directly from within a text (so-called tool) simply by pointing at it with the mouse. However, the core of this Chapter is a presentation of Oberon's text system as a case study in program modularization. The concerns of managing a text and displaying it are nicely separated. Both the text manager and the text display feature an abstract public interface as well as an internally hidden data structure. Finally in this Chapter, Oberon's type-font management and the toolbox for editing are discussed and, in particular, an abstract printer interface is defined.

Chapters 6 - 9 describe the inner core, still in a top-down path. Chapter 6 explains the loader of program modules and motivates the introduction of the data type Module. The chapter includes the management of the memory part holding program code and defines the format in which compiled modules are stored as object files. Furthermore, it discusses the problems of binding separately compiled modules together and of referencing objects defined in other modules. It is explained how the processor's addressing modes support this objective in the case of the Ceres computer.

Chapter 7 is devoted to the file system, a part of crucial importance, because files are involved in almost every program and computation. The chapter consist of two distinct parts, the first describing the structure of files, i.e. their representation on disk storage with its sequential characteristics, the second describing the directory of file names and its organisation as a B-tree for obtaining fast searches.

The management of memory is the subject of Chapter 8. A single, central storage management was one of the key design decisions, guaranteeing an efficient and economical use of storage. The chapter explains the store's partitioning into specific areas. Its central concern, however, is the discussion of dynamic storage management in the partition called the heap. As an exception, the algorithm for allocation (corresponding to the intrinsic procedure NEW) and for retrieval (called garbage collection) are explained in their principles rather than through concrete program listings. The reason for this is that they are programmed in assembler code rather than in the language Oberon, and that therefore their details are of less general interest to the readership.

At the lowest level of the module hierarchy we find device drivers. They are desribed in Chapter 9, which contains drivers for some widely accepted interface standards: an RS-232 line driver used in modules Input for the keybord, and module V24 for data links, an RS-485 line driver (module SCC) used for the network connecting workstations, and a SCSI driver usable for interfaces to disks and possibly other devices via a 8-bit parallel bus.

The second part of the book, consisting of Chapter 10 - 14, is devoted to what may be called first applications of the basic Oberon System. These chapters are therefore independent of each other, making reference to Chapters 3 - 9 only.

Although the Oberon System is well-suited for operating stand-alone workstations, a facility for connecting a set of computers should be considered as fundamental. Module Net, which makes transmission of files among workstations connected by a bus-like network possible, is the subject of

Chapter 10. It presents not only the problems of network access, of transmission failures and collisions, but also those of naming partners. The solutions are implemented in a surprisingly compact module which uses the network driver presented in Chapter 9.

When a set of workstations is connected in a network, the desire for a central server appears. A central facility serving as a file distribution service, as a printing station, and as a storage for electronic mail is presented in Chapter 11. It emerges by extending the Net module of Chapter 10, and is a convincing application of the tasking facilities explained in section 2.2. In passing we note that the server operates on a machine that is not under observation by a user. This circumstance requires an increased degree of robustness, not only against transmission failures, but also against data that do not conform to defined formats.

The presented system of servers demonstrates that Oberon's single-thread scheme need not be restricted to single-user systems. The fact that every command or request, once accepted, is processed until completion, is acceptable if the request does not occupy the processor for too long, which is mostly the case in the presented server applications. Requests arriving when the processor is engaged are queued. Hence, the processor handles requests one at a time instead of interleaving them which, in general, results in faster overall performance due to the adsence of frequent task switching.

Chapter 12 describes the Oberon Compiler. Although here it appears as an application module, it naturally plays a distinguished role, because the system (and the compiler itself) is formulated in the language which the compiler translates into code. Together with the text editor it was the principal tool in the system's development. The use of straight-forward algorithms for parsing and symbol table organization led to a reasonably compact piece of software (see Section 2.3). A main contributor to this result is the language's definition: the language is devoid of complicated structures and rarely used embellishments. Its structure is regular and its syntax compact.

The compiler and thereby the chapter is partitioned into three main parts. The first is language-specific, but does not refer to any particular target computer. This part is therefore of most general interest to the readership. The second part is, essentially, language-independent, but is specifically tailored to the instruction set of the target computer; it discusses the selection of instructions. The third part describes the module which puts instructions into the particular format defined by the target machine.

Although the algorithms and details decribed in the latter two parts are machine-specific, much would remain similar for other target computers with similar architectures. Our choice of the National Semiconductor 32000 processor (eight years ago) may appear mistaken, because it happens to be not widely known. In contrast to similar architectures (like Motorola 680x0 and Intel 80x86) it is distinguished by a much more regular instruction set. This is the most attractive property for compiler designers, and it is even more so for the compiler's description. Every irregularity is a source of additional complexity. Even in retrospect, the 32000 was by far the best choice from the point of view of description. And we presume that our readers wish to not merely copy, but to understand our programs.

Texts play a predominant role in the Oberon System. Their preparation is supported by the system's major tool, the editor. In Chapter 13 we describe another editor, one that handles graphic objects. At first, only horizontal and vertical lines and short captions are introduced as objects. The major difference to texts lies in the fact that their coordinates in the drawing plane do not follow from those of their predecessor automatically, because they form a set rather than a sequence. Each object carries its own, independent coordinates. The influence of this seemingly small difference upon an editor are far-reaching and permeate the entire design. There exist hardly any similarities between a text and a graphics editor. Perhaps one should be mentioned: the partitioning into three parts. The bottom module defines the respective abstract data structure for texts or graphics, together with, of course, the procedures handling the structure, such as searches, insertions, and deletions. The middle module in the hierarchy defines a respective frame and contains all procedures concerned with displaying the respective objects including the frame handler defining interpretation of mouse and keyboard events. The top modules are the respective tool modules (Edit, Draw). The presented graphics editor is particularly interesting in so far as it constitutes a convincing example of Oberon's extensibility. The graphics editor is integrated into the entire system; it embeds its graphic frames into menu-viewers and uses the facilities of the text system for its caption elements. And lastly, new kinds of elements can be incorporated by the mere addition of new modules, i.e. without expanding, even without recompiling the existing ones. Three examples are shown in Chapter 13 itself: rectangles, circles, and ellipses.

The Draw System has been extensively used for the preparation of diagrams of electronic circuits. This application suggests a concept that is useful elsewhere too, namely a recursive definition of the notion of object. A set of objects may be regarded as an object itself and be given a name. Such an object is called a macro. It is a challenge to the designer to implement a macro facility such that it is also extensible, i.e. in no way refers to the type of its elements, not even in its input operations of files on which macros are stored.

At this point the reader may have become aware that our presented applications are those that were actually required by our own project. This at least bears the guarantee that they were not only designed but used. In fact, many have been used by hundreds of people, and many daily over several years. Chapter 14 indeed presents two other such tools, namely one used for installing an Oberon System on a new, bare machine, and two used to recover from failures of the disk. Although rarely employed, the first was indispensible for the development of the system. The maintenance or recovery tools are invaluable assets when failures occur. And they do! Chapter 14 covers material that is rarely presented in the literature.

3. The Tasking System

Eventually, it is its generic ability to perform custom tasks orderly that turns a rigid computing device into a versatile universal tool. Consequently, modelling and scheduling of tasks are principal and crucial issues in the design of any operating system. Of course, we cannot expect a single fixed tasking metaphor to be the ideal solution for all possible modes of use. For example, different metaphors are probably appropriate in the cases of a closed central system serving a large set of users in time-sharing mode on one hand, and of a personal workstation that is operated by a single user with a high degree of interactivity on the other hand.

In the case of Oberon we have consciously concentrated on personal workstations. More precisely, we have directed Oberon's tasking facilities towards a single-user interactive personal workstation that is possibly integrated into a local area network. We start the presentation in Section 3.1 with a clarification of the notion of *task*. In Section 3.2 we continue with a detailed explanation of the scheduling strategy. Then, in Section 3.3 we shall introduce the concept of *command*. And finally, Section 3.4 provides an overview of predefined system-oriented toolboxes. A *toolbox* is a coherent collection of commands that are devoted to a specific topic. Example topics are system control and diagnosis, display management, and file management.

3.1. The Concept of Task

In principle, we distinguish two categories of tasks in Oberon: *Interactive tasks* and *background tasks*. Roughly said, interactive tasks are bound to local regions on the display screen and to interactions with their contents. In contrast, background tasks are global. They are not necessarily related to any specific displayed entity.

3.1.1. Interactive Tasks

Every interactive task is represented by a so-called *viewer*. Viewers constitute the interface to Oberon's display-system and embody a variety of roles that are collected in an abstract data type *Viewer*. We shall give a deeper insight into the display system in Chapter 4. For the moment it suffices to know that viewers are represented graphically as rectangles on the display screen and that they are implicit carriers of interactive tasks. Figure 3.1 shows a typical Oberon display screen that is divided up into seven viewers corresponding to seven simultaneously active interactive tasks.

In order to get firmer ground under our feet we give the programmed declaration of type *Viewer* in a slightly abstracted form:

```
Viewer = POINTER TO ViewerDesc;

ViewerDesc = RECORD
    X, Y, W, H: INTEGER;
    handle: Handler;
    state: INTEGER
 END;
```

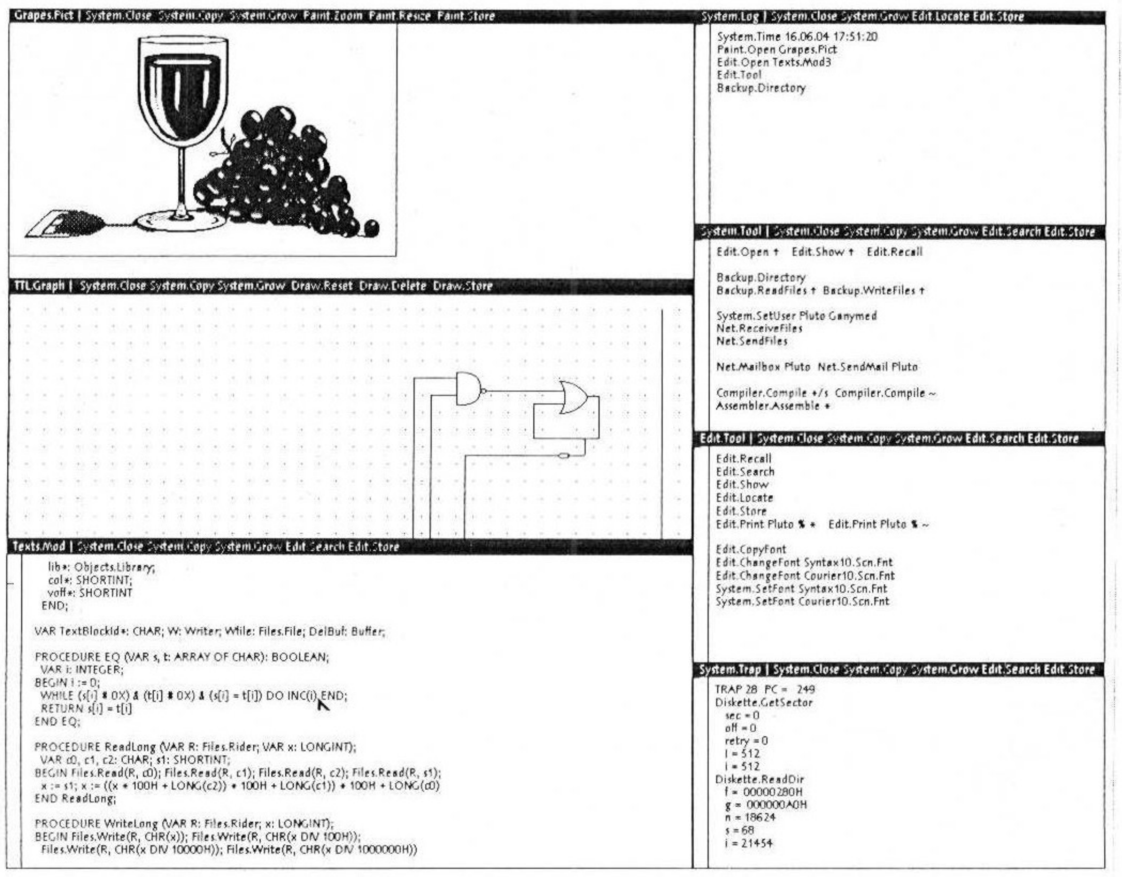
X, *Y*, *W*, *H* define the viewer's rectangle on the screen, i.e. location *X*, *Y* of the lower left corner relative to the display origin, width *W* and height *H*. The variable state informs about the current state of visibility (visible, closed, covered), and handle represents the functional interface of viewers. The type of the handler is

```
Handler = PROCEDURE (V: Viewer; VAR M: ViewerMsg);
```

where *ViewerMsg* is some base type of messages whose exact declaration is of minor importance for the moment:

```
ViewerMsg = RECORD ... (*basic parameter fields*) END;
```

However, we should point out the use of object-oriented terminology. It is justified because handle is a procedure variable whose identity depends on the specific viewer. A call *V.handle(V, M)* can therefore be interpreted as the sending of a message *M* to be handled individually by the method of the receiving viewer *V*.


Grapes.Pict | System.Close System.Copy System.Grow Paint.Zoom Paint.Resize Paint.Store
System.Log | System.Close System.Grow Edit.Locate Edit.Store
TTL.Graph | System.Close System.Copy System.Grow Draw.Reset Draw.Delete Draw.Store
System.Tool | System.Close System.Copy System.Grow Edit.Search Edit.Store
Edit.Tool | System.Close System.Copy System.Grow Edit.Search Edit.Store
Texts.Mod | System.Close System.Copy System.Grow Edit.Search Edit.Store
System.Trap | System.Close System.Copy System.Grow Edit.Search Edit.Store

```
System.Time 16.06.04 17:51:20
Paint.Open Grapes.Pict
Edit.Open Texts.Mod3
Edit.Tool
Backup.Directory
```

```
Edit.Open ↑   Edit.Show ↑   Edit.Recall

Backup.Directory
Backup.ReadFiles ↑  Backup.WriteFiles ↑

System.SetUser Pluto Ganymed
Net.ReceiveFiles
Net.SendFiles

Net.Mailbox Pluto  Net.SendMail Pluto

Compiler.Compile */s  Compiler.Compile ~
Assembler.Assemble *
```

```
Edit.Recall
Edit.Search
Edit.Show
Edit.Locate
Edit.Store
Edit.Print Pluto % *   Edit.Print Pluto % ~

Edit.CopyFont
Edit.ChangeFont Syntax10.Scn.Fnt
Edit.ChangeFont Courier10.Scn.Fnt
System.SetFont Syntax10.Scn.Fnt
System.SetFont Courier10.Scn.Fnt
```

```
    lib*: Objects.Library;
    col*: SHORTINT;
    voff*: SHORTINT
  END;

VAR TextBlockId*: CHAR; W: Writer; Wfile: Files.File; DelBuf: Buffer;

PROCEDURE EQ (VAR s, t: ARRAY OF CHAR): BOOLEAN;
  VAR i: INTEGER;
BEGIN i := 0;
  WHILE (s[i] # 0X) & (t[i] # 0X) & (s[i] = t[i]) DO INC(i) END;
  RETURN s[i] = t[i]
END EQ;

PROCEDURE ReadLong (VAR R: Files.Rider; VAR x: LONGINT);
  VAR c0, c1, c2: CHAR; s1: SHORTINT;
BEGIN Files.Read(R, c0); Files.Read(R, c1); Files.Read(R, c2); Files.Read(R, s1);
  x := s1; x := ((x * 100H + LONG(c2)) * 100H + LONG(c1)) * 100H + LONG(c0)
END ReadLong;

PROCEDURE WriteLong (VAR R: Files.Rider; x: LONGINT);
BEGIN Files.Write(R, CHR(x)); Files.Write(R, CHR(x DIV 100H));
  Files.Write(R, CHR(x DIV 10000H)); Files.Write(R, CHR(x DIV 1000000H))
```

```
TRAP 28  PC =  249
Diskette.GetSector
  sec = 0
  off = 0
  retry = 0
  l = 512
  i = 512
Diskette.ReadDir
  f = 00000280H
  g = 000000A0H
  n = 18624
  s = 68
  i = 21454
```

Figure 3.1 Typical Oberon display configuration consisting of seven viewers

We recognize an important difference between the standard object-oriented model and our handler paradigm. The standard model is *closed* in the sense that only a fixed set of messages is understood by a given class of objects. In contrast, the handler paradigm is *open* because it defines just the root *(ViewerMsg)* of a potentially unlimited tree of extending message types. For example, a concrete handler might be able to handle messages of type *MyViewerMsg*, where

```
MyViewerMsg = RECORD (ViewerMsg)
    mypar: MyParameters
END;
```

is an extended type of *ViewerMsg*.

It is worth noting that our open object-oriented model is extremely flexible. For example, extending the set of message types that are handled by an object is a mere implementation issue, that is, it has no effect on the object's compile-time interface. It is fair to mention though that such a high degree of flexibility does not come for free. The price to pay is the obligation of explicit message dispatching at runtime. Our object model is therefore *runtime dispatched*. The following Chapters will exemplify this property.

Finally coming back to the perspective of tasks, we should point out that each sending of a message to a viewer corresponds to an activation or reactivation of the interactive task that is represents.

3.1.2. Background Tasks

Oberon background tasks are not connected a priori with any specific aggregate in the system. Seen technically, they are instances of an abstract data type consisting of type declarations *Task* and *TaskDesc* together with intrinsic operations *Install* and *Remove*:

```
Task = POINTER TO TaskDesc;

TaskDesc = RECORD
    safe: BOOLEAN;
    handle: PROCEDURE
END;

PROCEDURE Install (T: Task);
PROCEDURE Remove (T: Task);
```

The procedures *Install* and *Remove* are called explicitly in order to transfer the state of the specified task from *not ready* to *ready* and from *ready* to *not ready* respectively. The field named *safe* in *TaskDesc* distinguishes so-called *safe tasks*. In contrast to potentially unsafe tasks they are not cancelled automatically after a program trap. The procedure variable *handle* is again used for the reactivation of the task. We should view a call of the parameterless procedure *handle* as the sending of an implicit message *continue*.

A concrete background task is normally a type-extension of the abstract type *Task*. Typically, the extending part refers to the object(s) this task is operating on:

```
MyTask = POINTER TO MyTaskDesc;

MyTaskDesc = RECORD (TaskDesc)
    myobj: MyObjType
END;
```

It may contribute to an improved understanding, if we give two realistic examples of concrete background tasks. The first one is a system-wide garbage collector collecting unused memory. The second example is a network monitor monitoring incoming traffic on a local area network. In both examples the state of the task is captured by global system variables. We shall come back to these topics in Chapters 8 and 10 respectively. Table 3.1 summarizes Oberon's tasking model.

We should not end this Section without drawing an important conclusion. Transfers of control between tasks are implemented in Oberon as ordinary calls and returns of ordinary procedures (procedure variables, actually). Preemption is not possible. From that we imply that active periods of tasks are sequentially ordered and can be controlled by a single flow (thread, process). This simplification pays well: Locks of common resources are completely dispensable and deadlocks are not a topic at all.

Table 3.1

task type	create	to ready	(re)activate	passivate	to not ready
interactive	create viewer	open viewer	send message	terminate handling	close viewer
background	create task	install	send *continue*	terminate handling	remove

3.2. The Task Scheduler

We start from the general assumption that, at any given time, a number of well-determined tasks are ready in the system to be serviced. Remember that two categories of tasks exist: Interactive tasks and background tasks. They differ substantially in the criteria of activation or reactivation and in the priority of dispatching. Interactive tasks are (re)activated exclusively upon interactions by the user and are dispatched with high priority. In contrast, background tasks are polled with low priority.

We already know that interactive tasks are activated by sending messages. The types of messages used for this purpose are *InputMsg* and *ControlMsg* reporting on keyboard events and mouse events respectively. Slightly simplified, they are declared as

```
InputMsg = RECORD (ViewerMsg)
    id: INTEGER;
    X, Y: INTEGER;
    keys: SET;
    ch: CHAR
END;

ControlMsg = RECORD (ViewerMsg)
    id: INTEGER;
    X, Y: INTEGER
END;
```

The field *id* specifies the exact request transmitted with this reactivation. In the case of *InputMsg* the possible requests are *consume* (the character specified by field ch) and *track* (mouse, starting from state given by keys and X, Y). In case of *ControlMsg* the choice is *mark* (the viewer at position X, Y) or *neutralize*. Marking means moving the global system pointer (typically represented as a star-shaped mark) to the current position of the mouse. Neutralizing a viewer is equivalent to removing all marks and graphical attributes from this viewer.

All tasking facilities are collected in one module, called *Oberon*. In particular, the module's definition exposes the declarations of the abstract data type *Task* and of the message types *InputMsg* and *ControlMsg*. The module's most important contribution, however, is the task scheduler that can be regarded as the system's dynamic centre.

Before we can study the scheduler in detail we need some more preparation. We start with the institution of the *focus viewer*. By definition, this is a distinguished viewer that applied for consuming subsequent keyboard input. Note that the focus viewer is actually a *focus task*. However, recalling our definition of tasks, we regard the terms viewer and interactive task as interchangeable.

Module *Oberon* provides the following facilities in connection with the focus viewer: A global variable *FocusViewer*, a procedure *PassFocus* to transfer the role of focus to a new viewer, and a defocus variant of *ControlMsg* to notify the old focus viewer of such a transfer.

Next, we reveal the implementation of the abstract type *Task* that is hidden from the clients. It is based on a ring of task descriptors and on a pointer to the previously activated task in the ring. The ring is guaranteed never to be empty because the above mentioned garbage collector is installed as a safe task at system loading time

We can now scrutinize the following version of the task scheduler. The reader should relate this to procedure *Loop* in the module *Oberon* listed in detail at the end of this Chapter.

```
get mouse position and state of keys;
LOOP
  IF keyboard input available THEN read character
    IF character is escape THEN
      broadcast neutralize message to viewers
    ELSIF character is setup THEN
      send mark message to viewer containing mouse
    ELSE send consume message to focus viewer
    END;
    get mouse position and state of keys
  ELSIF at least one key pressed THEN
    REPEAT
      send track message to viewer containing mouse;
      get mouse position and state of keys
    UNTIL all keys released
  ELSE (*no key pressed*)
    send track message to viewer containing mouse;
    get mouse position and state of keys;
    WHILE mouse unmoved and no keyboard input DO
```

```
      take next task in ring as current task;
      IF current task is unsafe THEN remove it from ring END;
      send continue message to current task;
      assure current task in ring again;
      get mouse position and state of keys
     END
    END
   END
```

Having consciously excluded exceptional program behaviour in our explanations so far, it seems fair enough to add some conceptual remarks about the way of continuation in case of a program trap or, in other words, in case of a failing task. Of course, the handling of such a case can be pursued on many different levels of abstraction. In accordance with our general top-down approach we focus our current attention to the level of our tasking model.

We can identify three sequential actions of recovery after a program failure:

```
recovery after program failure = BEGIN
  save current system state;
  call installed trap handler;
  roll back to start of task scheduler
END
```

Essentially, the system state is determined by the values of all global and local variables at the given time. The trap handler typically opens an extra viewer displaying the cause of the trap and the saved system state. Figure 3.1 shows a trap viewer at the lower right corner of the display screen.

Notice in the program fragment above that unsafe background tasks are removed from the ring of ready tasks before reactivation and are installed again only after successful return. Consequently, unsafe tasks are eliminated automatically after failing. This is an effective precaution against cascades of repeated failures. Obviously, no such precaution is necessary in the case of interactive tasks because their reactivation is under control of the system user.

In summary, Oberon is a multitasking system based on a two-category model. Interactive tasks are interfacing with the display system and are scheduled with high priority upon user interactions. Background tasks are stand-alone and are scheduled with low priority. Task activations are modelled as message passing and eventually as calls of procedures assigned to variables. They are sequentially ordered and controlled by a single process.

3.3. The Concept of Command

In short, an operating system constitutes a general purpose platform on which application software packages can build. The platform appears to software designers as interface to "the system" and (in particular) to the underlying hardware. Unfortunately, interfaces defined by more conventional operating systems suffer from an all too primitive access mechanism that is based solely on the concept of "software interrupt" or "supervisor call" and on files taking the role of connecting "pipes". The situation is especially ironic in comparison with the development of high-level programming languages towards abstraction.

We have put greatest emphasis in Oberon to close the semantic gap between application software packages and the system platform. The result of our effort is a highly expressive and consistent *application programming interface* in the form of an explicit hierarchy of module definitions. Perhaps the most significant and most conspicuous outcome of this approach is a collection of very powerful and system-wide *abstract data types* like *Task*, *Frame*, *Viewer*, *File*, *Font*, *Text*, *Module*, *Reader*, *Scanner*, *Writer* etc..

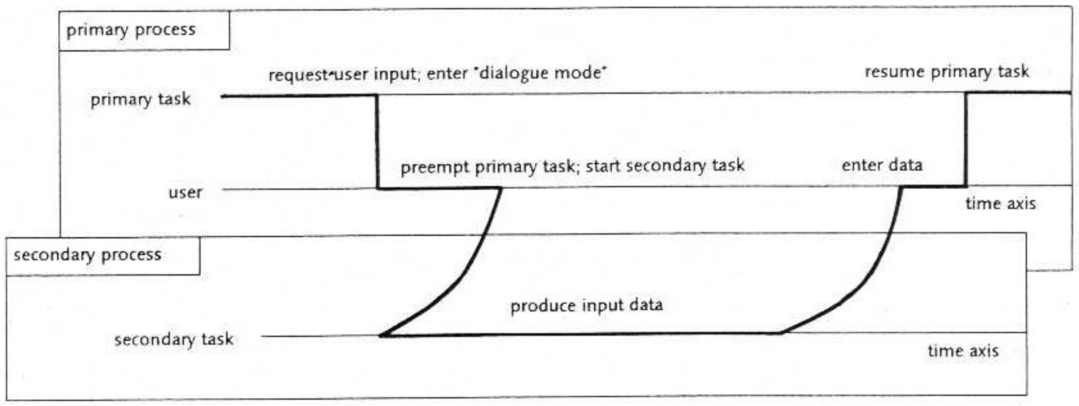


Figure 3.2 Typical trace of processing in a classical interactive system.

3.3.1. Atomic Actions

The most important because most generic function of any operating system is executing programs. Our next step is therefore a clarification of the term *program*, as it is used in Oberon. We should consider a static aspect as well as a dynamic aspect. Statically, an Oberon program is simply a package of software together with an entry point. More formally, it is a pair *(M**, P), where *M* is an arbitrary module, *P* is an exported parameterless procedure of *M*, and *M** denotes the hierarchy consisting of *M* itself and of all directly and indirectly imported modules. Notice that two hierarchies *M** and *N** are not disjoint in general, even if *M* and *N* are different modules. Rather, their intersection is a superset of the operating system.

Viewed dynamically, an Oberon program is defined as an atomic action operating on the global system state, where atomic means "without user interaction". Note that this definition is just a compelling consequence of our model of non-preemptive task scheduling with the benefit of a single carrier process. We can argument like this: When a traditional interactive program requires input from the user in order to be able to proceed, there is no justification whatsoever not to allow the user to preempt the current task and to start another task with the aim of producing the required input data. Therefore, a traditional interactive program can be viewed as a sequence of atomic actions separated by interactions that possibly include actions of other programs. Figures 3.2 and 3.3 visualize this argumentation by opposing possible traces of processing in a more traditional interactive system and in an Oberon system respectively.

As a quintessence, Oberon programs are represented in the form of exported parameterless procedures that do not interact with the user of the system. In honor of these distinguishing properties such procedures are called *commands*.

Returning to the calling and execution of programs we now arrive at the following refinement:

```
call program (M*, P) = BEGIN
  load module hierarchy M*; call command P
END
```

The system interface to the command mechanism itself is again provided by module *Oberon*. Its primary operation can be paraphrased as "call a command by its name and pass a list of actual parameters":

```
PROCEDURE Call (VAR name: ARRAY OF CHAR;
  par: ParList; new: BOOLEAN; VAR res: INTEGER);
```

name is the name of the desired command in the form *M.P*, *par* is the list of actual parameters, new is an option guaranteeing preliminary loading of a new version of *M**, and *res* is a result code. Type *ParList* is declared essentially as

```
ParList = POINTER TO ParRec;
ParRec = RECORD
  vwr: Viewers.Viewer;
  text: Texts.Text;
  pos: LONGINT
END;
```

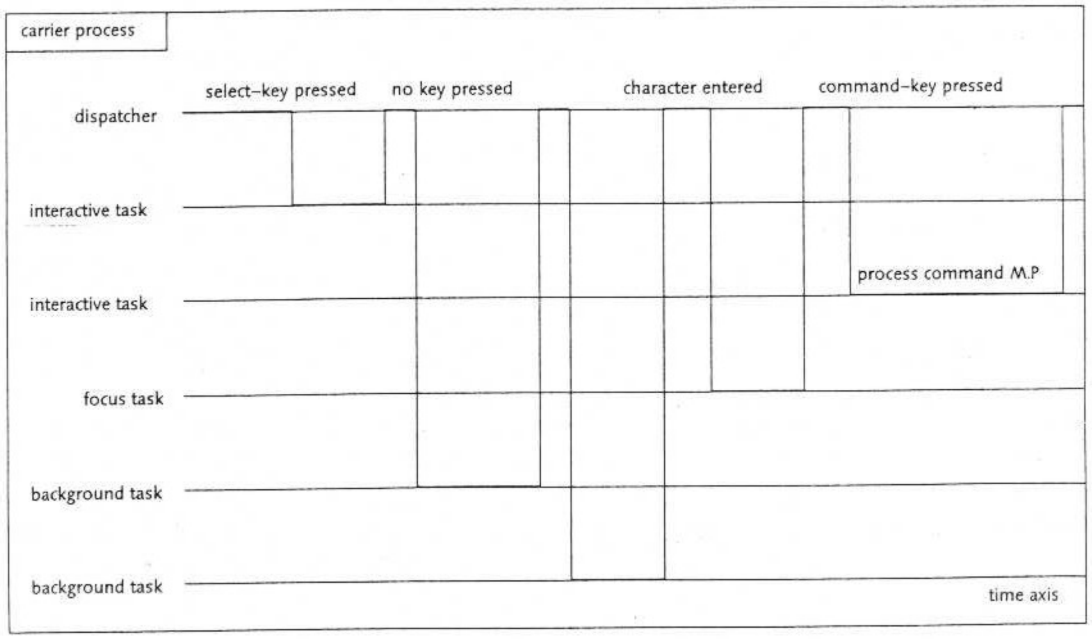


Figure 3.3 Typical trace of processing in the Oberon system.

Parameter *vwr* indicates the calling viewer (task) and the pair *(text, pos)* of parameters specifies the starting position *pos* of a textual parameter list within text. Notice the occurrence of another abstract data type with name *Text* that is exported by module *Texts*. We shall devote the entire Chapter 5 to a thorough presentation of Oberon's text system. For the moment we can simply look at a text as a sequence of characters.

The list of actual parameters is put at the disposal of the called command by module *Oberon* in the form of an exported global variable

```
Par: ParList
```

The actual list of parameters may well be an extension of the standard parameter list ParList. In such a case, the extending fields represent non-standard and customized parameters.

In principle, commands operate on the entire system and can access the current global state via the system's powerful modular interface, of which the list of actual parameters is just one component. Another one is the so-called *system log* which is a system-wide protocol reporting on the progress of command execution and on exceptional events in chronological order.

The log is represented as a global variable of type Text:

```
Log: Texts.Text;
```

It should have become clear by now that implementors of versatile and adaptable commands may rely on a rich arsenal of global facilities that reflect the current system state and make it accessible. In other words, they may rely on a high degree of system integration. Therefore, we find in Oberon an extraordinarily broad spectrum of integrated notions. For example, the system distinguishes itself by a complete integration of the abstract data types *Viewer* and *Text* that we encountered above. They will be the subjects of Chapters 4 and 5.

Module *Oberon* assists the integration of these types with the following conceptual features, of which the first two are familiar to us already: Standard parameter list for commands, system log, generic text selection, generic copy-over for text, and generic copy viewer. At this point we should perhaps add a word of clarification to our use of the term "generic". It is synonymous with "interpretable individually by any viewer (interactive task)", and is typically used in connection with messages or orders whose receiver's exact identity is unknown.

We now go into a brief discussion of the generic facilities without, however, leaving the level of our current abstraction and understanding.

3.3.2. Generic Text Selection

Textual selections are characterized by a text, a stretch of characters within that text, and a time stamp. Without further qualification "the text selection" always means "the most recent text selection". It can be obtained programmatically by calling procedure *GetSelection*:

```
  PROCEDURE GetSelection (VAR text: Texts.Text; VAR beg, end, time: LONGINT);
```

The parameters specify the desired stretch of text starting at position *beg* and ending at *end - 1* as well as the associated time stamp. The procedure is implemented by a broadcast of a so-called selection message to all viewers. The declaration of this message is

```
        SelectionMsg = RECORD (ViewerMsg)
          time: LONGINT;
          text: Texts.Text;
          beg, end: LONGINT
        END;
```

3.3.3. Generic Copy-Over for Text

The aim is an integrated order "copy-over text". A variant of type *ViewerMsg* is defined to the purpose of transmitting such requests:

```
        CopyOverMsg = RECORD (ViewerMsg)
          text: Texts.Text;
          beg, end: LONGINT
        END;
```

Typically, receivers of a copy-over message copy the specified stretch of text to their local focus.

3.3.4. Generic Copy Viewer

Generic copying is synonymous with reproducing and cloning. It is the most elementary generic operation possible. Again, a variant of type *ViewerMsg* is used for the purpose of transmitting requests of the desired type:

```
        CopyMsg = RECORD (ViewerMsg)
          vwr: Viewers.Viewer
        END;
```

Receivers of a *copy* message generate a clone of themselves and return it to the sender via field *vwr*.

We now summarize this Section: Oberon is an operating system that presents itself to its clients in the form of a highly expressive modular interface that exports many powerful abstract data types like, for example, *Viewer* and *Text*. A rich arsenal of global and generic facilities serve the purpose of system integration. Programs in Oberon are modelled as so-called commands, i.e. as exported parameterless procedures that do not interact with the user. The collection of commands provided by a module appears as its user interface. Parameters are passed to commands via a global parameter list, registered by the calling task in the central module *Oberon*. Commands operate on the global state of the system.

3.4. Toolboxes

In a modular programming environment software modules may appear in many different forms. Some familiar examples are listed in Table 3.2: Collection of logically connected declarations of data and of types, capsule representing an abstract data type, framework for the implementation of an object class, and library of service procedures.

Oberon adds another form: The *toolbox*. By definition, this is a pure collection of commands in the sense of the previous Section.

Toolboxes distinguish themselves principally from the other forms of modules by the fact that they lie on top of the modular hierarchy. Toolbox modules are "imported" by system users at run-time. In other words, their definitions define the *user interface*.

As a rule of thumb there exists a toolbox for every topic or application. Table 3.3 lists system oriented topics together with the name of the associated toolbox and a reference to a Chapter explaining the commands.

Table 3.2

form of module	role of definition	role of implementation
declarations	declare data and objects	void
abstract data type	define interface	implement operations
framework for class	define object generator	implement methods
service procedures	define parameters	implement services
toolbox	define user interface	implement user interface

Table 3.3

topic	toolbox	chapters
system management	System	3
display management	System	4
text editing	Edit	5
module management	System	6
file management	System	7
system inspection	System	8, 12
network management	Net	10
compiling	Compiler	12
graphics editing	Draw	13

As an example of a toolbox definition we quote an annotated version of module *System*:

```
DEFINITION System;

(*System management*)
  PROCEDURE SetUser; (*identification*)
  PROCEDURE SetFont; (*for typed text*)
  PROCEDURE SetColor; (*for typed text and graphics*)
  PROCEDURE Time; (*set or display*)
  PROCEDURE Collect; (*garbage*)

(*Display management*)
  PROCEDURE Open; (*viewer*)
  PROCEDURE OpenLog; (*viewer*)
  PROCEDURE Close; (*viewer*)
  PROCEDURE CloseTrack;
  PROCEDURE Recall; (*most recently closed viewer*)
  PROCEDURE Copy; (*viewer*)
  PROCEDURE Grow; (*viewer*)

(*Module management*)
  PROCEDURE Free; (*specified modules*)
  PROCEDURE ShowCommands; (*of specified module*)
  PROCEDURE ShowModules; (*loaded*)

(*File management*)
  PROCEDURE Directory;
  PROCEDURE CopyFiles;
  PROCEDURE RenameFiles;
  PROCEDURE DeleteFiles;)

(*System inspection*)
  PROCEDURE Watch; (*memory and disk storage*)
  PROCEDURE State; (*of global module variables*)

END System;
```

In principle, commands can be interpreted by any interactive task in an arbitrary and individual way. However, if the task is represented by a textual viewer, we obtain an attractive universal command interpreter simply by interpreting the underlying text. If the text is a list of command names followed by parameters we call it a *tool*.

More precisely, a tool is a text obeying the following syntax in EBNF-notation (Extended Backus-Naur Formalism):

```
tool = { [Comment] CommandName [ParameterList] }.
```

If present, the textual parameter list is made available to the called command via fields *text* and *pos* in the global parameter list *Par* that is exported by module *Oberon*. Because this parameter list is interpreted individually by every command, its format is completely open. However, we fixed some conventions and rules for the purpose of a standardized user interface:

1.) The elements of a textual parameter list are universal syntactical tokens like name, literal string, integer, real number, long real number, and special character.

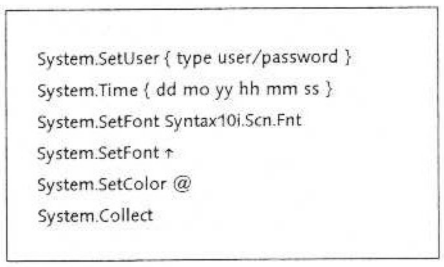
2.) A reference-character "^" in the textual parameter list refers to the current text selection for continuation. In the special case of the reference character following the command name immediately, the entire parameter list is represented by the text selection.

3.) A mark-character "*" in the textual parameter list refers to the currently marked viewer. Typically, the mark-character replaces the name of a file. In such a case the contents of the viewer marked by the system pointer is processed by the command interpreter instead of the contents of a file.

4.) An *at*-character "@" in the textual parameter list indicates that the selection marks the (beginning of the) text which is taken as operand.

5.) A terminator-character "~" terminates the textual parameter list in case of a variable number of parameters.

Because tools are ordinary and editable texts (in contrast to conventional menus) they can be customized "on the fly". We refer again to Figure 3.1 that shows a typical Oberon screen layout consisting of two vertical tracks, a wider *user track* on the left and a narrow *system track* on the right. Three documents are displayed in the user track: A text, a graphic, and a picture. In the system track we find one log-viewer displaying the system log, two tool-viewers making available the standard system tool and a customized private tool respectively, and one trap viewer at the bottom.



```
System.SetUser { type user/password }
System.Time { dd mo yy hh mm ss }
System.SetFont Syntax10i.Scn.Fnt
System.SetFont ↑
System.SetColor @
System.Collect
```

Figure 3.4 An excerpt of a system management tool.

Let us exemplify the concepts of command and tool by the system control section of the *System* toolbox. Consisting of the commands *SetUser*, *Time*, *SetFont*, *SetColor*, and *Collect* it is used to control system-wide facilities. In detail, their function is installing the user's identification, displaying or setting the system time, presetting the system type-font for typed text, setting the system color, and activating the garbage collector. The implementations are included in the Implementations Section at the end of this Chapter. Figure 3.4 presents a possible excerpt of a textual tool consisting of system control commands.

And this concludes the Section. In summary, the toolbox is a special form of an Oberon module. It is defined as a collection of commands. Appearing at the top of the modular hierarchy the toolboxes in their entirety fix the system's user interface. Tools are sequences of textually represented command calls. They are editable and customizable. In a typical Oberon screen layout the tools are displayed in viewers within the system track.

Complete Implementations

```
MODULE Oberon; (*JG 6.9.90*)

  IMPORT Kernel, Modules, Input, Display, Fonts, Viewers, Texts;

  CONST
    consume* = 0; track* = 1; (*input message id*)
    defocus* = 0; neutralize* = 1; mark* = 2; (*control message id*)
    BasicCycle = 20;
    ESC = 1BX; SETUP = 0A4X;

  TYPE
    Painter* = PROCEDURE (x, y: INTEGER);
   Marker* = RECORD Fade*, Draw*: Painter END;

   Cursor* = RECORD
     marker*: Marker; on*: BOOLEAN; X*, Y*: INTEGER
   END;

   ParList* = POINTER TO ParRec;

   ParRec* = RECORD
     vwr*: Viewers.Viewer;
     frame*: Display.Frame;
     text*: Texts.Text;
     pos*: LONGINT
   END;

   InputMsg* = RECORD (Display.FrameMsg)
     id*: INTEGER;
     keys*: SET;
     X*, Y*: INTEGER;
     ch*: CHAR;
     fnt*: Fonts.Font;
     col*, voff*: SHORTINT
   END;

   SelectionMsg* = RECORD (Display.FrameMsg)
     time*: LONGINT;
     text*: Texts.Text;
     beg*, end*: LONGINT
   END;

   ControlMsg* = RECORD (Display.FrameMsg)
     id*, X*, Y*: INTEGER
   END;

   CopyOverMsg* = RECORD (Display.FrameMsg)
     text*: Texts.Text;
     beg*, end*: LONGINT
   END;

   CopyMsg* = RECORD (Display.FrameMsg)
     F*: Display.Frame
   END;
   Task* = POINTER TO TaskDesc;

   TaskDesc* = RECORD
     next: Task;
     safe*: BOOLEAN;
     handle*: PROCEDURE
   END;

  VAR
   User*: ARRAY 8 OF CHAR;
   Password*: LONGINT;

   Arrow*, Star*: Marker;
   Mouse*, Pointer*: Cursor;

   FocusViewer*: Viewers.Viewer;
   Log*: Texts.Text;
   Par*: ParList; (*actual parameters*)

   CurTask*, PrevTask: Task;

   CurFnt*: Fonts.Font; CurCol*, CurOff*: SHORTINT;

   DW, DH, CL, H0, H1, H2, H3: INTEGER;

   ActCnt: INTEGER; (*action count for GC*)
   Mod: Modules.Module;

  PROCEDURE Min (i, j: INTEGER): INTEGER;
  BEGIN IF i <= j THEN RETURN i ELSE RETURN j END
  END Min;

  (*user identification*)

  PROCEDURE Code(VAR s: ARRAY OF CHAR): LONGINT;
   VAR i: INTEGER; a, b, c: LONGINT;
  BEGIN
   a := 0; b := 0; i := 0;
   WHILE s[i] # 0X DO
     c := b; b := a; a := (c MOD 509 + 1) * 127 + ORD(s[i]);
     INC(i)
   END;
   IF b >= 32768 THEN b := b - 65536 END;
   RETURN b * 65536 + a
  END Code;

  PROCEDURE SetUser* (VAR user, password: ARRAY OF CHAR);
  BEGIN COPY(user, User); Password := Code(password)
  END SetUser;

  (*clocks*)

  PROCEDURE GetClock* (VAR t, d: LONGINT);
  BEGIN Kernel.GetClock(t, d)
  END GetClock;
```

```
PROCEDURE SetClock* (t, d: LONGINT);
BEGIN Kernel.SetClock(t, d)
END SetClock;

PROCEDURE Time* (): LONGINT;
BEGIN RETURN Input.Time()
END Time;

(*cursor handling*)

PROCEDURE* FlipArrow (X, Y: INTEGER);
BEGIN
  IF X < CL THEN
    IF X > DW - 15 THEN X := DW - 15 END
  ELSE
    IF X > CL + DW - 15 THEN X := CL + DW - 15 END
  END;
  IF Y < 15 THEN Y := 15 ELSIF Y > DH THEN Y := DH END;
  Display.CopyPattern(Display.white, Display.arrow, X, Y - 15, 2)
END FlipArrow;

PROCEDURE* FlipStar (X, Y: INTEGER);
BEGIN
  IF X < CL THEN
    IF X < 7 THEN X := 7 ELSIF X > DW - 8 THEN X := DW - 8 END
  ELSE
    IF X < CL + 7 THEN X := CL + 7
       ELSIF X > CL + DW - 8 THEN X := CL + DW – 8
     END
  END ;
  IF Y < 7 THEN Y := 7 ELSIF Y > DH - 8 THEN Y := DH - 8 END;
  Display.CopyPattern(Display.white, Display.star, X - 7, Y - 7, 2)
END FlipStar;

PROCEDURE OpenCursor* (VAR c: Cursor);
BEGIN c.on := FALSE; c.X := 0; c.Y := 0
END OpenCursor;

PROCEDURE FadeCursor* (VAR c: Cursor);
BEGIN IF c.on THEN c.marker.Fade(c.X, c.Y); c.on := FALSE END
END FadeCursor;

PROCEDURE DrawCursor* (VAR c: Cursor; VAR m: Marker; X, Y: INTEGER);
BEGIN
  IF c.on & ((X # c.X) OR (Y # c.Y) OR (m.Draw # c.marker.Draw)) THEN
    c.marker.Fade(c.X, c.Y); c.on := FALSE
  END;
  IF ~c.on THEN
    m.Draw(X, Y); c.marker := m; c.X := X; c.Y := Y; c.on := TRUE
  END
END DrawCursor;

(*display management*)

PROCEDURE RemoveMarks* (X, Y, W, H: INTEGER);
```

```
BEGIN
  IF (Mouse.X > X - 16) & (Mouse.X < X + W + 16)
    & (Mouse.Y > Y - 16) & (Mouse.Y < Y + H + 16) THEN FadeCursor(Mouse)
  END;
  IF (Pointer.X > X - 8) & (Pointer.X < X + W + 8)
     & (Pointer.Y > Y - 8) & (Pointer.Y < Y + H + 8) THEN FadeCursor(Pointer)
  END
END RemoveMarks;

PROCEDURE* HandleFiller (V: Display.Frame; VAR M: Display.FrameMsg);
BEGIN
  WITH V: Viewers.Viewer DO
    IF M IS InputMsg THEN
      WITH M: InputMsg DO
        IF M.id = track THEN DrawCursor(Mouse, Arrow, M.X, M.Y) END
      END;
    ELSIF M IS ControlMsg THEN
      WITH M: ControlMsg DO
        IF M.id = mark THEN DrawCursor(Pointer, Star, M.X, M.Y) END
     END
    ELSIF M IS Viewers.ViewerMsg THEN
      WITH M: Viewers.ViewerMsg DO
        IF (M.id = Viewers.restore) & (V.W > 0) & (V.H > 0) THEN
          RemoveMarks(V.X, V.Y, V.W, V.H);
          Display.ReplConst(Display.black, V.X, V.Y, V.W, V.H, 0)
        ELSIF (M.id = Viewers.modify) & (M.Y < V.Y) THEN
          RemoveMarks(V.X, M.Y, V.W, V.Y - M.Y);
          Display.ReplConst(Display.black, V.X, M.Y, V.W, V.Y - M.Y, 0)
        END
      END
    END
  END
END HandleFiller;

PROCEDURE OpenDisplay* (UW, SW, H: INTEGER);
  VAR Filler: Viewers.Viewer;
BEGIN
   Input.SetMouseLimits(Viewers.curW + UW + SW, H);
   Display.ReplConst(Display.black, Viewers.curW, 0, UW + SW, H, 0);
   NEW(Filler); Filler.handle := HandleFiller;
   Viewers.InitTrack(UW, H, Filler); (*init user track*)
   NEW(Filler); Filler.handle := HandleFiller;
   Viewers.InitTrack(SW, H, Filler) (*init system track*)
END OpenDisplay;

PROCEDURE DisplayWidth* (X: INTEGER): INTEGER;
BEGIN RETURN DW
END DisplayWidth;

PROCEDURE DisplayHeight* (X: INTEGER): INTEGER;
BEGIN RETURN DH
END DisplayHeight;

PROCEDURE OpenTrack* (X, W: INTEGER);
  VAR Filler: Viewers.Viewer;
BEGIN
```

```
  NEW(Filler); Filler.handle := HandleFiller;
  Viewers.OpenTrack(X, W, Filler)
END OpenTrack;

PROCEDURE UserTrack* (X: INTEGER): INTEGER;
BEGIN RETURN X DIV DW * DW
END UserTrack;

PROCEDURE SystemTrack* (X: INTEGER): INTEGER;
BEGIN RETURN X DIV DW * DW + DW DIV 8 * 5
END SystemTrack;

PROCEDURE UY (X: INTEGER): INTEGER;
  VAR fil, bot, alt, max: Display.Frame;
BEGIN
  Viewers.Locate(X, 0, fil, bot, alt, max);
  IF fil.H >= DH DIV 8 THEN RETURN DH END;
  RETURN max.Y + max.H DIV 2
END UY;

PROCEDURE AllocateUserViewer* (DX: INTEGER; VAR X, Y: INTEGER);
BEGIN
  IF Pointer.on THEN X := Pointer.X; Y := Pointer.Y
  ELSE X := DX DIV DW * DW; Y := UY(X)
  END
END AllocateUserViewer;

PROCEDURE SY (X: INTEGER): INTEGER;
  VAR fil, bot, alt, max: Display.Frame;
BEGIN
  Viewers.Locate(X, DH, fil, bot, alt, max);
  IF fil.H >= DH DIV 8 THEN RETURN DH END;
  IF max.H >= DH - H0 THEN RETURN max.Y + H3 END;
  IF max.H >= H3 - H0 THEN RETURN max.Y + H2 END;
  IF max.H >= H2 - H0 THEN RETURN max.Y + H1 END;
  IF max # bot THEN RETURN max.Y + max.H DIV 2 END;
  IF bot.H >= H1 THEN RETURN bot.H DIV 2 END;
  RETURN alt.Y + alt.H DIV 2
END SY;

PROCEDURE AllocateSystemViewer* (DX: INTEGER; VAR X, Y: INTEGER);
BEGIN
  IF Pointer.on THEN X := Pointer.X; Y := Pointer.Y
    ELSE X := DX DIV DW * DW + DW DIV 8 * 5; Y := SY(X)
  END
END AllocateSystemViewer;

PROCEDURE MarkedViewer* (): Viewers.Viewer;
BEGIN RETURN Viewers.This(Pointer.X, Pointer.Y)
END MarkedViewer;

PROCEDURE PassFocus* (V: Viewers.Viewer);
  VAR M: ControlMsg;
BEGIN M.id := defocus; FocusViewer.handle(FocusViewer, M); FocusViewer := V
END PassFocus;
```

```
(*command interpretation*)

PROCEDURE Call* (VAR name: ARRAY OF CHAR; par: ParList; new: BOOLEAN;
   VAR res: INTEGER);
   VAR Mod: Modules.Module; P: Modules.Command; i, j: INTEGER;
BEGIN res := 1;
  i := 0; j := 0;
  WHILE name[j] # 0X DO
    IF name[j] = "." THEN i := j END;
    INC(j)
  END;
  IF i > 0 THEN
    name[i] := 0X;
      IF new THEN Modules.Free(name, FALSE) END;
      Mod := Modules.ThisMod(name);
      IF Modules.res = 0 THEN
         INC(i); j := i;
         WHILE name[j] # 0X DO name[j - i] := name[j]; INC(j) END;
         name[j - i] := 0X;
         P := Modules.ThisCommand(Mod, name);
         IF Modules.res = 0 THEN
            Par := par; Par.vwr := Viewers.This(par.frame.X, par.frame.Y); P; res := 0
         END
      ELSE res := Modules.res
      END
   END
END Call;

PROCEDURE GetSelection* (VAR text: Texts.Text; VAR beg, end, time: LONGINT);
   VAR M: SelectionMsg;
BEGIN
   M.time := -1; Viewers.Broadcast(M);
   text := M.text; beg := M.beg; end := M.end; time := M.time
END GetSelection;

PROCEDURE* GC;
   VAR x: LONGINT;
BEGIN IF ActCnt <= 0 THEN Kernel.GC; ActCnt := BasicCycle END
END GC;

PROCEDURE Install* (T: Task);
   VAR t: Task;
BEGIN t := PrevTask;
   WHILE (t.next # PrevTask) & (t.next # T) DO t := t.next END;
   IF t.next = PrevTask THEN T.next := PrevTask; t.next := T END
END Install;

PROCEDURE Remove* (T: Task);
   VAR t: Task;
BEGIN t := PrevTask;
   WHILE (t.next # T) & (t.next # PrevTask) DO t := t.next END;
   IF t.next = T THEN t.next := t.next.next; PrevTask := t.next END;
   IF CurTask = T THEN CurTask := PrevTask.next END
END Remove;

PROCEDURE Collect* (count: INTEGER);
```

```
BEGIN ActCnt := count
END Collect;

PROCEDURE SetFont* (fnt: Fonts.Font);
BEGIN CurFnt := fnt
END SetFont;

PROCEDURE SetColor* (col: SHORTINT);
BEGIN CurCol := col
END SetColor;

PROCEDURE SetOffset* (voff: SHORTINT);
BEGIN CurOff := voff
END SetOffset;

PROCEDURE Loop*;
  VAR V: Viewers.Viewer; M: InputMsg; N: ControlMsg;
     prevX, prevY, X, Y: INTEGER; keys: SET; ch: CHAR;
BEGIN
  LOOP
    Input.Mouse(keys, X, Y);
    IF Input.Available() > 0 THEN Input.Read(ch);
      IF ch < 0F0X THEN
        IF ch = ESC THEN
          N.id := neutralize; Viewers.Broadcast(N); FadeCursor(Pointer)
        ELSIF ch = SETUP THEN
          N.id := mark; N.X := X; N.Y := Y; V := Viewers.This(X, Y); V.handle(V, N)
        ELSE
          IF ch < " " THEN
            IF ch = 1X THEN ch := 83X (*ƒ*)
            ELSIF ch = 0FX THEN ch := 84X (*„*)
            ELSIF ch = 15X THEN ch := 85X (*…*)
            END
          ELSIF ch > "~" THEN
            IF ch = 81X THEN ch := 80X (*€*)
            ELSIF ch = 8FX THEN ch := 81X (*   *)
            ELSIF ch = 95X THEN ch := 82X (*‚*)
            END
          END;
          M.id := consume; M.ch := ch; M.fnt := CurFnt; M.col := CurCol; M.voff := CurOff;
          FocusViewer.handle(FocusViewer, M);
          DEC(ActCnt)
        END
      ELSIF ch = 0F1X THEN Display.SetMode(0, {})   (*on*)
      ELSIF ch = 0F2X THEN Display.SetMode(0, {0})  (*off*)
      ELSIF ch = 0F3X THEN Display.SetMode(0, {2})  (*inv*)
      END
    ELSIF keys # {} THEN
      M.id := track; M.X := X; M.Y := Y; M.keys := keys;
      REPEAT
        V := Viewers.This(M.X, M.Y); V.handle(V, M);
        Input.Mouse(M.keys, M.X, M.Y)
      UNTIL M.keys = {};
      DEC(ActCnt)
    ELSE
      IF (X # prevX) OR (Y # prevY) OR ~Mouse.on THEN
```

```
            M.id := track; M.X := X; M.Y := Y; M.keys := keys; V := Viewers.This(X, Y);
            V.handle(V, M);
            prevX := X; prevY := Y
          END;
          CurTask := PrevTask.next;
          IF ~CurTask.safe THEN PrevTask.next := CurTask.next END;
          CurTask.handle; PrevTask.next := CurTask; PrevTask := CurTask
        END
      END
    END Loop;

BEGIN User[0] := 0X;
    Arrow.Fade := FlipArrow; Arrow.Draw := FlipArrow;
    Star.Fade := FlipStar; Star.Draw := FlipStar;
    OpenCursor(Mouse); OpenCursor(Pointer);

    DW := Display.Width; DH := Display.Height; CL := Display.ColLeft;
    H3 := DH - DH DIV 3;
    H2 := H3 - H3 DIV 2;
    H1 := DH DIV 5;
    H0 := DH DIV 10;

    OpenDisplay(DW DIV 8 * 5, DW DIV 8 * 3, DH);
    FocusViewer := Viewers.This(0, 0);

    CurFnt := Fonts.Default;
    CurCol := Display.white;
    CurOff := 0;

    Collect(BasicCycle);
    NEW(PrevTask);
    PrevTask.handle := GC;
    PrevTask.safe := TRUE;
    PrevTask.next := PrevTask;

    Mod := Modules.ThisMod("System");
    Display.SetMode(0, {})

END Oberon.



MODULE System; (* JG 11.11.90*)

    IMPORT Kernel, Input, Oberon, Fonts, Texts;

    CONST
      StandardMenu = "System.Close System.Copy System.Grow Edit.Search Edit.Store";
      LogMenu = "System.Close System.Grow Edit.Locate Edit.Store";

    VAR W: Texts.Writer;

    PROCEDURE Max (i, j: LONGINT): LONGINT;
    BEGIN IF i >= j THEN RETURN i ELSE RETURN j END
    END Max;
```

```
(* ------------- Toolbox for system management ---------------*)

PROCEDURE SetUser*;
  VAR i: INTEGER; ch: CHAR;
    user: ARRAY 8 OF CHAR;
    password: ARRAY 16 OF CHAR;
BEGIN
  i := 0; Input.Read(ch);
  WHILE (ch # "/") & (i < 7) DO user[i] := ch; INC(i); Input.Read(ch) END;
  user[i] := 0X; i := 0; Input.Read(ch);
  WHILE (ch > " ") & (i < 15) DO password[i] := ch; INC(i); Input.Read(ch) END;
  password[i] := 0X;
  Oberon.SetUser(user, password)
END SetUser;

PROCEDURE SetFont*;
  VAR beg, end, time: LONGINT;
    T: Texts.Text; S: Texts.Scanner;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN
      Texts.OpenScanner(S, T, beg); Texts.Scan(S);
      IF S.class = Texts.Name THEN Oberon.SetFont(Fonts.This(S.s)) END
    END
  ELSIF S.class = Texts.Name THEN Oberon.SetFont(Fonts.This(S.s))
  END
END SetFont;

PROCEDURE SetColor*;
  VAR beg, end, time: LONGINT;
    T: Texts.Text; S: Texts.Scanner; ch: CHAR;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN
      Texts.OpenReader(S, T, beg); Texts.Read(S, ch); Oberon.SetColor(S.col)
    END
  ELSIF S.class = Texts.Int THEN Oberon.SetColor(SHORT(SHORT(S.i)))
  END
END SetColor;

PROCEDURE SetOffset*;
  VAR beg, end, time: LONGINT;
    T: Texts.Text;S: Texts.Scanner; ch: CHAR;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN
      Texts.OpenReader(S, T, beg); Texts.Read(S, ch); Oberon.SetColor(S.voff)
    END
  ELSIF S.class = Texts.Int THEN Oberon.SetOffset(SHORT(SHORT(S.i)))
  END
END SetOffset;

PROCEDURE Time*;
```

```
    VAR par: Oberon.ParList;
      S: Texts.Scanner;
      t, d, hr, min, sec, yr, mo, day: LONGINT;
  BEGIN par := Oberon.Par;
    Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
    IF S.class = Texts.Int THEN (*set date*)
      day := S.i; Texts.Scan(S); mo := S.i; Texts.Scan(S); yr := S.i; Texts.Scan(S);
      hr := S.i; Texts.Scan(S); min := S.i; Texts.Scan(S); sec := S.i;
      t := (hr*64 + min)*64 + sec; d := (yr*16 + mo)*32 + day;
      Kernel.SetClock(t, d)
    ELSE (*read date*)
      Texts.WriteString(W, "System.Time");
      Oberon.GetClock(t, d); Texts.WriteDate(W, t, d); Texts.WriteLn(W);
      Texts.Append(Oberon.Log, W.buf)
    END
  END Time;

  PROCEDURE Collect*;
  BEGIN Oberon.Collect(0)
  END Collect;

BEGIN Texts.OpenWriter(W)
END System.
```

4. The Display System

The display screen is the most important part of the interface presented by a personal workstation to its users. At first sight, it simply represents a rectangular output area. However, in combination with the mouse, it quickly develops into a sophisticated interactive input/output platform of almost unlimited flexibility. It is mainly its Janus-faced characteristic that makes the display screen stand out from ordinary external devices to be managed by the operating system. In the current Chapter we shall give more detailed insight into the reasons for the central position the display system takes within the operating system, and for its determining influence on the entire system architecture. In particular, we shall show that the display system is a natural basis or anchor for functional extensibility.

4.1. Screen Layout Model

In the early seventies, Xerox PARC in California launched the Smalltalk-project with the goal of conceiving and developing new and more natural ways to communicate with personal computers [Goldberg]. Perhaps the most conspicuous among several significant achievements of this endeavour is the idea of applying the desktop metaphor to the display screen. This metaphor comprises a desktop and a collection of possibly mutually overlapping pages of paper that are laid out on the desktop. By projecting such a configuration onto the surface of a screen we get the (today) familiar picture of Figure 4.1(a) showing a collection of partially or totally visible rectangular areas on a background, so-called *windows* or *viewers*.

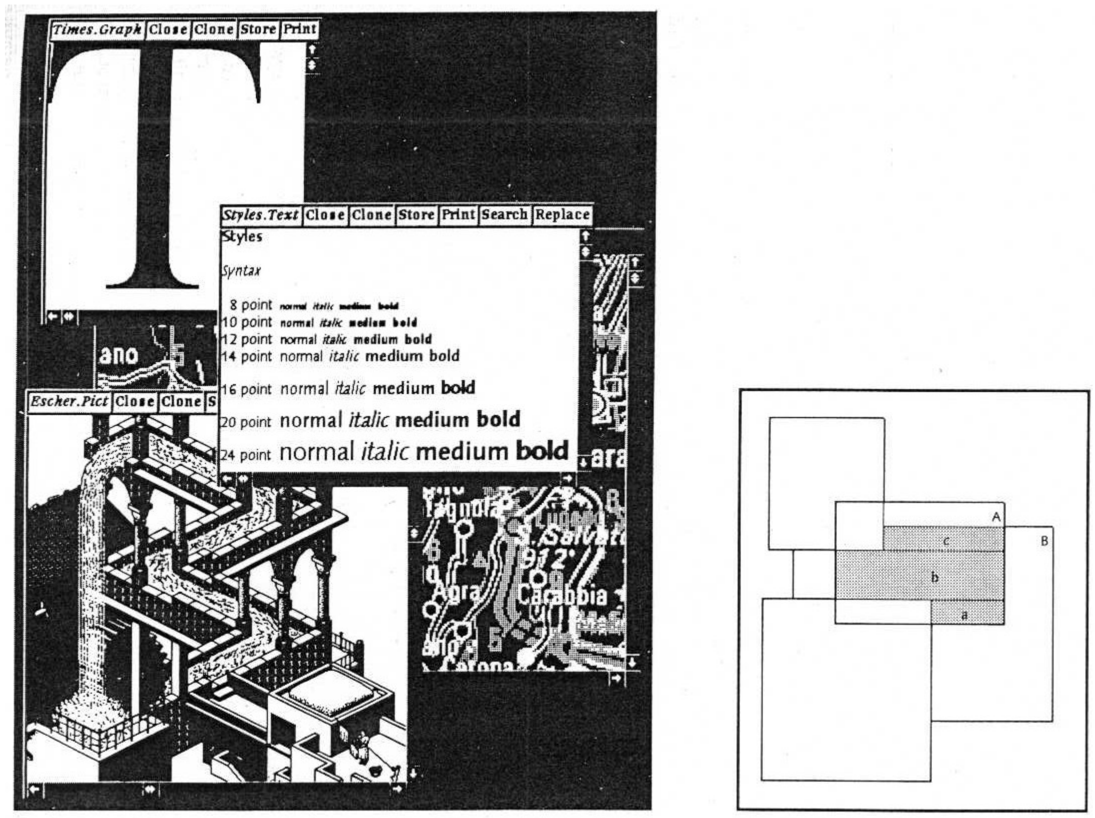
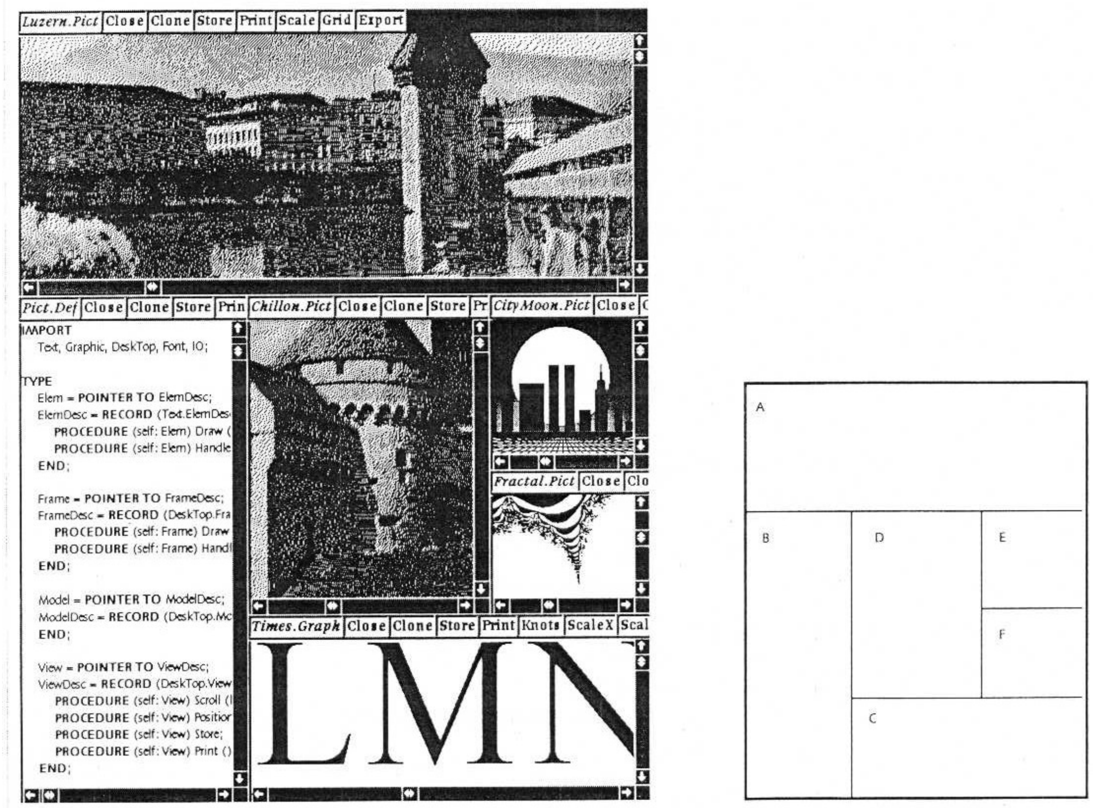

Times.Graph Close Clone Store Print
Styles.Text Close Clone Store Print Search Replace
Styles
Syntax
8 point normal italic medium bold
10 point normal italic medium bold
12 point normal italic medium bold
14 point normal italic medium bold
16 point normal italic medium bold
20 point normal italic medium bold
24 point normal italic medium bold
Escher.Pict Close Clone S
A
B
c
b
a

Figure 4.1 (a) Simulated desktop, showing overlapping viewers. (b) Partial overlappings in the desktop model.

The desktop metaphor is used by many modern operating systems and user interface shells both as a natural model for the system to separate displayed data belonging to different tasks, and as a powerful tool for users to organize the display screen interactively, according to individual taste and preference.

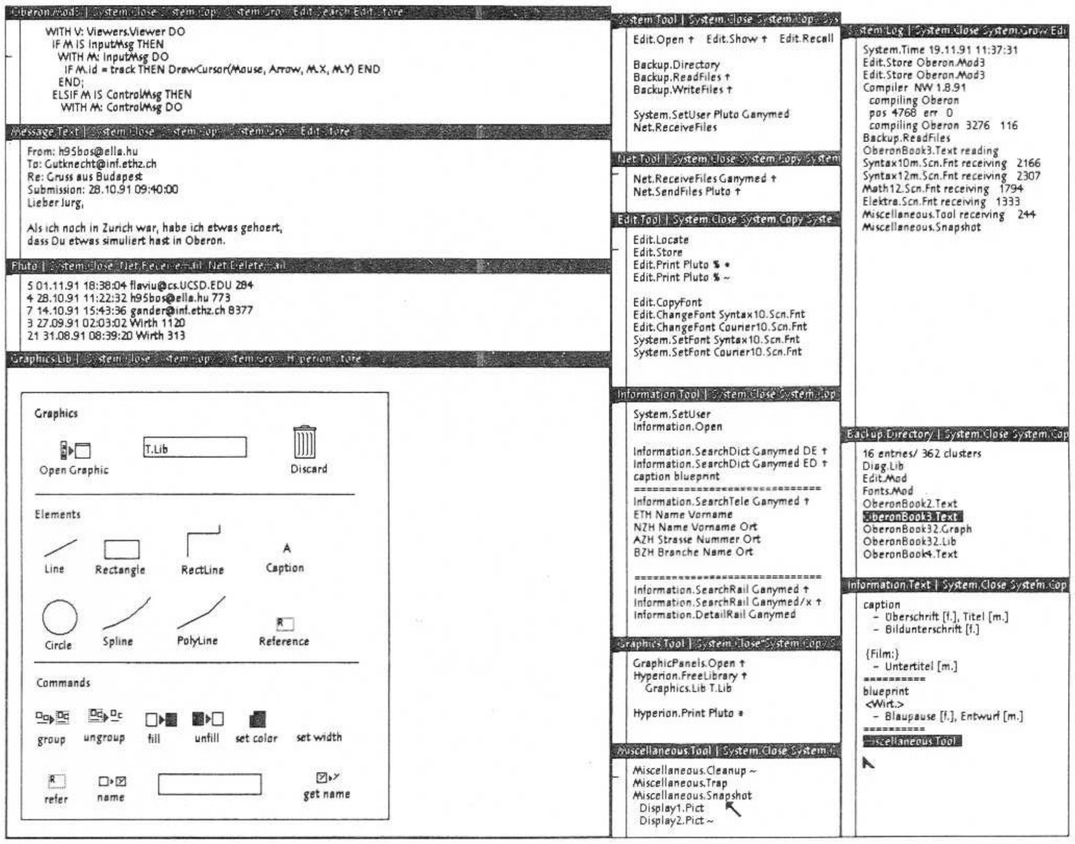
However, there are inherent drawbacks in the metaphor. They are primarily connected with overlapping. Firstly, any efficient management of overlapping viewers must rely on a subordinate management of (arbitrary) sub-rectangles and on sophisticated clipping operations. This is so because partially overlapped viewers must be partially restored under control of the viewer manager. For example, in Figure 4.1(b), rectangles *a*, *b*, and *c* of viewer *A* ought to be restored individually after closing of viewer *B*. Secondly, there is a significant danger of covering viewers completely and losing them forever. And thirdly, no canonical heuristic algorithms exist for automatic allocation of screen space to newly opened viewers.

Experience has shown that partial overlapping is desirable and beneficial in rare cases only, and so the additional complexity of its management [Binding, Wille] is hard to justify. Therefore, alternate strategies to structure a display screen have been looked for. An interesting class of established solutions can be titled as *tiling*. There are several variants of tiling [Cohen]. Perhaps the most obvious one (because most unconstrained one) is based on iterated horizontal or vertical splitting of existing viewers. Starting with the full screen and successively opening viewers *A*, *B*, *C*, *D*, *E*, and *F* we get to a configuration as in Figure 4.2. A second variant is hierarchic tiling. Again, the hierarchy starts with a full screen that is now decomposed into a number of vertical tracks, each of which is further decomposed into a number of horizontal viewers. Figure 4.3 shows a snapshot of a hierarchically tiled display screen. We decided in favor of this kind of tiling in Oberon, mainly because the algorithm of reusing the area of a closed viewer is simpler and more uniform. For example, assume that in Figure 4.2 viewer *F* has been closed. Then, it is straightforward to reverse the previous opening operation by extending viewer *E* at its bottom end. However, if the closed viewer is *B*, no such simple procedure exists. For example, the freed area can be shared between viewers *C* and *D* by making them extend to their left. Clearly, no such complicated situations can occur in the case of hierarchic tiling.



```
IMPORT
   Text, Graphic, DeskTop, Font, IO;

TYPE
   Elem = POINTER TO ElemDesc;
   ElemDesc = RECORD (Text.ElemDes
      PROCEDURE (self: Elem) Draw (
      PROCEDURE (self: Elem) Handle
   END;

   Frame = POINTER TO FrameDesc;
   FrameDesc = RECORD (DeskTop.Fra
      PROCEDURE (self: Frame) Draw
      PROCEDURE (self: Frame) Handl
   END;

   Model = POINTER TO ModelDesc;
   ModelDesc = RECORD (DeskTop.Mc
   END;

   View = POINTER TO ViewDesc;
   ViewDesc = RECORD (DeskTop.View
      PROCEDURE (self: View) Scroll (I
      PROCEDURE (self: View) Positior
      PROCEDURE (self: View) Store;
      PROCEDURE (self: View) Print ()
   END;
```

Figure 4.2 (a) Screen layout produced by unconstrained tiling. (b) Viewer configuration resulting from uncontrained tiling.


Oberon.Mod3 | System.Close System.Copy System.Grow Edit.Search Edit.Store
Message.Text | System.Close System.Copy System.Grow Edit.Store
Pluto | System.Close Net.ReceiveMail Net.DeleteMail
Graphics.Lib | System.Close System.Copy System.Grow Hyperion.Store
Graphics
T.Lib
Open Graphic
Discard
Elements
Line
Rectangle
RectLine
A
Caption
Circle
Spline
PolyLine
Reference
Commands
group
ungroup
fill
unfill
set color
set width
refer
name
get name
System.Tool | System.Close System.Copy Sys
Net.Tool | System.Close System.Copy System
Edit.Tool | System.Close System.Copy Syste
Information.Tool | System.Close System.Cop
Graphics.Tool | System.Close System.Copy S
Miscellaneous.Tool | System.Close System.C
System.Log | System.Close System.Grow Edi
Backup.Directory | System.Close System.Cop
Information.Text | System.Close System.Cop

```
WITH V: Viewers.Viewer DO
  IF M IS InputMsg THEN
    WITH M: InputMsg DO
      IF M.id = track THEN DrawCursor(Mouse, Arrow, M.X, M.Y) END
    END;
  ELSIF M IS ControlMsg THEN
    WITH M: ControlMsg DO
```

```
From: h95bos@ella.hu
To: Gutknecht@inf.ethz.ch
Re: Gruss aus Budapest
Submission: 28.10.91 09:40:00
Lieber Jurg,

Als ich noch in Zurich war, habe ich etwas gehoert,
dass Du etwas simuliert hast in Oberon.
```

```
5 01.11.91 18:38:04 flaviu@cs.UCSD.EDU 284
4 28.10.91 11:22:32 h95bos@ella.hu 773
7 14.10.91 15:43:36 gander@inf.ethz.ch 8377
3 27.09.91 02:03:02 Wirth 1120
21 31.08.91 08:39:20 Wirth 313
```

```
Edit.Open ↑   Edit.Show ↑   Edit.Recall

Backup.Directory
Backup.ReadFiles ↑
Backup.WriteFiles ↑

System.SetUser Pluto Ganymed
Net.ReceiveFiles
```

```
Net.ReceiveFiles Ganymed ↑
Net.SendFiles Pluto ↑
```

```
Edit.Locate
Edit.Store
Edit.Print Pluto % *
Edit.Print Pluto % ~

Edit.CopyFont
Edit.ChangeFont Syntax10.Scn.Fnt
Edit.ChangeFont Courier10.Scn.Fnt
System.SetFont Syntax10.Scn.Fnt
System.SetFont Courier10.Scn.Fnt
```

```
System.SetUser
Information.Open

Information.SearchDict Ganymed DE ↑
Information.SearchDict Ganymed ED ↑
caption blueprint
==============================
Information.SearchTele Ganymed ↑
ETH Name Vorname
NZH Name Vorname Ort
AZH Strasse Nummer Ort
BZH Branche Name Ort

==============================
Information.SearchRail Ganymed ↑
Information.SearchRail Ganymed/x ↑
Information.DetailRail Ganymed
```

```
GraphicPanels.Open ↑
Hyperion.FreeLibrary ↑
  Graphics.Lib T.Lib

Hyperion.Print Pluto *
```

```
Miscellaneous.Cleanup ~
Miscellaneous.Trap
Miscellaneous.Snapshot
 Display1.Pict
 Display2.Pict ~
```

```
System.Time 19.11.91 11:37:31
Edit.Store Oberon.Mod3
Edit.Store Oberon.Mod3
Compiler  NW 1.8.91
 compiling Oberon
 pos 4768  err  0
 compiling Oberon  3276   116
Backup.ReadFiles
OberonBook3.Text reading
Syntax10m.Scn.Fnt receiving   2166
Syntax12m.Scn.Fnt receiving   2307
Math12.Scn.Fnt receiving   1794
Elektra.Scn.Fnt receiving   1333
Miscellaneous.Tool receiving   244
Miscellaneous.Snapshot
```

```
16 entries/ 362 clusters
Diag.Lib
Edit.Mod
Fonts.Mod
OberonBook2.Text
OberonBook3.Text
OberonBook32.Graph
OberonBook32.Lib
OberonBook4.Text
```

```
caption
  - Überschrift [f.], Titel [m.]
  - Bildunterschrift [f.]

{Film:}
  - Untertitel [m.]
==========
blueprint
<Wirt.>
  - Blaupause [f.], Entwurf [m.]
==========
Miscellaneous.Tool
```

Figure 4.3 Screen layout produced by hierarchic tiling.

Hierarchic tiling is also used in Xerox PARC's Cedar system [Teitelman]. However, the Oberon variant differs from the Cedar variant in some respects. Firstly, Oberon supports quick temporary context switching by overlaying one track or any contiguous sequence of tracks with new layers. In Figure 4.4 a snapshot of a standard Oberon display screen is graphically represented. It suggests two original tracks and two levels of overlay, where the top layer is screen-filling. Secondly, unlike Cedar display screens, Oberon displays do not provide reserved areas for system-wide facilities. As depicted in Figure 4.5, standard Cedar screens feature a command row at the top and an icon row at the bottom. And thirdly, Oberon is based on a different heuristic strategy for the automatic placement of new viewers. As a Cedar default invariant, the area of every track is divided up evenly among the viewers in this track. When a new viewer is to be placed, the existing viewers in the track are requested to reduce their size and move up appropriately. The newly opened viewer is then allocated in the freed spot at the bottom. In contrast, Oberon normally splits the largest existing viewer in a given track into two halves of equal size. As an advantage of this latter allocation strategy we note that existing contents are kept stable.

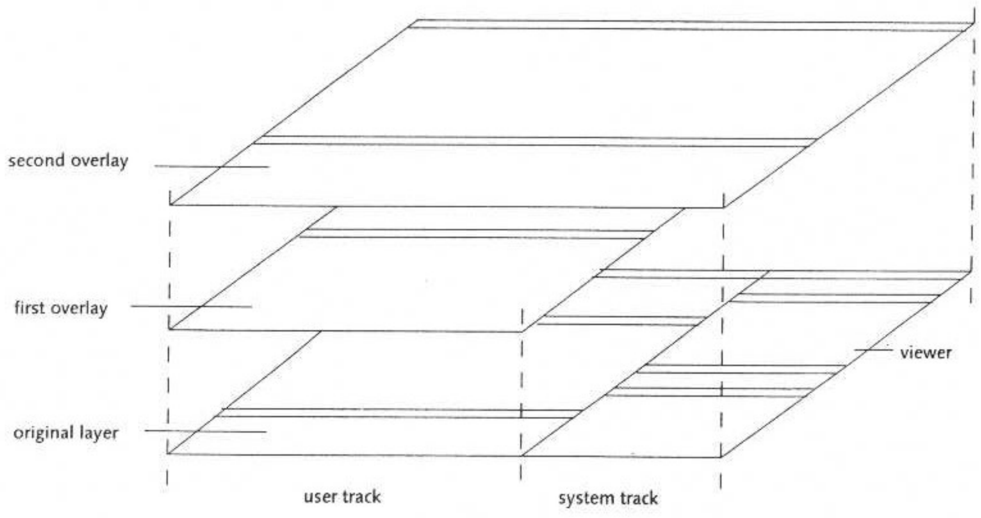
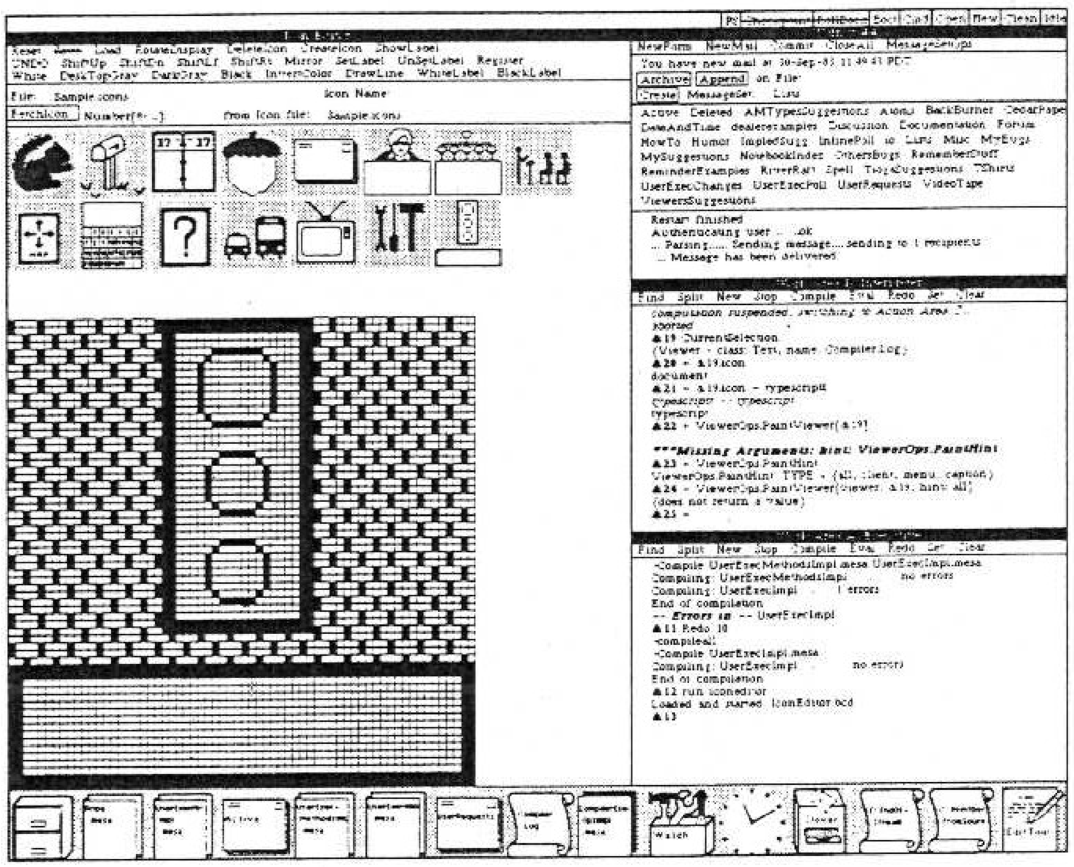


Figure 4.4 Overlays of tracks and of sequences of tracks.


Reset Load RoundDisplay DeleteIcon CreateIcon ShowLabel
UNDO ShiftUp ShiftDn ShiftLf ShiftRt Mirror SetLabel UnSetLabel Register
White DeskTopGray DarkGray Black InvertColor DrawLine WhiteLabel BlackLabel
File: Sample.icons
Icon Name
FetchIcon Number[0-]
from Icon file: Sample.icons
NewForm NewMail Commit CloseAll MessageSetOps
Archive Append on File:
Create MessageSet: Luis
Active Deleted AMTypesSuggestions Aloud BackBurner CedarPaper
DateAndTime dealerexamples Discussion Documentation Forum
HowTo Humor ImpliedSugg InlinePoll io Luis Misc MyBugs
MySuggestions NotebookIndex OthersBugs RememberStuff
ReminderExamples RiverRaft Spell TiogaSuggestions TShirts
UserExecChanges UserExecPoll UserRequests VideoTape
ViewersSuggestions
Find Split New Stop Compile Eval Redo Set Clear
Find Split New Stop Compile Eval Redo Set Clear
Watch
Clover
EditTool

```
You have new mail at 30-Sep-85 11:49:41 PDT
```

```
Restart finished
Authenticating user ... ok
... Parsing..... Sending message.... sending to 1 recipients
... Message has been delivered
```

```
computation suspended, switching to Action Area 2
aborted
▲19 CurrentSelection
(Viewer - class: Text, name: CompilerLog)
▲20 ← &19.icon
document
▲21 ← &19.icon ← typescript
typescript -- typescript
typescript
▲22 ← ViewerOps.PaintViewer[&19]

***Missing Arguments: hint: ViewerOps.PaintHint
▲23 ← ViewerOps.PaintHint
ViewerOps.PaintHint: TYPE = {all, client, menu, caption}
▲24 ← ViewerOps.PaintViewer[viewer: &19, hint: all]
(does not return a value)
▲25 ←
```

```
-Compile UserExecMethodsImpl.mesa UserExecImpl.mesa
Compiling: UserExecMethodsImpl          no errors
Compiling: UserExecImpl         1 errors
End of compilation
-- Errors in -- UserExecImpl
▲11 Redo 10
-compileall
-Compile UserExecImpl.mesa
Compiling: UserExecImpl            no errors
End of compilation
▲12 run iconeditor
Loaded and started IconEditor.bcd
▲13
```

Figure 4.5 The layout of a standard Cedar screen showing command row and icon row.

4.2. Viewers as Objects

Although everybody seems to agree on the meaning of the term *viewer*, no two different system designers actually do. The original role of a viewer as merely a separate display area has meanwhile become heavily overloaded with additional functionality. Depending on the underlying system are viewers individual views on a certain configuration of objects, carriers of tasks, processes, applications, etc. Therefore, we first need to define our own precise understanding of the concept of viewer.

The best guide to this aim is the abstract data type *Viewer* that we introduced in Chapter 3. We recapitulate: Type *Viewer* serves as a template describing viewers abstractly as “black boxes” in terms of a state of visibility, a rectangle on the display screen, and a message handler. The exact functional interface provided by a given variant of viewer is determined by the set of messages accepted. This set is structured as a customized hierarchy of type extensions.

We can now obtain a more concrete specification of the role of viewer by identifying some basic categories of universal messages that are expected to be accepted by all variants of viewer. For example, we know that messages reporting about user interactions as well as messages defining a generic operation are universal. These two categories of universal messages document the roles of viewers as interactive tasks and as parts of an integrated system respectively.

In total, there are four such categories. They are listed in Table 4.1, together with the corresponding topics and message dispatchers.

Table 4.1

Dispatcher	Topic	Message
Task scheduler	dispatching of interactive tasks	reports user interaction
Command interpreter	processing of integrated command	defines generic operation
Viewer manager	organizing the display area	requests change of location or size
Document manager	operating on documents	reports change of contents or format

These topics essentially define the role of Oberon viewers. In short, we may look at an Oberon viewer as a non-overlapped rectangular box on the screen both acting as an integrated display area for some objects of a document and representing an interactive task in the form of a sensitive editing area.

Shifting emphasis a little and regarding the various message dispatchers as subsystems, we recognize immediately the role of viewers as integrators of the different subsystems via message-based interfaces. In this light type *Viewer* appears as a common object-oriented basis of Oberon's subsystems.

The topics emphasized in Table 4.1 constitute some kind of backbone of the contents of the Chapters 3, 4 and 5. Task scheduling and command interpreting are already familiar to us from Sections 3.2 and 3.3. Viewer management and text management will be the topics of Sections 4.4 and 5.2 respectively. Thereby, the built-in type *Text* will serve as a prime example of a document type.

The activities that a viewer performs are basically controlled by *events* or, more precisely, by messages representing *event notices*. We shall explain this in detail in Sections 4.4 and 5.3 in the cases of an abstract class of standard viewers and a class of viewers displaying standard text respectively.

Here is a preliminary overview of some archetypal kinds of message:

- After each key stroke a *keyboard message* containing the typed character is sent to the current *focus viewer* and after each mouse click a *mouse message* reporting the new state of the mouse is sent to the viewer containing the current mouse position.
- A message often represents some *generic operation* that is expected to be interpreted individually by its recipients. Obvious examples in our context are "return current textual selection", "copy-over stretch of text", and "produce a copy (clone)". Notice that generic operations are the key to extensibility.

- In a tiling viewer environment, every opening of a new viewer and every change of size or location of an existing viewer has an obvious effect on adjacent viewers. The viewer manager therefore issues a message for every affected viewer requesting it to adjust its size appropriately.
- Whenever the contents or the format of a document has changed, a message notifying all visible viewers of the change is broadcast. Notice that broadcasting messages by a *model* (document) to the entirety of its potential *views* (viewers) is an interesting implementation of the famous *MVC (model-view-controller)* pattern that dispenses models from "knowing" (registering) their views.

4.3. Frames as Basic Display Entities

When we introduced viewers in Chapter 3 and in the previous Section, we simplified with the aim of abstraction. We know already that viewers appear as elements of second order in the tiling hierarchy. Having treated them as black boxes so far we have not revealed anything about the continuation of the hierarchy. As a matter of fact, viewers are neither elementary display entities nor atoms. They are just a special case of so-called *display frames*. Display frames or frames in short are arbitrary rectangles displaying a collection of objects or an excerpt of a document. In particular, frames may recursively contain other frames, a capability that makes them an extremely powerful tool for any display organizer.

The type *Frame* is declared as

```
Frame = POINTER TO FrameDesc;

FrameDesc = RECORD
  next, dsc: Frame;
  X, Y, W, H: INTEGER;
  handle: Handler
END;
```

The components *next* and *dsc* are connections to further frames. Their names suggest a multi-level recursive hierarchical structure: *next* points to the next frame on the same level, while *dsc* points to the (first) descendant, i.e. to the next lower level of the hierarchy of nested frames. *X*, *Y*, *W*, *H*, and the handler *handle* serve the original purpose to that we introduced them. In particular, the handler allows frames to react individually on the receipt of messages. Its type is

```
Handler = PROCEDURE (F: Frame; VAR M: FrameMsg);
```

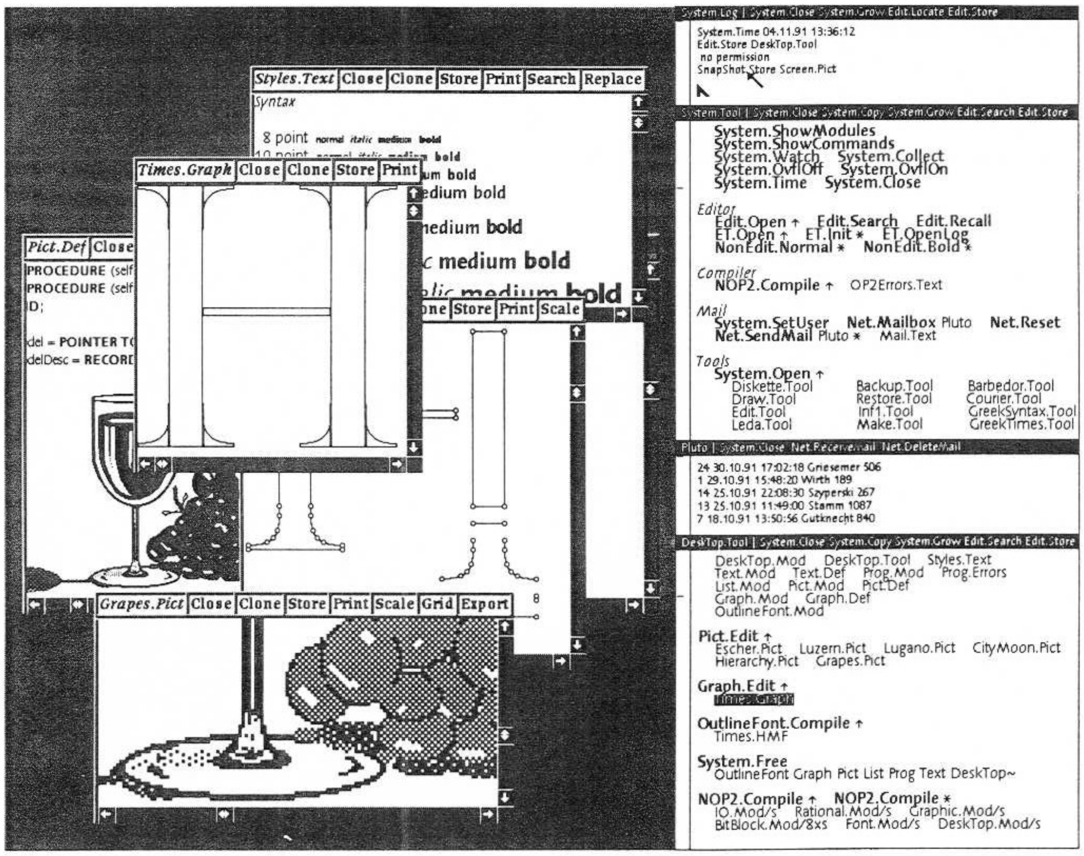
where *FrameMsg* represents the root of a potentially unlimited tree hierarchy of possible messages to frames:

```
FrameMsg = RECORD END;
```

Having now introduced the concept of frames, we can reveal the whole truth about viewers. As a matter of fact, type *Viewer* is a derived type, it is a type extension of *Frame*:

```
Viewer = POINTER TO ViewerDesc;

ViewerDesc = RECORD (FrameDesc)
  state: INTEGER
END;
```

These declarations formally express the fact that viewers are nothing but a special case (or variant or subclass) of general frames, additionally featuring a state of visibility. In particular, viewers inherit the hierarchical structure of frames. This is an extremely useful property immediately opening an unlimited spectrum of possibilities for designers of a specific subclass of viewers to organize the representing rectangular area. For example, the area of viewers of, say, class *Desktop* may take the role of a background being covered by an arbitrary collection of possibly mutually overlapping frames. See Figure 4.6 for an example. In other words, our decision of using a tiling viewer scheme *globally* can easily be overwritten *locally*.


Styles.Text Close Clone Store Print Search Replace
Syntax
8 point normal italic medium bold
Times.Graph Close Clone Store Print
medium bold
Pict.Def Close
PROCEDURE (self
PROCEDURE (self
Store Print Scale
Grapes.Pict Close Clone Store Print Scale Grid Export

```
System.Log | System.Close System.Grow Edit.Locate Edit.Store
System.Time 04.11.91 13:36:12
Edit.Store DeskTop.Tool
 no permission
SnapShot.Store Screen.Pict

System.Tool | System.Close System.Copy System.Grow Edit.Search Edit.Store
   System.ShowModules
   System.ShowCommands
   System.Watch    System.Collect
   System.OvflOff   System.OvflOn
   System.Time    System.Close

Editor
   Edit.Open ↑    Edit.Search    Edit.Recall
   ET.Open ↑    ET.Init *    ET.OpenLog
   NonEdit.Normal *    NonEdit.Bold *

Compiler
   NOP2.Compile ↑    OP2Errors.Text

Mail
   System.SetUser    Net.Mailbox Pluto    Net.Reset
   Net.SendMail Pluto *    Mail.Text

Tools
   System.Open ↑
      Diskette.Tool      Backup.Tool      Barbedor.Tool
      Draw.Tool          Restore.Tool     Courier.Tool
      Edit.Tool          Inf1.Tool        GreekSyntax.Tool
      Leda.Tool          Make.Tool        GreekTimes.Tool

Pluto | System.Close  Net.ReceiveMail  Net.DeleteMail
24 30.10.91 17:02:18 Griesemer 506
1 29.10.91 15:48:20 Wirth 189
14 25.10.91 22:08:30 Szyperski 267
13 25.10.91 11:49:00 Stamm 1087
7 18.10.91 13:50:56 Gutknecht 840

DeskTop.Tool | System.Close System.Copy System.Grow Edit.Search Edit.Store
   DeskTop.Mod    DeskTop.Tool    Styles.Text
   Text.Mod    Text.Def    Prog.Mod    Prog.Errors
   List.Mod    Pict.Mod    Pict.Def
   Graph.Mod    Graph.Def
   OutlineFont.Mod

Pict.Edit ↑
   Escher.Pict    Luzern.Pict    Lugano.Pict    CityMoon.Pict
   Hierarchy.Pict    Grapes.Pict

Graph.Edit ↑
   Times.Graph

OutlineFont.Compile ↑
   Times.HMF

System.Free
   OutlineFont Graph Pict List Prog Text DeskTop~

NOP2.Compile ↑    NOP2.Compile *
   IO.Mod/s    Rational.Mod/s    Graphic.Mod/s
   BitBlock.Mod/8xs    Font.Mod/s    DeskTop.Mod/s
```

Figure 4.6 A viewer class desktop organizing overlapping frames.

An even more important example of a predefined structure is provided by the abstract class of so-called *menu viewers* whose shape is familiar from most snapshots taken of the standard Oberon display screen. A menu viewer consists of a thin rectangular boundary line and an interior area being vertically decomposed into a menu region at the top and a contents region at the bottom (see Figure 4.7).

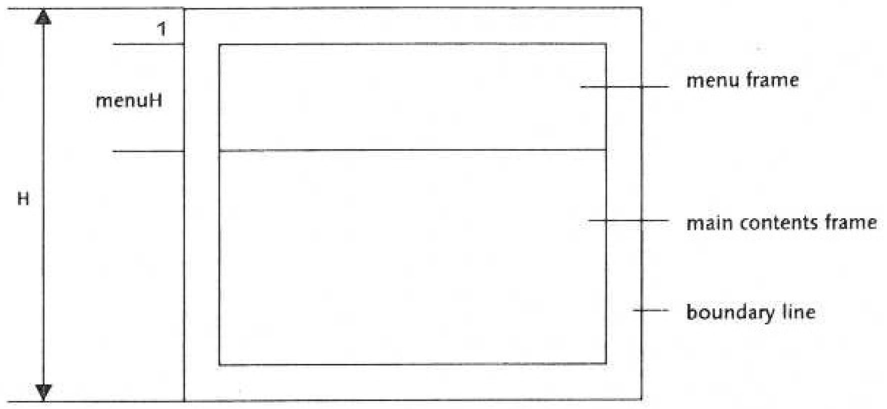


Figure 4.7 The compositional structure of a menu viewer.

In terms of data structures, the class of menu viewers is defined as a type extension of *Viewer* with an additional component *menuH* specifying the height of the menu frame:

```
MenuViewer = POINTER TO MenuViewerDesc;

MenuViewerDesc = RECORD (ViewerDesc)
  menuH: INTEGER
END;
```

Each menu viewer *V* specifies exactly two descendants: The menu frame *V.dsc* and the frame of main contents or *main frame V.dsc.next*. Absolutely nothing is fixed about the contents of the two descendant frames. In the standard case, however, the menu frame is a text frame, displaying a line of commands in inverse video mode. By definition, the nature of the main frame specifies the type of the viewer. If it is a text frame as well, then we call the viewer a *text viewer*, if it a graphics frame, we call it a *graphics viewer* etc.

4.4. Display Management

Oberon's display system comprises two main topics: Viewer management and cursor handling. Let us first turn to the much more involved topic of viewer management and postpone cursor handling to the end of this Section. Before we can actually begin our explanations we need to introduce the concept of the *logical display area*. It is modeled as two-dimensional Cartesian plane housing the totality of objects to be displayed. The essential point of this abstraction is a rigorous decoupling of any aspects of physical display devices. As a matter of fact, any concrete assignment of display monitors to certain finite regions of the display area is a pure matter of configuring the system.

Being a subsystem of a system with a clear modular structure the display system appears in the form of a small hierarchy of modules. Its core is a linearly ordered set consisting of three modules: *Display*, *Viewers*, and *MenuViewers*, the latter building upon the formers. Conceptually, each module contributes an associated class of display-oriented objects and a collection of related service routines.

Table 4.2 provides an overview of the subsystem viewer management. In this table, modules on upper lines import modules on lower lines and types on upper lines extend types on lower lines.

Table 4.2

Module	Type	Service
MenuViewers	Viewer	Message handling for menu viewers
Viewers	Viewer	Tiling viewer management
Display	Frame	Block-oriented raster operations

Inspecting the column titled *Type* in Table 4.2 we recognize precisely our familiar types *Frame*, *Viewer*, and *MenuViewer* respectively, where the latter is an abbreviation of *MenuViewers.Viewer*.

In addition to the core modules of the display system a section in module *Oberon* provides a specialized application programming interface that simplifies the use of the viewer management package by applications in the case of standard Oberon display configurations. We shall come back to this topic in Section 4.6.

For the moment let us concentrate on the core of the viewer management and in particular on the modules *Viewers* and *MenuViewers*, saving the discussion of the module *Display* for the next Section. Typically, we start the presentation of a module by listing and commenting its definition, and we end it by discussing its implementation.

4.4.1. Viewers

Focusing first on module *Viewers* we can roughly define the domain of its responsibility as "initializing and maintaining the global layout of the display area". From the previous discussion we are well acquainted already with the structure of the global display space as well as with its building blocks: The display area is hierarchically tiled with display frames, where the first two levels in the frame hierarchy correspond to *tracks* and *viewers* respectively.

This is the formal definition:

```
DEFINITION Viewers;

  IMPORT Display;

  CONST restore = 0; modify = 1; suspend = 2; (*message ids*)

  TYPE
    Viewer = POINTER TO ViewerDesc;

    ViewerDesc = RECORD (Display.FrameDesc)
      state: INTEGER
    END;

    ViewerMsg = RECORD (Display.FrameMsg)
      id: INTEGER;
      X, Y, W, H: INTEGER;
      state: INTEGER
    END;

  VAR curW: INTEGER;

  (*track handling*)
  PROCEDURE InitTrack (W, H: INTEGER; Filler: Viewer);
  PROCEDURE OpenTrack (X, W: INTEGER; Filler: Viewer);
  PROCEDURE CloseTrack (X: INTEGER);

  (*viewer handling*)
  PROCEDURE Open (V: Viewer; X, Y: INTEGER);
  PROCEDURE Change (V: Viewer; Y: INTEGER);
  PROCEDURE Close (V: Viewer);

  (*miscellaneous*)
  PROCEDURE This (X, Y: INTEGER): Viewer;
  PROCEDURE Next (V: Viewer): Viewer;

  PROCEDURE Recall (VAR V: Viewer);
  PROCEDURE Locate (X, H: INTEGER; VAR fil, bot, alt, max: Viewer);

  PROCEDURE Broadcast (VAR M: Display.FrameMsg);

END Viewers.
```

Some comments: A first group of procedures consisting of *InitTrack*, *OpenTrack*, and *CloseTrack* supports the track structure of the display area. *InitTrack* creates a new track of width *W* and height *H* by partitioning off a vertical strip of width *W* from the display area. In addition, *InitTrack* initializes the newly created track with a *filler viewer* that is supplied as parameter. The filler viewer essentially serves as background filling up the track at its top end. It reduces to height *0* if the track is covered completely by productive viewers.

Configuring the display area is part of system initialization after startup. It amounts to executing a sequence of steps of the form

```
NEW(Filler); Filler.handle := HandleFiller; InitTrack(W, H, Filler)
```

where *HandleFiller* is supposed to handle messages that require modifications of size and cursor drawing.

The global variable *curW* indicates the width of the already configured part of the display area. Note that configuring starts with *x = 0* and is non-reversible in the sense that the grid defined by the initialized tracks cannot be refined later. However, remember that it can be made coarser at any time by overlaying a contiguous sequence of existing tracks by a single new track.

Procedure *OpenTrack* serves exactly this purpose. The track (or sequence of tracks) to be overlaid in the display-area must be spanned by the segment *[X, X + W).* Procedure *CloseTrack* is inverse to *OpenTrack*. It is called to close the (topmost) track located at *X* in the display area, and to restore the previously covered track (or sequence of tracks).

The next three procedures are used to organize viewers within individual tracks. Procedure *Open* allocates a given viewer at a given position. More precisely, *Open* locates the viewer containing the point *(X, Y),* splits it horizontally at height *Y*, and opens the viewer *V* in the lower part of the area. In the special case of *Y* coinciding with the upper boundary line of the located viewer this is closed automatically. Procedure *Change* allows to change the height of a given viewer *V* by moving its upper boundary line to a new location *Y* (within the limits of its neighbors). Procedure *Close* removes the given viewer *V* from the display area. Figure 4.8 makes these operations clear.

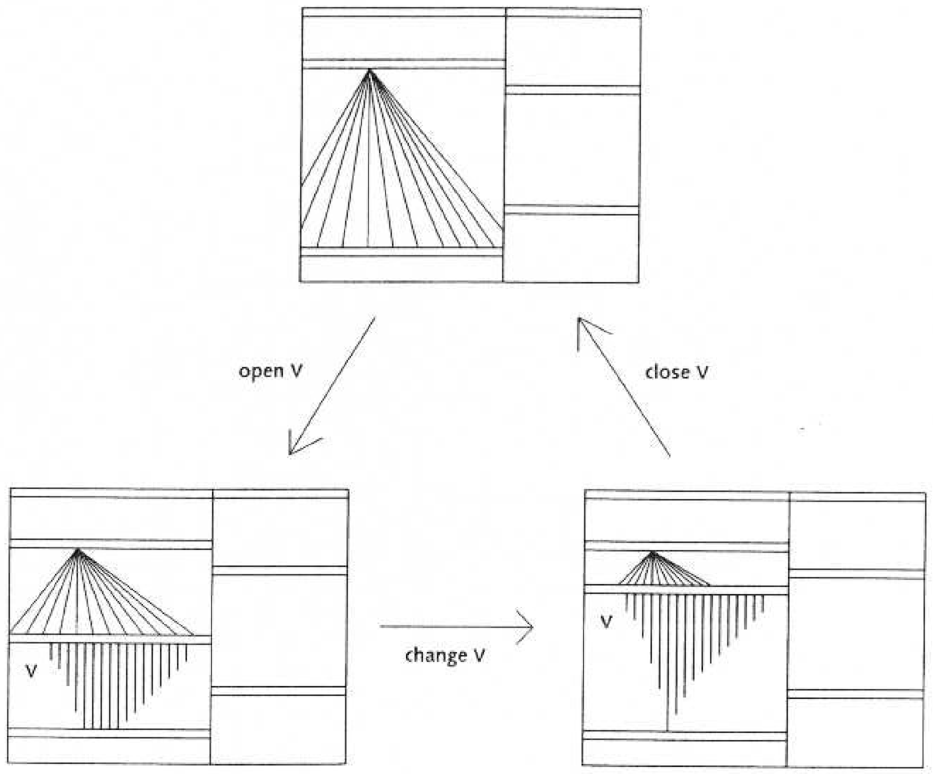


Figure 4.8 The basic operations on viewers.

The last group of procedures provides miscellaneous services. Procedure *This* identifies the viewer displayed at *(X, Y).* Procedure *Next* returns the next upper neighbor of a given displayed viewer *V*. Procedure *Recall* allows recalling and restoring the most recently closed viewer. *Locate* is a procedure that assists heuristic allocation of new viewers. For any given track and desired minimum height, procedure *Locate* offers a choice of some distinguished viewers in the track: the filler viewer, the viewer at the bottom, an alternative choice, and the viewer of maximum height. Finally, procedure *Broadcast* broadcasts a message to the display area, that is, sends the given message to all viewers that are currently displayed.

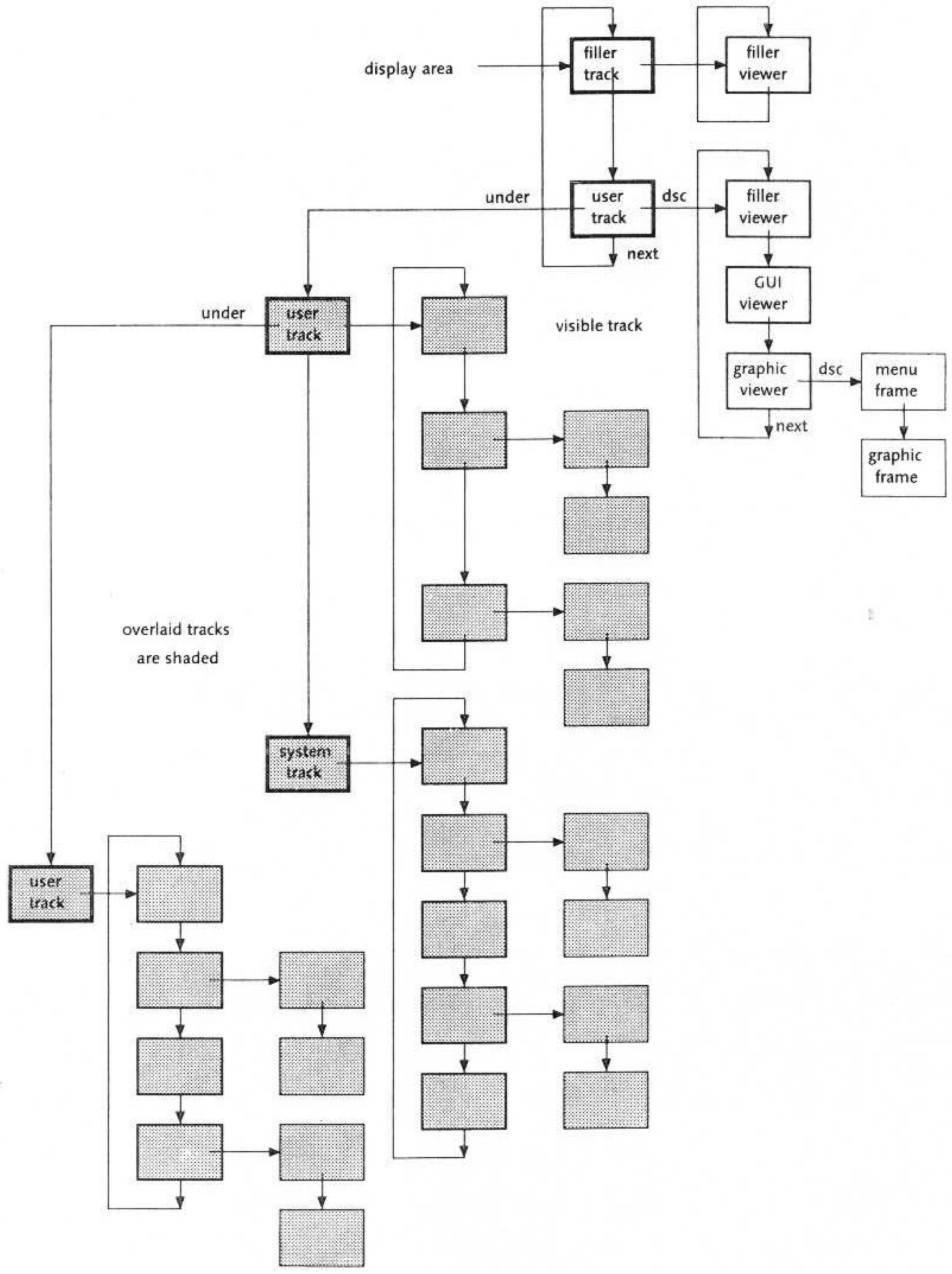


Figure 4.9 A snapshot of the internal display data structure corresponding to the display layout of Figure 4.4.

It is now time to throw a glance behind the scenes. Let us start with revealing module *Viewer*'s internal data structure. Remember that according to the principle of information hiding an internal data structure is fully private to the containing module and accessible through the module's procedural interface only. Figure 4.9 shows a data structure view of the display snapshot taken in Figure 4.4. Note that the overlaid tracks and viewers are still part of the internal data structure.

In the data structure we recognize an anchor that represents the display area and points to a list of tracks, each of them in turn pointing to a list of viewers, each of them in turn pointing to a list of arbitrary sub-frames. Both the list of tracks and the list of viewers are closed to a ring, where the filler track (filling up the display area) and the filler viewers (filling up the tracks) act as anchors. Additionally, each track points to a (possibly empty) list of tracks lying underneath.

Technically, the track descriptor type *TrackDesc* is a private extension of the viewer descriptor type *ViewerDesc*. Repeating the declarations of viewer descriptors and frame descriptors, we get to this hierarchy of types:

```
TrackDesc = RECORD (ViewerDesc)
  under: Display.Frame
END;


ViewerDesc = RECORD (FrameDesc)
  state: INTEGER
END;

FrameDesc = RECORD
  next, dsc: Frame;
  X, Y, W, H: INTEGER;
  handle: Handler
END;
```

It is noteworthy that the data structure of the viewer manager is *heterogeneous* with *Frame* as base type. It provides a nice example of a nested hierarchy of frames with the additional property that the first two levels correspond to the first two levels in the type hierarchy defined by *Track*, *Viewer*, and *Frame*.

In an object-oriented environment objects are autonomous entities in principle. However, they may be bound to some higher instance (other than the system) temporarily. For example, we can look at the objects belonging to a module's private data structure as bound to this module. Deciding if an object is currently bound is then a fundamental problem. In the case of viewers, this information is contained in an extra instance variable called *state*.

As a system invariant we have for every viewer *V*

V is bound to module Viewers <=> V.state # 0

If we call *visible* any displayed viewer and *suspended* any viewer that is covered by an overlaying track we can refine this invariant to

{V is visible <=> V.state > 0 } and { V is suspended <=> V.state < 0 }

In addition, more detailed information about the kind of viewer *V* is given by the magnitude |V.state|:

Table

|V.state|	kind of viewer
0	closed
1	filler
> 1	productive

Two side remarks:

- The magnitude |*V.state*| is kept invariant by module *Viewers*. It could be used, for example, to distinguish different levels of importance or preference with the aim of supporting a smarter algorithm for heuristic allocation of new viewers.
- Although there is no language facility to enforce it, the variable *state* is to be treated as read-only by every module other than *Viewers*.

We are now prepared to understand how the exported procedures of module *Viewers* work behind the scenes. All of them operate on the internal dynamic data structure just explained. Some use the structure as a reference only or operate on individual elements (procedures *This*, *Next*, *Locate*, *Change*), others add new elements to the structure (procedures *InitTrack*, *OpenTrack*, *Open*), and even others remove elements (procedures *CloseTrack, Close*). Most procedures have side-effects on the size or state of existing elements.

Let us now change perspective and look at module *Viewers* as a general low-level manager for viewers whose exact contents are unknown to it (and whose controlling software might have been developed years later only). In short, let us look at module *Viewers* as a manager of *black boxes*. Such an abstraction immediately makes it impossible for the implementation to call fixed procedures for, say, changing a viewer's size or state. The needed facility is a message-oriented interface.

Module *Viewer*'s contribution to this message interface corresponds to the third category of messages listed in Table 4.1. Their common type is

```
ViewerMsg = RECORD (Display.FrameMsg)
  id: INTEGER;
  X, Y, W, H: INTEGER;
  state: INTEGER
 END;
```

There exist three variants of this type, specified by the field *id*: Restore contents, modify height (extend or reduce at bottom), and suspend (close temporarily or permanently). The additional components of the message inform about the desired new location, size, and state.

The following Table 4.3 lists senders, messages, and recipients of viewer messages.

Table 4.3

Originator	Message	Recicpients
OpenTrack	Suspend temporarily	Viewers covered by opening track
CloseTrack	Suspend permanently	Viewers in closing track
	Restore	Viewers covered by closing track
Open	Modify or suspend permanently	Upper neighbour of opening viewer
Change	Modify	Upper neighbour of changing viewer
Close	Suspend permanently	Closing viewer

4.4.2. Menu Viewers

So far, we have treated viewers abstractly as black boxes. Our next step is now to focus on a special class of viewers called *menu viewers*. Remembering the definition given earlier we know that a menu viewer is characterized by a structure consisting of two vertically tiled “descendant” frames, a *menu frame* at the top and a *frame of contents* at the bottom. Because the nature and contents of these frames are typically unknown by their “ancestor” (or “parent”) viewer, a collection of abstract messages is again a promising form of interface. As net effect, the handling of menu viewers boils down to a combination of preprocessing, transforming and forwarding messages to the descendant frames. In summary, the display space in Oberon is hierarchically organized and message passing within the display space obeys the pattern of strict *parental control*.

Again, we start our more detailed discussion with a module definition:

```
DEFINITION MenuViewers;
```

```
  IMPORT Viewers, Display;

  CONST extend = 0; reduce = 1; move = 2; (*message ids*)

  TYPE
    Viewer = POINTER TO ViewerDesc;

    ViewerDesc = RECORD (Viewers.ViewerDesc)
      menuH: INTEGER
    END;

    ModifyMsg = RECORD (Display.FrameMsg)
      id: INTEGER;
      dY, Y, H: INTEGER
    END;

  PROCEDURE Handle (V: Display.Frame; VAR M: Display.FrameMsg);
  PROCEDURE New (Menu, Main: Display.Frame; menuH, X, Y: INTEGER): Viewer;

END MenuViewers.
```

The interface represented by this definition is conspicuously narrow. There are just two procedures: A generator procedure *New* and a standard message handler *Handle*. The generator returns a newly created menu viewer displaying the two (arbitrary) frames passed as parameters. The message handler implements the entire *"behavior"* of an object and in particular the above mentioned dispatcher functionality.

Message handlers in Oberon are implemented in the form of "procedure variables" that obviously must be initialized properly at object creation time. In other words, some concrete behavior must explicitly be bound to each object, where different instances of the same object type could potentially have a different behavior and/ or the same instance could change its behavior during its lifetime. Our object model is therefore *instance-centered*.

Conceptually, the creation of an object is an atomic action consisting of three basic steps:

```
allocate memory block; install message handler; initialize state variables
```

In the case of a standard menu viewer *V* this can be expressed as

```
NEW(V); V.handle := Handle; V.dsc := Menu; V.dsc.next := Main; V.menuH := menuH
```

With that, calling *New* is equivalent with

```
create V; open V at X, Y
```

where opening *V* needs assistance by module *Viewers*.

The implementation of procedure *Handle* embodies the standard strategy of message handling by menu viewers. The following code is a coarse view of it.

Message handler for menu viewers

```
IF message reports about user interaction THEN
  IF variant is mouse tracking THEN
    IF mouse is in menu region THEN
      IF mouse is in upper menu region and left key is pressed THEN
        handle changing of viewer
      ELSE delegate handling to menu-frame
      END
    ELSE
      IF mouse is in main-frame THEN delegate handling to main-frame END
    END
  ELSIF variant is keyboard input THEN
    delegate handling to menu frame;
    delegate handling to main frame
  END
ELSIF message defines generic operation THEN
  IF message requests copy (clone) THEN
    send copy message to menu frame to get a copy (clone);
    send copy message to main frame to get a copy (clone);
    create menu viewer clone from copies
  ELSE
    delegate handling to menu frame;
    delegate handling to main frame
  END
ELSIF message reports about change of contents THEN
   delegate handling to menu frame;
   delegate handling to main frame
ELSIF message requests change of location or size THEN
  IF operation is restore THEN
     draw viewer area and border;
     send modify message to menu frame to make it extend from height 0;
     send modify message to main frame to make it extend from height 0
  ELSIF operation is modify THEN
     IF operation is extend THEN
       extend viewer area and border;
       send modify message to menu frame to make it extend;
       send modify message to main frame to make it extend
     ELSE (*reduce*)
       send modify message to main frame to make it reduce;
       send modify message to menu frame to make it reduce;
       reduce viewer area and border
     END
  ELSIF operation is suspend THEN
     send modify message to main frame to make it reduce to height 0;
     send modify message to menu frame to make it reduce to height 0
  END
END
```

In principle, the handler acts as a *message dispatcher* that either processes a message directly and/or delegates its processing to the descendant frames. Note that the handler's main alternative statement discriminates precisely among the four basic categories of messages identified by Table 4.1.

From the above outlined algorithm handling *copy messages*, that is, requests for generating a *copy* or *clone* of a menu viewer, we can derive a general recursive scheme for the creation of a clone of an arbitrary frame:

```
send copy message to each element in the list of descendants;
generate copy of original frame descriptor;
attach copies of descendants to the copy of descriptor
```

The essential point here is the use of new *outgoing* messages in order to process a given *incoming* message. We can regard message processing as a transformation that maps incoming messages into a set of outgoing messages, with possible side-effects. The simplest case of such a transformation is known as *delegation*. In this case, the input message is simply passed on to the descendant(s).

As a fine point we clarify that the above algorithm is designed to create a *deep* copy of a composite object (a menu viewer in our case). If a *shallow* copy would be desired, the descendants would not have to be copied, and the original descendants instead of their copies would be attached to the copy of the composite object.

Another example of message handling is provided by mouse tracking. Assume that a *mouse message* is received by a menu viewer while the mouse is located in the upper part of its menu frame and the left mouse key is kept down. This means "change viewer's height by moving its top line vertically". No message to express the required transformation of the sub-frames yet exists. Consequently, module *MenuViewers* takes advantage of our open message model and simply introduces an appropriate message type called *ModifyMsg*:

```
ModifyMsg = RECORD (Display.FrameMsg)
  id: INTEGER;
  dY, Y, H: INTEGER
END;
```

The field *id* specifies one of two variants: *extend* or *reduce*. The first variant of the message requests the receiving frame to move by the vertical translation vector *dY* and then to extend to height *H* at bottom. The second variant requests the frame to reduce to height *H* at bottom and then to move by *dY*. In both cases *Y* indicates the *Y*-coordinate of the new lower-left corner. Figure 4.10 summarizes graphically.

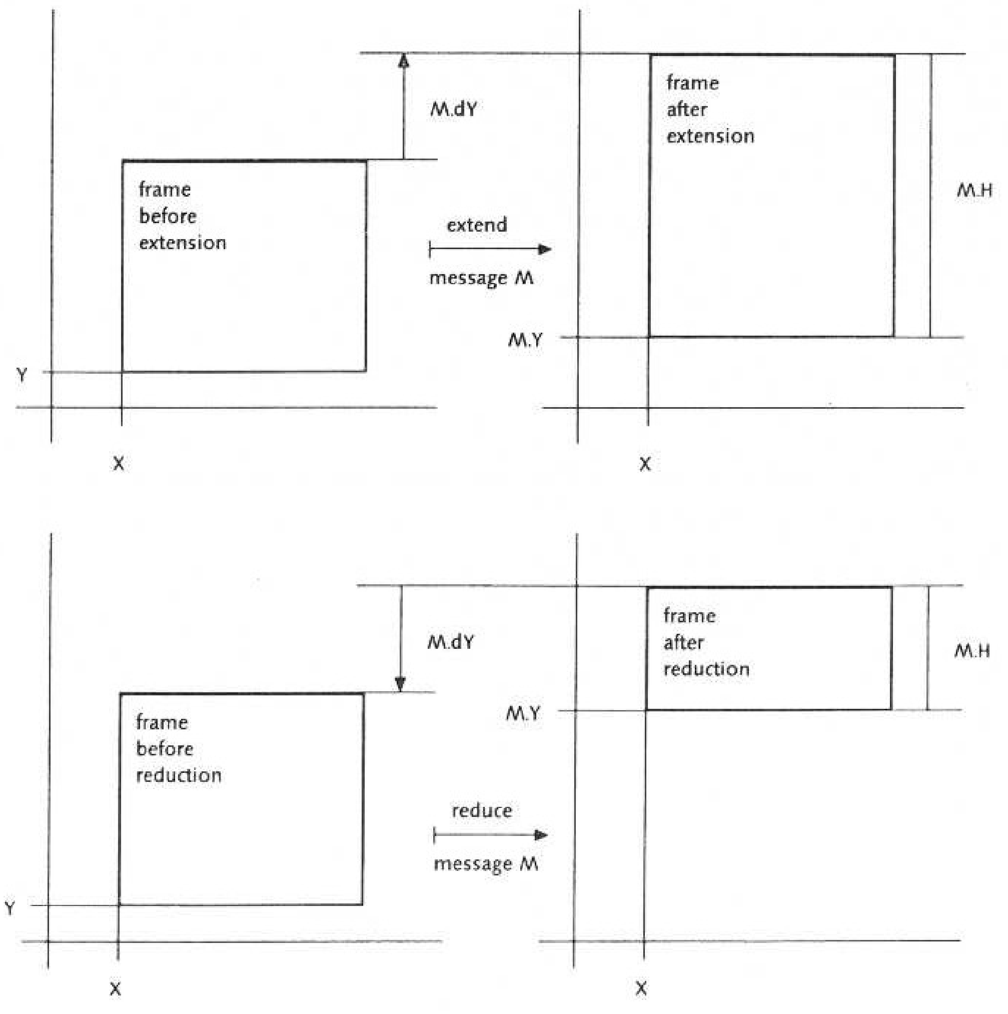


Figure 4.10 The modify frame operation.

Messages arriving from the viewer manager and requesting the receiving viewer to extend or reduce at its bottom are also mapped into messages of type *ModifyMsg* as well. Of course, no translation is needed in these cases, and *dY* is 0.

The attentive reader might perhaps have asked why the standard handler is exported by module *MenuViewers* at all. The thought behind is reusability of code. For example, a message handler for a subclass of menu viewers could be implemented effectively by reusing menu viewer's standard handler. After having handled all new or differing cases first it would simply call the standard handler subsequently.

4.4.3. Cursor Management

Traditionally, a cursor indicates and visualizes on the screen the current location of the caret in a text or, more generally, the current *focus* of attention. A small arrow or similar graphic symbol is typically used for this purpose. In Oberon, we have slightly generalized and abstracted this concept. A cursor is a path in the logical display area whose current position can be made visible by a *marker*.

The viewer manager and the cursor handler are two separate users of the same display area. Actually, we should imagine two parallel planes, one displaying viewers and the other displaying cursors. If there is just one physical plane we take care of painting markers non-destructively, for example in inverse-video mode. Then, no precondition must be established before drawing a marker. However, in the case of a viewer task painting destructively in its viewer's area, the area must be locked first after turning invisible all markers in the area.

The technical support of cursor management is again contained in module *Oberon*. The corresponding application programming interface is

```
DEFINITION Oberon;
    ...
   TYPE
      Marker = RECORD
        Fade, Draw: PROCEDURE (x, y: INTEGER)
      END;

      Cursor = RECORD
        marker: Marker; on: BOOLEAN; X, Y: INTEGER
      END;

    VAR
      Arrow, Star: Marker;
      Mouse, Pointer: Cursor;

     PROCEDURE OpenCursor (VAR c: Cursor);
     PROCEDURE FadeCursor (VAR c: Cursor);
     PROCEDURE DrawCursor (VAR c: Cursor; VAR m: Marker; X, Y: INTEGER);

     PROCEDURE MarkedViewer (): Viewers.Viewer;
     PROCEDURE RemoveMarks (X, Y, W, H: INTEGER);
     ...
  END Oberon.
```

The state of a cursor is given by its mode of visibility (*on*), its position *(X, Y)* in the display area, and the current marker. *Marker* is an abstract data type with an interface consisting of two operations *Fade* and *Draw*. The main benefit we can draw from this abstraction is once more conceptual independence of the underlying hardware. For example, *Fade* and *Draw* can adapt to a given monitor hardware with built-in cursor support or, in case of absence of such support, can simply be implemented as identical procedures (an involution) drawing the marker pattern in inverse video mode.

The functional interface to cursors consists of three operations: *OpenCursor* to open a new cursor, *FadeCursor* to switch off the marker of an open cursor, and *DrawCursor* to extend the path of a cursor to a new position and mark it with the given marker. We emphasize that the marker representing a given cursor can change its shape dynamically on the fly.

Two cursors, *Mouse* and *Pointer* are predefined. They represent the mouse and an interactively controlled global system pointer respectively. Typically (but not necessarily) these cursors are visualized by the built-in markers *Arrow* (a small arrow pointing to north-west) and *Star* (a star symbol) respectively. The pointer can be used to mark any displayed object. It serves primarily as an implicit parameter of commands.

Two assisting service procedures *MarkedViewer* and *RemoveMarks* are added in connection with the predefined cursors. *MarkedViewer* returns the viewer that is currently marked by the pointer. Its resulting value is equivalent to *Viewers.This(Pointer.X, Pointer.Y). RemoveMarks* turns invisble the predefined cursors within a given rectangle in the display area. This procedure is used to lock the rectangle for its caller.

Let us recapitulate the essential points and characteristics of Oberon's concept of cursor handling.

1.) By virtue of the use of abstract markers and of the logical display area any hardware dependence is encapsulated in system modules and is therefore hidden from the application programmer. Cursors are moving uniformly within the whole display area, even across screen boundaries.

2.) Cursor handling is decentralized by delegating it to the individual handlers that are installed in viewers. Typically, a handler reacts on the receipt of a mouse tracking message by drawing the mouse cursor at the indicated new position. The benefit of such individualized handling is flexibility. For example, a smart local handler might choose the shape of the visualizing marker depending on the exact location, or it might force the cursor onto a grid point.

3.) Even though cursor handling is decentralized, there is some intrinsic support for cursor drawing built into the declaration of type *Cursor*. Cursors are objects of full value and, as such, can "memorize" their current state. Consequently, the interface operations *FadeCursor* and *DrawCursor* need to refer to the desired future state only.

4.) Looking at the viewer manager as one user of the display area, the cursor handler is a second user of the same resource. If there is just one physical plane implementing the display area, any region must be locked by a current user before destructive painting. Therefore, markers are usually painted non-destructively in inverse-video mode.

Let us now summarize the entire Section. The central resource managed by the display subsystem is the logical display area whose purpose is abstraction from the underlying display monitor hardware. The display area is primarily used by the viewer manager for the accommodation of tracks and viewers. They are just the first two levels of a potentially unlimited nested hierarchy of display frames. For example, standard menu viewers contain two subordinate frames: A menu frame and a main frame of contents. Viewers are treated as black boxes by the viewer manager and are addressed via messages. Viewers and, more generally frames, are used as elements of message-based interfaces connecting the display subsystem with other subsystems like the task scheduler and the various document managers. Finally, the display area also provides a base space for the movement of cursors. In Oberon, a cursor is a marked path. Two standard cursors Mouse and Pointer are predefined.

4.5. Raster Operations

In Section 4.4 we introduced the display area as an abstract concept, modeled as two-dimensional Cartesian plane. So far, this information was sufficient because we were interested in its global structure only and ignored contents completely. If we are now interested in the contents, we need to reveal more details about the model.

The Cartesian plane representing the display area is *discrete*. We shall consider points in the display area as grid points or *picture elements (pixels)*, and we assume contents to be generated by assigning colors to the pixels. For the moment, the number of possible colors a pixel can attain is irrelevant. In the binary case of two colors we think of one color representing *background* and the other color representing *foreground*.

The most elementary operation generating contents in a discrete plane is "set color of pixel" or "set pixel" for short. However, there are few algorithms actually building directly on this atomic operation. Much more important in practice are block-oriented operations, traditionally called *raster operations*. By a *block* we mean a rectangular area of pixels whose bounding lines are parallel to the axes of the coordinate system.

Raster operations are based on a common principle of operation: A block of width *SW* and height *SH* of source pixels is placed at a given point of destination *(DX, DY)* in the display area. In the simplest case, the destination block *(DX, DY, SW, SH)* is plainly overwritten by the source block. In general, the new value of a pixel in the destination block is a combination of its old value and the value of the corresponding source pixel:

d := f(s, d)

f is sometimes called *mode* of combination of the raster operation.

In the binary case we have the following modes:

Table

mode	f
replace	s
paint	s OR d
invert	s XOR d

Note that *invert* is equivalent with inverse video mode if s is *TRUE* for all pixels.

There are many different variants of raster operations. Some refer to a source block in the display area, others specify a constant pattern to be taken as source block. Some variants require replication of the source block within a given destination block (DX, DY, DW, DH) rather than simple placement.

The challenge with designing a raster interface was to find a unified, small and complete set of raster operations that covers all needs, in particular the need of placing character glyphs. The amazingly compact resulting set of raster operations is exported by module Display:

```
DEFINITION Display;
    ...
  CONST
    black = 0; white = 15; (*colors*)
    replace = 0; paint = 1; invert = 2; (*operation modes*)

  PROCEDURE CopyBlock (SX, SY, W, H, DX, DY, mode: INTEGER);

  PROCEDURE CopyPattern (col: INTEGER; pat: Pattern; DX, DY, mode: INTEGER);
  PROCEDURE Dot (col: INTEGER; DX, DY: LONGINT; mode: INTEGER);

  PROCEDURE ReplPattern (
    col: INTEGER; pat: Pattern; DX, DY, DW, DH, mode: INTEGER);
  PROCEDURE ReplConst (col: INTEGER; DX, DY, DW, DH, mode: INTEGER);
    ...
END Display.
```

In the parameter lists, *mode* is the mode of combination (*replace*, *paint*, or *invert*). *CopyBlock* copies the source block *(SX, SY, W, H)* to position *(DX, DY)* and uses *mode* to combine new contents in the destination block *(DX, DY, W, H)*. It is assumed tacitly that the numbers of colors per pixel in the source block and in the destination area are identical. It is perhaps informative to know that *CopyBlock* is essentially equivalent with the famous *BitBlt* (bit block transfer) in the *SmallTalk* project [Goldberg]. In Oberon, *CopyBlock* is used primarily for scrolling contents within a viewer.

The remaining raster operations use a constant pattern. Conceptually, we should regard type *Pattern* as a pointer:

```
Pattern = POINTER TO PatternDesc;

PatternDesc = RECORD
  w, h: SHORTINT;
  raster: ARRAY (w + 7) DIV 8 * h OF SYSTEM.BYTE
END;
```

w and *h* are width and height of a block containing the binary pattern data defined by *raster*. The pattern data are given as a linear sequence of bytes to be poured into the block from left to right and from bottom to top.

There are two non-conceptual problems with this declaration. First, arrays of variable length are not allowed in Oberon. The second problem concerns economy of memory usage. Looking at type-fonts as large collections of character patterns, it would be extremely wasteful to allocate a separate record for every single pattern. We shall see in Chapter 5 how sequences of character patterns are packed. As a way out we decided to define type *Pattern* as LONGINT (in the sense of "memory address"), together with a pattern constructor

```
PROCEDURE SetPattern (
  VAR image: ARRAY OF SYSTEM.BYTE; W, H: INTEGER; VAR pat: Pattern);
```

Some standard patterns are predefined in module *Display* and exported as global variables of type *Pattern*. Among them are patterns *arrow*, *star*, and *cross* intended to represent markers, a hook marking the caret, and a downward arrow. A second group of predefined patterns supports drawing graphics. It includes several grey tone patterns and a grid pattern.

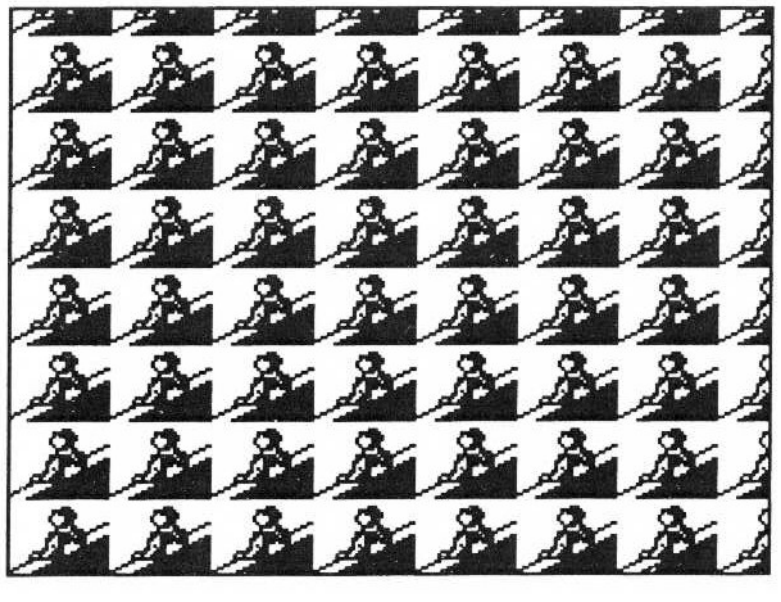


Figure 4.11 Visualization of the replicate pattern operation.

The parameter *col* in the pattern-oriented raster operations specifies the pattern's foreground color. Colors *black* and *white* are predefined. Procedure *CopyPattern* copies the colored pattern to location *(DX, DY)* in the display area, using the given combination mode. It is probably the most frequently used operation of all because it is needed to write text. Procedure *ReplPattern* replicates the given pattern to the given destination block. It starts at bottom left and proceeds from left to right and from bottom to top. Figure 4.11 exemplifies the way this operation works. Procedures *Dot* and *ReplConst* are special cases of *CopyPattern* and *ReplPattern* respectively, taking a fixed implicit pattern consisting of a single foreground pixel. Dot is exactly our previously mentioned "set pixel". *ReplConst* is used to draw horizontal and vertical lines as well as rectangles.

So far, we have carefully avoided any reference to the underlying hardware. However, eventually, the raster operations operate on concrete bitmaps mirroring the contents of concrete display monitors. In our original implementation they are programmed in assembler code for efficiency reasons. We decided to include the necessary support directly in place. For this reason, we burdened two more domains of responsibility on module Display: a) Mapping display monitors to the display area and b) acting as device driver.

Here is the relevant part of module *Display*'s definition:

```
DEFINITION Display;
...

 VAR (*map*)
   Unit: LONGINT;
   Width, Height: INTEGER;
   Bottom, UBottom: INTEGER;
   Left, ColLeft: INTEGER;

 PROCEDURE Map (X: INTEGER): LONGINT;

 (*device drivers*)
 PROCEDURE SetMode (X: INTEGER; s: SET);

 (*color table*)
 PROCEDURE SetColor (col, red, green, blue: INTEGER);
 PROCEDURE GetColor (col: INTEGER; VAR red, green, blue: INTEGER);

 (*hardware cursor*)
 PROCEDURE SetCursor (mode: SET);
 PROCEDURE DrawCX (X, Y: INTEGER);
 PROCEDURE FadeCX (X, Y: INTEGER);
...

END Display.
```

This definition (and even more so its implementation) provides support for a restricted class of possible configurations only. Any number of display monitors is theoretically possible. However, they must be mapped to a regular horizontal array of predefined cells in the display area. Each cell is vertically split into two congruent regions, where the corresponding monitor is supposed to be able to select and display one of the two regions alternatively. Finally, it is assumed that all cells of black-and-white monitors are allocated to the left of all cells of color monitors. Figure 4.12 gives a good impression of such a configuration.

Under these restrictions any concrete configuration can be parameterized by the variables of the definition above. *Unit*, *Width*, and *Height* specify the extent of a displayed region, where *Width* and *Height* are width and height in pixel units, and *Unit* is the size of a pixel in units of 1/36000 mm. 1/36000 mm is a common divisor of all of the standard metric units used by the typesetting community, like mm, inch, Pica point and point size of usual printing devices. *Bottom* and *UBottom* specify the bottom *y*-coordinate of the primary region and the secondary region respectively. Finally, *Left* and *ColLeft* give the left *x*-coordinate of the area of black-and-white monitors and of color monitors respectively.

We conclude these explanations with a short functional description of the procedures listed in the above definition: To a given *x*-coordinate, procedure *Map* returns the starting address of the (primary) bitmap corresponding to the display monitor at this position. This procedure allows a client to transform any given pair *(X, Y)* of coordinates into a memory address and thus to implement private raster operations. The remaining procedures are driver-specific. Obviously, they are tailored to certain concrete types of monitors.

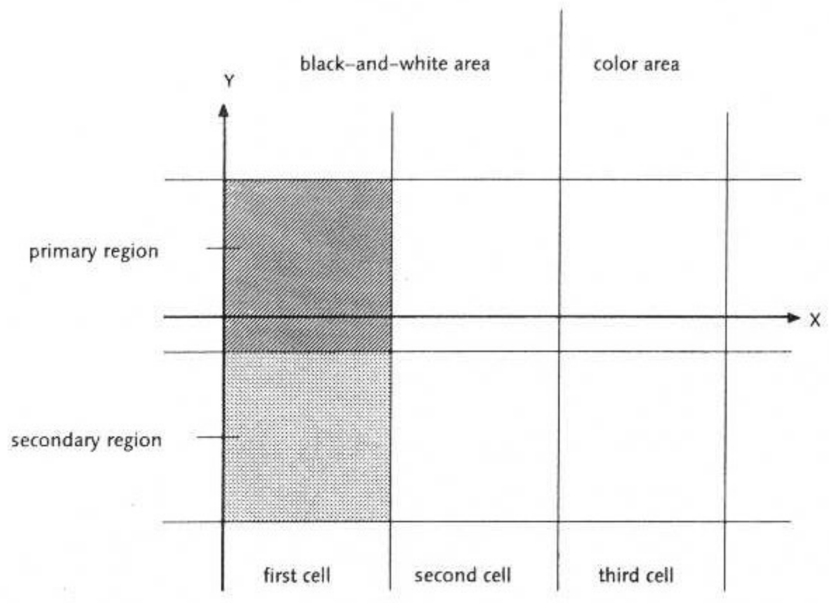


Figure 4.12 The standard regular cell structure of the display area.

Procedure *SetMode* sets the display mode of the monitor at position *X*. Typically, the mode selects among normal, inverse video, and display screen off. Also, it specifies the region to be displayed (*primary* or *secondary*). Procedures *SetColor* and *GetColor* maintain the (common) color table of the color screens. This table maps color numbers to colors composed of the basic elements *red*, *green*, and *blue*. The remaining procedures support hardware cursor management. *SetCursor* selects among two possible cursor classes: Crosshair or pattern. Finally, procedures *DrawCX* and *FadeCX* draw and erase the selected cursor at the given position.

4.6. Standard Display Configurations and Toolbox

Let us now take up again our earlier topic of configuring the display area. We have seen that no specific layout of the display area is distinguished by the general viewer management itself. However, some support of the familiar standard Oberon display look is provided by module *Oberon*.

In the terminology of this module, a standard configuration consists of one or several horizontally adjacent displays, where a *display* is a pair consisting of two tracks of equal height, a *user track* on the left and a *system track* on the right. Figure 4.13 shows a standard configuration featuring two displays of equal size, one black-and-white and one colored. Note that even though no reference to any physical monitor is made, a display is typically associated with a monitor in reality.

This is the relevant excerpt of the definition:

```
DEFINITION Oberon;
 ...

  PROCEDURE OpenDisplay (UW, SW, H: INTEGER);
  PROCEDURE OpenTrack (X, W: INTEGER);

  PROCEDURE DisplayWidth (X: INTEGER): INTEGER;
  PROCEDURE DisplayHeight (X: INTEGER): INTEGER;
  PROCEDURE UserTrack (X: INTEGER): INTEGER;
  PROCEDURE SystemTrack (X: INTEGER): INTEGER;

  PROCEDURE AllocateUserViewer (DX: INTEGER; VAR X, Y: INTEGER);
  PROCEDURE AllocateSystemViewer (DX: INTEGER; VAR X, Y: INTEGER);
...
END Oberon.
```

Procedure *OpenDisplay* initializes and opens a new display of the dimensions *H* (height), *UW* (width of user track), and *SW* (width of system track). Procedure *OpenTrack* overlays the sequence of existing tracks spanned by the segment *[X, X + W)* by a new track. Both procedure *OpenDisplay* and *OpenTrack* take from the client the burden of creating a filler viewer.

The next group of procedures *DisplayWidth*, *DisplayHeight*, *UserTrack* and *SystemTrack* return width or height of the respective structural entity located at position *X* in the display area.

Procedures *AllocateUserViewer* and *AllocateSystemViewer* make proposals for the allocation of a new viewer in the desired track of the display located at *DX*. In first priority, the location is determined by the system pointer that can be set manually. If the pointer is not set, a location is calculated on the basis of some heuristics whose strategies rely on different splitting fractions that are applied in the user track and in the system track respectively, with the aim of generating aesthetically satisfactory layouts.

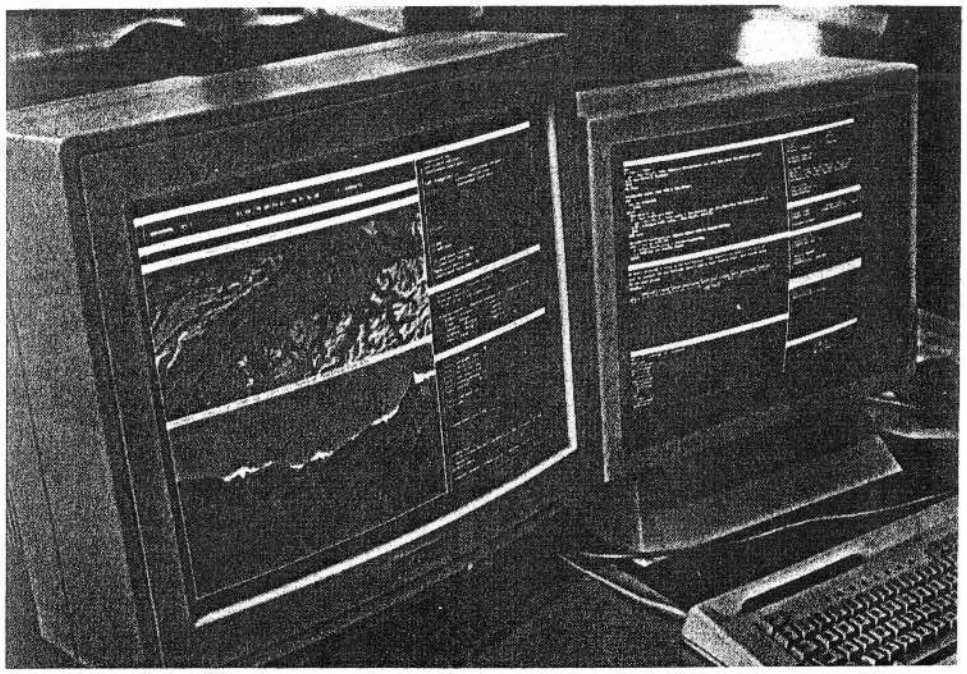


Figure 4.13 Standard Oberon configuration featuring two logically adjacent displays of equal size and structure.

In addition to the programming interface provided by module *Oberon* for the case of standard display layouts, the display management section in the *System* toolbox provides a user interface:

```
DEFINITION System;

(*Display management*)
  PROCEDURE Open; (*viewer*)
```

```
    PROCEDURE OpenLog; (*viewer*)
    PROCEDURE Close; (*viewer*)
    PROCEDURE CloseTrack;
    PROCEDURE Recall; (*most recently closed viewer*)
    PROCEDURE Copy; (*viewer*)
    PROCEDURE Grow; (*viewer*)
  END System.
```

In turn, these commands are called to open a text viewer in the system track, open a viewer displaying the system log text, close a viewer, close a track, recall (and reopen) the most recently closed viewer, copy a viewer, and grow a viewer. The commands *Close*, *CloseTrack*, *Recall*, *Copy*, and *Grow* are generic. *Close*, *Copy*, and *Grow* are typically included in the title bar of a menu viewer. Their detailed implementations follow subsequently.

Literature

[Binding] C. Binding, User Interface Components based on a Multiple Window Package, University of Washington, Seattle, Technical Report 85-08-07.

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[Teitelman] W. Teitelman, "A tour through Cedar", IEEE Software, 1, (2), 44-73 (1984).

Complete Implementations

```
MODULE Viewers; (*JG 14.9.90*)

  IMPORT Display;

  CONST
    restore* = 0; modify* = 1; suspend* = 2; (*message id*)
    inf = MAX(INTEGER);

  TYPE
    Viewer* = POINTER TO ViewerDesc;

    ViewerDesc* = RECORD (Display.FrameDesc)
      state*: INTEGER
    END;

    (*state > 1: displayed
      state = 1: filler
      state = 0: closed
      state < 0: suspended*)

    ViewerMsg* = RECORD (Display.FrameMsg)
      id*: INTEGER;
      X*, Y*, W*, H*: INTEGER;
      state*: INTEGER
    END;

    Track = POINTER TO TrackDesc;

    TrackDesc = RECORD (ViewerDesc)
      under: Display.Frame
    END;

  VAR
    curW*, minH*, DW, DH: INTEGER;
    FillerTrack: Track; FillerViewer, buf: Viewer; (*for closed viewers*)

  PROCEDURE Open* (V: Viewer; X, Y: INTEGER);
    VAR T, u, v: Display.Frame; M: ViewerMsg;
    BEGIN
      IF (V.state = 0) & (X < inf) THEN
      IF Y > DH THEN Y := DH END;
      T := FillerTrack.next;
      WHILE X >= T.X + T.W DO T := T.next END;
      u := T.dsc; v := u.next;
      WHILE Y > v.Y + v.H DO u := v; v := u.next END;
      IF Y < v.Y + minH THEN Y := v.Y + minH END;
      IF (v.next.Y # 0) & (Y > v.Y + v.H - minH) THEN
        WITH v: Viewer DO
          V.X := T.X; V.W := T.W; V.Y := v.Y; V.H := v.H;
          M.id := suspend; M.state := 0;
          v.handle(v, M); v.state := 0; buf := v;
          V.next := v.next; u.next := V;
          V.state := 2
        END
      ELSE
        V.X := T.X; V.W := T.W; V.Y := v.Y; V.H := Y - v.Y;
        M.id := modify; M.Y := Y; M.H := v.Y + v.H - Y;
        v.handle(v, M); v.Y := M.Y; v.H := M.H;
        V.next := v; u.next := V;
        V.state := 2
      END
    END
  END Open;

  PROCEDURE Change* (V: Viewer; Y: INTEGER);
    VAR v: Display.Frame; M: ViewerMsg;
  BEGIN
    IF V.state > 1 THEN
      IF Y > DH THEN Y := DH END;
      v := V.next;
      IF (v.next.Y # 0) & (Y > v.Y + v.H - minH) THEN
        Y := v.Y + v.H - minH
      END;
      IF Y >= V.Y + minH THEN
        M.id := modify; M.Y := Y; M.H := v.Y + v.H - Y;
        v.handle(v, M); v.Y := M.Y; v.H := M.H;
        V.H := Y - V.Y
      END
    END
  END Change;

    PROCEDURE RestoreTrack (S: Display.Frame);
    VAR T, t, v: Display.Frame; M: ViewerMsg;
  BEGIN
    WITH S: Track DO
      t := S.next;
      WHILE t.next.X # S.X DO t := t.next END;
      T := S.under;
      WHILE T.next # NIL DO T := T.next END;
      t.next := S.under; T.next := S.next;
      M.id := restore;
      REPEAT t := t.next;
        v := t.dsc;
        REPEAT v := v.next; v.handle(v, M);
          WITH v: Viewer DO v.state := - v.state END
        UNTIL v = t.dsc
      UNTIL t = T
    END
  END RestoreTrack;

  PROCEDURE Close* (V: Viewer);
    VAR T, U: Display.Frame; M: ViewerMsg;
  BEGIN
    IF V.state > 1 THEN
      U := V.next; T := FillerTrack;
      REPEAT T := T.next UNTIL V.X < T.X + T.W;
      IF (T(Track).under = NIL) OR (U.next # V) THEN
        M.id := suspend; M.state := 0;
        V.handle(V, M); V.state := 0; buf := V;
        M.id := modify; M.Y := V.Y; M.H := V.H + U.H;
        U.handle(U, M); U.Y := M.Y; U.H := M.H;
        WHILE U.next # V DO U := U.next END;
        U.next := V.next
      ELSE (*close track*)
        M.id := suspend; M.state := 0;
        V.handle(V, M); V.state := 0; buf := V;
        U.handle(U, M); U(Viewer).state := 0;
        RestoreTrack(T)
      END
    END
  END Close;

  PROCEDURE Recall* ( VAR V: Viewer);
  BEGIN V := buf
  END Recall;

  PROCEDURE This* (X, Y: INTEGER): Viewer;
    VAR T, V: Display.Frame;
  BEGIN
    IF (X < inf) & (Y < DH) THEN
      T := FillerTrack;
      REPEAT T := T.next UNTIL X < T.X + T.W;
      V := T.dsc;
      REPEAT V := V.next UNTIL Y < V.Y + V.H;
      RETURN V(Viewer)
    ELSE RETURN NIL
    END
  END This;

  PROCEDURE Next* (V: Viewer): Viewer;
  BEGIN RETURN V.next(Viewer)
  END Next;

  PROCEDURE Locate* (X, H: INTEGER; VAR fil, bot, alt, max: Display.Frame);
    VAR T, V: Display.Frame;
  BEGIN
    IF X < inf THEN
      T := FillerTrack;
      REPEAT T := T.next UNTIL X < T.X + T.W;
      fil := T.dsc; bot := fil.next;
      IF bot.next # fil THEN
        alt := bot.next; V := alt.next;
        WHILE (V # fil) & (alt.H < H) DO
          IF V.H > alt.H THEN alt := V END; V := V.next
        END
      ELSE alt := bot
      END;
      max := T.dsc; V := max.next;
      WHILE V # fil DO
        IF V.H > max.H THEN max := V END; V := V.next
      END
    END
  END Locate;

  PROCEDURE InitTrack* (W, H: INTEGER; Filler: Viewer);
    VAR S: Display.Frame; T: Track;
```

```
BEGIN
  IF Filler.state = 0 THEN
    Filler.X := curW; Filler.W := W; Filler.Y := 0; Filler.H := H;
    Filler.state := 1;
    Filler.next := Filler;
    NEW(T);
    T.X := curW; T.W := W; T.Y := 0; T.H := H;
    T.dsc := Filler; T.under := NIL;
    FillerViewer.X := curW + W; FillerViewer.W := inf - FillerViewer.X;
    FillerTrack.X := FillerViewer.X; FillerTrack.W := FillerViewer.W;
    S := FillerTrack;
    WHILE S.next # FillerTrack DO S := S.next END;
    S.next := T; T.next := FillerTrack;
    curW := curW + W
  END
END InitTrack;

PROCEDURE OpenTrack* (X, W: INTEGER; Filler: Viewer);
  VAR newT: Track; S, T, t, v: Display.Frame; M: ViewerMsg;
BEGIN
  IF (X < inf) & (Filler.state = 0) THEN
    S := FillerTrack; T := S.next;
    WHILE X >= T.X + T.W DO S := T; T := S.next END;
    WHILE X + W > T.X + T.W DO T := T.next END;
    M.id := suspend;
    t := S;
    REPEAT t := t.next; v := t.dsc;
      REPEAT v := v.next;
        WITH v: Viewer DO
          M.state := -v.state; v.handle(v, M); v.state := M.state
        END
      UNTIL v = t.dsc
    UNTIL t = T;
    Filler.X := S.next.X; Filler.W := T.X + T.W - S.next.X; Filler.Y := 0; Filler.H := DH;
    Filler.state := 1;
    Filler.next := Filler;
    NEW(newT);
    newT.X := Filler.X; newT.W := Filler.W; newT.Y := 0; newT.H := DH;
    newT.dsc := Filler; newT.under := S.next; S.next := newT;
    newT.next := T.next; T.next := NIL
  END
END OpenTrack;

PROCEDURE CloseTrack* (X: INTEGER);
  VAR T, V: Display.Frame; M: ViewerMsg;
BEGIN
  IF X < inf THEN
    T := FillerTrack;
    REPEAT T := T.next UNTIL X < T.X + T.W;
    IF T(Track).under # NIL THEN
      M.id := suspend; M.state := 0; V := T.dsc;
      REPEAT V := V.next; V.handle(V, M); V(Viewer).state := 0 UNTIL V = T.dsc;
      RestoreTrack(T)
    END
  END
END CloseTrack;
```

```
  PROCEDURE Broadcast* (VAR M: Display.FrameMsg);
    VAR T, V: Display.Frame;
  BEGIN
    T := FillerTrack.next;
    WHILE T # FillerTrack DO
      V := T.dsc;
      REPEAT V := V.next; V.handle(V, M) UNTIL V = T.dsc;
      T := T.next
    END
  END Broadcast;

BEGIN buf := NIL;
  NEW(FillerViewer);
  FillerViewer.X := 0; FillerViewer.W := inf; FillerViewer.Y := 0; FillerViewer.H := DH;
  FillerViewer.next := FillerViewer;
  NEW(FillerTrack);
  FillerTrack.X := 0; FillerTrack.W := inf; FillerTrack.Y := 0; FillerTrack.H := DH;
  FillerTrack.dsc := FillerViewer;
  FillerTrack.next := FillerTrack;
  curW := 0; minH := 1;
  DW := Display.Width; DH := Display.Height
END Viewers.

MODULE MenuViewers; (*JG 26.8.90*)

  IMPORT Input, Display, Texts, Viewers, Oberon;

  CONST extend* = 0; reduce* = 1;

  TYPE
    Viewer* = POINTER TO ViewerDesc;

    ViewerDesc* = RECORD (Viewers.ViewerDesc)
      menuH*: INTEGER
    END;

    ModifyMsg* = RECORD (Display.FrameMsg)
      id*: INTEGER;
      dY*, Y*, H*: INTEGER
    END;

  PROCEDURE Copy (V: Viewer; VAR V1: Viewer);
    VAR Menu, Main: Display.Frame; M: Oberon.CopyMsg;
  BEGIN
    Menu := V.dsc; Main := V.dsc.next;
    NEW(V1); V1^ := V^; V1.state := 0;
    Menu.handle(Menu, M); V1.dsc := M.F;
    Main.handle(Main, M); V1.dsc.next := M.F
  END Copy;

  PROCEDURE Draw (V: Viewers.Viewer);
  BEGIN
    Display.ReplConst(Display.white, V.X, V.Y, 1, V.H, 0);
    Display.ReplConst(Display.white, V.X + V.W - 1, V.Y, 1, V.H, 0);
    Display.ReplConst(Display.white, V.X + 1, V.Y, V.W - 2, 1, 0);
  Display.ReplConst(Display.white, V.X + 1, V.Y + V.H - 1, V.W - 2, 1, 0)
END Draw;

PROCEDURE Extend (V: Viewer; newY: INTEGER);
  VAR dH: INTEGER;
BEGIN dH := V.Y - newY;
  IF dH > 0 THEN
    Display.ReplConst(Display.black, V.X + 1, newY + 1, V.W - 2, dH, 0);
    Display.ReplConst(Display.white, V.X, newY, 1, dH, 0);
    Display.ReplConst(Display.white, V.X + V.W - 1, newY, 1, dH, 0);
    Display.ReplConst(Display.white, V.X + 1, newY, V.W - 2, 1, 0)
  END
END Extend;

PROCEDURE Reduce (V: Viewer; newY: INTEGER);
BEGIN Display.ReplConst(Display.white, V.X + 1, newY, V.W - 2, 1, 0)
END Reduce;

PROCEDURE Grow (V: Viewer; oldH: INTEGER);
  VAR dH: INTEGER;
BEGIN dH := V.H - oldH;
  IF dH > 0 THEN
    Display.ReplConst(Display.white, V.X, V.Y + oldH, 1, dH, 0);
    Display.ReplConst(Display.white, V.X + V.W - 1, V.Y + oldH, 1, dH, 0);
    Display.ReplConst(Display.white, V.X + 1, V.Y + V.H - 1, V.W - 2, 1, 0)
  END
END Grow;

PROCEDURE Shrink (V: Viewer; newH: INTEGER);
BEGIN Display.ReplConst(Display.white, V.X + 1, V.Y + newH - 1, V.W - 2, 1, 0)
END Shrink;

PROCEDURE Adjust (F: Display.Frame; id, dY, Y, H: INTEGER);
  VAR M: ModifyMsg;
BEGIN M.id := id; M.dY := dY; M.Y := Y; M.H := H; F.handle(F, M); F.Y := Y; F.H := H
 END Adjust;

PROCEDURE Restore (V: Viewer);
  VAR Menu, Main: Display.Frame;
BEGIN
  Menu := V.dsc; Main := V.dsc.next;
  Oberon.RemoveMarks(V.X, V.Y, V.W, V.H);
  Draw(V);
  Menu.X := V.X + 1; Menu.Y := V.Y + V.H - 1; Menu.W := V.W - 2; Menu.H := 0;
  Main.X := V.X + 1; Main.Y := V.Y + V.H - V.menuH; Main.W := V.W - 2; Main.H := 0;
  IF V.H > V.menuH + 1 THEN
    Adjust(Menu, extend, 0, V.Y + V.H - V.menuH, V.menuH - 1);
    Adjust( Main, extend, 0, V.Y + 1, V.H - V.menuH - 1)
  ELSE Adjust(Menu, extend, 0, V.Y + 1, V.H - 2)
  END
END Restore;

PROCEDURE Modify (V: Viewer; Y, H: INTEGER);
  VAR Menu, Main: Display.Frame;
BEGIN
  Menu := V.dsc; Main := V.dsc.next;
  IF Y < V.Y THEN (*extend*)
    Oberon.RemoveMarks(V.X, Y, V.W, V.Y - Y);
     Extend(V, Y);
    IF H > V.menuH + 1 THEN
      Adjust(Menu, extend, 0, Y + H - V.menuH, V.menuH - 1);
      Adjust(Main, extend, 0, Y + 1, H - V.menuH - 1)
    ELSE Adjust(Menu, extend, 0, Y + 1, H - 2)
    END
  ELSIF Y > V.Y THEN (*reduce*)
    Oberon.RemoveMarks(V.X, V.Y, V.W, V.H);
    IF H > V.menuH + 1 THEN
      Adjust(Main, reduce, 0, Y + 1, H - V.menuH - 1);
      Adjust(Menu, reduce, 0, Y + H - V.menuH, V.menuH - 1)
    ELSE
      Adjust(Main, reduce, 0, Y + H - V.menuH, 0);
      Adjust(Menu, reduce, 0, Y + 1, H - 2)
    END;
    Reduce(V, Y)
  END
END Modify;

PROCEDURE Change (V: Viewer; X, Y: INTEGER; Keys: SET);
  VAR Menu, Main: Display.Frame;
    V1: Viewers.Viewer; keysum: SET; Y0, dY, H: INTEGER;
BEGIN (*Keys # {}*)
  Menu := V.dsc; Main := V.dsc.next;
  Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, X, Y);
  Display.ReplConst(Display.white, V.X + 1, V.Y + V.H - 1 - V.dsc.H, V.W - 2, V.dsc.H, 2);
  Y0 := Y;
  keysum := Keys;
  LOOP
    Input.Mouse(Keys, X, Y);
    IF Keys = {} THEN EXIT END;
    keysum := keysum + Keys;
    Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, X, Y)
  END;
  Display.ReplConst(Display.white, V.X + 1, V.Y + V.H - 1 - V.dsc.H, V.W - 2, V.dsc.H, 2);
  IF ~(0 IN keysum) THEN
    IF 1 IN keysum THEN V1 := Viewers.This(X, Y);
      IF Y < V1.Y + V.menuH + 2 THEN Y := V1.Y + V.menuH + 2 END;
      Viewers.Close(V); Viewers.Open(V, X, Y); Restore(V)
    ELSE
      IF Y > Y0 THEN (*extend*) dY := Y - Y0;
        V1 := Viewers.Next(V);
        IF V1.state > 1 THEN
          IF (V1 IS Viewer) & (V1.H >= V1(Viewer).menuH + 2) THEN
            IF dY > V1.H - V1(Viewer).menuH - 2 THEN dY := V1.H - V1(Viewer).menuH - 2 END
          ELSIF dY > V1.H - Viewers.minH THEN dY := V1.H - Viewers.minH
          END
        ELSIF dY > V1.H THEN dY := V1.H
        END;
        Viewers.Change(V, V.Y + V.H + dY);
        Oberon.RemoveMarks(V.X, V.Y, V.W, V.H);
        Grow(V, V.H - dY);
        IF V.H > V.menuH + 1 THEN
          Adjust(Menu, extend, dY, V.Y + V.H - V.menuH, V.menuH - 1);
        Adjust(Main, extend, dY, V.Y + 1, V.H - V.menuH - 1)
      ELSE Adjust(Menu, extend, dY, V.Y + 1, V.H - 2)
      END
    ELSIF Y < Y0 THEN (*reduce*) dY := Y0 - Y;
      IF dY > V.H - V(Viewer).menuH - 2 THEN dY := V.H - V(Viewer).menuH - 2 END;
      Oberon.RemoveMarks(V.X, V.Y, V.W, V.H);
      H := V.H - dY;
      IF H > V.menuH + 1 THEN
        Adjust(Main, reduce, dY, V.Y + 1, H - V.menuH - 1);
        Adjust(Menu, reduce, dY, V.Y + H - V.menuH, V.menuH - 1)
      ELSE
        Adjust(Main, reduce, dY, V.Y + H - V.menuH, 0);
        Adjust(Menu, reduce, dY, V.Y + 1, H - 2)
      END;
      Shrink(V, H);
      Viewers.Change(V, V.Y + H)
    END
  END
 END
END Change;

PROCEDURE Suspend (V: Viewer);
 VAR Menu, Main: Display.Frame;
BEGIN
 Menu := V.dsc; Main := V.dsc.next;
 Adjust(Main, reduce, 0, V.Y + V.H - V.menuH, 0);
 Adjust(Menu, reduce, 0, V.Y + V.H - 1, 0)
END Suspend;

PROCEDURE Handle* (V: Display.Frame; VAR M: Display.FrameMsg);
 VAR Menu, Main: Display.Frame; V1: Viewer;
BEGIN
 WITH V: Viewer DO
  Menu := V.dsc; Main := V.dsc.next;
  IF M IS Oberon.InputMsg THEN
   WITH M: Oberon.InputMsg DO
    IF M.id = Oberon.track THEN
     IF M.Y < V.Y + 1 THEN Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, M.X, M.Y)
     ELSIF M.Y < V.Y + V.H - V.menuH THEN Main.handle(Main, M)
     ELSIF M.Y < V.Y + V.H - V.menuH + 2 THEN Menu.handle(Menu, M)
     ELSIF M.Y < V.Y + V.H - 1 THEN
      IF 2 IN M.keys THEN Change(V, M.X, M.Y, M.keys)
      ELSE Menu.handle(Menu, M)
      END
     ELSE Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, M.X, M.Y)
     END
    ELSE Menu.handle(Menu, M); Main.handle(Main, M)
    END
   END
  ELSIF M IS Oberon.ControlMsg THEN
   WITH M: Oberon.ControlMsg DO
    IF M.id = Oberon.mark THEN
     Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, M.X, M.Y);
     Oberon.DrawCursor(Oberon.Pointer, Oberon.Star, M.X, M.Y)
    ELSE Menu.handle(Menu, M); Main.handle(Main, M)
    END
```

```
      END
    ELSIF M IS Oberon.CopyMsg THEN
      WITH M: Oberon.CopyMsg DO Copy(V(Viewer), V1); M.F := V1 END
    ELSIF M IS Viewers.ViewerMsg THEN
      WITH M: Viewers.ViewerMsg DO
        IF M.id = Viewers.restore THEN Restore(V)
        ELSIF M.id = Viewers.modify THEN Modify(V, M.Y, M.H)
        ELSIF M.id = Viewers.suspend THEN Suspend(V)
        END
      END
    ELSE Menu.handle(Menu, M); Main.handle(Main, M)
    END
  END
 END Handle;

 PROCEDURE New* (Menu, Main: Display.Frame; menuH, X, Y: INTEGER): Viewer;
  VAR V: Viewer;
 BEGIN NEW(V);
  V.handle := Handle; V.dsc := Menu; V.dsc.next := Main; V.menuH := menuH;
  Viewers.Open(V, X, Y); Restore(V);
  RETURN V
 END New;

END MenuViewers.

MODULE System; (*JG 3.10.90*)

 IMPORT Viewers, MenuViewers, Oberon, Texts, TextFrames;

 CONST
  StandardMenu = "System.Close System.Copy System.Grow Edit.Search Edit.Store";
  LogMenu = "System.Close System.Grow Edit.Locate Edit.Store";

 VAR W: Texts.Writer;

 PROCEDURE Max (i, j: LONGINT): LONGINT;
 BEGIN IF i >= j THEN RETURN i ELSE RETURN j END
 END Max;

 (* ------------- Toolbox for standard display ---------------*)

 PROCEDURE Open*;
  VAR par: Oberon.ParList;
    V: Viewers.Viewer;
    T: Texts.Text; S: Texts.Scanner;
    X, Y: INTEGER;
    beg, end, time: LONGINT;
 BEGIN
  par := Oberon.Par;
  Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") OR (S.line # 0) THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S) END
  END;
  IF S.class = Texts.Name THEN
    Oberon.AllocateSystemViewer(par.vwr.X, X, Y);
    V := MenuViewers.New(
      TextFrames.NewMenu(S.s, StandardMenu),
      TextFrames.NewText(TextFrames.Text(S.s), 0),
      TextFrames.menuH,
      X, Y)
  END
END Open;

PROCEDURE OpenLog*;
  VAR V: Viewers.Viewer; X, Y: INTEGER;
BEGIN
  Oberon.AllocateSystemViewer(Oberon.Par.vwr.X, X, Y);
  V := MenuViewers.New(
    TextFrames.NewMenu("System.Log", LogMenu),
    TextFrames.NewText(Oberon.Log, Max(0, Oberon.Log.len - 200)),
    TextFrames.menuH,
    X, Y)
END OpenLog;

PROCEDURE Close*;
  VAR  par: Oberon.ParList; V: Viewers.Viewer;
BEGIN par := Oberon.Par;
  IF par.frame = par.vwr.dsc THEN V := par.vwr
  ELSE V := Oberon.MarkedViewer()
  END;
  Viewers.Close(V)
END Close;

PROCEDURE CloseTrack*;
  VAR V: Viewers.Viewer;
BEGIN V := Oberon.MarkedViewer(); Viewers.CloseTrack(V.X)
END CloseTrack;

PROCEDURE Recall*;
  VAR V: Viewers.Viewer; M: Viewers.ViewerMsg;
BEGIN
  Viewers.Recall(V);
  IF V.state = 0 THEN
    Viewers.Open(V, V.X, V.Y + V.H); M.id := Viewers.restore; V.handle(V, M)
  END
END Recall;

PROCEDURE Copy*;
  VAR V, V1: Viewers.Viewer; M: Oberon.CopyMsg; N: Viewers.ViewerMsg;
BEGIN
  V := Oberon.Par.vwr; V.handle(V, M); V1 := M.F(Viewers.Viewer);
  Viewers.Open(V1, V.X, V.Y + V.H DIV 2);
  N.id := Viewers.restore; V1.handle(V1, N)
END Copy;

PROCEDURE Grow*;
  VAR V, V1: Viewers.Viewer; M: Oberon.CopyMsg; N: Viewers.ViewerMsg;
    DW, DH: INTEGER;
BEGIN V := Oberon.Par.vwr;
  DW := Oberon.DisplayWidth(V.X); DH := Oberon.DisplayHeight(V.X);
  IF V.H < DH - Viewers.minH THEN Oberon.OpenTrack(V.X, V.W)
```

```
    ELSIF V.W < DW THEN Oberon.OpenTrack(Oberon.UserTrack(V.X), DW)
    END;
    IF (V.H < DH - Viewers.minH) OR (V.W < DW) THEN
      V.handle(V, M); V1 := M.F(Viewers.Viewer);
      Viewers.Open(V1, V.X, DH);
      N.id := Viewers.restore; V1.handle(V1, N)
    END
  END Grow;

  PROCEDURE OpenViewers;
  VAR V: Viewers.Viewer; t, d: LONGINT; X, Y: INTEGER;
  BEGIN
  Oberon.GetClock(t, d); Texts.WriteString(W, "System.Time");
  Texts.WriteDate(W, t, d); Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf);
  Oberon.AllocateSystemViewer(0, X, Y);
  V := MenuViewers.New(
    TextFrames.NewMenu("System.Log", LogMenu),
    TextFrames.NewText(Oberon.Log, 0),
    TextFrames.menuH,
    X, Y);
  Oberon.AllocateSystemViewer(0, X, Y);
  V := MenuViewers.New(
    TextFrames.NewMenu("System.Tool", StandardMenu),
    TextFrames.NewText(TextFrames.Text("System.Tool"), 0),
    TextFrames.menuH,
    X, Y)
  END OpenViewers;

BEGIN
  Texts.OpenWriter(W);
  Oberon.Log := TextFrames.Text("");
  OpenViewers
END System.
```

5. The Text System

At the beginning of the computing era, *text* was the only medium mediating information between users and computers. Not only was a textual notation used to denote all kinds of data like names and numbers (represented by sequences of digits respectively), but also for the specification of programs (based on the notions of formal language and syntax) and of commands and (by their name). Actually, not even the most modern and most sophisticated computing environments have been able to make falter the dominating role of *text* substantially. At most, they have introduced alternative models like *graphical user interfaces* (GUI) as a graphical replacement of command lines.

There are many reasons for the popularity of text in general and in connection with computers in particular. To name but a few: Text containing an arbitrary amount of information can be built from a small alphabet of widely standardized elements (characters), their building pattern is extremely simple (lining up elements), and the resulting structure is most elementary (a sequence). And perhaps most importantly, *syntactically structured text* can be parsed and interpreted.

In computing terminology, sequences of elements are called *files* and, in particular, sequences of characters are known as *text files*. Looking at their binary representation, we find them excellently suited to be stored in computer memories and on external media. Remember that individual characters are usually encoded in one byte each (ASCII-code). We can therefore identify the binary structure of text files with sequences of bytes, matching perfectly the structure of any underlying computer storage. We should recall at this point that, with the possible exception of *line-break* control characters, rendering information is not part of ordinary text files. For example, the choices of type-font and of paragraph formatting parameters are entirely left to the rendering interpreter.

Unfortunately, in conventional computing environments, text is merely used for input/ output and not exploited optimally. Input texts are typically read from the keyboard under control of some editor, interpreted and then discarded. Output text is volatile. Once displayed on the screen it is no longer available to any other parts of the program. The root of the problem is easily located: Conventional operating systems neither feature an integrated management nor an abstract programming interface for texts.

Of course, such poor support of text on the level of programming must reflect itself on the user surface. More often than not, users are forced to retype a certain string of text instead of simply getting it from elsewhere on the screen. Investigations have shown that, in average, up to 80% of required input text is displayed somewhere already.

Motivated by our positive experience with integrated text in the *Cedar* system [Teitelman] we decided to provide a central text management in Oberon at a sufficiently low system level. However, this is not enough. We actually need an abstract programming interface for text that is, an *abstract data type Text*, together with a complete set of operations. We shall devote Section 5.1 to the explanation of this data type. In Section 5.2 we take a closer look at the basic text management in Oberon, including data structures and algorithms used for the implementation.

Text frames are a special class of display frames. They appear typically (but not necessarily) as frames within a menu viewer (see Section 4.4.2). Their role is double-faced: a) Rendering text on the display screen and b) interpreting editing commands. The details will be discussed in Section 5.3.

With the aim of exploiting the power of modern bitmap-displays and also of using the results of earlier projects in the field of digital font design, we decided to include graphical attributes and in particular *font specifications* in Oberon texts. In Section 5.4 we shall explain the font machinery, starting from an abstract level and proceeding down to the level of raster data.

5.1. Text as an Abstract Data Type

The concept of abstraction is the most important achievement of programming language development. It provides a powerful tool to create simplified views on complicated program components. Two prominent examples of program abstractions are *definitions (interfaces)* and *abstract data types*. These notions embody “public views” on a certain piece of program and on a certain kind of objects respectively.

We shall now give a precise definition of the notion of *text* in Oberon by presenting it as an abstract data type. It is important not to confuse this type with the far less powerful type *string* as it is often supported by advanced programming languages. We will rigorously avoid it in this Section to reveal any aspects of implementation. Our viewpoint is that of an application program operating on text or using text as a medium of communication.

Let us first get a refined understanding of *characters*. We know that characters represent textual elements of information. However, each character also refers to some specific graphical pattern, often called *glyph*. In Oberon, we do justice to both aspects by thinking of the ASCII-code as an index range for type-fonts. We let characters be represented as pairs *(font, ref)*, where *font* designates a font and *ref* is the character's ASCII-code. We shall treat the topic of fonts and glyphs thoroughly in Section 5.4. Adding two more attributes *color* and vertical *offset* we get to a quadruple representation of characters *(font, ref, col, voff)*. The components *font*, *color*, and vertical *offset* together are often referred to as *looks*. We can now roughly declare a text as a “sequence of attributed characters”.

Formally, we define the following descriptor type

```
Text = POINTER TO TextDesc;

TextDesc = RECORD
   len: LONGINT;
   notify: Notifier
END;
```

There is only one state variable and one method. The variable *len* represents the current length of the described text (i.e. the number of characters in the sequence). The procedure variable *notify* is included as a method (occasionally called after-method) to notify interested clients of state changes.

By definition, each abstract data type comes with a complete set of operations. In the case of *Text*, three different topics need to be considered, *loading (from file)/ storing (to file)*, *editing*, and *accessing* respectively.

5.1.1. Loading and Storing

Let us start with the file topic. We first introduce a pair of mutually inverse operations called *internalize* and *externalize*. Their meaning is "load from file and build up an internal data structure" and "serialize the internal data structure and store on file". There are three corresponding procedures:

```
PROCEDURE Open (T: Text; name: ARRAY OF CHAR);
PROCEDURE Load (T: Text; f: Files.File; pos: LONGINT; VAR len: LONGINT);
PROCEDURE Store (T: Text; f: Files.File; pos: LONGINT; VAR len: LONGINT);
```

Logical entities like texts are stored in Oberon on external media in the form of *sections*. A section is addressed by a pair *(file, pos)* consisting of a file descriptor and a starting position. In general, the structure of sections obeys the following syntax:

```
section = identification type length contents.
```

Procedure *Open* internalizes a named text file (consisting of a single text section), procedure *Load* internalizes an arbitrary text section starting at *(f, pos)*, and *Store* externalizes a text section to *(f, pos)*. The parameter *T* designates the internalized text. *len* returns the length of the section. Note that in case of *Load* the identification of the section must have been read and consumed before the loader is called.

5.1.2. Editing

Our next group of operations supports text editing. It comprises four procedures:

```
PROCEDURE Delete (T: Text; beg, end: LONGINT);
PROCEDURE Insert (T: Text; pos: LONGINT; B: Buffer);
PROCEDURE Append (T: Text; B: Buffer);
PROCEDURE ChangeLooks (T: Text; beg, end: LONGINT;
   sel: SET; fnt: Fonts.Font; col, voff: SHORTINT);
```

Again, we should first explain the types of parameters. Procedures *Delete* and *ChangeLooks* each take a *stretch of text* as an argument which, by definition, is an interval *[beg, end)* within the given text. In the parameter lists of *Insert* and *Append* we recognize a new data type *Buffer*.

Buffers are a facility to hold anonymous sequences of characters. Type *Buffer* presents itself as another abstract data type:

```
Buffer = POINTER TO BufDesc;

BufDesc = RECORD
    len: LONGINT
END;
```

len specifies the current length of the buffered sequence. The following procedures represent the intrinsic operations on buffers:

```
PROCEDURE OpenBuf (B: Buffer);
PROCEDURE Copy (SB, DB: Buffer);
PROCEDURE Save (T: Text; beg, end: LONGINT; B: Buffer);
PROCEDURE Recall (VAR B: Buffer);
```

Their function is in turn opening a given buffer *B*, copying a buffer *SB* to *DB*, saving a stretch *[beg, end)* of text in a given buffer, and recalling the most recently deleted stretch of text and put it into buffer *B*.

We are now prepared to understand how the editing procedures work. Procedure *Delete* deletes the given stretch *[beg, end)* within text *T*, *Insert* inserts the buffer's contents at position pos within text *T*, and *Append(T, B)* is a shorthand form for *Insert(T, T.len, B)*. Note that, as a side-effect of *Insert* and *Append*, the buffer involved is emptied. Finally, procedure *ChangeLooks* allows to change selected looks within the given stretch *[beg, end)* of text *T*. *sel* is a mask selecting a subset of the set of looks *{ font, color, vertical offset }*.

It is now time to come back to the *notifier* concept. Recapitulate that *notify* is an “after-method”. It must be installed by the client when opening the text and is called at the end of every editing operation. Its procedural type is

```
Notifier = PROCEDURE (T: Text; op: INTEGER; beg, end: LONGINT);
```

The parameters *op*, *beg*, and *end* report about the operation *(op)* that calls the notifier and on the affected stretch *[beg, end)* of the text. There are three different possible variants of *op* corresponding to the three different editing operations: *op* = *delete*, *insert*, *replace* correspond to procedures *Delete*, *Insert* (and *Append*), and *ChangeLooks* respectively.

By far the most important application of the notifier is updating the display, i.e. adjusting all affected views that are currently displayed to the new state of the text. We shall come back to this important point when we discuss text frames in Section 5.3.

In concluding this Section it is perhaps worth noting that the group of operations just discussed has been designed to be equally useful for both interactive text editors and programmed text generators/ manipulators.

5.1.3. Accessing

Let us now turn to the third and last group of operations on texts: Accessing. According to the principle of separation of concerns, one of our guiding principles, the access mechanism operates on extra aggregates called *readers* and *writers* rather than on texts themselves.

Readers are used to read texts sequentially. Their type is declared as

```
Reader = RECORD
    eot: BOOLEAN; (*end of text*)
```

```
        fnt: Fonts.Font;
        col: SHORTINT;
        voff: SHORTINT
    END;
```

A reader must first be setup at some given position in the text and can then be moved forward incrementally by reading character-by-character. Its state variables indicate end-of-text and expose the looks of the previously read character.

The corresponding operators are

```
PROCEDURE OpenReader (VAR R: Reader; T: Text; pos: LONGINT);
PROCEDURE Read (VAR R: Reader; VAR ch: CHAR);
```

Procedure *OpenReader* sets up a reader *R* at position *pos* in text *T*. Procedure *Read* returns the character at the current position of *R* and makes *R* move to the next position.

The current position of reader *R* is returned by a call to the function *Pos*:

```
PROCEDURE Pos (VAR R: Reader): LONGINT;
```

In Chapter 3 we learnt that texts are often used in Oberon as parameter lists of commands. To a command interpreter, however, a text appears as a sequence of *tokens* much rather than as a sequence of characters. Therefore, we adopted the well-known concepts of *syntax* and *scanning* from the discipline of compiler construction. The Oberon scanner recognizes tokens of some universal classes. They are *name*, *string*, *integer*, *real*, *longreal*, and *special character*.

The exact syntax of universal Oberon tokens is:

```
token = name | string | integer | real | longreal | spexchar.

name = ident { "." ident }.
ident = letter { letter | digit }.
string = '"' { char } '"' | "'" { char } "'".
integer = ["+"|"-"] number.
real = ["+"|"-"] number "." number ["E" ["+"|"-"] number].
longreal = ["+"|"-"] number "." number ["D" ["+"|"-"] number].
number = digit { digit }.
spexchar = any character except letters, digits, space, tabulator, and carriage-return.
```

Type *Scanner* is defined analogously as

```
Scanner = RECORD (Reader)
    nextCh: CHAR;
    line: INTEGER;
    class: INTEGER;
    i: LONGINT;
    x: REAL;
    y: LONGREAL;
    c: CHAR;
    len: SHORTINT;
    s: ARRAY 32 OF CHAR
  END;
```

This type is actually a variant record type with *class* as discriminating tag. Depending on its class the value of the current token is stored in one of the fields *i*, *x*, *y*, *c*, or *s*. *len* gives the length of *s*, *nextCh* typically exposes the character terminating the current token, and *line* counts the number of lines scanned.

The operations on scanners are

```
PROCEDURE OpenScanner (VAR S: Scanner; T: Text; pos: LONGINT);
PROCEDURE Scan (VAR S: Scanner);
```

They correspond exactly to their counterparts *OpenReader* and *Read* respectively.

It is important to be aware that an arbitrary number of readers and scanners can coexist on one and the same text. Typically, readers and scanners are controlled by and bound to some specific activity and are of a *transient* nature, in contrast to their host texts that typically have a much longer life in the system's object heap. This fact manifests itself by the absence of any possibility to reference readers and scanners by pointers.

Writers are dual to readers. They serve the purpose of creating and extending texts. However, again, they do not operate on texts directly. Rather, they act as self-contained aggregates continuously consuming and buffering textual data.

The formal declaration of type *Writer* resembles that of type *Reader*:

```
Writer = RECORD
    buf: Buffer;
    fnt: Fonts.Font;
    col: SHORTINT;
    voff: SHORTINT
END;
```

buf is an internal buffer containing the consumed data. *fnt*, *col*, and *voff* specify the current looks for the next character consumed by this writer.

The following procedures together constitute the basic management of writers:

```
PROCEDURE OpenWriter (VAR W: Writer);
PROCEDURE SetFont (VAR W: Writer; fnt: Fonts.Font);
PROCEDURE SetColor (VAR W: Writer; col: SHORTINT);
PROCEDURE SetOffset (VAR W: Writer; voff: SHORTINT);
```

Procedure *OpenWriter* opens a new writer with an empty buffer. Procedures *SetFont*, *SetColor*, and *SetOffset* set the respective current look. For example, *SetFont(W, fnt)* is equivalent to *W.fnt := fnt*. These procedures are included because *fnt*, *col*, and *voff* are considered read-only for clients.

The question arising is how data is produced and transferred to writers. The answer is a set of writer procedures, each of them handling an individual data type:

```
PROCEDURE Write (VAR W: Writer; ch: CHAR);
PROCEDURE WriteLn (VAR W: Writer);
PROCEDURE WriteString (VAR W: Writer; s: ARRAY OF CHAR);
PROCEDURE WriteInt (VAR W: Writer; x, n: LONGINT);
PROCEDURE WriteHex (VAR W: Writer; x: LONGINT);
PROCEDURE WriteReal (VAR W: Writer; x: REAL; n: INTEGER);
PROCEDURE WriteRealFix (VAR W: Writer; x: REAL; n, k: INTEGER);
PROCEDURE WriteRealHex (VAR W: Writer; x: REAL);
PROCEDURE WriteLongReal (VAR W: Writer; x: LONGREAL; n: INTEGER);
PROCEDURE WriteLongRealHex (VAR W: Writer; x: LONGREAL);
PROCEDURE WriteDate (VAR W: Writer; t, d: LONGINT);
```

It may help to study the following schematic fragment of a client program that creates textual output:

```
open writer; set desired font;
REPEAT
    process;
    write result to writer;
    append writer buffer to output text
UNTIL ended
```

Of course, writers can be reused. For example, a single global writer is typically shared by all of the procedures within a module. In this case, the writer needs to be opened once at module loading time only.

The main benefit of such a rigorous decoupling of writing operations and editing operations on texts is the option of choosing freely the granularity at which a text (and its displayed image) is updated.

Let us summarize: *Text* in Oberon is a powerful abstract data type with intrinsic operations from three areas: Loading/storing, editing, and accessing. The latter two areas on their part introduce further abstract types called *Buffer*, *Reader*, *Scanner*, and *Writer*. In combination they guarantee a clean and rigorous separation of the concerns text, editing text, and accessing text. An after-method is used to allow context-dependent post-processing of editing operations. It is used primarily for preserving consistency between text models and their displayed views.

5.2. Text Management

The art and challenge of modularization lie in finding an effective decomposition into modules with relatively thin interfaces or, in other words, into modules with a great potential for information hiding. Text systems provide a nice exercise to this topic. A closer analysis immediately leads to the following separate tasks corresponding with *Model*, *View* and *Controller* of the *MVC* scheme: Text management, text rendering, and text editing. If we combine *View* and *Controller* and add an auxiliary font handling module *Fonts*, we arrive at the linear three-module import hierarchy displayed in Table 5.1.

Table 5.1

Module	Object Type	Service
TextFrames	Frame	Text rendering and editing
Texts	Text	Text management
Fonts	Font	Font management

Notice that, in contrast to the display-subsystem, the associated object types are not connected hierarchically.

Separate Sections 5.3 and 5.4 will be devoted to modules *TextFrames* and *Fonts* respectively. In the current Section we direct our attention to module *Texts*. Regarding it as a model of the abstract data type *Text* presented in the previous Section, its definition is congruent with the specification of the abstract data type itself, and we need not repeat it here.

The actual topics of this Section are internal representation and file representation of texts. We first emphasize that the internal representation is a completely private matter of module *Texts*. It is encapsulated and hidden from clients. In particular, the representation could be changed at any time without invalidating a single client module. In principle, the same is true for the file representation. However, its stability is of paramount importance in reality because it serves the additional purposes of backing up text on external media and of porting text to other environments.

Our choice of an internal representation of text was determined by a catalogue of requirements and desired properties. The wish list is:

1.) lean data structure
2.) closed under editing operations
3.) efficient editing operations
4.) efficient sequential reading
5.) efficient direct positionning
6.) super efficient internalizing
7.) preserving file representations

With the exception of 5.), we found these requirements met perfectly by an adequately generalized variant of the *piece chain* technique that was originally used for Xerox PARC's Bravo text editor and also for ETH's former document editors *Dyna* and *Lara* [Gutknecht]. The original piece chain is able to describe a vanilla text without looks. It is based on two principles:

1.) A text is regarded as a sequence of *pieces*, where a piece is a section of a text file consisting of a sequence of contiguous characters.

2.) Every piece is represented by a descriptor *(f, pos, len),* where the components designate a file, a starting position, and a length respectively. The whole text is represented as a chain of piece descriptors (in short: piece chain). The editing operations operate on the chain of piece descriptors rather than on the pieces themselves.

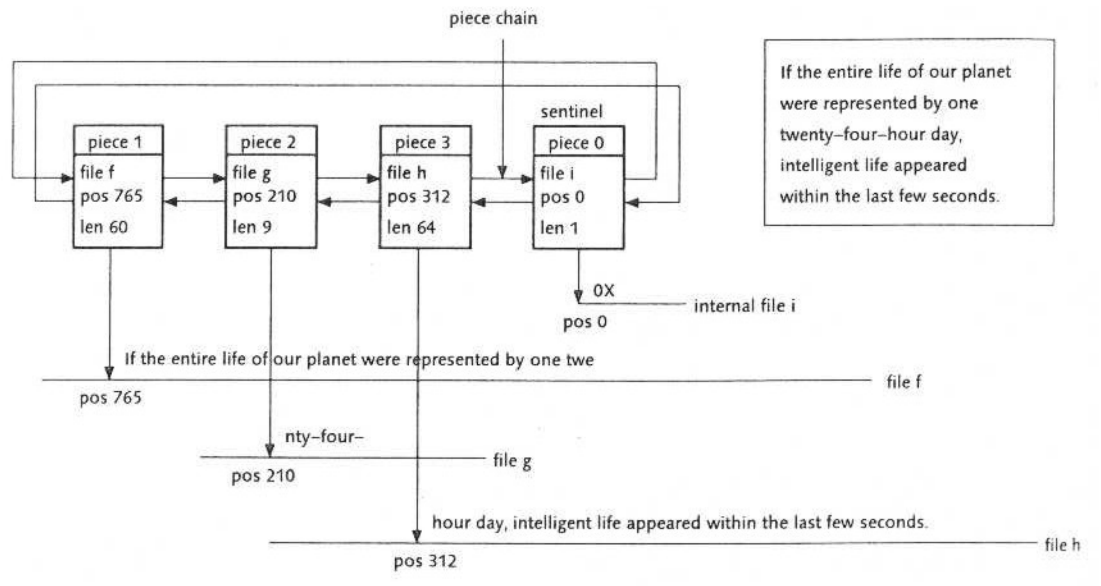
piece chain
sentinel
piece 1
file f
pos 765
len 60
piece 2
file g
pos 210
len 9
piece 3
file h
pos 312
len 64
piece 0
file i
pos 0
len 1
If the entire life of our planet were represented by one twenty–four–hour day, intelligent life appeared within the last few seconds.
0X
internal file i
pos 0
If the entire life of our planet were represented by one twe
file f
pos 765
nty–four–
file g
pos 210
hour day, intelligent life appeared within the last few seconds.
file h
pos 312

Figure 5.1 Piece chain representing a text.

Figure 5.1 shows a typical piece chain representing (the current state of) a text. Investigating the effects of the basic editing operations *delete* and *insert* on the piece chain we find these algorithms:

```
delete stretch [beg, end) of text = BEGIN
    split pieces at beg and at end;
    remove piece descriptors from beg to end from the chain
END

insert stretch of text at pos = BEGIN
    split piece at pos;
    insert piece descriptors representing the stretch at pos
END
```

Of course, splitting is superfluous if the desired splitting point happens to coincide with the beginning of a piece. Figures 5.2 and 5.3 show the resulting piece chain after a delete and an insert-operation respectively.

Checking our wish list above we immediately recognize the requirements 1.), 2.), and 3.) as met. Requirement 4.) is also met under the assumption of an efficient mechanism for direct positioning in files. Requirement 6.) can be checked off because the piece list initially consists of a single piece spanning the entire text file. Finally, requirement 7.) is met simply because the operations do not affect file representations at all.

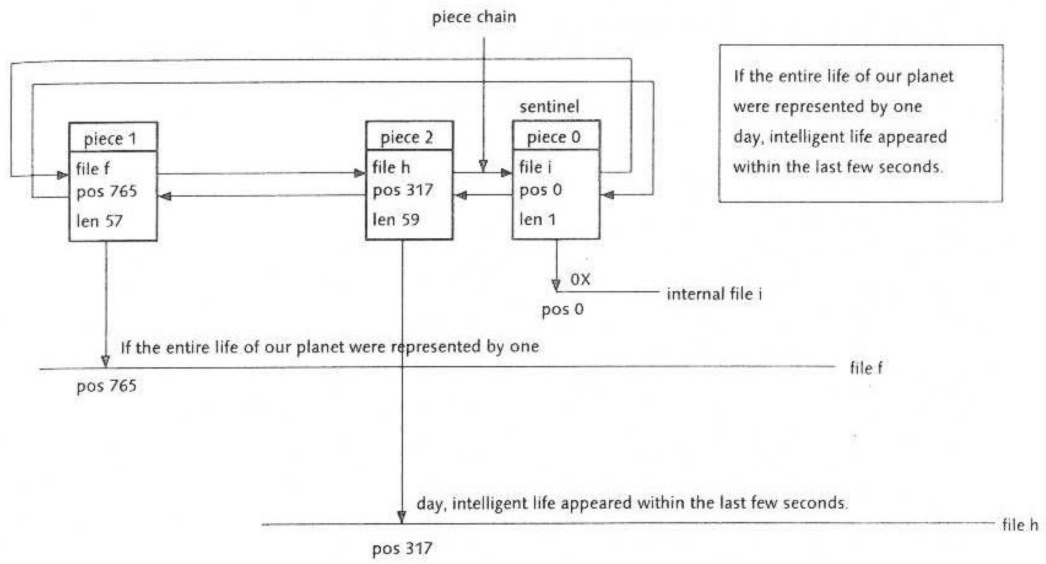
piece chain
sentinel
piece 1
file f
pos 765
len 57
piece 2
file h
pos 317
len 59
piece 0
file i
pos 0
len 1
0X
internal file i
pos 0
If the entire life of our planet were represented by one
file f
pos 765
day, intelligent life appeared within the last few seconds.
file h
pos 317
If the entire life of our planet were represented by one day, intelligent life appeared within the last few seconds.

Figure 5.2 Piece chain after delete operation.

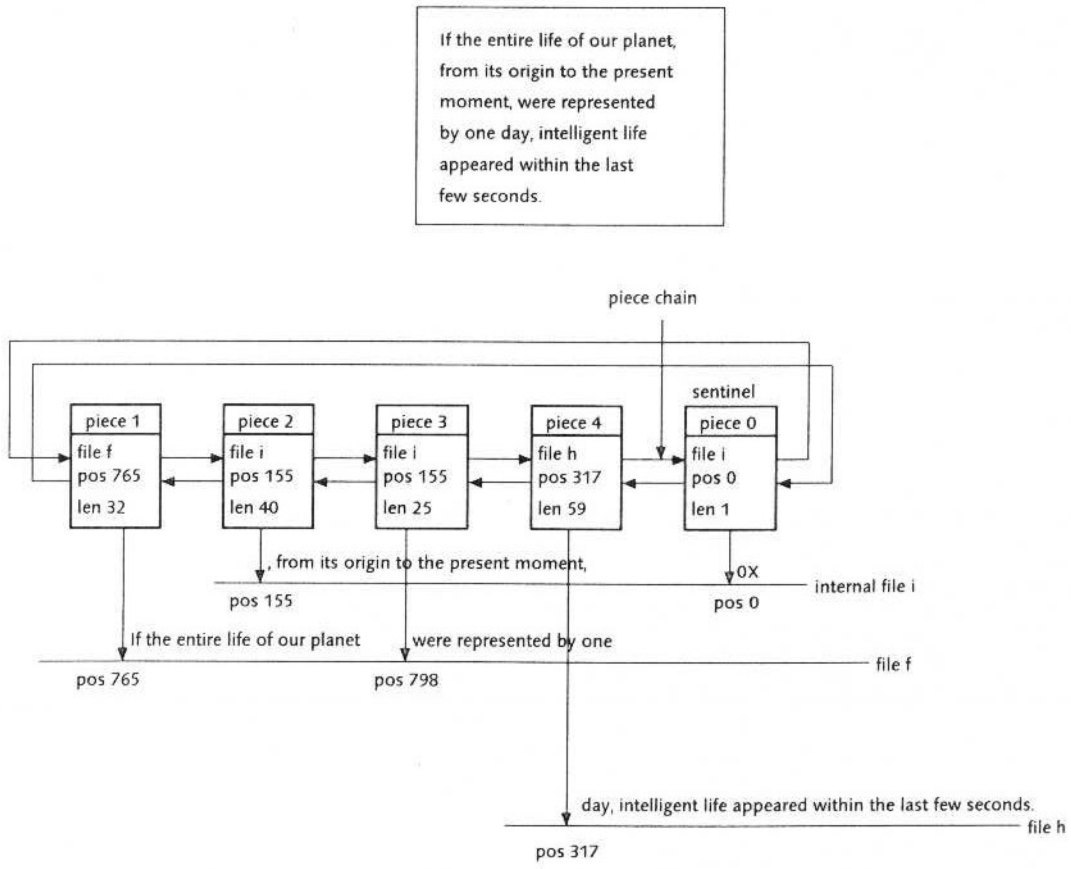
If the entire life of our planet, from its origin to the present moment, were represented by one day, intelligent life appeared within the last few seconds.
piece chain
sentinel
piece 1
file f
pos 765
len 32
piece 2
file i
pos 155
len 40
piece 3
file i
pos 155
len 25
piece 4
file h
pos 317
len 59
piece 0
file i
pos 0
len 1
, from its origin to the present moment,
pos 155
0X
internal file i
pos 0
If the entire life of our planet
were represented by one
file f
pos 765
pos 798
day, intelligent life appeared within the last few seconds.
file h
pos 317

Figure 5.3 Piece chain after insert operation.

In Oberon we adopted the piece chain technique to texts with looks. Formally, we first define a *run* as a stretch of text whose characters show identical looks. Now, we require the piece chain to subordinate itself to the run structure. This obviously means that every piece is contained within a single run. Figure 5.4 visualizes such a piece chain representing a text with varying looks. There are only two new aspects compared to the original version of the piece chain discussed above: An additional operation to *change looks* and the initial state of the piece chain.

```
change looks in a stretch [beg, end) of text = BEGIN
    split pieces at beg and at end;
    change looks in piece descriptors from beg to end in the chain
END
```

This shows that requirements 2.) and 3.) in the wish list are still satisfied.

Initially, the pieces are identical with runs, and the number of elements in the piece chain is equal to the number of runs. Because this number is typically small in comparison with the total number of characters in a text requirement 6.) is still met.

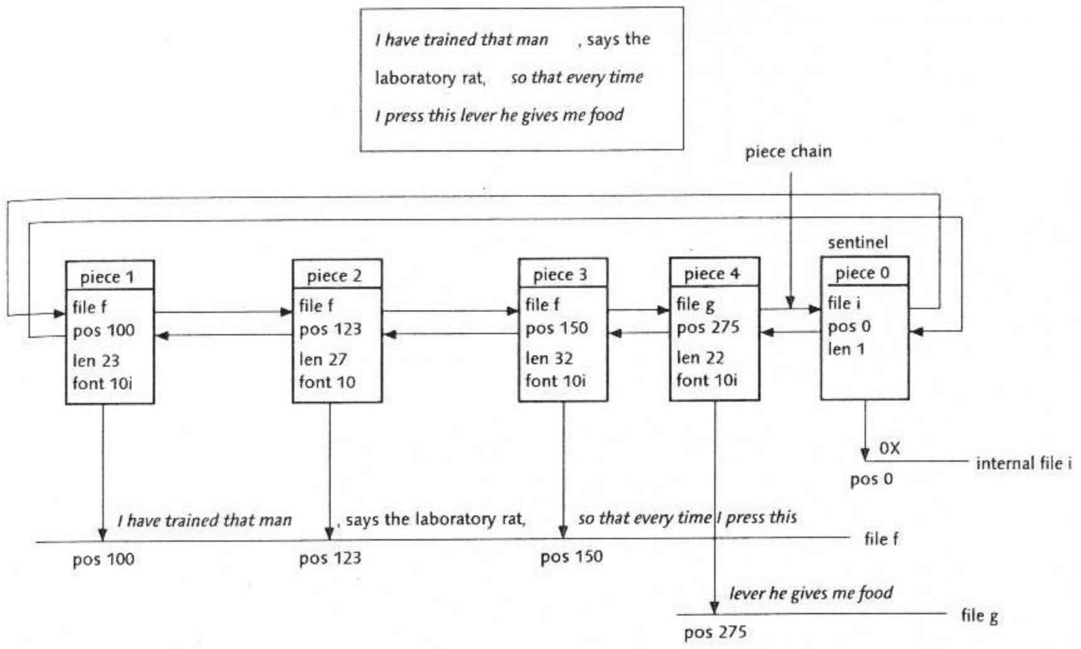

Figure 5.4 Generalized piece chain representing a text with looks.

We conclude that the new aspects do not invalidate the positive rating given above to the piece chain with regard to requirements 1.), 2.), 3.), 4.), 6.), and 7.) in our wish list. However, the requirement of efficient direct positioning remains. The problem is the necessity to scan through the piece list sequentially in order to locate the piece that contains the desired position. We investigated different solutions of this efficiency problem. They are based on different data structures connecting the piece descriptors, among them a piece tree and a variant of the piece chain featuring an additional long-distance link.

Eventually, we decided in favor of a simpler solution. To its justification we point out that the typical scenario is zooming into a local region of text for editing, i.e. positioning to an arbitrary remote location once and subsequently positioning to locations in its neighborhood many times. Therefore, an appropriate solution is caching the most recently calculated values *(pos, piece)* of the translation map. Of course, this does not solve the problem in the case of cache misses. Notice, however, that the problem is acute only in the case of extremely long piece chains that do not occur in ordinary texts and editing sessions.

We shall now illustrate the piece technique at the example of two important but basic operations: *Insert* and *read*. Let us start with an overview of the data types involved. Apart from some auxiliary private variables marked with an arrow, the types *Text*, *Buffer*, and *Reader* are already familiar to us from the previous Section. Type *Piece* is completely private. It is hidden from the clients.

```
   Text = POINTER TO TextDesc;
   Notifier = PROCEDURE (T: Text; op: INTEGER; beg, end: LONGINT);
   TextDesc = RECORD
     len: LONGINT;
     notify: Notifier;
→ trailer: Piece;
→ org: LONGINT;
→ pce: Piece
   END;

   Buffer = POINTER TO BufDesc;
   BufDesc = RECORD
     len: LONGINT;
 → header, last: Piece
   END;

   Reader = RECORD
     (Files.Rider)
     eot: BOOLEAN;
     fnt: Fonts.Font;
     col: SHORTINT;
     voff: SHORTINT;
 → ref: Piece;
 → org: LONGINT;
 → off: LONGINT
   END;

 → Piece = POINTER TO PieceDesc;
 → PieceDesc = RECORD
     f: Files.File;
     off: LONGINT;
     len: LONGINT;
     fnt: Fonts.Font;
     col: SHORTINT;
     voff: SHORTINT;
     prev, next: Piece
   END;
```

As depicted in Figure 5.1, the piece chain is implemented as a doubly linked list with a sentinel piece closing it to a ring. The field *trailer* in type *TextDesc* points to the sentinel piece. Fields *org* and *pce* implement a translation cache consisting of one entry *(org, pce)* only. It links a position *org* with a piece *pce*. The fields *header* and *last* in type *Buffer* reveal the implementation of buffers as piece chains. They point to the first and last piece descriptors respectively. Finally, the fields *ref*, *org*, and *off* in type *Reader* memorize the current piece, its origin, and the current offset within this piece.

Notice that readers are actually type extensions of so-called file *riders*. Riders play the same role for files as readers do for texts. For details see Chapter 7 on files.

The fields *f*, *off*, and *len* in type *Piece* specify the underlying file, starting position in the file, and length of the piece. *fnt*, *col*, and *voff* are its looks. Finally *prev* and *next* are pointers to the previous piece and the next piece in the chain respectively.

FindPiece and *SplitPiece* are auxiliary procedures that are used by almost all piece-oriented operations.

```
    PROCEDURE FindPiece (T: Text; pos: LONGINT; VAR org: LONGINT; VAR p: Piece);
      VAR n: INTEGER;
    BEGIN
1)    IF pos < T.org THEN T.org := -1; T.pce := T.trailer END;
2)    org := T.org; p := T.pce;
      n := 0;
3)    WHILE pos >= org + p.len DO org := org + p.len; p := p.next; INC(n) END;
4)    IF n > 50 THEN T.org := org; T.pce := p END
    END FindPiece;
```

Explanations (referring to the line numbers in the above code excerpt)

1) invalidate cache if new position < position in cache
2) use cache as starting point
3) traverse piece chain
4) update cache if more than 50 pieces traversed

```
1)  PROCEDURE SplitPiece (p: Piece; off: LONGINT; VAR pr: Piece);
      VAR q: Piece;
    BEGIN
2)    IF off > 0 THEN NEW(q);
        q.fnt := p.fnt; q.col := p.col; q.voff := p.voff;
        q.len := p.len - off;
        q.f := p.f; q.off := p.off + off;
        p.len := off;
3)      q.next := p.next; p.next := q;
4)      q.prev := p; q.next.prev := q;
        pr := q
      ELSE pr := p
      END
    END SplitPiece;
```

Explanations:

1) return right part piece pr after split
2) generate new piece only if remaining length > 0
3) insert new piece in forward chain
4) insert new piece in backward chain

Procedure *Insert* handles text insertion. It operates on a buffer that contains the stretch of text to be inserted:

```
    PROCEDURE Insert (T: Text; pos: LONGINT; B: Buffer);
      VAR pl, pr, p, qb, qe: Piece; org, end: LONGINT;
    BEGIN
1)    FindPiece(T, pos, org, p); SplitPiece(p, pos - org, pr);
2)    IF T.org >= org THEN
        T.org := org - p.prev.len; T.pce := p.prev
      END;
      pl := pr.prev; qb := B.header.next;
3)    IF (qb # NIL) & (qb.f = pl.f) & (qb.off = pl.off + pl.len)
      & (qb.fnt = pl.fnt) & (qb.col = pl.col) & (qb.voff = pl.voff) THEN
        pl.len := pl.len + qb.len; qb := qb.next
      END;
      IF qb # NIL THEN qe := B.last;
4)      qb.prev := pl; pl.next := qb; qe.next := pr; pr.prev := qe
      END;
5)    T.len := T.len + B.len; end := pos + B.len;
```

```
      6)    B.last := B.header; B.last.next := NIL; B.len := 0;
      7)    T.notify(T, insert, pos, end)
          END Insert;
```

Explanations:

1) split piece to isolate point of insertion
2) adjust cache if necessary
3) merge pieces if possible
4) insert buffer
5) update text length
6) empty buffer
7) notify

Procedure *Read* implements sequential reading of characters in texts. It operates on a text reader:

```
            PROCEDURE Read (VAR R: Reader; VAR ch: CHAR);
            BEGIN
          1)  Files.Read(R, ch); R.fnt := R.ref.fnt; R.col := R.ref.col; R.voff := R.ref.voff;
              INC(R.off);
          2)  IF R.off = R.ref.len THEN
          3)    IF R.ref.f = WFile THEN R.eot := TRUE END;
                R.org := R.org + R.off; R.off := 0;
          4)    R.ref := R.ref.next; R.org := R.org + R.off; R.off := 0;
          5)    Files.Set(R, R.ref.f, R.ref.off)
              END
            END Read;
```

Explanations:

1) read character from file and update looks in reader
2) if piece boundary reached
3) check if sentinel piece reached
4) move reader to next piece
5) position file rider

Procedure *Read* is typically used as a primitive by text scanners and in particular by the built-in scanner *Scan* for the recognition of universal tokens, as they were defined in the previous Section. Scanning is a rather complex operation that, for example, includes the conversion of a sequence of digits into an internal floating-point representation. Some low-level assistance for such conversions in both directions is provided by module *Reals* whose implementation is machine-dependent. This module is also used by *WriteReal* procedures.

```
DEFINITION Reals;
  PROCEDURE Convert (x: REAL; n: INTEGER; VAR d: ARRAY OF CHAR);
  PROCEDURE ConvertH (x: REAL; VAR d: ARRAY OF CHAR);
  PROCEDURE ConvertHL (x: LONGREAL; VAR d: ARRAY OF CHAR);
  PROCEDURE ConvertL (x: LONGREAL; n: INTEGER; VAR d: ARRAY OF CHAR);
  PROCEDURE Expo (x: REAL): INTEGER;
  PROCEDURE ExpoL (x: LONGREAL): INTEGER;
  PROCEDURE FSR (): LONGINT;
  PROCEDURE SetFSR (status: LONGINT);
  PROCEDURE Ten (e: INTEGER): REAL;
  PROCEDURE TenL (e: INTEGER): LONGREAL;
  PROCEDURE Valid (x: REAL): BOOLEAN;
  PROCEDURE ValidL (x: LONGREAL): BOOLEAN;
END Reals.
```

In spite of its apparent simplicity the piece chain technique interoperates with other system components in a quite subtle way. For example, after a while of editing, there are typically numerous cross references between the documents involved. In other words, pieces of one document may point to foreign files, that is, to files that were originally related with other documents. As a consequence, the file system must either employ some smart garbage collection algorithm or not recycle file pages at all, even if a new version of a file of the same name has been created in the meantime.

A problem of another kind again affecting the file system arises if, say, a single text line is composed of several small pieces. Then, reading this line sequentially may necessitate several quick jumps to different positions in different files. Depending on the quality of the file buffering mechanism this may lead to significantly hesitant mouse tracking.

And finally, typed characters that are supposed to be inserted into a text need to be stored on a continuously growing file, the so-called *keyboard file*. For this file, several readers and one writer must be allowed to exist concurrently.

As a consequence, the following qualities of the underlying file system are necessary for the piece technique to work properly:

1. Once a file page is allocated it must not be reused (until system restart).
2. A versatile file buffering mechanism supporting multiple buffers per file is required.
3. Files must be allowed to be open in read mode and in write mode simultaneously.

The format of text sections in files obeys a set of syntactical rules ("productions") that can easily be specified in EBNF-notation:

```
TextSection = ident header {char}.
header = type offset run {run} null length.
run = font [name] color offset length.
```

In the *TextSection* production *ident* is an identifier for text blocks. In the *header* production *type* is a type-discriminator, *offset* is the offset to the character part, *run* is a run-descriptor, *null* is a null-character, and *length* is the length of the character sequence. In the *run* production *font*, *color*, and *offset* are specifications of looks, and *length* is the run-length. In order to save space, font names are coded as ordinal numbers within a text section. If and only if a font appears for the first time in a text block it is followed by the font's name.

Let us conclude this Section with two side-remarks and a summary.

Remarks:

- For compatibility reasons, plain ASCII-files are accepted as text files as well. They are mapped to texts consisting of a single run with standard looks.

- Internalizing a text section from a file is extremely efficient because it is obviously sufficient to read the header and translate it into the initial state of the piece chain.

Summary: The mechanism used for the implementation of the abstract data type *Text* is completely hidden from clients. It is a generalized version of the original piece chain technique, adapted to texts with looks. The piece chain technique is based on the principle of indirection: Operations operate on descriptors of texts rather than on texts themselves. The benefits are efficiency and non-destructive operations. However, the technique works properly only in combination with a suitable file system.

5.3. Text Frames

The tasks of text frames are text rendering and user interaction. A text frame represents a text view and a controller in the form of an interactive text editor. Technically, text frames are a subclass of display frames and, as such, are objects with an open message interface of the kind explained in Chapter 4.

The geometric layout of text frames is determined by two areas: A rectangle of contents and a vertical scroll-bar along the left borderline. The type of text frames is a direct extension of type *Display.Frame*:

```
Frame = POINTER TO FrameDesc;
```

```
FrameDesc = RECORD (Display.FrameDesc)
  text: Texts.Text;
  org: LONGINT;
  col: INTEGER;
  lsp: INTEGER;
  left, right, top, bot: INTEGER;
  markH: INTEGER;
  time: LONGINT;
  mark, car, sel: INTEGER;
  carloc: Location;
  selbeg, selend: Location
END;
```

Fields *text* and *org* specify the text part to be displayed, the former referring to the underlying text and the latter designating the starting position of the displayed part. Fields *col* and *lsp* are rendering parameters. They specify the frame's background color and line spacing. Fields *left*, *right*, *top*, and *bot* are margins. They determine the rectangle of contents. *mark* represents the state of the *position marker*, which is a small horizontal bar indicating the position of the displayed part relative to the whole text. *markH* represents its location within the text frame.

Caret and *selection* are two important features associated with a text frame. The caret indicates a potential "point of insertion" and serves as an implicit parameter for placing consumed characters (for example from the keyboard). The selection is a stretch of displayed text. It also typically serves as a parameter for various operations and commands, among them *delete* and *change looks*. The state and location of the caret is given by the variables *car* and *carloc* respectively. Analogously, the state of the selection and its begin and end are reflected by the fields *sel*, *selbeg*, and *selend* in the frame descriptor. Field *time* is a time stamp on the current selection.

In principle, caret and selection could be regarded as ingredients of the underlying text (the model) equally well. However, we deliberately decided to associate these features with frames (views) in order to get increased flexibility. For example, two different selections in adjacent viewers displaying the same text are normally interpreted as one extensive selection of their span.

The auxiliary type *Location* summarizes information about a location in a text frame. Its definition is:

```
Location = RECORD
  org, pos: LONGINT;
  dx, x, y: INTEGER
END;
```

x, *y* specifies the envisaged location relative to the text frame's origin and *dx* is the width of the character at this location. *pos* is the corresponding position in the text and *org* is the origin position of the corresponding text line.

Remember that the "capabilities" of a frame object are determined solely by its message handler. It is therefore worth the while to study the text frame handler. This is a rough description:

```
      PROCEDURE Handle (F: Display.Frame; VAR M: Display.FrameMsg);
        VAR F1: Frame;
      BEGIN
        WITH F: Frame DO
          IF M IS Oberon.InputMsg THEN
             WITH M: Oberon.InputMsg DO
1)              IF M.id = Oberon.track THEN Edit(F, M.X, M.Y, M.keys)
                ELSIF M.id = Oberon.consume THEN
2)                IF F.car # 0 THEN Write(F, M.ch, M.fnt, M.col, M.voff) END
                END
             END
          ELSIF M IS Oberon.ControlMsg THEN
            WITH M: Oberon.ControlMsg DO
```

```
 3)        IF M.id = Oberon.defocus THEN Defocus(F)
 4)        ELSIF M.id = Oberon.neutralize THEN Neutralize(F)
           END
         END
       ELSIF M IS Oberon.SelectionMsg THEN
 5)        WITH M: Oberon.SelectionMsg DO GetSelection(F, M.text, M.beg, M.end, M.time)
END
       ELSIF M IS Oberon.CopyOverMsg THEN
 6)        WITH M: Oberon.CopyOverMsg DO CopyOver(F, M.text, M.beg, M.end) END
       ELSIF M IS Oberon.CopyMsg THEN
 7)        WITH M: Oberon.CopyMsg DO Copy(F, F1); M.F := F1 END
       ELSIF M IS MenuViewers.ModifyMsg THEN
 8)        WITH M: MenuViewers.ModifyMsg DO Modify(F, M.id, M.dY, M.Y, M.H) END
       ELSIF M IS UpdateMsg THEN
           WITH M: UpdateMsg DO
 9)          IF F.text = M.text THEN Update(F, M) END
           END
       END
     END
   END Handle;
```

Explanations:

1) Mouse tracking message: Call built-in editor immediately
2) Consume message: In case of valid caret insert character
3) Defocus message: Remove caret
4) Neutralize message: Remove caret and selection
5) Selection message: Return current selection with time stamp
6) Copyover message: Copy given stretch of text to caret
7) Copy message: Create a copy (clone)
8) Modify message: Translate and change size
9) Update message: If text was changed then update display

We recognize again our categories of universal messages introduced in Chapter 4, Table 4.1: Messages in lines 1) and 2) report about user interactions. Messages in 3), 4), 5), 6), and 7) specify some generic operation. Messages in 8) require a change of location or size. Messages of the latter kind arrive from the ancestor menu viewer. They are generated by the interaction handler and by the preprocessor of original viewer messages. Finally, messages in line 9) report about changes of contents.

The text frame handler is encapsulated in a module called *TextFrames*. This module exports the above introduced types *Frame* (text frame) and *Location*, as well as the procedure *Handle*. Furthermore, it exports type *UpdateMsg* to report on changes made to a displayable text.

```
UpdateMsg = RECORD (Display.FrameMsg)
  id: INTEGER;
  text: Texts.Text;
  beg, end: LONGINT
END;
```

Field *id* names one of the operators *replace*, *insert*, or *delete*. The remaining fields *text*, *beg*, and *end* restrict the change to a range. Additional procedures generate a new standard menu text frame and main contents text frame respectively:

```
PROCEDURE NewMenu (name, commands: ARRAY OF CHAR): Frame;
PROCEDURE NewText (text: Texts.Text; pos: LONGINT): Frame;
```

This completes the minimum definition of module *TextFrames*. However, this module additionally exports a set of useful service procedures that support the composition of custom handlers from elements of the standard handler:

```
PROCEDURE Edit (F: Frame; X, Y: INTEGER; Keys: SET);
PROCEDURE Write (F: Frame; ch: CHAR; fnt: Fonts.Font; col, voff: SHORTINT);
PROCEDURE Defocus (F: Frame);
PROCEDURE Neutralize (F: Frame);
PROCEDURE GetSelection (F: Frame; VAR text: Texts.Text;
  VAR beg, end, time: LONGINT);
PROCEDURE CopyOver (F: Frame; text: Texts.Text; beg, end: LONGINT);
PROCEDURE Copy (F: Frame; VAR F1: Frame);
PROCEDURE Modify (F: Frame; id, dY, Y, H: INTEGER);
PROCEDURE Update (F: Frame; VAR M: UpdateMsg);
```

The module also supports mouse tracking inside text frames:

```
PROCEDURE TrackCaret (F: Frame; X, Y: INTEGER; VAR keysum: SET);
PROCEDURE TrackSelection (F: Frame; X, Y: INTEGER; VAR keysum: SET);
PROCEDURE TrackLine (F: Frame; X, Y: INTEGER; VAR org: LONGINT;
  VAR keysum: SET);
PROCEDURE TrackWord (F: Frame; X, Y: INTEGER; VAR pos: LONGINT;
  VAR keysum: SET);
```

Let us now take a look at the implementation of some selected operations. For this purpose, we must first explain the notion of *line descriptor* that is used to optimize the operation of locating positions within text frames.

```
Line = POINTER TO LineDesc;

LineDesc = RECORD
    len: LONGINT;
    wid: INTEGER;
    eot: BOOLEAN;
    next: Line
END;
```

Each line descriptor provides detailed information about a single line of text that is currently displayed: *len* is the number of characters on the line, *wid* is the line width, *eot* indicates terminating line, and *next* points to the next line descriptor.

Text frames maintain a private data structure called *line-chain* that describes the list of text lines displayed:

```
Frame = POINTER TO FrameDesc;

FrameDesc = RECORD (Display.FrameDesc)
    text: Texts.Text;
    org: LONGINT;
    col: INTEGER;
    lsp: INTEGER;
    left, right, top, bot: INTEGER;
    markH: INTEGER;
    time: LONGINT;
    mark, car, sel: INTEGER;
    carloc: Location;
    selbeg, selend: Location;
→  trailer: Line
END;
```

Field *trailer* represents a sentinel element that closes the line chain to a ring.

The line-chain contains useful summary information about the current contents of the text frame. It can be used beneficially by some related data types, for example by type *Location* that was introduced earlier:

```
 Location = RECORD
   org, pos: LONGINT;
   dx, x, y: INTEGER;
→ lin: Line
 END;
```

The built-in editor procedure *Edit* is a worthwhile part to look at in some detail. It is called by the task scheduler to handle mouse events within a text frame. The following code excerpt shows nicely how the different components of the text system interoperate.

```
PROCEDURE Edit (F: Frame; X, Y: INTEGER; Keys: SET);
  VAR
   M: Oberon.CopyOverMsg;
   R: Texts.Reader;
   text: Texts.Text; buf: Texts.Buffer;
    cmd: INTEGER;
    time, pos, beg, end: LONGINT;
    keysum: SET;
    ch: CHAR;
BEGIN
  Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, X, Y);
  IF X < F.X + Min(F.left, barW) THEN
    IF (0 IN Keys) OR (1 IN Keys) THEN keysum := Keys;
      REPEAT
        Input.Mouse(Keys, X, Y);
        keysum := keysum + Keys;
        Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, X, Y)
      UNTIL Keys = {};
      IF ~(2 IN keysum) THEN
        IF (0 IN keysum) OR (F.Y + F.H < Y) THEN pos := 0
          ELSE pos := (F.Y + F.H - Y) * (F.text.len) DIV F.H
        END;
        RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
      ELSIF ~(0 IN keysum) THEN
        RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
        Show(F, F.text.len)
      END
    ELSIF 2 IN Keys THEN
      TrackLine(F, X, Y, pos, keysum);
      IF (pos >= 0) & ~(0 IN keysum) THEN
        RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
        Show(F, pos)
      END
    END
ELSE
  IF 0 IN Keys THEN
    TrackSelection(F, X, Y, keysum);
    IF F.sel # 0 THEN
      IF (2 IN keysum) & ~(1 IN keysum) THEN
        Oberon.PassFocus(Viewers.This(F.X, F.Y));
        Oberon.GetSelection(text, beg, end, time);
        Texts.Delete(text, beg, end); SetCaret(F, beg)
      ELSIF (1 IN keysum) & ~(2 IN keysum) THEN
        Oberon.GetSelection(text, beg, end, time);
        M.text := text; M.beg := beg; M.end := end;
        Oberon.FocusViewer.handle(Oberon.FocusViewer, M)
      END
```

```
49)      END
50)    ELSIF 1 IN Keys THEN
51)      TrackWord(F, X, Y, pos, keysum);
52)      IF (pos >= 0) & ~(0 IN keysum) THEN Call(F, pos, 2 IN keysum) END
53)    ELSIF 2 IN Keys THEN
54)      Oberon.PassFocus(Viewers.This(F.X, F.Y)); TrackCaret(F, X, Y, keysum);
55)      IF F.car # 0 THEN
56)        IF (1 IN keysum) & ~(0 IN keysum) THEN
57)          Oberon.GetSelection(text, beg, end, time);
58)          IF time >= 0 THEN
59)            NEW(buf); Texts.OpenBuf(buf);
60)            Texts.Save(text, beg, end, buf);
61)            Texts.Insert(F.text, F.carloc.pos, buf);
62)            SetCaret(F, F.carloc.pos + (end - beg))
63)          END
64)        ELSIF (0 IN keysum) & ~(1 IN keysum) THEN
65)          Oberon.GetSelection(text, beg, end, time);
66)          IF time >= 0 THEN
67)            Texts.OpenReader(R, F.text, F.carloc.pos); Texts.Read(R, ch);
68)            Texts.ChangeLooks(text, beg, end, {0, 1, 2}, R.fnt, R.col, R.voff)
69)          END
70)        END
73)      END
74)     END
75)    END
76)  END Edit;
```

Explanations:

11) Update cursor

12) - 35) handling of mouse within scroll bar

13) - 28) If right key or middle key pressed
14) - 18) Track mouse until all keys released
19) - 24) If left key was not interclicked
20) - 22) calculate new top origin
23) remove all markers to monopolize frame
24) jump to new top origin
25) - 28) If right key was not pressed
26) remove all markers to monopolize frame
27) jump to the end

29) - 35) If left key is pressed
30) track mouse to determine new top line
31) - 34) if valid then scroll to new top line

36) - 75) handling of mouse within text area

37) - 49) if right key pressed ("select-key")
38) track mouse to determine selection
39) - 49) if selection valid
40) - 43) if left key interclicked (but not middle key)
41) grab focus
42) get selection
43) delete selected stretch of text
44) - 48) if middle key interclicked (but not left key)
45) get selection
46) - 47) copy over selected stretch to focus

```
50) - 52) if middle key pressed ("execute-key")
  51) track mouse to determine name
  52) if valid then call command with this name

50) - 74) if left key pressed ("point-key")
  54) grab focus and track mouse to determine caret
  55) - 73) if caret valid
    56) - 63) if middle key interclicked (but not right)
      57) get newest selection
      58) - 63) if existing
        59) create and open buffer
        60) save newest selection in buffer
        61) insert it at caret
      64) - 70)
        65) get newest selection
        66) - 69) if existing
          67) open reader at caret and read one character
          68) change looks of selected stretch to those of character read
```

In particular we see that the editing operation is determined by the first key pressed *(primary key)* and can then be varied by "interclicking" that is, by clicking a *secondary key* while holding down the primary key. As a convention, (inter)clicking all keys means annulling the operation. Notice that the interpretation of mouse events in the scroll-bar area differs from the interpretation in the text area. Tables 5.2a and 5.2b summarize the two cases. They can easily be derived from the above explanations.

Table 5.2a (in scroll bar)

key	-	left
left	scroll line to top	-
middle	jump to mouse	jump to end
right	jump to start	-

Table 5.2b (in text area)

key	-	left	middle
left	set caret	-	copy looks
middle	execute command	load and execute command	-
right	select	select and delete	select and copy

In the text area the keys are interpreted according to their generic semantics:

left key = point key
middle key = execute key
right key = select key

Let us "zoom into" one of the editing operations, for example into *TrackCaret* on line 54).

```
     PROCEDURE TrackCaret (F: Frame; X, Y: INTEGER; VAR keysum: SET);
       VAR loc: Location; keys: SET;
     BEGIN
1)     IF F.trailer.next # F.trailer THEN
2)       LocateChar(F, X - F.X, Y - F.Y, F.carloc);
3)       FlipCaret(F);
4)       keysum := {};
         REPEAT
           Input.Mouse(keys, X, Y);
           keysum := keysum + keys;
           Oberon.DrawCursor(Oberon.Mouse, Oberon.Mouse.marker, X, Y);
```

```
          LocateChar(F, X - F.X, Y - F.Y, loc);
          IF loc.pos # F.carloc.pos THEN FlipCaret(F); F.carloc := loc; FlipCaret(F) END
    5)      UNTIL keys = {};
    6)      F.car := 1
         END
       END TrackCaret;
```

Explanations:

1) guard guarantees non-empty line-chain
2) locates the character pointed at
3) drags caret to new location
4) - 5) tracks mouse and drags caret accordingly
6) set caret state

TrackCaret makes use of two auxiliary procedures *FlipCaret* and *LocateChar*. *FlipCaret* is used to turn off or on the pattern of the caret. *LocateChar* is an important operation that is used to locate the character at a given Cartesian position *(x, y)* within the frame.

```
      PROCEDURE FlipCaret (F: Frame);
      BEGIN
   1)   IF F.carloc.x < F.W THEN
   2)     IF (F.carloc.y >= 10) & (F.carloc.x + 12 < F.W) THEN
   3)       Display.CopyPattern(Display.white, Display.hook,
               F.X + F.carloc.x, F.Y + F.carloc.y - 10, 2)
          END
        END
      END FlipCaret;
```

Explanations:

1) - 2) if there is room for drawing the caret
3) copy standard hook-shaped pattern to caret location in inverse video mode

```
      PROCEDURE LocateChar (F: Frame; x, y: INTEGER; VAR loc: Location);
        VAR R: Texts.Reader;
          pat: Display.Pattern;
          pos, lim: LONGINT;
          ox, dx, u, v, w, h: INTEGER;
   1)  BEGIN LocateLine(F, y, loc);
   2)    lim := loc.org + loc.lin.len - 1;
   3)    pos := loc.org; ox := F.left;
   4)    Texts.OpenReader(R, F.text, loc.org); Texts.Read(R, nextCh);
   5)    LOOP
          IF pos = lim THEN dx := eolW; EXIT END;
   6)      Display.GetChar(R.fnt.raster, nextCh, dx, u, v, w, h, pat);
           IF ox + dx > x THEN EXIT END;
           INC(pos); ox := ox + dx; Texts.Read(R, nextCh)
   7)    END;
   8)    loc.pos := pos; loc.dx := dx; loc.x := ox
       END LocateChar;
```

Explanations:

1) locate text line corresponding to at *y*
2) set limit to the last actual character on this line
3) start locating loop with first character on this line
4) setup reader and read first character of this line
5) - 7) scan through characters of this line until limit or *x* is reached

```
    6) get character width dx of current character
  8) return location found
```

Notice that the need to read characters from the text (again) in *LocateChar* has its roots in the so-called *proportional fonts* texts are represented in. We found that keeping character widths is an unnecessary optimization thanks to the buffering capabilities of the underlying file system. In the case of *fixed-pitch fonts* a simple division by the character width would be sufficient, of course.

Finally, procedure *LocateLine* uses the line-chain to locate the desired text line without reading text at all.

```
      PROCEDURE LocateLine (F: Frame; y: INTEGER; VAR loc: Location);
        VAR T: Texts.Text; L: Line; org: LONGINT; cury: INTEGER;
      BEGIN T := F.text;
   1)   org := F.org; L := F.trailer.next; cury := F.H - F.top - asr;
   2)   WHILE (L.next # F.trailer) & (cury > y + dsr) DO
          org := org + L.len; L := L.next; cury := cury - lsp
   3)   END;
   4)   loc.org := org; loc.lin := L; loc.y := cury
      END LocateLine;
```

Explanations:

```
1) start with first line in the frame
2) -  3) traverse line chain until last line or y is reached
4) return found line
```

After text editing text rendering is our next topic. Let us pursue the case in that a user pressed the point-key and then interclicked the middle key, corresponding to line 56) in procedure *Edit*. Remember that *notifier* is called at the end of every editing operation and in particular at the end of *Texts.Insert*. In case of standard text frames, the notifier simply *broadcasts* an update message into the display space:

```
PROCEDURE NotifyDisplay (T: Texts.Text; op: INTEGER; beg, end: LONGINT);
  VAR M: UpdateMsg;
BEGIN M.id := op; M.text := T; M.beg := beg; M.end := end; Viewers.Broadcast(M)
END NotifyDisplay;
```

Let us now take the perspective of a text frame *receiving* an update message. Looking at line 9) in the text frame handler, we see that procedure *Update* is called, which in turn calls procedure *Insert* in *TextFrames*:

```
      PROCEDURE Insert (F: Frame; beg, end: LONGINT);
        VAR R: Texts.Reader; L, L0, l: Line;
          org, len: LONGINT; curY, botY, Y0, Y1, Y2, dY, wid: INTEGER;
      BEGIN
        IF beg < F.org THEN F.org := F.org + (end - beg)
        ELSE
   1)     org := F.org; L := F.trailer.next; curY := F.Y + F.H - F.top - asr;
          WHILE (L # F.trailer) & (org + L.len <= beg) DO
            org := org + L.len; L := L.next; curY := curY - lsp
   2)     END;
   3)     IF L # F.trailer THEN
            botY := F.Y + F.bot + dsr;
   4)       Texts.OpenReader(R, F.text, org); Texts.Read(R, nextCh);
   5)       len := beg - org; wid := Width(R, len);
   6)       ReplConst (F.col, F, F.X + F.left + wid, curY - dsr, L.wid - wid, lsp, 0);
   7)       DisplayLine(F, L, R, F.X + F.left + wid, curY, len);
   8)       org := org + L.len; curY := curY - lsp;
            Y0 := curY; L0 := L.next;
            WHILE (org <= end) & (curY >= botY) DO
```

```
              NEW(l);
              Display.ReplConst(F.col, F.X + F.left, curY - dsr, F.W - F.left, lsp, 0);
              DisplayLine(F, l, R, F.X + F.left, curY, 0);
              L.next := l; L := l;
              org := org + L.len; curY := curY - lsp
 9)          END;
10)          IF L0 # L.next THEN Y1 := curY;
11)            L.next := L0;
             WHILE (L.next # F.trailer) & (curY >= botY) DO
               L := L.next; curY := curY - lsp
12)           END;
              L.next := F.trailer;
              dY := Y0 - Y1;
              IF Y1 > curY + dY THEN
13)              Display.CopyBlock
                  (F.X + F.left, curY + dY + lsp - dsr, F.W - F.left, Y1 - curY - dY,
                   F.X + F.left, curY + lsp - dsr,
                   0);
                Y2 := Y1 - dY
              ELSE Y2 := curY
              END;
14)            curY := Y1; L := L0;
              WHILE curY # Y2 DO
                Display.ReplConst(F.col, F.X + F.left, curY - dsr, F.W - F.left, lsp, 0);
                DisplayLine(F, L, R, F.X + F.left, curY, 0);
                L := L.next; curY := curY - lsp
15)            END
             END
           END
         END;
16)    UpdateMark(F)
     END Insert;
```

Some explanations:

1) - 2) search line where inserted part starts
3) if it is displayed in this viewer
4) setup reader on this line
5) get width of unaffected part of line (avoid touching it)
6) clear remaining part of line
7) display new remaining part of line
8) - 9) display newly inserted text lines
10) if it was not a one line update
11) - 12) skip overwritten text lines
13) use fast block move to adjust reusable lines
14) - 15) redisplay previously overwritten text lines
16) adjust position marker

Special care is exercised in the implementation to avoid "flickering" and to minimize processing time. Concretely, the following measures are taken:

1.) Avoid writing the same data again.
2.) Keep the number of newly rendered text lines at a minimum.
3.) Use block move to adjust reusable displayed lines.

Of course, the rules governing the rendering and formatting process crucially influence the complexity of procedures like *Insert*. For text frames we have consciously chosen the simplest possible set of formatting rules. They can be summarized as:

1.) For a given text frame the distance between lines is constant.
2.) There are no implicit line breaks.

It is exactly this set of rules that makes it possible to display a text line in *one pass*. Two passes are inevitable if line distances have to adjust to font sizes or if lines must be broken implicitly.

Update algorithms make use of the following one-pass rendering procedures *Width* and *DisplayLine*:

```
     PROCEDURE Width (VAR R: Texts.Reader; len: LONGINT): INTEGER;
       VAR pat: Display.Pattern; pos: LONGINT; ox, dx, x, y, w, h: INTEGER;
  1)  BEGIN pos := 0; ox := 0;
        WHILE pos # len DO
          Display.GetChar(R.fnt.raster, nextCh, dx, x, y, w, h, pat);
          ox := ox + dx; INC(pos); Texts.Read(R, nextCh)
  2)    END;
  3)    RETURN ox
    END Width;
```

Explanations:

1) - 2) scan through len characters of this line
3) return accumulated width

Notice that procedures *Width* and *LocateChar* are similar. Therefore the above comment about relying on the buffering capabilities of the underlying file system applies to procedure *Width* equally well.

```
     PROCEDURE DisplayLine (F: Frame; L: Line;
       VAR R: Texts.Reader; X, Y: INTEGER; len: LONGINT);
       VAR pat: Display.Pattern; NX, dx, x, y, w, h: INTEGER;
  1)  BEGIN NX := F.X + F.W;
  2)    WHILE (nextCh # CR) & (R.fnt # NIL) DO
  3)      Display.GetChar(R.fnt.raster, nextCh, dx, x, y, w, h, pat);
  4)      IF (X + x + w <= NX) & (h # 0) THEN
  5)        Display.CopyPattern(R.col, pat, X + x, Y + y, 2)
  6)      END;
  7)      X := X + dx; INC(len); Texts.Read(R, nextCh)
  8)    END;
  9)    L.len := len + 1; L.wid := X + eolW - (F.X + F.left);
 10)    L.eot := R.fnt = NIL; Texts.Read(R, nextCh)
     END DisplayLine;
```

Explanations:

1) set right margin
2) - 8) display characters of this line
   3) get width *dx*, box *x, y, w, h*, and pattern *pat* of next character
   4) if there is enough space in the rectangle of contents
   5) display pattern
   7) jump to location of next character; read next character
9) - 10) setup line descriptor

Procedure *DisplayLine* is again similar to *LocateChar*, and the comment on relying on the file system's buffering capabilities applies once more. The principal difference between *LocateChar* and *Width* on one hand and *DisplayLine* on the other hand is the fact that the latter accesses the display screen physically. Therefore, possession of the screen lock is a tacit precondition for calling *DisplayLine*.

A quick look at an auxiliary procedure that updates the *position marker* concludes our tour behind the scenes of the text system:

```
     PROCEDURE UpdateMark (F: Frame);
       VAR oldH: INTEGER;
     BEGIN
```

```
1)    oldH := F.markH; F.markH := SHORT(F.org * F.H DIV (F.text.len + 1));
      IF (F.mark > 0) & (F.left >= barW) & (F.markH # oldH) THEN
2)      Display.ReplConst(Display.white, F.X + 1, F.Y + F.H - 1 - oldH, markW, 1, 2);
3)      Display.ReplConst(Display.white, F.X + 1, F.Y + F.H - 1 - F.markH, markW, 1, 2)
      END
    END UpdateMark;
```

Explanations

1) shows how the marker's position is calculated. Roughly said, the invariant proportion is

distance from top of frame / frame height
= text position of first character in frame / text length

2) erase the old marker
3) draw the new marker

And this in turn concludes our Section on text frames. Recapitulating the most important points: The tasks of text editing (input oriented) and text rendering (output oriented) are combined in the concept of text frames. Text frames constitute a subclass of display frames and are implemented in a separate module called *TextFrames*. The implementation of *TextFrames* accesses the displayed text exclusively via the “official” abstract interface of module *Texts* discussed in Section 5.2. It maintains a private data structure of line chains to accelerate locating requests. Text frames use simple formatting rules that allow super-efficient rendering of text in a single pass. In particular, line spacing is fixed for every text frame. Therefore, different styles of a base font are possible within a given text frame while different sizes are not.

Putting into relation the different derivations of type *Display.Frame* that we came across in Chapters 4 and 5, we obtain the type hierarchy of Table 5.3, where types on upper lines are an extension of their corresponding base type on lower lines:

Table 5.3

Viewers.Track	MenuViewers.Viewer	
Viewers.Viewer		TextFrames.Frame
Display.Frame		

5.4. The Font Machinery

We have seen in the previous Sections that Oberon texts support attribute specifications (“looks”) for characters. Three different attributes are supported: *Font*, *color*, and *vertical offset*. Let us first focus on the *font* attribute. A font can be regarded as a style the standard character set is designed in. Typically, an entire text is typeset in a single style, that is, there is one font per text. However, sometimes, an author wants to emphasize titles or words by changing the size of the font or by varying it to **bold face** or *italics*. In special texts, special characters like mathematical symbols or other kinds of icons may occur. In even more complex documents, mathematical or chemical formulae might flow within the text.

These observations lead us to a different interpretation of the notion of font. We can regard a font as an *indexed library* of (graphical) objects, mostly but not necessarily *glyphs*. In the case of ordinary characters it is natural to use the ASCII-code as an index, and we arrive at an interpretation of text as sequence of pairs *(library, index)*. Notice that this is a very general view that, in principle, is equivalent with defining text as sequence of arbitrary objects.

The imaging model of characters provides two levels of abstraction. On the first level, characters are black boxes given by a set of metric data *x*, *y*, *w*, *h*, and *dx*. *(x, y)* is a vector from the current point of reference on the base line to the origin of the box. *w* and *h* are width and height of the box, and *dx* is the distance to the point of reference of the next character on the same base line. On the second level of abstraction, a character is given by a digital pattern or *glyph* that is to be rendered into the box. Figure 5.5 visualizes this model of characters.

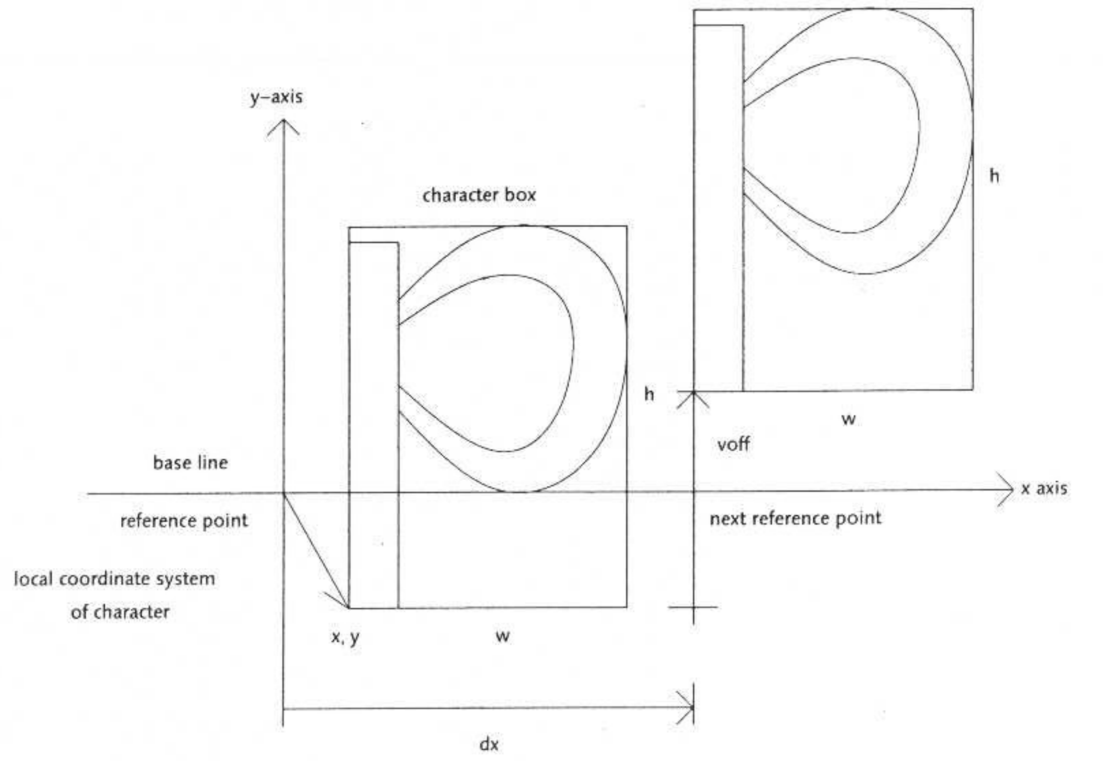

Figure 5.5 The geometric character model.

The additional two character attributes *color* and *vertical offset* appear now as parameters for the character model. The vertical offset allows translating the *y*-coordinate in the vector *(x, y)* to *y + voff*, and the *color* attribute specifies the foreground color of the pattern.

Good examples of procedures operating on the first level of abstraction are *LocateChar* and *Width* that we discussed in the previous Section, as well as text formatters for a remote printer. In contrast, procedure *DisplayLine* operates on the second level.

The representation of characters as digital patterns is merely the last step in a complex process. At the beginning is a generic description of the shape of each character in the form of *outlines* and *hints*. Outlines are typically composed of straight lines and spline-curves. Hints are included to assist the digitizer in its effort to faithfully map the filled character outlines into the device raster. For example, hinting can guarantee consistency of serif shapes and stem widths across an entire font within a text, independent of the relative positions of the characters with respect to the grid lines. Automatic digitization produces digital patterns of sufficiently high quality for printing media resolutions. For screen resolutions, however, we prefer to add a hand-tuning step. This is the reason why digital patterns are not produced "on the fly" in Oberon.

Oberon's font management is encapsulated in module *Fonts*, with a low-level extension in the module *Display* that we already know from Chapter 4. The interface to module *Fonts* is very simple and narrow:

```
MODULE Fonts;

  IMPORT Display;

  TYPE
     Name = ARRAY 32 OF CHAR;
```

```
      Font = POINTER TO FontDesc;
      FontDesc = RECORD
        name: Name;
        height, minX, maxX, minY, maxY INTEGER;
        raster: Display.Font
      END;

    VAR Default: Font;

    PROCEDURE This (name: ARRAY OF CHAR): Font;

  END Fonts.
```

Component *name* in type *Font* is the name of the underlying file. Components *height*, *minX*, *maxX*, *minY*, and *maxY* are line height and summary metric data, and field *raster* refers to the mentioned low-level extension in module *Display*. Default is a system-wide *default font*. It is installed at system loading time. This is a procedure to internalize a font from a file given by its name.

This is the definition of the low-level extension of the font management:

```
MODULE Display;
  ...
  TYPE
    Font = POINTER TO Bytes;
    Bytes = RECORD END;

    PROCEDURE GetChar (f: Font; ch: CHAR; VAR dx, x, y, w, h: INTEGER;
     VAR p: Pattern);
  ...
END Display.
```

Type *Display.Font* is a pointer to a record of open length containing the metric descriptions and patterns of all characters contained in the font. Procedure *GetChar* returns the metric data *dx*, *x*, *y*, *w*, *h*, and the pattern *p* of character *ch* in font *f*.

Type *Font* should be regarded as an abstract data type with two intrinsic operations *This* and *GetChar*. Thinking of the immutable nature of fonts, multiple internal copies of the same font are certainly undesired. Therefore, internalized fonts are *cached* in a private list that manifests itself in a private field *next* in type *FontDesc*:

```
   Font = POINTER TO FontDesc;
   FontDesc = RECORD
     name: Name;
     height, minX, maxX, minY, maxY: INTEGER;
     raster: Display.Font;
→    next: Font
   END;
```

The cache is maintained by the internalizing procedure *This* according to the following scheme:

```
search font in cache;
IF found THEN return cached internalization
  ELSE internalize font; cache it
END
```

The implementation of type *Font* did not give many nuts to crack. One is an undesired side-effect of caching. The problem arises if a font is used for a limited time only. Because it is cached it will never be collected by the system's garbage collector again. In extreme cases such as a print server with many large fonts there is a good chance for the memory to be filled up with no-longer-used fonts. The only clean way out in this and in analogous cases is making the font cache known to the garbage collector.

We conclude this Section with a formal specification of the font file format. Note that on one hand, the file format is completely private to the managing module and on the other hand, it must be ultimately stable because it is probably used for long-term backup and for wide-range data exchange.

This is an EBNF specification of Oberon font files:

```
FontFile = ident header contents.
header = abstraction family variant height minX maxX minY maxY.
contents = nofRuns { beg end } { dx x y w h } { rasterByte }.
```

ident, *abstraction*, *family*, and *variant* are one-byte values indicating file identification, abstraction (first level without raster bytes, second level with raster bytes), font family (*Times Roman*, *Syntax* etc.), and variant (bold face, italics etc.). The values *height*, *minX*, *maxX*, *minY* and *maxY* are two bytes long. They give line height, minimum *x*-coordinate (of a box), maximum *x*-coordinate, minimum *y*-coordinate, and maximum *y*-coordinate respectively. All values in production *contents* are two bytes long. *nofRuns* specifies the number of runs within the ASCII-code range (intervals occupied without gaps) and every pair *[beg, end)* describes one run. The tuples *(dx, x, y, w, h)* are the metric data of the occupied characters (in their ASCII-code order), and the sequence of *rasterByte* gives the total of raster information.

In summary, fonts in Oberon are indexed libraries of objects. The objects are descriptions of character images in two levels of abstraction: As metric data of black boxes and as binary patterns (glyphs). Type *Font* is an abstract data type with intrinsic operations to internalize and to get character object data. Internalized fonts are cached in a private list.

5.5. The Edit Toolbox

We have seen that every text frame integrates an interactive text editor that we can regard as an interpreter of a set of built-in commands *(intrinsic commands)*. Of course, we would like to be able to extend this set by customized editing commands *(extrinsic commands)*. It is indeed a worthwhile test for every framework or basic toolbox to try and add additional tools seamlessly. Module *Edit* is the result of such an attempt. It is a toolbox of consisting of some standard extrinsic editing commands.

Its definition is

```
DEFINITION Edit;
  PROCEDURE Open; (*text viewer*)
  PROCEDURE Show; (*text*)
  PROCEDURE Locate; (*position*)
  PROCEDURE Search; (*pattern*)
  PROCEDURE Store; (*text*)

  PROCEDURE Recall; (*deleted text*)
  PROCEDURE CopyFont;
  PROCEDURE ChangeFont;
  PROCEDURE ChangeColor;
  PROCEDURE ChangeOffset;

  PROCEDURE Print; (*text*)
END Edit.
```

The first group of commands in this toolbox is used to display, locate, and store texts or parts of texts. In turn they open a text file and display it, open a program text and show the declaration of a given object, locate a given position in a displayed text (main application: locating an error found by the compiler), search a pattern, and store the current state of a displayed text. Commands in the next group are related with editing. They allow restoring of the previously deleted part of text, copying a font to the current text selection, and change attributes of the current text selection. Notice that the commands *CopyFont*, *ChangeFont*, *ChangeColor*, and *ChangeOffset* are extrinsic variations of the intrinsic *copy-look* operation. Finally, the *Print* command causes the specified text to be printed.

The implementations of the toolbox commands are given in the Implementations Section. Note that the implementation of the *Print* command relies on a module called *Printer*. Consisting of a collection of procedures for accessing a printing device and printing text strings and graphical elements, this module represents an *abstract printer*.

It is defined as follows:

```
DEFINITION Printer;
  VAR PageWidth, PageHeight, res: INTEGER; (*result*)
  PROCEDURE Open (VAR name, user: ARRAY OF CHAR; password: LONGINT);
    (*res = 0: opened, 1: no printer, 2: no link, 3: bad response, 4: no permission*)
  PROCEDURE UseListFont (VAR name: ARRAY OF CHAR);
  PROCEDURE String (x, y: INTEGER; VAR s, fname: ARRAY OF CHAR);
  PROCEDURE ContString (VAR s, fname: ARRAY OF CHAR); (*continuation*)
   PROCEDURE Line (x0, y0, x1, y1: INTEGER);
  PROCEDURE Circle (x0, y0, r: INTEGER);
  PROCEDURE Ellipse (x0, y0, a, b: INTEGER);
  PROCEDURE Spline (x0, y0, n, open: INTEGER; VAR X, Y: ARRAY OF INTEGER);
  PROCEDURE Picture (x, y, w, h, mode: INTEGER; adr: LONGINT);
  PROCEDURE ReplConst (x, y, w, h: INTEGER);
  PROCEDURE ReplPattern (x, y, w, h, col: INTEGER);
  PROCEDURE Page (nofcopies: INTEGER);
  PROCEDURE Close;
END Printer.
```

Explanations:

The printing model is page-oriented. Procedures *Open* and *Close* are used to open and close a printing session. Procedure *UseListFont* installs a suitable font for printing lists. Procedures *String*, *ContString*, *Line*, *Circle*, *Ellipse*, *Spline*, *Picture*, *ReplConst*, and *ReplPattern* are called in order to place a string, a straight line, a circle, an ellipse, a spline curve, a digitized picture, or a shaded rectangle onto the current page. These procedures are typically called repetitively until the desired page is laid out completely. Then, procedure *Page* is called to produce the actual hardcopy of this page.

The implementation of module *Printer* depends on the environment. Alternatively, it might drive a local printer or generate a program for remote printing. In Chapter 10 a variant is presented for a local area network with an integrated print server. For every printing session a so-called *print file* is generated and subsequently sent to the server.

Literature

[Gutknecht] J. Gutknecht, "Concept of the Text Editor Lara",
Communications of the ACM, Sept. 1985, Vol.28, No. 9.

[Teitelman] W. Teitelman, "A tour through Cedar",
IEEE Software, 1, (2), 44-73 (1984).

Complete Implementations

```
MODULE Fonts; (*JG 18.11.90*)

  IMPORT Display, SYSTEM, Files;

  CONST FontFileId = 0DBX;

  TYPE
    Name* = ARRAY 32 OF CHAR;

    Font* = POINTER TO FontDesc;
    FontDesc* = RECORD
    name*: Name;
    height*, minX*, maxX*, minY*, maxY*: INTEGER;
    raster*: Display.Font;
    next: Font
  END;

VAR Default*, First: Font; nofFonts: INTEGER;

PROCEDURE This* (name: ARRAY OF CHAR): Font;

  TYPE
    RunRec = RECORD beg, end: INTEGER END;
    BoxRec = RECORD dx, x, y, w, h: INTEGER END;

  VAR
    F: Font;
    f: Files.File; R: Files.Rider;
    NofBytes, RasterBase, A, a: LONGINT;
    NofRuns, NofBoxes: INTEGER;
    k, l, m, n: INTEGER;
    ch: CHAR;

    run: ARRAY 16 OF RunRec;
    box: ARRAY 256 OF BoxRec;

  PROCEDURE Enter (d: LONGINT);
  BEGIN
    SYSTEM.PUT(A, d MOD 256); INC(A);
    SYSTEM.PUT(A, d DIV 256); INC(A)
  END Enter;

BEGIN F := First;
  WHILE (F # NIL) & (name # F.name) DO F := F.next END;
  IF F = NIL THEN
    f := Files.Old(name);
    IF f # NIL THEN
      Files.Set(R, f, 0); Files.Read(R, ch);
      IF ch = FontFileId THEN
        Files.Read(R, ch); (*abstraction*)
        Files.Read(R, ch); (*family*)
        Files.Read(R, ch); (*variant*)
        NEW(F);
        Files.ReadBytes(R, F.height, 2);
        Files.ReadBytes(R, F.minX, 2); Files.ReadBytes(R, F.maxX, 2);
        Files.ReadBytes(R, F.minY, 2); Files.ReadBytes(R, F.maxY, 2);
        Files.ReadBytes(R, NofRuns, 2);
        NofBoxes := 0; k := 0;
        WHILE k # NofRuns DO
          Files.ReadBytes(R, run[k].beg, 2); Files.ReadBytes(R, run[k].end, 2);
          NofBoxes := NofBoxes + run[k].end - run[k].beg;
          INC(k)
        END;
        NofBytes := 512 + 5; l := 0;
        WHILE l # NofBoxes DO
          Files.ReadBytes(R, box[l].dx, 2);
          Files.ReadBytes(R, box[l].x, 2); Files.ReadBytes(R, box[l].y, 2);
          Files.ReadBytes(R, box[l].w, 2); Files.ReadBytes(R, box[l].h, 2);
          NofBytes := NofBytes + 5 + (box[l].w + 7) DIV 8 * box[l].h;
          INC(l)
        END;
        SYSTEM.NEW(F.raster, NofBytes);
        RasterBase := SYSTEM.VAL(LONGINT, F.raster);
        A := RasterBase; a := A + 512;
        SYSTEM.PUT(a, 0X); INC(a); (*dummy ch*)
        SYSTEM.PUT(a, 0X); INC(a);
        SYSTEM.PUT(a, 0X); INC(a);
        SYSTEM.PUT(a, 0X); INC(a);
        SYSTEM.PUT(a, 0X); INC(a);
        k := 0; l := 0; m := 0;
        WHILE k < NofRuns DO
          WHILE m < run[k].beg DO Enter(515); INC(m) END;
          WHILE m < run[k].end DO Enter(a + 3 - RasterBase);
            SYSTEM.PUT(a, box[l].dx MOD 256); INC(a);
            SYSTEM.PUT(a, box[l].x MOD 256); INC(a);
            SYSTEM.PUT(a, box[l].y MOD 256); INC(a);
            SYSTEM.PUT(a, box[l].w MOD 256); INC(a);
            SYSTEM.PUT(a, box[l].h MOD 256); INC(a);
            n := (box[l].w + 7) DIV 8 * box[l].h;
            WHILE n # 0 DO
              Files.Read(R, ch); SYSTEM.PUT(a, ch); INC(a); DEC(n)
            END;
            INC(l); INC(m)
          END;
          INC(k)
        END;
        WHILE m < 256 DO Enter(515); INC(m) END;
        COPY(name, F.name);
        IF nofFonts < 12 THEN INC(nofFonts); F.next := First; First := F END
      ELSE F := Default
      END
    ELSE F := Default
    END
  END;
  RETURN F
 END This;

BEGIN Default := This("Syntax10.Scn.Fnt"); nofFonts := 1
END Fonts.
```

```
MODULE Texts; (*JG 21.11.90*)

 IMPORT Files, Fonts, Reals;

 CONST
    (*symbol classes*)
    Inval* = 0;       (*invalid symbol*)
   Name* = 1;        (*name s (length len)*)
   String* = 2;      (*literal string s (length len)*)
   Int* = 3;         (*integer i (decimal or hexadecimal)*)
   Real* = 4;        (*real number x*)
   LongReal* = 5;  (*long real number y*)
   Char* = 6;        (*special character c*)
   TAB = 9X; CR = 0DX; maxD = 9;

  (* TextBlock = TextBlockId off run {run} 0 len {AsciiCode}.
  run = fnt [name] col voff len. *)

  TextBlockId = 1FFH;

  replace* = 0; insert* = 1; delete* = 2; (*op-codes*)

TYPE
  Piece = POINTER TO PieceDesc;
  PieceDesc = RECORD
    f: Files.File;
    off: LONGINT;
    len: LONGINT;
    fnt: Fonts.Font;
    col: SHORTINT;
    voff: SHORTINT;
    prev, next: Piece
  END;

  Text* = POINTER TO TextDesc;

  Notifier* = PROCEDURE (T: Text; op: INTEGER; beg, end: LONGINT);

  TextDesc* = RECORD
    len*: LONGINT;
    notify*: Notifier;
    trailer: Piece;
    org: LONGINT; (*cache*)
    pce: Piece
  END;

  Reader* = RECORD (Files.Rider)
    eot*: BOOLEAN;
    fnt*: Fonts.Font;
    col*: SHORTINT;
    voff*: SHORTINT;
    ref: Piece;
    org: LONGINT;
    off: LONGINT
  END;

  Scanner* = RECORD (Reader)
    nextCh*: CHAR;
    line*: INTEGER;
    class*: INTEGER;
    i*: LONGINT;
    x*: REAL;
    y*: LONGREAL;
    c*: CHAR;
    len*: SHORTINT;
    s*: ARRAY 32 OF CHAR
  END;
  Buffer* = POINTER TO BufDesc;
  BufDesc* = RECORD
    len*: LONGINT;
    header, last: Piece
  END;

  Writer* = RECORD Files.Rider)
    buf*: Buffer;
    fnt*: Fonts.Font;
    col*: SHORTINT;
    voff*: SHORTINT
  END;

VAR W: Writer; WFile: Files.File; DelBuf: Buffer;

PROCEDURE EQ (VAR s, t: ARRAY OF CHAR): BOOLEAN;
  VAR i: INTEGER;
BEGIN i := 0;
  WHILE (s[i] # 0X) & (t[i] # 0X) & (s[i] = t[i]) DO INC(i) END;
  RETURN s[i] = t[i]
END EQ;

PROCEDURE ReadName (VAR R: Files.Rider; VAR name: ARRAY OF CHAR);
  VAR i: INTEGER; ch: CHAR;
BEGIN
  i := 0; Files.Read(R, ch);
  WHILE ch # 0X DO name[i] := ch; INC(i); Files.Read(R, ch) END;
  name[i] := 0X
END ReadName;

PROCEDURE WriteName (VAR W: Files.Rider; VAR name: ARRAY OF CHAR);
  VAR i: INTEGER; ch: CHAR;
BEGIN
  i := 0; ch := name[i];
  WHILE ch # 0X DO Files.Write(W, ch); INC(i); ch := name[i] END;
  Files.Write(W, 0X)
END WriteName;

PROCEDURE Load* (T: Text; f: Files.File; pos: LONGINT; VAR len: LONGINT);
  VAR
    R: Files.Rider;
    Q, q, p: Piece;
    off: LONGINT;
    N, fnt: SHORTINT;
    FName: ARRAY 32 OF CHAR;
     Dict: ARRAY 32 OF Fonts.Font;
BEGIN
  N := 1;
  NEW(Q); Q.f := WFile; Q.off := 0; Q.len := 1; Q.fnt := NIL; Q.col := 0; Q.voff := 0; p := Q;
  Files.Set(R, f, pos); Files.ReadBytes(R, off, 4);
  LOOP
    Files.Read(R, fnt);
    IF fnt = 0 THEN EXIT END;
    IF fnt = N THEN
      ReadName(R, FName);
      Dict[N] := Fonts.This(FName);
      INC(N)
    END;
    NEW(q);
    q.fnt := Dict[fnt];
    Files.Read(R, q.col);
    Files.Read(R, q.voff);
    Files.ReadBytes(R, q.len, 4);
    q.f := f; q.off := off;
    off := off + q.len;
    p.next := q; q.prev := p; p := q
  END;
  p.next := Q; Q.prev := p;
  T.trailer := Q; Files.ReadBytes(R, T.len, 4);
  T.org := -1; T.pce := T.trailer; (*init cache*)
  len := off - pos
END Load;

PROCEDURE Open* (T: Text; name: ARRAY OF CHAR);
  VAR f: Files.File; R: Files.Rider; Q, q: Piece;
    id: INTEGER; len: LONGINT;
BEGIN
  f := Files.Old(name);
  IF f # NIL THEN
     Files.Set(R, f, 0); Files.ReadBytes(R, id, 2);
    IF id = TextBlockId THEN Load(T, f, 2, len)
    ELSE (*Ascii file*)
      len := Files.Length(f);
      NEW(Q); Q.fnt := NIL; Q.col := 0; Q.voff := 0; Q.f := WFile; Q.off := 0; Q.len := 1;
      NEW(q); q.fnt := Fonts.Default; q.col := 15; q.voff := 0; q.f := f; q.off := 0; q.len := len;
      Q.next := q; q.prev := Q; q.next := Q; Q.prev := q;
      T.trailer := Q; T.len := len;
      T.org := -1; T.pce := T.trailer (*init cache*)
    END
  ELSE (*create new text*)
    NEW(Q); Q.fnt := NIL; Q.col := 0; Q.voff := 0; Q.f := WFile; Q.off := 0; Q.len := 1;
    Q.next := Q; Q.prev := Q;
    T.trailer := Q; T.len := 0;
    T.org := -1; T.pce := T.trailer (*init cache*)
  END
END Open;

PROCEDURE OpenBuf* (B: Buffer);
BEGIN NEW(B.header); (*null piece*)
  B.last := B.header; B.len := 0
END OpenBuf;

PROCEDURE FindPiece (T: Text; pos: LONGINT; VAR org: LONGINT; VAR p: Piece);
  VAR n: INTEGER;
BEGIN
  IF pos < T.org THEN T.org := -1; T.pce := T.trailer END;
  org := T.org; p := T.pce; (*from cache*)
  n := 0;
  WHILE pos >= org + p.len DO org := org + p.len; p := p.next; INC(n) END;
  IF n > 50 THEN T.org := org; T.pce := p END
END FindPiece;
```

```
PROCEDURE SplitPiece (p: Piece; off: LONGINT; VAR pr: Piece);
  VAR q: Piece;
BEGIN
  IF off > 0 THEN NEW(q);
    q.fnt := p.fnt; q.col := p.col; q.voff := p.voff;
    q.len := p.len - off;
    q.f := p.f; q.off := p.off + off;
    p.len := off;
    q.next := p.next; p.next := q;
    q.prev := p; q.next.prev := q;
    pr := q
  ELSE pr := p
  END
END SplitPiece;

PROCEDURE OpenReader* (VAR R: Reader; T: Text; pos: LONGINT);
  VAR p: Piece; org: LONGINT;
BEGIN
  FindPiece(T, pos, org, p);
  R.ref := p; R.org := org; R.off := pos - org;
  Files.Set(R, R.ref.f, R.ref.off + R.off); R.eot := FALSE
END OpenReader;

PROCEDURE Read* (VAR R: Reader; VAR ch: CHAR);
BEGIN
  Files.Read(R, ch); R.fnt := R.ref.fnt; R.col := R.ref.col; R.voff := R.ref.voff;
  INC(R.off);
  IF R.off = R.ref.len THEN
    IF R.ref.f = WFile THEN R.eot := TRUE END;
    R.org := R.org + R.off; R.off := 0;
    R.ref := R.ref.next; R.org := R.org + R.off; R.off := 0;
    Files.Set(R, R.ref.f, R.ref.off)
  END
END Read;

PROCEDURE Pos* (VAR R: Reader): LONGINT;
BEGIN RETURN R.org + R.off
END Pos;

PROCEDURE Store* (T: Text; f: Files.File; pos: LONGINT; VAR len: LONGINT);
  VAR
    p, q: Piece;
    R: Reader; W: Files.Rider;
    off, rlen: LONGINT; id: INTEGER;
    N, n: SHORTINT; ch: CHAR;
    Dict: ARRAY 32 OF Fonts.Name;
BEGIN
  Files.Set(W, f, pos);
  id := TextBlockId; Files.WriteBytes(W, id, 2);
  Files.WriteBytes(W, off, 4); (*place holder*)
  N := 1;
  p := T.trailer.next;
  WHILE p # T.trailer DO
    rlen := p.len; q := p.next;
    WHILE (q # T.trailer) & (q.fnt = p.fnt) & (q.col = p.col) & (q.voff = p.voff) DO
      rlen := rlen + q.len; q := q.next
      END;
      Dict[N] := p.fnt.name;
      n := 1;
      WHILE ~EQ(Dict[n], p.fnt.name) DO INC(n) END;
      Files.Write(W, n);
      IF n = N THEN WriteName(W, p.fnt.name); INC(N) END;
      Files.Write(W, p.col);
      Files.Write(W, p.voff);
      Files.WriteBytes(W, rlen, 4);
      p := q
    END;
    Files.Write(W, 0); Files.WriteBytes(W, T.len, 4);
    off := Files.Pos(W);
    OpenReader(R, T, 0); Read(R, ch);
    WHILE ~R.eot DO Files.Write(W, ch); Read(R, ch) END;
    Files.Set(W, f, pos + 2); Files.WriteBytes(W, off, 4); (*fixup*)
    len := off + T.len - pos
  END Store;

  PROCEDURE Save* (T: Text; beg, end: LONGINT; B: Buffer);
    VAR p, q, qb, qe: Piece; org: LONGINT;
  BEGIN
    IF end > T.len THEN end := T.len END;
    FindPiece(T, beg, org, p);
    NEW(qb); qb^ := p^;
    qb.len := qb.len - (beg - org);
    qb.off := qb.off + (beg - org);
    qe := qb;
    WHILE end > org + p.len DO
      org := org + p.len; p := p.next;
      NEW(q); q^ := p^; qe.next := q; q.prev := qe; qe := q
    END;
    qe.next := NIL; qe.len := qe.len - (org + p.len - end);
    B.last.next := qb; qb.prev := B.last; B.last := qe;
    B.len := B.len + (end - beg)
  END Save;

  PROCEDURE Copy* (SB, DB: Buffer);
    VAR Q, q, p: Piece;
  BEGIN
    p := SB.header; Q := DB.last;
    WHILE p # SB.last DO p := p.next;
      NEW(q); q^ := p^; Q.next := q; q.prev := Q; Q := q
    END;
    DB.last := Q; DB.len := DB.len + SB.len
  END Copy;

  PROCEDURE ChangeLooks* (T: Text; beg, end: LONGINT; sel: SET; fnt: Fonts.Font; col, voff:
SHORTINT);
    VAR pb, pe, p: Piece; org: LONGINT;
  BEGIN
    IF end > T.len THEN end := T.len END;
    FindPiece(T, beg, org, p); SplitPiece(p, beg - org, pb);
    FindPiece(T, end, org, p); SplitPiece(p, end - org, pe);
    p := pb;
    REPEAT
    IF 0 IN sel THEN p.fnt := fnt END;
    IF 1 IN sel THEN p.col := col END;
    IF 2 IN sel THEN p.voff := voff END;
    p := p.next
  UNTIL p = pe;
  T.notify(T, replace, beg, end)
END ChangeLooks;

 PROCEDURE Insert* (T: Text; pos: LONGINT; B: Buffer);
  VAR pl, pr, p, qb, qe: Piece; org, end: LONGINT;
BEGIN
  FindPiece(T, pos, org, p); SplitPiece(p, pos - org, pr);
  IF T.org >= org THEN (*adjust cache*)
    T.org := org - p.prev.len; T.pce := p.prev
  END;
  pl := pr.prev; qb := B.header.next;
  IF (qb # NIL) & (qb.f = pl.f) & (qb.off = pl.off + pl.len)
    & (qb.fnt = pl.fnt) & (qb.col = pl.col) & (qb.voff = pl.voff) THEN
    pl.len := pl.len + qb.len; qb := qb.next
  END;
  IF qb # NIL THEN qe := B.last;
    qb.prev := pl; pl.next := qb; qe.next := pr; pr.prev := qe
  END;
   T.len := T.len + B.len; end := pos + B.len;
  B.last := B.header; B.last.next := NIL; B.len := 0;
  T.notify(T, insert, pos, end)
END Insert;

PROCEDURE Append* (T: Text; B: Buffer);
BEGIN Insert(T, T.len, B)
END Append;

PROCEDURE Delete* (T: Text; beg, end: LONGINT);
  VAR pb, pe, pbr, per: Piece; orgb, orge: LONGINT;
BEGIN
  IF end > T.len THEN end := T.len END;
  FindPiece(T, beg, orgb, pb); SplitPiece(pb, beg - orgb, pbr);
  FindPiece(T, end, orge, pe); SplitPiece(pe, end - orge, per);
  IF T.org >= orgb THEN (*adjust cache*)
    T.org := orgb - pb.prev.len; T.pce := pb.prev
  END;
  DelBuf.header.next := pbr; DelBuf.last := per.prev;
  DelBuf.last.next := NIL; DelBuf.len := end - beg;
  per.prev := pbr.prev; pbr.prev.next := per;
  T.len := T.len - DelBuf.len;
  T.notify(T, delete, beg, end)
 END Delete;

PROCEDURE Recall* (VAR B: Buffer); (*deleted text*)
BEGIN B := DelBuf; NEW(DelBuf); OpenBuf(DelBuf)
END Recall;

PROCEDURE OpenScanner* (VAR S: Scanner; T: Text; pos: LONGINT);
BEGIN OpenReader(S, T, pos); S.line := 0; Read(S, S.nextCh)
END OpenScanner;
```

```
(*floating point formats:
  x = 1.m * 2^(e-127)   bit 0: sign, bits 1- 8: e, bits  9-31: m
  x = 1.m * 2^(e-1023)  bit 0: sign, bits 1-11: e, bits 12-63: m *)

PROCEDURE Scan* (VAR S: Scanner);
  CONST maxD = 32;
  VAR ch, term: CHAR;
    neg, negE, hex: BOOLEAN;
    i, j, h: SHORTINT;
    e: INTEGER; k: LONGINT;
    x, f: REAL; y, g: LONGREAL;
    d: ARRAY maxD OF CHAR;

  PROCEDURE ReadScaleFactor;
  BEGIN Read(S, ch);
    IF ch = "-" THEN negE := TRUE; Read(S, ch)
    ELSE negE := FALSE;
      IF ch = "+" THEN Read(S, ch) END
    END;
    WHILE ("0" <= ch) & (ch <= "9") DO
      e := e*10 + ORD(ch) - 30H; Read(S, ch)
    END
  END ReadScaleFactor;

BEGIN ch := S.nextCh; i := 0;
  LOOP
    IF ch = CR THEN INC(S.line)
    ELSIF (ch # " ") & (ch # TAB) THEN EXIT
    END ;
    Read(S, ch)
  END;
  IF ("A" <= CAP(ch)) & (CAP(ch) <= "Z") THEN (*name*)
    REPEAT S.s[i] := ch; INC(i); Read(S, ch)
    UNTIL (CAP(ch) > "Z")
      OR ("A" > CAP(ch)) & (ch > "9")
      OR ("0" > ch) & (ch # ".")
      OR (i = 31);
    S.s[i] := 0X; S.len := i; S.class := 1
  ELSIF ch = 22X THEN (*literal string*)
    Read(S, ch);
    WHILE (ch # 22X) & (ch >= " ") & (i # 31) DO
      S.s[i] := ch; INC(i); Read(S, ch)
    END;
    S.s[i] := 0X; S.len := i+1; Read(S, ch); S.class := 2
  ELSE
    IF ch = "-" THEN neg := TRUE; Read(S, ch) ELSE neg := FALSE END ;
    IF ("0" <= ch) & (ch <= "9") THEN (*number*)
      hex := FALSE; j := 0;
      LOOP d[i] := ch; INC(i); Read(S, ch);
        IF ch < "0" THEN EXIT END;
        IF "9" < ch THEN
          IF ("A" <= ch) & (ch <= "F") THEN hex := TRUE; ch := CHR(ORD(ch)-7)
          ELSIF ("a" <= ch) & (ch <= "f") THEN hex := TRUE; ch := CHR(ORD(ch)-27H)
          ELSE EXIT
          END
        END
      END;
      IF ch = "H" THEN (*hex number*)
        Read(S, ch); S.class := 3;
        IF i-j > 8 THEN j := i-8 END ;
        k := ORD(d[j]) - 30H; INC(j);
        IF (i-j = 7) & (k >= 8) THEN DEC(k, 16) END ;
        WHILE j < i DO k := k*10H + (ORD(d[j]) - 30H); INC(j) END ;
        IF neg THEN S.i := -k ELSE S.i := k END
      ELSIF ch = "." THEN (*read real*)
        Read(S, ch); h := i;
        WHILE ("0" <= ch) & (ch <= "9") DO d[i] := ch; INC(i); Read(S, ch) END ;
        IF ch = "D" THEN
          e := 0; y := 0; g := 1;
          REPEAT y := y*10 + (ORD(d[j]) - 30H); INC(j) UNTIL j = h;
          WHILE j < i DO g := g/10; y := (ORD(d[j]) - 30H)*g + y; INC(j) END ;
          ReadScaleFactor;
          IF negE THEN
            IF e <= 308 THEN y := y / Reals.TenL(e) ELSE y := 0 END
          ELSIF e > 0 THEN
            IF e <= 308 THEN y := Reals.TenL(e) * y ELSE HALT(40) END
          END ;
          IF neg THEN y := -y END ;
          S.class := 5; S.y := y
        ELSE e := 0; x := 0; f := 1;
          REPEAT x := x*10 + (ORD(d[j]) - 30H); INC(j) UNTIL j = h;
          WHILE j < i DO f := f/10; x := (ORD(d[j])-30H)*f + x; INC(j) END;
          IF ch = "E" THEN ReadScaleFactor END ;
          IF negE THEN
            IF e <= 38 THEN x := x / Reals.Ten(e) ELSE x := 0 END
          ELSIF e > 0 THEN
            IF e <= 38 THEN x := Reals.Ten(e) * x ELSE HALT(40) END
          END ;
          IF neg THEN x := -x END ;
          S.class := 4; S.x := x
        END ;
        IF hex THEN S.class := 0 END
      ELSE (*decimal integer*)
        S.class := 3; k := 0;
        REPEAT k := k*10 + (ORD(d[j]) - 30H); INC(j) UNTIL j = i;
        IF neg THEN S.i := -k ELSE S.i := k END;
        IF hex THEN S.class := 0 ELSE S.class := 3 END
      END
    ELSE S.class := 6;
      IF neg THEN S.c := "-" ELSE S.c := ch; Read(S, ch) END
    END
  END;
  S.nextCh := ch
END Scan;

PROCEDURE OpenWriter* (VAR W: Writer);
BEGIN
  NEW(W.buf); OpenBuf(W.buf); W.fnt := Fonts.Default; W.col := 15; W.voff := 0;
  Files.Set(W, Files.New(""), 0)
END OpenWriter;

PROCEDURE SetFont* (VAR W: Writer; fnt: Fonts.Font);
```

```
BEGIN W.fnt := fnt
END SetFont;

PROCEDURE SetColor* (VAR W: Writer; col: SHORTINT);
BEGIN W.col := col
END SetColor;

PROCEDURE SetOffset* (VAR W: Writer; voff: SHORTINT);
BEGIN W.voff := voff
END SetOffset;

PROCEDURE Write* (VAR W: Writer; ch: CHAR);
  VAR p: Piece;
BEGIN
  IF (W.buf.last.fnt # W.fnt) OR (W.buf.last.col # W.col) OR (W.buf.last.voff # W.voff) THEN
    NEW(p);
    p.f := Files.Base(W); p.off := Files.Pos(W); p.len := 0;
    p.fnt := W.fnt; p.col := W.col; p.voff:= W.voff;
    p.next := NIL; W.buf.last.next := p;
    p.prev := W.buf.last; W.buf.last := p
  END;
  Files.Write(W, ch);
  INC(W.buf.last.len); INC(W.buf.len)
END Write;

PROCEDURE WriteLn* (VAR W: Writer);
BEGIN Write(W, CR)
END WriteLn;

PROCEDURE WriteString* (VAR W: Writer; s: ARRAY OF CHAR);
  VAR i: INTEGER;
BEGIN i := 0;
  WHILE s[i] >= " " DO Write(W, s[i]); INC(i) END
END WriteString;

PROCEDURE WriteInt* (VAR W: Writer; x, n: LONGINT);
  VAR i: INTEGER; x0: LONGINT;
    a: ARRAY 11 OF CHAR;
BEGIN i := 0;
  IF x < 0 THEN
    IF x = MIN(LONGINT) THEN WriteString(W, " -2147483648"); RETURN
    ELSE DEC(n); x0 := -x
    END
  ELSE x0 := x
  END;
  REPEAT
    a[i] := CHR(x0 MOD 10 + 30H); x0 := x0 DIV 10; INC(i)
  UNTIL x0 = 0;
  WHILE n > i DO Write(W, " "); DEC(n) END;
  IF x < 0 THEN Write(W, "-") END;
  REPEAT DEC(i); Write(W, a[i]) UNTIL i = 0
END WriteInt;

PROCEDURE WriteHex* (VAR W: Writer; x: LONGINT);
  VAR i: INTEGER; y: LONGINT;
    a: ARRAY 10 OF CHAR;
```

```
BEGIN i := 0; Write(W, " ");
  REPEAT y := x MOD 10H;
    IF y < 10 THEN a[i] := CHR(y + 30H) ELSE a[i] := CHR(y + 37H) END;
    x := x DIV 10H; INC(i)
  UNTIL i = 8;
  REPEAT DEC(i); Write(W, a[i]) UNTIL i = 0
END WriteHex;

PROCEDURE WriteReal* (VAR W: Writer; x: REAL; n: INTEGER);
  VAR e: INTEGER; x0: REAL;
    d: ARRAY maxD OF CHAR;
BEGIN e := Reals.Expo(x);
  IF e = 0 THEN
    WriteString(W, "  0");
    REPEAT Write(W, " "); DEC(n) UNTIL n <= 3
  ELSIF e = 255 THEN
    WriteString(W, " NaN");
    WHILE n > 4 DO Write(W, " "); DEC(n) END
  ELSE
    IF n <= 9 THEN n := 3 ELSE DEC(n, 6) END;
    REPEAT Write(W, " "); DEC(n) UNTIL n <= 8;
    (*there are 2 < n <= 8 digits to be written*)
    IF x < 0.0 THEN Write(W, "-"); x := -x ELSE Write(W, " ") END;
    e := (e - 127) * 77  DIV 256;
    IF e >= 0 THEN x := x / Reals.Ten(e) ELSE x := Reals.Ten(-e) * x END;
    IF x >= 10.0 THEN x := 0.1*x; INC(e) END;
    x0 := Reals.Ten(n-1); x := x0*x + 0.5;
    IF x >= 10.0*x0 THEN x := x*0.1; INC(e) END;
    Reals.Convert(x, n, d);
    DEC(n); Write(W, d[n]); Write(W, ".");
    REPEAT DEC(n); Write(W, d[n]) UNTIL n = 0;
    Write(W, "E");
    IF e < 0 THEN Write(W, "-"); e := -e ELSE Write(W, "+") END;
    Write(W, CHR(e DIV 10 + 30H)); Write(W, CHR(e MOD 10 + 30H))
  END
END WriteReal;

PROCEDURE WriteRealFix* (VAR W: Writer; x: REAL; n, k: INTEGER);
  VAR e, i: INTEGER; sign: CHAR; x0: REAL;
    d: ARRAY maxD OF CHAR;

  PROCEDURE seq(ch: CHAR; n: INTEGER);
  BEGIN WHILE n > 0 DO Write(W, ch); DEC(n) END
  END seq;

  PROCEDURE dig(n: INTEGER);
  BEGIN
    WHILE n > 0 DO
      DEC(i); Write(W, d[i]); DEC(n)
    END
  END dig;

BEGIN e := Reals.Expo(x);
  IF k < 0 THEN k := 0 END;
  IF e = 0 THEN seq(" ", n-k-2); Write(W, "0"); seq(" ", k+1)
  ELSIF e = 255 THEN WriteString(W, " NaN"); seq(" ", n-4)
  ELSE e := (e - 127) * 77 DIV 256;
    IF x < 0 THEN sign := "-"; x := -x ELSE sign := " " END;
    IF e >= 0 THEN  (*x >= 1.0,  77/256 = log 2*) x := x/Reals.Ten(e)
      ELSE (*x < 1.0*) x := Reals.Ten(-e) * x
    END;
    IF x >= 10.0 THEN x := 0.1*x; INC(e) END;
    (* 1 <= x < 10 *)
    IF k+e >= maxD-1 THEN k := maxD-1-e
      ELSIF k+e < 0 THEN k := -e; x := 0.0
    END;
    x0 := Reals.Ten(k+e); x := x0*x + 0.5;
    IF x >= 10.0*x0 THEN INC(e) END;
    (*e = no. of digits before decimal point*)
    INC(e); i := k+e; Reals.Convert(x, i, d);
    IF e > 0 THEN
      seq(" ", n-e-k-2); Write(W, sign); dig(e);
      Write(W, "."); dig(k)
    ELSE seq(" ", n-k-3);
      Write(W, sign); Write(W, "0"); Write(W, ".");
      seq("0", -e); dig(k+e)
    END
  END
END WriteRealFix;

PROCEDURE WriteRealHex* (VAR W: Writer; x: REAL);
  VAR i: INTEGER;
    d: ARRAY 8 OF CHAR;
BEGIN Reals.ConvertH(x, d); i := 0;
  REPEAT Write(W, d[i]); INC(i) UNTIL i = 8
END WriteRealHex;

PROCEDURE WriteLongReal* (VAR W: Writer; x: LONGREAL; n: INTEGER);
  CONST maxD = 16;
  VAR e: INTEGER; x0: LONGREAL;
    d: ARRAY maxD OF CHAR;
BEGIN e := Reals.ExpoL(x);
  IF e = 0 THEN
    WriteString(W, "  0");
    REPEAT Write(W, " "); DEC(n) UNTIL n <= 3
  ELSIF e = 2047 THEN
    WriteString(W, " NaN");
    WHILE n > 4 DO Write(W, " "); DEC(n) END
  ELSE
    IF n <= 10 THEN n := 3 ELSE DEC(n, 7) END;
    REPEAT Write(W, " "); DEC(n) UNTIL n <= maxD;
    (*there are 2 <= n <= maxD digits to be written*)
    IF x < 0 THEN Write(W, "-"); x := -x ELSE Write(W, " ") END;
    e := SHORT(LONG(e - 1023) * 77 DIV 256);
    IF e >= 0 THEN x := x / Reals.TenL(e) ELSE x := Reals.TenL(-e) * x END ;
    IF x >= 10.0D0 THEN x := 0.1D0 * x; INC(e) END ;
    x0 := Reals.TenL(n-1); x := x0*x + 0.5D0;
    IF x >= 10.0D0*x0 THEN x := 0.1D0 * x; INC(e) END ;
    Reals.ConvertL(x, n, d);
    DEC(n); Write(W, d[n]); Write(W, ".");
    REPEAT DEC(n); Write(W, d[n]) UNTIL n = 0;
    Write(W, "D");
```

```
      IF e < 0 THEN Write(W, "-"); e := -e ELSE Write(W, "+") END;
      Write(W, CHR(e DIV 100 + 30H)); e := e MOD 100;
      Write(W, CHR(e DIV 10 + 30H));
      Write(W, CHR(e MOD 10 + 30H))
    END
  END WriteLongReal;

  PROCEDURE WriteLongRealHex* (VAR W: Writer; x: LONGREAL);
    VAR i: INTEGER;
      d: ARRAY 16 OF CHAR;
  BEGIN Reals.ConvertHL(x, d); i := 0;
    REPEAT Write(W, d[i]); INC(i) UNTIL i = 16
  END WriteLongRealHex;

   PROCEDURE WriteDate* (VAR W: Writer; t, d: LONGINT);

    PROCEDURE WritePair(ch: CHAR; x: LONGINT);
    BEGIN Write(W, ch);
      Write(W, CHR(x DIV 10 + 30H)); Write(W, CHR(x MOD 10 + 30H))
    END WritePair;

  BEGIN
    WritePair(" ", d MOD 32); WritePair(".", d DIV 32 MOD 16); WritePair(".", d DIV 512 MOD 128);
    WritePair(" ", t DIV 4096 MOD 32); WritePair(":", t DIV 64 MOD 64); WritePair(":", t MOD 64)
  END WriteDate;

BEGIN
  NEW(DelBuf); OpenBuf(DelBuf);
  OpenWriter(W); Write(W, 0X);
  WFile := Files.Base(W)
END Texts.
```

```
MODULE TextFrames; (*JG 8.10.90*)

  IMPORT Input, Modules, Display, Viewers, MenuViewers, Fonts, Texts, Oberon;

  CONST
    replace* = 0; insert* = 1; delete* = 2; (*message id*)
    CR = 0DX;

  TYPE
    Line = POINTER TO LineDesc;

    LineDesc = RECORD
      len: LONGINT;
      wid: INTEGER;
      eot: BOOLEAN;
      next: Line
    END;

    Location* = RECORD
      org*, pos*: LONGINT;
      dx*, x*, y*: INTEGER;
      lin: Line
    END;
  Frame* = POINTER TO FrameDesc;

  FrameDesc* = RECORD (Display.FrameDesc)
    text*: Texts.Text;
    org*: LONGINT;
    col*: INTEGER;
    lsp*: INTEGER;
    left*, right*, top*, bot*: INTEGER;
    markH*: INTEGER;
    time*: LONGINT;
    mark*, car*, sel*: INTEGER;
    carloc*: Location;
    selbeg*, selend*: Location;
    trailer: Line
  END;

  (*mark < 0: arrow mark
    mark = 0: no mark
    mark > 0: position mark*)

  UpdateMsg* = RECORD (Display.FrameMsg)
    id*: INTEGER;
    text*: Texts.Text;
    beg*, end*: LONGINT
  END;

VAR
  menuH*, barW*, left*, right*, top*, bot*, lsp*: INTEGER; (*standard sizes*)
  asr, dsr, selH, markW, eolW: INTEGER;
  par: Oberon.ParList; nextCh: CHAR;
  W, KW: Texts.Writer; (*keyboard writer*)

PROCEDURE Min (i, j: INTEGER): INTEGER;
BEGIN IF i >= j THEN RETURN j ELSE RETURN i END
END Min;

(*------------------display support------------------------*)

PROCEDURE ReplConst (col: INTEGER; F: Frame; X, Y, W, H: INTEGER; mode: INTEGER);
BEGIN
  IF X + W <= F.X + F.W THEN Display.ReplConst(col, X, Y, W, H, mode)
  ELSIF X < F.X + F.W THEN Display.ReplConst(col, X, Y, F.X + F.W - X, H, mode)
  END
END ReplConst;

PROCEDURE FlipMark (F: Frame);
BEGIN
  IF (F.mark > 0) & (F.left >= barW) THEN
    Display.ReplConst(Display.white, F.X + 1, F.Y + F.H - 1 - F.markH, markW, 1, 2)
  END
END FlipMark;

PROCEDURE UpdateMark (F: Frame);
  VAR oldH: INTEGER;
BEGIN
  oldH := F.markH; F.markH := SHORT(F.org * F.H DIV (F.text.len + 1));
  IF (F.mark > 0) & (F.left >= barW) & (F.markH # oldH) THEN
    Display.ReplConst(Display.white, F.X + 1, F.Y + F.H - 1 - oldH, markW, 1, 2);
    Display.ReplConst(Display.white, F.X + 1, F.Y + F.H - 1 - F.markH, markW, 1, 2)
  END
END UpdateMark;

PROCEDURE Width (VAR R: Texts.Reader; len: LONGINT): INTEGER;
  VAR pat: Display.Pattern; pos: LONGINT; ox, dx, x, y, w, h: INTEGER;
BEGIN pos := 0; ox := 0;
  WHILE pos # len DO
    Display.GetChar(R.fnt.raster, nextCh, dx, x, y, w, h, pat);
    ox := ox + dx; INC(pos); Texts.Read(R, nextCh)
  END;
  RETURN ox
END Width;

PROCEDURE DisplayLine (F: Frame; L: Line;
  VAR R: Texts.Reader; X, Y: INTEGER; len: LONGINT);
  VAR pat: Display.Pattern; NX, dx, x, y, w, h: INTEGER;
BEGIN NX := F.X + F.W;
  WHILE (nextCh # CR) & (R.fnt # NIL) DO
    Display.GetChar(R.fnt.raster, nextCh, dx, x, y, w, h, pat);
    IF (X + x + w <= NX) & (h # 0) THEN
      Display.CopyPattern(R.col, pat, X + x, Y + y, 2)
    END;
    X := X + dx; INC(len); Texts.Read(R, nextCh)
  END;
  L.len := len + 1; L.wid := X + eolW - (F.X + F.left);
  L.eot := R.fnt = NIL; Texts.Read(R, nextCh)
END DisplayLine;

PROCEDURE Validate (T: Texts.Text; VAR pos: LONGINT);
  VAR R: Texts.Reader;
BEGIN
  IF pos > T.len THEN pos := T.len
  ELSIF pos > 0 THEN
    DEC(pos); Texts.OpenReader(R, T, pos);
    REPEAT Texts.Read(R, nextCh); INC(pos) UNTIL R.eot OR (nextCh = CR)
  ELSE pos := 0
  END
END Validate;

PROCEDURE Mark* (F: Frame; mark: INTEGER);
BEGIN
  IF ((mark >= 0) = (F.mark < 0)) & (F.H >= 16) THEN
    Display.CopyPattern(Display.white, Display.downArrow, F.X, F.Y, 2)
  END;
  IF ((mark > 0) = (F.mark <= 0)) & (F.H > 0) & (F.left >= barW) THEN
    Display.ReplConst(Display.white, F.X + 1, F.Y + F.H - 1 - F.markH, markW, 1, 2)
  END;
  F.mark := mark
END Mark;

PROCEDURE Restore* (F: Frame);
  VAR R: Texts.Reader; L, l: Line; curY, botY: INTEGER;
BEGIN (*F.mark = 0*)
```

```
  Display.ReplConst(F.col, F.X, F.Y, F.W, F.H, 0);
  IF F.left >= barW THEN
    Display.ReplConst(Display.white, F.X + barW - 1, F.Y, 1, F.H, 2)
  END;
  Validate(F.text, F.org);
  botY := F.Y + F.bot + dsr;
  Texts.OpenReader(R, F.text, F.org); Texts.Read(R, nextCh);
  L := F.trailer; curY := F.Y + F.H - F.top - asr;
  WHILE ~L.eot & (curY >= botY) DO
    NEW(l);
    DisplayLine(F, l, R, F.X + F.left, curY, 0);
    L.next := l; L := l; curY := curY - lsp
  END;
  L.next := F.trailer;
  F.markH := SHORT(F.org * F.H DIV (F.text.len + 1))
END Restore;

PROCEDURE Suspend* (F: Frame);
BEGIN (*F.mark = 0*)
  F.trailer.next := F.trailer
END Suspend;

PROCEDURE Extend* (F: Frame; newY: INTEGER);
  VAR R: Texts.Reader; L, l: Line; org: LONGINT; curY, botY: INTEGER;
BEGIN (*F.mark = 0*)
  Display.ReplConst(F.col, F.X, newY, F.W, F.Y - newY, 0);
  IF F.left >= barW THEN
    Display.ReplConst(Display.white, F.X + barW - 1, newY, 1, F.Y - newY, 2)
  END;
  F.H := F.H + F.Y - newY; F.Y := newY;
  IF F.trailer.next = F.trailer THEN Validate(F.text, F.org) END;
  L := F.trailer; org := F.org; curY := F.Y + F.H - F.top - asr;
  WHILE L.next # F.trailer DO
    L := L.next; org := org + L.len; curY := curY - lsp
  END;
  botY := F.Y + F.bot + dsr;
  Texts.OpenReader(R, F.text, org); Texts.Read(R, nextCh);
  WHILE ~L.eot & (curY >= botY) DO NEW(l);
    DisplayLine(F, l, R, F.X + F.left, curY, 0);
    L.next := l; L := l; curY := curY - lsp
  END;
  L.next := F.trailer;
  F.markH := SHORT(F.org * F.H DIV (F.text.len + 1))
END Extend;

PROCEDURE Reduce* (F: Frame; newY: INTEGER);
  VAR L: Line; curY, botY: INTEGER;
BEGIN (*F.mark = 0*)
  F.H := F.H + F.Y - newY; F.Y := newY;
  botY := F.Y + F.bot + dsr;
  L := F.trailer; curY := F.Y + F.H - F.top - asr;
  WHILE (L.next # F.trailer) & (curY >= botY) DO
    L := L.next; curY := curY - lsp
  END;
  L.next := F.trailer;
  IF curY + asr > F.Y THEN
```

```
    Display.ReplConst(F.col, F.X + F.left, F.Y, F.W - F.left, curY + asr - F.Y, 0)
  END;
  F.markH := SHORT(F.org * F.H DIV (F.text.len + 1));
  Mark(F, 1)
END Reduce;

PROCEDURE Show* (F: Frame; pos: LONGINT);
  VAR R: Texts.Reader; L, l: Line;
    org: LONGINT; curY, botY, Y0: INTEGER; keys: SET;
BEGIN
  IF F.trailer.next # F.trailer THEN
    Validate(F.text, pos);
    IF pos < F.org THEN Mark(F, 0);
      Display.ReplConst(F.col, F.X + F.left, F.Y, F.W - F.left, F.H, 0);
      botY := F.Y; F.Y := F.Y + F.H; F.H := 0;
      F.org := pos; F.trailer.next := F.trailer; Extend(F, botY);
      Mark(F, 1)
    ELSIF pos > F.org THEN
      org := F.org; L := F.trailer.next; curY := F.Y + F.H - F.top - asr;
      WHILE (L.next # F.trailer) & (org # pos) DO
        org := org + L.len; L := L.next; curY := curY - lsp;
      END;
      IF org = pos THEN
        F.org := org; F.trailer.next := L; Y0 := curY;
        WHILE L.next # F.trailer DO
          org := org + L.len; L := L.next; curY := curY - lsp
        END;
        Display.CopyBlock
          (F.X + F.left, curY - dsr, F.W - F.left, Y0 + asr - (curY - dsr),
          F.X + F.left, curY - dsr + F.Y + F.H - F.top - asr - Y0, 0);
        curY := curY + F.Y + F.H - F.top - asr - Y0;
        Display.ReplConst(F.col, F.X + F.left, F.Y, F.W - F.left, curY - dsr - F.Y, 0);
        botY := F.Y + F.bot + dsr;
        org := org + L.len; curY := curY - lsp;
        Texts.OpenReader(R, F.text, org); Texts.Read(R, nextCh);
        WHILE ~L.eot & (curY >= botY) DO NEW(l);
          DisplayLine(F, l, R, F.X + F.left, curY, 0);
          L.next := l; L := l; curY := curY - lsp
        END;
        L.next := F.trailer;
        UpdateMark(F)
      ELSE Mark(F, 0);
        Display.ReplConst(F.col, F.X + F.left, F.Y, F.W - F.left, F.H, 0);
        botY := F.Y; F.Y := F.Y + F.H; F.H := 0;
        F.org := pos; F.trailer.next := F.trailer; Extend(F, botY);
        Mark(F, 1)
      END
    END
  END
END Show;

PROCEDURE LocateLine (F: Frame; y: INTEGER; VAR loc: Location);
  VAR T: Texts.Text; L: Line; org: LONGINT; cury: INTEGER;
BEGIN T := F.text;
  org := F.org; L := F.trailer.next; cury := F.H - F.top - asr;
  WHILE (L.next # F.trailer) & (cury > y + dsr) DO
```

```
    org := org + L.len; L := L.next; cury := cury - lsp
  END;
  loc.org := org; loc.lin := L; loc.y := cury
END LocateLine;

PROCEDURE LocateString (F: Frame; x, y: INTEGER; VAR loc: Location);
  VAR R: Texts.Reader; pat: Display.Pattern;
    bpos, pos, lim: LONGINT; bx, ex, ox, dx, u, v, w, h: INTEGER;
BEGIN LocateLine(F, y, loc);
  lim := loc.org + loc.lin.len - 1;
  bpos := loc.org; bx := F.left;
  pos := loc.org; ox := F.left;
  Texts.OpenReader(R, F.text, loc.org); Texts.Read(R, nextCh);
  LOOP
    LOOP (*scan string*)
      IF (pos = lim) OR (nextCh <= " ") THEN EXIT END;
      Display.GetChar(R.fnt.raster, nextCh, dx, u, v, w, h, pat);
      INC(pos); ox := ox + dx; Texts.Read(R, nextCh)
    END;
    ex := ox;
    LOOP (*scan gap*)
      IF (pos = lim) OR (nextCh > " ") THEN EXIT END;
      Display.GetChar(R.fnt.raster, nextCh, dx, u, v, w, h, pat);
      INC(pos); ox := ox + dx; Texts.Read(R, nextCh)
    END;
    IF (pos = lim) OR (ox > x) THEN EXIT END;
    Display.GetChar(R.fnt.raster, nextCh, dx, u, v, w, h, pat);
    bpos := pos; bx := ox;
    INC(pos); ox := ox + dx; Texts.Read(R, nextCh)
  END;
  loc.pos := bpos; loc.dx := ex - bx; loc.x := bx
END LocateString;

PROCEDURE LocateChar (F: Frame; x, y: INTEGER; VAR loc: Location);
  VAR R: Texts.Reader; pat: Display.Pattern;
    pos, lim: LONGINT; ox, dx, u, v, w, h: INTEGER;
BEGIN LocateLine(F, y, loc);
  lim := loc.org + loc.lin.len - 1;
  pos := loc.org; ox := F.left;
  Texts.OpenReader(R, F.text, loc.org); Texts.Read(R, nextCh);
  LOOP
    IF pos = lim THEN dx := eolW; EXIT END;
    Display.GetChar(R.fnt.raster, nextCh, dx, u, v, w, h, pat);
    IF ox + dx > x THEN EXIT END;
    INC(pos); ox := ox + dx; Texts.Read(R, nextCh)
  END;
  loc.pos := pos; loc.dx := dx; loc.x := ox
END LocateChar;

PROCEDURE LocatePos (F: Frame; pos: LONGINT; VAR loc: Location);
  VAR T: Texts.Text; R: Texts.Reader; L: Line; org: LONGINT; cury: INTEGER;
BEGIN T := F.text;
  org := F.org; L := F.trailer.next; cury := F.H - F.top - asr;
  IF pos < org THEN pos := org END;
  WHILE (L.next # F.trailer) & (pos >= org + L.len) DO
    org := org + L.len; L := L.next; cury := cury - lsp
  END;
  IF pos >= org + L.len THEN pos := org + L.len - 1 END;
  Texts.OpenReader(R, T, org); Texts.Read(R, nextCh);
  loc.org := org; loc.pos := pos; loc.lin := L;
  loc.x := F.left + Width(R, pos - org); loc.y := cury
END LocatePos;

PROCEDURE Pos* (F: Frame; X, Y: INTEGER): LONGINT;
  VAR loc: Location;
BEGIN LocateChar(F, X - F.X, Y - F.Y, loc);
  RETURN loc.pos
END Pos;

PROCEDURE FlipCaret (F: Frame);
BEGIN
  IF F.carloc.x < F.W THEN
    IF (F.carloc.y >= 10) & (F.carloc.x + 12 < F.W) THEN
      Display.CopyPattern(Display.white, Display.hook, F.X + F.carloc.x, F.Y + F.carloc.y - 10, 2)
    END
  END
END FlipCaret;

PROCEDURE SetCaret* (F: Frame; pos: LONGINT);
BEGIN LocatePos(F, pos, F.carloc); FlipCaret(F); F.car := 1
END SetCaret;

PROCEDURE TrackCaret* (F: Frame; X, Y: INTEGER; VAR keysum: SET);
  VAR loc: Location; keys: SET;
BEGIN
  IF F.trailer.next # F.trailer THEN
    LocateChar(F, X - F.X, Y - F.Y, F.carloc);
    FlipCaret(F);
    keysum := {};
    REPEAT
      Input.Mouse(keys, X, Y);
      keysum := keysum + keys;
      Oberon.DrawCursor(Oberon.Mouse, Oberon.Mouse.marker, X, Y);
      LocateChar(F, X - F.X, Y - F.Y, loc);
      IF loc.pos # F.carloc.pos THEN FlipCaret(F); F.carloc := loc; FlipCaret(F) END
    UNTIL keys = {};
    F.car := 1
  END
END TrackCaret;

PROCEDURE RemoveCaret* (F: Frame);
BEGIN IF F.car # 0 THEN FlipCaret(F); F.car := 0 END
END RemoveCaret;

PROCEDURE FlipSelection (F: Frame; VAR beg, end: Location);
  VAR T: Texts.Text; L: Line; Y: INTEGER;
BEGIN T := F.text;
  L := beg.lin; Y := F.Y + beg.y - 2;
  IF L = end.lin THEN ReplConst(Display.white, F, F.X + beg.x, Y, end.x - beg.x, selH, 2)
  ELSE
    ReplConst(Display.white, F, F.X + beg.x, Y, F.left + L.wid - beg.x, selH, 2);
    LOOP
```

```
      L := L.next; Y := Y - lsp;
      IF L = end.lin THEN EXIT END;
      ReplConst(Display.white, F, F.X + F.left, Y, L.wid, selH, 2)
    END;
    ReplConst(Display.white, F, F.X + F.left, Y, end.x - F.left, selH, 2)
  END
END FlipSelection;

PROCEDURE SetSelection* (F: Frame; beg, end: LONGINT);
BEGIN
  IF F.sel # 0 THEN FlipSelection(F, F.selbeg, F.selend) END;
  LocatePos(F, beg, F.selbeg); LocatePos(F, end, F.selend);
  IF F.selbeg.pos < F.selend.pos THEN
    FlipSelection(F, F.selbeg, F.selend); F.time := Oberon.Time(); F.sel := 1
  END
END SetSelection;

PROCEDURE TrackSelection* (F: Frame; X, Y: INTEGER; VAR keysum: SET);
  VAR loc: Location; keys: SET;
BEGIN
  IF F.trailer.next # F.trailer THEN
    IF F.sel # 0 THEN FlipSelection(F, F.selbeg, F.selend) END;
    LocateChar(F, X - F.X, Y - F.Y, loc);
    IF (F.sel # 0) & (loc.pos = F.selbeg.pos) & (F.selend.pos = F.selbeg.pos + 1) THEN
      LocateChar(F, F.left, Y - F.Y, F.selbeg)
    ELSE F.selbeg := loc
    END;
    INC(loc.pos); loc.x := loc.x + loc.dx; F.selend := loc;
    FlipSelection(F, F.selbeg, F.selend);
    keysum := {};
    REPEAT
      Input.Mouse(keys, X, Y);
      keysum := keysum + keys;
      Oberon.DrawCursor(Oberon.Mouse, Oberon.Mouse.marker, X, Y);
      LocateChar(F, X - F.X, Y - F.Y, loc);
      IF loc.pos < F.selbeg.pos THEN loc := F.selbeg END;
      INC(loc.pos); loc.x := loc.x + loc.dx;
      IF loc.pos < F.selend.pos THEN FlipSelection(F, loc, F.selend); F.selend := loc
      ELSIF loc.pos > F.selend.pos THEN FlipSelection(F, F.selend, loc); F.selend := loc
      END
    UNTIL keys = {};
    F.time := Oberon.Time(); F.sel := 1
  END
END TrackSelection;

PROCEDURE RemoveSelection* (F: Frame);
BEGIN IF F.sel # 0 THEN FlipSelection(F, F.selbeg, F.selend); F.sel := 0 END
END RemoveSelection;

PROCEDURE TrackLine* (F: Frame; X, Y: INTEGER; VAR org: LONGINT; VAR keysum: SET);
  VAR T: Texts.Text; old, new: Location; keys: SET;
BEGIN
  IF F.trailer.next # F.trailer THEN T := F.text;
    LocateLine(F, Y - F.Y, old);
    ReplConst(Display.white, F, F.X + F.left, F.Y + old.y - dsr, old.lin.wid, 2, 2);
    keysum := {};
```

```
      REPEAT
        Input.Mouse(keys, X, Y);
        keysum := keysum + keys;
        Oberon.DrawCursor(Oberon.Mouse, Oberon.Mouse.marker, X, Y);
        LocateLine(F, Y - F.Y, new);
        IF new.org # old.org THEN
          ReplConst(Display.white, F, F.X + F.left, F.Y + old.y - dsr, old.lin.wid, 2, 2);
          ReplConst(Display.white, F, F.X + F.left, F.Y + new.y - dsr, new.lin.wid, 2, 2);
          old := new
        END
      UNTIL keys = {};
      ReplConst(Display.white, F, F.X + F.left, F.Y + new.y - dsr, new.lin.wid, 2, 2);
      org := new.org
    ELSE org := -1
    END
  END TrackLine;

  PROCEDURE TrackWord* (F: Frame; X, Y: INTEGER; VAR pos: LONGINT; VAR keysum:
SET);
    VAR T: Texts.Text; old, new: Location; keys: SET;
   BEGIN
     IF F.trailer.next # F.trailer THEN T := F.text;
      LocateString(F, X - F.X, Y - F.Y, old);
      ReplConst(Display.white, F, F.X + old.x, F.Y + old.y - dsr, old.dx, 2, 2);
      keysum := {};
      REPEAT
        Input.Mouse(keys, X, Y);
        keysum := keysum + keys;
        Oberon.DrawCursor(Oberon.Mouse, Oberon.Mouse.marker, X, Y);
        LocateString(F, X - F.X, Y - F.Y, new);
        IF new.pos # old.pos THEN
          ReplConst(Display.white, F, F.X + old.x, F.Y + old.y - dsr, old.dx, 2, 2);
          ReplConst(Display.white, F, F.X + new.x, F.Y + new.y - dsr, new.dx, 2, 2);
          old := new
        END
      UNTIL keys = {};
      ReplConst(Display.white, F, F.X + new.x, F.Y + new.y - dsr, new.dx, 2, 2);
      pos := new.pos
    ELSE pos := -1
    END
  END TrackWord;

  PROCEDURE Replace* (F: Frame; beg, end: LONGINT);
    VAR R: Texts.Reader; L: Line; org, len: LONGINT; curY, wid: INTEGER;
  BEGIN
    IF end > F.org THEN
      IF beg < F.org THEN beg := F.org END;
      org := F.org; L := F.trailer.next; curY := F.Y + F.H - F.top - asr;
      WHILE (L # F.trailer) & (org + L.len <= beg) DO
        org := org + L.len; L := L.next; curY := curY - lsp
      END;
      IF L # F.trailer THEN
        Texts.OpenReader(R, F.text, org); Texts.Read(R, nextCh);
        len := beg - org; wid := Width(R, len);
        ReplConst(F.col, F, F.X + F.left + wid, curY - dsr, L.wid - wid, lsp, 0);
        DisplayLine(F, L, R, F.X + F.left + wid, curY, len);
        org := org + L.len; L := L.next; curY := curY - lsp;
        WHILE (L # F.trailer) & (org <= end) DO
          Display.ReplConst(F.col, F.X + F.left, curY - dsr, F.W - F.left, lsp, 0);
          DisplayLine(F, L, R, F.X + F.left, curY, 0);
          org := org + L.len; L := L.next; curY := curY - lsp
        END
      END
    END;
    UpdateMark(F)
  END Replace;

  PROCEDURE Insert* (F: Frame; beg, end: LONGINT);
    VAR R: Texts.Reader; L, L0, l: Line;
      org, len: LONGINT; curY, botY, Y0, Y1, Y2, dY, wid: INTEGER;
  BEGIN
    IF beg < F.org THEN F.org := F.org + (end - beg)
    ELSE
      org := F.org; L := F.trailer.next; curY := F.Y + F.H - F.top - asr;
      WHILE (L # F.trailer) & (org + L.len <= beg) DO
        org := org + L.len; L := L.next; curY := curY - lsp
      END;
      IF L # F.trailer THEN
        botY := F.Y + F.bot + dsr;
        Texts.OpenReader(R, F.text, org); Texts.Read(R, nextCh);
        len := beg - org; wid := Width(R, len);
        ReplConst (F.col, F, F.X + F.left + wid, curY - dsr, L.wid - wid, lsp, 0);
        DisplayLine(F, L, R, F.X + F.left + wid, curY, len);
        org := org + L.len; curY := curY - lsp;
        Y0 := curY; L0 := L.next;
        WHILE (org <= end) & (curY >= botY) DO NEW(l);
          Display.ReplConst(F.col, F.X + F.left, curY - dsr, F.W - F.left, lsp, 0);
          DisplayLine(F, l, R, F.X + F.left, curY, 0);
          L.next := l; L := l;
          org := org + L.len; curY := curY - lsp
        END;
        IF L0 # L.next THEN Y1 := curY;
          L.next := L0;
          WHILE (L.next # F.trailer) & (curY >= botY) DO
            L := L.next; curY := curY - lsp
          END;
          L.next := F.trailer;
          dY := Y0 - Y1;
          IF Y1 > curY + dY THEN
            Display.CopyBlock
            (F.X + F.left, curY + dY + lsp - dsr, F.W - F.left, Y1 - curY - dY,
            F.X + F.left, curY + lsp - dsr,
            0);
            Y2 := Y1 - dY
          ELSE Y2 := curY
          END;
          curY := Y1; L := L0;
          WHILE curY # Y2 DO
            Display.ReplConst(F.col, F.X + F.left, curY - dsr, F.W - F.left, lsp, 0);
            DisplayLine(F, L, R, F.X + F.left, curY, 0);
            L := L.next; curY := curY - lsp
          END
        END
      END
    END;
    UpdateMark(F)
  END Insert;

  PROCEDURE Delete* (F: Frame; beg, end: LONGINT);
    VAR R: Texts.Reader; L, L0, l: Line;
      org, org0, len: LONGINT; curY, botY, Y0, Y1, wid: INTEGER;
  BEGIN
    IF end <= F.org THEN F.org := F.org - (end - beg)
    ELSE
      IF beg < F.org THEN
        F.trailer.next.len := F.trailer.next.len + (F.org - beg);
        F.org := beg
      END;
      org := F.org; L := F.trailer.next; curY := F.Y + F.H - F.top - asr;
      WHILE (L # F.trailer) & (org + L.len <= beg) DO
        org := org + L.len; L := L.next; curY := curY - lsp
      END;
      IF L # F.trailer THEN
        botY := F.Y + F.bot + dsr;
        org0 := org; L0 := L; Y0 := curY;
        WHILE (L # F.trailer) & (org <= end) DO
          org := org + L.len; L := L.next; curY := curY - lsp
        END;
        Y1 := curY;
        Texts.OpenReader(R, F.text, org0); Texts.Read(R, nextCh);
        len := beg - org0; wid := Width(R, len);
        ReplConst (F.col, F, F.X + F.left + wid, Y0 - dsr, L0.wid - wid, lsp, 0);
        DisplayLine(F, L0, R, F.X + F.left + wid, Y0, len);
        Y0 := Y0 - lsp;
        IF L # L0.next THEN
          L0.next := L;
          L := L0; org := org0 + L0.len;
          WHILE L.next # F.trailer DO
            L := L.next; org := org + L.len; curY := curY - lsp
          END;
          Display.CopyBlock
            (F.X + F.left, curY + lsp - dsr, F.W - F.left, Y1 - curY,
            F.X + F.left, curY + lsp - dsr + (Y0 - Y1), 0);
          curY := curY + (Y0 - Y1);
          Display.ReplConst (F.col, F.X + F.left, F.Y, F.W - F.left, curY + lsp - (F.Y + dsr), 0);
          Texts.OpenReader(R, F.text, org); Texts.Read(R, nextCh);
          WHILE ~L.eot & (curY >= botY) DO NEW(l);
            DisplayLine(F, l, R, F.X + F.left, curY, 0);
            L.next := l; L := l; curY := curY - lsp
          END;
          L.next := F.trailer
        END
      END
    END;
    UpdateMark(F)
  END Delete;

  (*------------------message handling------------------------*)
```

```
PROCEDURE RemoveMarks (F: Frame);
BEGIN RemoveCaret(F); RemoveSelection(F)
END RemoveMarks;

PROCEDURE NotifyDisplay* (T: Texts.Text; op: INTEGER; beg, end: LONGINT);
  VAR M: UpdateMsg;
BEGIN M.id := op; M.text := T; M.beg := beg; M.end := end; Viewers.Broadcast(M)
END NotifyDisplay;

PROCEDURE Call* (F: Frame; pos: LONGINT; new: BOOLEAN);
  VAR S: Texts.Scanner; res: INTEGER;
BEGIN
  Texts.OpenScanner(S, F.text, pos); Texts.Scan(S);
  IF S.class = Texts.Name THEN
    par.vwr := Viewers.This(F.X, F.Y);
    par.frame := F; par.text := F.text; par.pos := pos + S.len;
    Oberon.Call(S.s, par, new, res);
    IF res > 1 THEN
      Texts.WriteString(W, "Call error: ");
      IF res = 2 THEN
        Texts.WriteString(W, " not an obj-file or error in file")
      ELSIF res = 3 THEN
        Texts.WriteString(W, Modules.imported);
        Texts.WriteString(W, " imported with bad key from ");
        Texts.WriteString(W, Modules.importing)
      ELSIF res = 4 THEN
        Texts.WriteString(W, " not enough space")
      END;
      Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
    END
  END
END Call;

PROCEDURE Write* (F: Frame; ch: CHAR; fnt: Fonts.Font; col, voff: SHORTINT);
BEGIN (*F.car # 0*)
  IF ch = 7FX THEN
    IF F.carloc.pos > F.org THEN
      Texts.Delete(F.text, F.carloc.pos - 1, F.carloc.pos);
      SetCaret(F, F.carloc.pos - 1)
    END
  ELSIF (20X <= ch) & (ch < 86X) OR (ch = 0DX) OR (ch = 9X) THEN
    KW.fnt := fnt; KW.col := col; KW.voff := voff; Texts.Write(KW, ch);
    Texts.Insert(F.text, F.carloc.pos, KW.buf);
    SetCaret(F, F.carloc.pos + 1)
  END
END Write;

PROCEDURE Defocus* (F: Frame);
EGIN RemoveCaret(F)
END Defocus;

PROCEDURE Neutralize* (F: Frame);
BEGIN RemoveMarks(F)
END Neutralize;
```

```
PROCEDURE Modify* (F: Frame; id, dY, Y, H: INTEGER);
BEGIN
  Mark(F, 0); RemoveMarks(F);
  IF id = MenuViewers.extend THEN
    IF dY > 0 THEN
      Display.CopyBlock(F.X, F.Y, F.W, F.H, F.X, F.Y + dY, 0); F.Y := F.Y + dY
    END;
    Extend(F, Y)
  ELSIF id = MenuViewers.reduce THEN
    Reduce(F, Y + dY);
    IF dY > 0 THEN Display.CopyBlock(F.X, F.Y, F.W, F.H, F.X, Y, 0); F.Y := Y END
  END;
  IF F.H > 0 THEN Mark(F, 1) END
END Modify;

PROCEDURE Open* (
  F: Frame; H: Display.Handler; T: Texts.Text; org: LONGINT;
  col, left, right, top, bot, lsp: INTEGER);
  VAR L: Line;
BEGIN NEW(L);
  L.len := 0; L.wid := 0; L.eot := FALSE; L.next := L;
  F.handle := H; F.text := T; F.org := org; F.trailer := L;
  F.left := left; F.right := right; F.top := top; F.bot := bot;
  F.lsp := lsp; F.col := col; F.mark := 0; F.car := 0; F.sel := 0
END Open;

PROCEDURE Copy* (F: Frame; VAR F1: Frame);
BEGIN NEW(F1);
  Open(F1, F.handle, F.text, F.org, F.col, F.left, F.right, F.top, F.bot, F.lsp)
END Copy;

PROCEDURE CopyOver* (F: Frame; text: Texts.Text; beg, end: LONGINT);
  VAR buf: Texts.Buffer;
BEGIN
  IF F.car > 0 THEN
    NEW(buf); Texts.OpenBuf(buf);
    Texts.Save(text, beg, end, buf);
    Texts.Insert(F.text, F.carloc.pos, buf);
    SetCaret(F, F.carloc.pos + (end - beg))
  END
END CopyOver;

PROCEDURE GetSelection* (F: Frame; VAR text: Texts.Text; VAR beg, end, time: LONGINT);
BEGIN
  IF F.sel > 0 THEN
    IF F.time > time THEN
      text := F.text; beg := F.selbeg.pos; end := F.selend.pos; time := F.time
    ELSIF F.text = text THEN
      IF (F.time < time) & (F.selbeg.pos < beg) THEN beg := F.selbeg.pos
      ELSIF (F.time > time) & (F.selend.pos > end) THEN end := F.selend.pos; time := F.time
      END
    END
  END
END GetSelection;

PROCEDURE Update* (F: Frame; VAR M: UpdateMsg);
```

```
BEGIN (*F.text = M.text*)
  RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
  IF M.id = replace THEN Replace(F, M.beg, M.end)
  ELSIF M.id = insert THEN Insert(F, M.beg, M.end)
  ELSIF M.id = delete THEN Delete(F, M.beg, M.end)
  END
END Update;

PROCEDURE Edit* (F: Frame; X, Y: INTEGER; Keys: SET);
  VAR M: Oberon.CopyOverMsg;
    T: Texts.Text; R: Texts.Reader; buf: Texts.Buffer;
    time, pos, beg, end: LONGINT; keysum: SET; ch: CHAR;
BEGIN
  Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, X, Y);
  IF X < F.X + Min(F.left, barW) THEN
    IF (0 IN Keys) OR (1 IN Keys) THEN keysum := Keys;
      REPEAT
        Input.Mouse(Keys, X, Y);
        keysum := keysum + Keys;
        Oberon.DrawCursor(Oberon.Mouse, Oberon.Arrow, X, Y)
      UNTIL Keys = {};
      IF ~(2 IN keysum) THEN
        RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
        IF (0 IN keysum) OR (F.Y + F.H < Y) THEN pos := 0
        ELSE pos := (F.Y + F.H - Y) * (F.text.len) DIV F.H
        END;
        RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
        Show(F, pos)
      ELSIF ~(0 IN keysum) THEN
        RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
        Show(F, F.text.len)
      END
    ELSIF 2 IN Keys THEN
      TrackLine(F, X, Y, pos, keysum);
      IF (pos >= 0) & ~(0 IN keysum) THEN
        RemoveMarks(F); Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
        Show(F, pos)
      END
    END
  ELSE
    IF 0 IN Keys THEN
      TrackSelection(F, X, Y, keysum);
      IF F.sel # 0 THEN
        IF (2 IN keysum) & ~(1 IN keysum) THEN (*delete text*)
          Oberon.PassFocus(MenuViewers.Ancestor);
          Oberon.GetSelection(T, beg, end, time);
          Texts.Delete(T, beg, end); SetCaret(F, beg)
        ELSIF (1 IN keysum) & ~(2 IN keysum) THEN (*copy to focus*)
          Oberon.GetSelection(T, beg, end, time);
          M.text := T; M.beg := beg; M.end := end;
          Oberon.FocusViewer.handle(Oberon.FocusViewer, M)
        END
      END
    ELSIF 1 IN Keys THEN
      TrackWord(F, X, Y, pos, keysum);
      IF (pos >= 0) & ~(0 IN keysum) THEN Call(F, pos, 2 IN keysum) END
    ELSIF 2 IN Keys THEN
      Oberon.PassFocus(Viewers.This(F.X, F.Y)); TrackCaret(F, X, Y, keysum);
      IF F.car # 0 THEN
        IF (1 IN keysum) & ~(0 IN keysum) THEN (*copy from selection*)
          Oberon.GetSelection(T, beg, end, time);
          IF time >= 0 THEN
            NEW(buf); Texts.OpenBuf(buf);
            Texts.Save(T, beg, end, buf);
            Texts.Insert(F.text, F.carloc.pos, buf);
            SetCaret(F, F.carloc.pos + (end - beg))
          END
        ELSIF (0 IN keysum) & ~(1 IN keysum) THEN (*copy font*)
          Oberon.GetSelection(T, beg, end, time);
          IF time >= 0 THEN
            Texts.OpenReader(R, F.text, F.carloc.pos); Texts.Read(R, ch);
            Texts.ChangeLooks(T, beg, end, {0, 1, 2}, R.fnt, R.col, R.voff)
          END
        END
      END
    END
  END
END Edit;

PROCEDURE Handle* (F: Display.Frame; VAR M: Display.FrameMsg);
  VAR F1: Frame;
BEGIN
  WITH F: Frame DO
    IF M IS Oberon.InputMsg THEN
      WITH M: Oberon.InputMsg DO
        IF M.id = Oberon.track THEN Edit(F, M.X, M.Y, M.keys)
        ELSIF M.id = Oberon.consume THEN
          IF F.car # 0 THEN Write(F, M.ch, M.fnt, M.col, M.voff) END
        END
      END
    ELSIF M IS Oberon.ControlMsg THEN
      WITH M: Oberon.ControlMsg DO
        IF M.id = Oberon.defocus THEN Defocus(F)
        ELSIF M.id = Oberon.neutralize THEN Neutralize(F)
        END
      END
    ELSIF M IS Oberon.SelectionMsg THEN
      WITH M: Oberon.SelectionMsg DO GetSelection(F, M.text, M.beg, M.end, M.time) END
    ELSIF M IS Oberon.CopyOverMsg THEN
      WITH M: Oberon.CopyOverMsg DO CopyOver(F, M.text, M.beg, M.end) END
    ELSIF M IS Oberon.CopyMsg THEN
      WITH M: Oberon.CopyMsg DO Copy(F, F1); M.F := F1 END
    ELSIF M IS MenuViewers.ModifyMsg THEN
      WITH M: MenuViewers.ModifyMsg DO Modify(F, M.id, M.dY, M.Y, M.H) END
    ELSIF M IS UpdateMsg THEN
      WITH M: UpdateMsg DO
        IF F.text = M.text THEN Update(F, M) END
      END
    END
  END
END Handle;
```

```
  (*creation*)

  PROCEDURE Menu (name, commands: ARRAY OF CHAR): Texts.Text;
     VAR T: Texts.Text;
  BEGIN
    NEW(T); T.notify := NotifyDisplay; Texts.Open(T, "");
    Texts.WriteString(W, name); Texts.WriteString(W, " | "); Texts.WriteString(W, commands);
    Texts.Append(T, W.buf);
    RETURN T
  END Menu;

  PROCEDURE Text* (name: ARRAY OF CHAR): Texts.Text;
    VAR T: Texts.Text;
  BEGIN NEW(T); T.notify := NotifyDisplay; Texts.Open(T, name); RETURN T
  END Text;

  PROCEDURE NewMenu* (name, commands: ARRAY OF CHAR): Frame;
    VAR F: Frame;
  BEGIN NEW(F);
    Open(F, Handle, Menu(name, commands), 0, Display.white, left DIV 4, 0, 0, 0, lsp);
    RETURN F
  END NewMenu;

  PROCEDURE NewText* (text: Texts.Text; pos: LONGINT): Frame;
    VAR F: Frame;
  BEGIN NEW(F);
    Open(F, Handle, text, pos, Display.black, left, right, top, bot, lsp);
    RETURN F
  END NewText;

BEGIN
  menuH := Fonts.Default.height + 2; barW := menuH;
  left := barW + Fonts.Default.height DIV 2; right := Fonts.Default.height DIV 2;
  top := Fonts.Default.height DIV 2; bot := Fonts.Default.height DIV 2;
  asr := Fonts.Default.maxY; dsr := -Fonts.Default.minY; lsp := Fonts.Default.height;
  selH := Fonts.Default.height; markW := Fonts.Default.height DIV 2;
  eolW := Fonts.Default.height DIV 2;
  Texts.OpenWriter(W); Texts.OpenWriter(KW);
  NEW(par)
END TextFrames.
```

```
MODULE Edit; (*JG 26.11.91*)

  IMPORT Files, Display, Viewers, MenuViewers, Oberon, Fonts, Texts, TextFrames, Printer;

  CONST
    CR = 0DX; maxlen = 32;
    StandardMenu = "System.Close System.Copy System.Grow Edit.Search Edit.Store";

  VAR
    W: Texts.Writer;
    time: LONGINT;
    M: INTEGER;
    pat: ARRAY maxlen OF CHAR;
    d: ARRAY 256 OF INTEGER;
```

```
PROCEDURE Max (i, j: LONGINT): LONGINT;
BEGIN IF i >= j THEN RETURN i ELSE RETURN j END
END Max;

PROCEDURE Open*;
  VAR par: Oberon.ParList;
  T: Texts.Text; S: Texts.Scanner;
  V: Viewers.Viewer;
  X, Y: INTEGER;
  beg, end, time: LONGINT;
BEGIN
  par := Oberon.Par;
  Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") OR (S.line # 0) THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S) END
  END;
  IF S.class = Texts.Name THEN
    Oberon.AllocateUserViewer(par.vwr.X, X, Y);
    V := MenuViewers.New(
      TextFrames.NewMenu(S.s, StandardMenu),
      TextFrames.NewText(TextFrames.Text(S.s), 0),
      TextFrames.menuH,
      X, Y)
  END
END Open;

PROCEDURE Show*;
  VAR par: Oberon.ParList;
    T, t: Texts.Text;
    R: Texts.Reader; S: Texts.Scanner;
    V: Viewers.Viewer;
    X, Y, n, i, j: INTEGER;
    pos, len, beg, end, time: LONGINT;
    buf: ARRAY 32 OF CHAR;
    name: ARRAY 35 OF CHAR;
    M: INTEGER;
    pat: ARRAY maxlen OF CHAR;
    d: ARRAY 256 OF INTEGER;

  PROCEDURE Forward (n: INTEGER);
    VAR m: INTEGER; j: INTEGER;
  BEGIN m := M - n;
    j := 0;
    WHILE j # m DO buf[j] := buf[n + j]; INC(j) END;
    WHILE j # M DO Texts.Read(R, buf[j]); INC(j) END
  END Forward;

  BEGIN
  par := Oberon.Par;
  Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") OR (S.line # 0) THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S) END
  END;
  IF S.class = Texts.Name THEN
```

```
    i := -1; j := 0;
    WHILE S.s[j] # 0X DO
      IF S.s[j] = "." THEN i := j END;
      name[j] := S.s[j]; j := j+1
    END;
    IF i < 0 THEN name[j] := "."; i := j END;
    name[i+1] := "M"; name[i+2] := "o"; name[i+3] := "d"; name[i+4] := 0X;
    t := TextFrames.Text(name);
    IF j > i THEN (*object name specified*)
      j := i+1; M := 0;
      WHILE (M # maxlen) & (S.s[j] # 0X) DO pat[M] := S.s[j]; j := j+1; M := M+1 END;
      j := 0;
      WHILE j # 256 DO d[j] := M; INC(j) END;
      j := 0;
      WHILE j # M - 1 DO d[ORD(pat[j])] := M - 1 - j; INC(j) END;
      pos := 0; len := t.len;
      Texts.OpenReader(R, t, pos);
      Forward(M); pos := pos + M;
      LOOP j := M;
        REPEAT DEC(j) UNTIL (j < 0) OR (buf[j] # pat[j]);
        IF (j < 0) OR (pos >= len) THEN EXIT END;
        n := d[ORD(buf[M-1])];
        Forward(n); pos := pos + n
      END
    ELSE pos := 0
    END;
    Oberon.AllocateUserViewer(par.vwr.X, X, Y);
    V := MenuViewers.New(
      TextFrames.NewMenu(name, StandardMenu),
      TextFrames.NewText(t, pos-200),
      TextFrames.menuH,
      X, Y)
  END
END Show;

PROCEDURE Store*;
  VAR par: Oberon.ParList;
    V: Viewers.Viewer;
    Text: TextFrames.Frame;
    T: Texts.Text; S: Texts.Scanner;
    f: Files.File;
    beg, end, time, len: LONGINT;

  PROCEDURE Backup (VAR name: ARRAY OF CHAR);
    VAR res, i: INTEGER; bak: ARRAY 32 OF CHAR;
  BEGIN i := 0;
    WHILE name[i] # 0X DO bak[i] := name[i]; INC(i) END;
    bak[i] := "."; bak[i+1] := "B"; bak[i+2] := "a"; bak[i+3] := "k"; bak[i+4] := 0X;
    Files.Rename(name, bak, res)
  END Backup;

BEGIN
  Texts.WriteString(W, "Edit.Store ");
  par := Oberon.Par;
  IF par.frame = par.vwr.dsc THEN
    V := par.vwr; Texts.OpenScanner(S, V.dsc(TextFrames.Frame).text, 0)
  ELSE V := Oberon.MarkedViewer(); Texts.OpenScanner(S, par.text, par.pos)
  END;
  Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S) END
  END;
  IF (S.class = Texts.Name) & (V.dsc # NIL) & (V.dsc.next IS TextFrames.Frame) THEN
    Text := V.dsc.next(TextFrames.Frame);
    TextFrames.Mark(Text, -1);
    Texts.WriteString(W, S.s); Texts.WriteLn(W);
    Texts.Append(Oberon.Log, W.buf);
    Backup(S.s);
    f := Files.New(S.s);
    Texts.Store(Text.text, f, 0, len);
    Files.Register(f);
    TextFrames.Mark(Text, 1)
  END
END Store;

PROCEDURE CopyFont*;
  VAR
    T: Texts.Text; R: Texts.Reader;
    V: Viewers.Viewer; F: Display.Frame;
    beg, end: LONGINT;
    X, Y: INTEGER;
    ch: CHAR;
BEGIN
  V := Oberon.MarkedViewer(); F := V.dsc;
  X := Oberon.Pointer.X; Y := Oberon.Pointer.Y;
  LOOP
    IF F = NIL THEN EXIT END;
    IF (X >= F.X) & (X < F.X + F.W) & (Y >= F.Y) & (Y < F.Y + F.H) THEN
      IF F IS TextFrames.Frame THEN
        WITH F: TextFrames.Frame DO
          Texts.OpenReader(R, F.text, TextFrames.Pos(F, X, Y));
          Texts.Read(R, ch);
          Oberon.GetSelection(T, beg, end, time);
          IF time >= 0 THEN Texts.ChangeLooks(T, beg, end, {0}, R.fnt, 0, 0) END
        END
      END;
      EXIT
    END;
    F := F.next
  END
END CopyFont;

PROCEDURE ChangeFont*;
  VAR par: Oberon.ParList;
    T: Texts.Text; S: Texts.Scanner;
    beg, end: LONGINT;
BEGIN
  Oberon.GetSelection(T, beg, end, time);
  IF time >= 0 THEN par := Oberon.Par;
    Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
    IF S.class = Texts.Name THEN
```

```
      Texts.ChangeLooks(T, beg, end, {0}, Fonts.This(S.s), 0, 0)
    END
  END
END ChangeFont;

PROCEDURE ChangeColor*;
  VAR par: Oberon.ParList;
    T: Texts.Text; S: Texts.Scanner;
    col: SHORTINT; ch: CHAR;
    beg, end, time: LONGINT;
BEGIN par := Oberon.Par;
  Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
  IF S.class = Texts.Int THEN col := SHORT(SHORT(S.i))
  ELSIF (S.class = Texts.Char) & (S.c = "^") & (par.frame(TextFrames.Frame).sel > 0) THEN
    Texts.OpenReader(S, par.text, par.frame(TextFrames.Frame).selbeg.pos);
    Texts.Read(S, ch); col := S.col
  ELSE col := Oberon.CurCol
  END ;
  Oberon.GetSelection(T, beg, end, time);
  IF time >= 0 THEN Texts.ChangeLooks(T, beg, end, {1}, NIL, col, 0) END
END ChangeColor;

PROCEDURE ChangeOffset*;
  VAR par: Oberon.ParList;
    T: Texts.Text; S: Texts.Scanner;
    voff: SHORTINT; ch: CHAR;
    beg, end, time: LONGINT;
BEGIN par := Oberon.Par;
  Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
  IF S.class = Texts.Int THEN voff := SHORT(SHORT(S.i))
  ELSIF (S.class = Texts.Char) & (S.c = "^") & (par.frame(TextFrames.Frame).sel > 0) THEN
    Texts.OpenReader(S, par.text, par.frame(TextFrames.Frame).selbeg.pos);
    Texts.Read(S, ch); voff := S.voff
  ELSE voff := Oberon.CurOff
  END ;
  Oberon.GetSelection(T, beg, end, time);
  IF time >= 0 THEN Texts.ChangeLooks(T, beg, end, {2}, NIL, voff, 0) END
END ChangeOffset;

PROCEDURE Search*;
  VAR V: Viewers.Viewer;
    Text: TextFrames.Frame;
    T: Texts.Text; R: Texts.Reader;
    pos, beg, end, prevTime, len: LONGINT; n, i, j: INTEGER;
    buf: ARRAY 32 OF CHAR;

  PROCEDURE Forward (n: INTEGER);
    VAR m: INTEGER; j: INTEGER;
  BEGIN m := M - n;
    j := 0;
    WHILE j # m DO buf[j] := buf[n + j]; INC(j) END;
    WHILE j # M DO Texts.Read(R, buf[j]); INC(j) END
  END Forward;

BEGIN
  V := Oberon.Par.vwr;
  IF Oberon.Par.frame # V.dsc THEN V := Oberon.MarkedViewer() END;
  IF (V.dsc # NIL) & (V.dsc.next IS TextFrames.Frame) THEN
    Text := V.dsc.next(TextFrames.Frame);
    TextFrames.Mark(Text, -1);
    prevTime := time; Oberon.GetSelection(T, beg, end, time);
    IF time > prevTime THEN
          Texts.OpenReader(R, T, beg);
      i := 0; pos := beg;
      REPEAT Texts.Read(R, pat[i]); INC(i); INC(pos)
      UNTIL (i = maxlen) OR (pos = end);
      M := i;
      j := 0;
      WHILE j # 256 DO d[j] := M; INC(j) END;
      j := 0;
      WHILE j # M - 1 DO d[ORD(pat[j])] := M - 1 - j; INC(j) END
    END;
    IF Text.car > 0 THEN pos := Text.carloc.pos ELSE pos := 0 END;
    len := Text.text.len;
    Texts.OpenReader(R, Text.text, pos);
    Forward(M); pos := pos + M;
    LOOP j := M;
      REPEAT DEC(j) UNTIL (j < 0) OR (buf[j] # pat[j]);
      IF (j < 0) OR (pos >= len) THEN EXIT END;
      n := d[ORD(buf[M-1])];
      Forward(n); pos := pos + n
    END;
    IF j < 0 THEN
      TextFrames.RemoveSelection(Text);
      TextFrames.RemoveCaret(Text);
      Oberon.RemoveMarks(Text.X, Text.Y, Text.W, Text.H);
      TextFrames.Show(Text, pos - 200);
      Oberon.PassFocus(V);
      TextFrames.SetCaret(Text, pos)
    END;
    TextFrames.Mark(Text, 1)
  END
END Search;

PROCEDURE Locate*;
  VAR V: Viewers.Viewer;
    Text: TextFrames.Frame;
    T: Texts.Text; S: Texts.Scanner;
    beg, end, time: LONGINT;
BEGIN
  V := Oberon.MarkedViewer();
  IF (V.dsc # NIL) & (V.dsc.next IS TextFrames.Frame) THEN
    Text := V.dsc.next(TextFrames.Frame);
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN
      Texts.OpenScanner(S, T, beg);
      REPEAT Texts.Scan(S) UNTIL (S.class >= Texts.Int); (*skip names*)
      IF S.class = Texts.Int THEN
        TextFrames.RemoveSelection(Text);
        TextFrames.RemoveCaret(Text);
        Oberon.RemoveMarks(Text.X, Text.Y, Text.W, Text.H);
        TextFrames.Show(Text, Max(0, S.i - 200));
        Oberon.PassFocus(V);
        TextFrames.SetCaret(Text, S.i)
      END
    END
  END
END Locate;

PROCEDURE Recall*;
  VAR V: Viewers.Viewer;
    Menu, Main: Display.Frame;
    buf: Texts.Buffer;
    pos: LONGINT;
BEGIN V := Oberon.FocusViewer;
  IF V IS MenuViewers.Viewer THEN
    Menu := V.dsc; Main := V.dsc.next;
    IF (Main IS TextFrames.Frame) & (Main(TextFrames.Frame).car > 0) THEN
      WITH Main: TextFrames.Frame DO
        Texts.Recall(buf);
        pos := Main.carloc.pos + buf.len;
        Texts.Insert(Main.text, Main.carloc.pos, buf);
        TextFrames.SetCaret(Main, pos)
      END
    ELSIF (Menu IS TextFrames.Frame) & (Menu(TextFrames.Frame).car > 0) THEN
      WITH Menu: TextFrames.Frame DO
        Texts.Recall(buf);
        pos := Menu.carloc.pos + buf.len;
        Texts.Insert(Menu.text, Menu.carloc.pos, buf);
        TextFrames.SetCaret(Menu, pos)
      END
    END
  END
END Recall;

PROCEDURE Print*;

  CONST
    textX = 160; textY = 225; botY = 100;

  VAR
    par: Oberon.ParList;
    V: Viewers.Viewer;
    Menu, Text: TextFrames.Frame;
    T, source: Texts.Text;
    R: Texts.Reader; S: Texts.Scanner;
    fnt: Fonts.Font;
    id, ch: CHAR;
    pageno: SHORTINT; listing: BOOLEAN;
    nofcopies, len, lsp, Y, topY: INTEGER;
    beg, end, time: LONGINT;

  PROCEDURE SendHeader;
    VAR pno: ARRAY 4 OF CHAR;
  BEGIN Printer.String(textX, Printer.PageHeight-125, S.s, Fonts.Default.name);
    IF pageno DIV 10 = 0 THEN pno[0] := " " ELSE pno[0] := CHR(pageno DIV 10 + 30H) END ;
    pno[1] := CHR(pageno MOD 10 + 30H); pno[2] := 0X;
    Printer.String(Printer.PageWidth-236, Printer.PageHeight-125, pno, Fonts.Default.name)
```

```
END SendHeader;

PROCEDURE PrintUnit (source: Texts.Text; pos: LONGINT);
  VAR i: INTEGER; new: BOOLEAN;
    buf: ARRAY 200 OF CHAR;
BEGIN Texts.WriteString(W, S.s);
  IF source.len # 0 THEN
    Texts.WriteString(W, " printing"); Texts.WriteInt(W, nofcopies, 3);
    Texts.Append(Oberon.Log, W.buf);
    lsp := Fonts.Default.height * 7 DIV 2; pageno := 0;
    SendHeader; Y := topY;
    Texts.OpenReader(R, source, pos);
    IF ~listing THEN
      REPEAT Texts.Read(R, ch);
        new := TRUE; fnt := R.fnt;
        WHILE ~R.eot & (ch # CR) DO
          i := 0;
          REPEAT buf[i] := ch; INC(i); Texts.Read(R, ch)
          UNTIL R.eot OR (ch = CR) OR (R.fnt # fnt);
          buf[i] := 0X;
          IF new THEN Printer.String(textX, Y, buf, fnt.name)
            ELSE Printer.ContString(buf, fnt.name)
          END;
          new := FALSE; fnt := R.fnt
        END;
        Y := Y - lsp;
        IF Y < botY THEN
          Printer.Page(nofcopies); INC(pageno); SendHeader; Y := topY
        END
      UNTIL R.eot
    ELSE lsp := 32;
      REPEAT Texts.Read(R, ch);
        WHILE ~R.eot & (ch # CR) DO
          i := 0;
          REPEAT buf[i] := ch; INC(i); Texts.Read(R, ch)
          UNTIL R.eot OR (ch = CR);
          buf[i] := 0X;
          Printer.String(textX, Y, buf, Fonts.Default.name)
        END;
        Y := Y - lsp;
        IF Y < botY THEN
          Printer.Page(nofcopies); INC(pageno); SendHeader; Y := topY
        END
      UNTIL R.eot
    END;
    IF Y < topY THEN Printer.Page(nofcopies) END
  ELSE Texts.WriteString(W, " not found")
  END;
  Texts.WriteLn(W);
  Texts.Append(Oberon.Log, W.buf)
END PrintUnit;

PROCEDURE Option;
  VAR ch: CHAR;
BEGIN nofcopies := 1;
  IF S.nextCh = "/" THEN
```

```
      Texts.Read(S, ch);
      IF (ch >= "0") & (ch <= "9") THEN nofcopies := ORD(ch) - 30H END ;
      WHILE ch > " " DO Texts.Read(S, ch) END;
      S.nextCh := ch
    END
  END Option;

BEGIN par := Oberon.Par;
  Texts.WriteString(W, "Edit.Print"); Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf);
  Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
  IF S.class = Texts.Name THEN
    Printer.Open(S.s, Oberon.User, Oberon.Password);
    IF Printer.res = 0 THEN
      topY := Printer.PageHeight - textY; Texts.Scan(S);
      IF (S.class = Texts.Char) & (S.c = "%") THEN
        listing := TRUE; Printer.UseListFont(Fonts.Default.name); Texts.Scan(S)
      ELSE listing := FALSE
      END;
      IF (S.class = Texts.Char) & (S.c = "*") THEN
        Option; V := Oberon.MarkedViewer();
        IF (V.dsc IS TextFrames.Frame) & (V.dsc.next IS TextFrames.Frame) THEN
           Menu := V.dsc(TextFrames.Frame); Text := V.dsc.next(TextFrames.Frame);
          Texts.OpenScanner(S, Menu.text, 0); Texts.Scan(S);
          TextFrames.Mark(Text, -1); PrintUnit(Text.text, 0); TextFrames.Mark(Text, 1)
        END
      ELSE
        WHILE S.class = Texts.Name DO
          Option; NEW(source); Texts.Open(source, S.s); PrintUnit(source, 0);
          Texts.Scan(S)
        END;
        IF (S.class = Texts.Char) & (S.c = "^") THEN Oberon.GetSelection(T, beg, end, time);
          IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S);
            IF S.class = Texts.Name THEN
              Option; NEW(source); Texts.Open(source, S.s); PrintUnit(source, 0)
            END
          END
        END
      END;
      Printer.Close
    ELSE
      IF Printer.res = 1 THEN Texts.WriteString(W, " no printer")
        ELSIF Printer.res = 2 THEN Texts.WriteString(W, " no link")
        ELSIF Printer.res = 3 THEN Texts.WriteString(W, " printer not ready")
        ELSIF Printer.res = 4 THEN Texts.WriteString(W, " no permission")
      END;
      Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
    END
  ELSE Texts.WriteString(W, " no printer specified");
    Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
  END
END Print;

PROCEDURE InitPattern;
  VAR j: INTEGER;
BEGIN
  pat[0] := " "; M := 1; time := -1; j := 0;
```

```
    WHILE j # 256 DO d[j] := M; INC(j) END
  END InitPattern;

BEGIN Texts.OpenWriter(W); InitPattern
END Edit.
```

6. The Module Loader

6.1. Linking and Loading

When the execution of a command M.P is requested, module M containing procedure P must be loaded, unless it is already loaded because a command from the same module had been executed earlier or the module had been imported by another module before. Modules are available in the form of so-called object files, generated by the compiler (or the assembler). The term loading refers to the transfer of the module code from the file into main store, from where the processor fetches individual instructions. This transfer involves also a certain amount of transformation as required by the object file format on the one hand and the storage layout on the other. A system typically consists of many modules, and hence loading modules also involves linking them together, in particular linking them with already loaded modules. Before loading, references to another module's objects are relative to the base address of this module; the linking or binding process converts them into absolute addresses.

The linking process may require a significant amount of address computations. But they are simple enough and, if the data are organized in an appropriate way, can be executed very swiftly. Nevertheless, and surprisingly, in many operating systems linking needs more time than compilation. The remedy which system designers offer is a separation of linking from loading. A set of compiled modules is first linked; the result is a linked object file with absolute addresses. The loader then merely transfers the object file into main store.

We consider this an unfortunate proposal. Instead of trying to cure an inadequacy with the aid of an additional processing stage and an additional tool, it is wiser to cure the malady at its core, namely to speed up the linking process itself. Indeed, there is no separate linker in the Oberon system. The linker and loader are integrated and fast enough to avoid any desire for pre-linking. Furthermore, the extensibility of a system crucially depends on the possibility to link additional modules to the ones already loaded by calls from any module. This is called dynamic loading. This is not possible with pre-linked object files. Newly loaded modules simply refer to the loaded ones, whereas pre-linked files lead to the presence of multiple copies of the same module code.

Evidently, the essence of linking is the conversion of relative addresses as generated by the compiler for all external references into absolute addresses as required during program execution. There exist two different strategies for this task.

1. External references are directly patched in the code. The object file contains a list of the locations of all external references. It is called the fixup list.
2. A separate link table is provided with external references to be converted. The actual references within the program code directly refer to these table entries, and only indirectly to the objects.

The advantage of the first strategy is execution speed, because all external references are direct during program execution. The advantage of the second strategy is an expedient linking process, because there are far fewer conversions to be performed - instead of one for every reference, only one for every referenced object. A further advantage is that no fixup list is required; the entire compiled code remains untouched. Also, code density is significantly increased: an external address in the code is an index to the table (typically 8 bits) rather than a full address (typically 32 bits). A slight disadvantage is, of course, the need for a (short) link table.

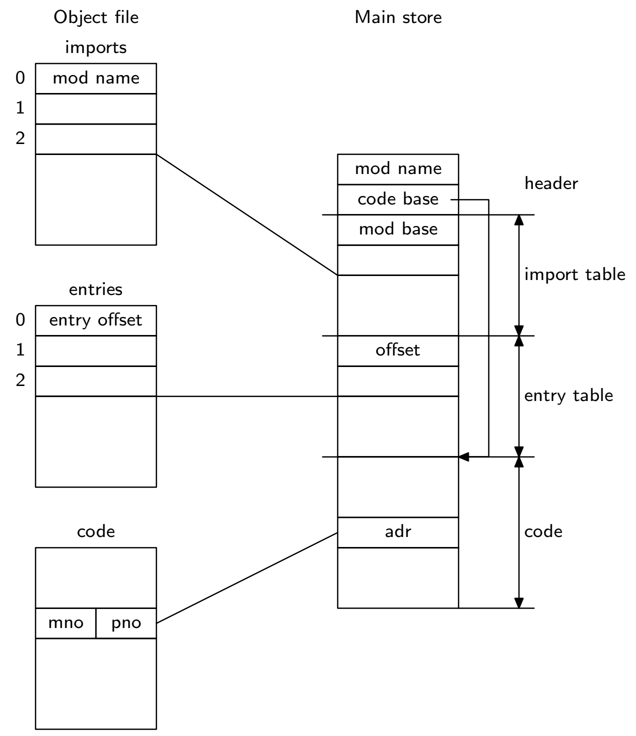

Fig. 6.1. Linkage Information

Before proceeding, we must consider an additional complication. Assume that a module B is to be compiled which is a client of (i.e. it imports) module A. The interface of A - in the form of a symbol file - does not specify the entry addresses of its exported procedures, but merely specifies a unique number (pno) for each one of them. The reason for this is that in this way the implementation of A may be modified, causing a change of entry addresses without affecting its interface specification. And this is a crucial property of the scheme of separate compilation of modules: changes of the implementation of A must not necessitate the recompilation of clients (B). The consequence is that the binding of entry addresses to procedure numbers must be performed by the linker. In order to make this possible, the object file must contain a list (table) of its entry addresses, one for each procedure number used as index to the table.

Similarly, the object file must contain a table of imported modules, containing their names. An external reference in the program code then appears in the form of a pair consisting of a module number (mno) - used as index to the import table (of modules) - and a procedure number (pno), used as index to the entry table of this module.

Such linkage information must not only be provided in each object file, but also be present along with each loaded module's program code, because a module to be loaded must be linkable with modules loaded at any earlier time without reading their object files again. The linkage tables contained in the file and in main store are shown in Fig. 6.1.

In the linking process, first the import table in the file (containing module names) is transformed into the internal import table containing the addresses of the respective modules. Then the entry offsets are merely copied. And finally, the code is loaded and address computations are performed either at every location of the link table (strategy 2) or at every location in the code specified by the fixup list (strategy 1). The resulting (absolute) address of a procedure specified by mno and pno is

```
    adr = imptab[mno].codebase + imptab[mno].entry[pno]
```

The module name must be available for each module, because it is needed by the loader for the searches conducted during the construction of the import table. Procedure names are not needed, as they have been transformed by the compiler into numbers unique for each module.

For external references to variables, the same scheme might be used, namely identifying each exported variable by an entry number (vno). The expression for its absolute address would then be given by

adr = imptab[mno].varbase + imptab[mno].entry[vno].

However, this is usually not done. Instead, the variable's offset is directly specified in the code. The variable's absolute address is computed as

adr = imptab[mno].varbase + offset

The drawback is that modifications of a module that change a variable's address require recompilation of all clients (because the symbol file contains the offset). This drawback is slight in practice, since exported variables are rare and are declared at the beginning of the program text. Additions or deletions of non- exported variables have no influence on the exported information.

6.2. Module Representation in the Oberon System

Our choice has been to use strategy 2 for handling external references. This can be justified only if the underlying hardware reduces the inherent loss in efficiency by adequate support in the form of addressing modes, and if thereby the gain in code density is significant. When using the NS32000 architecture, these requirements are satisfied; in particular, this architecture features a code density that is higher than most other processor's by a factor of 1.5 - 2.5.

Tests with an alternative compiler and loader, using strategy 1 and absolute addresses for external references produced code that was 15% longer on the average. In extreme cases with a larger number of external calls (using 6 instead of 2 bytes of code) the length increased by as much as 20%. Surprisingly, the data about speedup remained inconclusive.

Before proceeding, we present the layout of module information as defined by the NS32000 processor's external addressing mode

Every module has an associated module descriptor. It contains three pointers (base addresses), referring respectively to the module's data section (sb), link table (lb) and code (pb), all of which are part of the module block. In order to accelerate cross-module access, two processor registers are provided. Register MOD points to the descriptor of the module currently under control, and register SB (static base) points to its data section. These registers must be updated in every external procedure call and on its return, i.e. whenever control passes from one module to another. The process of a call is shown in Fig. 6.2. It is initiated by a CXP k instruction. k is the index of the link table entry of the called procedure. At the left we show the various parts of the calling module A, at the right those of the module containing the called procedure.

The transition from the calling to the called context can be described by the following sequence of microcode statements (pd is to be considered as a temporary variable):

```
CXP: pd := M[M[MOD].lb + 4k];     (* procedure descriptor*)
     SP := SP-4; M[SP] := MOD;    (* stack pointer*)
     SP := SP-4; M[SP] := PC;
     MOD := pd.mod        (* module pointer*)
     PC := M[MOD].pb + pd.offset(* program counter*)
     SB := M[MOD].sb;    (* static base*)
```

The microcode for a procedure return is

```
RXP: PC := M[SP]; SP := SP + 4;
     MOD := M[SP]; SP := SP + 4;
     SB := M[MOD].sb
```

From these programs it can be seen that a procedure call involves 6, a return 3 memory references, which is quite considerable. Code density, however, is also remarkable: 2 bytes for call and return each. We may compare the above program sections with the corresponding ones for the BSR and RET instructions which are used for calls of local procedures, where no module context switch occurs. It is evident that whenever possible, these simpler instructions should be used.

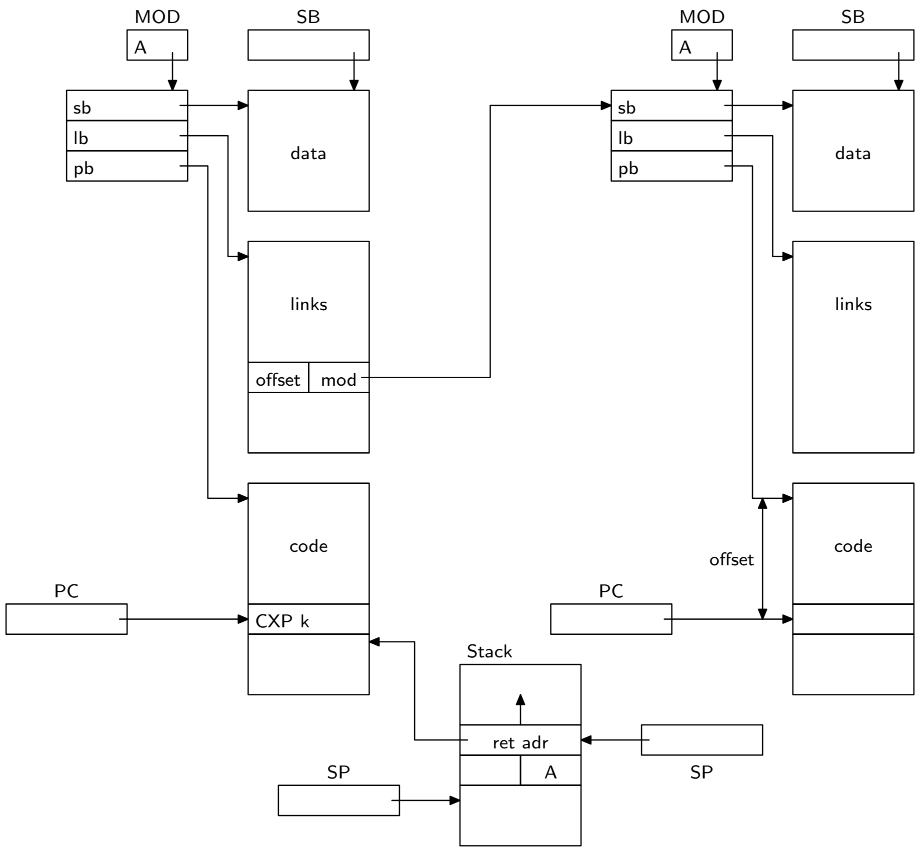

Fig. 6.2. Module layout and external procedure call of the NS32000 processor

```
BSR:  SP := SP-4; M[SP] := PC
      PC := PC + m

RET:  PC := M[SP]; SP := SP+4
```

m is a parameter specifying the procedure's offset. Both instructions require a single memory reference only. They correspond to the typical subroutine call mechanism present in most processors.

From the preceding presentation we conclude that a module block consists of three parts accessed during program execution: the code, the global data, and the link table, and two parts accessed by the loader while linking additional modules; the import and the entry tables. Furthermore, there exists a descriptor with the addresses of the three primary parts, and it is logical to augment it with two pointers referring to the import and entry tables.

Note: the descriptor is disjoint from the block, because the MOD register has only 16 bits and hence the descriptor must be stored within the address range 0... 0FFFFH.

In fact, the module block in the Oberon System contains two additional parts, namely a table of pointer offsets and a table of commands. The pointer offsets are used by the garbage collector. The table contains an entry for each global pointer variable specifying its offset in the data section. Global pointer variables are typically the roots of data structures and therefore serve as starting points of the mark phase in the garbage collection process (see Chapter 8).

The command table is accessed when a command is selected in some text by the user. The command's identifier must be transformed into an entry address, and this is achieved by a lookup in the module's command table. Each entry consists of the identifier followed by the offset. The same offsets also occur in the entry table.

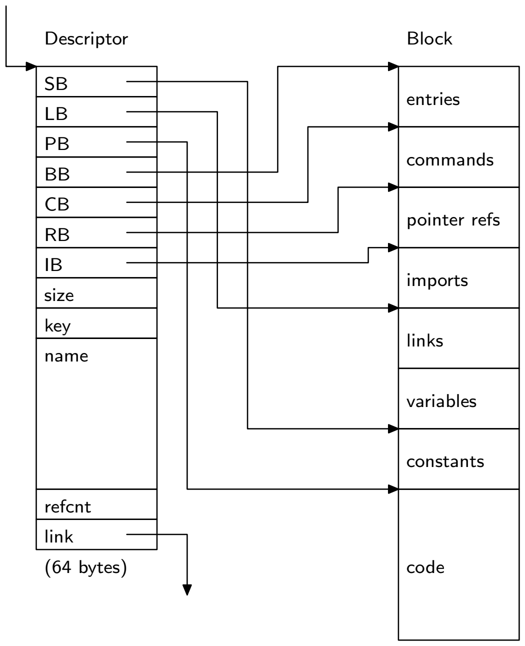

Fig. 6.3. Module descriptor and associated block

Both the pointer offset table and the command table must have their counterparts in the object file. The loader merely copies them into the block. Pointers to both tables are added to the descriptor, which can now be described in full by the following record declaration (see also Fig 6.3).

```
ModDesc = RECORD
            SB, LB, PB, BB, CB, RB, IB, size, key: LONGINT;
            name: ModName;
            refcnt: LONGINT;
            link: Module
        END;
Module = POINTER TO ModDesc
```

6.3. The Linking Loader

The loader is represented by procedure ThisMod in module Modules. This procedure accepts a name and returns a pointer to the specified module's descriptor. It first scans the list of descriptors for the named module. If it is not present, the module is loaded and added to the list.

When loading, the header of the respective object file is read first. It specifies the required size of the block. Both descriptor and block are allocated by procedure Kernel.AllocBlock. First, the header indicating the lengths of the various sections of the load file, and thereafter the import section are read. For each import, procedure ThisMod is called recursively. Because cyclic imports are excluded, recursion always terminates. After the loading of the imports, loading of the client proceeds by allocating a descriptor and a block, and then reading the remaining sections of the file. Each module is identified by its descriptor's address.

The link section contains two kinds of elements, both denoted by two integers mno and pno. The majority stands for procedures. The loader transforms the mno, pno pairs (module and procedure numbers) of the file's entry section into the respective procedure descriptors consisting of module descriptor address and entry offset. The second kind of element denotes base addresses of a module's data section. They are identified by a special value of pno (-1).

After the module has been loaded successfully, its initialisation body is executed. The corresponding procedure descriptor consist of the module (descriptor) address and an offset of zero.

```
MODULE  Modules;  (*NW 16.2.86 / 7.4.91*)
  IMPORT SYSTEM, Kernel, FileDir, Files;

  CONST ModNameLen* = 20; ObjMark = 0F8X;

  TYPE Module* = POINTER TO ModDesc;
    Command* = PROCEDURE;
    ModuleName* = ARRAY ModNameLen OF CHAR;

    ModDesc* = RECORD SB*, LB*, PB*, BB*, CB*, RB*, IB*, size*, key*: LONGINT;
        name*: ModuleName;
        refcnt*: LONGINT;
        link*: Module
      END ;

  VAR res*: INTEGER;
    importing*, imported*: ModuleName;
    loop: Command;

  PROCEDURE ReadName(VAR R: Files.Rider; VAR s: ARRAY OF CHAR; n: INTEGER);
    VAR ch: CHAR; i: INTEGER;
  BEGIN i := 0;
    REPEAT Files.Read(R, ch); s[i] := ch; INC(i)
    UNTIL ch = 0X;
    WHILE i < n DO Files.Read(R, ch); s[i] := 0X; INC(i) END
  END ReadName;

  PROCEDURE OpenFile(VAR F: Files.File; VAR name: ARRAY OF CHAR);
    VAR i: INTEGER; ch: CHAR;
      Fname: ARRAY 32 OF CHAR;
  BEGIN i := 0; ch := name[0]; (*make file name*)
    WHILE ch > 0X DO Fname[i] := ch; INC(i); ch := name[i] END ;
    Fname[i] := "."; Fname[i+1] := "O"; Fname[i+2] := "b"; Fname[i+3] := "j"; Fname[i+4] := 0X;
    F := Files.Old(Fname)
  END OpenFile;

  PROCEDURE PD(mod: Module; pc: LONGINT): LONGINT;
  BEGIN (*procedure descriptor*)
    RETURN ASH(pc, 16) + SYSTEM.VAL(LONGINT, mod)
  END PD;

  PROCEDURE ThisMod*(name: ARRAY OF CHAR): Module;
    (*search module in list; if not found, load module*)

    VAR
      mod, impmod, md: Module;
      ch: CHAR; mno, pno: SHORTINT;
      i, j: INTEGER;
      nofentries, nofimps, nofptrs, comsize, noflinks, constsize, codesize: INTEGER;
      varsize, size, key, impkey, k, p, q, pos1, pos2: LONGINT;
      init: Command;
      F: Files.File; R: Files.Rider;
      modname, impname: ModuleName;
      Fname: ARRAY FileDir.FnLength OF CHAR;
      import: ARRAY 16 OF Module;

    PROCEDURE err(n: INTEGER);
    BEGIN
      IF res = 0 THEN res := n; COPY(name, imported) END
    END err;
```

```
BEGIN res := 0; mod := SYSTEM.VAL(Module, Kernel.ModList);
  LOOP
    IF name = mod.name THEN EXIT END ;
    mod := mod.link;
    IF mod = NIL THEN EXIT END
  END ;
  IF mod = NIL THEN (*load*)
    OpenFile(F, name);
    IF F # NIL THEN
      Files.Set(R, F, 0); Files.Read(R, ch); (*header*)
      IF ch # ObjMark THEN err(2); RETURN NIL END ;
      Files.Read(R, ch);
      IF ch # "6" THEN err(2); RETURN NIL END ;
      Files.ReadBytes(R, k, 4);  (*skip*)
      Files.ReadBytes(R, nofentries, 2); Files.ReadBytes(R, comsize, 2);
      Files.ReadBytes(R, nofptrs, 2); Files.ReadBytes(R, nofimps, 2);
      Files.ReadBytes(R, noflinks, 2); Files.ReadBytes(R, varsize, 4);
      Files.ReadBytes(R, constsize, 2); Files.ReadBytes(R, codesize, 2);
      Files.ReadBytes(R, key, 4); ReadName(R, modname, ModNameLen);
      i := (nofentries + nofptrs)*2 + comsize;
      pos1 := Files.Pos(R); Files.Set(R, F, pos1 + i + 3);
      INC(i, nofimps*2); k := (i MOD 4) + i;
      (*imports*) Files.Read(R, ch);
      IF ch # 85X THEN err(4); RETURN NIL END ;
      res := 0; i := 0;
      WHILE (i < nofimps) & (res = 0) DO
        Files.ReadBytes(R, impkey, 4); ReadName(R, impname, 0); Files.Read(R, ch);
        impmod := ThisMod(impname);
        IF res = 0 THEN
          IF impmod.key = impkey THEN import[i] := impmod; INC(i); INC(impmod.refcnt)
          ELSE res := 3; imported := impname; importing := modname
          END
        END
      END ;
      IF res # 0 THEN
        WHILE i > 0 DO DEC(i); DEC(import[i].refcnt) END ;
        RETURN NIL
      END ;

      pos2 := Files.Pos(R);
      size := k + noflinks*4 + constsize + codesize + varsize;
      Kernel.AllocBlock(q, p, size); mod := SYSTEM.VAL(Module, q);
      mod.size := size;
      mod.BB := p;
      mod.CB := nofentries*2 + p;
      mod.RB := comsize + mod.CB;
      mod.IB := nofptrs*2 + mod.RB;
      mod.LB := k + p;
      mod.SB := (noflinks*4 + varsize) + mod.LB;
      mod.PB := constsize + mod.SB;
      mod.refcnt := 0;
      mod.key := key;
      mod.name := modname;
      (*entries*) q :=  mod.CB; Files.Set(R, F, pos1); Files.Read(R, ch);
      IF ch # 82X THEN err(4); RETURN NIL END ;
      WHILE p < q DO Files.Read(R, ch); SYSTEM.PUT(p, ch); INC(p) END ;

      (*commands*) q := mod.RB; Files.Read(R, ch);
      IF ch # 83X THEN err(4); RETURN NIL END ;
      WHILE p < q DO Files.Read(R, ch); SYSTEM.PUT(p, ch); INC(p) END ;

      (*pointer references*) q := mod.IB; Files.Read(R, ch);
      IF ch # 84X THEN err(4); RETURN NIL END ;
      WHILE p < q DO Files.Read(R, ch); SYSTEM.PUT(p, ch); INC(p) END ;

      i := 0;
      WHILE i < nofimps DO SYSTEM.PUT(p, import[i]); INC(p, 2); INC(i) END ;

      (*links*) Files.Set(R, F, pos2+1); p := mod.LB; q := noflinks*4 + p;
      WHILE p < q DO
              Files.Read(R, pno); Files.Read(R, mno);
              IF mno > 0 THEN md := import[mno-1] ELSE md := mod END ;
              IF pno = -1 THEN SYSTEM.PUT(p, md.SB)   (*data segment entry*)
              ELSE SYSTEM.GET(pno*2 + md.BB, i);
                      SYSTEM.PUT(p, PD(md, i))    (*procedure entry*)
              END ;
              INC(p, 4)
      END ;

      (*variables*) q := mod.SB;
      WHILE p < q DO SYSTEM.PUT(p, 0); INC(p) END ;

      (*constants*) q := mod.PB; Files.Read(R, ch);
      IF ch # 87X THEN err(4); RETURN NIL END ;
      WHILE p < q DO Files.Read(R, ch); SYSTEM.PUT(p, ch); INC(p) END ;

      (*code*) q := p + codesize; Files.Read(R, ch);
      IF ch # 88X THEN err(4); RETURN NIL END ;
      WHILE p < q DO Files.Read(R, ch); SYSTEM.PUT(p, ch); INC(p) END ;

      (*type descriptors*) Files.Read(R, ch);
      IF ch # 89X THEN err(4); RETURN NIL END ;
      LOOP Files.ReadBytes(R, i, 2);
              IF R.eof OR (i MOD 100H = 8AH) THEN EXIT END ;
              Files.ReadBytes(R, j, 2);  (*adr*)
              SYSTEM.NEW(md, i);
              p := SYSTEM.VAL(LONGINT, md); q := p + i;
              REPEAT Files.Read(R, ch); SYSTEM.PUT(p, ch); INC(p) UNTIL p = q;
              SYSTEM.PUT(mod.SB + j, md)
      END ;

      init := SYSTEM.VAL(Command, mod); init;
    ELSE COPY(name, imported); err(1)
    END
  END ;
  RETURN mod
END ThisMod;

PROCEDURE ThisCommand*(mod: Module; name: ARRAY OF CHAR): Command;
  VAR i: INTEGER; ch: CHAR;
      comadr: LONGINT; com: Command;
BEGIN com := NIL;
  IF mod # NIL THEN
    comadr := mod.CB; res := 5;
```

```
      LOOP SYSTEM.GET(comadr, ch); INC(comadr);
        IF ch = 0X THEN (*not found*) EXIT END ;
        i := 0;
        LOOP
                IF ch # name[i] THEN EXIT END ;
                INC(i);
                IF ch = 0X THEN res := 0; EXIT END ;
                SYSTEM.GET(comadr, ch); INC(comadr)
        END ;
        IF res = 0 THEN (*match*)
                SYSTEM.GET(comadr, i); com := SYSTEM.VAL(Command, PD(mod, i)); EXIT
        ELSE
                WHILE ch > 0X DO SYSTEM.GET(comadr, ch); INC(comadr) END ;
                INC(comadr, 2)
        END
      END
    END ;
    RETURN com
  END ThisCommand;

  PROCEDURE unload(mod: Module; all: BOOLEAN);
    VAR p: LONGINT; k: INTEGER;
      imp: Module;
  BEGIN p := mod.IB;
    WHILE p < mod.LB DO  (*scan imports*)
      SYSTEM.GET(p, k); imp := SYSTEM.VAL(Module, LONG(k));
      IF imp # NIL THEN
        DEC(imp.refcnt);
        IF all & (imp.refcnt = 0) THEN unload(imp, all) END
      END ;
      INC(p, 2)
    END ;
    Kernel.FreeBlock(SYSTEM.VAL(LONGINT, mod))
  END unload;

  PROCEDURE Free*(name: ARRAY OF CHAR; all: BOOLEAN);
    VAR mod: Module;
  BEGIN mod :=  SYSTEM.VAL(Module, Kernel.ModList);
    LOOP
      IF mod = NIL THEN res := 1; EXIT END ;
      IF name = mod.name THEN
        IF mod.refcnt = 0 THEN unload(mod, all); res := 0 ELSE res := 2 END ;
        EXIT
      END ;
      mod := mod.link
    END
  END Free;
 BEGIN
  IF Kernel.err = 0 THEN loop := ThisCommand(ThisMod("Oberon"), "Loop") END ;
  loop
END Modules.
```

The frequent use of the low-level procedures SYSTEM.GET and SYSTEM.PUT is easily justified in base modules such as the loader or device drivers. After all, here data are transferred into untyped main storage.

The object file consists of several sections, each of which is headed by an identification byte (see Sect. 6.5). These bytes are used as a check against corrupted files. A mismatch between read and expected check byte leads to an abortion of the loading process. The cause of the termination is recorded in the global variable res with the following values:

0	loading completed
1	object file not available
2	referenced file is not an object file or is of wrong version
3	key mismatch
4	corrupted object file
5	command not found

When an error is detected, the names of the modules involved are recorded in the (exported) variables imported and importing.

Procedure ThisCommand yields the procedure descriptor for the specified command by performing a linear search of the specified module's command table.

When a module is no longer needed, it should be possible to unload it; and when it is to be replaced by a new, perhaps corrected version, it must be unloaded. Obviously, in a hierarchy of modules, no module must be removed before its clients are removed. A procedure for unloading must therefore ensure that no clients exist.

For this purpose, each module descriptor is given a reference count. The field refcnt is initialized to zero when a module is loaded, and incremented each time the module is imported by a newly loaded client. Procedure Free checks whether or not this count is zero. Its parameter all indicates whether only the specified module is to be unloaded, or the process is to be transitive, i.e. applied to all its imports, too. Hence Free, or rather the local procedure unload, is recursive. We emphasize that unloading is never automatic, but must be explicitly requested by the system's user. The global variable res records the result of unloading:

0:	unloading completed
1:	module is not loaded
2:	cannot be unloaded, because clients exist

Unloading a module is a tricky operation. One must make sure that no references to the unloaded module exist in the remaining modules and data structures. Unfortunately, this is not at all easy and is not guaranteed in the Oberon System. The violating culprits are procedure variables. If a procedure of a module A is assigned to a variable of a module B, and if A is unloaded, the procedure variable holds a dangling reference to the unloaded module's code block. In systems with virtual addressing (Ceres-1 and Ceres-2), the problem is solved by never reusing code addresses, i.e. by strictly sequential allocation in virtual address space. A dangling reference then points to a not allocated page, causing an address (NIL) trap when used. The situation is unsatisfactory, however, when code space is reused (Ceres-3).

6.4. The Toolbox of the Loader

User commands directed to the loader are contained in module System. The box comprises the following three commands:

```
System.ShowModules
System.ShowCommands modname
System.Free {modname} ~
```

The first command opens a viewer and provides a list of all loaded modules. The list indicates the block length and the number of clients importing a module (the reference count). System.ShowCommands opens a viewer and lists the commands provided by the specified module. The commands are prefixed by the module name, and hence can immediately be activated by a mouse click. System.Free is called in order to remove modules either to regain storage space or to replace a module by a newly compiled version.

```
PROCEDURE ShowModules*;
  VAR T: Texts.Text;
    V: Viewers.Viewer;
    M: Modules.Module;
    X, Y: INTEGER;
BEGIN T := TextFrames.Text("");
  Oberon.AllocateSystemViewer(Oberon.Par.vwr.X, X, Y);
  logV := MenuViewers.New(TextFrames.NewMenu("System.ShowModules", StandardMenu),
          TextFrames.NewText(T, 0), TextFrames.menuH, X, Y);
  M := SYSTEM.VAL(Modules.Module, Kernel.ModList);
  WHILE M # NIL DO
    Texts.WriteString(W, M.name); Texts.WriteInt(W, M.size, 8);
    Texts.WriteInt(W, M.refcnt, 4); Texts.WriteLn(W); M := M.link
  END;
  Texts.Append(T, W.buf)
END ShowModules;

PROCEDURE ShowCommands*;
  VAR M: Modules.Module;
    comadr, beg, end, time: LONGINT; ch: CHAR;
    T: Texts.Text;
    S: Texts.Scanner;
    V: Viewers.Viewer;
    X, Y: INTEGER;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "^") THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S) END
  END ;
  IF S.class = Texts.Name THEN
    M := Modules.ThisMod(S.s);
    IF M # NIL THEN comadr := M.CB;
      Oberon.AllocateSystemViewer(Oberon.Par.vwr.X, X, Y); T := TextFrames.Text("");
      V := MenuViewers.New(TextFrames.NewMenu("System.Commands", StandardMenu),
            TextFrames.NewText(T, 0), TextFrames.menuH, X, Y);
      LOOP SYSTEM.GET(comadr, ch); INC(comadr);
        IF ch = 0X THEN EXIT END ;
        Texts.WriteString(W, S.s); Texts.Write(W, ".");
        REPEAT Texts.Write(W, ch); SYSTEM.GET(comadr, ch); INC(comadr)
        UNTIL ch = 0X;
        Texts.WriteLn(W); INC(comadr, 2)
      END ;
      Texts.Append(T, W.buf)
    END
  END
END ShowCommands;

PROCEDURE Free1(VAR S: Texts.Scanner);
BEGIN Texts.WriteString(W, S.s); Texts.WriteString(W, " unloading");
  Texts.Append(Oberon.Log, W.buf);
  IF S.nextCh # "*" THEN Modules.Free(S.s, FALSE)
    ELSE Modules.Free(S.s, TRUE); Texts.Scan(S); Texts.WriteString(W, " all")
  END;
  IF Modules.res # 0 THEN Texts.WriteString(W, " failed") END;
  Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
END Free1;
```

```
PROCEDURE Free*;
  VAR T: Texts.Text;
    V: Viewers.Viewer;
    beg, end, time: LONGINT;
BEGIN Texts.WriteString(W, "System.Free"); Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf);
  Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  WHILE S.class = Texts.Name DO Free1(S); Texts.Scan(S) END ;
  IF (S.class = Texts.Char) & (S.c = "^") THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S);
      IF S.class = Texts.Name THEN Free1(S) END
    END
  END
END Free;
```

6.5. The Oberon Object File Format

An object file consists of a sequence of blocks, containing the various data to be loaded as described in the preceding sections of this chapter. The file starts with an identification byte (F8), marking the file to be an object file, and each block is headed by an identification byte. The header block contains the module's name and key, and the number of items in the subsequent blocks. The syntax of object files is the following:

Object File =	HeaderBlock EntryBlock CommandBlock PointerBlock ImportBlock LinkBlock DataBlock CodeBlock TypeBlock [ReferenceBlock].
HeaderBlock =	0F8X versionCode refBlkPos:4 nofEntries:2 comSize:2 nofPtrs:2 nofImps:2 nofLinks:2 varSize:4 codeSize:2 key:4 Name.
Entry Block =	82X {entryAdr:2}.
CommandBlock =	83X {Name entryAdr:2} 0X [0X].
PointerBlock =	84X {pointerOffset:2}.
ImportBlock =	85X {key:4 Name 0X}.
LinkBlock =	86X {procNumber moduleNumber}.
DataBlock =	87X {byte}.
CodeBlock =	88X {byte}.
TypeBlock =	89X {tdsize:2 tdadr:2 {byte}}.
ReferenceBlock =	8AX {ProcRef}.
ProcRef =	0F8X entryAdr:2 Name {LocalRef}.
LocalRef =	mode form adr:4 Name.
Name =	{byte} 0X.

For terminal symbols a suffix :n denotes the number of bytes used (unless it is 1).

The reference block at the end of the file is ignored by the loader, but used by the error trap routine in order to list the values of local variables at the time of the trap. For further details see procedure Trap in Sect. 12.9. The header block contains a reference to this block in order to allow the trap routine to swiftly position its reader.

7. The File System

7.1 Files

It is essential that a computer system has a facility for storing data over longer periods of time and for retrieving the stored data. Such a facility is called a *file system*. Evidently, a file system cannot accommodate all possible data types and structures that will be programmed in the future. Hence, it is necessary to provide a simple, yet flexible enough base structure that allows any data structure to be mapped onto this base structure (and vice-versa) in a reasonably straight-forward and efficient way. This base structure, called *file*, is a sequence of bytes. As a consequence, any given structure to be transformed into a file must be sequentialized. The notion of sequence is indeed fundamental, and it requires no further explanation and theory. We recall that texts are sequences of characters, and that characters are typically represented as bytes.

The sequence is also the natural abstraction of all physically moving storage media. Among them are magnetic tapes and disks. Magnetic media have the welcome property of non-volatility and are therefore the primary choices for storing data over longer periods of time, especially over periods where the equipment is switched off.

A further advantage of the sequence is that its transmission between media is simple too. The reason is that its structural information is inherent and need not be encoded and transmitted in addition to the actual data. This implicitness of structural information is particularly convenient in the case of moving storage media, because they impose strict timing constraints on transmission of consecutive elements. Therefore, the process which generates (or consumes) the data must be effectively decoupled from the transmission process that observes the timing constraints. In the case of sequences, this decoupling is simple to achieve by dividing a sequence into subsequences which are buffered. A sequence is output to the storage medium by alternately generating data (and filling the buffer holding the current subsequence) and transmitting data (fetching elements from the buffer and transmitting them). The size of the subsequences (and the buffer) depends on the storage medium under consideration: there must be no timing constraints between accesses to consecutive subsequences.

The file is not a static data structure like the array or the record, because the length may increase dynamically, i.e. during program execution. On the other hand, the sequence is less flexible than general dynamic structures, because it cannot change its form, but only its length, since elements can only be appended but not inserted. It might therefore be called a semi-dynamic structure.

The discipline of purely sequential access to a file is enforced by restricting access to calls of specific procedures, typically read and write procedures for scanning and generating a file. In the jargon of data processing, a file must be *opened* before reading or writing is possible. The opening implies the initialization of a reading and writing mechanism, and in particular the fixing of its initial position. Hence each (opened) file not only has a value and a length, but also a position attributed to it. If reading must occur from several positions (still sequentially) alternately, the file is "multiply opened"; it implies that the same file is represented by several variables, each denoting a different position.

This widespread view of files is conceptually unappealing, and the Oberon file system therefore departs from it by introducing the notion of a *rider*. A file simply has a value, the sequence of bytes, and a length, the number of bytes in the sequence. Reading and writing occurs through a rider, which denotes a position. "Multiple opening" is achieved by simply using several riders riding on the same file. Thereby the two concepts of data structure (file) and access mechanism (rider) are clearly distinct and properly disentangled.

Given a file *f*, a rider *r* is placed on a file by the call *Files.Set (r, f, pos)*, where pos indicates the position from which reading or writing is to start. Calls of *Files.Read (r, x)* and *Files.Write (r, x)* implicitly increment the position beyond the element read or written, and the file is implicitly denoted via the explicit parameter *r*, which denotes a rider. The rider has two (visible) attributes, namely *r.eof* and *r.res*. The former is set to FALSE by *Files.Set*, and to TRUE when a read operation could not be performed, because the end of the file had been reached. r.res serves as a result variable in procedures *ReadBytes* and *WriteBytes* allowing one to check for correct termination.

A file system must not only provide the concept of a sequence with its accessing mechanism, but also a registry. This implies that files be identified, that they can be given a name by which they are registered and retrieved. The registry or collection of registered names is called the file system's *directory*. Here we wish to emphasize that the concepts of files as data structure with associated access facilities on the one hand, and the concept of file naming and directory management on the other hand must also be considered separately and as independent notions. In fact, in the Oberon system their implementation underscores this separation by the existence of two modules: *Files* and *FileDir*. The following procedures are made available. They are summarized by the interface specification (definition) of module *Files*.

```
DEFINITION Files;
  IMPORT SYSTEM;
  TYPE File = POINTER TO Handle;
    Handle = RECORD END ;
    Rider = RECORD res: INTEGER; eof: BOOLEAN END ;

  PROCEDURE Old(name: ARRAY OF CHAR): File;
  PROCEDURE New(name: ARRAY OF CHAR): File;
  PROCEDURE Register(f: File);
  PROCEDURE Close(f: File);
  PROCEDURE Purge(f: File);
  PROCEDURE Length(f: File): LONGINT;
  PROCEDURE GetDate(f: File; VAR time, date: LONGINT);

  PROCEDURE Set(VAR r: Rider; f: File; pos: LONGINT);
  PROCEDURE Read(VAR r: Rider; VAR x: SYSTEM.BYTE);
  PROCEDURE ReadBytes(VAR r: Rider; VAR x: ARRAY OF SYSTEM.BYTE; n: LONGINT);
  PROCEDURE Write(VAR r: Rider; x: SYSTEM.BYTE);
  PROCEDURE WriteBytes(VAR r: Rider; VAR x: ARRAY OF SYSTEM.BYTE; n: LONGINT);
  PROCEDURE Pos(VAR r: Rider): LONGINT;
  PROCEDURE Base(VAR r: Rider): File;

  PROCEDURE Rename(old, new: ARRAY OF CHAR; VAR res: INTEGER);
  PROCEDURE Delete(name: ARRAY OF CHAR; VAR res: INTEGER);
END Files.
```

New(name) yields a new (empty) file without registering it in the directory. *Old(name)* retrieves the file with the specified name, or yields NIL, if it is not found in the directory. *Register(f)* inserts the name of f (specified in the call of New) in the directory. An already existing entry with this name is replaced. *Close(f)* must be called after writing is completed and the file is not to be registered. *Close* actually stands for "close buffers", and is implied in the procedure *Register*. Procedure *Purge* will be explained at the end of section 7.2.

The sequential scan of a file *f* is programmed as shown in the following template:

```
f := Files.Old(name);
IF f # NIL THEN
    Files.Set (r, f, 0); Files.Read (r, x);
    WHILE ~ r.eof DO ... x ...; Files.Read(r, x) END
END
```

The analogous template for a purely sequential writing is:

```
f := Files.New(name); Files.Set(r, f, 0); ...
WHILE ... DO Files.Write (r, x); ... END
Files.Register(f)
```

There exist two further procedures; they do not change any files, but only affect the directory. *Delete(name, res)* causes the removal of the named entry from the directory. *Rename(old, new, res)* causes the replacement of the directory entry old by new.

It may surprise the reader that these two procedures, which affect the directory only, are exported from module *Files* instead of *FileDir*. The reason is that the presence of the two modules, together forming the file system, is also used for separating the interface into a public and a private (or semi-public) part. The definition (in the form of a symbol file) of *FileDir* is not intended to be freely available, but restricted to use by system programmers. This allows the export of certain sensitive data, (such as file headers) and sensitive procedures (such as *Enumerate*) without the danger of misuse by inadvertant users.

Module *Files* constitutes a most important interface whose stability is utterly essential, because it is used by almost every module programmed. During the entire time span of development of the Oberon system, this interface had changed only once. We also note that this interface is very terse, a factor contributing to its stability. Yet, the offered facilities have in practice over years proved to be both necessary and sufficient.

7.2 Implementation of Files on a Random-Access Store

A file cannot be allocated as a block of contiguous storage locations, because its length is not fixed. Neither can it be represented as a linked list of individual elements, because this would lead to inefficient use of storage - more might be used for the links than the elements themselves. The solution generally adopted is a compromise between the two extremes: files are represented as lists of blocks (subsequently called *sectors*) of fixed length. A block is appended when the last one is filled. On the average, each file therefore wastes half of a sector. Typical sector sizes are 0.5, 1, 2, or 4 Kbytes, depending on the device used as store.

It immediately follows that access to an element is not as simple as in the case of an array. The primary concern in the design of a file system and access scheme must be the efficiency of access to individual elements while scanning the sequence, at least in the case when the next element lies within the same sector. This access must be no more complicated than a comparison of two variables followed by an indexed access to the file element and the incrementing of an address pointing to the element's successor. If the successor lies in another sector, the procedure may be more involved, as transitions to the next sector occur much less frequently.

The second most crucial design decision concerns the data structure in which sectors are organized; it determines how a succeding sector is located. The simplest solution is to link sectors in a list. This is acceptable if access is to be restricted to purely sequential scans. Although this would be sufficient for most applications, it is unnecessarily restrictive for media other than purely sequential ones (tapes). After all, it is sometimes practical to position a rider at an arbitrary point in the file rather than always at its beginning. This is made possible by the use of an indexed sector table, typically stored as a header in the file. The table is an array of the addresses of the file's data sectors. Unfortunately, the length of the table needed is unknown. Choosing a fixed length for all files is controversial, because it inevitably leads to either a limitation of file length (when chosen too small) that is unacceptable in some applications, or to a large waste of file space (when chosen too large). Experience shows that in practice most files are quite short, i.e. in the order of a few thousand bytes. The dilemma is avoided by a two-level table, i.e. by using a table of tables.

The scheme chosen in Oberon is slightly more complex in order to favor short files (< 64 K bytes): Each file header contains a table of 64 entries, each pointing to a 1K byte sector. Additionally, it contains a table of 12 entries, the so-called extensions, each pointing to an index sector containing 256 further sector pointers. The file length is thereby limited to 64 + 12*256 sectors, or 3211264 bytes (minus the length of the header). The chosen structure is illustrated in Fig. 7.1. sec[0] always points to the sector containg the file header.

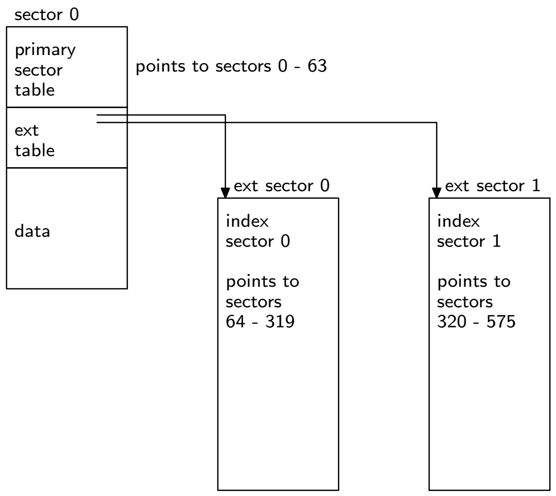

Fig. 7.1. File header and extension sectors

The header contains some additional data, namely the length of the file (in bytes), its name, and date and time of its creation. The size of the header is 352 bytes; the remaining 672 bytes of the first sector are used for data. Hence, truly short files occupy a single sector only. The declaration of the file header is contained in the definition of module *FileDir*. An abbreviated version containing the fields relevant so far is:

```
FileHeader = RECORD
    leng: LONGINT;
    ext: ARRAY 12 OF SectorPointer;
    sec: ARRAY 64 OF SectorPointer
END
```

We now turn our attention to the implementation of file access, and first present a system that uses main storage for the file data instead of a disk and therefore avoids the problems introduced by sector buffering. The key data structure in this connection is the *Rider*, represented as a record.

```
Rider = RECORD
    pos: LONGINT;
    file: File;
    adr: LONGINT
END
```

A rider is initialised by a call *Set(r, f, pos)*, which places the rider *r* on file *f* at position *pos*. From this it is clear that the rider record must contain fields denoting the attached file and the rider's position on it. We note that they are *not* exported. However, their values can be obtained by the function procedures *Pos(r)* and *Base(r)*. This allows a (hidden) representation most appropriate for an efficient implementation of *Read* and *Write* without being unsafe.

Consider now the call *Read(r, x)*; its task is to assign the value of the byte designated by the rider's position to *x* and to advance the position to the next byte. Considering the structure by which file data are represented, we easily obtain the following program, assuming that the position is legal, i.e. non-negative and less than the file's length. *a, b, c* are local variables, HS is the size of the header (in sector 0), SS is the sector size, typically a power of 2 in order to make division efficient.

```
a := (r.pos + HS) DIV SS;  b := (r.pos + HS) MOD SS;
IF a < 64 THEN c := r.file.sec[a]
ELSE c := r.file.ext[(a - 64) DIV 256].sec[(a - 64) MOD 256]
END ;
SYSTEM.GET(c + b, x) ; INC (r.pos)
```

In order to gain efficiency, we use the low-level procedure GET that assigns the value at address c+b to x. This program is reasonably short, but involves considerable address computations at *every* access, and in particular at positions larger than 64 * SS. Fortunately, there exists an easy remedy, namely that of caching the address of the current position. This explains the presence of the field *adr* in the rider record. The resulting program is shown below; note that in order to avoid the addition of HS, *pos* is defined to denote the genuine position, i.e. the abstract position augmented by HS.

```
SYSTEM.GET(r.adr, x); INC(r.adr); INC(r.pos);
IF r.pos MOD SS = 0 THEN
    m := r.pos DIV SS;
    IF m < 64 THEN r.adr := r.file.sec[m]
    ELSE r.adr := r.file.ext[(m - 64) DIV 256].sec[(m - 64) MOD 256]
    END
END
```

We emphasize that in all but one out of 1024 cases only three instructions and a single test are to be executed. This improvement therefore is crucial to the efficiency of file access, and to that of the entire Oberon System. We now present the entire file module.

```
MODULE MFiles;   (*NW 24.8.90 / 12.10.90*)
   IMPORT SYSTEM, Kernel, FileDir;

   (*A file consists of a sequence of sectors. The first sector contains the header.
     Part of the header is the sector table, an array of addresses to the sectors.
     A file is referenced through riders each of which indicates a position.*)

   CONST
     HS  = FileDir.HeaderSize;
     SS  = FileDir.SectorSize;
     STS= FileDir.SecTabSize;
     XS  = FileDir.IndexSize;

   TYPE File*   = POINTER TO Header;
     Index  = POINTER TO FileDir.IndexSector;

     Rider* =
       RECORD eof*: BOOLEAN;
         res*: LONGINT;
         file: File;
         pos: LONGINT;
         unused: File;
         adr: LONGINT;
       END ;

     Header =
       RECORD mark: LONGINT;
         name: FileDir.FileName;
         len, time, date: LONGINT;
         ext:  ARRAY FileDir.ExTabSize OF Index;
         sec: FileDir.SectorTable
       END ;

   PROCEDURE Old*(name: ARRAY OF CHAR): File;
     VAR head: LONGINT;
       namebuf: FileDir.FileName;
   BEGIN COPY(name, namebuf);
     FileDir.Search(namebuf, head); RETURN SYSTEM.VAL(File, head)
   END Old;

   PROCEDURE New*(name: ARRAY OF CHAR): File;
     VAR f: File; head: LONGINT;
```

```
BEGIN f := NIL; Kernel.AllocSector(0, head);
   IF head # 0 THEN
      f := SYSTEM.VAL(File, head); f.mark := FileDir.HeaderMark;
      f.len := HS; COPY(name, f.name);
      Kernel.GetClock(f.time, f.date); f.sec[0] := head
   END ;
   RETURN f
END New;

PROCEDURE Register*(f: File);
BEGIN
   IF (f # NIL) & (f.name[0] > 0X) THEN FileDir.Insert(f.name, f.sec[0]) END ;
END Register;

PROCEDURE Length*(f: File): LONGINT;
BEGIN RETURN f.len - HS
END Length;

PROCEDURE GetDate*(f: File; VAR t, d: LONGINT);
BEGIN t := f.time; d := f.date
END GetDate;

PROCEDURE Set*(VAR r: Rider; f: File; pos: LONGINT);
   VAR m: INTEGER; n: LONGINT;
BEGIN  r.eof := FALSE; r.res := 0; r.unused := NIL;
   IF f # NIL THEN
      IF pos < 0 THEN r.pos := HS
      ELSIF pos > f.len-HS THEN r.pos := f.len
      ELSE r.pos := pos+HS
      END ;
      r.file := f; m := SHORT(r.pos DIV SS); n := r.pos MOD SS;
      IF m < STS THEN r.adr := f.sec[m] + n
      ELSE r.adr := f.ext[(m-STS) DIV XS].x[(m-STS) MOD XS] + n
      END
   END
END Set;

PROCEDURE Read*(VAR r: Rider; VAR x: SYSTEM.BYTE);
   VAR m: INTEGER;
BEGIN
   IF r.pos < r.file.len THEN
      SYSTEM.GET(r.adr, x); INC(r.adr); INC(r.pos);
      IF r.adr MOD SS = 0 THEN
         m := SHORT(r.pos DIV SS);
         IF m < STS THEN r.adr := r.file.sec[m]
         ELSE r.adr := r.file.ext[(m-STS) DIV XS].x[(m-STS) MOD XS]
         END
      END
   ELSE x := 0X; r.eof := TRUE
   END
END Read;

PROCEDURE ReadBytes*(VAR r: Rider; VAR x: ARRAY OF SYSTEM.BYTE; n: LONGINT);
   VAR src, dst, m: LONGINT; k: INTEGER;
BEGIN m := r.pos - r.file.len + n;
   IF m > 0 THEN DEC(n, m); r.res := m; r.eof := TRUE END ;
   src := r.adr; dst := SYSTEM.ADR(x); m := (-r.pos) MOD SS;
   LOOP
      IF n <= 0 THEN EXIT END ;
      IF n <= m THEN SYSTEM.MOVE(src, dst, n); INC(r.pos, n); r.adr := src+n; EXIT END ;
      SYSTEM.MOVE(src, dst, m); INC(r.pos, m); INC(dst,m); DEC(n, m);
      k := SHORT(r.pos DIV SS); m := SS;
      IF k < STS THEN src := r.file.sec[k]
      ELSE src := r.file.ext[(k-STS) DIV XS].x[(k-STS) MOD XS]
      END
    END
  END ReadBytes;

  PROCEDURE Write*(VAR r: Rider; x: SYSTEM.BYTE);
    VAR k, m, n: INTEGER; ix: LONGINT;
  BEGIN
    IF r.pos < r.file.len THEN
      m := SHORT(r.pos DIV SS); INC(r.pos);
      IF m < STS THEN r.adr := r.file.sec[m]
      ELSE r.adr := r.file.ext[(m-STS) DIV XS].x[(m-STS) MOD XS]
      END
    ELSE
      IF r.adr MOD SS = 0 THEN
        m := SHORT(r.pos DIV SS);
        IF m < STS THEN Kernel.AllocSector(0, r.adr); r.file.sec[m] := r.adr
        ELSE n := (m-STS) DIV XS; k := (m-STS) MOD XS;
              IF k = 0 THEN (*new index*)
                      Kernel.AllocSector(0, ix); r.file.ext[n] := SYSTEM.VAL(Index, ix)
              END ;
              Kernel.AllocSector(0, r.adr); r.file.ext[n].x[k] := r.adr
        END
      END ;
      INC(r.pos); r.file.len := r.pos
    END ;
    SYSTEM.PUT(r.adr, x); INC(r.adr)
  END Write;

  PROCEDURE WriteBytes*(VAR r: Rider;
      VAR x: ARRAY OF SYSTEM.BYTE; n: LONGINT);
    VAR src, dst, m, ix: LONGINT;
      k, lim, h0, h1: INTEGER;
  BEGIN src := SYSTEM.ADR(x); dst := r.adr; m := (-r.pos) MOD SS;
    lim := SHORT(r.file.len DIV SS);
    LOOP
      IF n <= 0 THEN EXIT END ;
      IF m = 0 THEN
        k := SHORT(r.pos DIV SS); m := SS;
        IF k > lim THEN
          Kernel.AllocSector(0, dst);
          IF k < STS THEN r.file.sec[k] := dst
          ELSE h1 := (k-STS) DIV XS; h0 := (k-STS) MOD XS;
            IF h0 = 0 THEN (*new extension index*)
              Kernel.AllocSector(0, ix); r.file.ext[h1] := SYSTEM.VAL(Index, ix)
            END ;
            r.file.ext[h1].x[h0] := dst
          END
        ELSIF k < STS THEN dst := r.file.sec[k]
        ELSE dst := r.file.ext[(k-STS) DIV XS].x[(k-STS) MOD XS]
        END ;
      END ;
      IF n < m THEN
```

```
        SYSTEM.MOVE(src, dst, n); INC(r.pos, n); r.adr := dst + n;
        IF r.pos >= r.file.len THEN r.file.len := r.pos END ;
        EXIT
      END ;
      SYSTEM.MOVE(src, dst, m); INC(r.pos, m);
      IF r.pos >= r.file.len THEN r.file.len := r.pos END ;
      INC(src, m); DEC(n, m); m := 0
    END
  END WriteBytes;

  PROCEDURE Pos*(VAR r: Rider): LONGINT;
  BEGIN RETURN r.pos - HS
  END Pos;

  PROCEDURE Base*(VAR r: Rider): File;
  BEGIN RETURN r.file
  END Base;

END MFiles.
```

Allocation of a new sector occurs upon creating a file (*Files.New*), and when writing at the end of a file after the current sector had been filled. Procedure *AllocSector* yields the address of the allocated sector. It is determined by a search in the sector reservation table for a free sector. In this table, every sector is represented by a single bit indicating whether or not the sector is allocated. Although conceptually belonging to the file system, this table resides within module *Kernel*, because for safety reasons it is write-protected in user mode.

Deallocation of a file's sectors could occur as soon as the file is no longer accessible, neither through a variable of any loaded module nor from the file directory. However, this moment is difficult to determine. Therefore, the method of garbage collection is used in Oberon for the deallocation of file space. In consideration of the fact that file space is large and sector garbage collection relatively time-consuming, we confine this process to system initialization. It is represented by procedure *FileDir.Init*. At that time, the only referenced files are those registered in the directory. *Init* therefore scans the entire directory and records the sectors referenced in each file in the sector reservation table (see Sect. 7.4).

For applications where system initialization is supposed to occur very infrequently, such as for server systems, a procedure *Files.Purge* is provided. Its effect is to return the sectors used by the specified file to the pool of free sectors. Evidently, the programmer then bears the responsibility to guarantee that no references to the purged file continue to exist. This may be possible in a closed server system, but files should not be purged under normal circumstances, as a violation of said precondition will lead to unpredictable disaster.

The following procedures used for allocating, deallocating, and marking sectors in the sector reservation table are defined in module Kernel:

```
PROCEDURE AllocSector(hint: LONGINT; VAR sec: LONGINT);   (*used in Write*)
PROCEDURE MarkSector(sec: LONGINT);  (*used in Init*)
PROCEDURE FreeSector(sec: LONGINT);  (*used in Purge*)
```

Procedure *ReadBytes* and *WriteBytes* are provided for fast transfer of sequences of bytes. The increased speed is obtained through the use of block move instructions. In the case of *ReadBytes*, the result field r.res indicates the number of bytes requested but not delivered. It is greater than zero only if the end of the file had been reached; *r.res* > 0 implies r.eof. A measure of the gain in speed is indicated by the following data. A file of 32K bytes read sequentially by (32000 calls of) *Read(r, ch)* takes about 0,25 s (on Ceres-3 using RAM for "disk"-sectors). The same file read in blocks of 1K bytes using *ReadBytes(r, block, 1024)* takes only about 0.013 s. This amounts to a speedup factor of 18, which is very significant.

7.3 Implementation of Files on a Disk

First we recall that the organization of files as sets of individually allocated blocks (sectors) is inherently required by the allocation considerations of dynamically growing sequences. However, if the storage medium is a tape or a disk, there exists an additional reason for the use of blocks. They constitute the subsequences to be individually buffered for transmission in order to overcome the timing constraints imposed by the medium. If an adequate space utilization is to be achieved, the blocks must not be too long. A typical size is 1, 2, or 4K bytes.

This necessity of buffering has a profound influence on the implementation of file access. The complication arises because the abstraction of the sequence of individual bytes needs to be maintained. The increase in complexity of file access is considerable, as can be seen by comparing the program listings of the two respective implementations.

The first, obvious measure is to copy the file's sector table into primary store when a file is "opened" through a call of *New()* or *Old()*. The record holding this copy is the file descriptor (called *handle*), and the value f denoting the file points to this handle (instead of the actual header on disk). The descriptor also contains the remaining information stored in the header, in particular the file's length.

If a file is read (or written) in purely sequential manner, a single buffer is appropriate for the transfer of data. For reading, the buffer is filled by reading a sector from the disk, and bytes are picked up individually from the buffer. For writing, bytes are deposited individually, and the buffer is written onto disk as a whole when full. The buffer is associated with the file, and a pointer to it is contained in the descriptor.

However, we recall that several riders may be placed on a file and be moved independently. It might be appealing to associate a buffer with each rider. But this proposal must quickly be rejected when we realize that several riders may be active at neighbouring positions. If these positions refer to the same sector, which is duplicated in the riders' distinct buffers, the buffers may easily become inconsistent. Obviously, buffers must not be associated with riders, but with the file itself. The descriptor therefore contains the head of a list of linked buffers. Each buffer is identified by its position in the file. An invariant of the system is that no two buffers represent the same sector.

Even with the presence of a single rider, the possibility of having several buffers associated with a file can be advantageous, if a rider is frequently repositioned. It becomes a question of strategy and heuristics when to allocate a new buffer. In the Oberon system, we have adopted the following solution:

1. The first buffer is created when the file is opened (New, Old).
2. Additional buffers may be allocated when a rider is placed (or repositioned) on the file.
3. At most four buffers are connected to the same file.
4. Purely sequential movements of riders do not cause allocation of buffers.
5. Separate buffers are generated when extensions of the file's sector table need be accessed (rider position > 64K). Each buffers the 256 sector addresses of the respective index sector.

The outlined scheme requires and is based upon the following data structures and types:

```
File =      POINTER TO Handle;
Buffer =    POINTER TO BufferRecord;
Index =     POINTER TO IndexRecord;

Handle =    RECORD next: File;
                aleng, bleng: INTEGER;        (*file length*)
                nofbufs: INTEGER;  (*no. of buffers allocated*)
                modH: BOOLEAN;  (*header has been modified*)
                firstbuf:Buffer:         (*head of buffer chain*)
                sechint: DiskAdr;      (*sector hint*)
                name: FileDir.FileName;
                time, date: LONGINT;
                ext: ARRAY FileDir.ExTabSize OF Index;
```

```
                    sec: ARRAY 64 OF DiskAdr
                END;

    BufferRecord =      RECORD apos, lim: INTEGER;    (*lim = no. of bytes*)
                    mod: BOOLEAN;     (*buffer has been modified*)
                    next: Buffer;(*buffer chain*)
                    data: FileDir.DataSector
                END;

    IndexRecord = RECORD adr: DiskAdr;
                    mod: BOOLEAN;     (*index record has been modified*)
                    sec: FileDir.IndexSector
                END;

    Rider =     RECORD eof: BOOLEAN;          (*end of file reached*)
                    res: LONGINT;        (*no. of unread bytes*)
                    file: File;
                    apos, bpos: INTEGER;          (*position*)
                    buf: Buffer   (*hint: likely buffer*)
                END ;
```

In order to increase efficiency of access, riders have been provided with a field containing the address of the element of the rider's position. From the conditions stated above for the allocation of buffers, it is evident that the value of this field can be a hint only. This implies that there can be no reliance on its information. Whenever it is used, its validity has to be checked. The check consists in a comparison of the riders' position *r.apos* with the hinted buffer's actual position *r.buf.apos*. If they differ, a buffer with the desired position must be searched and, if not present, allocated. The advantage of the hint lies in the fact that the hint is correct with a very high probability. The check is included in procedures *Read*, *ReadBytes, Write, and WriteBytes.*

Some fields of the record types require additional explanations:

1. The length is stored in a "preprocessed" form, namely by the two integers *aleng* and *bleng* such that aleng is a sector number and

```
    length    = (aleng * SS) + bleng - HS
    aleng     = (length + HS) DIV SS
    bleng     = (length + HS) MOD SS
```

The same holds for the form of the position in riders (apos, bpos).

2. The field *nofbufs* indicates the number of buffers in the list headed by *firstbuf*:

    1 <= nofbufs <= Maxbufs.

3. Whenever data are written into a buffer, the file becomes inconsistent, i.e. the data on the disk are outdated. The file is updated, i.e. the buffer is copied into the corresponding disk sector, whenever the buffer is reallocated, e.g. during sequential writing after the buffer is full and is "advanced". During sequential reading, a buffer is also advanced and reused, but needs not be copied onto disk, because it is still consistent. Whether a buffer is consistent or not is indicated by its state variable *mod* (modified). Similarly, the field *modH* in the file descriptor indicates whether or not the header had been modified.

4. The field *sechint* records the number of the last sector allocated to the file and serves as a hint to the kernel's allocation procedure, which allocates a next sector with an address larger than the hint. This is a measure to gain speed in sequential scans.

5. The buffer's position is specified by its field *apos*. Used as index in the file header's sector table, it yields the sector corresponding to the current buffer contents. The field *lim* specifies the number of bytes s stored in the buffer. Reading cannot proceed beyond this limiting index; writing beyond it implies an increase in the file's length. All buffers except the one for the last sector are filled and specify lim = SS.

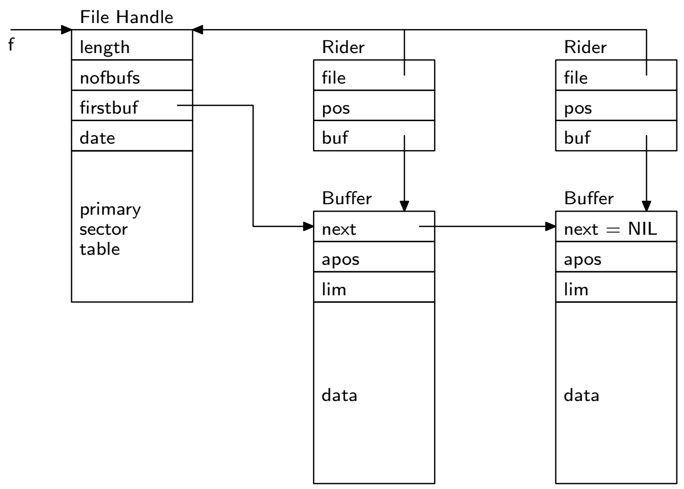

Fig. 7.2. File f with two riders and two buffers

6. The hidden rider field *buf* is merely a hint to speed up localization of the concerned buffer. A hint is likely, but not guaranteed to be correct. Its validity must be checked before use. The buffer hint is invalidated when a buffer is reallocated and/or a rider is repositioned.

The structure of riders remains practically the same as for files using main store. The hidden field *adr* is merely replaced by a pointer to the buffer covering the rider's position. A configuration of a file *f* with two riders is shown in Fig 7.2.

```
MODULE Files;  (*NW 11.1.86 / 22.1.91*)
  IMPORT SYSTEM, Kernel, FileDir;

  (*A file consists of a sequence of pages. The first page contains the header.
    Part of the header is the page table, an array of disk addresses to the pages.
    A file is referenced through riders each of which indicate a position.*)

CONST MaxBufs  = 4;
    HS = FileDir.HeaderSize;
    SS  = FileDir.SectorSize;
    STS = FileDir.SecTabSize;
    XS = FileDir.IndexSize;

  TYPE  DiskAdr = LONGINT;
    File*   = POINTER TO Handle;
    Buffer   = POINTER TO BufferRecord;
    FileHd  = POINTER TO FileDir.FileHeader;
    Index  = POINTER TO IndexRecord;

    Rider* =
      RECORD eof*: BOOLEAN;
        res*: LONGINT;
        file: File;
        apos, bpos: INTEGER;
        buf: Buffer;
        unused: LONGINT
      END ;

    Handle =
      RECORD next: File;
        aleng, bleng: INTEGER;
        nofbufs: INTEGER;
        modH: BOOLEAN;
        firstbuf: Buffer;
        sechint: DiskAdr;
        name: FileDir.FileName;
        time, date: LONGINT;
        unused: ARRAY 1 OF LONGINT;
        ext:  ARRAY FileDir.ExTabSize OF Index;
        sec: FileDir.SectorTable
      END ;

    BufferRecord =
      RECORD apos, lim: INTEGER;
        mod: BOOLEAN;
        next: Buffer;
        data: FileDir.DataSector
      END ;

    IndexRecord =
      RECORD adr: DiskAdr;
        mod: BOOLEAN;
        sec: FileDir.IndexSector
      END ;

    (*aleng * SS + bleng = length (including header)
      apos * SS + bpos = current position
      0 <= bpos <= lim <= SS
      0 <= apos <= aleng < PgTabSize
      (apos < aleng) & (lim = SS) OR (apos = aleng) *)

  VAR root: File;  (*list of open files*)

  PROCEDURE Check(VAR s: ARRAY OF CHAR;
        VAR name: FileDir.FileName; VAR res: INTEGER);
    VAR i: INTEGER; ch: CHAR;
  BEGIN ch := s[0]; i := 0;
    IF ("A" <= CAP(ch)) & (CAP(ch) <= "Z") THEN
      LOOP name[i] := ch; INC(i); ch := s[i];
        IF ch = 0X THEN
              WHILE i < FileDir.FnLength DO name[i] := 0X; INC(i) END ;
              res := 0; EXIT
        END ;
        IF ~(("A" <= CAP(ch)) & (CAP(ch) <= "Z")
              OR ("0" <= ch) & (ch <= "9") OR (ch = ".")) THEN res := 3; EXIT
        END ;
        IF i = FileDir.FnLength THEN res := 4; EXIT END ;
      END
    ELSIF ch = 0X THEN name[0] := 0X; res := -1
    ELSE res := 3
    END
  END Check;

  PROCEDURE Old*(name: ARRAY OF CHAR): File;
    VAR i, k, res: INTEGER;
      f: File;
      header: DiskAdr;
      buf: Buffer;
      head: FileHd;
      namebuf: FileDir.FileName;
      inxpg: Index;
  BEGIN f := NIL; Check(name, namebuf, res);
    IF res = 0 THEN
```

```
        FileDir.Search(namebuf, header);
        IF header # 0 THEN f := root;
          WHILE (f # NIL) & (f.sec[0] # header) DO f := f.next END ;
          IF f = NIL THEN
                NEW(buf); buf.apos := 0; buf.next := buf; buf.mod := FALSE;
                head := SYSTEM.VAL(FileHd, SYSTEM.ADR(buf.data));
                Kernel.GetSector(header, head^);
                NEW(f); f.aleng := head.aleng; f.bleng := head.bleng;
                f.time := head.time; f.date := head.date;
                IF f.aleng = 0 THEN buf.lim := f.bleng ELSE buf.lim := SS END ;
                f.firstbuf := buf; f.nofbufs := 1; f.name[0] := 0X;
                f.sec := head.sec;
                k := (f.aleng + (XS-STS)) DIV XS; i := 0;
                WHILE i < k DO
                        NEW(inxpg); inxpg.adr := head.ext[i]; inxpg.mod := FALSE;
                        Kernel.GetSector(inxpg.adr, inxpg.sec); f.ext[i] := inxpg; INC(i)
                END ;
                WHILE i < FileDir.ExTabSize DO f.ext[i] := NIL; INC(i) END ;
                f.sechint := header; f.modH := FALSE; f.next := root; root := f
          END
        END
    END ;
    RETURN f
END Old;

PROCEDURE New*(name: ARRAY OF CHAR): File;
    VAR i, res: INTEGER;
        f: File;
        header: DiskAdr;
        buf: Buffer;
        head: FileHd;
        namebuf: FileDir.FileName;
BEGIN f := NIL; Check(name, namebuf, res);
    IF res <= 0 THEN
        NEW(buf); buf.apos := 0; buf.mod := FALSE; buf.lim := HS; buf.next := buf;
        head := SYSTEM.VAL(FileHd, SYSTEM.ADR(buf.data));
        head.mark := FileDir.HeaderMark;
        head.aleng := 0; head.bleng := HS; head.name := namebuf;
        Kernel.GetClock(head.time, head.date);
        NEW(f); f.aleng := 0; f.bleng := HS; f.modH := TRUE;
        f.time := head.time; f.date := head.date;
        f.firstbuf := buf; f.nofbufs := 1; f.name := namebuf; f.sechint := 0;
        i := 0;
        REPEAT f.ext[i] := NIL; head.ext[i] := 0; INC(i) UNTIL i = FileDir.ExTabSize;
        i := 0;
        REPEAT f.sec[i] := 0; head.sec[i] := 0; INC(i) UNTIL i = STS
    END ;
    RETURN f
END New;

PROCEDURE UpdateHeader(f: File; VAR h: FileDir.FileHeader);
    VAR k: INTEGER;
BEGIN h.aleng := f.aleng; h.bleng := f.bleng;
    h.sec := f.sec; k := (f.aleng + (XS-STS)) DIV XS;
    WHILE k > 0 DO DEC(k); h.ext[k] := f.ext[k].adr END
END UpdateHeader;
PROCEDURE ReadBuf(f: File; buf: Buffer; pos: INTEGER);
```

```
   VAR sec: DiskAdr;
BEGIN
   IF pos < STS THEN sec := f.sec[pos]
   ELSE sec := f.ext[(pos-STS) DIV XS].sec.x[(pos-STS) MOD XS]
   END ;
   Kernel.GetSector(sec, buf.data);
   IF pos < f.aleng THEN buf.lim := SS ELSE buf.lim := f.bleng END ;
   buf.apos := pos; buf.mod := FALSE
END ReadBuf;

PROCEDURE WriteBuf(f: File; buf: Buffer);
   VAR i, k: INTEGER;
      secadr: DiskAdr; inx: Index;
BEGIN
   IF buf.apos < STS THEN
      secadr := f.sec[buf.apos];
      IF secadr = 0 THEN
         Kernel.AllocSector(f.sechint, secadr);
         f.modH := TRUE; f.sec[buf.apos] := secadr; f.sechint := secadr
      END ;
      IF buf.apos = 0 THEN
         UpdateHeader(f, SYSTEM.VAL(FileDir.FileHeader, buf.data)); f.modH := FALSE
      END
   ELSE i := (buf.apos - STS) DIV XS; inx := f.ext[i];
      IF inx = NIL THEN
         NEW(inx); inx.adr := 0; inx.sec.x[0] := 0; f.ext[i] := inx; f.modH := TRUE
      END ;
      k := (buf.apos - STS) MOD XS; secadr := inx.sec.x[k];
      IF secadr = 0 THEN
         Kernel.AllocSector(f.sechint, secadr);
         f.modH := TRUE; inx.mod := TRUE; inx.sec.x[k] := secadr; f.sechint := secadr
      END
   END ;
   Kernel.PutSector(secadr, buf.data); buf.mod := FALSE
END WriteBuf;

PROCEDURE Buf(f: File; pos: INTEGER): Buffer;
   VAR buf: Buffer;
BEGIN buf := f.firstbuf;
   LOOP
      IF buf.apos = pos THEN EXIT END ;
      buf := buf.next;
      IF buf = f.firstbuf THEN buf := NIL; EXIT END
   END ;
   RETURN buf
END Buf;

PROCEDURE GetBuf(f: File; pos: INTEGER): Buffer;
   VAR buf: Buffer;
BEGIN buf := f.firstbuf;
   LOOP
      IF buf.apos = pos THEN EXIT END ;
      IF buf.next = f.firstbuf THEN
         IF f.nofbufs < MaxBufs THEN (*allocate new buffer*)
               NEW(buf); buf.next := f.firstbuf.next; f.firstbuf.next := buf;
               INC(f.nofbufs)
         ELSE (*take one of the buffers*) f.firstbuf := buf;
```

```
            IF buf.mod THEN WriteBuf(f, buf) END
        END ;
        buf.apos := pos;
        IF pos <= f.aleng THEN ReadBuf(f, buf, pos) END ;
        EXIT
      END ;
      buf := buf.next
    END ;
    RETURN buf
END GetBuf;

PROCEDURE Unbuffer(f: File);
  VAR i, k: INTEGER;
    buf: Buffer;
    inx: Index;
    head: FileDir.FileHeader;
BEGIN buf := f.firstbuf;
  REPEAT
    IF buf.mod THEN WriteBuf(f, buf) END ;
    buf := buf.next
  UNTIL buf = f.firstbuf;
  k := (f.aleng + (XS-STS)) DIV XS; i := 0;
  WHILE i < k DO
    inx := f.ext[i]; INC(i);
    IF inx.mod THEN
      IF inx.adr = 0 THEN
            Kernel.AllocSector(f.sechint, inx.adr); f.sechint := inx.adr; f.modH := TRUE
      END ;
      Kernel.PutSector(inx.adr, inx.sec); inx.mod := FALSE
    END
  END ;
  IF f.modH THEN
    IF f.sec[0] = 0 THEN Kernel.AllocSector(0, f.sec[0]) END ;
    Kernel.GetSector(f.sec[0], head); UpdateHeader(f, head);
    Kernel.PutSector(f.sec[0], head); f.modH := FALSE
  END
END Unbuffer;

PROCEDURE Register*(f: File);
BEGIN
  IF (f # NIL) & (f.name[0] > 0X) THEN
    Unbuffer(f); FileDir.Insert(f.name, f.sec[0]); f.next := root; root := f
  END ;
END Register;

PROCEDURE Close*(f: File);
BEGIN
  IF f # NIL THEN Unbuffer(f) END ;
END Close;

PROCEDURE Purge*(f: File);
  VAR a, i, j, k: INTEGER;
    ind: FileDir.IndexSector;
BEGIN
  IF f # NIL THEN a := f.aleng + 1; f.aleng := 0;
    IF a <= STS THEN i := a
    ELSE i := STS; DEC(a, i);
      j := (a-1) MOD XS; k := (a-1) DIV XS;
      WHILE k >= 0 DO
            Kernel.GetSector(f.ext[k].adr, ind);
            REPEAT DEC(j); Kernel.FreeSector(ind.x[j])
            UNTIL j = 0;
            Kernel.FreeSector(f.ext[k].adr); j := XS; DEC(k)
      END
    END ;
    REPEAT DEC(i); Kernel.FreeSector(f.sec[i])
    UNTIL i = 0
  END
END Purge;

PROCEDURE Length*(f: File): LONGINT;
BEGIN RETURN LONG(f.aleng)*SS + f.bleng - HS
END Length;

PROCEDURE GetDate*(f: File; VAR t, d: LONGINT);
BEGIN t := f.time; d := f.date
END GetDate;

PROCEDURE Set*(VAR r: Rider; f: File; pos: LONGINT);
  VAR a, b: INTEGER;
BEGIN  r.eof := FALSE; r.res := 0;
  IF f # NIL THEN
    IF pos < 0 THEN a := 0; b := HS
    ELSIF pos < LONG(f.aleng)*SS + f.bleng - HS THEN
      a := SHORT((pos + HS) DIV SS); b := SHORT((pos + HS) MOD SS);
    ELSE a := f.aleng; b := f.bleng
    END ;
    r.file := f; r.apos := a; r.bpos := b; r.buf := f.firstbuf
  ELSE r.file:= NIL
  END
END Set;

PROCEDURE Read*(VAR r: Rider; VAR x: SYSTEM.BYTE);
  VAR buf: Buffer;
BEGIN
  IF r.apos # r.buf.apos THEN r.buf := GetBuf(r.file, r.apos) END ;
  IF r.bpos < r.buf.lim THEN
    x := r.buf.data.B[r.bpos]; INC(r.bpos)
  ELSIF r.apos < r.file.aleng THEN
    INC(r.apos); buf := Buf(r.file, r.apos);
    IF buf = NIL THEN
      IF r.buf.mod THEN WriteBuf(r.file, r.buf) END ;
      ReadBuf(r.file, r.buf, r.apos)
    ELSE r.buf := buf
    END ;
    x := r.buf.data.B[0]; r.bpos := 1
  ELSE
    x := 0X; r.eof := TRUE
  END
END Read;

PROCEDURE ReadBytes*(VAR r: Rider; VAR x: ARRAY OF SYSTEM.BYTE; n: LONGINT);
  VAR src, dst, m: LONGINT; buf: Buffer;
BEGIN dst := SYSTEM.ADR(x);
  IF LEN(x) < n THEN HALT(25) END ;
  IF r.apos # r.buf.apos THEN r.buf := GetBuf(r.file, r.apos) END ;
  LOOP
    IF n <= 0 THEN EXIT END ;
    src := SYSTEM.ADR(r.buf.data.B) + r.bpos; m := r.bpos + n;
    IF m <= r.buf.lim THEN
      SYSTEM.MOVE(src, dst, n); r.bpos := SHORT(m); r.res := 0; EXIT
    ELSIF r.buf.lim = SS THEN
      m := r.buf.lim - r.bpos;
      IF m > 0 THEN SYSTEM.MOVE(src, dst, m); INC(dst, m); DEC(n, m) END ;
      IF r.apos < r.file.aleng THEN
            INC(r.apos); r.bpos := 0; buf := Buf(r.file, r.apos);
            IF buf = NIL THEN
                    IF r.buf.mod THEN WriteBuf(r.file, r.buf) END ;
                    ReadBuf(r.file, r.buf, r.apos)
            ELSE r.buf := buf
            END
      ELSE r.res := n; r.eof := TRUE; EXIT
      END
    ELSE m := r.buf.lim - r.bpos;
      IF m > 0 THEN SYSTEM.MOVE(src, dst, m); r.bpos := r.buf.lim END ;
      r.res := n - m; r.eof := TRUE; EXIT
    END
  END
END ReadBytes;

PROCEDURE NewExt(f: File);
  VAR i, k: INTEGER; ext: Index;
BEGIN k := (f.aleng - STS) DIV XS;
  IF k = FileDir.ExTabSize THEN HALT(23) END ;
  NEW(ext); ext.adr := 0; ext.mod := TRUE; f.ext[k] := ext; i := XS;
  REPEAT DEC(i); ext.sec.x[i] := 0 UNTIL i = 0
END NewExt;

PROCEDURE Write*(VAR r: Rider; x: SYSTEM.BYTE);
  VAR f: File; buf: Buffer;
BEGIN
  IF r.apos # r.buf.apos THEN r.buf := GetBuf(r.file, r.apos) END ;
  IF r.bpos >= r.buf.lim THEN
    IF r.bpos < SS THEN
      INC(r.buf.lim); INC(r.file.bleng); r.file.modH := TRUE
    ELSE f := r.file; WriteBuf(f, r.buf); INC(r.apos); buf := Buf(r.file, r.apos);
      IF buf = NIL THEN
        IF r.apos <= f.aleng THEN ReadBuf(f, r.buf, r.apos)
        ELSE r.buf.apos := r.apos; r.buf.lim := 1; INC(f.aleng); f.bleng := 1; f.modH := TRUE;
          IF (f.aleng - STS) MOD XS = 0 THEN NewExt(f) END
        END
      ELSE r.buf := buf
      END ;
      r.bpos := 0
    END
  END ;
  r.buf.data.B[r.bpos] := x; INC(r.bpos); r.buf.mod := TRUE
END Write;

PROCEDURE WriteBytes*(VAR r: Rider; VAR x: ARRAY OF SYSTEM.BYTE;
    n: LONGINT);
  VAR src, dst, m: LONGINT; f: File; buf: Buffer;
BEGIN src := SYSTEM.ADR(x);
```

```
  IF LEN(x) < n THEN HALT(25) END ;
  IF r.apos # r.buf.apos THEN r.buf := GetBuf(r.file, r.apos) END ;
  LOOP
    IF n <= 0 THEN EXIT END ;
    r.buf.mod := TRUE; dst := SYSTEM.ADR(r.buf.data.B) + r.bpos; m := r.bpos + n;
    IF m <= r.buf.lim THEN
      SYSTEM.MOVE(src, dst, n); r.bpos := SHORT(m); EXIT
    ELSIF m <= SS THEN
      SYSTEM.MOVE(src, dst, n); r.bpos := SHORT(m);
      r.file.bleng := SHORT(m); r.buf.lim := SHORT(m); r.file.modH := TRUE; EXIT
    ELSE m := SS - r.bpos;
      IF m > 0 THEN SYSTEM.MOVE(src, dst, m); INC(src, m); DEC(n, m) END ;
      f := r.file; WriteBuf(f, r.buf); INC(r.apos); r.bpos := 0; buf := Buf(f, r.apos);
      IF buf = NIL THEN
        IF r.apos <= f.aleng THEN ReadBuf(f, r.buf, r.apos)
        ELSE r.buf.apos := r.apos; r.buf.lim := 0; INC(f.aleng); f.bleng := 0; f.modH := TRUE;
          IF (f.aleng - STS) MOD XS = 0 THEN NewExt(f) END
        END
      ELSE r.buf := buf
      END
    END
  END
END WriteBytes;

PROCEDURE Pos*(VAR r: Rider): LONGINT;
BEGIN RETURN LONG(r.apos)*SS + r.bpos - HS
END Pos;

PROCEDURE Base*(VAR r: Rider): File;
BEGIN RETURN r.file
END Base;

PROCEDURE Delete*(name: ARRAY OF CHAR; VAR res: INTEGER);
  VAR adr: DiskAdr;
      namebuf: FileDir.FileName;
BEGIN Check(name, namebuf, res);
  IF res = 0 THEN
    FileDir.Delete(namebuf, adr);
    IF adr = 0 THEN res := 2 END
  END
END Delete;

PROCEDURE Rename*(old, new: ARRAY OF CHAR; VAR res: INTEGER);
  VAR adr: DiskAdr;
      oldbuf, newbuf: FileDir.FileName;
      head: FileDir.FileHeader;
BEGIN Check(old, oldbuf, res);
  IF res = 0 THEN
    Check(new, newbuf, res);
    IF res = 0 THEN
      FileDir.Delete(oldbuf, adr);
      IF adr # 0 THEN
        FileDir.Insert(newbuf, adr);
        Kernel.GetSector(adr, head); head.name := newbuf; Kernel.PutSector(adr, head)
      ELSE res := 2
      END
    END
```

```
      END
    END Rename;

  BEGIN Kernel.FileRoot := SYSTEM.ADR(root)
  END Files.
```

Some comments concerning module Files follow.

1. After the writing of a file has been completed, its name is usually registered in the directory. *Register* invokes procedure *Unbuffer*. It inspects the associated buffers and copies those onto disk which had been modified. During this process, new index sectors may have to be transferred as well. If a file is to remain anonymous and local to a module or command, i.e. is not to be registered, but merely to be read, the release of buffers must be specified by an explicit call to *Close* (meaning "close buffers"), which also invokes *Unbuffer*.

2. Procedure *Old* (and for reasons of consistency also *New*) deviates from the general Oberon programming rule that an object be allocated by the calling (instead of the called) module. This rule would suggest the statements

```
      New(f); Files.Open(f, name)
```

instead of *f := Files.Old(name)*. The justification for the rule is that any extension of the type of *f* could be allocated, providing for more flexibility. And the reason for our deviation in the case of files is that, upon closer inspection, not a new file, but only a new descriptor is to be allocated. The distinction becomes evident when we consider that several statements *f := Files.Old(name)* with different *f* and identical name may occur, probably in different modules. In this case, it is necessary that the *same* descriptor is referenced by the delivered pointers in order to avoid file inconsistency. Each (opened) file must have exactly one descriptor. When a file is opened, the first action is therefore to inspect whether a descriptor of this file already exists. For this purpose, all descriptors are linked together in a list anchored by the global variable root and linked by the descriptor field *next*. This measure may seem to solve the problem of avoiding inconsistencies smoothly. However, there exists a pitfall that is easily overlooked: all opened files would permanently remain accessible via *root*, and the garbage collector could never remove a file descriptor nor its associated buffers. This would be unacceptable. We have found no better solution to this problem than to design the garbage collector such that it excludes this list from its mark phase.

3. Sector pointers are represented by sector numbers of type LONGINT. Actually, we use the numbers multiplied by 29. This implies that any single-bit error leads to a number which is not a multiple of 29, and hence can easily be detected. Thereby the crucial sector addresses are software parity checked and are safe (against single-bit errors) even on computers without hardware parity check. The check is performed by procedures *Kernel.GetSector* and *Kernel.PutSector*.

7.4 The File Directory

A directory is a set of pairs, each pair consisting of a name (key) and an object (here: file). It serves to retrieve objects by their name. If efficiency matters, the directory is organized as an ordered set, ordered according to the keys. The most frequently used structures for ordered sets are trees and hash tables. The latter have disadvantages when the size of the set is unknown, particularly when its order of magnitude is unknown, and when deletions occur. The Oberon system therefore uses a tree structure for its file directory, more specifically a B-tree, which was developed especially for cases where not individual pairs, but only sets of pairs as a whole (placed on a disk sector) can be accessed.

For a thorough study of B-trees we refer the reader to the literature [1, 2]. Here it must suffice to specify the B-tree's principal characteristics:

1. In a B-tree of order N, each node (called *page*) contains m elements (pairs), where N <= m <= 2N, except the root, where 0 <= m <= 2N.
2. A page with m elements has either 0 descendants, in which case it is called a *leaf page*, or m + 1 descendants.
3. All leaf pages are on the same (bottom) level.

From 3. it follows that the B-tree is a balanced tree. Its height, and with it the longest path's length, has an upper bound of, roughly, 2 * log k, where k is the number of elements and the logarithm is taken to the base N and rounded up to the next larger integer. Its minimal height is log k taken to the base 2N.

On each page, space must be available for 2N elements and for 2N + 1 references to descendants. Hence, N is immediately determined by the size of a page and the size of elements. In the case of the Oberon system, names are limited to 32 characters (bytes), and the object is a reference to the associated file (4 bytes). Each descendant pointer takes 4 bytes, and the page size is given by the sector size (1024) minus the number of bytes needed to store m (2 bytes). Hence

N = ((1024 - 2 - 4) DIV (32 + 4 + 4)) DIV 2 = 12

A B-tree of height h and order 12 may contain the following minimal and maximal number of elements:

height	minimum	maximum
1	0	24
2	25	624
3	625	15624
4	15625	390624

It follows that the height of the B-tree will never be larger than 4, if the disk has a capacity of less than about 400 Mbyte, and assuming that each file occupies a single 1K sector. It is rarely larger than 3 in practice.

The definition of module *FileDir* shows the available directory operations. Apart from the procedures *Search, Insert, Delete*, and *Enumerate*, it contains some data definitions, and it should be considered as the non-public part of the file system's interface.

```
DEFINITION FileDir;
    IMPORT SYSTEM, Kernel;
    CONST
        FnLength = 32;      (*max length of file name*)
        SecTabSize = 64;    (*no. of entries in primary table*)
        ExTabSize = 12;
        SectorSize = 1024;
        IndexSize = SectorSize DIV 4;         (*no. of entries in index sector*)
        HeaderSize = 352;
        DirRootAdr = 29;
        DirPgSize = 24;     (*max no. of elements on page*)

    TYPE
        FileName = ARRAY FnLength OF CHAR;
        SectorTable = ARRAY SecTabSize OF LONGINT;
        ExtensionTable = ARRAY ExTabSize OF LONGINT;
        EntryHandler = PROCEDURE (name: FileName; sec: LONGINT; VAR continue: BOOLEAN);

        FileHeader = RECORD (Kernel.Sector)
                mark: LONGINT;
                name: FileName;
                aleng, bleng: INTEGER;
                date, time: LONGINT;
                ext: ExtensionTable;
                sec: SectorTable;
            END ;

        IndexSector = RECORD (Kernel.Sector)
                x: ARRAY IndexSize OF LONGINT;
            END ;
        DataSector = RECORD (Kernel.Sector)
            B: ARRAY SectorSize OF SYSTEM.BYTE;
          END ;

        DirEntry = RECORD
            name: FileName;
            adr, p: LONGINT;
          END ;

        DirPage = RECORD (Kernel.Sector)
            mark: LONGINT;
            m: INTEGER; (*no. of elements on page*)
            p0: LONGINT;
            e: ARRAY DirPgSize OF DirEntry;
          END ;

      PROCEDURE Search(VAR name: FileName; VAR fad: LONGINT);
      PROCEDURE Insert(VAR name: FileName; fad: LONGINT);
      PROCEDURE Delete(VAR name: FileName; VAR fad: LONGINT);
      PROCEDURE Enumerate(prefix: ARRAY OF CHAR; proc: EntryHandler);

END FileDir.
```

Procedures *Search*, *Insert*, and *Delete* represent the typical operations performed on a directory. Efficiency of the first operation is of primary importance. But the B-tree structure also guarantees efficient insertion and deletion, although the code for these operations is complex. Procedure *Enumerate* is used to obtain excerpts of the directory. The programmer must guarantee that no directory changes are performed by the parametric procedure of Enumerate.

As in the presentation of module *Files*, we first discuss a version that uses main storage rather than a disk for the directory. This allows us to concentrate on the algorithms for handling the directory, leaving out the additional complications due to the necessity to read pages (sectors) into main store for selective updating and of restoring them onto disk. In particular, we point out the definitions of the data types for B-tree nodes, called *DirPage*, and elements, called *DirEntry*. The component *E.p* of an entry *E* points to the page in which all elements (with index *k*) have keys *E.p.e[k].name* > *E.name*. The pointer *p.p0* points to a page in which all elements have keys *p.p0.e[k].name* < *p.e[0].name*. We can visualize these conditions by Fig. 7.3, where names have been replaced by integers as keys.

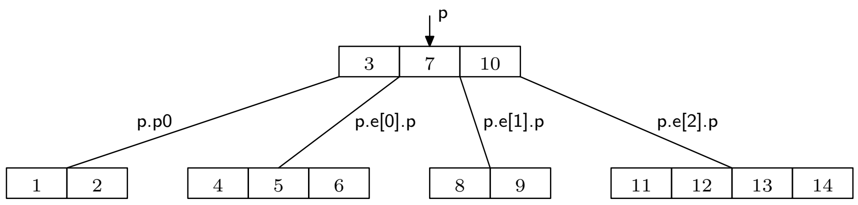

Fig. 7.3. Example of a B-tree of order 2

Procedure Search starts by inspecting the root page. It performs a binary search among its elements, according to the following algorithm. Let e[0 ... m-1] be the ordered keys and x the search argument.

```
L := 0;  R := m;
WHILE L < R DO
    i := (L+R) DIV 2;
    IF x <= e[i] THEN R := i ELSE L := i  + 1 END
END;
IF (R < m) & (x = e[R]) THEN found END
```

The invariant is

```
e[L-1] < x <= e[R]
```

If the desired element is not found, the search continues on the appropriate descendant page, if there is one. Otherwise the element is not contained in the tree.

Procedures *insert* and *delete* use the same algorithm for searching an element within a page. However, they use recursion instead of iteration to proceed along the search path of pages. We recall that the depth of recursion is at most four. The reason for the use of recursion is that it facilitates the formulation of structural changes, which are performed during the "unwinding" of recursion, i.e. on the return path. First, the insertion point (respectively the position of the element to be deleted) is searched, and then the element is inserted (deleted).

Upon insertion, the number of elements on the insertion page may become larger than 2N, violating B-tree condition 1. This situation is called *page overflow*. The invariant must be reestablished immediately. It could be achieved by moving one element from either end of the array e onto a neighbouring page. However, we choose not to do this, and instead to split the overflowing page into two pages immediately. The process of a *page split* is visualized by Fig 7.4, in which we distinguish between three cases, namely R < N, R = N, and R > N, where R marks the insertion point. *a* denotes the overflowing, *b* the new page, and *u* the inserted element.

The 2N + 1 elements (2N from the full page *a*, plus the one element *u* to be inserted) are equally distributed onto pages *a* and *b*. One element *v* is pushed up in the tree. It must be inserted in the ancestor page of *a*. Since that page obtains an additional descendant, it must also obtain an additional element in order to maintain B-tree rule 2.

A page split may thus propagate, because the insertion of element v in the ancestor page may require a split once again. If the root page is full, it is split too, and the emerging element *v* is inserted in a new root page containing a single element. This is the only way in which the height of a B-tree can increase.

When an element is to be deleted, it cannot simply be removed, if it resides on an internal page. In this case, it is first replaced by another element, namely one of the two neighbouring elements on a leaf page, i.e. the next smaller (or next larger) element, which is always on a leaf page. In the presented solution, the replacing element is the largest on the left subtree (see procedure del). Hence, the actual deletion always occurs on a leaf page.

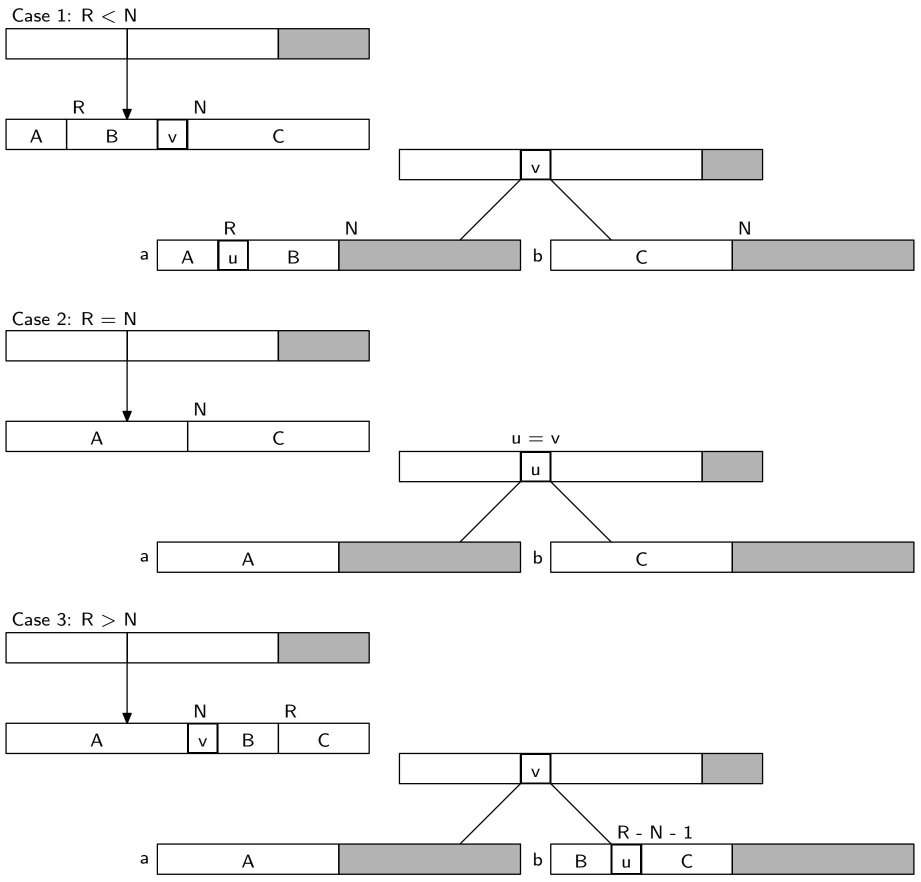

Fig. 7.4. Page split when inserting element u

Upon deletion, the number of elements in a page may become less than N, violating invariant 1. This event is called *page underflow*. Since restructuring the tree is a relatively complicated operation, we first try to reestablish the invariant by borrowing an element from a neighbouring page. In fact, it is reasonable to borrow several elements, and thereby to decrease the likelyhood of an underflow on the same page upon further deletions. The number of elements that could be taken from the neighbouring page b is b.m - N. Hence we will borrow

k = (b.m - N + 1) DIV 2

elements. The process of *page balancing* then distributes the elements of the underflowing and its neighbouring page equally to both pages (see procedure underflow).

However, if (and only if) the neighbouring page has no elements to spare, the two pages can and must be united. This action, called *page merge*, places the N-1 elements from the underflowing page, the N elements from the neighbouring page, plus one element from the ancestor page onto a single page of size 2N. One element must be taken from the ancestor page, because that page loses one descendant and invariant rule 2 must be maintained. The events of page balancing and merging are illustrated in Fig 7.5. *a* is the underflowing page, *b* its neighbouring page, and *c* their ancestor; *s* is the position in the ancestor page of (the pointer to the) underflowing page *a*. Two cases are distinguished, namely whether the underflowing page is the rightmost element (s = c.m) or not (see procedure *underflow*).

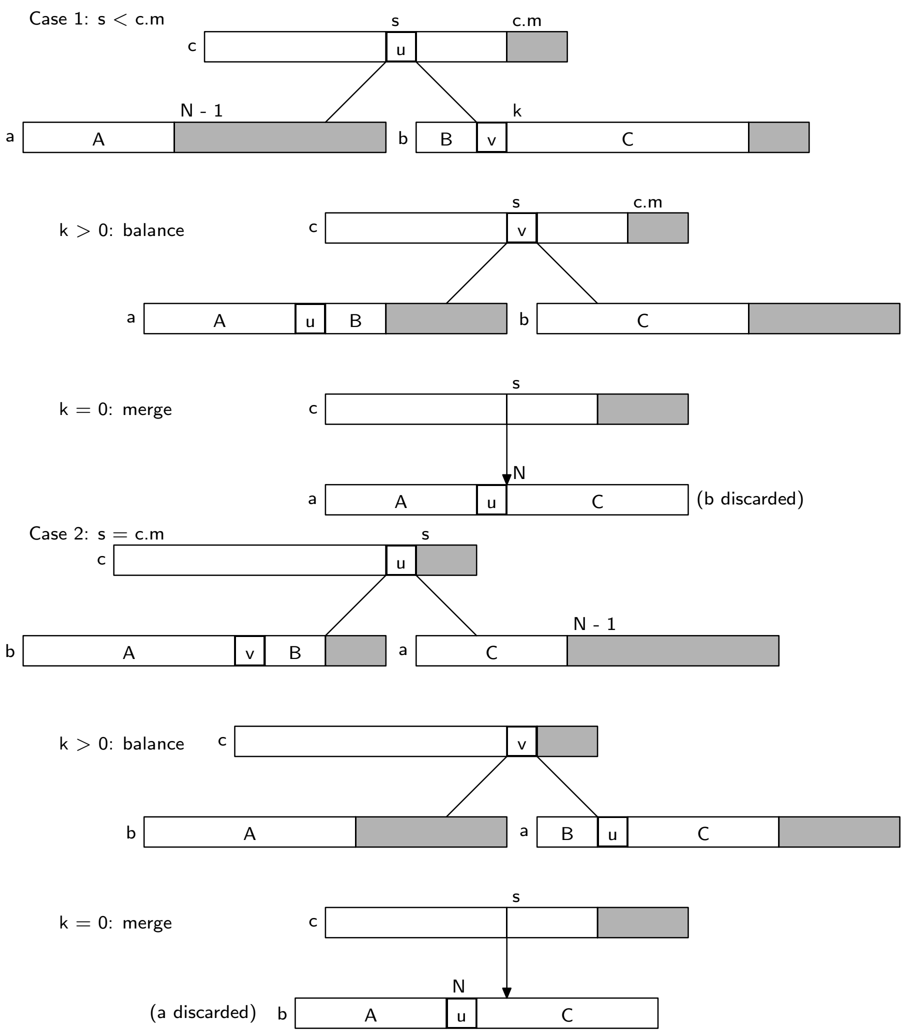

Fig. 7.5. Page balancing and merging when deleting element

Similarly to the splitting process, merging may propagate, because the removal of an element from the ancestor page may again cause an underflow, and perhaps a merge. The root page underflows only if its last element is removed. This is the only way in which the B-tree's height can decrease.

```
MODULE BTree;
  IMPORT Texts, Oberon;

  CONST N = 3;

  TYPE Page = POINTER TO PageRec;

    Entry = RECORD
            key, data: INTEGER;
            p: Page
          END ;

    PageRec = RECORD
            m: INTEGER;  (*no. of entries on page*)
            p0: Page;
            e: ARRAY 2*N OF Entry
          END ;

  VAR root: Page; W: Texts.Writer;
```

```
PROCEDURE search(x: INTEGER; a: Page; VAR data: INTEGER);
  VAR i, L, R: INTEGER;
BEGIN (*a # NIL*)
  LOOP L := 0; R := a.m;  (*binary search*)
    WHILE L < R DO
      i := (L+R) DIV 2;
      IF x <= a.e[i].key THEN R := i ELSE L := i+1 END
    END ;
    IF (R < a.m) & (a.e[R].key = x) THEN (*found*)
      data := a.e[R].data; EXIT
    END ;
    IF R = 0 THEN a := a.p0 ELSE a := a.e[R-1].p END ;
    IF a = NIL THEN (*not found*) EXIT END
  END
END search;

PROCEDURE insert(x: INTEGER; a: Page; VAR h: BOOLEAN; VAR v: Entry);
  (*a # NIL. Search key x in B-tree with root a; if found, increment counter.
    Otherwise insert new item with key x.  If an entry is to be passed up,
    assign it to v. h := "tree has become higher"*)
  VAR i, L, R: INTEGER;
    b: Page; u: Entry;
BEGIN (*a # NIL & ~h*)
  L := 0; R := a.m;  (*binary search*)
  WHILE L < R DO
    i := (L+R) DIV 2;
    IF x <= a.e[i].key THEN R := i ELSE L := i+1 END
  END ;
  IF (R < a.m) & (a.e[R].key = x) THEN (*found*) INC(a.e[R].data)
  ELSE (*item not on this page*)
    IF R = 0 THEN b := a.p0 ELSE b := a.e[R-1].p END ;
    IF b = NIL THEN (*not in tree, insert*)
      u.p := NIL; h := TRUE; u.key := x
    ELSE insert(x, b, h, u)
    END ;
    IF h THEN (*insert u to the left of a.e[R]*)
      IF a.m < 2*N THEN
        h := FALSE; i := a.m;
        WHILE i > R DO DEC(i); a.e[i+1] := a.e[i] END ;
        a.e[R] := u; INC(a.m)
      ELSE NEW(b); (*overflow; split a into a,b and assign the middle entry to v*)
        IF R < N THEN (*insert in left page a*)
          i := N-1; v := a.e[i];
          WHILE i > R DO DEC(i); a.e[i+1] := a.e[i] END ;
          a.e[R] := u; i := 0;
          WHILE i < N DO b.e[i] := a.e[i+N]; INC(i) END
        ELSE (*insert in right page b*)
          DEC(R, N); i := 0;
          IF R = 0 THEN v := u
          ELSE v := a.e[N];
            WHILE i < R-1 DO b.e[i] := a.e[i+N+1]; INC(i) END ;
            b.e[i] := u; INC(i)
          END ;
          WHILE i < N DO b.e[i] := a.e[i+N]; INC(i) END
        END ;
        a.m := N; b.m := N; b.p0 := v.p; v.p := b
      END
    END
  END
END insert;

PROCEDURE underflow(c, a: Page; s: INTEGER; VAR h: BOOLEAN);
  (*a = underflowing page, c = ancestor page,
    s = index of deleted entry in c*)
  VAR b: Page;
    i, k: INTEGER;
BEGIN (*h & (a.m = N-1) & (c.e[s-1].p = a) *)
  IF s < c.m THEN (*b := page to the right of a*)
    b := c.e[s].p; k := (b.m-N+1) DIV 2; (*k = nof items available on page b*)
    a.e[N-1] := c.e[s]; a.e[N-1].p := b.p0;
    IF k > 0 THEN (*balance by moving k-1 items from b to a*) i := 0;
      WHILE i < k-1 DO a.e[i+N] := b.e[i]; INC(i) END ;
      c.e[s] := b.e[k-1]; b.p0 := c.e[s].p;
      c.e[s].p := b; DEC(b.m, k); i := 0;
      WHILE i < b.m DO b.e[i] := b.e[i+k]; INC(i) END ;
      a.m := N-1+k; h := FALSE
    ELSE (*merge pages a and b, discard b*)  i := 0;
      WHILE i < N DO a.e[i+N] := b.e[i]; INC(i) END ;
      i := s; DEC(c.m);
      WHILE i < c.m DO c.e[i] := c.e[i+1]; INC(i) END ;
      a.m := 2*N; h := c.m < N
    END
  ELSE (*b := page to the left of a*)  DEC(s);
    IF s = 0 THEN b := c.p0 ELSE b := c.e[s-1].p END ;
    k := (b.m-N+1) DIV 2; (*k = nof items available on page b*)
    IF k > 0 THEN i := N-1;
      WHILE i > 0 DO DEC(i); a.e[i+k] := a.e[i] END ;
      i := k-1; a.e[i] := c.e[s]; a.e[i].p := a.p0;
      (*move k-1 items from b to a, one to c*)  DEC(b.m, k);
      WHILE i > 0 DO DEC(i); a.e[i] := b.e[i+b.m+1] END ;
      c.e[s] := b.e[b.m]; a.p0 := c.e[s].p;
      c.e[s].p := a; a.m := N-1+k; h := FALSE
    ELSE (*merge pages a and b, discard a*)
      c.e[s].p := a.p0; b.e[N] := c.e[s]; i := 0;
      WHILE i < N-1 DO b.e[i+N+1] := a.e[i]; INC(i) END ;
      b.m := 2*N; DEC(c.m); h := c.m < N
    END
  END
END underflow;

PROCEDURE delete(x: INTEGER; a: Page; VAR h: BOOLEAN);
  (*search and delete key x in B-tree a; if a page underflow arises,
    balance with adjacent page or merge; h := "page a is undersize"*)
  VAR i, L, R: INTEGER; q: Page;

  PROCEDURE del(p: Page; VAR h: BOOLEAN);
    VAR k: INTEGER; q: Page;  (*global a, R*)
  BEGIN k := p.m-1; q := p.e[k].p;
    IF q # NIL THEN del(q, h);
      IF h THEN underflow(p, q, p.m, h) END
    ELSE p.e[k].p := a.e[R].p; a.e[R] := p.e[k];
      DEC(p.m); h := p.m < N
    END
  END del;

BEGIN (*a # NIL*)
  L := 0; R := a.m;  (*binary search*)
  WHILE L < R DO
    i := (L+R) DIV 2;
    IF x <= a.e[i].key THEN R := i ELSE L := i+1 END
  END ;
  IF R = 0 THEN q := a.p0 ELSE q := a.e[R-1].p END ;
  IF (R < a.m) & (a.e[R].key = x) THEN (*found*)
    IF q = NIL THEN (*a is leaf page*)
      DEC(a.m); h := a.m < N; i := R;
      WHILE i < a.m DO a.e[i] := a.e[i+1]; INC(i) END
    ELSE del(q, h);
      IF h THEN underflow(a, q, R, h) END
    END
  ELSE delete(x, q, h);
    IF h THEN underflow(a, q, R, h) END
  END
END delete;

PROCEDURE Search*(key: INTEGER; VAR data: INTEGER);
BEGIN search(key, root, data)
END Search;

PROCEDURE Insert*(key: INTEGER; VAR data: INTEGER);
  VAR h: BOOLEAN; u: Entry; q: Page;
BEGIN h := FALSE; u.data := data; insert(key, root, h, u);
  IF h THEN (*insert new base page*)
    q := root; NEW(root);
    root.m := 1; root.p0 := q; root.e[0] := u
  END
END Insert;

PROCEDURE Delete*(key: INTEGER);
  VAR h: BOOLEAN;
BEGIN h := FALSE; delete(key, root, h);
  IF h THEN (*base page size underflow*)
    IF root.m = 0 THEN root := root.p0 END
  END
END Delete;

BEGIN NEW(root); root.m := 0
END BTree.
```

The B-tree is also a highly appropriate structure for enumerating its elements, because during the traversal of the tree each page is visited exactly once, and hence needs to be read (from disk) exactly once too. The traversal is programmed by the procedure *Enumerate* and uses recursion. It calls the parametric procedure proc for each element of the tree. The type of proc specifies as parameters the name and the (address of) the enumerated element. The third parameter continue is a Boolean VAR-parameter. If the procedure sets it to FALSE, the process of enumeration will be aborted.

Enumerate is used for obtaining listings of the names of registered files. For this purpose, the actual procedure substituted for *proc* merely enters the given name in a text and ignores the address (sector number) of the file, unless it requires special file information such as the file's size or creation date.

The set of visited elements can be restricted by specifying a string which is to be a prefix to all enumerated names. The least name with the specified prefix is directly searched and is the name (key) of the first element enumerated. The process then proceeds upto the first element whose name does not have the given prefix. Thereby, the process of obtaining all elements whose key has a given prefix avoids traversal of the whole tree, resulting in a significant speedup. If the prefix is the empty string, the entire tree is traversed.

The principle behind procedure *Enumerate* is shown by the following sketch, where we abstract from the B-tree structure and omit consideration of prefixes:

```
PROCEDURE Enumerate(
        proc: PROCEDURE (name: FileName; adr: INTEGER; VAR continue: BOOLEAN));
    VAR continue: BOOLEAN; this: DirEntry;
BEGIN continue := TRUE; this := FirstElement;
    WHILE continue & (this # NIL) DO
        proc(this.name, this.adr, continue); this := NextEntry(this)
    END
END Enumerate
```

From this sketch we may conclude that during the process of traversal the tree structure must not change, because the function *NextEntry* quite evidently relies on the structural information stored in the elements of structure itself. Hence, the actions of the parametric procedure must not affect the tree structure. Enumeration must not be used, for example, to delete a given set of files. In order to prevent the misuse of the indispensible facility of element enumeration, the interface of *FileDir* is not available to users in general.

The handling of the directory stored on disk follows exactly the same algorithms. The accessed pages are fetched from the disk as a whole (each page fits onto a single disk sector) and stored in buffers of type *DirPage*, from where individual elements can be accessed. In principle, these buffers can be local to procedures *insert* and *delete*. A single buffer is allocated globally, namely the one used by procedure *Search*. The reason for this exception is not only that iterative searching requires one buffer only, but because procedure *Files.Old* and in turn *Search* may be called when the processor is in the supervisor mode and hence uses the system- (instead of the user-) stack, which is small and would not accommodate sector buffers.

Naturally, an updated page needs to be stored back onto disk. Omission of sector restoration is a programming error that is very hard to diagnose, because some parts of the program are executed very rarely, and hence the error may look sporadic and mistakenly be attributed to malfunctioning hardware.

```
MODULE FileDir;   (*NW 12.1.86 / 23.8.90*)
  IMPORT SYSTEM, Kernel;
  (*File Directory is a B-tree with its root page at DirRootAdr.
    Each entry contains a file name and the disk address of the file's head sector*)

  CONST FnLength*    = 32;
    SecTabSize*   = 64;
    ExTabSize*   = 12;
    SectorSize*   = 1024;
    IndexSize*   = SectorSize DIV 4;
    HeaderSize*  = 352;
    DirRootAdr*  = 29;
    DirPgSize*   = 24;
    N = DirPgSize DIV 2;
    DirMark*    = 9B1EA38DH;
    HeaderMark* = 9BA71D86H;
    FillerSize = 52;

  TYPE DiskAdr      = LONGINT;
    FileName*       = ARRAY FnLength OF CHAR;
    SectorTable*    = ARRAY SecTabSize OF DiskAdr;
    ExtensionTable* = ARRAY ExTabSize OF DiskAdr;
    EntryHandler*   = PROCEDURE (name:FileName; sec: DiskAdr; VAR continue: BOOLEAN);
  FileHeader* =
    RECORD (Kernel.Sector)   (*allocated in the first page of each file on disk*)
      mark*: LONGINT;
      name*: FileName;
      aleng*, bleng*: INTEGER;
      date*, time*: LONGINT;
      ext*:  ExtensionTable;
      sec*: SectorTable;
      fill: ARRAY SectorSize - HeaderSize OF CHAR;
    END ;

  IndexSector* =
    RECORD (Kernel.Sector)
      x*: ARRAY IndexSize OF DiskAdr
    END ;

  DataSector* =
    RECORD (Kernel.Sector)
      B*: ARRAY SectorSize OF SYSTEM.BYTE
    END ;

  DirEntry* =  (*B-tree node*)
    RECORD
      name*: FileName;
      adr*:  DiskAdr; (*sec no of file header*)
      p*:    DiskAdr  (*sec no of descendant in directory*)
    END ;

  DirPage*  =
    RECORD (Kernel.Sector)
      mark*:  LONGINT;
      m*:     INTEGER;
      p0*:    DiskAdr;  (*sec no of left descendant in directory*)
      fill:  ARRAY FillerSize OF CHAR;
      e*:  ARRAY DirPgSize OF DirEntry
    END ;
PROCEDURE Search*(VAR name: FileName; VAR A: DiskAdr);
  VAR i, j, L, R: INTEGER; dadr: DiskAdr;
    a: DirPage;
BEGIN dadr := DirRootAdr;
  LOOP Kernel.GetSector(dadr, a);
    L := 0; R := a.m; (*binary search*)
    WHILE L < R DO
      i := (L+R) DIV 2;
      IF name <= a.e[i].name THEN R := i ELSE L := i+1 END
    END ;
    IF (R < a.m) & (name = a.e[R].name) THEN
      A := a.e[R].adr; EXIT (*found*)
    END ;
    IF R = 0 THEN dadr := a.p0 ELSE dadr := a.e[R-1].p END ;
    IF dadr = 0 THEN A := 0; EXIT  (*not found*) END
  END
END Search;

PROCEDURE insert(VAR name: FileName; dpg0:  DiskAdr;
        VAR h: BOOLEAN; VAR v: DirEntry;  fad: DiskAdr);
  (*h = "tree has become higher and v is ascending element"*)
  VAR ch: CHAR;
```

```
        i, j, L, R: INTEGER;
        dpg1: DiskAdr;
        u: DirEntry;
        a: DirPage;
BEGIN (*~h*) Kernel.GetSector(dpg0, a);
    L := 0; R := a.m; (*binary search*)
    WHILE L < R DO
        i := (L+R) DIV 2;
        IF name <= a.e[i].name THEN R := i ELSE L := i+1 END
    END ;
    IF (R < a.m) & (name = a.e[R].name) THEN
        a.e[R].adr := fad; Kernel.PutSector(dpg0, a)  (*replace*)
    ELSE (*not on this page*)
        IF R = 0 THEN dpg1 := a.p0 ELSE dpg1 := a.e[R-1].p END ;
        IF dpg1 = 0 THEN (*not in tree, insert*)
            u.adr := fad; u.p := 0; h := TRUE; j := 0;
            REPEAT ch := name[j]; u.name[j] := ch; INC(j)
            UNTIL ch = 0X;
            WHILE j < FnLength DO u.name[j] := 0X; INC(j) END
        ELSE
            insert(name, dpg1, h, u, fad)
        END ;
        IF h THEN (*insert u to the left of e[R]*)
            IF a.m < DirPgSize THEN
                h := FALSE; i := a.m;
                WHILE i > R DO DEC(i); a.e[i+1] := a.e[i] END ;
                a.e[R] := u; INC(a.m)
            ELSE (*split page and assign the middle element to v*)
                a.m := N; a.mark := DirMark;
                IF R < N THEN (*insert in left half*)
                        v := a.e[N-1]; i := N-1;
                        WHILE i > R DO DEC(i); a.e[i+1] := a.e[i] END ;
                        a.e[R] := u; Kernel.PutSector(dpg0, a);
                        Kernel.AllocSector(dpg0, dpg0); i := 0;
                        WHILE i < N DO a.e[i] := a.e[i+N]; INC(i) END
                ELSE (*insert in right half*)
                        Kernel.PutSector(dpg0, a);
                        Kernel.AllocSector(dpg0, dpg0); DEC(R, N); i := 0;
                        IF R = 0 THEN v := u
                        ELSE v := a.e[N];
                                WHILE i < R-1 DO a.e[i] := a.e[N+1+i]; INC(i) END ;
                                a.e[i] := u; INC(i)
                        END ;
                        WHILE i < N DO a.e[i] := a.e[N+i]; INC(i) END
                END ;
                a.p0 := v.p; v.p := dpg0
            END ;
            Kernel.PutSector(dpg0, a)
        END
    END
END insert;

PROCEDURE Insert*(VAR name: FileName; fad: DiskAdr);
    VAR  oldroot: DiskAdr;
        h: BOOLEAN; U: DirEntry;
        a: DirPage;
```

```
BEGIN h := FALSE;
   insert(name, DirRootAdr, h, U, fad);
   IF h THEN (*root overflow*)
      Kernel.GetSector(DirRootAdr, a);
      Kernel.AllocSector(DirRootAdr, oldroot); Kernel.PutSector(oldroot, a);
      a.mark := DirMark; a.m := 1; a.p0 := oldroot; a.e[0] := U;
      Kernel.PutSector(DirRootAdr, a)
   END
END Insert;

PROCEDURE underflow(VAR c: DirPage;  (*ancestor page*)
      dpg0:  DiskAdr; s: INTEGER; (*insertion point in c*) VAR h: BOOLEAN); (*c undersize*)
   VAR i, k: INTEGER;
         dpg1: DiskAdr;
         a, b: DirPage;  (*a := underflowing page, b := neighbouring page*)
BEGIN Kernel.GetSector(dpg0, a);
   (*h & a.m = N-1 & dpg0 = c.e[s-1].p*)
   IF s < c.m THEN (*b := page to the right of a*)
      dpg1 := c.e[s].p; Kernel.GetSector(dpg1, b);
      k := (b.m-N+1) DIV 2; (*k = no. of items available on page b*)
      a.e[N-1] := c.e[s]; a.e[N-1].p := b.p0;
      IF k > 0 THEN
         (*move k-1 items from b to a, one to c*) i := 0;
         WHILE i < k-1 DO a.e[i+N] := b.e[i]; INC(i) END ;
         c.e[s] := b.e[i]; b.p0 := c.e[s].p;
         c.e[s].p := dpg1; DEC(b.m, k); i := 0;
         WHILE i < b.m DO b.e[i] := b.e[i+k]; INC(i) END ;
         Kernel.PutSector(dpg1, b); a.m := N-1+k; h := FALSE
      ELSE (*merge pages a and b, discard b*) i := 0;
         WHILE i < N DO a.e[i+N] := b.e[i]; INC(i) END ;
         i := s; DEC(c.m);
         WHILE i < c.m DO c.e[i] := c.e[i+1]; INC(i) END ;
         a.m := 2*N; h := c.m < N
      END ;
      Kernel.PutSector(dpg0, a)
   ELSE (*b := page to the left of a*) DEC(s);
      IF s = 0 THEN dpg1 := c.p0 ELSE dpg1 := c.e[s-1].p END ;
      Kernel.GetSector(dpg1, b);
      k := (b.m-N+1) DIV 2; (*k = no. of items available on page b*)
      IF k > 0 THEN
         i := N-1;
         WHILE i > 0 DO DEC(i); a.e[i+k] := a.e[i] END ;
         i := k-1; a.e[i] := c.e[s]; a.e[i].p := a.p0;
         (*move k-1 items from b to a, one to c*) DEC(b.m, k);
         WHILE i > 0 DO DEC(i); a.e[i] := b.e[i+b.m+1] END ;
         c.e[s] := b.e[b.m]; a.p0 := c.e[s].p;
         c.e[s].p := dpg0; a.m := N-1+k; h := FALSE;
         Kernel.PutSector(dpg0, a)
      ELSE (*merge pages a and b, discard a*)
         c.e[s].p := a.p0; b.e[N] := c.e[s]; i := 0;
         WHILE i < N-1 DO b.e[i+N+1] := a.e[i]; INC(i) END ;
         b.m := 2*N; DEC(c.m); h := c.m < N
      END ;
      Kernel.PutSector(dpg1, b)
   END
END underflow;
```

```
PROCEDURE delete(VAR name: FileName; dpg0: DiskAdr; VAR h: BOOLEAN;
    VAR fad: DiskAdr);
(*search and delete entry with key name; if a page underflow arises,
  balance with adjacent page or merge; h := "page dpg0 is undersize"*)

  VAR i, j, k, L, R: INTEGER;
    dpg1: DiskAdr;
    a: DirPage;

  PROCEDURE del(dpg1: DiskAdr; VAR h: BOOLEAN);
    VAR dpg2: DiskAdr;  (*global: a, R*)
        b: DirPage;
  BEGIN Kernel.GetSector(dpg1, b); dpg2 := b.e[b.m-1].p;
    IF dpg2 # 0 THEN del(dpg2, h);
      IF h THEN underflow(b, dpg2, b.m, h); Kernel.PutSector(dpg1, b) END
    ELSE
      b.e[b.m-1].p := a.e[R].p; a.e[R] := b.e[b.m-1];
      DEC(b.m); h := b.m < N; Kernel.PutSector(dpg1, b)
    END
  END del;

BEGIN (*~h*) Kernel.GetSector(dpg0, a);
  L := 0; R := a.m; (*binary search*)
  WHILE L < R DO
    i := (L+R) DIV 2;
    IF name <= a.e[i].name THEN R := i ELSE L := i+1 END
  END ;
  IF R = 0 THEN dpg1 := a.p0 ELSE dpg1 := a.e[R-1].p END ;
  IF (R < a.m) & (name = a.e[R].name) THEN
    (*found, now delete*) fad := a.e[R].adr;
    IF dpg1 = 0 THEN  (*a is a leaf page*)
      DEC(a.m); h := a.m < N; i := R;
      WHILE i < a.m DO a.e[i] := a.e[i+1]; INC(i) END
    ELSE del(dpg1, h);
      IF h THEN underflow(a, dpg1, R, h) END
    END ;
    Kernel.PutSector(dpg0, a)
  ELSIF dpg1 # 0 THEN
    delete(name, dpg1, h, fad);
    IF h THEN underflow(a, dpg1, R, h); Kernel.PutSector(dpg0, a) END
  ELSE (*not in tree*) fad := 0
  END
END delete;

PROCEDURE Delete*(VAR name: FileName; VAR fad: DiskAdr);
  VAR h: BOOLEAN; newroot: DiskAdr;
    a: DirPage;
BEGIN h := FALSE;
  delete(name, DirRootAdr, h, fad);
  IF h THEN (*root underflow*)
    Kernel.GetSector(DirRootAdr, a);
    IF (a.m = 0) & (a.p0 # 0) THEN
      newroot := a.p0; Kernel.GetSector(newroot, a);
      Kernel.PutSector(DirRootAdr, a) (*discard newroot*)
    END
  END
END Delete;
```

```
PROCEDURE enumerate(VAR prefix:   ARRAY OF CHAR; dpg: DiskAdr;
    proc: EntryHandler; VAR continue: BOOLEAN);
  VAR i, j, diff: INTEGER; dpg1: DiskAdr; a: DirPage;
BEGIN Kernel.GetSector(dpg, a); i := 0;
  WHILE (i < a.m) & continue DO
    j := 0;
    LOOP
      IF prefix[j] = 0X THEN diff := 0; EXIT END ;
      diff := ORD(a.e[i].name[j]) - ORD(prefix[j]);
      IF diff # 0 THEN EXIT END ;
      INC(j)
    END ;
    IF i = 0 THEN dpg1 := a.p0 ELSE dpg1 := a.e[i-1].p END ;
    IF diff >= 0 THEN (*matching prefix*)
      IF dpg1 # 0 THEN enumerate(prefix, dpg1, proc, continue) END ;
      IF diff = 0 THEN
        IF continue THEN proc(a.e[i].name, a.e[i].adr, continue) END
      ELSE continue := FALSE
      END
    END ;
    INC(i)
  END ;
  IF continue & (i > 0) & (a.e[i-1].p # 0) THEN
    enumerate(prefix, a.e[i-1].p, proc, continue)
  END
END enumerate;

PROCEDURE Enumerate*(prefix: ARRAY OF CHAR; proc: EntryHandler);
  VAR b: BOOLEAN;
BEGIN b := TRUE; enumerate(prefix, DirRootAdr, proc, b)
END Enumerate;

PROCEDURE Init;
  VAR k: INTEGER;
    A: ARRAY 2000 OF DiskAdr;

  PROCEDURE MarkSectors;
    VAR L, R, i, j, n: INTEGER; x: DiskAdr;
      hd: FileHeader;
      B: IndexSector;

    PROCEDURE sift(L, R: INTEGER);
      VAR i, j: INTEGER; x: DiskAdr;
    BEGIN j := L; x := A[j];
      LOOP i := j; j := 2*j + 1;
        IF (j+1 < R) & (A[j] < A[j+1]) THEN INC(j) END ;
        IF (j >= R) OR (x > A[j]) THEN EXIT END ;
        A[i] := A[j]
      END ;
      A[i] := x
    END sift;

  BEGIN L := k DIV 2; R := k; (*heapsort*)
    WHILE L > 0 DO DEC(L); sift(L, R) END ;
    WHILE R > 0 DO
      DEC(R); x := A[0]; A[0] := A[R]; A[R] := x; sift(L, R)
    END ;
    WHILE L < k DO
```

```
        Kernel.GetSector(A[L], hd);
        IF hd.aleng < SecTabSize THEN j := hd.aleng + 1;
          REPEAT DEC(j); Kernel.MarkSector(hd.sec[j]) UNTIL j = 0
        ELSE j := SecTabSize;
          REPEAT DEC(j); Kernel.MarkSector(hd.sec[j]) UNTIL j = 0;
          n := (hd.aleng - SecTabSize) DIV 256; i := 0;
          WHILE i <= n DO
                Kernel.MarkSector(hd.ext[i]);
                Kernel.GetSector(hd.ext[i], B); (*index sector*)
                IF i < n THEN j := 256 ELSE j := (hd.aleng - SecTabSize) MOD 256 + 1 END ;
                REPEAT DEC(j); Kernel.MarkSector(B.x[j]) UNTIL j = 0;
                INC(i)
          END
        END ;
        INC(L)
      END
    END MarkSectors;

    PROCEDURE TraverseDir(dpg: DiskAdr);
      VAR i, j: INTEGER; a: DirPage;
    BEGIN Kernel.GetSector(dpg, a); Kernel.MarkSector(dpg); i := 0;
      WHILE i < a.m DO
        A[k] := a.e[i].adr; INC(k); INC(i);
        IF k = 2000 THEN MarkSectors; k := 0 END
      END ;
      IF a.p0 # 0 THEN
        TraverseDir(a.p0); i := 0;
        WHILE i < a.m DO
          TraverseDir(a.e[i].p); INC(i)
        END
      END
    END TraverseDir;

  BEGIN Kernel.ResetDisk; k := 0;
    TraverseDir(DirRootAdr); MarkSectors
  END Init;

BEGIN Init
END FileDir.
```

Oberon's file directory represents a single, ordered set of name-file pairs. It is therefore also called a *flat* directory. Its internal tree structure is not visible to the outside. In contrast, some file systems use a directory with a visible tree structure, notably UNIX. In a search, the name (key) guides the search path; the name itself displays structure, in fact, it is a sequence of names (usually separated by slashes or periods). The first name is then searched in the *root directory*, whose descendants are not files but *subdirectories*. The process is repeated, until the last name in the sequence has been used (and hopefully denotes a file).

Since the search path length in a tree increases with the logarithm of the number of elements, any subdivision of the tree inherently decreases performance since log(m + n) < log(m) + log (n) for any *m*, *n > 1*. It is justified only if there exist sets of elements with common properties. If these property values are stored once, namely in the subdirectory referencing all elements with common property values, instead of in every element, not only a gain in storage economy results, but possibly also in accesses which depend on those properties. The common properties are typically an owner's name, a password, and access rights (read or write protection), properties that primarily have significance in a multi-user environment. Since Oberon was conceived explicitly as a single-user system, there is little need for such facilities, and hence a flat directory offers the best performance with a simple implementation.

Every directory operation starts with an access to the root page. An obvious measure for improving efficiency is to store the root page "permanently" in main store. We have chosen not to do this for four reasons:

1. If the hardware fails, or if the computer is switched off before the root page is copied to disk, the file directory will be inconsistent with severe consequences.

2. The root page has to be treated differently from other pages, making the program more complex.

3. Directory accesses do not dominate the computing process; hence, any improvement would hardly be noticeable in overall system performance. The payoff for the added complexity would be small.

4. Procedure Init is called upon system initialization in order to construct the sector reservation table. Therefore, this procedure (and the module) must be allowed to refer to the structure of a file's sector table(s), which is achieved by placing its definitions into the module *FileDir* (instead of *Files*). Unlike *Enumerate*, *Init* traverses the entire B-tree. The sector numbers of files delivered by *TraverseDir* are entered into a buffer. When full, the entries are sorted, whereafter each file's head sector is read and the sectors indicated in its sector table are marked as reserved. The sorting speeds up the reading of the header sectors considerably. Nevertheless, the initialization of the sector reservation table clearly dominates the start-up time of the computer. For a file system with 10'000 files it takes in the order of 15s to record all files.

7.5. The Toolbox of File Utilities

We conclude this Chapter with a presentation of the commands which constitute the toolbox for file handling. These commands are contained in module *System*, and they serve to copy, rename, and delete files, and to obtain excerpts of the file directory.

Procedures *CopyFiles*, *RenameFiles*, and *DeleteFiles* all follow the same pattern. The parameter text is scanned for file names, and for each operation a corresponding procedure is called. If the parameter text contains an arrow, it is interpreted as a pointer to the most recent text selection which indicates the file name. In the cases of *CopyFiles* and *RenameFiles* which require two names for a single action, the names are separated by "=>" indicating the direction of the copy or rename actions.

```
PROCEDURE CopyFile(name: ARRAY OF CHAR; VAR S: Texts.Scanner);
  VAR f, g: Files.File; Rf, Rg: Files.Rider; ch: CHAR;
BEGIN Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "=") THEN Texts.Scan(S);
    IF (S.class = Texts.Char) & (S.c = ">") THEN Texts.Scan(S);
      IF S.class = Texts.Name THEN
        Texts.WriteString(W, name); Texts.WriteString(W, " => "); Texts.WriteString(W, S.s);
        Texts.WriteString(W, " copying"); Texts.Append(Oberon.Log, W.buf);
        f := Files.Old(name);
        IF f # NIL THEN g := Files.New(S.s);
          Files.Set(Rf, f, 0); Files.Set(Rg, g, 0); Files.Read(Rf, ch);
          WHILE ~Rf.eof DO Files.Write(Rg, ch); Files.Read(Rf, ch) END;
          Files.Register(g)
        ELSE Texts.WriteString(W, " failed")
        END ;
        Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
      END
    END
  END
END CopyFile;

PROCEDURE CopyFiles*;
  VAR beg, end, time: LONGINT; res: INTEGER;
    T: Texts.Text;
    S: Texts.Scanner;
```

```
BEGIN Texts.WriteString(W, "System.CopyFiles"); Texts.WriteLn(W);
  Texts.Append(Oberon.Log, W.buf);
  Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  WHILE S.class = Texts.Name DO CopyFile(S.s, S); Texts.Scan(S) END ;
  IF (S.class = Texts.Char) & (S.c = "^") THEN Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN
      Texts.OpenScanner(S, T, beg); Texts.Scan(S);
      IF S.class = Texts.Name THEN CopyFile(S.s, S) END
    END
  END
END CopyFiles;

PROCEDURE RenameFile(name: ARRAY OF CHAR; VAR S: Texts.Scanner);
  VAR res: INTEGER;
BEGIN Texts.Scan(S);
  IF (S.class = Texts.Char) & (S.c = "=") THEN Texts.Scan(S);
    IF (S.class = Texts.Char) & (S.c = ">") THEN Texts.Scan(S);
      IF S.class = Texts.Name THEN
        Texts.WriteString(W, name); Texts.WriteString(W, " => "); Texts.WriteString(W, S.s);
        Texts.WriteString(W, " renaming"); Texts.Append(Oberon.Log, W.buf);
        Files.Rename(name, S.s, res);
        IF res > 1 THEN Texts.WriteString(W, " failed") END;
        Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
      END
    END
  END
END RenameFile;

PROCEDURE RenameFiles*;
  VAR beg, end, time: LONGINT; res: INTEGER;
    T: Texts.Text;
    S: Texts.Scanner;
BEGIN Texts.WriteString(W, "System.RenameFiles"); Texts.WriteLn(W);
  Texts.Append(Oberon.Log, W.buf);
  Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  WHILE S.class = Texts.Name DO RenameFile(S.s, S); Texts.Scan(S) END ;
  IF (S.class = Texts.Char) & (S.c = "^") THEN
    Oberon.GetSelection(T, beg, end, time);
    IF time >= 0 THEN
      Texts.OpenScanner(S, T, beg); Texts.Scan(S);
      IF S.class = Texts.Name THEN RenameFile(S.s, S) END
    END
  END
END RenameFiles;

PROCEDURE DeleteFile (VAR name: ARRAY OF CHAR);
  VAR res: INTEGER;
BEGIN Texts.WriteString(W, name); Texts.WriteString(W, " deleting");
  Texts.Append(Oberon.Log, W.buf); Files.Delete(name, res);
  IF res # 0 THEN Texts.WriteString(W, " failed") END;
  Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
END DeleteFile;

PROCEDURE DeleteFiles*;
  VAR beg, end, time: LONGINT;
    T: Texts.Text;
    S: Texts.Scanner;
BEGIN Texts.WriteString(W, "System.DeleteFiles"); Texts.WriteLn(W);
```

```
    Texts.Append(Oberon.Log, W.buf);
    Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
    WHILE S.class = Texts.Name DO DeleteFile(S.s); Texts.Scan(S) END ;
    IF (S.class = Texts.Char) & (S.c = "^") THEN
      Oberon.GetSelection(T, beg, end, time);
      IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S);
        IF S.class = Texts.Name THEN DeleteFile(S.s) END
      END
    END
  END DeleteFiles;
```

Procedure *Directory* serves to obtain excerpts of the file directory. It makes use of procedure *FileDir.Enumerate*. The parametric procedure *List* tests whether or not the delivered name matches the pattern specified by the parameter of the directory command. If it matches, the name is listed in the text of the viewer opened in the system track. Since the pattern may contain one or several asterisks (wild cards), the test consists of a sequence of searches of the pattern parts (separated by the asterisks) in the file name. In order to reduce the number of calls of *List*, *Enumerate* is called with the first part of the pattern as parameter prefix. Enumeration then starts with the least name having the specified prefix, and terminates as soon as all names with this prefix have been scanned.

If the specified pattern is followed by an option directive "/date", then not only file names are listed, but also the listed files' creation date and length. This requires that not only the directory sectors on the disk are traversed, but that additionally for each listed file its header sector must be read. The two procedures use the global variables *pat* and *diroption*.

```
  PROCEDURE* List(name: FileDir.FileName; adr: LONGINT; VAR cont: BOOLEAN);
    VAR i0, i1, j0, j1: INTEGER; f: BOOLEAN; hp: FileDir.FileHeader;
  BEGIN i0 := pos; j0 := pos; f := TRUE;
    LOOP
      IF pat[i0] = "*" THEN INC(i0);
        IF pat[i0] = 0X THEN EXIT END
      ELSE
        IF name[j0] # 0X THEN f := FALSE END;
        EXIT
      END;
      f := FALSE;
      LOOP
        IF name[j0] = 0X THEN EXIT END;
        i1 := i0; j1 := j0;
        LOOP
          IF (pat[i1] = 0X) OR (pat[i1] = "*") THEN f := TRUE; EXIT END ;
          IF pat[i1] # name[j1] THEN EXIT END;
          INC(i1); INC(j1)
        END ;
        IF f THEN j0 := j1; i0 := i1; EXIT END;
        INC(j0)
      END;
      IF ~f THEN EXIT END
    END ;
    IF f THEN
      Texts.WriteString(W, name);
      IF diroption = "d" THEN
        Kernel.GetSector(adr, hp);
        Texts.WriteString(W, "    "); Texts.WriteDate(W, hp.time, hp.date);
        Texts.WriteInt(W, LONG(hp.aleng)*FileDir.SectorSize + hp.bleng - FileDir.HeaderSize, 8)
      END ;
      Texts.WriteLn(W)
    END
  END List;

  PROCEDURE Directory*;
    VAR X, Y, i: INTEGER; ch: CHAR;
      R: Texts.Reader;
      T, t: Texts.Text;
      V: Viewers.Viewer;
      beg, end, time: LONGINT;
      pre: ARRAY 32 OF CHAR;
  BEGIN Texts.OpenReader(R, Oberon.Par.text, Oberon.Par.pos); Texts.Read(R, ch);
    WHILE ch = " " DO Texts.Read(R, ch) END;
    IF (ch = "^") OR (ch = 0DX) THEN
      Oberon.GetSelection(T, beg, end, time);
      IF time >= 0 THEN
        Texts.OpenReader(R, T, beg); Texts.Read(R, ch);
        WHILE ch <= " " DO Texts.Read(R, ch) END
      END
    END ;
    i := 0;
    WHILE (ch > " ") & (ch # "/") DO pat[i] := ch; INC(i); Texts.Read(R, ch) END;
    pat[i] := 0X;
    IF ch = "/" THEN Texts.Read(R, diroption) ELSE diroption := 0X END;
    i := 0;
    WHILE pat[i] > "*" DO pre[i] := pat[i]; INC(i) END;
    pre[i] := 0X; pos := i;
    Oberon.AllocateSystemViewer(Oberon.Par.vwr.X, X, Y); t := TextFrames.Text("");
    V := MenuViewers.New(
      TextFrames.NewMenu("System.Directory", StandardMenu),
      TextFrames.NewText(t, 0), TextFrames.menuH, X, Y);
    FileDir.Enumerate(pre, List); Texts.Append(t, W.buf)
  END Directory;
```

References

1. R. Bayer and E. M. McCreight. Organization and maintenance of large ordered indexes. *Acta Informatica*, *1*, 3, (1972), 173-189.

2. D. Comer. The ubiquiteous B-tree. *ACM Comp Surveys*, *11*, 2, (June 1979), 121-137.

8. Storage Layout and Management

8.1. Storage Layout and Run-time Organization

A crucial property of the Oberon System is centralized resource management. Its advantage is that replication of management algorithms and a premature partitioning of resources are avoided. The disadvantage is that management algorithms are fixed once and forever and remain the same for all applications. The success of a centralized resource management therefore depends crucially on its flexibility and its efficient implementation. This Chapter presents the scheme and the algorithms governing main storage in the Oberon System.

The storage layout of the Oberon System is determined by the structure of code and data typical in the use of modular, high-level programming languages, and in particular of the language Oberon. It suggests the subdivision of storage into three areas.

1. The *block space*. Every module specifies procedures (code) and global (static) variables. Its initialization part can be regarded as a procedure implicitly called after loading. Upon loading, space must be allocated for code and data. Typically, modules contain very few or no global variables, hence the size of the allocated space is primarily determined by the code. The combined code and data space is called a block. Blocks are allocated in the block space.

2. The *workspace (stack)*. Execution of every command invokes a sequence of procedures, each of which uses (possibly zero) parameters and local variables. Since procedure calls and completions follow a strict first-in last-out order, the stack is the uniquely suited strategy for storage allocation for local data. Deallocation upon completion of a procedure is achieved by merely resetting the pointer identifying the top of the stack. Since this operation is implied in appropriate machine instructions (for returns), it costs zero execution time. Because Oberon is a single-process system, a single stack suffices. Furthermore, after completion of a command, the stack is empty. This fact will be important in simplifying the scheme for reclamation of dynamically allocated space.

3. The *dynamic space (heap)*. Apart from global (static) variables, and local (stack-allocated) variables, a program may refer to anonymous variables referenced through pointers. Such variables are allocated truly dynamically through calls of an explicit operation (NEW). These variables are allocated in the so-called heap. Their deallocation is "automatic", when free storage is needed and they are no longer referenced from any of the loaded modules. This process is called *garbage collection*.

Unfortunately, the number of distinct spaces is larger than two. If it were two, no arbitrary size limitation would be necessary; merely the sum of their sizes would be inherently limited by the size of the store. In the case of three spaces, arbitrarily determined size limits are unavoidable. The presence of an address-mapping hardware alleviates the problem, however, because the virtual address space is so large that limits will hardly ever be reached.

Furthermore, we note that both the stack and the heap space must be genuinely allocated, i.e. any address within the space must denote a physically present location. Hence, there is no point in making the virtual address space of their sum larger than the entire physical store. The size of the virtual block space then becomes the difference between virtual and physical address space. The resulting layout is shown in Fig. 8.1. The upper end of the address space is reserved for device registers.

If address mapping is unavailable, as in the case of Ceres-3 which lacks a memory management unit, the fixing of size limitations is unavoidable. The chosen layout for Ceres-3 is shown in Fig. 8.2; the stack is limited to 128K bytes.

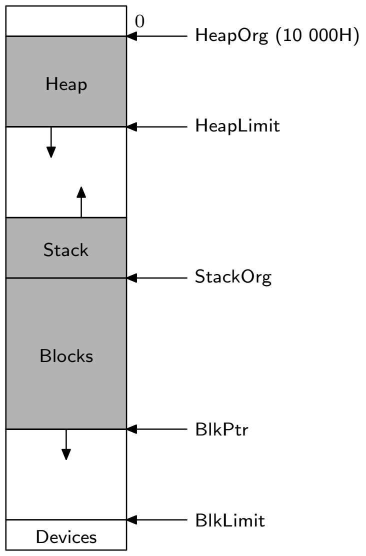

Fig. 8.1. Storage layout for Ceres-1 and Ceres-2

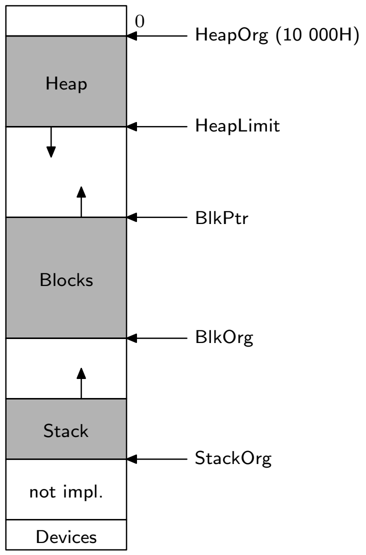

Fig. 8.2. Storage layout for Ceres-3

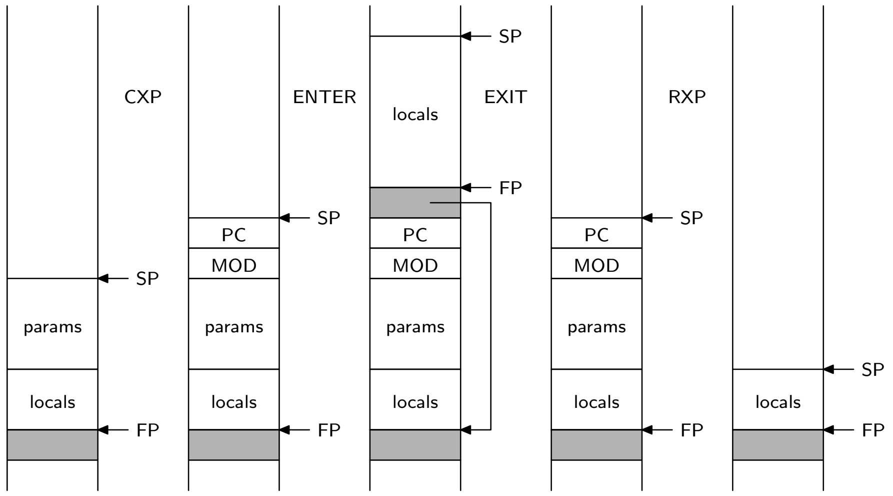

Fig. 8.3. State of stack before and after procedure call and return

The area with address range 0...FFFFH contains

1. The NIL-page (0...FFFH) which remains permanently unallocated. The purpose of this measure is to let references via a NIL-pointer invoke addressing traps.
2. The system stack (1000H - 17FFH) which is used by interrupt routines executed in supervisor mode, including the trap handler.
3. Allocation tables for pages and disk sectors.
4. Module descriptors (4000H - 7FFFH).
5. Blocks for the permanently resident modules of the inner core, i.e. *Kernel, FileDir, Files* and *Modules*.

The workspace is organized in the usual fashion as a stack of procedure activation records. Its top is denoted by the SP-Register. A second register, the so-called *frame pointer* FP is the anchor of the dynamic chain of activation records. A new element is added upon procedure call in two steps. The first step is performed after the loading of parameters by the call instruction (CXP for calls of external, BSR for calls of local procedures). The second step is performed by the ENTER instruction which is the first instruction of every procedure body. An activation record is removed, also in two steps, upon procedure completion by the instructions EXIT and RXP for external or RET for local procedures. The state of the workspace before and after these four steps is shown in Fig 8.3.

It follows that local variables are addressed relative to the FP value with negative offsets. Parameters are addressed relative to FP with positive offsets, starting at 12 for external procedures called by a CXP instruction, and at 8 for local procedures, where the MOD register is not pushed onto the stack by the call instruction.

Global variables and constants (strings) are accessed via the SB register (static base). The value of this register is automatically adjusted by the CXP and RXP instruction as well as by interrupts and traps.

8.2. Allocation of Module Blocks

As indicated in the preceding section, storage for global (static) variables, for constants, and for the program code of modules, is allocated in the block space. Every module is represented by a single block. In addition, each module is assigned a module descriptor containing various pointers into sections of the block (see Chap. 6). The separation into a descriptor and a block is imposed by the architecture of the NS32000 processor which supports module structures through its external addressing mode. The physical separation is necessary because descriptor addresses are confined to 16 bit values and therefore cannot be managed in the same way as general, dynamic storage. This is rather unfortunate.

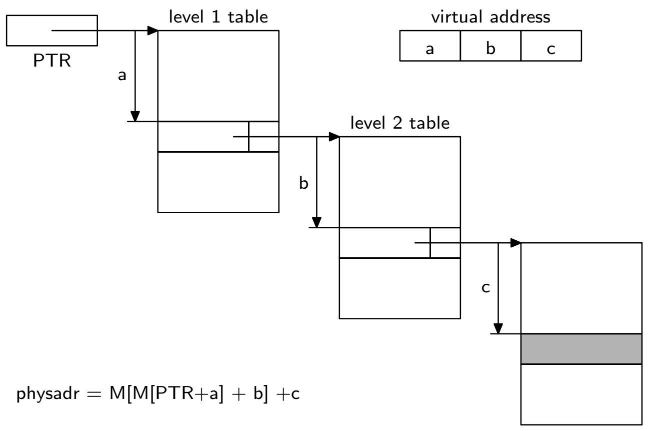

Fig. 8.4. NS32000 virtual addressing scheme

Block management is represented by the two procedures *Kernel.AllocBlock* and *Kernel.FreeBlock*. Implementations differ for the various models of the Ceres computer. This is because Ceres-1 and Ceres-2 incorporate the concept of virtual storage represented by an address mapping memory management unit (MMU), whereas Ceres-3 does not. In the former case, allocated (physical) pages are registered in a *page reservation table*. The store is regarded as a set of pages, and the table contains a single bit for each page, 0 signifying that the respective page has been allocated. Each block consists of an integral number of pages whose size is given in the following table.

computer	processir	page size
Ceres-1	NS32032	512
Ceres-2	NS32532	4096
Ceres-3	NS32GX32	1024

In the case of Ceres-1 and Ceres-2, the virtual address space for blocks is so large that new blocks can be given steadily increasing addresses without regard to any holes that may have arisen because of released blocks. The required physical pages are obtained by simply scanning the reservation table. Block release merely consists of marking the released pages as free in the table.

Naturally, the appropriate entries in the page tables must be marked (or reset), and possibly new page tables need to be allocated as well. We emphasize that these operations must be performed with the MMU switched off and with all interrupts disabled.

The NS32000 MMU architecture uses a two-stage table scheme shown in Fig 8.4. The reason is the following: The page table must be large enough to cover the entire virtual address range. Assuming a page size of 4 Kbytes and an address space of 4 Gbytes (32-bit addresses), no less than 220 elements are required, resulting in a table of 4 Mbytes, which clearly is unacceptable. Using a two-level scheme, each entry of the (primary) table points to a second-level table which itself covers a large section of the store. In the NS32532 processor, all tables have a size of 4 Kbytes and consist of 1K (= 1024) entries. Hence, every second-level table covers a space of 1024 * 4 Mbytes = 4 Mbytes, and therefore a first-level page of 1K entries suffices to cover the entire virtual space of 4 Gbytes.

The disadvantage of the two stage scheme is, of course, that upon a translation cache miss not only two, but three memory accesses are required to access a word. (For further details we refer the reader to the literature and the processor manual).

The handling of the tables is concentrated in two internal Kernel routines for allocating and freeing physical pages. They consist of about 75 instructions.

Of course, the need of a triple access for every memory reference is avoided by a translation cache in the unit. Nevertheless, a decrease in performance is unavoidable for each cache miss. Furthermore, an additional subcycle is required for *every* access in order to look up the cached translation table. The Ceres-3 computer includes no MMU and address translation. As a consequence, each block must consist of an integral number of physically adjacent pages. Holes generated by the release of blocks must be reused. We employ the simple scheme of keeping a list of holes, and of allocating a new block in the first hole encountered that is large enough (first-fit strategy). Considering the relative infrequency of module releases, efforts to improve the strategy are not worth the resulting added complexity.

It is remarkable that the code for block allocation and release without virtual addressing is only marginally more complicated than with it. (69 vs. 49 instructions). If the routines for managing page tables are included, it becomes even simpler (69. vs. 124 instructions). The only remaining advantages of an MMU are a better storage utilization, because no holes occur (a negligible advantage), and that inadvertent references to unloaded modules, e.g. via installed procedures, lead to an invalid address trap.

It is worth recalling that the concept of address mapping was introduced as a requirement for virtual memory implemented with disks as backing store, where pages could be moved into the background in order to obtain space for newly required pages, and could then be retrieved from disk on demand, i.e. when access was requested. This scheme is called *demand paging*. It is not used in the Oberon system, and one may fairly state that demand paging has lost its significance with the availability of large, primary stores.

Experience in the use of Ceres leads to the conclusion that whereas address translation through an MMU was an essential feature for multi-user operating systems, it constitutes a dispensible overkill for single-user workstations. The fact that modern semiconductor technology made it possible to integrate the entire translation and caching scheme into a single chip, or even into the processor itself, led to the hiding (and ignoring) of the scheme's considerable complexity. Its side effects on execution speed are essentially unpredictable. This makes systems with MMU virtually unusable for applications with tight real-time constraints.

8.3. Management of Dynamic Storage

The term *dynamic storage* is used here for all variables that are allocated neither statically (global variables) nor on the stack (local variables), but through invocation of the intrinsic procedure NEW. Such variables are anonymous and are referenced exclusively via pointers. The space in which they are allocated is called the heap.

The space allocated to such dynamic variables becomes free and reusable as soon as the last reference to it vanishes. This event is hard, and in multiprocess systems even impossible to detect. The usual remedy is to ignore it and instead to determine the accessibility of all allocated variables (records, objects) only at the time when more storage space is needed. This process is then called *garbage collection*.

The Oberon System does not provide an explicit deallocation procedure allowing the programmer to signal that a variable will no longer be referenced. The first reason for this omission is that usually a programmer would not know when to call for deallocation. And secondly, this "hint" could not be taken as trustworthy. An erroneous deallocation, i.e. one occurring when there still exist references to the object in question, could lead to a multiple allocation of the same space with disastrous consequences. Hence, it appears wise to fully rely on system management to determine which areas of the store are truly reusable.

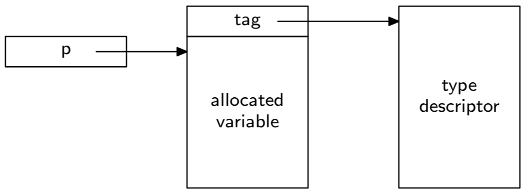

Fig. 8.5. Effect of procedure NEW(p)

Before discussing the scheme for storage reclamation, which is the primary subject of dynamic storage management, we turn our attention to the problem of allocation, i.e. the implementation of procedure NEW. The simplest solution is to maintain a list of free blocks and to pick the first one large enough.

This strategy leads to a relatively large fragmentation of space and produces many small elements, particularly in the first part of the list. We therefore employ a somewhat more refined scheme and maintain five lists of available space. Four of them contain pieces of fixed size, namly 16, 32, 64, and 128 bytes. The fifth list contains pieces whose size is any multiple of 128. Procedure NEW rounds up the requested size to the least of these values and picks the first element of the respective list. We note that the choice of the values permits the merging of any two contiguous elements into an element of the next list. This scheme keeps fragmentation, i.e. the emergence of small pieces in large numbers, reasonably low with minimal effort. The body of procedure NEW consists of only 100 instructions, and typically only a small fraction of them needs to be executed.

The statement NEW(p) is compiled into an instruction sequence assigning the address of pointer variable p to a fixed register (R0) and the type tag to another register (R1). The type tag is a pointer to a type descriptor containing information required by the garbage collector. This includes the size of the space occupied and now to be allocated. The effect of NEW is the assignment of the address of the allocated block to p, and the assignment of the tag to a prefix of the block. (see Fig. 8.5)

Note: The Oberon compiler for Ceres also features a procedure SYSTEM.NEW(p, n). It allows one to allocate a block without a fixed type identified by a descriptor. Here the size n is placed in the block's prefix in place of the tag. Bit 0 indicates whether bits 0-23 represent a tag or a size. Such a facility is required because descriptors are also elements in the heap, and they lack a descriptor of the descriptor, since the system can rely on their known structure.

In conclusion, we emphasize that this scheme makes the allocation of an object very efficient. Nevertheless, it is considerably more costly than that of a variable explicitly declared.

We now turn to the problem of storage reclamation or garbage collection. There exist two essentially different schemes: the reference counting and the mark-scan schemes. In the former, every object carries a (hidden) reference count, indicating the number of existing references.

NEW(p)	initializes the reference count of p^ to 1.
q := p	decrements the reference count of q^ by 1, performs the assignment, then increments the reference count of p^ by 1. When a reference count reaches zero, the element is linked into the free list.

There are two disadvantages inherent in this approach. The first is the non-negligible overhead in pointer assignments. The second is that circular data structures never become recognized as free, even if no external references point to their elements.

The Ceres-Oberon system employs the second scheme which involves no hidden operations like the reference counting scheme, but relies on a process initiated when free storage has become scarce and more is needed. It consists of two phases. In the first phase, all referenced and therefore still accessible elements are marked. In the second phase, their unmarked complement is released. The first phase is called the *mark phase*, the second the *scan phase*. Its primary disadvantage is that the process may be started at moments unpredictable to the system's user. During the process, the computer then appears to be blocked. It follows that an interactive system using mark-scan garbage collection must guarantee that the process is sufficiently fast in order to be hardly noticeable. Modern processors make this possible, even with large main stores. Nevertheless, finding all accessible nodes in an entire computer system within a second appears to be a formidable feat.

We recognize that the mark phase essentially is a tree traversal, or rather a forest traversal. The roots of the trees are all named pointer variables in existence. We shall postpone the question of how these roots are to be found, and first present a quick tutorial about tree traversal. In general, nodes of the traversed structure may contain many pointers (branches). We shall, however, first restrict our attention to a *binary tree*, because the essential problem and its solution can be explained better in this way.

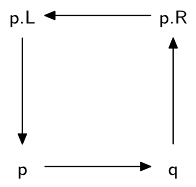

Fig. 8.6. Rotation of pointers

The essential problem alluded to is that of storage utilization by the traversal algorithm itself. Typically, information about the nodes already visited must be retained, be it explicitly, or implicitly as in the case of use of recursion. Such a strategy is plainly unacceptable, because the amount of storage needed may become very large, and because garbage collection is typically initiated just when more storage is unavailable. The task may seem impossible, yet a solution lies in the idea of inverting pointers along the path traversed, thus keeping the return path open. It is embodied in the following procedure, whose task is to traverse the tree given by the parameter *root*, and to mark every node. Mark values are assumed to be initially 0. Let the data structure be defined by the types

```
Ptr =      POINTER TO Node;
Node =     RECORD m: INTEGER;  L, R: Ptr END;
```

and the algorithm by the procedure

```
PROCEDURE traverse(root: Ptr);
  VAR p, q, r; Ptr;
BEGIN p := root; q := root;
  REPEAT (* p # NIL *) INC(p.m); (*mark*)
    IF p.L # NIL THEN
      r := p.L; p.L :=  p.R; p.R := q; q := p; p := r
    ELSE
      p.L := p.R; p.R := q; q:= NIL
    END
  UNTIL p = q
END traverse
```

We note that only three local variables are required, independent of the size of the tree to be traversed. The third, *r*, is in fact merely an auxiliary variable to perform the rotation of values *p.L, p.R, q*, and *p* as shown in Fig. 8.6. A snapshot of a tree traversal is shown in Fig. 8.7.

The pair *p, q* of pointers marks the position of the process. The algorithm traverses the tree in a left to right, depth first fashion. When it returns to the root, all nodes have been marked.

How are these claims convincingly supported? The best way is by analyzing the algorithm at an arbitrary node. We start with the hypothesis *H* that, given the initial state *P*, the algorithm will reach state *Q*, (see Fig 8.8).

State *Q* differs from *P* by the node and its descendants *B* and *C* having been marked, and by an exchange of *p* and *q*. We now apply the algorithm to state *P*, assuming that *B* and *C* are not empty. The process is illustrated in Fig 8.9. *P0* stands for *P* in Fig. 8.7.

Transitions P0 $\rightarrow$ P1, P2 $\rightarrow$ P3, and P4 $\rightarrow$ P5 are the direct results of applying the pointer rotation as specified by the sequence of five assignments in the algorithm. Transitions P1 $\rightarrow$ P2 and P3 $\rightarrow$ P4 follow from the hypothesis *H* being applied to the states *P1* and *P3*: subtrees are marked and *p, q* interchanged. We note in passing that the node is visited three times. Progress is recorded by the mark value which is incremented from 0 to 3.

Fig. 8.9. demonstrates that, if *H* holds for steps P1 $\rightarrow$ P2 and P3 $\rightarrow$ P4, then it also holds for step P0 $\rightarrow$ P5, which visits the subtree *p*. Hence, it also holds for the step root $\rightarrow$ root, which traverses the entire tree.

This proof by recursion relies on the algorithm performing correct transitions also in the case of *p.L* being NIL, i.e. B being the empty tree. In this case, state *P1* is skipped; the first transition is P0 $\rightarrow$ P2.

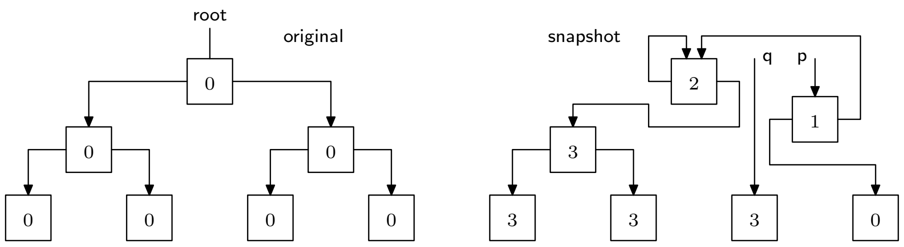

Fig. 8.7. Tree traversal

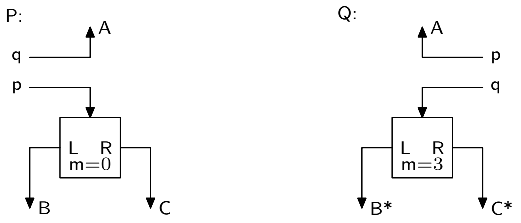

Fig. 8.8. Transition from state P to state Q

If *p.L* is again NIL, i.e. also *C* is empty, the next transition is P2 → P4. This concludes the demonstration of the algorithm's correctness.

We now modify the algorithm of tree traversal to the case where the structure is not confined to a binary tree, but may be a tree of any degree, i.e. each node may have any number n of descendants. For practical purposes, however, we restrict n to be in the range 0 ≤ n ≤ N, and therefore may represent all nodes by the type

```
Node =  RECORD m, n: INTEGER;
          dsc: ARRAY N OF Node
        END
```

In principle, the binary tree traversal algorithm might be adopted almost without change, merely extending the rotation of pointers from *p.L, p.R, q, p* to *p.dsc[0], ... , p.dsc[n-1], q, p*. However, this would be an unnecessarily inefficient solution. The following is merely a more effective variant.

```
PROCEDURE traverse(root: Ptr);
  VAR k: INTEGER; p, q, r: Ptr;
BEGIN p := root; q := root;
  LOOP (* p # NIL*) k := p.m; INC(p.m); (*mark*)
    IF k < p.n THEN
      r := p.dsc[k];
      IF r # NIL THEN p.dsc[k] := q; q := p; p := r END
    ELSIF p = q THEN EXIT
    ELSE k := q.m - 1;
      r := q.dsc[k];  q.dsc[k] := p; p := q; q := r
    END
  END
END traverse
```

We note that the mark value, starting with zero (unmarked), is used as a counter of descendants already traversed, and hence as an index to the descendant field to be processed next. The algorithm can be applied not only to trees, but to arbitrary structures, including circular ones, if the continuation condition *k < p.n* is extended to *(k < p.n) & (r.m = 0)*. This causes a descendant that is already marked to be skipped.

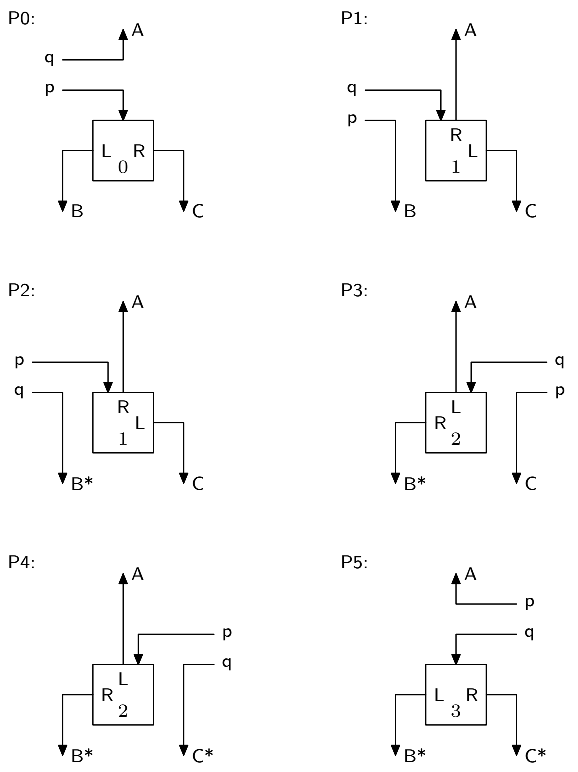

Fig. 8.9. Transitions from P0 to P5, visiting node three times

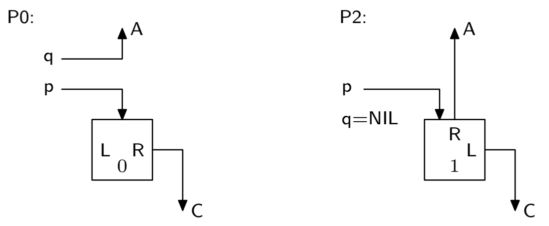

Fig. 8.10. Direct transition from P0 to P2, if p.L = NIL

Oberon's garbage collector uses exactly this algorithm. The mark is included in each record's hidden prefix. The prefix takes 4 bytes only; 3 are used for the tag or the size, one is reserved for the garbage collector and used as mark. It follows that no record may contain more than 255 pointers. The number n of pointers (descendants) in a record is contained in the record's type descriptor. (Records without descriptor, generated by SYSTEM.NEW, must not contain descendants.)

Type descriptors consist of the following fields (excluding the prefix):

size	in bytes, of the described type, (3 bytes)
n	number of descendants in the described type (1 byte)
base	a table of pointers to the descriptors of the base types (7 elements)
offsets	of the descendant pointers in the described type (2 bytes each)

Type descriptors themselves have a prefix containing a mark field and the size of the descriptor, which is at least 36 (3 bytes for size, 1 byte for n, 4 for the prefix, and 28 for the base tag table).

We emphasize that type descriptors need to be allocated in the heap. They cannot be placed among the module's constants in the block space, although they are constants, because elements in the heap may refer to a descriptor even after the module defining the type had been unloaded. This is the case when a structure rooted in a variable of base type *T* declared in a module *M* contains elements of an extension *T'* defined in module *M'*, after *M'* had been unloaded, but when *M* is still present.

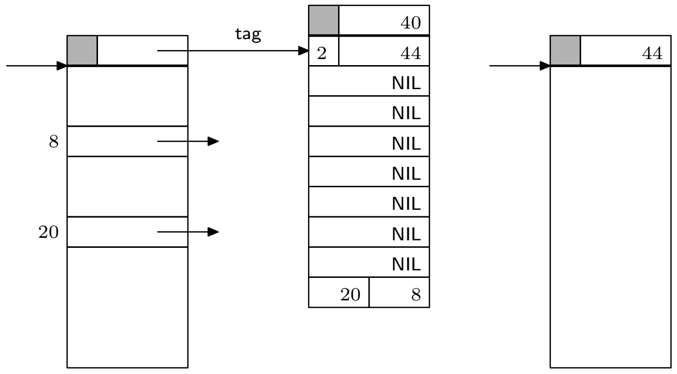

Fig. 8.11. Records with and without type descriptor

The scan phase is performed by a relatively straight-forward algorithm. The heap, i.e. the storage area between *HeapOrg* and *HeapLimit* (the latter is a variable), is scanned element by element, starting at *HeapOrg*. Elements marked are unmarked, and unmarked elements are freed by linking them into the appropriate list of available space.

As the heap may always contain free elements, the scan phase must be able to recognize them in order to skip them or merge them with an adjacent free element. For this purpose, the free elements are also considered as prefixed. The prefix serves to determine the element's size and to recognize it as free due to a special (negative) mark value. The encountered mark values and the action to be taken are:

mark value	state	action
= 0	unmarked	collect, mark free
> 0	marked	unmark
< 0	free	skip or merge

8.4. The Kernel

The NS32000 processor has two distinct modes of operation, the supervisor and the user mode. The former permits, the latter prohibits execution of certain special instructions and access to protected parts of the store. Since we wish to make use of this protection facility for certain resource allocation tables whose corruption would lead to disaster, access to them needs to be made in supervisor mode. It can only be entered by a supervisor call instruction which causes a trap. There is, however, no facility in the language Oberon for the handling of traps. The trap handler is therefore programmed in assembler code, which also allows the expression of priviledged instructions. Module *Kernel* is the collection of assembler-coded procedures executed in supervisor mode.

In passing we note that only base modules can be assembler-coded, because the assembler purposely does not accept specification of imports. The prime justification for programming in assembler code is the need for efficiency, mostly achieved by judicious use of the few available registers. Efficiency is primarily important in leaf procedures, i.e. procedures that do not call upon other procedures. Therefore it is quite appropriate to restrict the use of the assembler to leaf modules.

The procedures in the kernel can be partitioned into four groups: block management, sector management, heap management, and miscellaneous. Furthermore, the kernel exports certain (read-only) variables. They reflect the state of the different managers and indicate the amounts of store already allocated.

```
MODULE Kernel;  (*NW  11.4.86 / 12.4.91*)
    TYPE Sector* = RECORD END ;
        IntProc*  = PROCEDURE;
```

```
      VAR ModList*:    LONGINT;
            NofPages*, NofSectors*, allocated*:  LONGINT;
            StackOrg*, HeapLimit*: LONGINT;
            FileRoot*, FontRoot*: LONGINT;
            SectNo*:     LONGINT;

            pc*, sb*, fp*, sp0*, sp1*, mod*, eia*: LONGINT; (*status upon trap*)
            err*, pcr*: INTEGER;

   (* Block management*)
      PROCEDURE AllocBlock(VAR dadr, blkadr: LONGINT; size: LONGINT);
      PROCEDURE FreeBlock(dadr: LONGINT);

   (* Heap management - garbage collector*)
      PROCEDURE GC;

   (* Disk sector management*)
      PROCEDURE AllocSector(hint: LONGINT; VAR sec: LONGINT);
      PROCEDURE MarkSector(sec: LONGINT);
      PROCEDURE FreeSector(sec: LONGINT);
      PROCEDURE GetSector(src: LONGINT; VAR dest: Sector);
      PROCEDURE PutSector(dest: LONGINT; VAR src: Sector);
      PROCEDURE ResetDisk;

   (* Miscellaneous*)
      PROCEDURE InstallIP(P: IntProc; chan: INTEGER);
      PROCEDURE InstallTrap(P: IntProc);
      PROCEDURE SetICU(n: CHAR);
      PROCEDURE GetClock(VAR time, date: LONGINT);
      PROCEDURE SetClock(time, date: LONGINT);
   END Kernel.
```

Procedures GetClock and SetClock represent the interface to the real-time clock. Both time and date are encoded as (long) integers as follows:

```
      time = (hour*64 + min)*64 + sec
      date = (year*16 + month)*32 + day
```

The command Watch in module System allows the user to inspect the amounts of allocated resources.

```
   PROCEDURE Watch*;
   BEGIN
      Texts.WriteString(W, "System.Watch"); Texts.WriteLn(W);
      Texts.WriteInt(W, Kernel.NofPages, 1); Texts.WriteString(W, " pages, ");
      Texts.WriteInt(W, Kernel.NofSectors, 1); Texts.WriteString(W, " sectors, ");
      Texts.WriteInt(W, Kernel.allocated, 1); Texts.WriteString(W, " bytes allocated");
      Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
   END Watch;
```

9. Device Drivers

9.1. Overview

Device drivers are procedures that constitute the immediate interface between hardware and software. They refer to those parts of the computer hardware that are usually called peripheral. Computers typically contain a system bus which transmits data among its different parts. Processor and memory are considered as its internal parts; the remaining parts, such as disk, keyboard, display, etc, are considered as external or peripheral, notwithstanding the fact that they are often contained in the same cabinet.

Such peripheral devices are connected to the system bus via special registers (data buffers) and transceivers (switches, buffers in the sense of digital electronics). These registers and transceivers are addressed by the processor in the same way as memory locations - they are said to be memory-mapped - and they constitute the hardware interface between processor bus and device. References to them are typically confined to specific driver procedures which constitute the software interface.

Drivers are inherently hardware specific, and the justification of their existence is precisely that they encapsulate these specifics and present to their clients an appropriate abstraction of the device. Evidently, this abstraction must still reflect the essential characteristics of the device, but not the details (such as e.g. the addresses of its interface registers).

Our justification to present the drivers connecting the Oberon system with the Ceres computer in detail is on the one hand the desire for completeness. But on the other hand it is also in recognition of the fact that their design represents an essential part of the engineering task in building a system. This part may look trivial from a conceptual point of view; it certainly is not so in practice.

In order to reduce the number of interface types, standards have been established. The Ceres computer also uses such interface standards, and we will concentrate on them in the following presentations. The following devices are considered:

1. Keyboard. It is considered as a serial device delivering one byte of input data per key stroke. It is connected by a serial line according to the RS-232 and ASCII (American Standard Code for Information Interchange) standards. The software is contained in module Input (Sect. 9.2).

2. Mouse. The Ceres-mouse is a pointing device delivering coordinates in addition to 3 key states. For Ceres-1 and Ceres-2, the interface is non-standard; for Ceres-3, a serial transmission is used relying on the RS-232 standard. The software is part of module Input.

3. Display. The interface to the display is an area of memory that contains the displayed information, one bit per pixel for the monochrome and four bits per pixel for a color display. The default size is 800 lines and 1024 dots per line. The software is module Display, which primarily consists of operations to draw frequently occurring patterns, so-called raster-ops (see Chap. 4).

4. Disk. The disk interface of Ceres-1 and Ceres-2 is non-standard and will not be described. The driver is contained in module Kernel. Ceres-3 operates without disk, but an optional hard disk can be connected through the standard SCSI interface described in Sect. 9.4.

5. Diskette. The 3.5" diskette uses the same non-standard interface as the hard disk. Software: module Diskette. This interface is not described in this book.

6. Serial line. This is the standard RS-232 serial interface allowing connections to be established between computers and to communicate over telephone lines via modems. The software interface is module V24 described in Sect. 9.2. Transmission rates go up to 19.2 Kbit/s.

7. Network. Ceres computers may be connected by a local area network using the RS-485 standard. It operates with a transmission rate of 230 Kbit/s, and information is sent in packets of up to 512 bytes in

the SDLC standard format. The interface software is module SCC described in Sect. 9.3; the interface hardware is a component called Serial Communications Controller.

8. Real-time clock. A clock providing time and date is included in the Ceres computers and is used to record the creation time and date of files. Its interface is non-standard, hardly of general interest, and contained in module Kernel.

In all driver modules described below, procedures SYSTEM.PUT, SYSTEM.GET, and SYSTEM.BIT are used to access the registers of the device interface. Their first parameter is a (long) integer specifying the address of the register.

9.2. The RS-232 ASCII Standard for Keyboard and Serial Line

All models of the Ceres computer are equipped with a component called a Universal Asynchronous Receiver and Transmitter (UART). It has an 8-bit parallel connection to the system bus, and two external connections, one for the transmitter and one for the receiver, resulting in a duplex transmission line. The UART performs the serialization of 8 bits upon sending and deserialization upon receiving. The 8 bits form a short packet, also called frame, and they are augmented by a start bit (always 1). There is no fixed time interval between consecutive packets. Therefore, transmission is called asynchronous. However, within the packet there exists a fixed frequency and transmission is synchronous. The clock rates of the transmitter and the receiver must therefore be the same. The start bit is used to trigger the shift clock of the receiver. There is also a minimal time interval guaranteed between the last bit of a packet and the start bit of the next packet. It is measured in terms of bit-times, and one may therefore think of a number of "stop-bits" as filling this interval. Finally, the packet may be augmented by a parity bit. The format of such a packet is shown in Fig. 9.1.

The Ceres computer uses the Signetics 2692 UART, which contains two (almost) independent line interfaces called channels A and B. It also makes it possible to select several parameters, such as the transmission rate, the number of data bits, of stop bits, and the type of parity check (none, even, odd). The chosen values are stored in the UART's parameter registers. The registers of primary importance are the data register and the status register.

When sending a byte, the processor must wait until the UART is ready. The ready state is asserted by bit 2 in the status register. Then the data byte is loaded into the data register, thereby automatically initiating transmission.

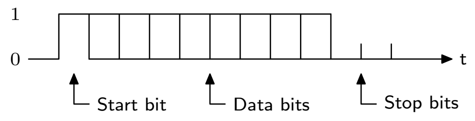

Fig. 9.1. ASCII character packet

For receiving a byte, one might use an analogous scheme. However, this would possibly introduce undesireable timing constraints and dependencies. We must consider the act of receiving a byte as part of the act of transmission, i.e. as an action intimately connected with sending a byte. Sending and receiving must be performed at the same time. The UART itself provides some decoupling through its data buffers. However, they contain only a single byte (or a small number of them), and it is highly desirable to achieve greater decoupling.

This is possible by providing larger data buffers - typically on the side of the receiver - and by letting the main processor transfer a byte into that buffer as soon as it has been received. This requires that the processor be borrowed for a brief moment, which is achieved by a processor interrupt. No polling of the UART status for input is necessary in this case.

Channel A of the UART is used for the keyboard (input only). It is handled by module Input, whose interface is listed below.

```
DEFINITION Input;
   PROCEDURE Available(): INTEGER;
   PROCEDURE Read(VAR ch: CHAR);
```

```
    PROCEDURE Mouse(VAR keys: SET; VAR x, y: INTEGER);
    PROCEDURE SetMouseLimits(w, h: INTEGER);
    PROCEDURE Time(): LONGINT;
  END Input.
```

The function procedure Available indicates the number of characters collected in the input buffer. If its value is greater than zero, Read delivers the next character (byte) from the buffered input stream. If no characters are available, Read implies a delay until a character has been received.

Module Input also contains the interface to the mouse (pointing device). The hardware contains two counters, one for the x-direction, one for the y-direction of movement. Procedure Mouse delivers the values of these counters and the state of the three buttons (keys). The latter are represented by the set element 0 for the right, 1 for the middle, and 2 for the left button. SetMouseLimits permits to determine the limiting coordinate values of the rectangle into which the mouse position is mapped and where the cursor is drawn. The position "wraps around" in both the horizontal and vertical directions. Changing the limits is useful when several displays are to be installed which are considered to lie in the same drawing plane, side by side.

The UART component also contains an additional counter - it is truly a multi-purpose chip - that is incremented every 1/300 s and may serve for measuring elapsed time. The value of this counter is delivered by procedure Time.

```
MODULE Input;   (*NW 5.10.86 / 15.11.90   Ceres-2*)
  IMPORT SYSTEM, Kernel;

  CONST N = 32;
    MOUSE = 0FFFFB000H; UART = 0FFFFC000H; ICU = 0FFFF9000H;

  VAR MW, MH: INTEGER; (*mouse limits*)
    T: LONGINT;  (*time counter*)
    n, in, out: INTEGER;
    buf: ARRAY N OF CHAR;

  PROCEDURE Available*(): INTEGER;
  BEGIN RETURN n
  END Available;

  PROCEDURE Read*(VAR ch: CHAR);
  BEGIN
    REPEAT UNTIL n > 0;
    DEC(n); ch := buf[out]; out := (out+1) MOD N
  END Read;

  PROCEDURE Mouse*(VAR keys: SET; VAR x, y: INTEGER);
    VAR u: LONGINT;
  BEGIN SYSTEM.GET(MOUSE, u);
    keys := {0,1,2} - SYSTEM.VAL(SET, u DIV 1000H MOD 8);
    x := SHORT(u MOD 1000H) MOD MW;
    y := SHORT(u DIV 10000H) MOD 819;
    IF y >= MH THEN y := 0 END
  END Mouse;

  PROCEDURE SetMouseLimits*(w, h: INTEGER);
  BEGIN MW := w; MH := h
  END SetMouseLimits;

  PROCEDURE Time*(): LONGINT;
    VAR lo, lo1, hi: CHAR; t: LONGINT;
  BEGIN
    REPEAT SYSTEM.GET(UART+28, lo); SYSTEM.GET(UART+24, hi);
      t := T - LONG(ORD(hi))*256 - ORD(lo); SYSTEM.GET(UART+28, lo1)
    UNTIL lo1 = lo;
    RETURN t
  END Time;

  PROCEDURE+ KBINT;
    VAR ch: CHAR;
  BEGIN SYSTEM.GET(UART+12, ch);  (*RHRA*)
    IF ch = 0FFX THEN HALT(24) END ;
    IF n < N THEN buf[in] := ch; in := (in+1) MOD N; INC(n) END
  END KBINT;

  PROCEDURE+ CTInt;
    VAR dmy: CHAR;
  BEGIN SYSTEM.GET(UART+60, dmy); (*stop timer*)
    INC(T, 0FFFFH); SYSTEM.GET(UART+56, dmy) (*restart timer*)
  END CTInt;

BEGIN MW := 1024; MH := 800;
  n := 0; in := 0; out := 0; T := 0FFFFH;
  Kernel.InstallIP(KBINT, 4); Kernel.InstallIP(CTInt, 0);
  SYSTEM.PUT(UART+16, 10X);  (*ACR*)
  SYSTEM.PUT(UART+ 8, 15X);  (*CRA enable*)
  SYSTEM.PUT(UART,    13X);  (*MR1A, RxRdy -Int, no parity, 8 bits*)
  SYSTEM.PUT(UART,     7X);  (*MR2A  1 stop bit*)
  SYSTEM.PUT(UART+ 4, 44X);  (*CSRA, rate = 300 bps*)
  SYSTEM.PUT(UART+52, 14X);  (*OPCR  OP4 = KB and OP3 = C/T int*)
  SYSTEM.PUT(UART+28, 0FFX); (*CTLR*)
  SYSTEM.PUT(UART+24, 0FFX); (*CTUR*)
  SYSTEM.GET(UART+56, buf[0]);  (*start timer*)
  SYSTEM.PUT(ICU + 4, 18X);  (*clear ICU IMR and IRR bits 0*)
  SYSTEM.PUT(ICU + 4, 1CX);  (*clear ICU IMR and IRR bits 4*)
END Input.
```

Some comments follow:

1. The fact that many properties of the UART can be parameterized leads to a longer initialization sequence. We refrain from explaining all the details specific to the Signetics 2692 part and refer to the pertinent device specifications. Here it may suffice to state that the RS-232 transmission for the keyboard uses a rate of 300 bit/s, 8 bits without parity check, and 1 stop bit.

2. An interrupt handler is declared in Oberon as a parameterless procedure marked with a plus sign. The keyboard interrupt handler KBINT receives a single character. If it is the abort character (cntl-shift-delete), a trap is induced by the statement HALT(24). This enables the operator to interrupt a computation when it appears to be non-terminating.

3. The keyboard buffer is designed as a circular buffer. When full, incoming characters are ignored (except abort).

4. The UART's timer (counter) has 16 bits and is accessed in two steps, reading the high and low half respectively. A 32 bit extension is provided in the form of variable T, which is incremented by 216 upon each timer interrupt, which occurs when the UART-counter t has reached zero. Since the UART counter is decremented every 1/300 s, the value delivered by procedure Time is computed as T - t.

5. Before an interrupt channel can be active, three conditions must be satisfied:

   1. The processor interrupt must be enabled. It normally is.
   2. The interrupt mechanism of the device must be enabled.
   3. The interrupt control unit (ICU) lying between devices and processor must let the respective interrupt signal pass.

The third condition is established by the last two statements of the module's initialization sequence, one instruction being necessary for the keyboard's interrupt, one for the timer's.

6. The mouse counter values serve as coordinates for the cursor to be displayed on the screen. For this reason, they are confined to the ranges 0 <= x < MW and 0 <= y < MH. The limit values can be set by procedure SetMouseLimits according to the dimension (resolution) of the available display.

Channel B of the UART leads to an external RS-232 (V24) connector. This serial line is not employed by the Oberon system and hence is freely available to the user. Its software interface is module V24.

```
DEFINITION V24;
  IMPORT SYSTEM;
  PROCEDURE Start(CSR, MR1, MR2: CHAR);
  PROCEDURE SetOP(s: SET);
  PROCEDURE ClearOP(s: SET);
  PROCEDURE IP(n: INTEGER): BOOLEAN;
  PROCEDURE SR(n: INTEGER): BOOLEAN;
  PROCEDURE Available(): INTEGER;
  PROCEDURE Receive(VAR x: SYSTEM.BYTE);
  PROCEDURE Send(x: SYSTEM.BYTE);
  PROCEDURE Break;
  PROCEDURE Stop;
END V24.
```

The channel's receiver and transmitter are started by calling procedure Start. It has three parameters whose values are codes for the transmission clock rate the parity mode, the number of bits per byte, and for the number of stop bits. Procedure Available denotes the number of bytes available (received) in the input buffer. Receive delivers the next byte of the sequence, and Send dispatches the byte specified by the parameter. SR yields the value of the specified bit in the status register, and Stop serves to turn off both transmitter and receiver.

The Signetics 2692 dual UART's exaggerated multi-purpose nature becomes apparent at this point: in addition to the two channels and a counter/timer, it also contains an input and an output register (7 and 8 bits respectively) with external connections (pins). On the Ceres computer, these signals are used in various ways and must not be used by the programmer, except the following:

input:	0	DCD	(data carrier detected)
	1	CTS	(clear to send)
	2	DSR	(data set ready)
output:	0	DTR	(data terminal ready)
	1	RTS	(request to send)

The meaning of these bits is derived from their use in connection with modems. Procedures SetOP and ClearOP serve to set and clear those bits of the UART's output register (OP) which are specified in their set parameter. Function procedure IP serves to test the specified bit in the UART's input register (IP). And finally, procedure Break serves to apply a break signal (0 value during at least 20 ms) to the serial line. The following table lists the principal registers of the UART.

RHRA/B	receiver holding register	received data
THRA/B	transmitter holding reg.	data to be transmitted
MR1A/B	mode register 1	Rx control, parity mode and type, no. of bits per byte
MR2A/B	mode register 2	channel mode, Tx control, stop bit length
CRA/B	command register	
CSRA/B	clock select register	receiver and transmitter clock rates
SRA/B	status register	RxRdy, TxRdy; overrun, parity, framing errors
OPCR	output port configuration register	
IPCR	input port change register	
ISR	interrupt status register	
IMR	interrupt mask register	

CTUR	counter/timer upper byte value
CTLR	counter/timer lower byte value

```
MODULE V24;  (*NW 18.3.89 / 19.1.91*)
   (*interrupt-driven UART channel B*)
   IMPORT SYSTEM, Kernel;

   CONST BufLen = 512;
      UART = 0FFFFC000H; ICU = 0FFFF9000H;

   VAR in, out: INTEGER;
      buf: ARRAY BufLen OF SYSTEM.BYTE;

   PROCEDURE+ Int;
   BEGIN SYSTEM.GET(UART+44, buf[in]); in := (in+1) MOD BufLen
   END Int;

   PROCEDURE Start*(CSR, MR1, MR2: CHAR);
   BEGIN in := 0; out := 0;  Kernel.InstallIP(Int, 2);
      SYSTEM.PUT(UART+40, 30X); (*CRB reset transmitter*)
      SYSTEM.PUT(UART+40, 20X); (*CRB reset receiver*)
      SYSTEM.PUT(UART+36, CSR); (*CSRB clock rate*)
      SYSTEM.PUT(UART+40, 15X); (*CRB enable Tx and Rx, pointer to MR1*)
      SYSTEM.PUT(UART+32, MR1); (*MR1B, parity, nof bits*)
      SYSTEM.PUT(UART+32, MR2); (*MR2B stop bits*)
      SYSTEM.PUT(UART+20, 20X); (*IMR  RxRdy Int enable*)
      SYSTEM.PUT(ICU + 4, 1AX); (*ICU  IMR and IRR bit 2*)
   END Start;

   PROCEDURE SetOP*(s: SET);
   BEGIN SYSTEM.PUT(UART+56, s)
   END SetOP;

   PROCEDURE ClearOP*(s: SET);
   BEGIN SYSTEM.PUT(UART+60, s)
   END ClearOP;

   PROCEDURE IP*(n: INTEGER): BOOLEAN;
   BEGIN RETURN SYSTEM.BIT(UART+52, n)
   END IP;

   PROCEDURE SR*(n: INTEGER): BOOLEAN;
   BEGIN RETURN SYSTEM.BIT(UART+36, n)
   END SR;

   PROCEDURE Available*(): INTEGER;
   BEGIN RETURN (in - out) MOD BufLen
   END Available;

   PROCEDURE Receive*(VAR x: SYSTEM.BYTE);
   BEGIN
      REPEAT UNTIL in # out;
      x := buf[out]; out := (out+1) MOD BufLen
   END Receive;

   PROCEDURE Send*(x: SYSTEM.BYTE);
   BEGIN
      REPEAT UNTIL SYSTEM.BIT(UART+36, 2);
      SYSTEM.PUT(UART+44, x)
   END Send;
```

```
    PROCEDURE Break*;
      VAR i: LONGINT;
    BEGIN SYSTEM.PUT(UART+40, 60X); i := 500000;
      REPEAT DEC(i) UNTIL i = 0;
      SYSTEM.PUT(UART+40, 70X)
    END Break;

    PROCEDURE Stop*;
    BEGIN SYSTEM.PUT(UART+20, 0); (*IMR disable Rx-Int*)
      SYSTEM.PUT(ICU + 4, 3AX)  (*ICU chan 2*)
    END Stop;
END V24.
```

9.3. The RS-485 SDLC Standard for a Network

The Ceres/Oberon System also features a network connection. The principal differences between the RS-232 line and the network connection are that of a point-to-point line vs. a bus with multiple taps, and that of asynchronous vs. synchronous transmission. Asynchronous transmission as described in the preceding section is uneconomical if transmission speeds beyond 20 Kbit/s are desired, because too much time is wasted between consecutive bytes. Synchronous transmission improves performance, and it is used by the Ceres computers for interconnection in a local area network.

Strictly speaking, the difference between so-called asynchronous and synchronous transmission lies in the packet length only, because the former uses synchronicity during the transmission of each byte, too. The price for longer packets lies in the need for more accurate clocks; clock accuracy limits packet length, unless some encoding scheme is used to transmit the clock together with data. The RS-485 and SDLC Standards do not specify such an encoding; the clock is not transmitted. It is fixed here to 230 Kbit/s, yielding about 30 Kbyte/s.

A direct consequence is that computation of the byte sequence and transmission of the packet cannot be interleaved due to the strict timing constraints. Since one byte must be sent every 30 us, the data of the entire packet must be ready before transmission is initiated.

The SDLC (Synchronous Data Link Control) standard specifies a fixed packet format of variable length. The role of the start bit is taken by a start byte, a so-called flag. It is followed by the data bytes, and the packet is terminated by another flag. The flag consists of 6 consecutive '1's. Hence, any occurrence of 6 consecutive '1's must not occur within the data section. The problem is solved by the transmitter automatically inserting and the receiver removing a zero bit after every occurrence of five consecutive ones. If the bit following the 5 ones is not a zero, a flag was received. This zero insertion (and deletion), as well as the pre- and postfixing of a flag, is performed automatically by the interface hardware component SCC (Zilog 8530).

In order to detect transmission errors, the transmitter computes a cyclic redundancy code (CRC) over the data and appends it to the data stream, just before the terminating flag. The receiver computes the same code and compares it with the received code. If the difference is not zero, a status bit is set which must be inspected for each received packet.

The SDLC Standard also requires that the first byte of the packet - the one after the flag - specify the receiver's address. This is necessary, because in a network the recipient is not automatically determined like in a point-to-point connection. Every station is therefore given a unique identification. Beyond this, we postulate some additional properties of packets. Each packet consist of a header followed by the data. The first 9 bytes constitute the header, of which the first is the destination address, the second byte denotes the sender's address, and the third a packet type. It is followed by two bytes indicating the packet length (in bytes). (The remaining four bytes are currently not used). The resulting packet format is shown in Fig. 9.2, and it is reflected by the data type Header.

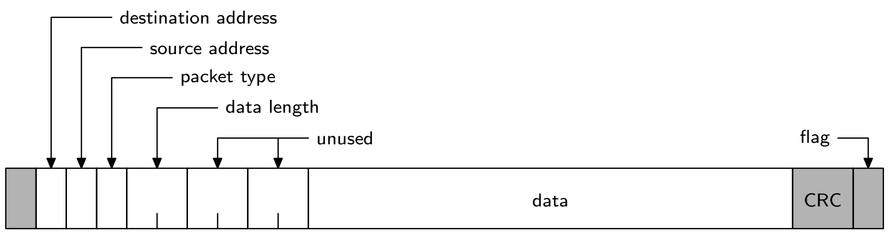

Fig. 9.2. Ceres-net packet format

```
DEFINITION SCC;
  TYPE Header =
      RECORD valid: BOOLEAN; dadr, sadr, typ: SHORTINT;
        len: INTEGER; (*of data following header*)
        destLink, srcLink: INTEGER  (*unused*)
      END ;

  PROCEDURE Start(filter: BOOLEAN);
  PROCEDURE Send(VAR head: Header; VAR buf: ARRAY OF SYSTEM.BYTE);
  PROCEDURE Available(): INTEGER;
  PROCEDURE ReceiveHead(VAR head: Header);
  PROCEDURE Receive(VAR x: SYSTEM.BYTE);
  PROCEDURE Skip(m: INTEGER);
  PROCEDURE Stop;
END SCC.
```

As in the case of the V24 interface, the receiver buffers the incoming data stream (without flags and CRC). Procedure Receive picks consecutive bytes from the buffer. The number of buffered bytes is given by procedure Available. The task of receiving is simplified by procedure ReceiveHead. It is called when a next packet is expected. The field valid has the meaning "packet has been received and header is valid".

Transmitter and receiver can be switched on and off by calls to procedures Start and Stop. The former features a Boolean parameter filter with the meaning "filter out packets which are not addressed to this station". The interface chip is capable of comparing the first header byte (destination address) with its own station's address (stored in a register), and to discard a packet upon mismatch. An active filter is of course the normal mode of operation, because in this mode discarded packets do not require interaction with the computer's processor.

The SCC-driver program is, as one expects, dominated by accesses to the device's registers. The primary function of these registers is indicated by the Table below; for further details we refer to the controller's data sheets. It must suffice to say that registers (except the data register) are accessed in two steps. First the register's number is sent to the control port, and thereafter its value is transferred. (Register number and value are time-multiplexed; see procedure PUT). The following table gives an overview of the available device registers:

Write-Registers

0	Command register
1	Transmit/receive interrupt and data transfer mode definition
2	Interrupt vector
3	Receive parameters and control
4	Transmit/receive miscellaneous parameters and modes
5	Transmit parameter and control
6	Sync characters or SDLC address field (filter)
7	Sync character or SDLC flag
8	Transmit buffer (data)
9	Master interrupt control
10	Miscellaneous transmitter/receiver control bits
11	Clock mode control

12	Baud rate generator time constant (low byte)
13	Baud rate generator time constant (high byte)
14	Miscellaneous control bits
15	External/Status interrupt control

Read-Registers

0	Transmit/receive buffer status
1	Status register (errors, end of frame)
2	Interrupt vector
3	Interrupts pending
8	Received data buffer
10	Status bits

```
MODULE SCC;  (*NW 13.11.87 / 22.8.90  Ceres-2*)
    IMPORT SYSTEM, Kernel;

    CONST BufLen = 2048;
        com = 0FFFFD008H; (*commands and status, SCC channel A*)
        dat = 0FFFFD00CH;
        DIPS   = 0FFFFFC00H;
        ICU    = 0FFFF9004H;
        RxCA = 0;  (*R0: Rx Char Available*)
        TxBE = 2;  (*R0: Tx Buffer Empty*)
        Hunt = 4;  (*R0: Sync/Hunt*)
        TxUR = 6;  (*R0: Tx UnderRun*)
        RxOR = 5;  (*R1: Rx OverRun*)
        CRC  = 6;  (*R1: CRC error*)
        EOF  = 7;  (*R1: End Of Frame*)

    TYPE Header* =
        RECORD valid*: BOOLEAN;
            dadr*, sadr*, typ*: SHORTINT;
            len*: INTEGER; (*of data following header*)
            destLink*, srcLink*: INTEGER  (*link numbers*)
        END ;

    VAR in, out: INTEGER;
        Adr: SHORTINT;
        SCCR3: CHAR;
        buf: ARRAY BufLen OF CHAR;

    PROCEDURE PUT(r: SHORTINT; x: SYSTEM.BYTE);
    BEGIN SYSTEM.PUT(com, r); SYSTEM.PUT(com, x)
    END PUT;

    PROCEDURE+ Int1;
        VAR del, oldin: INTEGER; stat: SET; dmy: CHAR;
    BEGIN SYSTEM.GET(dat, buf[in]);
        PUT(1, 0X); (*disable interrupts*)
        oldin := in; in := (in+1) MOD BufLen; del := 16;
        LOOP
            IF SYSTEM.BIT(com, RxCA) THEN del := 16;
                IF in # out THEN SYSTEM.GET(dat, buf[in]); in := (in+1) MOD BufLen
                ELSE SYSTEM.GET(dat, dmy)
                END
            ELSE SYSTEM.PUT(com, 1X); DEC(del);
                IF SYSTEM.BIT(com, EOF) & (del <= 0) OR (del <= -16) THEN EXIT END
            END
        END ;
```

```
   SYSTEM.PUT(com, 1X); SYSTEM.GET(com, stat);
   IF (RxOR IN stat) OR (CRC IN stat) OR (in = out) THEN
      in := oldin  (*reset buffer*)
   ELSE in := (in-2) MOD BufLen     (*remove CRC*)
   END ;
   SYSTEM.PUT(com, 30X);  (*error reset*)
   SYSTEM.PUT(com, 10X);  (*reset ext/stat interrupts*)
   PUT( 1,   8X);  (*enable Rx-Int on 1st char*)
   SYSTEM.PUT(com, 20X);  (*enable Rx-Int on next char*)
   PUT( 3, SCCR3);  (*enter hunt mode*)
END Int1;

PROCEDURE Start*(filter: BOOLEAN);
BEGIN in := 0; out := 0;
   IF filter THEN SCCR3 := 0DDX ELSE SCCR3 := 0D9X END ;
   SYSTEM.GET(DIPS, Adr); Adr := Adr MOD 40H;
   Kernel.InstallIP(Int1, 1);
   PUT( 9,  80X);  (*reset A, disable all interrupts*)
   PUT( 4,  20X);  (*SDLC mode*)
   PUT( 1,   0X);  (*disable all interrupts*)
   PUT( 2,   0X);  (*interrupt vector*)
   PUT( 3, SCCR3);  (*8bit, hunt mode, Rx-CRC on, adr search, Rx off*)
   PUT( 5, 0E1X);  (*8bit, SDLC, Tx-CRC on, Tx off*)
   PUT( 6,  Adr);  (*SDLC-address*)
   PUT( 7,  7EX);  (*SDLC flag*)
   PUT( 9,   6X);  (*master int on, no vector*)
   PUT(10, 0E0X);  (*FM0*)
   PUT(11, 0F7X);  (*Xtal, RxC = DPLL TxC = rate genL*)
   PUT(12,   6X);  (*lo byte of rate gen: Xtal DIV 16*)
   PUT(13,   0X);  (*hi byte of rate gen*)
   PUT(14, 0A0X);  (*DPLL = Xtal*)
   PUT(14, 0C0X);  (*FM mode*)
   PUT( 3, SCCR3);  (*Rx enable, enter hunt mode*)
   SYSTEM.PUT(com, 80X);  (*TxCRC reset*)
   PUT(15,   0X);  (*mask ext interrupts*)
   SYSTEM.PUT(com, 10X);
   SYSTEM.PUT(com, 10X); (*reset ext/status*)
   PUT( 1,   0X);  (*Rx-Int on 1st char off*)
   PUT( 9,  0EX);  (*no A reset, enable int, disable daisy chain*)
   PUT( 1,   8X);  (*enable Rx Int*)
   PUT(14,  21X);  (*enter search mode*)
   SYSTEM.PUT(ICU, 19X);  (*clear IRR and IMR bits, channel 1*)
END Start;

PROCEDURE SendPacket*(VAR head, buf: ARRAY OF SYSTEM.BYTE);
   VAR i, len: INTEGER;
BEGIN head[2] := Adr;
   len := ORD(head[5])*100H + ORD(head[4]);
   LOOP (*sample line*) i := 60;
      REPEAT DEC(i) UNTIL SYSTEM.BIT(com, Hunt) OR (i = 0);
      IF i > 0 THEN (*line idle*) EXIT END ;
      i := LONG(Adr)*128 + 800;  (*delay*)
      REPEAT DEC(i) UNTIL i = 0
   END ;
   Kernel.SetICU(0A2X);  (*disable interrupts!*)
   PUT( 5,  63X);  (*RTS, send 1s*)
   PUT( 5,  6BX);  (*RTS, Tx enable*)
```

```
      SYSTEM.PUT(com, 80X);      (*reset Tx-CRC*)
      SYSTEM.PUT(dat, ORD(head[1]));  (*send dest*)
      SYSTEM.PUT(com, 0C0X);     (*reset underrun/EOM flag*)
      REPEAT UNTIL SYSTEM.BIT(com, TxBE);
      i := 2;
      REPEAT SYSTEM.PUT(dat, head[i]); INC(i);
         REPEAT UNTIL SYSTEM.BIT(com, TxBE)
      UNTIL i = 10;
      i := 0;
      WHILE i < len DO
         SYSTEM.PUT(dat, buf[i]); INC(i); (*send data*)
         REPEAT UNTIL SYSTEM.BIT(com, TxBE)
      END ;
      REPEAT UNTIL SYSTEM.BIT(com, TxUR) & SYSTEM.BIT(com, TxBE);
      PUT( 5,  63X);  (*RTS, Tx disable, send 1s*)
      i := 300;
      REPEAT DEC(i) UNTIL i = 0;
      PUT( 5, 0E1X);  (*~RTS*)
      PUT( 1,   8X);  (*enable Rx-Int on 1st char*)
      PUT(14,  21X);  (*enter search mode*)
      SYSTEM.PUT(com, 20X); (*enable Rx-Int on next char*)
      PUT( 3, SCCR3);  (*enter hunt mode*)
      SYSTEM.PUT(ICU, 0A1X)  (*enable interrupts*)
   END SendPacket;

   PROCEDURE Available*(): INTEGER;
   BEGIN RETURN (in - out) MOD BufLen
   END Available;

   PROCEDURE Receive*(VAR x: SYSTEM.BYTE);
   BEGIN
      REPEAT UNTIL in # out;
      x := buf[out]; out := (out+1) MOD BufLen
   END Receive;

   PROCEDURE ReceiveHead*(VAR head: ARRAY OF SYSTEM.BYTE);
      VAR i: INTEGER;
   BEGIN
      IF (in - out) MOD BufLen >= 9 THEN head[0] := 1; i := 1;
         REPEAT Receive(head[i]); INC(i) UNTIL i = 10
      ELSE head[0] := 0
      END
   END ReceiveHead;

   PROCEDURE Skip*(m: INTEGER);
   BEGIN
      IF m <= (in - out) MOD BufLen THEN out := (out+m) MOD BufLen ELSE out := in END
   END Skip;

   PROCEDURE Stop*;
   BEGIN PUT(9, 80X);  (*reset SCCA*)
      SYSTEM.PUT(ICU, 39X); SYSTEM.PUT(ICU, 59X); (*reset IMR and IRR*)
   END Stop;

BEGIN Start(TRUE)
END SCC.
```

Some comments follow:

1. The sequence in which individual registers are initialized is essential for correct functioning. The lack of its specification in the part's documentation was a source of serious difficulties and headaches.

2. Some sections of the driver are very time-critical (particularly for Ceres-1). For example, after receiving an interrupt, the first byte must be read immediately. A queue of 3 bytes in the receiver hardware allows for enough time to disable interrupts, store the byte, and copy the buffer index (oldin) which is used as a reset point in case of a transmission error.

3. Before sending a packet, it must be verified that the line is free by testing the so-called hunt bit. If the line is busy, the line is polled again after a delay. The delay is influenced by the station's address, causing all stations to have a slightly different delay. Actual collisions can only be detected by the receiver through the CRC-check at the end of the packet.

4. After transmitting the last data byte, the line must be kept busy for transmitting CRC and flag, and for the receiver to terminate (stop bits!). This time span is in the order of 200us, which is too short for the timers' resolution, and hence must be programmed as a tight delay loop. The delay constant depends on the computer's clock rate and model. This is rather unfortunate.

5. The end of a packet is indicated by the EOF bit in the SCC's status register. Unfortunately it is not reliable. It sometimes signals the end prematurely. The situation is saved by testing a number of times while no further data bytes arrive. The resulting program section does not appear to be very neatly conceived; but software which fixes a hardware deficiency never does.

6. Procedure Skip serves to discard received data, namely the next m bytes. m is compared with the stored number of bytes given by n = (in-out) MOD BufLen, in order not to "overshoot". We leave the inclined reader to discover why the guard m <= n is correct, whereas m < n would be wrong.

9.4. A Disk Driver using the SCSI Interface

The Oberon System's procedural interface to the disk is represented by the two procedures Kernel.GetSector and Kernel.PutSector. Their details intimately depend on the disk controller used. Several standards have recently emerged for disk interfaces, and we therefore present one of them, namely the one called the Small Computer Systems Interface (SCSI), which is designed with sufficient generality to be also usable for devices other than disks, and even for fast data exchange between computers.

The Ceres-3 computer is equipped with this interface, and hence disks (or other devices) can be connected externally. We emphasize that SCSI constitutes a bus, and not only a point-to-point connection. However, at most 8 partners may be interconnected.

The SCSI signal bus consist of 8 data lines (plus parity) and several control lines (namely SEL, BSY, REQ, ACK, C/D, MSG, I/O, RST, and ATN). Hence, the 8 (or 9) bits composing a byte are transmitted in parallel. Bytes are transmitted asynchronously, i.e. without any timing dependencies within their sequence. This is possible with the aid of the two control signals REQ and ACK, which are used in the following way.

In order to transmit a byte from a master to a server, the latter first waits until the master applies the byte to the data lines and signals availability of the byte by asserting the REQ signal. The server then samples (reads) the data lines, asserts the ACK signal, and waits until the master deasserts (resets) the REQ signal. Finally, the server deasserts the ACK signal. The REQ signal is driven (determined) by the master and inspected by the server, the ACK signal is driven by the server and polled by the master. This sequence of actions is called a "handshake", and is used when transmitting a byte in either direction (see Fig. 9.3.). In the program listed subsequently, this transmission protocol is implemented by the two procedures Send (a sequence of n bytes) and Receive (a single byte).

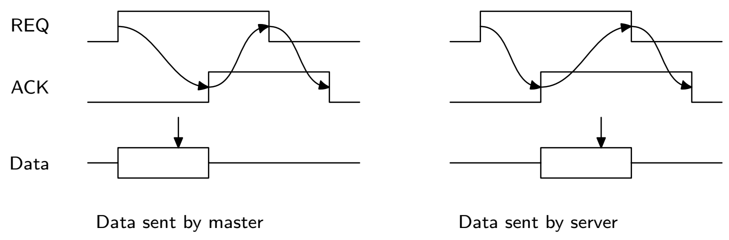

Fig. 9.3. The SCSI 'handshake'

In order to perform an entire transaction, such as the reading or writing of a disk sector, the SCSI Standard prescribes six phases (apart from neutral, or bus free). The agent starting the transaction, usually the computer, is called initiator, and the addressee is called the target. In systems where only one agent has the ability to act as initiator, the first action is to select a target. We recall that the SCSI Standard defines not a line, but rather a bus; hence the targeted partner must first be notified (selected). This selection phase is characterized by the control signal SEL being asserted, concurrently with one of the 8 data lines. The addressed device responds by asserting the control signal BSY. In the program listed below, the selection phase is described by procedure Select, which includes a timeout for the case that the addressed device does not respond (or does not exist). From this point onwards, the target acts as master, and the initiator as server.

The second phase is the command phase, in which the selected target requests, and the initiator replies by sending a command encoded as a sequence of bytes. This phase is identified by the C/D (command/data) signal being asserted and the MSG signal being deasserted. The command consists of a sequence of (at least 6) bytes. The first byte is the operation code, or command byte, the remaining ones its parameters. In the case of the target being a disk controller, the first byte is followed by 3 bytes specifying the sector address (most significant byte first), a byte specifying the number of disk sectors involved and a device specific byte.

If the command is acceptable to the target, the third phase is entered. This is the data phase, identified by both C/D and MSG signals being deasserted. Hence, the initiator waits for the REQ signal being asserted, and then tests the C/D signal. If it is not deasserted, the data phase is skipped. Otherwise, the specified number of data bytes are transmitted.

Then follows the status phase in which the target sends status information, typically a single byte. Zero indicates that the requested command had been completed.

The last phase is called the message phase, identified by both the C/D and MSG signals being asserted. In this phase, a message is transmitted from the target to the initiator. It has no significance in our application, but must be received anyway according to the rules of the Standard.

In systems where several agents have the capability to act as initiators, the danger exists that some of them may enter the selection phase at the very same moment. The consequences would be unpredictable. In order to avoid this unacceptable possibility, selection must be preceded by the arbitration phase. It is noteworthy that no single, central agency is required for granting bus access to one of the concurrent competitors. Arbitration is called distributed and proceeds as follows:

First, the initiator asserts the BSY signal and, at the same time, the data line corresponding to the initiator's address. If within a certain time span (arbitration delay = 200ns) no data line with higher number is asserted (by a competitor), the initiator is allowed to enter the selection phase by asserting SEL. Otherwise BSY is deasserted to give priority to the higher ranking competitor. We now understand the reason why only 8 instead of 28 devices can be connected to the SCSI bus; each data line must be associated with exactly one device.

The values of the signals characterizing the various phases are given in the following table:

Phase	SEL	BSY	C/D	MSG	I/O
neutral	0	0	x	x	x
arbitration	0	1	0	0	0
selection	1	0	0	0	0

command	0	1	1	0	0
data	0	1	0	0	0/1
status	0	1	1	0	1
message	0	1	1	1	0/1

The principal interface registers and their bit assignments are shown in Fig. 9.4. The full standard specifies further registers and facilities which are not relevant for our purpose.

1. When applying data to the bus, the ODR register is connected to the bus only if the following conditions are met: Bit 0 (DB) in the ICR is asserted, and the phases of initiator and target match.

2. A phase match exists, if the phase signals on the bus (I/O, C/D, MSG), as determined by the target, have the same values as are stored in the initiator's target command register. A phase mismatch is indicated in the BSR register (PHM).

3. RST ist the reset signal, DP the data bus parity, PCK indicates a parity check, and TAR specifies target mode of operation.

In the case of a disk drive as device (target), many commands are usually available. The ones of concern to us are a read and a write sector command. As explained above, the first byte always specifies the operation. It is followed by 3 bytes giving the sector number, one byte indicating the number of consecutive sectors to be transmitted, and a zero byte.

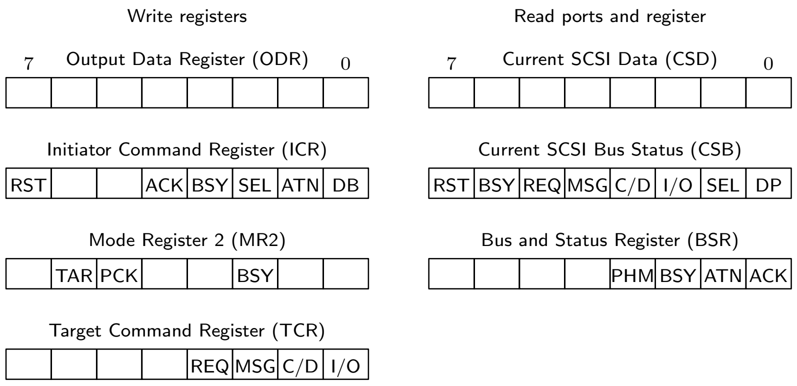

Fig. 9.4. Principal SCSI registers and bit assignments

```
MODULE Disk;  (*NW 12.4.90 / 2.10.90*)
    IMPORT SYSTEM, Kernel;

    CONST SS = 1024; devno = 0; maxSector = 102432;
        SCSI = 0FFFF8000H;
        ODR = SCSI;  (*output data register*)
        CSD = SCSI;  (*current SCSI data*)
        ICR = SCSI + 4;  (*initiator command register*)
        MR2 = SCSI + 8;  (*mode register*)
        TCR = SCSI + 12;  (*target command register*)
        SER = SCSI + 16;  (*select enable register*)
        CSB = SCSI + 16;  (*current SCSI bus status*)
        BSR = SCSI + 20;  (*bus status*)
        RPI = SCSI + 28;  (*reset parity and interrupts*)

    TYPE DiskAdr = LONGINT;
        Buffer = ARRAY 256 OF LONGINT;

    VAR stat*, msg: CHAR;

    PROCEDURE Select(n: LONGINT);
    BEGIN
        REPEAT UNTIL ~SYSTEM.BIT(CSB, 6);   (*~BSY*)
```

```
   REPEAT UNTIL ~SYSTEM.BIT(CSB, 1);   (*~SEL*)
   SYSTEM.PUT(ODR, {n}); SYSTEM.PUT(ICR, 5); (*SEL*)
   REPEAT UNTIL SYSTEM.BIT(CSB, 6)  (*BSY*)
END Select;

PROCEDURE Receive(VAR x: CHAR);
BEGIN
   REPEAT UNTIL SYSTEM.BIT(CSB, 5);   (*REQ*)
   SYSTEM.GET(CSD, x);
   SYSTEM.PUT(ICR, 10H);  (*assert ACK*)
   REPEAT UNTIL ~SYSTEM.BIT(CSB, 5);   (*~REQ*)
   SYSTEM.PUT(ICR, 0);   (*deassert ACK*)
END Receive;

PROCEDURE Send(x: CHAR);
BEGIN
   REPEAT UNTIL SYSTEM.BIT(CSB, 5);   (*REQ*)
   SYSTEM.PUT(ODR, x);
   SYSTEM.PUT(ICR, 11H);  (*assert ACK*)
   REPEAT UNTIL ~SYSTEM.BIT(CSB, 5);   (*REQ*)
   SYSTEM.PUT(ICR, 1)   (*deassert ACK*)
END Send;

PROCEDURE Reset*;
BEGIN SYSTEM.PUT(ICR, 80X); SYSTEM.PUT(TCR, 0); SYSTEM.PUT(ICR, 0);
   SYSTEM.PUT(MR2, 20X); SYSTEM.GET(RPI, stat)
END Reset;

PROCEDURE GetSector*(src: DiskAdr; VAR dest: Kernel.Sector);
   VAR adr, limit: LONGINT; x: CHAR;
BEGIN INC(src, src);
   SYSTEM.GET(RPI, x); (*reset parity*) Select(devno);
   SYSTEM.PUT(TCR, 2); SYSTEM.PUT(ICR, 1);
   Send(8X); Send(CHR(src DIV 10000H)); Send(CHR(src DIV 100H)); Send(CHR(src));
   Send(2X); Send(0X);
   SYSTEM.PUT(TCR, 1); SYSTEM.PUT(ICR, 0);
   adr := SYSTEM.ADR(dest); limit := adr + SS;
   LOOP Receive(x);
      IF ~SYSTEM.BIT(CSB, 3) THEN SYSTEM.PUT(adr, x); INC(adr)
      ELSE stat := x; EXIT
      END ;
      IF adr = limit THEN Receive(stat); EXIT END
   END ;
   Receive(msg); SYSTEM.PUT(TCR, 0); SYSTEM.PUT(ICR, 0)
END GetSector;

PROCEDURE PutSector*(dest: DiskAdr;VAR  src: Kernel.Sector);
   VAR adr, limit: LONGINT; x: CHAR;
BEGIN INC(dest, dest); Select(devno);
   SYSTEM.PUT(TCR, 2); SYSTEM.PUT(ICR, 1);
   Send(0AX); Send(CHR(dest DIV 10000H)); Send(CHR(dest DIV 100H));
   Send(CHR(dest));
   Send(2X); Send(0X);
   SYSTEM.PUT(TCR, 0); adr := SYSTEM.ADR(src); limit := adr + SS;
   REPEAT SYSTEM.GET(adr, x); Send(x); INC(adr)UNTIL adr = limit;
   Receive(stat); Receive(msg);
   SYSTEM.PUT(TCR, 0); SYSTEM.PUT(ICR, 0)
END PutSector;
```

```
    PROCEDURE Sense*;
      VAR x: CHAR;
    BEGIN Select(devno); SYSTEM.PUT(TCR, 2); SYSTEM.PUT(ICR, 1);
      Send(3X); Send(0X); Send(0X); Send(0X); Send(0X); Send(0X);
      REPEAT Receive(stat) UNTIL SYSTEM.BIT(CSB, 3);
      Receive(msg); SYSTEM.PUT(TCR, 0); SYSTEM.PUT(ICR, 0)
    END Sense;
END Disk.
```

10. The Network

10.1. Introduction

Workstations are typically, but not always, connected in a local environment by a network. There exist two basically different views of the architecture of such nets. The more demanding view is that all connected stations constitute a single, unified workspace (also called address-space), in which the individual processors operate. It implies the demand that the "thin" connections between processors are hidden from the users. At worst they might become apparent through slower data access rates between the machines. To hide the difference between access within a computer and access between computers is regarded primarily as a challenge to implementors.

The second, more conservative view, assumes that individual workstations are, although connected, essentially autonomous units which exchange data infrequently. Therefore, access of data on partner stations is initiated by explicit transfer commands. Commands handling external access are not part of the basic system, but rather are implemented in modules that might be regarded as applications.

In the Oberon System, we adhere to this second view, and in this chapter, we describe the module *Net*, which is an autonomous command module based on the network driver SCC presented in Section 9.3. It can be activated on any station connected in a network, and all of them are treated as equals. Such a set of loosely coupled stations may well operate in networks with moderate transmission rates and therefore with low-cost hardware interfaces and twisted-pair wires.

An obvious choice for the unit of transferred data is the file. The central theme of this chapter is therefore file transfer over a network. Some additional facilities offered by a dedicated server station will be the subject of Chapter 11. The commands to be presented here are a few only: *SendFiles*, *ReceiveFiles*, and *SendMsg*.

As explained in Chapter 2, Oberon is a single-process system where every command monopolizes the processor until termination. When a command involves communication over a network, (at least) two processors are engaged in the action at the same time. The Oberon paradigm therefore appears to exclude such cooperation; but fortunately it does not, and the solution to the problem is quite simple.

Every command is initiated by a user operating on a workstation. For the moment we call it the *master* (of the command under consideration). The addressed station - obviously called the *server* - must be in a state where it recognizes the command in order to engage in its execution. Since the command - called a *request* - arrives in encoded form over the network, an Oberon task represented by a handler procedure must be inserted into the event polling loop of the system. Such a handler must have the general form

```
IF event present THEN handle event END
```

The guard, in this case, must imply that a request was received from the network. We emphasize that the event is sensed by the server only after the command currently under execution, if any, has terminated. However, data arrive at the receiver immediately after they are sent by the master. Hence, any sizeable delay is inherently inadmissible, and the Oberon metaphor once again appears to fail. It does not fail, however, because the unavoidable, genuine concurrency of sender and receiver action is handled within the driver module which places the data into a buffer. The driver is activated by an interrupt, and its receiver buffer effectively decouples the partners and removes the stringent timing constraints. All this remains completely hidden within the driver module.

10.2. The Protocol

If more than a single agent participates in the execution of a command, a convention must be established and obeyed. It defines the set of requests, their encoding, and the sequence of data exchanges that follow. Such a convention is called a *protocol*. Since in our metaphor, actions initiated by the master and the server strictly follow each other in alternation, the protocol can be defined using EBNF (extended Backus-Naur formalism), well-known from the syntax specification of languages.

Items originating from the master will be written with normal font, those originating from the server appear in italics.

A simple form of the *ReceiveFile* request is defined as follows and will be refined subsequently:

ReceiveFile = SND filename (*ACK data* | *NAK*).

Here, the symbol SND represents the encoded request that the server send the file specified by the file name. ACK signals that the request is honoured and the requested data follow. The NAK symbol indicates that the requested file cannot be delivered. The transaction clearly consists of two parts, the request and the reply, one from each partner.

This simple-minded scheme fails because of the limitation of the size of each transmitted portion imposed by the network driver. We recall that module SCC restricts the data of each packet to 512 bytes. Evidently, files must be broken up and transmitted as a sequence of packets. The reason for this restriction is transmission reliability. The break-up allows the partner to confirm correct receipt of a packet by returning a short acknowledgement. Each acknowledgement also serves as request for the next packet. An exception is the last acknowledgement following the last data portion, which is characterized by its length being less than the admitted maximum. The revised protocol is defined as

ReceiveFile = SND filename (*DAT data* ACK {*DAT data* ACK} | *NAK*).

We now recall that each packet as defined in Section 9.3. is characterized by a type in its header. The symbols SND, DAT, ACK, and NAK indicate this packet type. The data portions of ACK and NAK packets are empty.

The revised protocol fails to cope with transmission errors. Correct transmission is checked by the driver through a cyclic redundancy check (CRC), and an erroneous packet is simple discarded. This implies that a receiver must impose a timing constraint. If an expected packet fails to arrive within a given time period (timeout), the request must be repeated. In our case, a request is implied by an acknowledgement. Hence, the acknowledgement must specify whether the next (normal case) or the previously requested (error case) packet must be sent. The solution is to attach a sequence number to each acknowledgement and to each data packet. These numbers are taken modulo 8, although in principle modulo 2 would suffice.

With the addition of a user identification and a password to every request, and of an alternate reply code NPR for "no permission", the protocol reaches its final form:

ReceiveFile = SND username password filename (*datastream* | *NAK* | *NPR*).
datastream = DAT_0 *data* ACK_1 {DAT_i *data* ACK_{i+1}}.

The protocol for file transmission from the master to the server is defined similarly:

SendFile = REC username password filename (*ACK0 datastream* | *NAK* | *NPR*).
datastream = DAT_0 data ACK_1 {DAT_i data ACK_{i+1}}.

The third request listed above, SendMsg, does not refer to any file, but merely transmits and displays a short message. It is included here for testing the link between two partners and perhaps for visibly acknowledging a rendered service by the message "done", or "thank you".

SendMsg = MSG message *ACK*.

10.3. Station Addressing

Every packet must carry a destination address as well as the sender's address. Addresses are station numbers. It would certainly be inconvenient for a user to remember the station number of a desired partner. Instead, the use of symbolic names is preferred. We have become accustomed to use the partner's initials for this purpose.

The source address is inserted automatically into packet headers by the driver. It is obtained from a dip switch set when a computer is installed and connected. But where should the destination address come from? From the start we reject the solution of an address table in every workstation because of the potential inconsistencies. The concept of a centralized authority holding a name/address dictionary is equally unattractive, because of the updates required whenever a person uses a different computer. Also, we have started from the premise to keep all participants in the network equal.

The most attractive solution lies in a decentralized name service. It is based on the broadcast facility, i.e. the possibility to send a packet to all connected stations, bypassing their address filters with a special destination address (-1). The broadcast is used for emitting a name request containing the desired partner's symbolic name. A station receiving the request returns a reply to the requester, if that name matches its own symbolic name. The requester then obtains the desired partner's address from the source address field of the received reply. The corresponding simple protocol is:

```
NameRequest = NRQ partnername [NRS].
```

Here, the already mentioned timeout facility is indispensible. The following summarizes the protocol developed so far:

```
protocol =    {request}.
request =     ReceiveFile | SendFile | SendMsg | NameRequest.
```

The overhead incurred by name requests may be reduced by using a local address dictionary. In practice, a single entry is satisfactory. A name request is then needed whenever the partner changes.

10.4. The Implementation

Module *Net* is an implementation of the facilities outlined above. The program is listed below. It starts with a number of auxiliary, local procedures. They are followed by procedure Serve which is to be installed as an Oberon Task, and the commands *SendFiles, ReceiveFiles*, and *SendMsg*, each of which has its counterpart within procedure *Serve*. At the end are the commands for starting and stopping the server facility.

For a more detailed presentation we select procedure *ReceiveFiles*. It starts out by reading the first parameter which designates the partner station from the command line. Procedure *FindPartner* issues the name request, unless the partner's address has already been determined by a previous command. The global variable partner records a symbolic name (id) whose address is stored in the destination field of the global variable head0, which is used as header in every packet sent by procedure *SCC.SendPacket*. The variable partner may be regarded as a name cache with a single entry and with the purpose of reducing the number of issued name requests.

If the partner has been identified, the next parameter is read from the command line. It is the name of the file to be transmitted. If the parameter has the form *name0:name1*, the file stored on the server as *name0.name1* is fetched and stored locally as name1. Hence, name0 serves as a prefix of the file name on the server station.

Thereafter, the request parameters are concatenated in the local buffer variable *buf*. They are the user's name and password followed by the file name. (User name and password remain unused by the server presented here). The command package is dispatched by the call *Send(SND, k, buf)*, where *k* denotes the length of the command parameter string. Then the reply packet is awaited by calling *ReceiveHead*. If the received packet's type is DAT with sequence number 0, a new file is established. Procedure *ReadData* receives the data and stores them in the new file, obeying the protocol defined in Section 10.2. This process is repeated for each file specified in the list of file names in the command line.

Procedure *ReceiveHead(T)* receives packets and discards them until one arrives from the partner from which it is expected. The procedure represents an input filter in addition to the one provided by the hardware. It discriminates on the basis of the packets' source address, whereas the hardware filter discriminates on the basis of the destination address. If no packet arrives within the allotted time T, a type code -1 is returned, signifying a timeout.

Procedure *ReceiveData* checks the sequence numbers of incoming data packets (type 0 - 7). If an incorrect number is detected, an ACK-packet with the previous sequence number is returned (type 16 - 23), requesting a retransmission. At most two retries are undertaken. This seems to suffice considering that also the server does not accept any other requests while being engaged in the transmission of a file.

The part corresponding to *ReceiveFiles* within procedure *Serve* is guarded by the condition *head1.typ = SND*. Variable *head1* is the recipient of headers whenever a packet is received by *ReceiveHead*. First, the request's parameters are scanned. *Id* and *pw* are ignored. Then the requested file is opened. If it exists, the transmission is handled by *ReceiveData*'s counterpart, procedure *SendData*. The time limit for receiving the next request is *T1*, whereas the limit of *ReceiveData* for receiving the next data packet is *T0*. *T1* is roughly *T0* multiplied by the maximum number of possible (re)transmissions. Before disengaging itself from a transaction, the sender of data waits until no further retransmission requests can be expected to arrive. The value *T0* (300) corresponds to 1s; the time for transmission of a packet of maximum length is about 16ms.

Procedure *SendFiles* is designed analogously; its counterpart in the server is guarded by the condition *head1.typ = REC*. The server accepts the request only if its state is unprotected (global variable *protected*). Otherwise the request is negatively acknowledged with an NPR packet. We draw attention to the fact that procedures *SendData* and *ReceiveData* are both used by command procedures as well as by the server.

```
MODULE Net;  (*NW 3.7.88 / 25.8.91*)
    IMPORT SCC, Files, Viewers, Texts, TextFrames, MenuViewers, Oberon;

        CONST PakSize = 512;
        T0 = 300; T1 = 1000;  (*timeouts*)

        ACK = 10H; NAK = 25H; NPR = 26H; (*acknowledgements*)
        NRQ = 34H; NRS = 35H; (*name request, response*)
        SND = 41H; REC = 42H; MSG = 44H;

    VAR W: Texts.Writer;
        Server: Oberon.Task;
        head0, head1: SCC.Header;
        partner, dmy: ARRAY 8 OF CHAR;
        protected: BOOLEAN;  (*write-protection*)

    PROCEDURE SetPartner(VAR name: ARRAY OF CHAR);
    BEGIN head0.dadr := head1.sadr; COPY(name, partner)
    END SetPartner;

    PROCEDURE Send(t: SHORTINT; L: INTEGER; VAR data: ARRAY OF CHAR);
    BEGIN head0.typ := t; head0.len := L; SCC.SendPacket(head0, data)
    END Send;

    PROCEDURE ReceiveHead(timeout: LONGINT);
        VAR time: LONGINT;
    BEGIN time := Oberon.Time() + timeout;
        LOOP SCC.ReceiveHead(head1);
            IF head1.valid THEN
                IF head1.sadr = head0.dadr THEN EXIT ELSE SCC.Skip(head1.len) END
            ELSIF Oberon.Time() >= time THEN head1.typ := -1; EXIT
            END
        END
    END ReceiveHead;

    PROCEDURE FindPartner(VAR name: ARRAY OF CHAR; VAR res: INTEGER);
        VAR time: LONGINT; k: INTEGER;
    BEGIN SCC.Skip(SCC.Available()); res := 0;
        IF name # partner THEN k := 0;
            WHILE name[k] > 0X DO INC(k) END ;
            head0.dadr := -1; Send(NRQ, k+1, name); time := Oberon.Time() + T1;
            LOOP SCC.ReceiveHead(head1);
                IF head1.valid THEN
                    IF head1.typ = NRS THEN SetPartner(name); EXIT
                    ELSE SCC.Skip(head1.len)
                    END
                ELSIF Oberon.Time() >= time THEN res := 1; partner[0] := 0X; EXIT
                END
            END
        END
    END FindPartner;

    PROCEDURE AppendS(VAR s, d: ARRAY OF CHAR; VAR k: INTEGER);
        VAR i: INTEGER; ch: CHAR;
    BEGIN i := 0;
        REPEAT ch := s[i]; d[k] := ch; INC(i); INC(k) UNTIL ch = 0X
    END AppendS;

    PROCEDURE AppendW(s: LONGINT; VAR d: ARRAY OF CHAR;
            n: INTEGER; VAR k: INTEGER);
        VAR i: INTEGER;
    BEGIN i := 0;
        REPEAT d[k] := CHR(s); s := s DIV 100H; INC(i); INC(k) UNTIL i = n
    END AppendW;

    PROCEDURE PickS(VAR s: ARRAY OF CHAR);
        VAR i: INTEGER; ch: CHAR;
    BEGIN i := 0;
        REPEAT SCC.Receive(ch); s[i] := ch; INC(i) UNTIL ch = 0X
    END PickS;

    PROCEDURE PickQ(VAR w: LONGINT);
        VAR c0, c1, c2: CHAR; s: SHORTINT;
    BEGIN SCC.Receive(c0); SCC.Receive(c1); SCC.Receive(c2); SCC.Receive(s);
        w := s; w := ((w * 100H + LONG(c2)) * 100H + LONG(c1)) * 100H + LONG(c0)
    END PickQ;

    PROCEDURE SendData(F: Files.File);
        VAR k: INTEGER;
            seqno: SHORTINT; x: CHAR;
            len: LONGINT;
            R: Files.Rider;
            buf: ARRAY PakSize OF CHAR;
    BEGIN Files.Set(R, F, 0); len := 0; seqno := 0;
        LOOP k := 0;
            LOOP Files.Read(R, x);
                IF R.eof THEN EXIT END ;
                buf[k] := x; INC(k);
                IF k = PakSize THEN EXIT END
            END ;
            REPEAT Send(seqno, k, buf); ReceiveHead(T1)
            UNTIL head1.typ # seqno + ACK;
            seqno := (seqno + 1) MOD 8; len := len + k;
            IF head1.typ # seqno + ACK THEN
                Texts.WriteString(W, " failed"); EXIT
            END ;
            IF k < PakSize THEN EXIT END
        END ;
        Texts.WriteInt(W, len, 7)
    END SendData;

    PROCEDURE ReceiveData(F: Files.File; VAR done: BOOLEAN);
        VAR k, retry: INTEGER;
```

```
        seqno: SHORTINT; x: CHAR;
        len: LONGINT;
        R: Files.Rider;
BEGIN Files.Set(R, F, 0); seqno := 0; len := 0; retry := 2;
    LOOP
        IF head1.typ = seqno THEN
            seqno := (seqno + 1) MOD 8; len := len + head1.len; retry := 2;
            Send(seqno + ACK, 0, dmy); k := 0;
            WHILE k < head1.len DO
                SCC.Receive(x); Files.Write(R, x); INC(k)
            END ;
            IF k < PakSize THEN done := TRUE; EXIT END
        ELSE DEC(retry);
            IF retry = 0 THEN
                Texts.WriteString(W, " failed"); done := FALSE; EXIT
            END ;
            Send(seqno + ACK, 0, dmy)
        END ;
        ReceiveHead(T0)
    END ;
    Texts.WriteInt(W, len, 7)
END ReceiveData;

PROCEDURE reply(msg: INTEGER);
BEGIN
    CASE msg OF
          0:
        | 1: Texts.WriteString(W, " no link")
        | 2: Texts.WriteString(W, " no permission")
        | 3: Texts.WriteString(W, " not done")
        | 4: Texts.WriteString(W, " not found")
        | 5: Texts.WriteString(W, " no response")
    END ;
    Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
END reply;

PROCEDURE* Serve;
    VAR i: INTEGER;
        done: BOOLEAN; ch: CHAR;
        F: Files.File;
        pw: LONGINT;
        Id: ARRAY 10 OF CHAR;
        FileName: ARRAY 32 OF CHAR;
BEGIN SCC.ReceiveHead(head1);
IF head1.valid THEN
    IF head1.typ = SND THEN
        PickS(Id); PickQ(pw); PickS(FileName);
        Texts.WriteString(W, Id); Texts.Write(W, " "); Texts.WriteString(W, FileName);
        F := Files.Old(FileName);
        IF F # NIL THEN
            Texts.WriteString(W, " sending"); SetPartner(Id);
            Texts.Append(Oberon.Log, W.buf); SendData(F)
        ELSE Send(NAK, 0, dmy); Texts.Write(W, "~")
        END ;
        reply(0)
    ELSIF head1.typ = REC THEN
        PickS(Id); PickQ(pw); PickS(FileName);
```

```
      IF ~protected THEN
        Texts.WriteString(W, Id); Texts.Write(W, " "); Texts.WriteString(W, FileName);
        F := Files.New(FileName);
        IF F # NIL THEN
          Texts.WriteString(W, " receiving"); SetPartner(Id);
          Texts.Append(Oberon.Log, W.buf);
          Send(ACK, 0, dmy); ReceiveHead(T0); ReceiveData(F, done);
          IF done THEN Files.Register(F) END
        ELSE Send(NAK, 0, dmy); Texts.Write(W, "~")
        END ;
        reply(0)
      ELSE Send(NPR, 0, dmy)
      END
    ELSIF head1.typ = MSG THEN i := 0;
      WHILE i < head1.len DO SCC.Receive(ch); Texts.Write(W, ch); INC(i) END ;
      Send(ACK, 0, dmy); reply(0)
    ELSIF head1.typ = NRQ THEN i := 0;
      LOOP SCC.Receive(ch); Id[i] := ch; INC(i);
        IF ch = 0X THEN EXIT END ;
        IF i = 7 THEN Id[7] := 0X; EXIT END
      END ;
      WHILE i < head1.len DO SCC.Receive(ch); INC(i) END ;
      IF Id = Oberon.User THEN SetPartner(Id); Send(NRS, 0, dmy) END
    ELSE SCC.Skip(head1.len)
    END
  END
  END Serve;

  PROCEDURE GetPar1(VAR S: Texts.Scanner);
  BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S)
  END GetPar1;

  PROCEDURE GetPar(VAR S: Texts.Scanner; VAR end: LONGINT);
    VAR T: Texts.Text; beg, tm: LONGINT;
  BEGIN Texts.Scan(S);
    IF (S.class = Texts.Char) & (S.c = "^") THEN
      Oberon.GetSelection(T, beg, end, tm);
      IF tm >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S) END
    ELSE end := Oberon.Par.text.len
    END
  END GetPar;

  PROCEDURE SendFiles*;
    VAR k: INTEGER;
      end: LONGINT;
      S: Texts.Scanner;
      F: Files.File;
      name: ARRAY 32 OF CHAR;
      buf: ARRAY 64 OF CHAR;
  BEGIN GetPar1(S);
    IF S.class = Texts.Name THEN
      FindPartner(S.s, k);
      IF k = 0 THEN
        GetPar(S, end);
        LOOP
          IF S.class # Texts.Name THEN EXIT END ;
          Texts.WriteString(W, S.s); k := 0; AppendS(S.s, name, k);
```

```
            IF S.nextCh = ":" THEN (*prefix*)
                Texts.Scan(S); Texts.Scan(S);
                IF S.class = Texts.Name THEN
                        name[k-1] := "."; AppendS(S.s, name, k);
                        Texts.Write(W, ":"); Texts.WriteString(W, S.s)
                END
            END ;
            F := Files.Old(S.s);
            IF F # NIL THEN k := 0;
                AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
                AppendS(name, buf, k); Send(REC, k, buf); ReceiveHead(T0);
                IF head1.typ = ACK THEN
                        Texts.WriteString(W, " sending"); Texts.Append(Oberon.Log, W.buf);
                        SendData(F); reply(0)
                ELSIF head1.typ = NPR THEN reply(2); EXIT
                ELSIF head1.typ = NAK THEN reply(3); EXIT
                ELSE reply(5); EXIT
                END
            ELSE reply(4)
            END ;
            IF Texts.Pos(S) >= end THEN EXIT END ;
            Texts.Scan(S)
          END
        ELSE reply(1)
        END
      END
    END SendFiles;

    PROCEDURE ReceiveFiles*;
      VAR k: INTEGER; done: BOOLEAN;
        end: LONGINT;
        S: Texts.Scanner;
        F: Files.File;
        name: ARRAY 32 OF CHAR;
        buf: ARRAY 64 OF CHAR;
    BEGIN GetPar1(S);
      IF S.class = Texts.Name THEN
        FindPartner(S.s, k);
        IF k = 0 THEN
          GetPar(S, end);
          LOOP
            IF S.class # Texts.Name THEN EXIT END ;
            Texts.WriteString(W, S.s); k := 0; AppendS(S.s, name, k);
            IF S.nextCh = ":" THEN (*prefix*)
                Texts.Scan(S); Texts.Scan(S);
                IF S.class = Texts.Name THEN
                        name[k-1] := "."; AppendS(S.s, name, k);
                        Texts.Write(W, ":"); Texts.WriteString(W, S.s)
                END
            END ;
            k := 0; AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
            AppendS(name, buf, k); Send(SND, k, buf);
            Texts.WriteString(W, " receiving"); Texts.Append(Oberon.Log, W.buf);
            ReceiveHead(T1);
            IF head1.typ = 0 THEN
                F := Files.New(S.s);
            IF F # NIL THEN
                ReceiveData(F, done);
                IF done THEN Files.Register(F); reply(0) ELSE EXIT END
            ELSE reply(3); Send(NAK, 0, dmy)
            END
          ELSIF head1.typ = NAK THEN reply(4)
          ELSIF head1.typ = NPR THEN reply(2); EXIT
          ELSE reply(5); EXIT
          END ;
          IF Texts.Pos(S) >= end THEN EXIT END ;
          Texts.Scan(S)
        END
      ELSE reply(1)
      END
    END
  END ReceiveFiles;

  PROCEDURE SendMsg*;
    VAR i: INTEGER; ch: CHAR;
      S: Texts.Scanner;
      msg: ARRAY 64 OF CHAR;
  BEGIN GetPar1(S);
    IF S.class = Texts.Name THEN
      FindPartner(S.s, i);
      IF i = 0 THEN
        Texts.Read(S, ch);
        WHILE (ch >= " ") & (i < 64) DO
          msg[i] := ch; INC(i); Texts.Read(S, ch)
        END ;
        Send(MSG, i, msg); ReceiveHead(T0);
        IF head1.typ # ACK THEN reply(3) END
      ELSE reply(1)
      END
    END
  END SendMsg;

  PROCEDURE StartServer*;
  BEGIN protected := TRUE; SCC.Start(TRUE);
    Oberon.Remove(Server); Oberon.Install(Server);
    Texts.WriteString(W, "  Server started");
    Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
  END StartServer;

  PROCEDURE Unprotect*;
  BEGIN protected := FALSE
  END Unprotect;

  PROCEDURE WProtect*;
  BEGIN protected := TRUE
  END WProtect;

  PROCEDURE Reset*;
  BEGIN SCC.Start(TRUE)
  END Reset;

  PROCEDURE StopServer*;
  BEGIN Oberon.Remove(Server); Texts.WriteString(W, "  Server stopped");
    Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
  END StopServer;
```

```
BEGIN Texts.OpenWriter(W); NEW(Server); Server.handle := Serve
END Net.
```

11. A Dedicated File-distribution, Mail, and Printer Server

11.1. Concept and Structure

In a system of loosely coupled workstations it is desirable to centralize certain services. A first example is a common file store. Even if every station is equipped with a disk for permanent data storage, a common file service is beneficial, e.g. for storing the most recent versions of system files, reference documents, reports, etc. A common repository avoids inconsistencies which are inevitable when local copies are created. We call this a *file distribution service*.

A centralized service is also desirable if it requires equipment whose cost and service would not warrant its acquisition for every workstation, particularly if the service is infrequently used. A prime example of this case is a *printing service*.

The third case is a communication facility in the form of *electronic mail*. The repository of messages must inherently be centralized. We imagine it to have the form of a set of mailboxes, one for each user in the system. A mailbox needs to be accessible at all times, i.e. also when its owner's workstation has been switched off.

A last example of a centralized service is a *time server*. It allows a station's real time clock to be synchronized with a central clock.

In passing we point out that every user has full control over his station, including the right to switch it on and off at any time. In contrast, the central server is continuously operational.

In this chapter, we present a set of server modules providing all above mentioned services. They rest on the basic Oberon System without module *Net* (see Chapter 10). In contrast to *Net*, module *NetServer*, which handles all network communication, contains no command procedures (apart from those for starting and stopping it). This is because it never acts as a master. The counterparts of its server routines reside in other modules, including (an extended version of) *Net*, on the individual workstations.

Routines for the file distribution service are the same as those contained in module *Net*, with the addition of permission checks based on the received user names and passwords. Routines for printing and mail service could in principle also be included in *NetServer* in the same way. But considerations of reliability and timing made this simple solution appear as unattractive. A weaker coupling in time of data transmission and data consumption is indeed highly desirable. Therefore, data received for printing or for dispatching into mailboxes are stored (by *NetServer*) into temporary files and thereafter "handed over" to the appropriate agent, i.e. the print server or the mail server.

This data-centered interface between servers - in contrast to procedural interfaces - has the advantage that the individual servers are independent in the sense that none imports any other. Therefore, their development could proceed autonomously. Their connection is instead a module which defines a data structure and associated operators for passing temporary files from one server to another. The data structure used for this purpose is the first-in-first-out queue. We call its elements tasks, because each one carries an objective and an object, the file to be processed. The module containing the FIFOs is called *Core*. The resulting structure of the involved modules is shown in Fig. 11.1.

Fig. 11.1. includes yet another server, *LineServer*, and shows the ease with which additional servers may be inserted in this scheme. They act as further sources and/or sinks for tasks, feeding or consuming the queues contained in *Core*. *LineServer* indeed produces and consumes tasks like *NetServer*. Instead of the RS-485 bus, it handles the RS-232 line which, connetced to a modem, allows access to the server over telephone lines. We refrain from describing this module in further detail, because in many ways it is a mirror of *NetServer*.

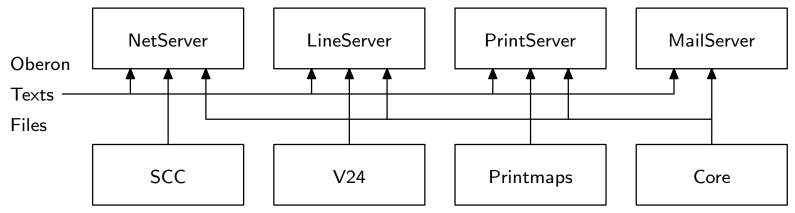

Fig. 11.1. Module structure of server system

A centralized, open server calls for certain protection measures against unauthorized use. We recall that requests always carry a user identification and a password as parameters. The server checks their validity by examining a table of users. The respective routines and the table are contained in module *Core* (see Sect. 11.5).

11.2. Electronic Mail Service

The heart of an e-mail service is the set of mailboxes stored on the dedicated, central server. Each registered user owns a mailbox. The evidently necessary operations are the insertion of a message and its retrieval. In contrast to customary letter boxes, however, a retrieved message need not necessarily be removed from the box; its retrieval produces a copy. The box thereby automatically becomes a repository, and messages can be retrieved many times. This scheme calls for an additional command which removes a message from the box. Also, a command is needed for delivering a table of contents, in which presumably each message is represented by an indication of its sender and time of arrival.

The mail scheme suggested above results in the following commands:

Net.Mailbox ServerName. This command fetches a table of contents of the current user's mailbox from the specified server and displays it in a new viewer. The user's name and password must have been registered previously by the command *System.SetUser.*

Net.SendMail ServerName. The text in the marked viewer is sent to the specified server. In order to be accepted, the text must begin with at least one line beginning with "To:" and containing at least one recipient. An example is shown in Fig. 11.2.

Net.ReceiveMail. This command is contained in the title bar (menu) of the viewer obtained when requesting the table of contents. Prior to issuing the command, the message to be read must have been specified by selecting a line in the table of contents in this viewer.

Net.DeleteMail. This command is also contained in the mailbox viewer's title bar. The message to be deleted must be selected before issuing the command.

Fig. 11.2. Viewer with Mail Directory and Messages received and to be sent

The mail system presented here is primarily intended to serve as an exchange for short messages which are typically sent, received, read, and discarded. Mailboxes are not intended to serve as long term archives for a large and ever growing number of long pieces of text. This restrictiveness of purpose allows to choose a reasonably simple implementation and results in an efficient, practically instantaneous access to messages when the server is idle.

The Oberon mail server used at ETH also provides communication with external correspondents. It connects to an external mail server which is treated as a source and a sink for messages (almost) like other customers. Additionally, messages sent to that server need to be encoded into a standardized format, and those received need to be decoded accordingly. The parts of module *MailServer* for encoding and decoding are not described in this book. We merly divulge the fact that its design and implementation took a multiple of the time spent on the fast, local message exchange, to which we confine this presentation.

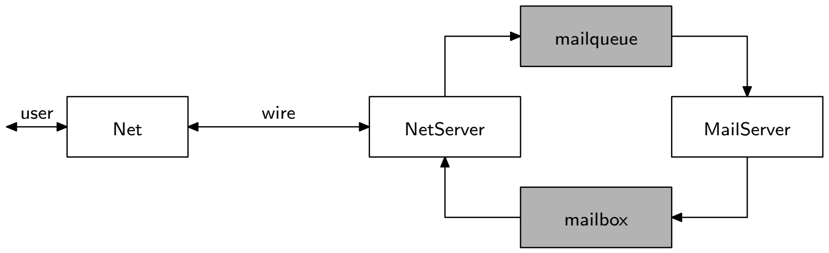

Fig. 11.3. Path of messages to and from mailbox

From the structures explained in Section 11.1. it follows that three agents are involved in the transfer of messages from the user into a mailbox. Therefore, additions to the server system distribute over three modules. New commands are added to module *Net* (see Section 10.4.); these procedures will be listed below. Their counterparts reside in module *NetServer* on the dedicated computer. The third agent is module *MailServer*; both are listed below in this Section. The latter handles the insertion of arriving messages into mailboxes. The path which a message traverses for insertion and retrieval is shown in Fig. 11.3. Rectangles with bold edges mark storage.

Communication between the master station and the dedicated server runs over the network and therefore calls for an extension of its protocol (see Sect. 10.2.). The additions directly correspond to the four commands given above.

MailBox	= MDIR username password (*datastream* | *NAK* | *NPR*).
SendMail	= RML username password (*ACK datastream* | *NAK* | *NPR*).
ReceiveMail	= SML username password msgno (*datastream* | *NAK* | *NPR*).
DeleteMail	= DML username password msgno (*ACK* | *NAK* | *NPR*).

The message number is taken from the selected line in the mailbox viewer. The data transmitted are taken as (unformatted) texts. This is in contrast to file transfers, where they are taken as any sequence of bytes. The four command procedures listed below belong in module *Net*; they are listed together with the auxiliary procedures *SendText* and *ReceiveText* which closely correspond to *SendData* and *ReceiveData* (see Sect. 10.4).

```
CONST MDIR = 4AH; SML = 4BH; RML = 4CH; DML = 4DH;

PROCEDURE SendText(T: Texts.Text);
  VAR k: INTEGER;
      seqno: SHORTINT; x: CHAR;
      R: Texts.Reader;
      buf: ARRAY PakSize OF CHAR;
  BEGIN Texts.OpenReader(R, T, 0); seqno := 0;
    LOOP k := 0;
      LOOP Texts.Read(R, x);
        IF R.eot THEN EXIT END ;
        buf[k] := x; INC(k);
        IF k = PakSize THEN EXIT END
      END ;
      REPEAT Send(seqno, k, buf); ReceiveHead(T1)
      UNTIL head1.typ # seqno + ACK;
      seqno := (seqno + 1) MOD 8;
      IF head1.typ # seqno + ACK THEN
        Texts.WriteString(W, " failed"); EXIT
      END ;
      IF k < PakSize THEN EXIT END
    END
  END SendText;

  PROCEDURE ReceiveText(T: Texts.Text);
    VAR k, retry: INTEGER;
```

```
      seqno: SHORTINT; x: CHAR;
  BEGIN seqno := 0; retry := 2;
    LOOP
      IF head1.typ = seqno THEN
        seqno := (seqno + 1) MOD 8; retry := 2;
        Send(seqno + 10H, 0, dmy); k := 0;
        WHILE k < head1.len DO
          SCC.Receive(x); Texts.Write(W, x); INC(k)
        END ;
        Texts.Append(T, W.buf);
        IF k < PakSize THEN EXIT END
      ELSE DEC(retry);
        IF retry = 0 THEN
          Texts.WriteString(W, " failed"); Texts.WriteLn(W);
          Texts.Append(Oberon.Log, W.buf); EXIT
        END ;
        Send(seqno + 10H, 0, dmy)
      END ;
      ReceiveHead(T0)
    END
  END ReceiveText;
  PROCEDURE Mailbox*;
    VAR k, X, Y: INTEGER;
      T: Texts.Text;
      V: Viewers.Viewer;
      S: Texts.Scanner;
      buf: ARRAY 32 OF CHAR;
  BEGIN GetPar1(S);
    IF S.class = Texts.Name THEN
      FindPartner(S.s, k);
      IF k = 0 THEN
        AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
        Send(MDIR, k, buf); ReceiveHead(T1);
        IF head1.typ = 0 THEN
          T := TextFrames.Text("");
          Oberon.AllocateSystemViewer(Oberon.Par.frame.X, X, Y);
          V := MenuViewers.New(
              TextFrames.NewMenu(S.s, "System.Close  Net.ReceiveMail  Net.DeleteMail"),
              TextFrames.NewText(T, 0), TextFrames.menuH, X, Y);
          ReceiveText(T)
        ELSIF head1.typ = NAK THEN reply(4)
        ELSIF head1.typ = NPR THEN reply(2)
        ELSE  reply(5)
        END
      ELSE reply(1)
      END
    END
  END Mailbox;

  PROCEDURE ReceiveMail*;
    VAR k, X, Y: INTEGER;
      T: Texts.Text;
      F: TextFrames.Frame;
      S: Texts.Scanner;
      V: Viewers.Viewer;
      buf: ARRAY 32 OF CHAR;
```

```
BEGIN F := Oberon.Par.frame(TextFrames.Frame);
  Texts.OpenScanner(S, F.text, 0); Texts.Scan(S); FindPartner(S.s, k);
  IF k = 0 THEN
    F := F.next(TextFrames.Frame);
    IF F.sel > 0 THEN
      Texts.OpenScanner(S, F.text, F.selbeg.pos); Texts.Scan(S);
      IF S.class = Texts.Int THEN
        k := 0; AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
        AppendW(S.i, buf, 2, k); Send(SML, k, buf); ReceiveHead(T1);
        IF head1.typ = 0 THEN
          T := TextFrames.Text("");
          Oberon.AllocateUserViewer(Oberon.Par.frame.X, X, Y);
          V := MenuViewers.New(
            TextFrames.NewMenu("Message.Text",
                    "System.Close  System.Copy  System.Grow  Edit.Store"),
            TextFrames.NewText(T, 0), TextFrames.menuH, X, Y);
          ReceiveText(T)
        ELSIF head1.typ = NAK THEN reply(4)
        ELSIF head1.typ = NPR THEN reply(2)
        ELSE  reply(5)
        END
      END
    END
  ELSE reply(1)
  END
END ReceiveMail;

PROCEDURE SendMail*;
  VAR k: INTEGER;
    S: Texts.Scanner;
    T, M: Texts.Text;
    v: Viewers.Viewer;
    buf: ARRAY 64 OF CHAR;
BEGIN GetPar1(S);
  IF S.class = Texts.Name THEN
    FindPartner(S.s, k);
    IF k = 0 THEN
      v := Oberon.MarkedViewer();
      IF (v.dsc # NIL) & (v.dsc.next IS TextFrames.Frame) THEN
        T := v.dsc.next(TextFrames.Frame).text;
        IF T.len < 60000 THEN
          Texts.OpenScanner(S, T, 0); Texts.Scan(S);
          IF (S.class = Texts.Name) & (S.s = "To") THEN
            M := v.dsc(TextFrames.Frame).text; Texts.OpenScanner(S, M, 0); Texts.Scan(S);
            IF S.class = Texts.Name THEN
              Texts.WriteString(W, S.s);
              AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
              Send(RML, k, buf); ReceiveHead(T1);
              IF head1.typ = ACK THEN
                Texts.WriteString(W, " mailing"); Texts.Append(Oberon.Log, W.buf);
                SendText(T); reply(0)
              ELSIF head1.typ = NPR THEN reply(2)
              ELSIF head1.typ = NAK THEN reply(3)
              ELSE reply(5)
              END
            END
          ELSE reply(8)
          END
        ELSE reply(9)
        END
      END
    ELSE reply(1)
    END
  END
END SendMail;

PROCEDURE DeleteMail*;
  VAR k: INTEGER; ch: CHAR;
    T: Texts.Text;
    F: TextFrames.Frame;
    S: Texts.Scanner;
    buf: ARRAY 32 OF CHAR;
BEGIN F := Oberon.Par.frame(TextFrames.Frame);
  Texts.OpenScanner(S, F.text, 0); Texts.Scan(S); FindPartner(S.s, k);
  IF k = 0 THEN
    F := F.next(TextFrames.Frame);
    IF F.sel > 0 THEN
      Texts.OpenScanner(S, F.text, F.selbeg.pos); Texts.Scan(S);
      IF S.class = Texts.Int THEN
        k := 0; AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
        AppendW(S.i, buf, 2, k); Send(DML, k, buf); ReceiveHead(T1);
        IF head1.typ = ACK THEN
          REPEAT Texts.Read(S, ch) UNTIL ch < " ";
          Texts.Delete(F.text, F.selbeg.pos, Texts.Pos(S))
        ELSIF head1.typ = NAK THEN reply(3)
        ELSIF head1.typ = NPR THEN reply(2)
        ELSE reply(5)
        END
      END
    END
  ELSE reply(1)
  END
END DeleteMail;
```

We now turn our attention to the command procedures' counterparts in module *NetServer* listed in this Section. In order to explain these routines, a description of their interface with the mail server and a definition of the structure of mailboxes must precede. We begin with the simplest case, the counterpart of *SendMail*. It is the part of procedure *NetServer.Serve* which is guarded by the condition *typ = RML*, indicating a request to receive mail. As in all other services, the parameters username and password are read and the admissibility of the request is checked. The check is performed by procedure *Core.UserNo* which yields a negative number if service is to be refused. In the affirmative case, procedure *ReceiveData* obtains the message and stores it on a file, which is thereafter inserted into the mail queue as a task to be handled by the mail server at a later time. This may involve distribution of the message into several mailboxes.

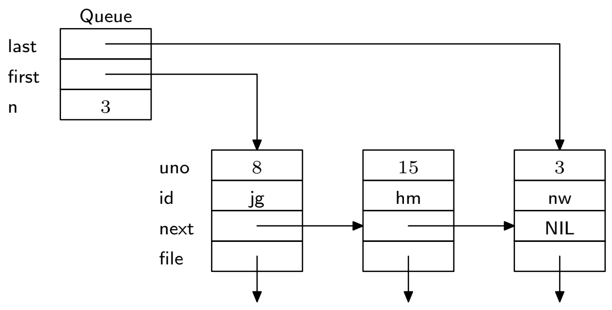

Fig. 11.4. Structure of task queue

Module *Core* is listed in Sect. 11.5. As mentioned before, it serves as link between the various server modules, defining the data types of the linking queues and also of mailboxes. Task queues are represented as FIFO-lists. The descriptor of type *Queue* contains a pointer to the first list element used for retrieval, and a pointer to the last element used for insertion (see Fig. 11.4.). These pointers are not exported; instead, the next task is obtained by calling procedure *Core.GetTask*, and it is deleted by *Core.RemoveTask*. There e*xist two exported variables of type Queue: MailQueue consumed by MailServer, and* PrintQueue consumed by *PrintServer* (see Sect. 11.3.). (In fact, we use a third queue: *LineQueue* consumed by *LineServer*). Elements of queues are of type *TaskDesc* which specifies the file representing the data to be consumed. Additionally, it specifies the user number and identification of the task's originator. Three procedures are provided by module *Core* for handling task queues:

PROCEDURE InsertTask(VAR q: Queue; F: Files.File; VAR id: ARRAY OF CHAR; uno: INTEGER);

PROCEDURE GetTask(VAR q: Queue; VAR F: Files.File; VAR id: ARRAY OF CHAR; VAR uno: INTEGER);

PROCEDURE RemoveTask(VAR q: Queue);

The server's counterparts of the remaining mail commands access mailboxes directly. The simplicity of the required actions - a result of a carefully chosen mailbox representation - and considerations of efficiency do not warrant a detour via task queue and mail server.

Every mailbox is represented as a file. This solution has the tremendous advantage that no special administration has to be introduced to handle a reserved partition of disk store for mail purposes. A mailbox file is partitioned into three parts: the block reservation part, the directory part, and the message part. Each part is quickly locatable, because the first two have a fixed length (32 and 31*32 = 992 bytes). The message part is regarded as a sequence of blocks (of 256 bytes), and each message occupies an integral number of adjacent blocks. Corresponding to each block, the block reservation part contains a single bit indicating whether or not the block is occupied by a message. Since the block reservation part is 32 bytes long, the message part contains at most 256 blocks, i.e. 64K bytes. The block length was chosen after an analysis of messages which revealed that the average message is less than 500 bytes long.

The directory part consists of an array of 31 elements of type *MailEntry*, a record with the following fields: *pos* and *len* indicate the index of the message's first block and the message's number of bytes; *time* and *date* indicate the message's time of insertion, and originator indicates the message's source. The entries are linked (field *next*) in chronological order of their arrival, and entry 0 serves as the list's header. It follows that a mailbox contains at most 30 messages. An example of a mailbox state is shown in Fig. 11.5.

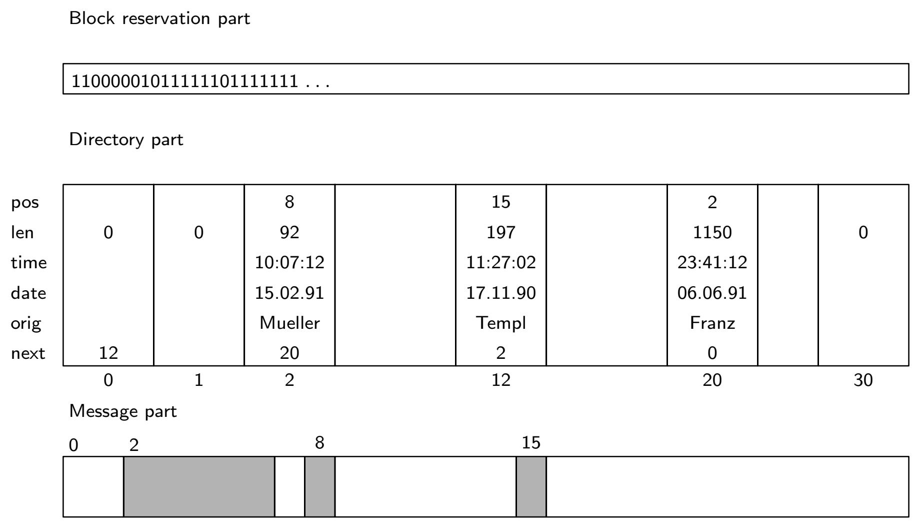

Fig. 11.5. State of a mailbox file

```
MailEntry =  RECORD
                pos, next: INTEGER;
                len: LONGINT;
                time, date: INTEGER;
                originator: ARRAY 20 OF CHAR
             END ;
MResTab =    ARRAY 8 OF SET;
MailDir =    ARRAY 31 OF MailEntry;
```

We are now in a position to inspect the handler for requests for message retrieval. It is guarded by the condition *typ = SML*. After a validity check, the respective requestor's mailbox file is opened. The last mailbox opened is retained by the global variable MF which acts as a single entry cache. The associated user number is given by the global variable *mailuno*. Since typically several requests involving the same mailbox follow, this measure avoids the repeated reopening of the same file. Thereafter, a rider is directly positioned at the respective directory entry for reading the message's length and position in the message part. The rider is repositioned accordingly, and transmission of the message is handled by procedure *SendMail*.

Requests for the mailbox directory are handled by the routine guarded by the condition *typ = MDIR*. The directory part must be read and converted into a text. This task is supported by various auxiliary procedures (Append) which concatenate supplied data in a buffer for latter transmission. We emphasize that this request does not require the reading of any other part of the file, and therefore is very swift.

The last of the four mail service requests (DML) deletes a specified message. Removal from the directory requires a relinking of the entries. Unused entries are marked by their *len* field having value 0. Also, the blocks occupied by the message become free. The block reservation part must be updated accordingly. Further details can be examined in the following program listing.

```
MODULE NetServer;  (*NW 15.2.90 / 22.11.91*)
  IMPORT SCC, Core, FileDir, Files, Texts, Oberon;

  CONST PakSize = 512; GCInterval = 50;
    T0 = 300; T1 = 1000;  (*timeouts*)
    maxFileLen = 100000H;

    ACK = 10H; NAK = 25H; NPR = 26H; (*acknowledgements*)
    NRQ = 34H; NRS = 35H; (*name request, response*)
    SND = 41H; REC = 42H; (*send / receive request*)
    FDIR = 45H; DEL = 49H;  (*directory and delete file requests*)
    PRT = 43H;  (*receive to print request*)
    TRQ = 46H; TIM = 47H; (*time requests*)
    MSG = 44H; NPW = 48H;  (*new password request*)
    TOT = 7FH; (*timeout*)
    MDIR = 4AH; SML = 4BH; RML = 4CH; DML = 4DH;

  VAR W: Texts.Writer;
    handler: Oberon.Task;

    head0, head1: SCC.Header;
    partner: Core.ShortName;
    seqno: SHORTINT;

    K, reqcnt, mailuno: INTEGER;
    protected: BOOLEAN;
    MF: Files.File;  (*last mail file accessed*)
    buf: ARRAY 1024 OF CHAR;  (*used by FDIR and MDIR*)
    dmy: ARRAY 4 OF CHAR;

  PROCEDURE EOL;
  BEGIN Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
  END EOL;

  PROCEDURE SetPartner(VAR name: ARRAY OF CHAR);
  BEGIN head0.dadr := head1.sadr; head0.destLink := head1.srcLink;
    COPY(name, partner)
  END SetPartner;

  PROCEDURE Send(t: SHORTINT; L: INTEGER; VAR data: ARRAY OF CHAR);
  BEGIN head0.typ := t; head0.len := L; SCC.SendPacket(head0, data)
  END Send;

  PROCEDURE ReceiveHead(timeout: LONGINT);
    VAR time: LONGINT;
  BEGIN time := Oberon.Time() + timeout;
    LOOP SCC.ReceiveHead(head1);
      IF head1.valid THEN
        IF head1.sadr = head0.dadr THEN EXIT
        ELSE SCC.Skip(head1.len)
        END
      ELSIF Oberon.Time() >= time THEN head1.typ := TOT; EXIT
      END
    END
  END ReceiveHead;

PROCEDURE AppendS(VAR s, d: ARRAY OF CHAR; VAR k: INTEGER);
    VAR i: INTEGER; ch: CHAR;
  BEGIN i := 0;
    REPEAT ch := s[i]; d[k] := ch; INC(i); INC(k) UNTIL ch = 0X
  END AppendS;

  PROCEDURE AppendW(s: LONGINT; VAR d: ARRAY OF CHAR; n: INTEGER;
      VAR k: INTEGER);
    VAR i: INTEGER;
  BEGIN i := 0;
    REPEAT d[k] := CHR(s); s := s DIV 100H; INC(i); INC(k) UNTIL i = n
  END AppendW;

  PROCEDURE AppendN(x: LONGINT; VAR d: ARRAY OF CHAR; VAR k: INTEGER);
    VAR i: INTEGER; u: ARRAY 8 OF CHAR;
  BEGIN i := 0;
```

```
   REPEAT u[i] := CHR(x MOD 10 + 30H); INC(i); x := x DIV 10 UNTIL x = 0;
   REPEAT DEC(i); d[k] := u[i]; INC(k) UNTIL i = 0
END AppendN;

PROCEDURE AppendDate(t, d: INTEGER; VAR buf: ARRAY OF CHAR; VAR k: INTEGER);
   PROCEDURE Pair(ch: CHAR; x: LONGINT);
   BEGIN buf[k] := ch; INC(k);
      buf[k] := CHR(x DIV 10 + 30H); INC(k); buf[k] := CHR(x MOD 10 + 30H); INC(k)
   END Pair;
BEGIN
   Pair(" ", d MOD 20H); Pair(".", d DIV 20H MOD 10H); Pair(".", d DIV 200H MOD 80H);
   Pair(" ", t DIV 800H MOD 20H); Pair(":", t DIV 20H MOD 40H); Pair(":", t MOD 20H * 2)
END AppendDate;

PROCEDURE SendBuffer(len: INTEGER; VAR done: BOOLEAN);
VAR i, kd, ks: INTEGER; ch: CHAR;
BEGIN
   REPEAT Send(seqno, len, buf); ReceiveHead(T1)
   UNTIL head1.typ # seqno + 10H;
   seqno := (seqno+1) MOD 8; kd := 0; ks := PakSize;
   WHILE ks < K DO buf[kd] := buf[ks]; INC(kd); INC(ks) END ;
   K := kd; done := head1.typ = seqno + 10H
END SendBuffer;

PROCEDURE* AppendDirEntry(name: FileDir.FileName; adr: LONGINT;
      VAR done: BOOLEAN);
   VAR i, kd, ks: INTEGER; ch: CHAR;
BEGIN i := 0; ch := name[0];
   WHILE ch > 0X DO buf[K] := ch; INC(i); INC(K); ch := name[i] END ;
   buf[K] := 0DX; INC(K);
   IF K >= PakSize THEN SendBuffer(PakSize, done) END
END AppendDirEntry;

PROCEDURE PickS(VAR s: ARRAY OF CHAR);
   VAR i, n: INTEGER; ch: CHAR;
BEGIN i := 0; n := SHORT(LEN(s))-1; SCC.Receive(ch);
   WHILE ch > 0X DO
      IF i < n THEN s[i] := ch; INC(i) END ;
      SCC.Receive(ch)
   END ;
   s[i] := 0X
END PickS;

PROCEDURE PickQ(VAR w: LONGINT);
   VAR c0, c1, c2: CHAR; s: SHORTINT;
BEGIN SCC.Receive(c0); SCC.Receive(c1); SCC.Receive(c2); SCC.Receive(s);
   w := s; w := ((w * 100H + LONG(c2)) * 100H + LONG(c1)) * 100H + LONG(c0)
END PickQ;

PROCEDURE PickW(VAR w: INTEGER);
   VAR c0: CHAR; s: SHORTINT;
BEGIN SCC.Receive(c0); SCC.Receive(s); w := s; w := w * 100H + ORD(c0)
END PickW;

PROCEDURE SendData(F: Files.File);
   VAR k: INTEGER;
      x: CHAR;
      len: LONGINT;
      R: Files.Rider;
```

```
BEGIN Files.Set(R, F, 0); len := 0; seqno := 0;
  LOOP k := 0;
    LOOP Files.Read(R, x);
      IF R.eof THEN EXIT END ;
      buf[k] := x; INC(k);
      IF k = PakSize THEN EXIT END
    END ;
    REPEAT Send(seqno, k, buf); ReceiveHead(T1)
    UNTIL head1.typ # seqno + 10H;
    seqno := (seqno + 1) MOD 8; len := len + k;
    IF head1.typ # seqno + 10H THEN EXIT END ;
    IF k < PakSize THEN EXIT END
  END
END SendData;
PROCEDURE ReceiveData(F: Files.File; VAR done: BOOLEAN);
  VAR k, retry: INTEGER;
    x: CHAR;
    len: LONGINT;
    R: Files.Rider;
BEGIN Files.Set(R, F, 0); seqno := 0; len := 0; retry := 4;
  LOOP
    IF head1.typ = seqno THEN
      seqno := (seqno + 1) MOD 8; len := len + head1.len;
      IF len > maxFileLen THEN
        Send(NAK, 0, dmy); done := FALSE; Files.Close(F); Files.Purge(F); EXIT
      END ;
      retry := 4; Send(seqno + 10H, 0, dmy); k := 0;
      WHILE k < head1.len DO
        SCC.Receive(x); Files.Write(R, x); INC(k)
      END ;
      IF k < PakSize THEN done := TRUE; EXIT END
    ELSE DEC(retry);
      IF retry = 0 THEN done := FALSE; EXIT END ;
      Send(seqno + 10H, 0, dmy)
    END ;
    ReceiveHead(T0)
  END
END ReceiveData;

PROCEDURE SendMail(VAR R: Files.Rider; len: LONGINT);
  VAR k: INTEGER; x: CHAR;
    buf: ARRAY PakSize OF CHAR;
BEGIN seqno := 0;
  LOOP k := 0;
    LOOP Files.Read(R, x);
      IF k = len THEN EXIT END ;
      buf[k] := x; INC(k);
      IF k = PakSize THEN EXIT END
    END ;
    REPEAT Send(seqno, k, buf); ReceiveHead(T1)
    UNTIL head1.typ # seqno + 10H;
    seqno := (seqno + 1) MOD 8; len := len - k;
    IF head1.typ # seqno + 10H THEN EXIT END ;
    IF k < PakSize THEN EXIT END
  END
END SendMail;
```

```
PROCEDURE* Serve;
  VAR i, j, k0, k1, n, uno: INTEGER;
    ch: CHAR; typ: SHORTINT;
    done: BOOLEAN;
    F: Files.File;
    R: Files.Rider;
    t, d, pw, npw, pos, len: LONGINT;
    Id: Core.ShortName;
    fname: Core.Name;
    mdir: Core.MailDir;
    mrtab: Core.MResTab;
BEGIN SCC.ReceiveHead(head1);
  IF ~head1.valid THEN RETURN END ;
  typ := head1.typ;
  IF typ = SND THEN
    PickS(Id); PickQ(pw); PickS(fname); SetPartner(Id);
    IF Core.UserNo(Id, pw) >= 0 THEN
      F := Files.Old(fname);
      IF F # NIL THEN SendData(F)
      ELSE Send(NAK, 0, dmy)
      END
    ELSE Send(NPR, 0, dmy)
    END
  ELSIF typ = REC THEN
    PickS(Id); PickQ(pw); PickS(fname); SetPartner(Id);
    IF ~protected & (Core.UserNo(Id, pw) >= 0) THEN
      F := Files.New(fname);
      Send(ACK, 0, dmy); ReceiveHead(T0);
      IF head1.valid THEN
        ReceiveData(F, done);
        IF done THEN Files.Register(F) END
      END
    ELSE Send(NPR, 0, dmy)
    END
  ELSIF typ = PRT THEN
    PickS(Id); PickQ(pw); SetPartner(Id); uno := Core.UserNo(Id, pw);
    IF uno >= 0 THEN
      F := Files.New("");
      Send(ACK, 0, dmy); ReceiveHead(T0);
      IF head1.valid THEN
        ReceiveData(F, done);
        IF done THEN Files.Close(F); Core.InsertTask(Core.PrintQueue, F, Id, uno) END
      END
    ELSE Send(NPR, 0, dmy)
    END
  ELSIF typ = DEL THEN
    PickS(Id); PickQ(pw); PickS(fname); SetPartner(Id);
    IF ~protected & (Core.UserNo(Id, pw) >= 0) THEN
      Files.Delete(fname, k);
      IF k = 0 THEN Send(ACK, 0, dmy) ELSE Send(NAK, 0, dmy) END
    ELSE Send(NPR, 0, dmy)
    END
  ELSIF typ = FDIR THEN
    PickS(Id); PickQ(pw); PickS(fname); SetPartner(Id); uno := Core.UserNo(Id, pw);
    IF uno >= 0 THEN
      K := 0; seqno := 0; FileDir.Enumerate(fname, AppendDirEntry);
```

```
        SendBuffer(K, done)
      ELSE Send(NPR, 0, dmy)
      END
    ELSIF typ = MDIR THEN
      PickS(Id); PickQ(pw); SetPartner(Id); uno := Core.UserNo(Id, pw);
      IF uno >= 0 THEN
        IF uno # mailuno THEN
          Core.GetFileName(uno, fname); MF := Files.Old(fname); mailuno := uno
        END ;
        K := 0; seqno := 0;
        IF MF # NIL THEN
          Files.Set(R, MF, 32); Files.ReadBytes(R, mdir, SIZE(Core.MailDir));
          i := mdir[0].next; j := 30; done := TRUE;
          WHILE (i # 0) & (j > 0) & done DO
              AppendN(i, buf, K); AppendDate(mdir[i].time, mdir[i].date, buf, K);
              buf[K] := " "; INC(K); AppendS(mdir[i].originator, buf, K);
              buf[K-1] := " "; AppendN(mdir[i].len, buf, K); buf[K] := 0DX; INC(K);
              IF K >= PakSize THEN SendBuffer(PakSize, done) END ;
              i := mdir[i].next; DEC(j)
          END
        END ;
        SendBuffer(K, done)
      ELSE Send(NPR, 0, dmy)
      END
    ELSIF typ = SML THEN (*send mail*)
      PickS(Id); PickQ(pw); PickW(n); SetPartner(Id); uno := Core.UserNo(Id, pw);
      IF uno >= 0 THEN
        IF uno # mailuno THEN
          Core.GetFileName(uno, fname); MF := Files.Old(fname); mailuno := uno
        END ;
        IF (MF # NIL) & (n > 0) & (n < 31) THEN
          Files.Set(R, MF, (n+1)*32);
          Files.ReadBytes(R, i, 2); Files.ReadBytes(R, j, 2); pos := LONG(i) * 100H;
          Files.ReadBytes(R, len, 4);
          IF len > 0 THEN Files.Set(R, MF, pos); SendMail(R, len)
          ELSE Send(NAK, 0, dmy)
          END
        ELSE Send(NAK, 0, dmy)
        END
      ELSE Send(NPR, 0, dmy)
      END
    ELSIF typ = RML THEN (*receive mail*)
      PickS(Id); PickQ(pw); SetPartner(Id); uno := Core.UserNo(Id, pw);
      IF uno >= 0 THEN
        F := Files.New("");
        Send(ACK, 0, dmy); ReceiveHead(T0);
        IF head1.valid THEN
          ReceiveData(F, done);
          IF done THEN Files.Close(F); Core.InsertTask(Core.MailQueue, F, Id, uno) END
        END
      ELSE Send(NPR, 0, dmy)
      END
    ELSIF typ = DML THEN (*delete mail*)
      PickS(Id); PickQ(pw); PickW(n); SetPartner(Id); uno := Core.UserNo(Id, pw);
      IF uno >= 0 THEN
        IF uno # mailuno THEN
```

```
            Core.GetFileName(uno, fname); MF := Files.Old(fname); mailuno := uno
          END ;
          IF (MF # NIL) & (n > 0) & (n < 31) THEN
            Files.Set(R, MF, 0);
            Files.ReadBytes(R, mrtab, 32); Files.ReadBytes(R, mdir, SIZE(Core.MailDir));
            i := 0; ks := 30;
            LOOP k := mdir[i].next; DEC(ks);
                IF (k = 0) OR (ks = 0) THEN Send(NAK, 0, buf); EXIT END ;
                IF k = n THEN
                        j := mdir[n].pos;
                        k := SHORT((mdir[n].len + LONG(j)*100H) DIV 100H) + 1;
                        REPEAT INCL(mrtab[j DIV 32], j MOD 32); INC(j) UNTIL j = k;
                        mdir[n].len := 0; mdir[i].next := mdir[n].next;
                        Files.Set(R, MF, 0); Files.WriteBytes(R, mrtab, 32);
                        Files.WriteBytes(R, mdir, SIZE(Core.MailDir)); Files.Close(MF);
                        Send(ACK, 0, dmy); EXIT
                END ;
                i := k
            END
          ELSE Send(NAK, 0, dmy)
          END
        ELSE Send(NPR, 0, dmy)
        END
      ELSIF typ = TRQ THEN
        Oberon.GetClock(t, d); SetPartner(Id); i := 0;
        AppendW(t, fname, 4, i); AppendW(d, fname, 4, i); Send(TIM, 8, fname)
      ELSIF typ = NRQ THEN i := 0;
        LOOP SCC.Receive(ch); Id[i] := ch; INC(i);
          IF ch = 0X THEN EXIT END ;
          IF i = 7 THEN Id[7] := 0X; EXIT END
        END ;
        WHILE i < head1.len DO SCC.Receive(ch); INC(i) END ;
        IF Id = Oberon.User THEN SetPartner(Id); Send(NRS, 0, dmy) END
      ELSIF typ = MSG THEN i := 0;
        WHILE i < head1.len DO SCC.Receive(ch); Texts.Write(W, ch); INC(i) END ;
        SetPartner(Id); Send(ACK, 0, dmy); EOL
      ELSIF typ = NPW THEN
        PickS(Id); PickQ(pw); uno := Core.UserNo(Id, pw);
        IF uno >= 0 THEN
          SetPartner(Id); Send(ACK, 0, dmy); ReceiveHead(T0);
          IF head1.typ = 0 THEN
            PickQ(npw); Core.SetPassword(uno, npw); Send(ACK, 0, dmy)
          ELSE Send(NAK, 0, dmy)
          END
        ELSE Send(NPR, 0, dmy)
        END
      ELSE SCC.Skip(head1.len)
      END ;
      Core.Collect
    END Serve;

    (*----------------------- Commands -------------------*)

    PROCEDURE Start*;
      VAR password: ARRAY 4 OF CHAR;
        S: Texts.Scanner;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
```

```
      IF S.class = Texts.Name THEN
        Oberon.Remove(handler); Oberon.Install(handler);
        reqcnt := 0; MF := NIL; mailuno := -2;
        password[0] := 0X; Oberon.SetUser(S.s, password);
        Texts.WriteString(W, "Net started  (NW 22.11.91)"); EOL
      END
    END Start;

    PROCEDURE Reset*;
    BEGIN SCC.Start(TRUE)
    END Reset;

    PROCEDURE Stop*;
    BEGIN Oberon.Remove(handler); Texts.WriteString(W, "Net stopped"); EOL
    END Stop;

    PROCEDURE Protect*;
    BEGIN protected := TRUE
    END Protect;

    PROCEDURE Unprotect*;
    BEGIN protected := FALSE
    END Unprotect;

  BEGIN Texts.OpenWriter(W); NEW(handler); handler.handle := Serve
  END NetServer.
```

In passing we note that the use of files for representing mailboxes, in combination with the file distribution services residing on the same server station, allows anyone to access (and inspect) any mailbox. Although we do not claim that this system provides secure protection against snooping, a minimal effort for protection was undertaken by a simple encoding of messages in mailbox files. This encoding is not shown in the program listings contained in this book.

One operation remains to be explained in more detail: the processing of tasks inserted into the mail queue. It consists of the insertion of the message represented by the task's file into one or several mailboxes. It involves the interpretation of the message's header, i.e. lines containing addresses, and the construction of a new header containing the name of the originator and the date of insertion into the mailbox. These actions are performed by procedures in module *MailServer*. Its procedure *Serve* is installed as an Oberon Task, and it is guarded by the condition *Core.MailQueue.n > 0*, indicating that at least one message needs to be dispatched.

The originator's name is obtained from *Core.GetUserName(uno),* where uno is the user number obtained from the queue entry. The actual time is obtained from *Oberon.GetClock*. The form of the new header is shown by the following example:

```
From: Gutknecht
At: 12.08.91 09:34:15
```

The received message's header is then searched for recipients. Their names are listed in header lines starting with "To" (or "cc"). After a name has been read, the corresponding user number is obtained by calling *Core.UserNum*. Then the message is inserted into the designated mailbox by procedure *Dispatch*. The search for recipients continues, until a line is encountered that does not begin with "To" (or "cc"). A negative user number indicates that the given name is not registered. In this case, the message is returned to the sender, i.e. inserted into the mailbox of the sender. An exception is the recipient "all" which indicates a broadcast to all registered users.

Procedure *Dispatch* first opens the mailbox file of the user specified by the recipient number rno. If a mailbox exists, its block reservation part (mrtab) and its directory part (mdir) are read. Otherwise a new, empty box is created. Then follows the search for a free slot in the directory and, if found, the search for a sufficient number of free, adjacent blocks in the message part. The number of required blocks is given by the message length. If either no free slot exists, or there is no large enough free space for the message part, the message is returned to the sender (identified by *sno*). If also this attempt fails, the message is redirected to the postmaster (with user number 0). The postmaster is expected to inspect his mailbox sufficiently often so that no overflow occurs. If the postmaster's mailbox also overflows, the message is lost.

Only if all conditions for a successful completion are satisfied, is insertion begun. It starts with the marking of blocks in the reservation table and with the insertion of the new directory information. Table and directory are then updated on the file. Thereafter, the message with the constructed new header is written into the message part.

```
MODULE MailServer;  (*NW 17.4.89 / 25.8.91*)
    IMPORT Core, Files, Texts, Oberon;

    VAR W: Texts.Writer;
      handler: Oberon.Task;

    PROCEDURE Dispatch(F: Files.File; rno, sno, hdlen: INTEGER;
        VAR orig, head: ARRAY OF CHAR);
    (*insert external message (from msg) in recipient rno's mail file*)
      VAR i, j, k, h: INTEGER;
        ch: CHAR; ok: BOOLEAN;
        pos, L, bdylen, tm, dt: LONGINT;
        fname: Core.Name;
        MF: Files.File; (*destination*)
        R, Q: Files.Rider;
        mrtab: Core.MResTab;
        mdir: Core.MailDir;
    BEGIN Core.GetFileName(rno, fname); MF := Files.Old(fname);
      IF MF # NIL THEN
        Files.Set(Q, MF, 0); Files.ReadBytes(Q, mrtab, 32);
        Files.ReadBytes(Q, mdir, SIZE(Core.MailDir))
      ELSE (*create new mailbox file*)
        MF := Files.New(fname); Files.Set(Q, MF, 0);  Files.Register(MF);
        mdir[0].next := 0; mrtab[0] := {4 .. 31}; i := 1;
        REPEAT mrtab[i] := {0 .. 31}; INC(i) UNTIL i = 7;
        mrtab[7] := {0 .. 29}; i := 0;
        REPEAT mdir[i].len := 0; INC(i) UNTIL i = 31
      END ;
      Files.Set(R, F, 0); bdylen := Files.Length(F);
      ok := FALSE; i := 0;
      REPEAT INC(i) UNTIL (i = 31) OR (mdir[i].len = 0);
      IF i < 31 THEN  (*free slot found, now find free blocks in file*)
        j := -1;
        REPEAT INC(j);
          IF j MOD 32 IN mrtab[j DIV 32] THEN
            h := j; k := SHORT((bdylen + hdlen + 255) DIV 256) + j;
            LOOP INC(h);
              IF h = k THEN ok := TRUE; EXIT END ;
              IF (h = 256) OR ~(h MOD 32 IN mrtab[h DIV 32]) THEN j := h; EXIT END
            END
          END
        UNTIL ok OR (j >= 255)
      END ;
      IF ok THEN (*insert msg in blocks j .. k-1*)
        pos := LONG(j) * 256; mdir[i].pos := j;
        REPEAT EXCL(mrtab[j DIV 32], j MOD 32); INC(j) UNTIL j = k;
        mdir[i].len := bdylen + hdlen;
        Oberon.GetClock(tm, dt);
        mdir[i].time := SHORT(tm DIV 2); mdir[i].date := SHORT(dt);
        j := 0;
        WHILE (j < 19) & (orig[j] > " ") DO mdir[i].originator[j] := orig[j]; INC(j) END ;
        mdir[i].originator[j] := 0X;
        mdir[i].next := mdir[0].next; mdir[0].next := i;
        Files.Set(Q, MF, 0); Files.WriteBytes(Q, mrtab, 32);
        Files.WriteBytes(Q, mdir, SIZE(Core.MailDir)); Files.Set(Q, MF, pos);
        j := 0;
        WHILE j < hdlen DO
          Files.Write(Q, head[j]); INC(j)
        END ;
        j := 0;
        WHILE j < bdylen DO
          Files.Read(R, ch); Files.Write(Q, ch); INC(j)
        END ;
        L := (-Files.Pos(Q)) MOD 256;
        WHILE L > 0 DO Files.Write(Q, 0); DEC(L) END ;
        Files.Close(MF)
      ELSIF (rno # sno) & (sno > 0) THEN (*return to sender*)
        Dispatch(F, sno, sno, hdlen, orig, head)
      ELSIF (rno # 0) & (sno # 0) THEN (*send to postmaster*)
        Dispatch(F, 0, sno, hdlen, orig, head)
      END
    END Dispatch;

    PROCEDURE* Serve;
      VAR i, j, sno, rno, hdlen: INTEGER;
        ch: CHAR;
        pos, dt, tm: LONGINT;
        F: Files.File; R: Files.Rider;
        Id: Core.ShortName;
        orig: Core.LongName;
        head, recip: ARRAY 64 OF CHAR;

      PROCEDURE Pair(ch: CHAR; x: LONGINT);
      BEGIN head[j] := ch; INC(j);
        head[j] := CHR(x DIV 10 + 30H); INC(j); head[j] := CHR(x MOD 10 + 30H); INC(j)
      END Pair;

    BEGIN
      IF Core.MailQueue.n > 0 THEN
        Core.GetTask(Core.MailQueue, F, Id, sno);
          Core.GetUserName(sno, orig); Oberon.GetClock(tm, dt);
          COPY("From: ", head); i := 0; j := 6;
          WHILE orig[i] > 0X DO head[j] := orig[i]; INC(i); INC(j) END ;
          head[j] := 0DX; INC(j); head[j] := "A"; INC(j); head[j] := "t"; INC(j);
          head[j] := ":"; INC(j);
          Pair(" ", dt MOD 20H); Pair(".", dt DIV 20H MOD 10H);
          Pair(".", dt DIV 200H MOD 80H);
          Pair(" ", tm DIV 1000H MOD 20H); Pair(":", tm DIV 40H MOD 40H);
          Pair(":", tm MOD 40H);
          head[j] := 0DX; hdlen := j+1;
          Files.Set(R, F, 0);
          LOOP (*next line*) pos := Files.Pos(R);
            REPEAT Files.Read(R, ch) UNTIL (ch > " ") OR R.eof;
            IF R.eof THEN EXIT END ;
            i := 0;
```

```
                REPEAT recip[i] := ch; INC(i); Files.Read(R, ch) UNTIL ch <= ":";
                recip[i] := 0X;
                IF (recip # "To") & (recip # "cc") THEN EXIT END ;
                LOOP (*next recipient*)
                  WHILE " " <= ch DO Files.Read(R, ch) END ;
                  IF ch < " " THEN EXIT END ;
                  i := 0;
                  WHILE ch > " " DO recip[i] := ch; INC(i); Files.Read(R, ch) END ;
                  recip[i] := 0X;
                  IF recip = "all" THEN rno := Core.NofUsers();
                          WHILE rno > 1 DO  (*exclude postmaster*)
                                  DEC(rno); Dispatch(F, rno, 0, hdlen, orig, head)
                          END
                  ELSE rno := Core.UserNum(recip);
                          IF rno < 0 THEN rno := sno END ;
                          Dispatch(F, rno, sno, hdlen, orig, head)
                  END ;
                  IF ch = "," THEN Files.Read(R, ch) END
                END
              END ;
            Core.RemoveTask(Core.MailQueue)
          END
        END Serve;

        (*------------------------ Commands --------------------------*)

        PROCEDURE Start*;
        BEGIN Oberon.Install(handler);
          Texts.WriteString(W, "Mailer started  (NW 25.8.91)");
          Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
        END Start;

        PROCEDURE State*;
        BEGIN Texts.WriteString(W, "Mail queue:"); Texts.WriteInt(W, Core.MailQueue.n, 3);
          Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
        END State;

        PROCEDURE Stop*;
        BEGIN Oberon.Remove(handler); Texts.WriteString(W, "Mailer stopped");
          Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
        END Stop;

    BEGIN Texts.OpenWriter(W); NEW(handler); handler.handle := Serve
    END MailServer.
```

Perhaps it may seem to the reader that the addition of a separate module *MailServer*, together with a new Oberon Task and the machinery of the mail queue is not warranted by the relative simplicity of the insertion operation, and that it could have been incorporated into module *NetServer* just as well as message extraction. The picture changes, however, if handling of external mail is to be added, and if access to mailboxes via other channels, such as the RS-232 line, is to be provided. The presented solution is based on a modular structure that facilitates such extensions without change of existing parts. External mail routines inevitably have to cope with message formats imposed by standards. Format transformations, encoding before sending to an external server and decoding before dispatching become necessary. Indeed, these operations have inflated module *MailServer* in a surprising degree. And lastly, the queuing machinery supports the easy insertion of additional message sources and provides a welcome decoupling and relaxation of timing constraints, particularly in the case of low-speed transmission media such as telephone lines.

11.3. Printing Service

The dedicated server machine is also used as the central printing facility for all workstations connected by the network. On workstations, print commands are part of various tool modules of editing systems. Examples are *Edit.Print* (Chapter 5), and *Draw.Print* (Chapter 13). Documents to be printed typically consist of various elements such as strings of characters, lines, circles, etc. The print commands enumerate these elements and for each element issue a call to the appropriate procedure in module *Printer*, whose interface is listed in Chapter 5. These procedures then concatenate the received information and send it to the printer server in an encoded form. The syntax of this data stream is the following:

```
PrintStream   =  Tag {element}.
element       =  string | continuation | line | xline | circle | ellipse | area | font | page.
string        =  0 fno x y {char}.
continuation  =  1 fno {char}.
line          =  2 0 x y w h.
xline         =  6 0 x0 y0 x1 y1.
circle        =  9 0 x y r.
ellipse       =  7 0 x y a b.
area          =  5 patno x y w h.
font          =  3 fno fontname.
page          =  4 copies.
```

x, y, w, h, r, a, b are position coordinates, *width, height, radius,* all encoded in 2 bytes. *fno* is a font number, *patno* is the number of the dot pattern by which the rectangular area is to be filled. The page command signals that the preceding elements form a page, and *copies* indicates the number of copies to be printed.

The print stream is transmitted to the server as a sequence of packets. The data received by calls of the print procedures are stored in a local buffer until the size of a packet is reached. Every print command must first establish the connection with the server by a call of *Printer.Open*. Furthermore, it must indicate page breaks by calling *Printer.Page*, and it must terminate with a call of *Printer.Close*. Evidently, the formatting of the document to be printed is the duty of the respective editor's print command. Module *Printer*, listed below, merely handles the encoding, buffering, and transmission.

```
MODULE Printer;  (*NW 27.6.88 / 11.3.91*)
    IMPORT SYSTEM, Input, SCC;

    CONST maxfonts = 16;
        PakSize = 512; Broadcast = -1;
        T0 = 300; T1 = 1200;
        ACK = 10H; NAK = 25H;
        NRQ = 34H; NRS = 35H;
        PRT = 43H; NPR = 26H; TOT = 7FH;

    VAR res*: INTEGER; (*0 = done, 1 = not done*)
        PageWidth*, PageHeight*: INTEGER;
        nofonts: INTEGER;
        seqno: SHORTINT;
        head0: SCC.Header;  (*sender*)
        head1: SCC.Header;  (*receiver*)
        in: INTEGER;
        PrinterName: ARRAY 10 OF CHAR;
        fontname: ARRAY maxfonts, 32 OF CHAR;
        buf: ARRAY PakSize OF SYSTEM.BYTE;

    PROCEDURE ReceiveHead;
        VAR time: LONGINT;
    BEGIN time := Input.Time() + T0;
```

```
  LOOP SCC.ReceiveHead(head1);
    IF head1.valid THEN
      IF head1.sadr = head0.dadr THEN EXIT ELSE SCC.Skip(head1.len) END
    ELSIF Input.Time() >= time THEN head1.typ := TOT; EXIT
    END
  END
END ReceiveHead;

PROCEDURE FindPrinter(VAR name: ARRAY OF CHAR);
  VAR time: LONGINT;
    id: ARRAY 10 OF CHAR;
BEGIN head0.typ := NRQ; head0.dadr := Broadcast; head0.len := 10;
  head0.destLink := 0; COPY(name, id); id[8] := 6X; id[9] := 0X;
  SCC.Skip(SCC.Available()); SCC.SendPacket(head0, id); time := Input.Time() + T1;
  LOOP SCC.ReceiveHead(head1);
    IF head1.valid THEN
      IF head1.typ = NRS THEN head0.dadr := head1.sadr; res := 0; EXIT
      ELSE SCC.Skip(head1.len)
      END
    ELSIF Input.Time() >= time THEN res := 1; EXIT
    END
  END
END FindPrinter;

PROCEDURE SendPacket;
BEGIN head0.typ := seqno; head0.len := in;
  REPEAT SCC.SendPacket(head0, buf); ReceiveHead;
  UNTIL head1.typ # seqno + ACK;
  seqno := (seqno+1) MOD 8;
  IF head1.typ # seqno + ACK THEN res := 1 END
END SendPacket;

PROCEDURE Send(x: SYSTEM.BYTE);
BEGIN buf[in] := x; INC(in);
  IF in = PakSize THEN SendPacket; in := 0 END
END Send;

PROCEDURE SendInt(k: INTEGER);
BEGIN Send(SHORT(k MOD 100H)); Send(SHORT(k DIV 100H))
END SendInt;

PROCEDURE SendBytes(VAR x: ARRAY OF SYSTEM.BYTE; n: INTEGER);
  VAR i: INTEGER;
BEGIN i := 0;
  WHILE i < n DO Send(x[i]); INC(i) END
END SendBytes;

PROCEDURE SendString(VAR s: ARRAY OF CHAR);
  VAR i: INTEGER;
BEGIN i := 0;
  WHILE s[i] > 0X DO Send(s[i]); INC(i) END ;
  Send(0)
END SendString;

PROCEDURE Open*(VAR name, user: ARRAY OF CHAR; password: LONGINT);
BEGIN nofonts := 0; in := 0; seqno := 0; SCC.Skip(SCC.Available());
  IF name # PrinterName THEN FindPrinter(name) ELSE res := 0 END ;
  IF res = 0 THEN
    SendString(user); SendBytes(password, 4);
    head0.typ := PRT; head0.len := in; SCC.SendPacket(head0, buf); in := 0;
    ReceiveHead;
    IF head1.typ = ACK THEN Send(0FCX) (*printfileid*)
    ELSIF head1.typ = NPR THEN res := 4 (*no permission*)
    ELSE res := 2 (*no printer*)
    END
  END
END Open;

PROCEDURE ReplConst*(x, y, w, h: INTEGER);
BEGIN Send(2); Send(0);
  SendInt(x); SendInt(y); SendInt(w); SendInt(h)
END ReplConst;

PROCEDURE fontno(VAR name: ARRAY OF CHAR): SHORTINT;
  VAR i, j: INTEGER;
BEGIN i := 0;
  WHILE (i < nofonts) & (fontname[i] # name) DO INC(i) END ;
  IF i = nofonts THEN
    IF nofonts < maxfonts THEN
      COPY(name, fontname[i]); INC(nofonts);
      Send(3); Send(SHORT(i)); j := 0;
      WHILE name[j] >= "0" DO Send(name[j]); INC(j) END ;
      Send(0)
    ELSE i := 0
    END
  END ;
  RETURN SHORT(i)
END fontno;

PROCEDURE UseListFont*(VAR name: ARRAY OF CHAR);
  VAR i: INTEGER;
    listfont: ARRAY 10 OF CHAR;
BEGIN listfont := "Gacha10l"; i := 0;
  WHILE (i < nofonts) & (fontname[i] # name) DO INC(i) END ;
  IF i = nofonts THEN
    COPY(name, fontname[i]); INC(nofonts);
    Send(3); Send(SHORT(i)); SendBytes(listfont, 9)
  END ;
END UseListFont;

PROCEDURE String*(x, y: INTEGER; VAR s, fname: ARRAY OF CHAR);
  VAR fno: SHORTINT;
BEGIN fno := fontno(fname); Send(1); Send(fno); SendInt(x); SendInt(y); SendString(s)
END String;

PROCEDURE ContString*(VAR s, fname: ARRAY OF CHAR);
  VAR fno: SHORTINT;
BEGIN fno := fontno(fname); Send(0); Send(fno); SendString(s)
END ContString;

PROCEDURE ReplPattern*(x, y, w, h, col: INTEGER);
BEGIN Send(5); Send(SHORT(col)); SendInt(x); SendInt(y); SendInt(w); SendInt(h)
END ReplPattern;

PROCEDURE Line*(x0, y0, x1, y1: INTEGER);
BEGIN Send(6); Send(0); SendInt(x0); SendInt(y0); SendInt(x1); SendInt(y1)
END Line;
```

```
   PROCEDURE Circle*(x0, y0, r: INTEGER);
   BEGIN Send(9); Send(0); SendInt(x0); SendInt(y0); SendInt(r)
   END Circle;

   PROCEDURE Ellipse*(x0, y0, a, b: INTEGER);
   BEGIN Send(7); Send(0); SendInt(x0); SendInt(y0); SendInt(a); SendInt(b)
   END Ellipse;

   PROCEDURE Picture*(x, y, w, h, mode: INTEGER; adr: LONGINT);
     VAR a0, a1: LONGINT; b: SHORTINT;
   BEGIN Send(8); Send(SHORT(mode));
     SendInt(x); SendInt(y); SendInt(w); SendInt(h);
     a0 := adr; a1 := LONG((w+7) DIV 8) * h + a0;
     WHILE (a0 < a1) & (res = 0) DO SYSTEM.GET(a0, b); Send(b); INC(a0) END
   END Picture;

   PROCEDURE Page*(nofcopies: INTEGER);
   BEGIN Send(4); Send(SHORT(nofcopies))
   END Page;

   PROCEDURE Close*;
   BEGIN SendPacket;
     WHILE nofonts > 0 DO DEC(nofonts); fontname[nofonts, 0] := " " END
   END Close;

 BEGIN PageWidth := 2336; PageHeight := 3425; in := 0; PrinterName[0] := 0X
 END Printer.
```

Module *Printer* acts as master of the communication. Its partner is module *NetServer*. The syntax of a print request is almost identical to that for sending a file:

PrintStream = PRT username password (*ACK datastream* | *NAK* | *NPR*).
datastream = DAT_0 data ACK_1 {DAT_i data ACK_{i+1}}.

The server routine handling the print request is guarded by the condition *typ = PRT* (see *NetServer* above), and it is almost the same as that for handling requests to receive a file. But instead of registering the received file, the file is inserted into *Core.PrintQueue*.

The printing tasks are extracted from the queue by a handler in module *PrintServer*, which constitutes an Oberon Task guarded by the condition *Core.PrintQueue.n > 0*, i.e. which becomes active, if the queue of print tasks is not empty. The server to be described here operates a laser printer capable of printing about 10 pages per minute. The shortest printing task therefore takes at least 6 seconds. Since every command in the Oberon System is inherently non-interruptible, a printing task must evidently be broken up into parts, if unacceptably long suspension of all other services is to be avoided. This is achieved by breaking up the printing process into phases and by returning control to the Oberon scheduler after each phase.

The processing of a page consists of two parts: First, the elements of the print stream are read and interpreted, resulting in their representation as a dot raster in a page map. Then the raster is transmitted to the printer while the page is printed. During the second part, the computer's processor is disengaged; the transfer is handled by direct memory access under printer control. Only the first part, which is typically much less time-consuming, requires the processor, which therefore is available to accept and interpret other requests during the second part. The printing process of a document is described by four phases, whose possible sequencing is shown by a control flow diagram in Fig. 11.6.

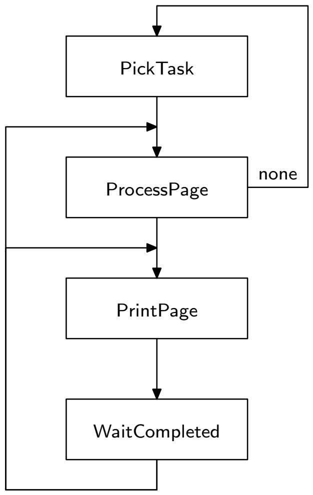

Fig. 11.6. Phases of printing process

Each of the four phases is represented by a handler procedure, one of which is installed as Oberon Task at any time. Whenever a phase terminates, the handler installs its selected successor. The raster is generated in the *ProcessPage* phase by procedures defined in module *Printmaps* whose interface is listed below.

```
DEFINITION Printmaps; (*NW 9.7.89 / 17.11.90*)
    VAR Pat*: ARRAY 10 OF LONGINT;
    PROCEDURE Map*(): LONGINT;
    PROCEDURE ClearPage*;
    PROCEDURE CopyPattern*(pat: LONGINT; X, Y: INTEGER);
    PROCEDURE ReplPattern*(pat: LONGINT; X, Y, W, H: INTEGER);
    PROCEDURE ReplConst*(X, Y, W, H: INTEGER);
    PROCEDURE Dot*(x, y: LONGINT);
END Printmaps.
```

These raster operations are very similar to those of module *Display* (see Chap. 4). They refer to the printer's bitmap rather than the displays', and they feature neither a mode nor a color parameter. For rastering characters, the same font file format is used as for the display.

```
MODULE PrintServer;  (*NW 17.4.89 / 25.8.91*)
    IMPORT SYSTEM, Core, Display, Printmaps, Files, Fonts, Texts, Oberon;

    CONST maxFnt = 32; N = 20; (*max dim of splines*)
      PR0 = 0FFF600H;
      proff = 0; prdy = 1; sbusy = 2; end = 3;  (*printer status*)
      BMwidth = 2336; BMheight = 3425;

    TYPE RealVector = ARRAY N OF REAL;
      Poly = RECORD a, b, c, d, t: REAL END ;
      PolyVector = ARRAY N OF Poly;

    VAR W: Texts.Writer;
      handler: Oberon.Task;

      uno, nofcopies, nofpages: INTEGER;
      PR: Files.Rider;  (*print rider*)
      font: ARRAY maxFnt OF Fonts.Font;

    PROCEDURE circle(x0, y0, r: LONGINT);
      VAR x, y, u: LONGINT;
    BEGIN u := 1 - r; x := r; y := 0;
      WHILE y <= x DO
          Printmaps.Dot(x0+x, y0+y); Printmaps.Dot(x0+y, y0+x);
          Printmaps.Dot(x0-y, y0+x); Printmaps.Dot(x0-x, y0+y);
          Printmaps.Dot(x0-x, y0-y); Printmaps.Dot(x0-y, y0-x);
          Printmaps.Dot(x0+y, y0-x); Printmaps.Dot(x0+x, y0-y);
          IF u < 0 THEN INC(u, 2*y+3) ELSE INC(u, 2*(y-x)+5); DEC(x) END ;
          INC(y)
      END
    END circle;

    PROCEDURE ellipse(x0, y0, a, b: LONGINT);
    BEGIN ...
    END ellipse;

    PROCEDURE^ ProcessPage;
    PROCEDURE^ PrintPage;
    PROCEDURE^ WaitForCompletion;

    PROCEDURE Terminate;
      VAR i: INTEGER;
    BEGIN Core.RemoveTask(Core.PrintQueue); i := 0;
      REPEAT font[i] := NIL; INC(i) UNTIL i = maxFnt  (*release fonts*)
    END Terminate;

    PROCEDURE Append(src: ARRAY OF CHAR;
          VAR dst: ARRAY OF SYSTEM.BYTE; VAR k: INTEGER);
      VAR i: INTEGER; ch: CHAR;
    BEGIN i := 0;
      REPEAT ch := src[i]; dst[k] := ch; INC(i); INC(k) UNTIL ch = 0X
    END Append;

    PROCEDURE* PickTask;
      VAR F: Files.File;
          Id: Core.ShortName;
          tag: CHAR;
    BEGIN
      IF (Core.PrintQueue.n > 0) & ~SYSTEM.BIT(PR0, proff)
            & SYSTEM.BIT(PR0, prdy) THEN
          Core.GetTask(Core.PrintQueue, F, Id, uno); nofpages := 0;
          Files.Set(PR, F, 0); Files.Read(PR, tag);
          IF tag = 0FCX THEN handler.handle := ProcessPage
          ELSE Texts.WriteString(W, Id); Texts.WriteString(W, " not a print file");
            Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf); Terminate
          END
      END
    END PickTask;

    PROCEDURE ProcessPage;
      VAR i, x, y, w, h, x0, x1, y0, y1: INTEGER;
          a, a0, a1: LONGINT;
          d, u: INTEGER;
          typ, sp: SHORTINT;
          ch: CHAR;
          fnt: Fonts.Font;
          fname: Core.Name;

      PROCEDURE String;
          VAR ch: CHAR;
            dx, x0, y0, w, h: INTEGER;
            fnt: Fonts.Font;
          pat: LONGINT;
        BEGIN fnt := font[sp MOD maxFnt];
          IF (x >= 0) & (y >= 0) & (fnt # NIL) & (y + fnt.height < BMheight) THEN
            LOOP Files.Read(PR, ch);
              IF ch = 0X THEN EXIT END ;
              Display.GetChar(fnt.raster, ch, dx, x0, y0, w, h, pat);
              IF (x + x0 + w <= BMwidth) & (h > 0) THEN
                Printmaps.CopyPattern(pat, x+x0, y+y0)
              END ;
              INC(x, dx)
            END
          END
        END String;

      BEGIN Printmaps.ClearPage;
        LOOP Files.Read(PR, typ);
          IF PR.eof THEN
            Core.IncPageCount(uno, nofpages); Terminate; handler.handle := PickTask; EXIT
          END ;
          Files.Read(PR, sp);
          IF typ = 0 THEN String
          ELSIF typ = 1 THEN
            Files.ReadBytes(PR, x, 2); Files.ReadBytes(PR, y, 2); String
          ELSIF typ = 2 THEN
            Files.ReadBytes(PR, x, 2); Files.ReadBytes(PR, y, 2);
            Files.ReadBytes(PR, w, 2); Files.ReadBytes(PR, h, 2);
            IF x < 0 THEN INC(w, x); x := 0 END ;
            IF x+w > BMwidth THEN w := BMwidth - x END ;
            IF y < 0 THEN INC(h, y); y := 0 END ;
            IF y+h > BMheight THEN h := BMheight - y END ;
            Printmaps.ReplConst(x, y, w, h)
          ELSIF typ = 3 THEN
            i := 0;
            REPEAT Files.Read(PR, fname[i]); INC(i) UNTIL fname[i-1] < "0";
            DEC(i); Append(".Pr3.Fnt", fname, i);
            fnt := Fonts.This(fname);
            IF fnt = Fonts.Default THEN fnt := Fonts.This("Syntax10.Pr3.Fnt") END ;
            font[sp MOD maxFnt] := fnt
          ELSIF typ = 4 THEN
            nofcopies := sp; handler.handle := PrintPage; EXIT
          ELSIF typ = 5 THEN  (*shaded area*)
            IF (sp < 0) OR (sp > 9) THEN sp := 2 END ;
            Files.ReadBytes(PR, x, 2); Files.ReadBytes(PR, y, 2);
            Files.ReadBytes(PR, w, 2); Files.ReadBytes(PR, h, 2);
            IF x < 0 THEN INC(w, x); x := 0 END ;
            IF x+w > BMwidth THEN w := BMwidth - x END ;
            IF y < 0 THEN INC(h, y); y := 0 END ;
            IF y+h > BMheight THEN h := BMheight - y END ;
            Printmaps.ReplPattern(Printmaps.Pat[sp], x, y, w, h)
          ELSIF typ = 6 THEN  (*line*)
            Files.ReadBytes(PR, x0, 2); Files.ReadBytes(PR, y0, 2);
            Files.ReadBytes(PR, x1, 2); Files.ReadBytes(PR, y1, 2);
            w := ABS(x1-x0); h := ABS(y1-y0);
            IF h <= w THEN
              IF x1 < x0 THEN u := x0; x0 := x1; x1 := u; u := y0; y0 := y1; y1 := u END ;
              IF y0 <= y1 THEN d := 1 ELSE d := -1 END ;
            u := (h-w) DIV 2;
            WHILE x0 < x1 DO
              Printmaps.Dot(x0, y0); INC(x0);
              IF u < 0 THEN INC(u, h) ELSE INC(u, h-w); INC(y0, d) END
            END
          ELSE
            IF y1 < y0 THEN u := x0; x0 := x1; x1 := u; u := y0; y0 := y1; y1 := u END ;
            IF x0 <= x1 THEN d := 1 ELSE d := -1 END ;
            u := (w-h) DIV 2;
            WHILE y0 < y1 DO
              Printmaps.Dot(x0, y0); INC(y0);
              IF u < 0 THEN INC(u, w) ELSE INC(u, w-h); INC(x0, d) END
            END
          END
        ELSIF typ = 7 THEN  (*ellipse*)
          Files.ReadBytes(PR, x, 2); Files.ReadBytes(PR, y, 2);
          Files.ReadBytes(PR, w, 2); Files.ReadBytes(PR, h, 2);
          ellipse(x, y, w, h)
        ELSIF typ = 8 THEN  (*picture*)
          Files.ReadBytes(PR, x, 2); Files.ReadBytes(PR, y, 2);
          Files.ReadBytes(PR, w, 2); Files.ReadBytes(PR, h, 2);
          ...
        ELSIF typ = 9 THEN  (*circle*)
          Files.ReadBytes(PR, x, 2); Files.ReadBytes(PR, y, 2);
          Files.ReadBytes(PR, w, 2); circle(x, y, w)
        ELSE Texts.WriteString(W, " error in print file at");
          Texts.WriteInt(W, Files.Pos(PR), 6); Texts.WriteInt(W, typ, 5);
          Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf);
          Terminate; handler.handle := PickTask; EXIT
        END
      END
    END ProcessPage;

    PROCEDURE PrintPage;
    BEGIN
      IF SYSTEM.BIT(PR0, prdy) THEN
        SYSTEM.PUT(PR0, Printmaps.Map()); handler.handle := WaitForCompletion;
        REPEAT UNTIL SYSTEM.BIT(PR0, end)
      END
    END PrintPage;

    PROCEDURE WaitForCompletion;
    BEGIN
      IF ~SYSTEM.BIT(PR0, end) THEN
        DEC(nofcopies); INC(nofpages);
        IF nofcopies > 0 THEN handler.handle := PrintPage; DEC(nofcopies)
        ELSE handler.handle := ProcessPage
        END
      END
    END WaitForCompletion;

    (*------------------------ Commands -------------------------*)

    PROCEDURE Start*;
    BEGIN
      IF ~SYSTEM.BIT(PR0, proff) THEN
        handler.handle := PickTask;
        Oberon.Remove(handler); Oberon.Install(handler);
```

```
      Texts.WriteString(W, "Printer started  (NW 25.8.91)")
    ELSE Texts.WriteString(W, "Printer off")
    END ;
    Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
  END Start;

  PROCEDURE State*;
    VAR s: SHORTINT;
  BEGIN Texts.WriteString(W, "Printer Queue:"); Texts.WriteInt(W, Core.PrintQueue.n, 4);
    Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
  END State;

  PROCEDURE Reset*;
  BEGIN; handler.handle := PickTask;
  END Reset;

  PROCEDURE Stop*;
  BEGIN Oberon.Remove(handler); Texts.WriteString(W, "Printer stopped");
    Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
  END Stop;

BEGIN Texts.OpenWriter(W); NEW(handler)
END PrintServer.
```

11.4. Miscellaneous Services

There exist a few additional services that are quite desirable under the presence of a central facility, and at the same time easy to include. They are briefly described in this section.

The set of commands of the file distribution service is augmented by *Net.DeleteFiles* and *Net.Directory*, allowing the remote deletion of files and inspection of the server's directory. The command procedures are listed below and must be regarded as part of module *Net* (Sect. 10.4). They communicate with their counterparts in module *NetServer* (Sect. 11.2.) according to the following protocol:

DeleteFile = DEL username password filename (*ACK* | *NAK* | *NPR*).
Directory = FDIR username password prefix (*datastream* | *NAK* | *NPR*).

The directory request carries a prefix; it uses procedure *FileDir.Enumerate* to obtain all file names starting with the specified prefix. Thereby the search can be limited to the relevant section of the directory.

```
PROCEDURE DeleteFiles*;
  VAR k: INTEGER;
    S: Texts.Scanner;
    buf: ARRAY 64 OF CHAR;
BEGIN GetPar1(S);
  IF S.class = Texts.Name THEN
    FindPartner(S.s, k);
    IF k = 0 THEN
      LOOP Texts.Scan(S);
        IF S.class # Texts.Name THEN EXIT END ;
        k := 0; AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
        AppendS(S.s, buf, k); Send(DEL, k, buf);
        Texts.WriteString(W, S.s); Texts.WriteString(W, " remote deleting");
        ReceiveHead(T1);
        IF head1.typ = ACK THEN reply(0)
        ELSIF head1.typ = NAK THEN reply(3)
        ELSIF head1.typ = NPR THEN reply(2); EXIT
        ELSE reply(5); EXIT
```

```
            END
          END
        ELSE reply(1)
        END
      END
    END DeleteFiles;
```

```
    PROCEDURE Directory*;
      VAR k, X, Y: INTEGER;
        T: Texts.Text;
        V: Viewers.Viewer;
        buf: ARRAY 32 OF CHAR;
        S: Texts.Scanner;
    BEGIN GetPar1(S);
      IF S.class = Texts.Name THEN
        FindPartner(S.s, k);
        IF k = 0 THEN
          Texts.Scan(S);
          IF S.class = Texts.Name THEN (*prefix*)
            AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
            AppendS(S.s, buf, k); Send(FDIR, k, buf); ReceiveHead(T1);
            IF head1.typ = 0 THEN
              T := TextFrames.Text("");
              Oberon.AllocateSystemViewer(Oberon.Par.frame.X, X, Y);
              V := MenuViewers.New(
                  TextFrames.NewMenu("Net.Directory", "System.Close  Edit.Store"),
                  TextFrames.NewText(T, 0), TextFrames.menuH, X, Y);
              ReceiveText(T)
            ELSIF head1.typ = NAK THEN reply(4)
            ELSIF head1.typ = NPR THEN reply(2)
            ELSE  reply(5)
            END
          END
        ELSE reply(1)
        END
      END
    END Directory;
```

Since requests to the server are always guarded by a password, a facility is necessary to set and change the password stored by the server. The respective command is *Net.SetPassword*, and its handler in the server is guarded by the condition *typ = NPW*. The corresponding protocol is

```
    NewPassword =     NPW username oldpassword
            (ACK DAT newpassword (ACK | NAK)  | NAK | NPR).
```

```
    PROCEDURE SetPassword*;
      VAR k: INTEGER; oldpw: LONGINT;
        S: Texts.Scanner;
        buf: ARRAY 64 OF CHAR;
    BEGIN GetPar1(S);
      IF S.class = Texts.Name THEN
        FindPartner(S.s, k);
        IF k = 0 THEN Texts.Scan(S);
          IF S.class = Texts.String THEN
            AppendS(Oberon.User, buf, k); AppendW(Oberon.Password, buf, 4, k);
            Send(NPW, k, buf); ReceiveHead(T1);
            IF head1.typ = ACK THEN
              k := 0; Oberon.SetUser(Oberon.User, S.s); AppendW(Oberon.Password, buf, 4, k);
              Send(0, 4, buf); ReceiveHead(T0);
              IF head1.typ = ACK THEN reply(7) ELSE reply(3) END
            ELSIF head1.typ = NPR THEN reply(2)
            ELSE reply(3)
            END
          END
        ELSE reply(1)
        END
      END
    END SetPassword;
```

Finally, procedure Net.GetTime allows the workstation's real time clock to be adjusted to that of the central server. The protocol is

```
GetTime =TRQ TIM time date.
```

```
PROCEDURE GetTime*;
  VAR t, d: LONGINT; res: INTEGER;
    S: Texts.Scanner;
BEGIN GetPar1(S);
  IF S.class = Texts.Name THEN
    FindPartner(S.s, res);
    IF res = 0 THEN
      Send(TRQ, 0, dmy); ReceiveHead(T1);
      IF head1.typ = TIM THEN
        PickQ(t); PickQ(d); Oberon.SetClock(t, d); reply(6)
      END
    ELSE reply(1)
    END
  END
END GetTime;
```

In concluding we summarize the entire protocol specification below. The combined server facility, comprising file distribution, electronic mail, printing, and time services is operating on a Ceres-1 computer (1 Mips) with a 2 MByte store, of which half is used by the printer's bitmap.

Summary of Protocol:

```
protocol      =   {request}.
request       =   ReceiveFile | SendFile | DeleteFile | Directory |
                  MailBox | SendMail | ReceiveMail | DeleteMail |
                  PrintStream | SendMsg | NameRequest | NewPassword | GetTime.
ReceiveFile   =   SND username password filename (datastream | NAK | NPR).
datastream    =   DAT0 data ACK1  {DATi data ACKi+1}.
SendFile      =   REC username password filename (ACK0 datastream | NAK | NPR).
datastream    =   DAT0 data ACK1  {DATi data ACKi+1}.
DeleteFile    =   DEL username password filename (ACK | NAK | NPR).
Directory     =   FDIR username password prefix (datastream | NAK | NPR).
MailBox       =   MDIR username password (datastream | NAK | NPR).
SendMail      =   RML username password (ACK datastream | NAK | NPR).
ReceiveMail   =   SML username password msgno (datastream | NAK | NPR).
DeleteMail    =   DML username password msgno (ACK | NAK | NPR).
PrintStream   =   PRT username password (ACK datastream | NAK | NPR).
SendMsg       =   MSG message ACK.
NameRequest   =   NRQ partnername [NRS].
NewPassword   =   NPW username oldpassword
                  (ACK DAT newpassword (ACK | NAK)  | NAK | NPR).
GetTime       =   TRQ TIM time date.
```

11.5. User Administration

It appears to be a universal law that centralization inevitably calls for an administration. The centralized mail and printing services make no exception. The typical duties of an administration are accounting and protection against misuse. It has to ensure that rendered services are counted and that no unauthorized user is taking advantage of the server. An additional duty is often the gathering of statistical data. In our case, accounting plays a very minor role, and the reason for the existence of the administration presented here is primarily protection.

We distinguish between two kinds of protection. The first is protection of the server's resources in general, the second is that of individual users' resources from being accessed by others. Whereas in the first case some validation of a user's identification might suffice, the second case requires the association of personal resources with user names. In any case, the central server must store data for each member of the set of registered users. Specifically, it must be able to check the admissibility of a user's request on the basis of stored information.

Evidently, a protection administration is similar in purpose and function to a lock. Quite regularly, locks are subjected to attempts of breaking them, and locksmiths are subjected to attempts of being outwitted. The race between techniques of breaking locks and that of better countermeasures is well known, and we do not even try to make a contribution to it. Our design is based on the premise that the Oberon Server operates in a harmonious environment. Nevertheless, a minimal amount of protection machinery was included. It raises the amount of effort required for breaking protection to a level which is not reached when curiosity alone is the motivation.

The data about users is held in a table in module *Core*. As was mentioned earlier, *Core* acts as connector between the various servers by means of task queues. Its second purpose is to provide the necessary access to user data via appropriate procedures.

In the simplest solution, each table entry would contain a user name only. For each request, the administration would merely test for the presence of the request's user name in the table. A significant step towards safe protection is the introduction of a password in addition to the user name. In order that a request be honoured, not only must the name be registered, but the delivered and the stored password must match. Evidently, abusive attempts would aim at recovering the stored passwords. Our solution lies in storing an encoded password. The command *System.SetUser*, which asks for a user identification and a password, immediately encodes the password, and the original is stored nowhere. The encoding algorithm is such that it is difficult to construct a corresponding decoder.

The mail service requires a third attribute in addition to identification and encoded password: the user's name as it is used for addressing messages. Identification typically consists of the user's initials; for the name we suggest the full last name of the user and discourage cryptic abbreviations.

The printing service makes an accounting facility desirable. A fourth field in each user table entry serves as a count for the number of printed pages. As a result, there are four fields: *id, name, password,* and *count*. The table is not exported, but only accessible via procedures. *Core* is a good example of a resource hiding module. The program is listed below, and a few additional comments follow here.

Procedures *UserNo(id)* and *UserNum(name)* yield the table index of the identified user; it is called *user number* and is used as a short encoding for recipients and senders within the mail server. In other servers, the number is merely used to check a request's validity.

The user information must certainly survive any intermission of server operation, be it due to software, hardware, or power failure. This requires that a copy of the user information is held on backup store (disk). The simplest solution would be to use a file for this purpose. But this would indeed make protection too vulnerable: files can be accessed easily, and we have refrained from introducing a file protection facility. Instead, the backup of the user information is held on a few permanently reserved sectors on the server machine, which are inaccessible to the file system.

```
MODULE Core;  (*NW 17.4.89 / 6.1.90*)
    IMPORT Kernel, Files;
```

```
CONST
  UTsize = 64;  (*max nof registered users*)
  UTsec0 = ;  (*adr of user table on disk*)
  UTsec1 = ;

TYPE
  ShortName* = ARRAY 8 OF CHAR;
  LongName* = ARRAY 16 OF CHAR;
  Name* = ARRAY 32 OF CHAR;

  MailEntry* = RECORD
      pos*, next*: INTEGER;
      len*: LONGINT;
      time*, date*: INTEGER;
      originator*: ARRAY 20 OF CHAR
    END ;

  MResTab* = ARRAY 8 OF SET;
  MailDir* = ARRAY 31 OF MailEntry;

  User = RECORD
      id: ShortName;
      name: LongName;
      password, count: LONGINT
    END ;

  SectorBuf = RECORD (Kernel.Sector)
      u: ARRAY 32 OF User
    END ;

  Task = POINTER TO TaskDesc;

  TaskDesc = RECORD
      file: Files.File;
      uno, class: INTEGER;
      name: ShortName;
      next: Task
    END ;

  Queue = RECORD n*: INTEGER;
      first, last: Task
    END ;

VAR PrintQueue*, MailQueue*: Queue;
  NUsers: INTEGER;
  UT:  ARRAY UTsize OF User;

PROCEDURE RestoreUsers*;
  VAR i: INTEGER; SB: SectorBuf;
BEGIN i := 0; Kernel.GetSector(UTsec0, SB);
  WHILE (i < 32) & (SB.u[i].id[0] > 0X) DO UT[i] := SB.u[i]; INC(i) END ;
  IF i = 32 THEN
    Kernel.GetSector(UTsec1, SB);
    WHILE (i < 64) & (SB.u[i-32].id[0] > 0X) DO UT[i] := SB.u[i-32]; INC(i) END
  END ;
  NUsers := i
END RestoreUsers;

PROCEDURE BackupUsers*;
  VAR i: INTEGER; SB: SectorBuf;
BEGIN i := NUsers;
```

```
  IF i >= 32 THEN
    IF i < 64 THEN SB.u[i-32].id[0] := 0X END ;
    WHILE i > 32 DO DEC(i); SB.u[i-32] := UT[i] END ;
    Kernel.PutSector(UTsec1, SB)
  END ;
  IF i < 32 THEN SB.u[i].id[0] := 0X END ;
  WHILE i > 0 DO DEC(i); SB.u[i] := UT[i] END ;
  Kernel.PutSector(UTsec0, SB)
END BackupUsers;

PROCEDURE Uno(VAR id: ShortName): INTEGER;
  VAR i: INTEGER;
BEGIN i := 0;
  WHILE (i < NUsers) & (UT[i].id # id) DO INC(i) END ;
  RETURN i
END Uno;

PROCEDURE NofUsers*(): INTEGER;
BEGIN RETURN NUsers
END NofUsers;

PROCEDURE UserNo*(VAR id: ShortName; pw: LONGINT): INTEGER;
  VAR i: INTEGER;  (* -1 = user is protected or not registered*)
BEGIN i := Uno(id);
  IF (i = NUsers) OR (UT[i].password # pw) & (UT[i].password # 0) THEN i := -1 END ;
  RETURN i
END UserNo;

PROCEDURE UserNum*(VAR name: ARRAY OF CHAR): INTEGER;
  VAR i, j: INTEGER;
BEGIN i := 0;
  LOOP
    IF i = UTsize THEN i := -1; EXIT END ;
    j := 0;
    WHILE (j < 4) & (CAP(name[j]) = CAP(UT[i].name[j])) DO INC(j) END ;
    IF j = 4 THEN EXIT END ;
    INC(i)
  END ;
  RETURN i
END UserNum;

PROCEDURE GetUserName*(uno: INTEGER; VAR name: LongName);
BEGIN name := UT[uno].name
END GetUserName;

PROCEDURE GetFileName*(uno: INTEGER; VAR name: ARRAY OF CHAR);
  VAR i: INTEGER; ch: CHAR;
BEGIN i := 0;
  LOOP ch := UT[uno].name[i];
    IF ch = 0X THEN EXIT END ;
    name[i] := ch; INC(i)
  END ;
  name[i] := "."; name[i+1] := "M"; name[i+2] := "a"; name[i+3] := "i"; name[i+4] := "l";
  name[i+5] := 0X
END GetFileName;

PROCEDURE GetUser*(uno: INTEGER; VAR id: ShortName; VAR name: LongName;
      VAR count: LONGINT; VAR protected: BOOLEAN);
BEGIN id := UT[uno].id; name := UT[uno].name; count := UT[uno].count;
```

```
   protected := UT[uno].password # 0
END GetUser;

PROCEDURE InsertUser*(VAR id: ShortName; VAR name: LongName);
   VAR i: INTEGER;
BEGIN i := Uno(id);
   IF (i = NUsers) & (i < UTsize-1) THEN
      UT[i].id := id; UT[i].name := name; INC(NUsers)
   END
END InsertUser;

PROCEDURE DeleteUser*(VAR id: ShortName);
   VAR i: INTEGER;
BEGIN i := Uno(id);
   IF i < NUsers THEN DEC(NUsers);
      WHILE i < NUsers DO UT[i] := UT[i+1]; INC(i) END
   END
END DeleteUser;

PROCEDURE ClearPassword*(VAR id: ShortName);
BEGIN UT[Uno(id)].password := 0
END ClearPassword;

PROCEDURE SetPassword*(uno: INTEGER; npw: LONGINT);
BEGIN UT[uno].password := npw; BackupUsers
END SetPassword;

PROCEDURE IncPageCount*(uno: INTEGER; n: LONGINT);
BEGIN INC(UT[uno].count, n); BackupUsers
END IncPageCount;

PROCEDURE SetCounts*(n: LONGINT);
   VAR i: INTEGER;
BEGIN i := 0;
   WHILE i < NUsers DO UT[i].count := n; INC(i) END
END SetCounts;

PROCEDURE PurgeUsers*(n: INTEGER);
BEGIN NUsers := 0
END PurgeUsers;

PROCEDURE InsertTask*(VAR Q: Queue; F: Files.File;
      VAR id: ARRAY OF CHAR; uno: INTEGER);
   VAR T: Task;
BEGIN NEW(T); T.file := F; COPY(id, T.name); T.uno := uno; T.next := NIL;
   IF Q.last # NIL THEN Q.last.next := T ELSE Q.first := T END ;
   Q.last := T; INC(Q.n)
END InsertTask;

PROCEDURE GetTask*(VAR Q: Queue; VAR F: Files.File;
      VAR id: ShortName; VAR uno: INTEGER);
BEGIN (*Q.first # NIL*)
   F := Q.first.file; id := Q.first.name; uno := Q.first.uno
END GetTask;

PROCEDURE RemoveTask*(VAR Q: Queue);
BEGIN (*Q.first # NIL*)
   Files.Purge(Q.first.file); Q.first := Q.first.next; DEC(Q.n);
   IF Q.first = NIL THEN Q.last := NIL END
END RemoveTask;
```

```
        PROCEDURE Reset(VAR Q: Queue);
        BEGIN Q.n := 0; Q.first := NIL; Q.last := NIL
        END Reset;

        PROCEDURE Collect*;
          VAR n: LONGINT;
        BEGIN
          IF Kernel.allocated > 300000 THEN Kernel.GC END
        END Collect;

    BEGIN RestoreUsers; Reset(PrintQueue); Reset(MailQueue); Reset(LineQueue)
    END Core.
```

Apart from procedures and variables constituting the queuing mechanism for tasks, the procedures exported from module *Core* all belong to the administration, and they can be divided into two categories. The first category contains the procedures used by the three servers presented in this Chapter, and they are *UserNo*, *UserNum*, *IncPageCount*, *SetPassword*, *GetUserName* and *GetFileName*. The second category consists of the procedures *NofUsers* and *GetUser* for inspecting table entries, and *InsertUser*, *DeleteUser*, *ClearPassword*, *ClearCounts*, and *Init* for making changes to the table.

The client of the latter category is a module *Users* which is needed by the human administrator of the server facility.

```
    MODULE Users;   (*NW 2.2.89 / 25.8.91*)
        IMPORT Texts, Viewers, Oberon, MenuViewers, TextFrames, Core;

        CONST TAB = 9X;
        VAR W: Texts.Writer;

        PROCEDURE List*;
          VAR x, y, i: INTEGER;
            protected: BOOLEAN;
            count: LONGINT;
            T: Texts.Text;
            V: Viewers.Viewer;
            id: Core.ShortName; name: Core.LongName;
        BEGIN i := 0; T := TextFrames.Text("");
          Oberon.AllocateUserViewer(Oberon.Par.frame.X, x, y);
          V := MenuViewers.New(
              TextFrames.NewMenu("Users.Text", "System.Close  Edit.Store"),
              TextFrames.NewText(T, 0), TextFrames.menuH, x, y);
          WHILE i < Core.NofUsers() DO
            Core.GetUser(i, id, name, count, protected);
            Texts.WriteInt(W, i, 4); Texts.Write(W, TAB);
            IF protected THEN Texts.Write(W, "#") END ;
            Texts.WriteString(W, id); Texts.Write(W, TAB); Texts.WriteString(W, name);
            Texts.WriteInt(W, count, 8); Texts.WriteLn(W); INC(i)
          END ;
          Texts.Append(T, W.buf)
        END List;

        PROCEDURE Insert*;
          VAR id: Core.ShortName; name: Core.LongName; S: Texts.Scanner;
        BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
          IF S.class = Texts.Name THEN
            COPY(S.s, id); Texts.Scan(S);
            IF S.class = Texts.Name THEN
              COPY(S.s, name); Core.InsertUser(id, name); Core.BackupUsers
            END
```

```
      END
    END Insert;

    PROCEDURE Delete*;
      VAR id: Core.ShortName; S: Texts.Scanner;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
      IF S.class = Texts.Name THEN
        COPY(S.s, id); Core.DeleteUser(id); Core.BackupUsers
      END
    END Delete;

    PROCEDURE ClearPassword*;
      VAR id: Core.ShortName; S: Texts.Scanner;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
      IF S.class = Texts.Name THEN
        COPY(S.s, id); Core.ClearPassword(id); Core.BackupUsers
      END
    END ClearPassword;

    PROCEDURE ClearCounts*;
    BEGIN Core.SetCounts(0); Core.BackupUsers
    END ClearCounts;

    PROCEDURE Init*;
      VAR id: Core.ShortName; name: Core.LongName; S: Texts.Scanner;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos);
      Core.PurgeUsers(0);
      LOOP Texts.Scan(S);
        IF S.class # Texts.Name THEN EXIT END ;
        COPY(S.s, id); Texts.Scan(S);
        IF S.class # Texts.Name THEN EXIT END ;
        COPY(S.s, name); Core.InsertUser(id, name)
      END ;
      Core.BackupUsers
    END Init;

  BEGIN Texts.OpenWriter(W)
  END Users.
```

The reader may at this point wonder why a more advanced concept of administration has not been chosen, which would allow the human administrator to operate the server remotely. A quick analysis of the consequences of this widely used approach reveals that a substantial amount of additions to our system would be required. The issue of security and protection would become inflated into dimensions that are hardly justified for our local system. The first consequence would be a differentiation among levels of protection. The administrator would become a so-called super-user with extra priviledges, such as changing the user table. And so the game of trying to break the protection measures starts to become an interesting challenge.

We have resisted the temptation to introduce additional complexity. Instead, we assume that physical access to the server station is reserved to the administrator. Naturally, module Users and in particular the symbol file of *Core* do not belong to the public domain. In concluding, we may point out that the impossibility of activating users' programs on the server station significantly reduces the possibilities for inflicting damage from the exterior.

12. The Compiler

12.1. Introduction

The compiler is the primary tool of the system builder. It therefore plays a prominent role in the Oberon System, although it is not part of the basic system. Instead, it constitutes a tool module - an application - with a single command: *Compile*. It translates program texts into machine code. Therefore, it is as a program inherently machine-dependent; it acts as the interface between source language and target computer.

In order to understand the process of compilation, the reader needs to be familiar with the source language Oberon and with the target computer, the NS-32000 processor architecture. For both the reader is referred to the literature [1].

The language is defined as an infinite set of sequences of symbols taken from the language's vocabulary. It is described by a set of equations called syntax. Each equation defines a syntactic construct, or more precisely, the set of sequences of symbols belonging to that construct. It specifies how that construct is composed of other syntactic constructs. The meaning of programs is defined in terms of semantic rules governing each such construct.

Compilation of a program text proceeds by analyzing the text and thereby decomposing it recursively into its constructs according to the syntax. When a construct is identified, code is generated according to the semantic rule associated with the construct. The components of the identified construct supply parameters for the generated code.

It follows that we distinguish between two kinds of actions: analyzing steps and code generating steps. In a rough approximation we may say that the former are source language dependent and target computer independent, whereas the latter are source language independent and target computer dependent. Although reality is somewhat more complex, the module structure of this compiler clearly reflects this division. The tool module *Compiler* is primarily dedicated to syntactic analysis. Upon recognition of a syntactic construct, an appropriate procedure is called from one of the code generator modules.

Oberon program texts are regarded as sequences of symbols rather than sequences of characters. Symbols themselves, however, are sequences of characters. We refrain from explaining the reasons for this distinction, but mention that apart from special characters and pairs such as +, &, <=, also identifiers, numbers, and strings are classified as symbols. Furthermore, certain capital letter sequences are symbols, such as IF, END, etc. Each time the syntax analyzer (parser) proceeds to read the next symbol, it does this by calling procedure *Get*, which constitutes the so-called scanner residing in module OCS (for Oberon Compiler Scanner). It reads from the source text as many characters as are needed to recognize the next symbol.

In passing we note that the scanner alone reflects the definition of symbols in terms of characters, whereas the parser is based on the notion of symbols only. The scanner implements the abstraction of symbols. The recognition of symbols within a character sequence is called *lexical analysis*.

Ideally the recognition of any syntactic construct, say A, consisting of subconstructs, say B1, B2, ... , Bn, leads to the generation of code that depends only on (1) the semantic rules associated with A, and (2) on (attributes of) B1, B2, ... , Bn. If this condition is satisfied, the construct is said to be context-free, and if all constructs of a language are *context-free*, then also the language is context-free. Syntax and semantics of Oberon adhere to this rule, although with a significant exception. This exception is embodied by the notion of declarations. The declaration of an identifier, say *x*, attaches permanent properties to *x*, such as the fact that *x* denotes a variable and that its type is *T*. These properties are "invisible" when parsing a statement containing *x*, because the declaration of *x* is not also part of the statement. The "meaning" of identifiers is thus inherently context-dependent.

Context-dependence due to declarations is the immediate reason for the use of a global data structure which represents the declared identifiers and their properties (attributes). Since this concept stems from early assemblers where identifiers (then called *symbols*) were registered in a linear table, the term *symbol table* tends to persist for this structure, although in this compiler it is considerably more complex than an array. Basically, it grows during the processing of declarations, and it is searched while expressions and statements are processed. Procedures for building and for searching are contained in module OCT.

A complication arises from the notion of exports and imports in Oberon. Its consequence is that the declaration of an identifier x may be in a module, say M, different from where x is referenced. If x is exported, the compiler includes x together with its attributes in the *symbol file* of the compiled module M. When compiling another module which imports M, that symbol file is read and its data are incorporated into the symbol table. Procedures for reading and writing symbol files are contained in module OCT, and no other module relies on information about the structure of symbol files.

The syntax is precisely and rigorously defined by a small set of syntactic equations. As a result, the parser is a reasonably perspicuous and short program. Unfortunately, the target computer's instruction set is complex, and as a result the program for generating code is much longer and more difficult to comprehend. This is particularly pronounced in the case of a CISC computer such as the NS-32000. Nevertheless, its instruction set is comparatively regular.

Unlike the parser which is fully contained in a single module, code generating procedures are distributed over three modules with the goal of keeping their sizes within reasonable limits (1000 lines). Procedures within module OCE are called mainly when parsing expressions. Apart from generating the corresponding code, the procedures perform the checks for type consistency of operands, and they compute the attributes of the processed construct. As they select the appropriate instructions, they directly reflect the instruction set of the target computer. Procedures in module OCH are of the same nature; they are primarily called when parsing statements instead of expressions.

The final production of code is performed by procedures in module OCC. They are typically called from OCE and OCH. In analogy with the scanner transforming character sequences into symbols, OCC-procedures transform (abstract) instructions into sequences of bits. Hence, this module reflects the binary encoding of instructions, i.e. the target computer's instruction formats.

The resulting module structure of the compiler is shown in Fig. 12.1 in a slightly simplified manner. In reality OCS is imported by all other modules due to their need for procedure *OCS.Mark*. This, however, will be explained later.

12.2. Code Patterns

Before it is possible to understand how code is generated, one needs to know *which* code is generated. In other words, we need to know the goal before we find the way leading to the goal. A fairly concise description of this goal is possible due to the structure of the language. As explained before, semantics are attached to each individual syntactic construct, independent of its context. Therefore, it suffices to list the expected code - instead of an abstract semantic rule - for each syntactic construct.

As a prerequisite to understanding the resulting instructions and in particular their parameters, we need to know where declared variables are stored, i.e. which are their addresses. This compiler uses the straight-forward scheme of sequential allocation of consecutively declared variables. An address is a pair consisting of a base address (in a register) and an offset. Global variables are allocated in the module's data section and the respective base address register is SB (see Chapter 6). Local variables are allocated in a procedure activation record on the stack; the respective base register is FP. Offsets are negative integers.

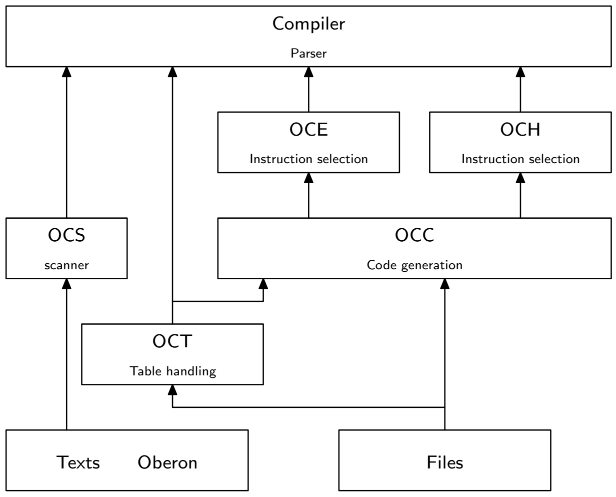

Fig. 12.1. Compiler’s module structure

The amount of storage needed for a variable (called its size) is determined by the variable's type. The sizes of basic types are prescribed by the target computer's data representation. The following holds for the NS processor:

Type	No. of bytes
SHORTINT, CHAR, BOOLEAN	1
INTEGER	2
LONGINT, REAL, SET, POINTER, PROCEDURE	4
LONGREAL	8

The size of an array is the size of the element type multiplied by the number of elements. The size of a record is the sum of the sizes of its fields.

A complication arises due to so-called alignment. By alignment is meant the adjustment of an address to a multiple of the variable's size. Alignment is performed for variable addresses as well as for record field offsets. The motivation for alignment is the avoidance of double memory references for variables being "distributed" over two adjacent words. Proper alignment enhances processing speed quite significantly. Variable allocation using alignment is shown by the example in Fig. 12.2

We note in passing that a reordering of the four variables avoids the occurrence of unused bytes, as shown in Fig. 12.3.

Before embarking on a discussion of various code patterns, we briefly present the most important addressing modes of the processor. d0 and d1 are integers, so-called *displacements* or *offsets*. R_n denotes a general purpose register ($0 \le n < 8$), SB the register holding the *Static Base* address of global data, and FP the register holding the *Frame Pointer*, i.e. the base address of data local to procedures. Parameters of branch instructions denote jump distances from the instruction's own location (PC-relative).

addressing mode	assembler notation	resulting address
register indirect	d0(Rn)	R[n] + d0
	d0(FP)	FP + d0
	d0(SB)	SB + d0
memory indirect	d1(d0(FP))	Mem[FP + d0] + d1
	d1(d0(SB))	Mem[SB + d0] + d1
indexed	adr[Rx:W]	adr + 2*Rx
top of stack	TOS	SP, represents push and pop operations
immediate	n	n = operand

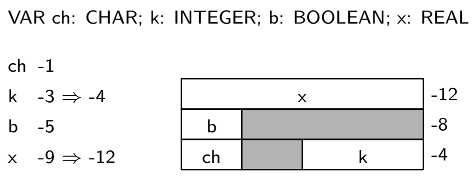

Fig. 12.2. Alignment of variables

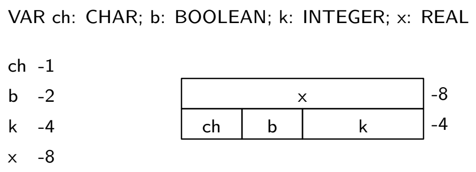

Fig. 12.3. Improved order of variables

Assignment of constants. The variables used in this example are global; their base register is SB. Each assignment results in a single instruction. The constant is embedded within the instruction and uses the immediate addressing mode. If the destination operand occupies more bytes than the source operand, sign extension is included (MOVX). For integers in the range -8 ... 7 special instructions with shorter encoding are used (MOVQ).

```
MODULE Pattern1;
    VAR ch: CHAR;            -1
      i: SHORTINT;           -2
      j: INTEGER;            -4
      k: LONGINT;            -8
      x: REAL;              -12
      s: SET;               -16
BEGIN                         0    ENTER      00 0
    ch := "0";                3    MOVB       48 -1(SB)
    i := 10;                  7    MOVB       10 -2(SB)
    j := 1000;               11    MOVW       1000 -4(SB)
    k := 0;                  16    MOVQD      0 -8(SB)
    x := 1.5;                19    MOVF       3FC00000 -12(SB)
    s := {0, 5, 8};          27    MOVD       00000121 -16(SB)
    j := j;                  34    MOVW       -4(SB) -4(SB)
    k := i;                  38    MOVXBD     -2(SB) -8(SB)
    k := j;                  43    MOVXWD     -4(SB) -8(SB)
    x := j                   48    MOVWF      -4(SB) -12(SB)
END Pattern1.                53    EXIT       00
                             55    RXP        0
```

Simple expressions: The result of an expression containing operators is always stored in a register before it is assigned to a variable or used in another operation. This is necessary in the general case for machines with two-operand instructions. It follows furthermore from the concept of context-free processing: the code for x+y, for example, is the same regardless of whether x := x+y or z := x+y is parsed, although the former could be represented by a single instruction on a two-address machine, whereas the latter cannot.

Registers for intermediate results are allocated sequentially in the orders R7, R6, ... , R0, and F6, F4, F2, F0, the latter for floating-point operands. Integer multiplication and division by powers of 2 are represented by fast, arithmetic shifts (ASH). Similarly, the modulus by a power of 2 is obtained by masking off leading bits (BIC). The operations of set union, difference, and intersection are represented by logical operations (OR, BIC, AND).

```
MODULE Pattern2;
    VAR i, j: INTEGER;          -2, -4
      k, n: LONGINT;            -8, -12
      x, y: REAL;               -16, -20
      s, t, u: SET;             -24, -28, -32
BEGIN                            0    ENTER     00 0
    i := (i + 1) * (i - 1);      3    MOVW      -2(SB)  R7
                                 6    ADDQW     1  R7
                                 8    MOVW      -2(SB)  R6
                                11    ADDQW     -1  R6
                                13    MULW      R6  R7
                                16    MOVW      R7 -2(SB)
    k := ABS(k) DIV 17;         19    ABSD      -8(SB)  R7
                                23    DIVD      17  R7
                                30    MOVD      R7 -8(SB)
    k := 8*n;                   33    MOVD      -12(SB)  R7
                                36    ASHD      3  R7
                                40    MOVD      R7 -8(SB)
    k := n DIV 2;               43    MOVD      -12(SB)  R7
                                46    ASHD      -1  R7
                                50    MOVD      R7 -8(SB)
    k := n MOD 16;              53    MOVD      -12(SB)  R7
                                56    BICD      FFFFFFF0  R7
                                62    MOVD      R7 -8(SB)
    x := -y / (x-1.5);          65    MOVF      -16(SB)  F6
                                69    SUBF      3FC00000  F6
                                76    MOVF      -20(SB)  F4
                                80    DIVF      F6  F4
                                83    NEGF      F4  F2
                                86    MOVF      F2 -16(SB)
    k := ENTIER(x);             90    FLOORFD   -16(SB)  R7
                                94    MOVD      R7 -8(SB)
    s := s + t * u              97    MOVD      -28(SB)  R7
                               100    ANDD      -32(SB)  R7
                               103    MOVD      -24(SB)  R6
                               106    ORD       R7  R6
                               108    MOVD      R6 -24(SB)
END Pattern2.                  111    EXIT      00
                               113    RXP       0
```

Indexed variables: References to elements of arrays make use of the indexed addressing mode. The index must be present in a register. It is loaded by a CHECK instruction which, apart from transferring the index value (with sign extension), also checks whether the index is within the bounds specified in the array's declaration. The subsequent flag instruction causes a trap, if the index lies outside the bounds. The bounding values are stored in the module's constant area and are addressed with base SB and with a positive offset.

If the reference is to an element of a multi-dimensional array (matrix), its address computation involves the INDEX instruction. The address of an element A[i_{k-1}, ... , i_1, i_0] of a k-dimensional array A with lengths n_{k-1}, ... , n_1, n_0 is

$$adr(A) + ((... ((i_{k-1} * n_{k-2}) + i_{k-2}) * n_{k-3} + ...) * n_1 + i_1) * n_0 + i_0$$

The instruction *INDEX r, a, b* computes *r := r*(a-1) + b*. The address of a designator with k indices can therefore be computed by k-1 successive *INDEX* instructions. If all indices are constants, the above polynomial is evaluated by the compiler. The resulting code then consists of a single instruction only.

```
MODULE Pattern3;
    VAR i, j, k, n: INTEGER;                        -2, -4, -6, -8
      a: ARRAY 10 OF INTEGER;                       -28
      b: ARRAY 10 OF LONGINT;                       -68
      x: ARRAY 10, 10 OF INTEGER;                   -268
      y: ARRAY 10, 10, 10 OF INTEGER;               -2268
BEGIN                         0    ENTER      00 0
    k := a[i];                3    CHECKW     R7 0(SB) -2(SB)
                                    8         FLAG
                                    9         MOVW      -28(SB)[R7:W] -6(SB)
    n := a[5];               14    MOVW       -18(SB) -8(SB)
    b[i] := 0;               18    CHECKW     R7 4(SB) -2(SB)
                                   23         FLAG
                                   24         MOVQD     0 -68(SB)[R7:D]
    x[i, j] := 2;            29    CHECKW     R7 8(SB) -2(SB)
                                   34         FLAG
                                   35         CHECKW    R6 12(SB) -4(SB)
                                   40         FLAG
                                   41         INDEXW    R7 9  R6
                                   46         MOVQW     2 -268(SB)[R7:W]
    y[i, j, k] := 3;         51    CHECKW     R7 16(SB) -2(SB)
                                   56         FLAG
                                   57         CHECKW    R6 20(SB) -4(SB)
                                   62         FLAG
                                   63         INDEXW    R7 9  R6
                                   68         CHECKW    R5 24(SB) -6(SB)
                                   73         FLAG
                                   74         INDEXW    R7 9  R5
                                   79         MOVQW     3 -2268(SB)[R7:W]
    y[3, 4, 5] := 6          84    MOVQW      6 -1578(SB)
END Pattern3.                88    EXIT       00
                                   90         RXP       0

index bounds:                 0    0, 9;  0, 9;  0, 9;  0, 9;  0, 9;  0, 9;  0, 9
```

Record fields and pointers: Fields of records are accessed by computing the sum of the record's (base) address and the field's offset. If the record variable is statically declared, the sum is computed by the compiler. In the case of a dynamically allocated variable, the base is given by the pointer through which the variable is referenced, and the addition is included in the indirect addressing mode. (An operand of the form d1(d0(SB)) denotes the address *Mem[SB+d0] + d1*). Dynamic allocation, expressed by the statement NEW(p), is represented by the three instructions

```
ADDR      p, R0
MOVD      dsc, R1
SVC       0
```

where dsc denotes the descriptor of the variable's type (see Pattern 13). The supervisor call assigns the address of the allocated variable to *p*. NIL is represented by 0.

```
MODULE Pattern4;
    TYPE Ptr = POINTER TO Node;
      Node = RECORD num: INTEGER;                   0
        name: ARRAY 8 OF CHAR;                      2
        next: Ptr                                   12
      END ;
    VAR p, q: Ptr;                                  -4, -8
```

```
BEGIN                        0    ENTER     00 0
    NEW(p);                  3    ADDRD     -4(SB)  R0
                             6    MOVD      4(SB)  R1
                             9    SVC       0
    NEW(q);                 11    ADDRD     -8(SB)  R0
                            14    MOVD      4(SB)  R1
                            17    SVC       0
    p.num := 6;             19    MOVQW     6 0(-4(SB))
    p.name[7] := "0";       23    MOVB      48 9(-4(SB))
    p.next := q;            28    MOVD      -8(SB) 12(-4(SB))
    p.next.next := NIL      33    MOVD      12(-4(SB))  R7
                            37    MOVQD     0 12(R7)
END Pattern4.               40    EXIT      00
                            42    RXP       0
```

Boolean expressions, If-, While-, and Repeat statements: Conditional statements imply that parts of them are skipped. This is done by the use of branch instructions whose operand specifies the distance of the branch. The instructions refer to the condition-register as an implicit operand. Its value is determined by a preceding instruction, typically a compare or a bit-test instruction.

The Boolean operators & and OR are purposely not defined as total functions, but rather by the equations

```
p & q     =  if p then q else FALSE
p OR q    =  if p then TRUE else q
```

Consequently, Boolean operators must be translated into branches too. Evidently, branches stemming from if statements and branches stemming from Boolean operators should be merged, if possible. The resulting code therefore does not necessarily mirror the structure of the if statement directly, as can be seen from the code in *Pattern5*. We must conclude that code generation for Boolean expressions differs in some aspects from that for arithmetic expressions.

The example of *Pattern5* is also used to exhibit the code resulting from the standard procedures INC, DEC, INCL, and EXCL. These procedures provide an opportunity to use shorter code in those cases where a single two-operand instruction suffices, i.e. when one of the arguments is identical with the destination.

```
MODULE Pattern5;
  VAR x: INTEGER; s: SET;      -2, -8
BEGIN                          0   ENTER     00 0
  IF x = 0 THEN                3   CMPQW     0 -2(SB)
                               6   BNE       6
      INC(x)                   9   ADDQW     1 -2(SB)
  END ;
  IF (x >= 0) & (x < 100) THEN 12  CMPQW     0 -2(SB)
                               15  BGT       14
                               18  CMPW      100 -2(SB)
                               23  BLE       6
      DEC(x)                   26  ADDQW     -1 -2(SB)
  END ;
  IF ODD(x) OR (x IN s) THEN   29  TBITB     0 -2(SB)
                               33  BFS       10
                               36  TBITW     -2(SB) -8(SB)
                               40  BFC       10
      INCL(s, 4)               43  ORD       00000010 -8(SB)
  END ;
  IF x < 0 THEN                50  CMPQW     0 -2(SB)
                               53  BLE       13
```

```
        EXCL(s, 0)           56  BICD       00000001 -8(SB)
                             63  BR         46
    ELSIF x < 10 THEN        66  CMPW       10 -2(SB)
                             71  BLE        13
        EXCL(s, 1)           74  BICD       00000002 -8(SB)
                             81  BR         28
    ELSIF x < 100 THEN       84  CMPW       100 -2(SB)
                             89  BLE        13
        EXCL(s, 2)           92  BICD       00000004 -8(SB)
    ELSE                     99  BR         10
        EXCL(s, 3)           102 BICD       00000008 -8(SB)
    END
END Pattern5.                109 EXIT       00
                             111 RXP        0

MODULE Pattern6;
    VAR i: INTEGER;
BEGIN                         0  ENTER      00 0
    i := 0;                   3  MOVQW      0 -2(SB)
    WHILE i < 10 DO           6  CMPW       10 -2(SB)
                             11  BLE        8
        INC(i)               14  ADDQW      1 -2(SB)
    END ;                    17  BR         -11
    REPEAT DEC(i)            19  ADDQW      -1 -2(SB)
    UNTIL i = 0              22  CMPQW      0 -2(SB)
                             25  BNE        -6
END Pattern6.                27  EXIT       00
                             29  RXP        0
```

Case statements serve to select a statement sequence from a set of cases according to an index value. Selection is represented by a direct branch to the selected case; the CASE instruction takes the branch distance from a table using the indexed addressing mode. We conclude from the following code that missing cases yield a table entry leading to a trap instruction (BPT 16). The table of offsets is located in the module's area for constants.

```
MODULE Pattern7;
    VAR i: INTEGER; s: SET;  -2, -8
BEGIN                         0    ENTER     00 0
    CASE i OF                 3    CHECKW    R7 0(SB) -2(SB)
                              9    BFS       58
                             12    CASEW     4(SB)[R7:W]
      0: s := {0, 31}        17    MOVD      80000001 -8(SB)
                             24    BR        45
    | 1: s := {1, 30}        27    MOVD      40000002 -8(SB)
                             34    BR        35
    | 2: s := {2, 29}        37    MOVD      20000004 -8(SB)
                             44    BR        25
    | 4: s := {4, 27}        47    MOVD      08000010 -8(SB)
                             54    BR        15
    | 5: s := {5, 26}        57    MOVD      04000020 -8(SB)
                             64    BR        5
                             67    BPT       16
    END
END Pattern7.                69    EXIT      00
                             71    RXP       0
```

```
index bounds:          0      0, 5
branch offset array:   4      5, 15, 25, 55, 35, 45
```

Procedures: Procedure bodies are surrounded by an ENTER and an EXIT instruction. They set and reset the values of the SP and FP registers (see Chapter 6). The latter holds the address of the procedure activation record on the stack. The (second) parameter of the ENTER instruction indicates the space taken by variables local to the procedure, rounded up to the next multiple of 4. Procedures (which are not exported) end with a RET instruction; its parameter indicates the space taken by parameters, which are addressed with positive offsets relative to the FP register.

Calls (within a module) use the BSR instruction. Parameters are pushed onto the stack prior to the BSR using the TOS addressing mode. Every parameter occupies at least 4 bytes (or a multiple thereof). In the case of value parameters the value is loaded, and in the case of VAR-parameters, the variable's address.

```
MODULE Pattern8;          0    ENTER     00 0
  VAR i: INTEGER;         3    BR        22

  PROCEDURE P(x: INTEGER; VAR y: INTEGER);
    VAR z: INTEGER;
  BEGIN                   8    ENTER     00 4
    z := x;              12    MOVW      12(FP) -2(FP)
    y := z               16    MOVW      -2(FP) 0(8(FP))
  END P;                 21    EXIT      00
                         23    RET       8

BEGIN P(5, i)            25    MOVQD     5 TOS
                         27    ADDRD     -2(SB) TOS
                         30    BSR       -22
END Pattern8.            32    EXIT      00
                         34    RXP       0
```

Function procedures are handled in exactly the same manner as proper procedures, except that a result specified by a RETURN statement is returned in register R0 or F0. If the function is called in an expression at a place where intermediate results are held in registers, these values are put onto the stack before the call, and they are restored after it, using SAVE and RESTORE instructions. (The BPT 17 instruction occurs at the end of each function procedure and guards against erroneous functions without executed RETURN statement).

```
MODULE Pattern9;          0    ENTER     00 0
  VAR x: REAL;            3    BR        39

  PROCEDURE F(x: REAL): REAL;
  BEGIN                   8    ENTER     00 0
    x := F(x * 0.5);     12    MOVF      8(FP)  F6
                         16    MULF      3F000000  F6
                         23    MOVF      F6 TOS
                         26    BSR       -18
                         28    MOVF      F0 8(FP)
    RETURN x             32    MOVF      8(FP)  F0
  END F;                 36    EXIT      00
                         38    RET       4
                         40    BPT       17

BEGIN x := F(F(10.0))    42    MOVF      41200000 TOS
                         49    BSR       -41
                         51    MOVF      R0 TOS
```

```
                                54    BSR        -46
                                56    MOVF       F0 -4(SB)
END Pattern9.                   60    EXIT       00
                                62    RXP        0
```

Dynamic array parameters are passed by loading a descriptor on the stack, regardless of whether they are value- or VAR- parameters. The descriptor consists of the actual variable's address and its index bounds (the lower bound always being 0). In the case of n-dimensional arrays, n bound pairs are required.

If the dynamic array is called by value, a copy of its value is made after procedure entry. The length is computed by incrementing the upper bound and dividing the sum by the array element size using a shift instruction, yielding the number of elements to be copied (R7). The copies are pushed onto the stack in a tight loop using the ACB instruction (Add, Compare, Branch). Thereafter, the address of the array in the descriptor is replaced by the address of the copy (SP).

Elements of dynamic arrays are accessed like those of static arrays using the CHECK instruction for loading the index into a register. Even when the index is a constant, the check cannot be performed by the compiler. The LEN function obtains the length from the upper bound, and by adding 1 to it.

```
MODULE Pattern10;                0    ENTER      00 0
                                 3    BR         94
  VAR a: ARRAY 10 OF CHAR;      -10
    b: ARRAY 4, 8 OF INTEGER;   -76

  PROCEDURE P0(x: ARRAY OF CHAR);
    VAR k: LONGINT;
  BEGIN                          8    ENTER      00 4
                                12    MOVD       12(FP)  R7
                                15    ADDQD      4  R7
                                17    ASHD       -2  R7
                                21    MOVD       8(FP)  R6
                                24    MOVD       -4( R6)[R7:D] TOS
                                28    ACBD       -1  R7 -4
                                31    ADDRD      0(SP) 8(FP)
    k := LEN(x)                 35    MOVD       12(FP)  R7
                                38    ADDQD      1  R7
                                40    MOVD       R7 -4(FP)
  END P0;                       43    EXIT       00
                                45    RET        8

  PROCEDURE P1(VAR x: ARRAY OF CHAR);
  BEGIN                         47    ENTER      00 0
    x[1] := "0"                 51    CHECKW     R7 12(FP) 0001
                                57    FLAG
                                58    MOVB       48 0(8(FP))[R7:B]
  END P1;                       64    EXIT       00
                                66    RET        8

  PROCEDURE P2(VAR x: ARRAY OF ARRAY OF INTEGER);
    VAR i, j: INTEGER;
  BEGIN                         68    ENTER      00 4
    x[i, j] := 3                72    CHECKW     R7 16(FP) -2(FP)
                                77    FLAG
                                78    CHECKW     R6 12(FP) -4(FP)
                                83    FLAG
                                84    INDEXW     R7 12(FP)  R6
```

```
                              88   MOVQW    3 0(8(FP))[R7:W]
  END P2;                     93   EXIT     00
                              95   RET      12

BEGIN P0(a);                  97   MOVD     0(SB) TOS
                             100   ADDRD    -10(SB) TOS
                             103   BSR      -95
  P1(a);                     106   MOVD     0(SB) TOS
                             109   ADDRD    -10(SB) TOS
                             112   BSR      -65
  P0("ABCDE")                115   MOVQD    5 TOS
                             117   ADDRD    12(SB) TOS
                             120   BSR      -112
  P2(b)                      123   MOVD     4(SB) TOS
                             126   MOVD     8(SB) TOS
                             129   ADDRD    -76(SB) TOS
                             133   BSR      -65
END Pattern10.               136   EXIT     00
                             138   RXP      0

index bounds and constants:    0   0, 9;  0, 3;  0, 7
                              12   "ABCDE"
```

Nested procedures: Whereas global and local variables are addressed using SB and FP as bases, the variables at intermediate levels are addressed by descending along the static chain in the stack. This is the case, if a variable *x* is referenced from a procedure *Q* which is local to another procedure *P* with local *x*. An element of the static chain is established when a local procedure is called; it denotes the address of the activation record of the procedure in which the calling procedure is declared locally. It is omitted, if the calling procedure is global, because then the environment is based on SB. The SB register may be regarded as an optimization feature for access of global variables built into the processor architecture.

Access to a variable local to the procedure immediately surrounding the procedure accessing the variable uses the indirect addressing mode. When the level difference between accessed variable and accessor is greater than 1, several instructions are required for descending along the chain. This, however, rarely occurs.

```
MODULE Pattern11;              0   ENTER    00 0
  VAR u: INTEGER;              3   BR       62

  PROCEDURE P;                 8   ENTER    00 4
    VAR x: INTEGER;           12   BR       44

    PROCEDURE Q;              15   ENTER    00 4
      VAR y: INTEGER;         19   BR       28

      PROCEDURE R;            22   ENTER    00
        VAR z: INTEGER;
      BEGIN u := z + y + x    26   MOVW     -2(FP)  R7
                              29   ADDW     -2(8(FP))  R7
                              33   MOVD     8(8(FP))  R6
                              37   ADDW     -2( R6)  R7
                              40   MOVW     R7 -2(SB)
      END R;                  43   EXIT     00
                              45   RET      4

    BEGIN R                   47   ADDRD    0(FP) TOS  static chain
```

```
                            50  BSR       -28
    END Q;                  52  EXIT      00
                            54  RET       4

  BEGIN Q                   56  ADDRD     0(FP) TOS  static chain
                            59  BSR       -44
  END P;                    61  EXIT      00
                            63  RET       0

BEGIN P                     65  BSR       -57
END Pattern11.              67  EXIT      00
                            69  RXP       0
```

External variables and procedures: When a procedure is imported from another module, its address is unavailable to the compiler. Instead, the procedure is identified by a number obtained from the imported module's symbol file. For calling an external procedure, the CXP instruction is generated instead of BSR (see Chapter 6). Its parameter is an index to the calling module's link table. The table entry contains the base address of the referenced module's descriptor and the procedure's offset in the module's code. These values are computed by the loader from a module number and the procedure's number, which are supplied by the compiler in the header of the object file (see Chapter 6). An RXP instruction instead of RET terminates exported procedures.

Imported variables are referenced using the external addressing mode. Their offset is added to the base address of the data area of the imported module which is contained in the link table. If n modules are imported, the first n entries of the table contain the respective base addresses. Hence, the first parameter of an external address is the module number, the second the offset.

In the following example, modules Pattern12a and Pattern12b both export a procedure and a variable. They are referenced from the importing module Pattern12c. The first two entries of the link table are data entries (indicated by the special value 255), the remaining entries refer to external procedures and their indices appear as parameters of CXP instructions.

```
MODULE Pattern12a;       0    ENTER      00 0
  VAR k*: INTEGER;       3    BR         16

  PROCEDURE P*;          8    ENTER      00 0
  BEGIN k := 1          12    MOVQW      1 -2(SB)
  END P;                15    EXIT       00
                              17         RXP       0

END Pattern12a.         19    EXIT       00
                              21         RXP       0

entry: 1, 8

MODULE Pattern12b;       0    ENTER      00 0
  VAR x*: REAL;          3    BR         18

  PROCEDURE P*;          8    ENTER      00 0
  BEGIN x := 1          12    MOVBF      1 -4(SB)
  END P;                17    EXIT       00
                              19         RXP       0

END Pattern12b.         21    EXIT       00
                              23         RXP       0

entry: 1, 8
```

```
MODULE Pattern12c;
  IMPORT Pattern12a, Pattern12b;

  VAR i: INTEGER; x: REAL;
BEGIN                        0    ENTER      00 0
  i := Pattern12a.k;         3    MOVW       EXT(1)-2 -2(SB)
  x := Pattern12b.x;         8    MOVF       EXT(2)-4 -8(SB)
  Pattern12a.P;             14    CXP        3
  Pattern12b.P              16    CXP        4
END Pattern12c.             18    EXIT       00
                                  20         RXP       0

imports:   0   Pattern12a
           1   Pattern12b

links      (data: mno, 255):
           1   1, 255
           2   2, 255
           (proc: mno, pno):
           3   1, 1
           4   2, 1
```

Record extensions with pointers: Fields of a record type R1, which is declared as an extension of a type R0, are simply appended to the fields of R0, i.e. their offsets are greater than those of the fields of R0. When a record is statically declared, its type is known by the compiler. If the record is referenced via a pointer, however, this is not the case. A pointer bound to a base type R0 may well refer to a record of an extension R1 of R0. Type tests (and type guards) allow to test for the actual type. This requires that a type can be identified at the time of program execution. Because the language defines name equivalence instead of structural equivalence of types, a type may be identified by a number. We use the address of a unique type descriptor for this purpose. Therefore, type tests consist of a simple address comparison which is very fast. Type descriptors are generated by the loader, and their address, called type tag, is stored in the module's area for constants. The type of a (dynamically allocated) variable is stored as a prefix to the record (with offset -4).

A type descriptor contains - in addition to information stored for use by the garbage collector - a table of tags of all base types. If, for instance, a type R2 is an extension of R1 which is an extension of R0, the descriptor of R2 contains the tags of R1 and R0 as shown in Fig. 12.4. The table has a fixed number of 7 entries.

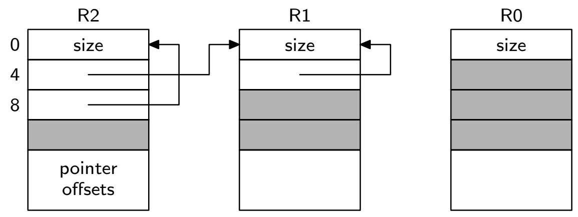

Fig. 12.4. Type descriptors

A type guard p(T) is equivalent to the statement

```
IF ~(p IS T) THEN HALT(18) END
```

but appears within variable designators. (Evidently, a single-byte instruction similar to FLAG, trapping on inequality would be useful in place of the instruction pair   BEQ 4, BPT 18).

```
MODULE Pattern13;            0    ENTER      00 0
  TYPE
    P0 = POINTER TO R0;
    P1 = POINTER TO R1;
    P2 = POINTER TO R2;
    R0 = RECORD x: INTEGER END ;
    R1 = RECORD (R0) y: INTEGER END ;
    R2 = RECORD (R1) z: INTEGER END ;
  VAR
    p0: P0;                 -4
    p1: P1;                 -8
    p2: P2;                 -12
BEGIN                        3    MOVD       4(SB) 4(4(SB))
                             8    MOVD       8(SB) 8(8(SB))
                            13    MOVD       4(SB) 4(8(SB))
  p0.x := 0;                18    MOVQW      0 0(-4(SB))
  p1.y := 1;                22    MOVQW      1 4(-8(SB))
  p0(P1).y := 2;            26    MOVD       -4(-4(SB))  R7
                            30    CMPD       4( R7) 4(SB)
                            34    BEQ        4
                            36    BPT        18
                            38    MOVQW      2 4(-4(SB))
  p0(P2).z := 3;            42    MOVD       -4(-4(SB))  R7
                            46    CMPD       8( R7) 8(SB)
                            50    BEQ        4
                            52    BPT        18
                            54    MOVQW      3 8(-4(SB))
  IF p1 IS P2 THEN          58    MOVD       -4(-8(SB))  R7
                            62    CMPD       8( R7) 8(SB)
                            66    BNE        7
    p0 := p2                69    MOVD       -12(SB) -4(SB
  END
END Pattern13.              73    EXIT       00
                            75    RXP        0
```

Type tags at 0, 4, 8 (SB)

Record extensions as VAR parameters: Records occurring as VAR-parameters may also require a type test at program execution time. This is because VAR-parameters effectively constitute hidden pointers. Type tests and type guards on VAR-parameters are handled in the same way as for variables referenced via pointers, with a slight difference, however. Statically declared record variables may be used as actual parameters, and they are not prefixed by a type tag. Therefore, the tag has to be supplied together with the variable's address when the procedure is called, i.e. when the actual parameter is established. Record structured VAR-parameters therefore consist of address and type tag. This is similar to dynamic array descriptors consisting of address and bounds.

The following example also exhibits a record assignment, in fact a projection of R1 onto R0. It is represented by a single instruction which moves multiple bytes (MOVM). Its last parameter is the number of bytes to be copied minus 1.

```
MODULE Pattern14;             0   ENTER      00 0
  TYPE                        3   BR         30
    R0 = RECORD a, b, c: LONGINT END ;
    R1 = RECORD (R0) x, y: LONGINT END ;
  VAR
    r0: R0;                 -12
    r1: R1;                 -32

  PROCEDURE P(VAR r: R0);     8   ENTER      00 0
  BEGIN r.a := 1;            12   MOVQD      1 0(8(FP))
    r(R1).x := 2             16   CMPD       4(12(FP)) 4(SB)
```

```
                           21  BEQ      4
                           23  BPT      18
                           25  MOVQD    2 12(8(FP))
  END P;                   29  EXIT     00
                           31  RET      8

BEGIN                      33  MOVD     4(SB) 4(4(SB))
  r0 := r1;                38  MOVMB    -32(SB) -12(SB) 11
  P(r1)                    44  MOVD     4(SB) TOS
                           47  ADDRD    -32(SB) TOS
                           50  BSR      -42
END Pattern14.             52  EXIT     00
                           54  RXP      0
```

Type tags at 0, 4 (SB)

Set elements: This last code pattern exhibits the construction of sets. If the specified elements are constants, the set value is computed by the compiler (see Pattern7). Otherwise, sequences of move and shift instructions are used. Since shift instructions do not check whether the shift count is within sensible bounds, the results are unpredictable, if elements outside the range 0 .. 31 are involved.

```
MODULE Pattern15;
  VAR s: SET; i, j: INTEGER;    -4, -6, -8
BEGIN                      0    ENTER    00 0
  s := {i};                3    MOVQD    1  R7
                           5    LSHD     -6(SB)  R7
                           9    MOVD     R7 -4(SB)
  s := {0 .. i};          12    MOVQD    -2  R7
                          14    LSHD     -6(SB)  R7
                          18    COMD     R7  R7
                          21    MOVD      R7 -4(SB)
  s := {i .. 27};         24    MOVQD    -1  R7
                          26    LSHD     -6(SB)  R7
                          30    BICD     F0000000  R7
                          36    MOVD     R7 -4(SB)
  s := {i .. j};          39    MOVQD    -1  R7
                          41    LSHD     -6(SB)  R7
                          45    MOVQD    -2  R6
                          47    LSHD     -8(SB)  R6
                          51    BICD     R6  R7
                          53    MOVD     R7 -4(SB)
  INCL(s, i)              56    MOVQD    1  R7
                          58    LSHD     -6(SB)  R7
                          62    ORD      R7 -4(SB)
END Pattern15.            65    EXIT     00
                          67    RXP      0
```

12.3. Internal Data Structures and Interfaces

In Section 12.1 it was explained that declarations inherently constitute context-dependence of the translation process. Although parsing still proceeds on the basis of a context-free syntax and relies on contextual information only in a few isolated instances, information provided by declarations affects the generated code significantly. During the processing of declarations, their information is transferred into the "symbol table", a data structure of considerable complexity, from where it is retrieved for the generation of code.

This dynamic data structure is defined in module OCT in terms of two record types called *Object* and *Struct* (see Def of OCT). These types pervade all other modules with the exception of the scanner. They are therefore explained before further details of the compiler are discussed.

For each declared identifier an instance of type *Object* is generated. The record holds the identifier and the properties associated with the identifier given in its declaration. Since Oberon is a *statically typed* language, every object has a type. It is represented in the record by its typ field, which is a pointer to a record of type *Struct*. Since many objects may be of the same type, it is appropriate to record the type's attributes only once and to refer to them via a pointer. The properties of type *Struct* will be discussed below.

The kind of object which a table entry represents is indicated by the field *mode*. Its values are denoted by declared integer constants: *Var* indicates that the entry describes a variable, *Con* a constant, *Fld* a record field, *Ind* a VAR-parameter, and *xProc* a procedure. Different kinds of entries carry different attributes. A variable or a parameter carries an address, a constant has a value, a record field has an offset, and a procedure has an entry address, a list of parameters, and a result type. For each kind the introduction of an extended record type would seem advisable. This was not done, however, for three reasons. First, the compiler was first formulated in (a subset of) Modula-2 which does not feature type extension. Second, not making use of type extensions would make it simpler to translate the compiler into other languages for porting the language to other computers. And third, all extensions were known at the time the compiler was planned. Hence extensibility provided no argument for the introduction of a considerable variety of types. The simplest solution lies in using the multi-purpose fields *a0, a1, a2,* and dsc for variant-specific attributes. For example, *a0* holds an address for variables, parameters, and procedures, an offset for record fields, and a value for constants.

The definition of a type yields a record of type *Struct*, regardless of whether it occurs within a type declaration, in which case also a record of type *Object* (mode = Typ) is generated, or in a variable declaration, in which case the type remains anonymous. All types are characterized by a form and a size. A type is either a basic type or a constructed type. In the latter case it refers to one or more other types. Constructed types are arrays, records, pointers, and procedural types. The attribute *form* refers to this classification. Its value is an integer allowing the use of case statements for an efficient discrimination.

Just as different object kinds are characterized by different attributes, different forms have different attributes. Again, the introduction of extensions of type Struct was avoided. Instead, some of the fields of type *Struct* remain unused in some cases, such as for basic types, and others are used for form-specific attributes. For example, the attribute *BaseTyp* refers to the element type in the case of an array, to the result type in the case of a procedural type, to the type to which a pointer is bound, or to the base type of a (extended) record type. The attribute link refers to the parameter list in the case of a procedural type, or to the list of fields in the case of a record type.

As an example, consider the following declarations. The corresponding data structure is shown in Fig. 12.5. For details, the reader is referred to the program listing of module OCT and the respective explanations.

```
CONST  N = 100;
TYPE   Ptr = POINTER TO Rec;
       Rec = RECORD n: INTEGER; p, q: Ptr END ;
VAR    k: INTEGER;
       a: ARRAY N OF INTEGER;
PROCEDURE P(x: INTEGER): INTEGER;
```

Only entries representing constructed types are generated during a compilation. An entry for each basic type is established by the compiler's initialization. It consists of an *Object* holding the standard type's identifier and a *Struct* indicating its form, denoted by one of the values *Byte, Bool, Char, SInt, Int, LInt, Real, LReal,* or *Set*. The object records of the basic types are anchored in global pointer variables (which actually should be regarded as constants).

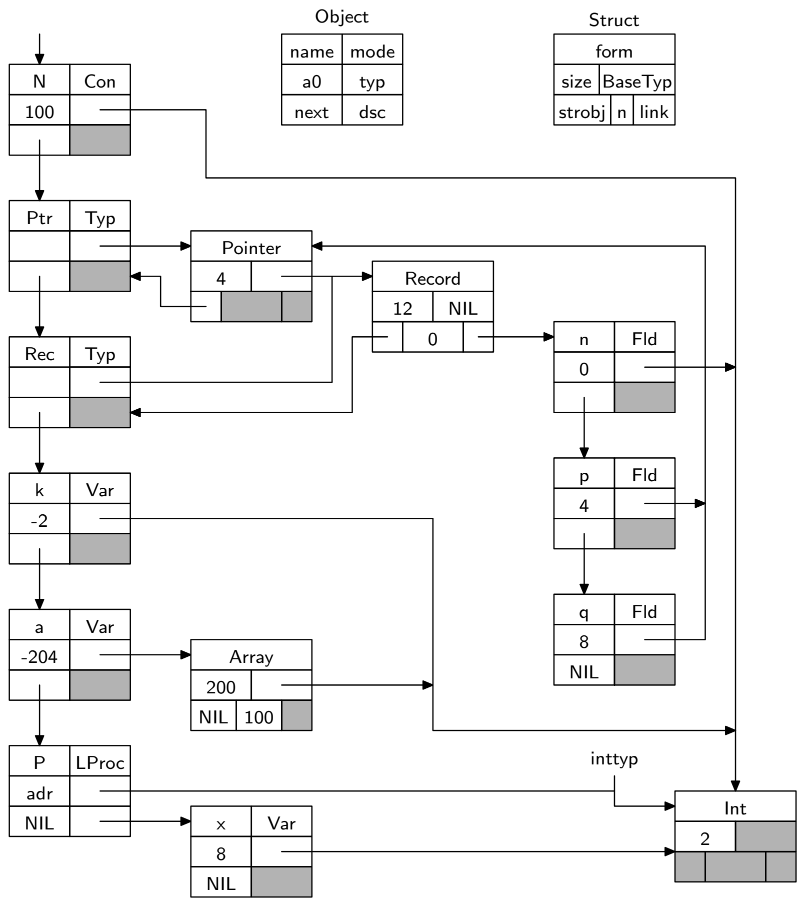

Fig. 12.5. Internal representation of declarations

Not only are entries created upon initialization for basic types, but also for all standard procedures. Therefore, every compilation starts out with a symbol table reflecting all standard, pervasive identifiers and the objects they stand for.

We now return to the subject of *Objects*. Whereas objects of basic modes (*Con, Var, Ind, Fld, Typ, xProc*, and *Mod*) directly reflect declared identifiers and constitute the context in which statements and expressions are compiled, compilations of expressions typically generate anonymous entities of additional, non-basic modes. Such entities reflect selectors, factors, terms, etc., i.e. constituents of expressions and statements. As such, they are of a transitory nature and hence are not represented by records allocated on the heap. Instead, they are represented by record variables local to the processing procedures and are therefore allocated on the stack. Their type is called *Item* and is a slight variation of the type *Object*.

Let us assume, for instance, that a term *x*y* is parsed. This implies that the operator and both factors have been parsed already. The factors *x* and *y* are represented by two variables of type *Item* of *Var* mode. The resulting term is again described by an item, and since the product is transitory, i.e. has significance only within the expression of which the term is a constituent, it is to be held in a temporary location, in a register. In order to express that an item is located in a register, a new, non-basic mode *Reg* is introduced.

Effectively, all non-basic modes reflect the target computer's architecture, in particular its addressing modes. The more addressing modes a computer offers, the more item modes are needed to represent them. The additional item modes and their corresponding addressing modes used in the compiler of the NS-32000 processor are:

VarX	indexed mode
IndX	indirect, indexed mode

Reg	direct register mode
RegI	indirect register mode
RegX	indirect, indexed register mode
Stk	stack mode (TOS)
Coc	condition code mode
Abs	absolute mode

The use of the types *Object, Item,* and *Struct* for the various modes and forms, and the meaning of their attributes are explained in the following tables:

Objects: Items:

	mode	a0	a1	dsc	lev	a0	a1	a2	obj	
0	Undef									
1	Var	adr			lev	adr	obj			
2	VarX				lev	adr		RX		
3	Ind	adr			lev	adr	off			
4	IndX				lev	adr	off	RX		
5	RegI					R	off			
6	RegX					R	off	RX		
7	Abs					adr				
8	Con	val				val	val			
						sadr	leng			(strings)
9	Stk									(stack)
10	Coc					CC	Tjmp	Fjmp		(condition code)
11	Reg					R				
12	Fld	off					off		obj	
13	Typ				mno	tadr			obj	
14	LProc	adr		pars		adr			obj	(local procedure)
15	XProc	pno	Ladr	pars	mno	pno	Ladr		obj	(external procedure)
16	SProc	fno				fno				(standard procedure)
17	CProc	cno	pars			cno			obj	(code procedure)
18	IProc	pno	Ladr			adr	Ladr		obj	(interrupt procedure)
19	Mod	mno	key			mno			obj	
20	Head	lev	psize							

Structures:

	form	BaseTyp	link	mno	n	adr
13	Pointer	PBaseTyp				
14	rocTyp	ResTyp	param			
15	Array	ElemTyp		mno	nofel	bounds
16	DynArr	ElemTyp				
17	Record	BaseTyp	fields	mno		descr

Items have an attribute called *lev* which is part of the address of the item. Positive values denote the level of nesting of the procedure in which the item is declared; lev = 0 implies a global object. Negative values indicate that the object is imported from the module with number *-lev*.

The three types *Object, Item,* and *Struct* are defined in the interface of module OCT, which also contains procedures for accessing the symbol table. Insert serves to register a new identifier, and it returns a pointer to the allocated record. Find returns the pointer to the object whose name equals the global scanner variable OCS.name, and the level of the identified object.

Procedure Import serves to read the specified symbol file and to enter its identifier in the symbol table (mode = Mod). FindImport retrieves an object with a name given by *OCS.name* from a previously imported module. Finally, Export generates the symbol file of the compiled module, containing descriptions of all objects and structures marked for export.

```
DEFINITION OCT;  (*Table handler*)
  TYPE
    Object = POINTER TO ObjDesc;
    Struct = POINTER TO StrDesc;
    ObjDesc = RECORD
          dsc, next: Object;
          typ: Struct;
          a0, a1: LONGINT;
          a2: INTEGER;
          mode: SHORTINT;
          marked: BOOLEAN;
          name: ARRAY 32 OF CHAR;
    END ;

    StrDesc = RECORD
          form, n, mno, ref: INTEGER;
          size, adr: LONGINT;
          BaseTyp: Struct;
          link, strobj: Object;
    END ;

    Item = RECORD
          mode, lev: INTEGER;
          a0, a1, a2: LONGINT;
          typ: Struct;
          obj: Object;
    END ;

  VAR topScope: Object;
    undftyp, bytetyp, booltyp, chartyp, sinttyp, inttyp, linttyp, realtyp, lrltyp,
    settyp, stringtyp, niltyp, notyp: Struct;
    nofGmod: INTEGER;
    GlbMod: ARRAY 24 OF Object;

  PROCEDURE Init;
  PROCEDURE Close;
  PROCEDURE FindImport (mod: Object; VAR res: Object);
  PROCEDURE Find (VAR res: Object; VAR level: INTEGER);
  PROCEDURE FindField (typ: Struct; VAR res: Object);
  PROCEDURE Insert (VAR name: ARRAY OF CHAR; VAR res: Object);
  PROCEDURE OpenScope (level: INTEGER);
  PROCEDURE CloseScope;
  PROCEDURE Import (VAR name, self, FileName: ARRAY OF CHAR);
  PROCEDURE Export (VAR name, FileName: ARRAY OF CHAR;
          VAR newSF: BOOLEAN; VAR key: LONGINT);
END OCT.
```

Before embarking on a presentation of the compiler's main module, the parser, an overview of its remaining modules is given in the form of their interfaces. The reader is invited to refer to them when studying the parser.

The interface of the scanner (OCS) is simple; its chief constituent is procedure *Get*. Each call yields the next symbol from the source text, identified by an integer. Global variables represent attributes of the read symbol in certain cases. If a number was read, *numtyp* indicates its type and *intval*, *realval*, or *lrlval* specify the numeric value. If an identifier or a string was read, *name* holds the ASCII values of the characters read.

Procedure *Mark* serves to generate a diagnostic output indicating an error number and the scanner's current position in the source text. The procedure is located in the scanner, because only the scanner has access to its current position. *Mark* is called from all other modules.

```
DEFINITION OCS;  (*Scanner*)
  IMPORT Texts;
  VAR numtyp: INTEGER;
      intval: LONGINT;
      realval: REAL;
      lrlval: LONGREAL;
      scanerr: BOOLEAN;
      name: ARRAY 128 OF CHAR;

  PROCEDURE Mark (n: INTEGER);
  PROCEDURE Get (VAR sym: INTEGER);
  PROCEDURE Init (source: Texts.Text; pos: LONGINT);
END OCS.
```

Module OCE contains the procedures for code selection and type consistency checking for expressions. The names of these procedures clearly indicate the respective constructs for which code is to be selected; a few additional explanations may nevertheless be helpful.

SetIntType is called to identify the exact numeric type of an item denoting a constant; the type depends on the value's magnitude. *TypeTest* is called to process a type test or a type guard. *Set0* constructs a singleton set item consisting of the element specified by the second parameter y, and *Set1* constructs a set with elements *y* to *z*. *MOp* and *Op* process constituents of expressions with monadic and dyadic operators respectively. And finally *StPar1*, *StPar2*, *StPar3*, and *StFct* process calls of standard procedures and functions generating in-line code.

```
DEFINITION OCE;
  IMPORT OCT;
  VAR inxchk: BOOLEAN;

  PROCEDURE SetIntType (VAR x: OCT.Item);
  PROCEDURE AssReal (VAR x: OCT.Item; y: REAL);
  PROCEDURE AssLReal (VAR x: OCT.Item; y: LONGREAL);
  PROCEDURE Index (VAR x, y: OCT.Item);
  PROCEDURE Field (VAR x: OCT.Item; y: OCT.Object);
  PROCEDURE DeRef (VAR x: OCT.Item);
  PROCEDURE TypTest (VAR x, y: OCT.Item; test: BOOLEAN);
  PROCEDURE In (VAR x, y: OCT.Item);
  PROCEDURE Set0 (VAR x, y: OCT.Item);
  PROCEDURE Set1 (VAR x, y, z: OCT.Item);
  PROCEDURE MOp (op: INTEGER; VAR x: OCT.Item);
  PROCEDURE Op (op: INTEGER; VAR x, y: OCT.Item);
  PROCEDURE StPar1 (VAR x: OCT.Item; fctno: INTEGER);
  PROCEDURE StPar2 (VAR p, x: OCT.Item; fctno: INTEGER);
  PROCEDURE StPar3 (VAR p, x: OCT.Item; fctno: INTEGER);
  PROCEDURE StFct (VAR p: OCT.Item; fctno, parno: INTEGER);
END OCE.
```

Procedures for processing statements are contained in module OCH. Assignments and procedure calls are processed by procedures *Assign*, *PrepCall*, *Call*, and *Param*. Procedures *Enter*, *Result*, and *Return* generate the code at the beginning and the end of procedure bodies.

If, while, repeat, and loop statements involve branches around the code of their constituents. Procedures *FJ* (forward jump), *CFJ* (conditional forward jump), *BJ* (backward jump), *CBJ* (conditional backward jump), and *LFJ* (long forward jump) serve to issue such branches. Finally, *CaseIn* and *CaseOut* generate code for case statements. *CaseIn* emits an indexed branch instruction using an address table generated by *CaseOut*.

```
DEFINITION OCH;
   IMPORT OCT;
   TYPE LabelRange = RECORD low, high, label: INTEGER END ;

   PROCEDURE Trap (n: INTEGER);
   PROCEDURE CompareParLists (x, y: OCT.Object);
   PROCEDURE Assign (VAR x, y: OCT.Item; param: BOOLEAN);
   PROCEDURE FJ (VAR loc: INTEGER);
   PROCEDURE CFJ (VAR x: OCT.Item; VAR loc: INTEGER);
   PROCEDURE BJ (loc: INTEGER);
   PROCEDURE CBJ (VAR x: OCT.Item; loc: INTEGER);
   PROCEDURE LFJ (VAR loc: INTEGER);
   PROCEDURE PrepCall (VAR x: OCT.Item; VAR fpar: OCT.Object);
   PROCEDURE Param (VAR ap: OCT.Item; f: OCT.Object);
   PROCEDURE Call (VAR x: OCT.Item);
   PROCEDURE Enter (mode: SHORTINT; pno: LONGINT; VAR L: INTEGER);
   PROCEDURE CopyDynArray (adr: LONGINT; typ: OCT.Struct);
   PROCEDURE Result (VAR x: OCT.Item; typ: OCT.Struct);
   PROCEDURE Return (mode: INTEGER; psize: LONGINT);
   PROCEDURE CaseIn (VAR x: OCT.Item; VAR L0, L1: INTEGER);
   PROCEDURE CaseOut (L0, L1, L2, L3, n: INTEGER; VAR tab: ARRAY OF LabelRange);
END OCH.
```

12. 4. The Parser

The main module, *Compiler,* constitutes the parser. Its single command *Compile* - at the end of the program listing - identifies the source text according to the Oberon command conventions. It then calls procedure *CompilationUnit* with the identified source text as parameter. The command forms are:

Compiler.Compile *	The source text is contained in the marked viewer.
Compiler.Compile ^	The most recent selection identifies the name of the source file.
Compiler.Compile @	The most recent selection identifies the beginning of the source text.
Compiler.Compile f0 f1 ... ~	f0, f1, ... are the names of source files.

File names and the characters * ^ and @ may be followed by an option specification /s, /x, /t. Option s enables the compiler to overwrite an existing symbol file, thereby invalidating clients. Option x suppresses index checks, and option t suppresses type guards.

The parser is designed according to the proven method of top-down, recursive descent parsing with a look-ahead of a single symbol. The last symbol read is represented by the global variable *sym*. Syntactic entities are mirrored by procedures of the same name. Their goal is to recognize the specified construct in the source text. The start symbol and corresponding procedure is *CompilationUnit*. The principal parser procedures are shown in Fig. 12.6., which also exhibits their calling hierarchy. Loops in the diagram indicate recursion in the syntactic definition. (Procedure *qualident* is omitted; it is called from many other procedures).

The rule of parsing strictly based on a single-symbol look-ahead and without reference to context is violated in three places. The prominent violation occurs in statements. If the first symbol of a statement is an identifier, the decision of whether an assignment or a procedure call is to be recognized is based on contextual information, namely the mode of the object denoted by the identifier. The second violation occurs in *qualident*; if the identifier x preceding the period denotes a module, it is recognized together with the subsequent identifier as a qualified identifier. Otherwise x supposedly denotes a record variable. The third violation is made in procedure *selector*; if an identifier is followed by a left parenthesis, the decision of whether a procedure call or a type guard is to be recognized is again made on the basis of contextual information, namely the mode of the identified object.

A fairly large part of the program is devoted to the discovery of errors. Not only should they be properly diagnosed. A much more difficult requirement is that the parsing process should continue on the basis of a good guess about the structure that the text should most likely have. The parsing process must continue with some assumption and possibly after skipping a short piece of the source text. Hence, this aspect of the parser is mostly based on heuristics. Incorrect assumptions about the nature of a syntactic error lead to secondary error diagnostics. There is no way to avoid them. A reasonably good result is obtained by the fact that procedure *OCS.Mark* inhibits an error report, if it lies less than 10 characters ahead of the last one. Also, the language Oberon is designed with the property that most large constructs begin with a unique symbol, such as IF, WHILE, CASE, RECORD, etc. These symbols facilitate the recovery of the parsing process in the erroneous text. More problematic are open constructs which neither begin nor end with key symbols, such as types, factors, and expressions. Relying on heuristics, the source text is skipped up to the first occurrence of a symbol which may begin a construct that follows the one being parsed. The employed scheme may not be the best possible, but it yields quite acceptable results and keeps the amount of program devoted to the handling of erroneous texts within justifiable bounds.

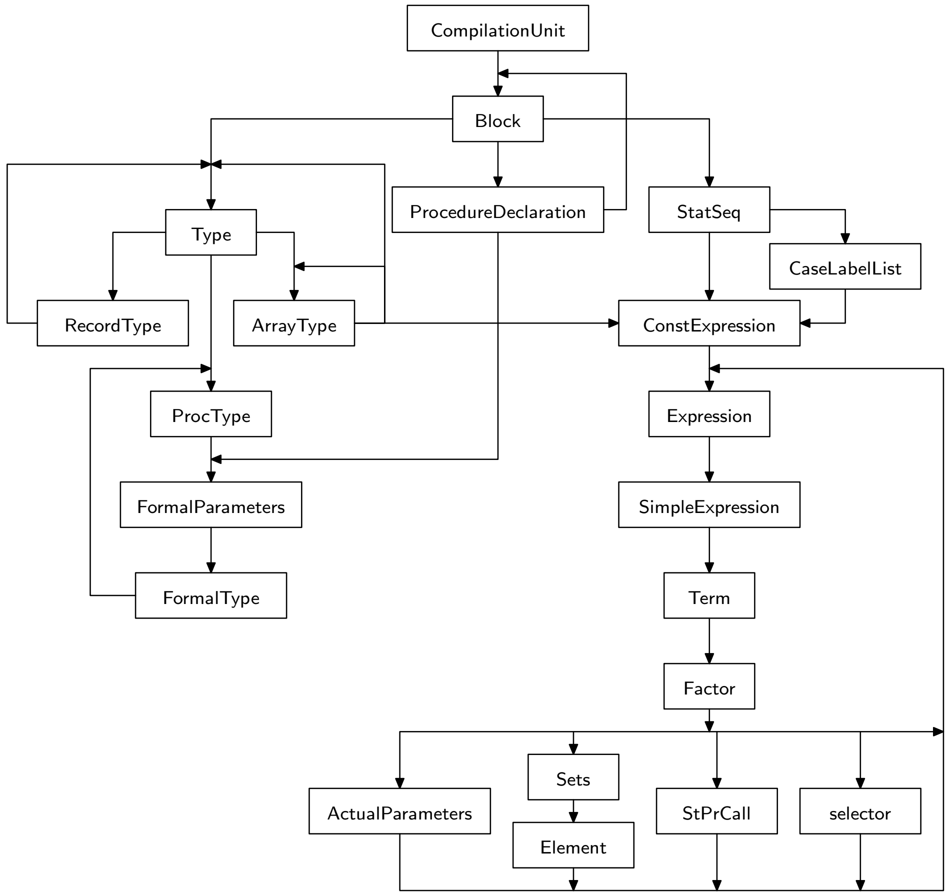

Fig. 12.6. Parser procedure hierarchy

Whereas the parser delegates type consistency checking and code generation to procedures mainly encapsulated in modules OCE and OCH, the processing of declarations is mostly handled by the routines which parse. Thereby an unjustifiably large number of very short procedures is avoided. However, the strict target-computer independence of the parser is lost. Information about variable allocation strategy including alignment, and about the sizes of basic types is used in the parser module. Whereas the former violation is harmless, because the allocation strategy is hardly controversial, the latter case constitutes a genuine target-dependence embodied in a number of explicitly declared constants. Mostly these constants are contained in the respective type definitions, represented by records of type *Struct* initialized by OCT. The following procedures allocate objects and generate elements of the symbol table:

Block	Object(Con), Object(Typ), Object(Var)
ProcedureDeclaration	Object(xProc)
FormalParameters	Object(Var), Object(Ind)
OCT.Import	Object(Mod)
RecordType	Object(Fld), Struct(Record)
ArrayType	Struct(Array)
ProcType	Struct(ProcTyp)
Type	Struct(Pointer)
FormalType	Struct(DynArr)

The language Oberon proper specifies only one kind of procedure. This compiler provides some variants, partly for reasons provided by the computer's instruction set. The compiler requests a specifier in the form of a single character following the symbol PROCEDURE for these variants, similar to the arrow (^) in the case of forward declarations. The variants are denoted by different modes in their descriptors:

1. Procedures which are to be assigned to variables must be marked with an asterisk (unless they are exported). This causes the compiler to treat them like external procedures (RXP at the end), such that they can be called uniformly with a CXPD instruction. Here *mode = XProc*.
2. The specifier "-" indicates that the procedure is called by an SVC instruction. (Note that supervisor calls are exclusively handled by the Kernel. Hence, the Oberon text declares a procedure heading only, followed by an empty body.) Here *mode = CProc*.
3. The specifier "+" indicates that the parameterless procedure is to be used as an interrupt handler. Its last instruction is RETT. Here *mode = IProc*.

An inherently nasty subject is the treatment of forward references in a single-pass compiler. In Oberon, there are two such cases:

1. Forward declarations of procedures. They are explicitly specified by ^ following the symbol PROCEDURE. The compiler processes the heading in the normal way and as an external procedure, assuming its body to be missing. When later in the text the full declaration is encountered, it must be properly associated with the already existing entry in the symbol table. Therefore, for every procedure declaration the table is first searched. If the given identifier is found and denotes a procedure (with address 0), the association is established and the parameter lists are compared by procedure *OCH.CompareParameters*. Otherwise a multiple definition of the same identifier is present.
2. Forward declarations of pointer types present a more difficult case, because there exists no explicit indication that a forward reference is present and that no undefined identifier should be diagnosed. If in a pointer declaration the base type (to which the pointer is bound) is not found in the symbol table, a forward reference is therefore assumed automatically. Entries for both the pointer type and its base type are generated (see procedure *Type*). The premature entry of type *Object* containing the name of the base type and with *mode = Undef* is connected with the pointer type through its *link* field. When later in the text a declaration of a record or an array type is encountered with the same identifier, the forward entry is recognized and the proper link is established (see procedure *Block*).

For both cases, the compiler checks for undefined forward references when the current declaration scope is closed. For procedures this occurs at the end of compilation (procedure *OCC.OutCode*), because only global procedures can be declared forward. For pointer types the check is performed at the end of the declaration sequence; procedure Block invokes *CheckUndefPointerTypes.*

A with statement

```
WITH x: T1 DO StatSeq END
```

states that within the statement sequence x is to be considered to be of type *T1*, which is presumably some extension of the type *T0* of which x is declared. Compilation of the with statement results in a regional type guard which verifies this assertion, i.e. whether x indeed refers to an object of type *T1*. The with statement represents the singular case where a symbol table entry - the type of *x* - is modified during compilation. When the end of the with statement is reached, the change must be reverted.

```
MODULE Compiler;   (*NW 7.6.87 / 16.3.91*)
  IMPORT Texts, Files, TextFrames, Viewers, Oberon, OCS, OCT, OCC, OCE, OCH;

  CONST NofCases = 128; MaxEntry = 64; ModNameLen = 20;
    RecDescSize = 8; AdrSize = 4; ProcSize = 4; PtrSize = 4;
    XParOrg = 12; LParOrg = 8; LDataSize = 2000H;

  (*symbol values*)
      times = 1; slash = 2; div = 3; mod = 4;
      and = 5; plus = 6; minus = 7; or = 8; eql = 9;
      neq = 10; lss = 11; leq = 12; gtr = 13; geq = 14;
      in = 15; is = 16; arrow = 17; period = 18; comma = 19;
      colon = 20; upto = 21; rparen = 22; rbrak = 23; rbrace = 24;
      of = 25; then = 26; do = 27; to = 28; lparen = 29;
      lbrak = 30; lbrace = 31; not = 32; becomes = 33; number = 34;
```

```
        nil = 35; string = 36; ident = 37; semicolon = 38; bar = 39;
        end = 40; else = 41; elsif = 42; until = 43; if = 44;
        case = 45; while = 46; repeat = 47; loop = 48; with = 49;
        exit = 50; return = 51; array = 52; record = 53; pointer = 54;
        begin = 55; const = 56; type = 57; var = 58; procedure = 59;
        import = 60; module = 61;

    (*object and item modes*)
        Var = 1; Ind = 3; Con = 8; Fld = 12; Typ = 13;
        LProc = 14; XProc = 15; SProc = 16; CProc = 17; IProc = 18; Mod = 19;

    (*structure forms*)
        Undef = 0; Pointer = 13; ProcTyp = 14; Array = 15; DynArr = 16; Record = 17;
        intSet = {4 .. 6}; labeltyps = {3 .. 6};

VAR W: Texts.Writer;
        sym, entno: INTEGER;
        newSF:      BOOLEAN;
        LoopLevel, ExitNo: INTEGER;
        LoopExit:  ARRAY 16 OF INTEGER;

PROCEDURE^ Type(VAR typ: OCT.Struct);
PROCEDURE^ FormalType(VAR typ: OCT.Struct);
PROCEDURE^ Expression(VAR x: OCT.Item);
PROCEDURE^ Block(VAR dsize: LONGINT);

PROCEDURE CheckSym(s: INTEGER);
BEGIN
    IF sym = s THEN OCS.Get(sym) ELSE OCS.Mark(s) END
END CheckSym;

PROCEDURE qualident(VAR x: OCT.Item);
    VAR mnolev: INTEGER; obj: OCT.Object;
BEGIN (*sym = ident*)
    OCT.Find(obj, mnolev); OCS.Get(sym);
    IF (sym = period) & (obj # NIL) & (obj.mode = Mod) THEN
        OCS.Get(sym); mnolev := SHORT(-obj.a0);
        IF sym = ident THEN
            OCT.FindImport(obj, obj); OCS.Get(sym)
        ELSE OCS.Mark(10); obj := NIL
        END
    END ;
    x.lev := mnolev; x.obj := obj;
    IF obj # NIL THEN
        x.mode := obj.mode; x.typ := obj.typ; x.a0 := obj.a0; x.a1 := obj.a1
    ELSE OCS.Mark(0); x.mode := Var;
        x.typ := OCT.undftyp; x.a0 := 0; x.obj := NIL
    END
END qualident;

PROCEDURE ConstExpression(VAR x: OCT.Item);
BEGIN Expression(x);
    IF x.mode # Con THEN
        OCS.Mark(50); x.mode := Con; x.typ := OCT.inttyp; x.a0 := 1
    END
END ConstExpression;

PROCEDURE NewStr(form: INTEGER): OCT.Struct;
    VAR typ: OCT.Struct;
BEGIN NEW(typ);
```

```
    typ.form := form; typ.mno := 0; typ.size := 4; typ.ref := 0;
    typ.BaseTyp := OCT.undftyp; typ.strobj := NIL; RETURN typ
END NewStr;

PROCEDURE CheckMark(VAR mk: BOOLEAN);
BEGIN OCS.Get(sym);
    IF sym = times THEN
        IF OCC.level = 0 THEN mk := TRUE ELSE mk := FALSE; OCS.Mark(47) END ;
        OCS.Get(sym)
    ELSE mk := FALSE
    END
END CheckMark;

PROCEDURE CheckUndefPointerTypes;
    VAR obj: OCT.Object;
BEGIN obj := OCT.topScope.next;
    WHILE obj # NIL DO
        IF obj.mode = Undef THEN OCS.Mark(48) END ;
        obj := obj.next
    END
END CheckUndefPointerTypes;

PROCEDURE RecordType(VAR typ: OCT.Struct);
    VAR adr, size: LONGINT;
        fld, fld0, fld1: OCT.Object;
        ftyp, btyp: OCT.Struct;
        base: OCT.Item;
BEGIN adr := 0; typ := NewStr(Record); typ.BaseTyp := NIL; typ.n := 0;
    IF sym = lparen THEN
        OCS.Get(sym); (*record extension*)
        IF sym = ident THEN
            qualident(base);
            IF (base.mode = Typ) & (base.typ.form = Record) THEN
                typ.BaseTyp := base.typ; typ.n := base.typ.n + 1; adr := base.typ.size
            ELSE OCS.Mark(52)
            END
        ELSE OCS.Mark(10)
        END ;
        CheckSym(rparen)
    END ;
    OCT.OpenScope(0); fld := NIL; fld1 := OCT.topScope;
    LOOP
        IF sym = ident THEN
            LOOP
                IF sym = ident THEN
                    IF typ.BaseTyp # NIL THEN
                        OCT.FindField(typ.BaseTyp, fld0);
                        IF fld0 # NIL THEN OCS.Mark(1) END
                    END ;
                    OCT.Insert(OCS.name, fld); CheckMark(fld.marked); fld.mode := Fld
                ELSE OCS.Mark(10)
                END ;
                IF sym = comma THEN OCS.Get(sym)
                ELSIF sym = ident THEN OCS.Mark(19)
                ELSE EXIT
                END
            END ;
```

```
      CheckSym(colon); Type(ftyp); size := ftyp.size; btyp := ftyp;
      WHILE btyp.form = Array DO btyp := btyp.BaseTyp END ;
      IF btyp.size >= 4 THEN INC(adr, (-adr) MOD 4)
      ELSIF btyp.size = 2 THEN INC(adr, adr MOD 2)
      END ;
      WHILE fld1.next # NIL DO
        fld1 := fld1.next; fld1.typ := ftyp; fld1.a0 := adr; INC(adr, size)
      END
    END ;
    IF sym = semicolon THEN OCS.Get(sym)
    ELSIF sym = ident THEN OCS.Mark(38)
    ELSE EXIT
    END
  END ;
  typ.size := (-adr) MOD 4 + adr; typ.link := OCT.topScope.next;
  CheckUndefPointerTypes; OCT.CloseScope
END RecordType;

PROCEDURE ArrayType(VAR typ: OCT.Struct);
  VAR x: OCT.Item; f, n: INTEGER;
BEGIN typ := NewStr(Array); ConstExpression(x); f := x.typ.form;
  IF f IN intSet THEN
    IF (x.a0 > 0) & (x.a0 <= MAX(INTEGER)) THEN n := SHORT(x.a0)
    ELSE n := 1; OCS.Mark(63)
    END
  ELSE OCS.Mark(51); n := 1
  END ;
  typ.n := n; OCC.AllocBounds(0, n-1, typ.adr);
  IF sym = of THEN
    OCS.Get(sym); Type(typ.BaseTyp)
  ELSIF sym = comma THEN
    OCS.Get(sym); ArrayType(typ.BaseTyp)
  ELSE OCS.Mark(34)
  END ;
  typ.size := n * typ.BaseTyp.size
END ArrayType;

PROCEDURE FormalParameters(VAR resTyp: OCT.Struct; VAR psize: LONGINT);
  VAR mode: SHORTINT;
      adr, size: LONGINT; res: OCT.Item;
      par, par1: OCT.Object; typ: OCT.Struct;
BEGIN par1 := OCT.topScope; adr := 0;
  IF (sym = ident) OR (sym = var) THEN
    LOOP
      IF sym = var THEN OCS.Get(sym); mode := Ind ELSE mode := Var END ;
      LOOP
        IF sym = ident THEN
          OCT.Insert(OCS.name, par); OCS.Get(sym); par.mode := mode
        ELSE OCS.Mark(10)
        END ;
        IF sym = comma THEN OCS.Get(sym)
        ELSIF sym = ident THEN OCS.Mark(19)
        ELSIF sym = var THEN OCS.Mark(19); OCS.Get(sym)
        ELSE EXIT
        END
      END ;
      CheckSym(colon); FormalType(typ);
      IF mode = Ind THEN (*VAR param*)
        IF typ.form = Record THEN size := RecDescSize
        ELSIF typ.form = DynArr THEN size := typ.size
        ELSE size := AdrSize
        END
      ELSE size := (-typ.size) MOD 4 + typ.size
      END ;
      WHILE par1.next # NIL DO
        par1 := par1.next; par1.typ := typ; DEC(adr, size); par1.a0 := adr
      END ;
      IF sym = semicolon THEN OCS.Get(sym)
      ELSIF sym = ident THEN OCS.Mark(38)
      ELSE EXIT
      END
    END
  END ;
  psize := psize - adr; par := OCT.topScope.next;
  WHILE par # NIL DO INC(par.a0, psize); par := par.next END ;
  CheckSym(rparen);
  IF sym = colon THEN
    OCS.Get(sym); resTyp := OCT.undftyp;
    IF sym = ident THEN qualident(res);
      IF res.mode = Typ THEN
        IF res.typ.form <= ProcTyp THEN resTyp := res.typ ELSE OCS.Mark(54) END
      ELSE OCS.Mark(52)
      END
    ELSE OCS.Mark(10)
    END
  ELSE resTyp := OCT.notyp
  END
END FormalParameters;

PROCEDURE ProcType(VAR typ: OCT.Struct);
  VAR psize: LONGINT;
BEGIN typ := NewStr(ProcTyp); typ.size := ProcSize;
  IF sym = lparen THEN
    OCS.Get(sym); OCT.OpenScope(OCC.level); psize := XParOrg;
    FormalParameters(typ.BaseTyp, psize); typ.link := OCT.topScope.next;
    OCT.CloseScope
  ELSE typ.BaseTyp := OCT.notyp; typ.link := NIL
  END
END ProcType;

PROCEDURE HasPtr(typ: OCT.Struct): BOOLEAN;
  VAR fld: OCT.Object;
BEGIN
  IF typ.form = Pointer THEN RETURN TRUE
  ELSIF typ.form = Array THEN RETURN HasPtr(typ.BaseTyp)
  ELSIF typ.form = Record THEN
    IF (typ.BaseTyp # NIL) & HasPtr(typ.BaseTyp) THEN RETURN TRUE END ;
    fld := typ.link;
    WHILE fld # NIL DO
      IF (fld.name = "") OR HasPtr(fld.typ) THEN RETURN TRUE END ;
      fld := fld.next
    END
  END ;
  RETURN FALSE
END HasPtr;

PROCEDURE SetPtrBase(ptyp, btyp: OCT.Struct);
BEGIN
  IF (btyp.form = Record) OR (btyp.form = Array) & ~HasPtr(btyp.BaseTyp) THEN
    ptyp.BaseTyp := btyp
  ELSE ptyp.BaseTyp := OCT.undftyp; OCS.Mark(57)
  END
END SetPtrBase;

PROCEDURE Type(VAR typ: OCT.Struct);
  VAR lev: INTEGER; obj: OCT.Object; x: OCT.Item;
BEGIN typ := OCT.undftyp;
  IF sym < lparen THEN OCS.Mark(12);
    REPEAT OCS.Get(sym) UNTIL sym >= lparen
  END ;
  IF sym = ident THEN qualident(x);
    IF x.mode = Typ THEN typ := x.typ;
      IF typ = OCT.notyp THEN OCS.Mark(58) END
    ELSE OCS.Mark(52)
    END
  ELSIF sym = array THEN
    OCS.Get(sym); ArrayType(typ)
  ELSIF sym = record THEN
    OCS.Get(sym); RecordType(typ); OCC.AllocTypDesc(typ); CheckSym(end)
  ELSIF sym = pointer THEN
    OCS.Get(sym); typ := NewStr(Pointer); typ.link := NIL; typ.size := PtrSize;
    CheckSym(to);
    IF sym = ident THEN OCT.Find(obj, lev);
      IF obj = NIL THEN (*forward ref*)
        OCT.Insert(OCS.name, obj); typ.BaseTyp := OCT.undftyp;
        obj.mode := Undef; obj.typ := typ; OCS.Get(sym)
      ELSE qualident(x);
        IF x.mode = Typ THEN SetPtrBase(typ, x.typ)
        ELSE typ.BaseTyp := OCT.undftyp; OCS.Mark(52)
        END
      END
    ELSE Type(x.typ); SetPtrBase(typ, x.typ)
    END
  ELSIF sym = procedure THEN
    OCS.Get(sym); ProcType(typ)
  ELSE OCS.Mark(12)
  END ;
  IF (sym < semicolon) OR (else < sym) THEN OCS.Mark(15);
    WHILE (sym < ident) OR (else < sym) & (sym < begin) DO
      OCS.Get(sym)
    END
  END
END Type;

PROCEDURE FormalType(VAR typ: OCT.Struct);
  VAR x: OCT.Item; typ0: OCT.Struct; a, s: LONGINT;
BEGIN typ := OCT.undftyp; a := 0;
  WHILE sym = array DO
    OCS.Get(sym); CheckSym(of); INC(a, 4)
  END ;
  IF sym = ident THEN qualident(x);
    IF x.mode = Typ THEN typ := x.typ;
      IF typ = OCT.notyp THEN OCS.Mark(58) END
    ELSE OCS.Mark(52)
    END
  ELSIF sym = procedure THEN OCS.Get(sym); ProcType(typ)
  ELSE OCS.Mark(10)
  END ;
  s := a + 8;
  WHILE a > 0 DO
    typ0 := NewStr(DynArr); typ0.BaseTyp := typ;
    typ0.size := s-a; typ0.adr := typ0.size-4; typ0.mno := 0; typ := typ0; DEC(a, 4)
  END
END FormalType;

PROCEDURE selector(VAR x: OCT.Item);
  VAR fld: OCT.Object; y: OCT.Item;
BEGIN
  LOOP
    IF sym = lbrak THEN OCS.Get(sym);
      LOOP
        IF (x.typ # NIL) & (x.typ.form = Pointer) THEN OCE.DeRef(x) END ;
        Expression(y); OCE.Index(x, y);
        IF sym = comma THEN OCS.Get(sym) ELSE EXIT END
      END ;
      CheckSym(rbrak)
    ELSIF sym = period THEN OCS.Get(sym);
      IF sym = ident THEN
        IF x.typ # NIL THEN
          IF x.typ.form = Pointer THEN OCE.DeRef(x) END ;
          IF x.typ.form = Record THEN
            OCT.FindField(x.typ, fld); OCE.Field(x, fld)
          ELSE OCS.Mark(53)
          END
        ELSE OCS.Mark(52)
        END ;
        OCS.Get(sym)
      ELSE OCS.Mark(10)
      END
    ELSIF sym = arrow THEN
      OCS.Get(sym); OCE.DeRef(x)
    ELSIF (sym = lparen) & (x.mode < Typ) & (x.typ.form # ProcTyp) THEN
      OCS.Get(sym);
      IF sym = ident THEN
        qualident(y);
        IF y.mode = Typ THEN OCE.TypTest(x, y, FALSE)
        ELSE OCS.Mark(52)
        END
      ELSE OCS.Mark(10)
      END ;
      CheckSym(rparen)
    ELSE EXIT
    END
  END
END selector;
```

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PROCEDURE IsParam(obj: OCT.Object): BOOLEAN;
BEGIN RETURN (obj # NIL) & (obj.mode <= Ind) & (obj.a0 > 0)
END IsParam;

PROCEDURE ActualParameters(VAR x: OCT.Item; fpar: OCT.Object);
  VAR apar: OCT.Item; R: SET;
BEGIN
  IF sym # rparen THEN
    R := OCC.RegSet;
    LOOP Expression(apar);
      IF IsParam(fpar) THEN
        OCH.Param(apar, fpar); fpar := fpar.next
      ELSE OCS.Mark(64)
      END ;
      OCC.FreeRegs(R);
      IF sym = comma THEN OCS.Get(sym)
      ELSIF (lparen <= sym) & (sym <= ident) THEN OCS.Mark(19)
      ELSE EXIT
      END
    END
  END ;
  IF IsParam(fpar) THEN OCS.Mark(65) END
END ActualParameters;
PROCEDURE StandProcCall(VAR x: OCT.Item);
  VAR y: OCT.Item; m, n: INTEGER;
BEGIN m := SHORT(x.a0); n := 0;
  IF sym = lparen THEN OCS.Get(sym);
    IF sym # rparen THEN
      LOOP
        IF n = 0 THEN Expression(x); OCE.StPar1(x, m); n := 1
        ELSIF n = 1 THEN Expression(y); OCE.StPar2(x, y, m); n := 2
        ELSIF n = 2 THEN Expression(y); OCE.StPar3(x, y, m); n := 3
        ELSE OCS.Mark(64); Expression(y)
        END ;
        IF sym = comma THEN OCS.Get(sym)
        ELSIF (lparen <= sym) & (sym <= ident) THEN OCS.Mark(19)
        ELSE EXIT
        END
      END ;
      CheckSym(rparen)
    ELSE OCS.Get(sym)
    END ;
    OCE.StFct(x, m, n)
  ELSE OCS.Mark(29)
  END
END StandProcCall;
PROCEDURE Element(VAR x: OCT.Item);
  VAR e1, e2: OCT.Item;
BEGIN Expression(e1);
  IF sym = upto THEN
    OCS.Get(sym); Expression(e2); OCE.Set1(x, e1, e2)
  ELSE OCE.Set0(x, e1)
  END ;
END Element;

PROCEDURE Sets(VAR x: OCT.Item);
  VAR y: OCT.Item;
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BEGIN x.typ := OCT.settyp; y.typ := OCT.settyp;
  IF sym # rbrace THEN
    Element(x);
    LOOP
      IF sym = comma THEN OCS.Get(sym)
      ELSIF (lparen <= sym) & (sym <= ident) THEN OCS.Mark(19)
      ELSE EXIT
      END ;
      Element(y); OCE.Op(plus, x, y)  (*x := x+y*)
    END
  ELSE x.mode := Con; x.a0 := 0
  END ;
  CheckSym(rbrace)
END Sets;

PROCEDURE Factor(VAR x: OCT.Item);
  VAR fpar: OCT.Object; gR, fR: SET;
BEGIN
  IF sym < lparen THEN OCS.Mark(13);
    REPEAT OCS.Get(sym) UNTIL sym >= lparen
  END ;
  IF sym = ident THEN
    qualident(x); selector(x);
    IF x.mode = SProc THEN StandProcCall(x)
    ELSIF sym = lparen THEN
      OCS.Get(sym); OCH.PrepCall(x, fpar);
      OCC.SaveRegisters(gR, fR, x); ActualParameters(x, fpar);
      OCH.Call(x); OCC.RestoreRegisters(gR, fR, x);
      CheckSym(rparen)
    END
  ELSIF sym = number THEN
    OCS.Get(sym); x.mode := Con;
    CASE OCS.numtyp OF
      1: x.typ := OCT.chartyp; x.a0 := OCS.intval
    | 2: x.a0 := OCS.intval; OCE.SetIntType(x)
    | 3: x.typ := OCT.realtyp; OCE.AssReal(x, OCS.realval)
    | 4: x.typ := OCT.lrltyp; OCE.AssLReal(x, OCS.lrlval)
    END
  ELSIF sym = string THEN
    x.typ := OCT.stringtyp; x.mode := Con;
    OCC.AllocString(OCS.name, x); OCS.Get(sym)
  ELSIF sym = nil THEN
    OCS.Get(sym); x.typ := OCT.niltyp; x.mode := Con; x.a0 := 0
  ELSIF sym = lparen THEN
    OCS.Get(sym); Expression(x); CheckSym(rparen)
  ELSIF sym = lbrak THEN
    OCS.Get(sym); OCS.Mark(29); Expression(x); CheckSym(rparen)
  ELSIF sym = lbrace THEN OCS.Get(sym); Sets(x)
  ELSIF sym = not THEN
    OCS.Get(sym); Factor(x); OCE.MOp(not, x)
  ELSE OCS.Mark(13); OCS.Get(sym); x.typ := OCT.undftyp; x.mode := Var; x.a0 := 0
  END
END Factor;
PROCEDURE Term(VAR x: OCT.Item);
  VAR y: OCT.Item; mulop: INTEGER;
BEGIN Factor(x);
```

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    WHILE (times <= sym) & (sym <= and) DO
      mulop := sym; OCS.Get(sym);
      IF mulop = and THEN OCE.MOp(and, x) END ;
      Factor(y); OCE.Op(mulop, x, y)
    END
  END Term;

  PROCEDURE SimpleExpression(VAR x: OCT.Item);
    VAR y: OCT.Item; addop: INTEGER;
  BEGIN
    IF sym = minus THEN OCS.Get(sym); Term(x); OCE.MOp(minus, x)
    ELSIF sym = plus THEN OCS.Get(sym); Term(x); OCE.MOp(plus, x)
    ELSE Term(x)
    END ;
    WHILE (plus <= sym) & (sym <= or) DO
      addop := sym; OCS.Get(sym);
      IF addop = or THEN OCE.MOp(or, x) END ;
      Term(y); OCE.Op(addop, x, y)
    END
  END SimpleExpression;

  PROCEDURE Expression(VAR x: OCT.Item);
    VAR y: OCT.Item; relation: INTEGER;
  BEGIN SimpleExpression(x);
    IF (eql <= sym) & (sym <= geq) THEN
      relation := sym; OCS.Get(sym);
      IF x.typ = OCT.booltyp THEN OCE.MOp(relation, x) END ;
      SimpleExpression(y); OCE.Op(relation, x, y)
    ELSIF sym = in THEN
      OCS.Get(sym); SimpleExpression(y); OCE.In(x, y)
    ELSIF sym = is THEN
      IF x.mode >= Typ THEN OCS.Mark(112) END ;
      OCS.Get(sym);
      IF sym = ident THEN
        qualident(y);
        IF y.mode = Typ THEN OCE.TypTest(x, y, TRUE) ELSE OCS.Mark(52) END
      ELSE OCS.Mark(10)
      END
    END
  END Expression;
  PROCEDURE ProcedureDeclaration;
    VAR proc, proc1, par: OCT.Object;
      L1: INTEGER;
      mode: SHORTINT; body: BOOLEAN;
      psize, dsize: LONGINT;
  BEGIN dsize := 0; proc := NIL; body := TRUE;
    IF (sym # ident) & (OCC.level = 0) THEN
      IF sym = times THEN mode := XProc
      ELSIF sym = arrow THEN (*forward*) mode := XProc; body := FALSE
      ELSIF sym = plus THEN mode := IProc
      ELSIF sym = minus THEN mode := CProc; body := FALSE
      ELSE mode := LProc; OCS.Mark(10)
      END ;
      OCS.Get(sym)
    ELSE mode := LProc
    END ;
    IF sym = ident THEN
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IF OCC.level = 0 THEN OCT.Find(proc1, L1) ELSE proc1 := NIL END;
IF (proc1 # NIL) & (proc1.mode = XProc)&(OCC.Entry(SHORT(proc1.a0)) = 0) THEN
  (*there exists a corresponding forward declaration*)
  IF mode = LProc THEN mode := XProc END ;
  NEW(proc); CheckMark(proc.marked)
ELSE
  IF proc1 # NIL THEN OCS.Mark(1); proc1 := NIL END ;
  OCT.Insert(OCS.name, proc); CheckMark(proc.marked);
  IF proc.marked & (mode = LProc) THEN mode := XProc END ;
  IF mode = LProc THEN proc.a0 := OCC.pc
  ELSIF mode # CProc THEN
    IF entno < MaxEntry THEN proc.a0 := entno; INC(entno)
    ELSE proc.a0 := 1; OCS.Mark(226)
    END
  END
END ;
proc.mode := mode; proc.typ := OCT.notyp; proc.dsc := NIL; proc.a1 := 0;
INC(OCC.level); OCT.OpenScope(OCC.level);
IF (mode = LProc) & (OCC.level = 1) THEN psize := LParOrg
ELSE psize := XParOrg
END ;
IF sym = lparen THEN
  OCS.Get(sym); FormalParameters(proc.typ, psize); proc.dsc := OCT.topScope.next
END ;
IF proc1 # NIL THEN  (*forward*)
  OCH.CompareParLists(proc.dsc, proc1.dsc);
  IF proc.typ # proc1.typ THEN OCS.Mark(118) END ;
  proc := proc1; proc.dsc := OCT.topScope.next
END ;
IF mode = CProc THEN
  IF sym = number THEN proc.a0 := OCS.intval; OCS.Get(sym)
  ELSE OCS.Mark(17)
  END
END ;
IF body THEN
  CheckSym(semicolon); OCT.topScope.typ := proc.typ;
  OCT.topScope.a1 := mode*10000H + psize; (*for RETURN statements*)
  OCH.Enter(mode, proc.a0, L1); par := proc.dsc;
  WHILE par # NIL DO
    (*code for dynamic array value parameters*)
    IF (par.typ.form = DynArr) & (par.mode = Var) THEN
      OCH.CopyDynArray(par.a0, par.typ)
    END ;
    par := par.next
  END ;
  Block(dsize); proc.dsc := OCT.topScope.next;  (*update*)
  IF proc.typ = OCT.notyp THEN OCH.Return(proc.mode, psize)
  ELSE OCH.Trap(17)
  END ;
  IF dsize >= LDataSize THEN OCS.Mark(209); dsize := 0 END ;
  OCC.FixupWith(L1, dsize); proc.a2 := OCC.pc;
  IF sym = ident THEN
    IF OCS.name # proc.name THEN OCS.Mark(4) END ;
    OCS.Get(sym)
  ELSE OCS.Mark(10)
  END
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      END ;
      DEC(OCC.level); OCT.CloseScope
    END
  END ProcedureDeclaration;

  PROCEDURE CaseLabelList(LabelForm: INTEGER;
            VAR n: INTEGER; VAR tab: ARRAY OF OCH.LabelRange);
    VAR x, y: OCT.Item; i, f: INTEGER;
  BEGIN
    IF ~(LabelForm IN labeltyps) THEN OCS.Mark(61) END ;
    LOOP ConstExpression(x); f := x.typ.form;
      IF f IN intSet THEN
        IF LabelForm < f THEN OCS.Mark(60) END
      ELSIF f # LabelForm THEN OCS.Mark(60)
      END ;
      IF sym = upto THEN
        OCS.Get(sym); ConstExpression(y);
        IF (y.typ.form # f) & ~((f IN intSet) & (y.typ.form IN intSet)) THEN OCS.Mark(60)
        END ;
        IF y.a0 < x.a0 THEN OCS.Mark(63); y.a0 := x.a0 END
      ELSE y := x
      END ;
      (*enter label range into ordered table*)  i := n;
      IF i < NofCases THEN
        LOOP
          IF i = 0 THEN EXIT END ;
          IF tab[i-1].low <= y.a0 THEN
            IF tab[i-1].high >= x.a0 THEN OCS.Mark(62) END ;
            EXIT
          END ;
          tab[i] := tab[i-1]; DEC(i)
        END ;
        tab[i].low := SHORT(x.a0); tab[i].high := SHORT(y.a0);
        tab[i].label := OCC.pc; INC(n)
      ELSE OCS.Mark(213)
      END ;
      IF sym = comma THEN OCS.Get(sym)
      ELSIF (sym = number) OR (sym = ident) THEN OCS.Mark(19)
      ELSE EXIT
      END
    END
  END CaseLabelList;

PROCEDURE StatSeq;
    VAR fpar: OCT.Object; xtyp: OCT.Struct;
        x, y: OCT.Item; L0, L1, ExitIndex: INTEGER;

    PROCEDURE CasePart;
      VAR x: OCT.Item; n, L0, L1, L2, L3: INTEGER;
          tab: ARRAY NofCases OF OCH.LabelRange;
    BEGIN n := 0; L3 := 0;
      Expression(x); OCH.CaseIn(x, L0, L1); OCC.FreeRegs({});
      CheckSym(of);
      LOOP
        IF sym < bar THEN
          CaseLabelList(x.typ.form, n, tab);
          CheckSym(colon); StatSeq; OCH.FJ(L3)
      END ;
      IF sym = bar THEN OCS.Get(sym) ELSE EXIT END
    END ;
    L2 := OCC.pc;
    IF sym = else THEN
      OCS.Get(sym); StatSeq; OCH.FJ(L3)
    ELSE OCH.Trap(16)
    END ;
    OCH.CaseOut(L0, L1, L2, L3, n, tab)
  END CasePart;

BEGIN
  LOOP
    IF sym < ident THEN OCS.Mark(14);
      REPEAT OCS.Get(sym) UNTIL sym >= ident
    END ;
    IF sym = ident THEN
      qualident(x); selector(x);
      IF sym = becomes THEN
        OCS.Get(sym); Expression(y); OCH.Assign(x, y, FALSE)
      ELSIF sym = eql THEN
        OCS.Mark(33); OCS.Get(sym); Expression(y); OCH.Assign(x, y, FALSE)
      ELSIF x.mode = SProc THEN
        StandProcCall(x);
        IF x.typ # OCT.notyp THEN OCS.Mark(55) END
      ELSE OCH.PrepCall(x, fpar);
        IF sym = lparen THEN
          OCS.Get(sym); ActualParameters(x, fpar); CheckSym(rparen)
        ELSIF IsParam(fpar) THEN OCS.Mark(65)
        END ;
        OCH.Call(x);
        IF x.typ # OCT.notyp THEN OCS.Mark(55) END
      END
    ELSIF sym = if THEN
      OCS.Get(sym); Expression(x); OCH.CFJ(x, L0); OCC.FreeRegs({});
      CheckSym(then); StatSeq; L1 := 0;
      WHILE sym = elsif DO
        OCS.Get(sym); OCH.FJ(L1); OCC.FixLink(L0);
        Expression(x); OCH.CFJ(x, L0); OCC.FreeRegs({});
        CheckSym(then); StatSeq
      END ;
      IF sym = else THEN
        OCS.Get(sym); OCH.FJ(L1); OCC.FixLink(L0); StatSeq
      ELSE OCC.FixLink(L0)
      END ;
      OCC.FixLink(L1); CheckSym(end)
    ELSIF sym = case THEN
      OCS.Get(sym); CasePart; CheckSym(end)
    ELSIF sym = while THEN
      OCS.Get(sym); L1 := OCC.pc;
      Expression(x); OCH.CFJ(x, L0); OCC.FreeRegs({});
      CheckSym(do); StatSeq; OCH.BJ(L1); OCC.FixLink(L0);
      CheckSym(end)
    ELSIF sym = repeat THEN
      OCS.Get(sym); L0 := OCC.pc; StatSeq;
      IF sym = until THEN
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            OCS.Get(sym); Expression(x); OCH.CBJ(x, L0)
         ELSE OCS.Mark(43)
         END
      ELSIF sym = loop THEN
         OCS.Get(sym); ExitIndex := ExitNo; INC(LoopLevel);
         L0 := OCC.pc; StatSeq; OCH.BJ(L0); DEC(LoopLevel);
         WHILE ExitNo > ExitIndex DO
            DEC(ExitNo); OCC.fixup(LoopExit[ExitNo])
         END ;
         CheckSym(end)
      ELSIF sym = with THEN
         OCS.Get(sym); x.obj := NIL; xtyp := NIL;
         IF sym = ident THEN
            qualident(x); CheckSym(colon);
            IF sym = ident THEN qualident(y);
               IF y.mode = Typ THEN
                  IF x.obj # NIL THEN
                        xtyp := x.typ; OCE.TypTest(x, y, FALSE); x.obj.typ := x.typ
                  ELSE OCS.Mark(130)
                  END
               ELSE OCS.Mark(52)
               END
            ELSE OCS.Mark(10)
            END
         ELSE OCS.Mark(10)
         END ;
         CheckSym(do); OCC.FreeRegs({}); StatSeq; CheckSym(end);
         IF xtyp# NIL THEN x.obj.typ := xtyp END
      ELSIF sym = exit THEN
         OCS.Get(sym); OCH.FJ(L0);
         IF LoopLevel = 0 THEN OCS.Mark(45)
         ELSIF ExitNo < 16 THEN LoopExit[ExitNo] := L0; INC(ExitNo)
         ELSE OCS.Mark(214)
         END
      ELSIF sym = return THEN OCS.Get(sym);
         IF OCC.level > 0 THEN
            IF sym < semicolon THEN
               Expression(x); OCH.Result(x, OCT.topScope.typ)
            ELSIF OCT.topScope.typ # OCT.notyp THEN OCS.Mark(124)
            END ;
            OCH.Return(SHORT(OCT.topScope.a1 DIV 10000H), SHORT(OCT.topScope.a1))
         ELSE (*return from module body*)
            IF sym < semicolon THEN Expression(x); OCS.Mark(124) END ;
            OCH.Return(XProc, XParOrg)
         END
      END ;
      OCC.FreeRegs({});
      IF sym = semicolon THEN OCS.Get(sym)
      ELSIF (sym <= ident) OR (if <= sym) & (sym <= return) THEN OCS.Mark(38)
      ELSE EXIT
      END
   END
END StatSeq;

PROCEDURE Block(VAR dsize: LONGINT);
   VAR typ, forward: OCT.Struct;
```

```
      obj, first: OCT.Object;
      x: OCT.Item;
      L0: INTEGER;
      adr, size: LONGINT;
      mk: BOOLEAN;
      id0: ARRAY 32 OF CHAR;
  BEGIN adr := -dsize; obj := OCT.topScope;
    WHILE obj.next # NIL DO obj := obj.next END ;
    LOOP
      IF sym = const THEN
        OCS.Get(sym);
        WHILE sym = ident DO
          COPY(OCS.name, id0); CheckMark(mk);
          IF sym = eql THEN OCS.Get(sym); ConstExpression(x)
          ELSIF sym = becomes THEN OCS.Mark(9); OCS.Get(sym); ConstExpression(x)
          ELSE OCS.Mark(9)
          END ;
          OCT.Insert(id0, obj); obj.mode := SHORT(x.mode);
          obj.typ := x.typ; obj.a0 := x.a0; obj.a1 := x.a1; obj.marked := mk;
          CheckSym(semicolon)
        END
      END ;
      IF sym = type THEN
        OCS.Get(sym);
        WHILE sym = ident DO
          typ := OCT.undftyp; OCT.Insert(OCS.name, obj); forward := obj.typ;
          obj.mode := Typ; obj.typ := OCT.notyp; CheckMark(obj.marked);
          IF sym = eql THEN OCS.Get(sym); Type(typ)
          ELSIF (sym = becomes) OR (sym = colon) THEN
            OCS.Mark(9); OCS.Get(sym); Type(typ)
          ELSE OCS.Mark(9)
          END ;
          obj.typ := typ;
          IF typ.strobj = NIL THEN typ.strobj := obj END ;
          IF forward # NIL THEN (*fixup*) SetPtrBase(forward, typ) END ;
          CheckSym(semicolon)
        END
      END ;
      IF sym = var THEN
        OCS.Get(sym);
        WHILE sym = ident DO
          OCT.Insert(OCS.name, obj); first := obj; CheckMark(obj.marked); obj.mode := Var;
          LOOP
            IF sym = comma THEN OCS.Get(sym)
            ELSIF sym = ident THEN OCS.Mark(19)
            ELSE EXIT
            END ;
            IF sym = ident THEN
              OCT.Insert(OCS.name, obj); CheckMark(obj.marked); obj.mode := Var
            ELSE OCS.Mark(10)
            END
          END ;
          CheckSym(colon); Type(typ); size := typ.size;
          IF size >= 4 THEN DEC(adr, adr MOD 4)
          ELSIF size = 2 THEN DEC(adr, adr MOD 2)
          END ;
```

```
                WHILE first # NIL DO
                   first.typ := typ; DEC(adr, size); first.a0 := adr; first := first.next
                END ;
                CheckSym(semicolon)
             END
          END ;
          IF (sym < const) OR (sym > var) THEN EXIT END ;
       END ;
       CheckUndefPointerTypes;
       IF OCC.level = 0 THEN OCH.LFJ(L0) ELSE OCH.FJ(L0) END ;
       WHILE sym = procedure DO
          OCS.Get(sym); ProcedureDeclaration; CheckSym(semicolon)
       END ;
       IF OCC.level = 0 THEN OCC.fixupL(L0); OCC.InitTypDescs
       ELSE OCC.fixupC(L0)
       END ;
       IF sym = begin THEN OCS.Get(sym); StatSeq END ;
       dsize := (adr MOD 4) - adr; CheckSym(end)
    END Block;

 PROCEDURE CompilationUnit(source: Texts.Text; pos: LONGINT);
       VAR L0: INTEGER; ch: CHAR;
             time, date, key, dsize: LONGINT;
             modid, impid, FName: ARRAY 32 OF CHAR;

       PROCEDURE MakeFileName(VAR name, FName: ARRAY OF CHAR;
             ext: ARRAY OF CHAR);
          VAR i, j: INTEGER; ch: CHAR;
       BEGIN i := 0;
          LOOP ch := name[i];
             IF ch = 0X THEN EXIT END ;
             FName[i] := ch; INC(i)
          END ;
          j := 0;
          REPEAT ch := ext[j]; FName[i] := ch; INC(i); INC(j)
          UNTIL ch = 0X
       END MakeFileName;

    BEGIN entno := 1; dsize := 0; LoopLevel := 0; ExitNo := 0;
       OCC.Init; OCT.Init; OCS.Init(source, pos); OCS.Get(sym);
       Texts.WriteString(W, "  compiling ");
       IF sym = module THEN OCS.Get(sym) ELSE OCS.Mark(16) END ;
       IF sym = ident THEN
          Texts.WriteString(W, OCS.name); Texts.Append(Oberon.Log, W.buf);
          L0 := 0; ch := OCS.name[0];
          WHILE (ch # 0X) & (L0 < ModNameLen-1) DO
             modid[L0] := ch; INC(L0); ch := OCS.name[L0]
          END ;
          modid[L0] := 0X;
          IF ch # 0X THEN OCS.Mark(228) END ;
          OCT.OpenScope(0); OCS.Get(sym);
          CheckSym(semicolon); OCH.Enter(Mod, 0, L0);
          IF sym = import THEN
             OCS.Get(sym);
             LOOP
                IF sym = ident THEN
                   COPY(OCS.name, impid); OCS.Get(sym);
          MakeFileName(impid, FName, ".Sym");
          IF sym = becomes THEN OCS.Get(sym);
            IF sym = ident THEN
                MakeFileName(OCS.name, FName, ".Sym"); OCS.Get(sym)
            ELSE OCS.Mark(10)
            END
          END ;
          OCT.Import(impid, modid, FName)
        ELSE OCS.Mark(10)
        END ;
        IF sym = comma THEN OCS.Get(sym)
        ELSIF sym = ident THEN OCS.Mark(19)
        ELSE EXIT
        END
      END ;
      CheckSym(semicolon)
    END ;
    IF ~OCS.scanerr THEN
      OCC.SetLinkTable(OCT.nofGmod+1);
      Block(dsize); OCH.Return(XProc, 12);
      IF sym = ident THEN
        IF OCS.name # modid THEN OCS.Mark(4) END ;
        OCS.Get(sym)
      ELSE OCS.Mark(10)
      END ;
      IF sym # period THEN OCS.Mark(18) END ;
      IF ~OCS.scanerr THEN
        Oberon.GetClock(time, date); key := (date MOD 4000H) * 20000H + time;
        MakeFileName(modid, FName, ".Sym");
        OCT.Export(modid, FName, newSF, key);
        IF newSF THEN Texts.WriteString(W, " new symbol file") END ;
        IF ~OCS.scanerr THEN
          MakeFileName(modid, FName, ".Obj");
          OCC.OutCode(FName, modid, key, entno, dsize);
          Texts.WriteInt(W, OCC.pc, 6); Texts.WriteInt(W, dsize, 6)
        END
      END
    END ;
    OCT.CloseScope
  ELSE OCS.Mark(10)
  END;
  OCC.Close; OCT.Close;
  Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
END CompilationUnit;

PROCEDURE Compile*;
  VAR beg, end, time: LONGINT;
    T: Texts.Text;
    S: Texts.Scanner;
    v: Viewers.Viewer;

  PROCEDURE Options;
    VAR ch: CHAR;
  BEGIN
    IF S.nextCh = "/" THEN
      LOOP Texts.Read(S, ch);
        IF ch = "x" THEN OCE.inxchk := FALSE
```

```
            ELSIF ch = "t" THEN OCC.typchk := FALSE
            ELSIF ch = "s" THEN newSF := TRUE
            ELSE S.nextCh := ch; EXIT
            END
          END
        END
      END Options;

    BEGIN OCE.inxchk := TRUE; OCC.typchk := TRUE; newSF := FALSE;
      Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
      IF S.class = Texts.Char THEN
        IF S.c = "*" THEN
          v := Oberon.MarkedViewer();
          IF (v.dsc # NIL) & (v.dsc.next IS TextFrames.Frame) THEN
            Options; CompilationUnit(v.dsc.next(TextFrames.Frame).text, 0)
          END
        ELSIF S.c = "^" THEN
          Oberon.GetSelection(T, beg, end, time);
          IF time >= 0 THEN
            Texts.OpenScanner(S, T, beg); Texts.Scan(S);
            IF S.class = Texts.Name THEN
              Options; Texts.WriteString(W, S.s); NEW(T); Texts.Open(T, S.s);
              IF T.len # 0 THEN CompilationUnit(T, 0)
              ELSE Texts.WriteString(W, " not found");
                Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
              END
            END
          END
        ELSIF S.c = "@" THEN
          Oberon.GetSelection(T, beg, end, time);
          IF time >= 0 THEN Options; CompilationUnit(T, beg) END
        END
      ELSE NEW(T);
        WHILE S.class = Texts.Name DO
          Options; Texts.WriteString(W, S.s); Texts.Open(T, S.s);
          IF T.len # 0 THEN CompilationUnit(T, 0)
          ELSE Texts.WriteString(W, " not found");
            Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
          END ;
          Texts.Scan(S)
        END
      END ;
      Oberon.Collect(0)
    END Compile;

  BEGIN Texts.OpenWriter(W);
    Texts.WriteString(W, "Compiler  NW 1.8.91"); Texts.WriteLn(W);
    Texts.Append(Oberon.Log, W.buf)
  END Compiler.
```

12.5. The Scanner

The scanner embodies the lexicographic definitions of the language, i.e. the definition of abstract symbols in terms of characters. The scanner's substance is procedure *Get,* which scans the source text and, for each call, identifies the next symbol. It is most important that this process be as efficient as possible. Therefore, use of a case statement is made to discriminate the various classes of characters, and to recognize letters indicating the presence of an identifier (or reserved word), and digits signalling the presence of a number. Also, the scanner recognizes comments and skips them. The global variable *ch* stands for the last character read.

A sequence of letters and digits may either denote an identifier or a key word. In order to determine which is the case, a search is made in a table containing all key words for each would-be identifier. This table is organized as a hash-table for reasons of efficiency. The hash function is the sum of all characters' ordinal numbers plus the number of them, modulo the table size. At most two comparisons suffice to detect the presence of a key word. The hash table is initialized when the compiler is loaded.

The presence of a digit signals a number. Procedure *Number* first scans the subsequent digits (and letters) and stores them in a buffer. This is necessary, because hexadecimal numbers are denoted by the postfix letter H (rather than a prefix character). The postfix letter X specifies that the digits denote a character.

There exists a single case where a look-ahead of a single character does not suffice to identify the next symbol. When a sequence of digits is followed by a period, this period may either be the decimal point of a real number, or it may be the first element of a range symbol (..). Fortunately, the problem can be solved locally as follows: If, after reading digits and a period, a second period is present, the number symbol is returned, and the look-ahead variable *ch* is assigned the special value 7FX. A subsequent call of *Get* then delivers the range symbol. Otherwise the period after the digit sequence belongs to the (real) number.

```
MODULE OCS;  (*NW 7.6.87 / 20.12.90*)
  IMPORT Files, Reals, Texts, Oberon;

    (* symbols:
          | 0         1          2          3          4
     -----------------------------------------------------------
      0   | null      *          /          DIV        MOD
      5   | &         +          -          OR         =
     10   | #         <          <=         >          >=
     15   | IN        IS         ^          .          ,
     20   | :         ..         )          ]          }
     25   | OF        THEN       DO         TO         (
     30   | [         {          ~          :=         number
     35   | NIL       string     ident      ;          |
     40   | END       ELSE       ELSIF      UNTIL      IF
     45   | CASE      WHILE      REPEAT     LOOP       WITH
     50   | EXIT      RETURN     ARRAY      RECORD     POINTER
     55   | BEGIN     CONST      TYPE       VAR        PROCEDURE
     60   | IMPORT    MODULE     eof *)

  CONST KW = 43;  (*size of hash table*)
        maxDig = 32;
        maxInt = 7FFFH;
        maxShInt = 7FH;
        maxExp = 38; maxLExp = 308;
        maxStrLen = 128;

  (*name, numtyp, intval, realval, lrlval are implicit results of Get*)
  VAR numtyp* : INTEGER; (* 1 = char, 2 = integer, 3 = real, 4 = longreal*)
    intval* : LONGINT;
    realval*: REAL;
    lrlval* : LONGREAL;
    scanerr*: BOOLEAN;
    name*   : ARRAY maxStrLen OF CHAR;
    R: Texts.Reader;
    W: Texts.Writer;
    ch: CHAR;     (*current character*)
```

```
   lastpos: LONGINT; (*error position in source file*)
   i: INTEGER;
   keyTab  : ARRAY KW OF
            RECORD symb, alt: INTEGER; id: ARRAY 12 OF CHAR END;

PROCEDURE Mark*(n: INTEGER);
   VAR pos: LONGINT;
BEGIN scanerr := TRUE; pos := Texts.Pos(R);
   IF lastpos + 10 < pos THEN
      Texts.WriteLn(W); Texts.WriteString(W, "  pos");
      Texts.WriteInt(W, pos, 6); Texts.WriteString(W, "  err");
      Texts.WriteInt(W, n, 4); Texts.Append(Oberon.Log, W.buf); lastpos := pos
   END
END Mark;

PROCEDURE String(VAR sym: INTEGER);
   VAR i: INTEGER;
BEGIN i := 0;
   LOOP Texts.Read(R, ch);
      IF ch = 22X THEN EXIT END ;
      IF ch < " " THEN Mark(3); EXIT END ;
      IF i < maxStrLen-1 THEN name[i] := ch; INC(i) ELSE Mark(212); i := 0 END
   END ;
   Texts.Read(R, ch);
   IF i = 1 THEN sym := 34; numtyp := 1; intval := ORD(name[0])
   ELSE sym := 36; name[i] := 0X (*string*)
   END
END String;

PROCEDURE Identifier(VAR sym: INTEGER);
   VAR i, k: INTEGER;
BEGIN i := 0; k := 0;
   REPEAT
      IF i < 31 THEN name[i] := ch; INC(i); INC(k, ORD(ch)) END ;
      Texts.Read(R, ch)
   UNTIL (ch < "0") OR ("9" < ch) & (CAP(ch) < "A") OR ("Z" < CAP(ch));
   name[i] := 0X;
   k := (k+i) MOD KW;  (*hash function*)
   IF (keyTab[k].symb # 0) & (keyTab[k].id = name) THEN sym := keyTab[k].symb
   ELSE k := keyTab[k].alt;
      IF (keyTab[k].symb # 0) & (keyTab[k].id = name) THEN sym := keyTab[k].symb
      ELSE sym := 37 (*ident*)
      END
   END
END Identifier;

PROCEDURE Hval(ch: CHAR): INTEGER;
   VAR d: INTEGER;
BEGIN d := ORD(ch) - 30H; (*d >= 0*)
   IF d >= 10 THEN
      IF (d >= 17) & (d < 23) THEN DEC(d, 7) ELSE d := 0; Mark(2) END
   END ;
   RETURN d
END Hval;

PROCEDURE Number;
   VAR i, j, h, d, e, n: INTEGER;
   x, f:   REAL;
```

```
    y, g: LONGREAL;
    lastCh: CHAR; neg: BOOLEAN;
    dig:    ARRAY maxDig OF CHAR;

    PROCEDURE ReadScaleFactor;
    BEGIN Texts.Read(R, ch);
      IF ch = "-" THEN neg := TRUE; Texts.Read(R, ch)
      ELSE neg := FALSE;
          IF ch = "+" THEN Texts.Read(R, ch) END
      END ;
      IF ("0" <= ch) & (ch <= "9") THEN
          REPEAT e := e*10 + ORD(ch)-30H; Texts.Read(R, ch)
          UNTIL (ch < "0") OR (ch >"9")
      ELSE Mark(2)
      END
    END ReadScaleFactor;

  BEGIN i := 0;
    REPEAT dig[i] := ch; INC(i); Texts.Read(R, ch)
    UNTIL (ch < "0") OR ("9" < ch) & (CAP(ch) < "A") OR ("Z" < CAP(ch));
    lastCh := ch; j := 0;
    WHILE (j < i-1) & (dig[j] = "0") DO INC(j) END ;
    IF ch = "." THEN Texts.Read(R, ch);
      IF ch = "." THEN lastCh := 0X; ch := 7FX END
    END ;
    IF lastCh = "." THEN (*decimal point*)
      h := i;
      WHILE ("0" <= ch) & (ch <= "9") DO (*read fraction*)
        IF i < maxDig THEN dig[i] := ch; INC(i) END ;
        Texts.Read(R, ch)
      END ;
      IF ch = "D" THEN
        y := 0; g := 1; e := 0;
        WHILE j < h DO y := y*10 + (ORD(dig[j])-30H); INC(j) END ;
        WHILE j < i DO g := g/10; y := (ORD(dig[j])-30H)*g + y; INC(j) END ;
        ReadScaleFactor;
        IF neg THEN
          IF e <= maxLExp THEN y := y / Reals.TenL(e) ELSE y := 0 END
        ELSIF e > 0 THEN
          IF e <= maxLExp THEN y := Reals.TenL(e) * y ELSE y := 0; Mark(203) END
        END ;
        numtyp := 4; lrlval := y
      ELSE x := 0; f := 1; e := 0;
        WHILE j < h DO x := x*10 + (ORD(dig[j])-30H); INC(j) END ;
        WHILE j < i DO f := f/10; x := (ORD(dig[j])-30H)*f + x; INC(j) END ;
        IF ch = "E" THEN ReadScaleFactor END ;
        IF neg THEN
          IF e <= maxExp THEN x := x / Reals.Ten(e) ELSE x := 0 END
        ELSIF e > 0 THEN
          IF e <= maxExp THEN x := Reals.Ten(e) * x ELSE x := 0; Mark(203) END
        END ;
        numtyp := 3; realval := x
      END
    ELSE (*integer*)
      lastCh := dig[i-1]; intval := 0;
      IF lastCh = "H" THEN
```

```
         IF j < i THEN
            DEC(i); intval := Hval(dig[j]); INC(j);
            IF i-j <= 7 THEN
               IF (i-j = 7) & (intval >= 8) THEN DEC(intval, 16) END ;
               WHILE j < i DO intval := Hval(dig[j]) + intval * 10H; INC(j) END
            ELSE Mark(203)
            END
         END
      ELSIF lastCh = "X" THEN
         DEC(i);
         WHILE j < i DO
            intval := Hval(dig[j]) + intval*10H; INC(j);
            IF intval > 0FFH THEN Mark(203); intval := 0 END
         END
      ELSE (*decimal*)
         WHILE j < i DO
            d := ORD(dig[j]) - 30H;
            IF d < 10 THEN
               IF intval <= (MAX(LONGINT) - d) DIV 10 THEN intval := intval*10 + d
               ELSE Mark(203); intval := 0
               END
            ELSE Mark(2); intval := 0
            END ;
            INC(j)
         END
      END ;
      IF lastCh = "X" THEN numtyp := 1 ELSE numtyp := 2 END
   END
END Number;
PROCEDURE Get*(VAR sym: INTEGER);
   VAR s: INTEGER; xch: CHAR;
   PROCEDURE Comment;          (* do not read after end of file *)
   BEGIN Texts.Read(R, ch);
      LOOP
         LOOP
            WHILE ch = "(" DO Texts.Read(R, ch);
               IF ch = "*" THEN Comment END
            END ;
            IF ch = "*" THEN Texts.Read(R, ch); EXIT END ;
            IF ch = 0X THEN EXIT END ;
            Texts.Read(R, ch)
         END ;
         IF ch = ")" THEN Texts.Read(R, ch); EXIT END ;
         IF ch = 0X THEN Mark(5); EXIT END
      END
   END Comment;

BEGIN
   LOOP (*ignore control characters*)
      IF ch <= " " THEN
         IF ch = 0X THEN ch := " "; EXIT
         ELSE Texts.Read(R, ch)
         END
      ELSIF ch > 7FX THEN Texts.Read(R, ch)
      ELSE EXIT
      END
```

```
  END ;
  CASE ch OF   (* " " <= ch <= 7FX *)
        " "  : s := 62; ch := 0X (*eof*)
     | "!", "$", "%", "'", "?", "@", "\", "_", "`": s :=  0; Texts.Read(R, ch)
     | 22X  : String(s)
     | "#"  : s := 10; Texts.Read(R, ch)
     | "&"  : s :=  5; Texts.Read(R, ch)
     | "("  : Texts.Read(R, ch);
                     IF ch = "*" THEN Comment; Get(s)
                             ELSE s := 29
                     END
     | ")"  : s := 22; Texts.Read(R, ch)
     | "*"  : s :=  1; Texts.Read(R, ch)
     | "+"  : s :=  6; Texts.Read(R, ch)
     | ","  : s := 19; Texts.Read(R, ch)
     | "-"  : s :=  7; Texts.Read(R, ch)
     | "."  : Texts.Read(R, ch);
                     IF ch = "." THEN Texts.Read(R, ch); s := 21 ELSE s := 18 END
     | "/"  : s := 2;  Texts.Read(R, ch)
     | "0".."9": Number; s := 34
     | ":"  : Texts.Read(R, ch);
                     IF ch = "=" THEN Texts.Read(R, ch); s := 33 ELSE s := 20 END
     | ";"  : s := 38; Texts.Read(R, ch)
     | "<"  : Texts.Read(R, ch);
                     IF ch = "=" THEN Texts.Read(R, ch); s := 12 ELSE s := 11 END
     | "="  : s :=  9; Texts.Read(R, ch)
     | ">"  : Texts.Read(R, ch);
                     IF ch = "=" THEN Texts.Read(R, ch); s := 14 ELSE s := 13 END
     | "A".."Z": Identifier(s)
     | "["  : s := 30; Texts.Read(R, ch)
     | "]"  : s := 23; Texts.Read(R, ch)
     | "^"  : s := 17; Texts.Read(R, ch)
     | "a".."z": Identifier(s)
     | "{"  : s := 31; Texts.Read(R, ch)
     | "|"  : s := 39; Texts.Read(R, ch)
     | "}"  : s := 24; Texts.Read(R, ch)
     | "~"  : s := 32; Texts.Read(R, ch)
     | 7FX  : s := 21; Texts.Read(R, ch)
  END ;
  sym := s
END Get;

PROCEDURE Init*(source: Texts.Text; pos: LONGINT);
BEGIN
  ch := " "; scanerr := FALSE; lastpos := -8;
  Texts.OpenReader(R, source, pos)
END Init;

PROCEDURE EnterKW(sym: INTEGER; name: ARRAY OF CHAR);
  VAR j, k: INTEGER;
BEGIN j := 0; k := 0;
  REPEAT INC(k, ORD(name[j])); INC(j)
  UNTIL name[j] = 0X;
  k := (k+j) MOD KW;  (*hash function*)
  IF keyTab[k].symb # 0 THEN
     j := k;
     REPEAT INC(k) UNTIL keyTab[k].symb = 0;
```

```
            keyTab[j].alt := k
          END ;
          keyTab[k].symb := sym; COPY(name, keyTab[k].id)
        END EnterKW;

    BEGIN i := KW;
        WHILE i > 0 DO
          DEC(i); keyTab[i].symb := 0; keyTab[i].alt := 0
        END ;
        keyTab[0].id := "";
        EnterKW(27, "DO"); EnterKW(44, "IF"); EnterKW(15, "IN"); EnterKW(16, "IS");
        EnterKW(25, "OF"); EnterKW( 8, "OR"); EnterKW(40, "END"); EnterKW( 4, "MOD");
        EnterKW(35, "NIL"); EnterKW(58, "VAR"); EnterKW(41, "ELSE"); EnterKW(50, "EXIT");
        EnterKW(26, "THEN"); EnterKW(49, "WITH"); EnterKW(52, "ARRAY");
        EnterKW(55, "BEGIN"); EnterKW(56, "CONST"); EnterKW(42, "ELSIF");
        EnterKW(43, "UNTIL"); EnterKW(46, "WHILE"); EnterKW(53, "RECORD");
        EnterKW(47, "REPEAT"); EnterKW(51, "RETURN"); EnterKW(59, "PROCEDURE");
        EnterKW(28, "TO"); EnterKW( 3, "DIV"); EnterKW(48, "LOOP"); EnterKW(57, "TYPE");
        EnterKW(60, "IMPORT"); EnterKW(61, "MODULE"); EnterKW(54, "POINTER");
        Texts.OpenWriter(W)
    END OCS.
```

12.6. Searching the Symbol Table, and Symbol Files

The symbol table constitutes the context in which statements and expressions are parsed. Each procedure establishes a scope of visibility of local identifiers. The records registering identifiers belonging to a scope are linked as a linear list. Procedures for generating and searching the lists are contained in module OCT. If a new identifier is to be added, procedure *Insert* first searches the list, and if the identifier is already present, a double definition is diagnosed. Otherwise the new element is appended, thereby preserving the order given by the source text.

Procedures, and therefore also scopes, may be nested. Each scope is represented by the list of its declared identifiers, and the list of the currently visible scopes are again connected as a list. Procedure *OpenScope* appends an element and procedure *CloseScope* removes it. The list of scopes is anchored in the global variable *topScope*, and it is treated like a stack. It consists of elements of type *Object*, each one being the header (*mode* = *Head*) of the list of declared entities. A snapshot of a symbol table is shown in Fig. 12.6. It is taken when the following declarations are parsed and when the statement S is reached.

```
VAR x: INTEGER;

PROCEDURE P(u: INTEGER);
BEGIN ... END P;

PROCEDURE Q(v: INTEGER);
  PROCEDURE R(w: INTEGER);
  BEGIN S END R;
BEGIN ... END Q;
```

A search of an identifier proceeds first through the scope list, and for each header its list of object records is scanned. This mirrors the scope rule of the language and guarantees that if several entities carry the same identifier, the most local one is selected. The linear list of objects represents the simplest implementation by far. A tree structure would in many cases be more efficient for searching, and would therefore seem more recommendable. Experiments have shown, however, that the gain in speed is marginal. The reason is that the lists are typically quite short. The superiority of a tree structure becomes manifest only when a large number of global objects is declared. We emphasize that when a tree structure is used for each scope, the linear lists must still be present, because the order of declarations is sometimes relevant in interpretation, e.g. in parameter lists.

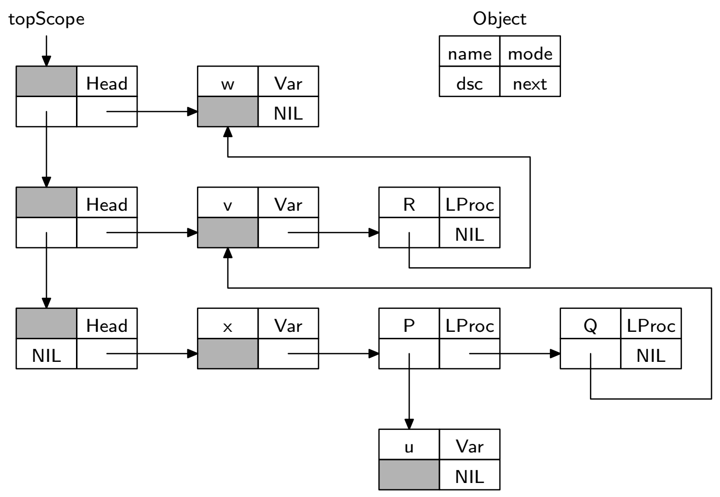

Fig. 12.7. Snapshot of a symbol table

Not only procedures, but also record types establish their own local scope. The list of record fields is anchored in the type record's field *link*, and it is searched by procedure *FindField*. If a record type *R1* is an extension of *R0*, then *R1*'s field list contains only the fields of the extension proper. The base type *R0* is referenced by the *BaseTyp* field of *R1*. Hence, a search for a field may have to proceed through the field lists of an entire sequence of record base types.

The major part of module OCT is devoted to input and output of symbol files. A symbol file is a linearized form of an excerpt of the symbol table containing descriptions of all exported (marked) objects. All exports are declared in the global scope. Procedure *Export* traverses the list of global objects and transfers them into the symbol file.

The major problem is to find an appropriate representation of pointers which must be converted to a form which is free of absolute addresses. The only pointers of relevance here are those referring to types, i.e. records of type *Struct*. The solution lies in assigning a unique reference number to each occurring type. Since efficiency of importing has priority over efficiency of exporting, these reference numbers should never constitute forward references, i.e. the definition of a reference must precede its occurence in the file. This consideration determines the method employed when exporting an object's type.

A type's reference number is recorded in the field *ref*. Its initial value 0 signals that the type has not yet been exported. When an identifier is to be exported and its type's reference is 0, the export of the type (*Struct*) precedes that of the identifier (*Object*), which therefore always refers to its type by a backward reference (see procedures *OutObjs* and *OutStr*). The first byte of every object's description in the file indicates its mode, and the first byte of every type's description indicates its form. The second byte is in both cases the type's reference number. Mode and form numbers are disjoint, thereby allowing an efficient identification of the next element in the file.

The structure of a symbol file is defined by the following syntax. Terminal symbols take one byte, unless specified otherwise by ": len". The following terminal symbols are mode and form specifiers or reference numbers for basic types with fixed values:

Con =1, Typ = 2, Var = 4, XProc = 5, CProc = 7, Pointer = 8, ProcTyp = 9, Array = 10, DynArr = 11, Record = 12, ParList = 13, ValPar = 14, VarPar = 15, FldList = 16, Fld = 17, HPtr = 18, Fixup = 19, Mod = 22. Byte = 1, Bool = 2, Char = 3, SInt = 4, Int = 5, LInt = 6, Real =7, LReal = 8, Set = 9, String = 10, Nil = 11, NoTyp = 12.

```
SymbolFile =        SymTag modAnchor {element}.
modAnchor =         Mod key:4 name.

element =       Con constant
              | Typ ref modno name
```

```
            | (Var | Fld) ref offset:2 name
            | (ValPar | VarPar) ref offset:4 name
            | ParList {element} (XProc ref pno | CProc ref len code) name
            | Pointer ref mno
            | ParList {element} ProcTyp ref mno
            | Array ref mno size:4 bndadr:2 nofel:4
            | DynArr ref mno size:4 lenoff:2
            | FldList {element} Record ref mno size:4 dscadr:2
            | HPtr offset:4
            | Fixup ref ref
            | modAnchor.

constant =  (Byte | Bool | Char | SInt) val name
            | Int val:2 name
            | (LInt | Real | Set) val:4 name
            | LReal val:8 name
            | String name name
            | Nil name.

name =      {char} 0X.
```

A procedure description with mode specifier *XProc* (or *CProc*) and a procedural type description with form specifier *ProcTyp* are preceded by a parameter list. The list is headed by the specifier *ParList*. Similarly, a record type description with form specifier *Record* is preceded by the list of field descriptions. This list is headed by the specifier *FldList*.

The specifier *HPtr* (in a field list) denotes a field with a pointer type. The field name itself is not exported; it is hidden. The reason for its occurrence in the symbol file is the following: If an extension of this record type is declared, a corresponding type descriptor is constructed. This descriptor must contain the offsets of all pointer fields for use by the garbage collector. Pointers inherited from the base type must not be missing.

The specifier *Fixup* mirrors a forward reference in a pointer type declaration. When reading a symbol file, it triggers a fixup of the base type in the respective pointer type (see procedure *Import*).

Objects exported from some module *M0* may refer in their declaration to some other module *M1* imported by *M0*. It would be unacceptable, if the import of *M0* would then also require the import of *M1*, i.e. imply the automatic reading of *M1*'s symbol file. It would trigger a chain reaction of imports that must be avoided. Fortunately, such a chain reaction can be avoided by making symbol files self-contained, i.e. by including in every symbol file the description of entities that stem from other modules. Such entities are always types.

The inclusion of types imported from other modules seems simple enough to handle: type descriptions must include a reference to the module from which the type was imported. This reference is a module number (*mno*); the name and key of the respective module is given by its anchor which, when read, causes a new entry in the array *LocMod* of imported modules (see procedure *Import*). However, there exists one additional complication that cannot be ignored. Consider a module *M0* importing a variable *x* from a module *M1*. Let the type *T* of *x* be defined in module *M2*. Also, assume *M0* to contain a variable y of type *M2.T*. Evidently, *x* and *y* are of the same type, and the compiler must recognize this fact. Hence, when importing *M1* during compilation of *M0*, the imported element *T* must not only be registered in the symbol table, but it must also be recognized as being identical to the *T* already imported from *M2* directly. It is rather fortunate that the language definition specifies equivalence of types on the basis of names rather than structure, because it allows type tests at execution time to be implemented by a simple address comparison.

The measures to be taken to satisfy the new requirements are as follows:

1. Every type element in a symbol file is given a module number referring to a module anchor. Before a type description is emitted to the file, its module anchor is emitted, unless this had been done previously on another occasion.

2. If a type to be exported has a name and stems from another, imported module, then also an element with specifier *Typ* is emitted. The name is obtained from the respective *Object* in the symbol table accessed via the type descriptor's *strobj* field. (This is the only reason for the presence of this field. Anonymous types are characterized by *strobj = NIL*).

3. When importing a module, it must be checked whether or not the module is already present, either in full or in part. And when a type is imported, its presence must also be checked. If it already exists, the new structure entry is made to refer to the already existing type entry (*struct[s] := ob0.next.typ*, see procedure *Import*).

There is yet another hurdle to be overcome. Types may be given several names; consider a (exported) type *T1* to be declared as *T1 = T0*. In this case, a type element named *T1* must be emitted referring by its reference number to the structural element associated with *T0* and emitted before (see procedure *OutObjs*). The following sample program may help the reader to understand the structure of symbol files and the way they are generated. It is followed by a listing of the corresponding symbol file in a decoded form.

```
MODULE Sample;
  CONST N* = 100;
  TYPE Ptr0* = POINTER TO Rec0;
    Rec0* = RECORD x, y: INTEGER END ;
    Rec1* = RECORD (Rec0) z: LONGINT END ;
    Ptr1* = Ptr0;
  VAR a*: ARRAY N OF Rec0;
  PROCEDURE P*(x: REAL; p: Ptr1): INTEGER;
  BEGIN END P;
END Sample.
```

```
Mod      key =  6E08D9E9         name = Sample
Con      ref = 4     val = 100   name = N
Pointer  ref = 16    base ref = 0   mno = 0
Typ      ref = 16    mno = 0        name = Ptr0

Record   ref = 17    base ref = 12  mno = 0    size = 4    adr = 0
Typ      ref = 17    mno = 0        name = Rec0

Record   ref = 18    base ref = 17  mno = 0    size = 8    adr = 4
Typ      ref = 18    mno = 0        name = Rec1
Typ      ref = 16    mno = 0        name = Ptr1
Array    ref = 19    elem ref = 17  mno = 0    size = 400  adr = 8    nofel = 100
Var      ref = 19    adr = -400     name = a

ValPar   ref = 7     adr = 16       name = x
ValPar   ref = 16    adr = 12       name = p
XProc    ref = 5     pno = 1        name = P
Fixup    ref = 16    ref = 17
```

After a symbol file has been generated, it is compared with the file from a previous compilation of the same module, if one exists. Only if the two files differ and if the compiler's s-option is enabled, is the old file replaced by the new version. The comparison is made by comparing byte after byte without consideration of the file's structure. This somewhat crude approach was chosen because of its simplicity and yielded good results in practice.

```
MODULE OCT;  (*NW 28.5.87 / 5.3.91*)
  IMPORT Files, OCS;

  CONST maxImps = 24; SFtag = 0FAX; firstStr = 16;
      maxStr = 80; maxUDP = 16; maxMod = 24; maxParLev = 6;
      PtrSize = 4; ProcSize = 4; NotYetExp = 0;
    (*object modes*)
      Var = 1; Ind = 3; Con = 8; Fld = 12; Typ = 13;
      XProc = 15; SProc = 16; CProc = 17; Mod = 19; Head = 20;
    (*structure forms*)
      Undef = 0; Byte = 1; Bool = 2; Char = 3; SInt = 4; Int = 5; LInt = 6;
      Real = 7; LReal = 8; Set = 9; String = 10; NilTyp = 11; NoTyp = 12;
      Pointer = 13; ProcTyp = 14; Array = 15; DynArr = 16; Record = 17;

TYPE
    Object* = POINTER TO ObjDesc;
    Struct* = POINTER TO StrDesc;

    ObjDesc* = RECORD
                    dsc*, next*: Object;
                    typ*:  Struct;
                    a0*, a1*:  LONGINT;
                    a2*: INTEGER;
                    mode*: SHORTINT;
                    marked*: BOOLEAN;
                    name*: ARRAY 32 OF CHAR;
            END ;

            StrDesc* = RECORD
                    form*, n*, mno*, ref*: INTEGER;
                    size*, adr*: LONGINT;
                    BaseTyp*: Struct;
                    link*, strobj*: Object
            END ;

            Item* =    RECORD
                    mode*, lev*: INTEGER;
                    a0*, a1*, a2*: LONGINT;
                    typ*: Struct;
                    obj*: Object
            END ;

  VAR topScope*: Object;
    undftyp*, bytetyp*, booltyp*, chartyp*, sinttyp*, inttyp*, linttyp*,
    realtyp*, lrltyp*, settyp*, stringtyp*, niltyp*, notyp*: Struct;
    nofGmod*: INTEGER;   (*nof imports*)
    GlbMod*:  ARRAY maxImps OF Object;

    universe, syslink: Object;
    strno, udpinx: INTEGER;  (*for export*)
    nofExp: SHORTINT;
    SR: Files.Rider;
    undPtr: ARRAY maxUDP OF Struct;

  PROCEDURE Init*;
  BEGIN topScope := universe; strno := 0; udpinx := 0; nofGmod := 0
  END Init;

  PROCEDURE Close*;
    VAR i: INTEGER;
  BEGIN Files.Set(SR, NIL, 0); i := 0;
    WHILE i < maxImps DO GlbMod[i] := NIL; INC(i) END
  END Close;

  PROCEDURE FindImport*(mod: Object; VAR res: Object);
    VAR obj: Object;
  BEGIN obj := mod.dsc;
    WHILE (obj # NIL) & (obj.name # OCS.name) DO obj := obj.next END ;
  IF (obj # NIL) & (obj.mode = Typ) & ~obj.marked THEN obj := NIL END ;
  res := obj
END FindImport;

PROCEDURE Find*(VAR res: Object; VAR level: INTEGER);
  VAR obj, head: Object;
BEGIN head := topScope;
  LOOP obj := head.next;
    WHILE (obj # NIL) & (obj.name # OCS.name) DO obj := obj.next END ;
    IF obj # NIL THEN level := SHORT(head.a0); EXIT END ;
    head := head.dsc;
    IF head = NIL THEN level := 0; EXIT END
  END ;
  res := obj
END Find;

PROCEDURE FindField*(typ: Struct; VAR res: Object);
  VAR obj: Object;
BEGIN (*typ.form = Record*)
  LOOP obj := typ.link;
    WHILE (obj # NIL) & (obj.name # OCS.name) DO obj := obj.next END ;
    IF obj # NIL THEN EXIT END ;
    typ := typ.BaseTyp;
    IF typ = NIL THEN EXIT END
  END ;
  res := obj
END FindField;

PROCEDURE Insert*(VAR name: ARRAY OF CHAR; VAR res: Object);
  VAR obj, new: Object;
BEGIN obj := topScope;
  WHILE (obj.next # NIL) & (obj.next.name # name) DO obj := obj.next END ;
  IF obj.next = NIL THEN NEW(new);
    new.dsc := NIL; new.next := NIL; COPY(name, new.name); obj.next := new; res := new
  ELSE res := obj.next;
    IF obj.next.mode # Undef THEN OCS.Mark(1) END
  END
END Insert;

PROCEDURE OpenScope*(level: INTEGER);
  VAR head: Object;
BEGIN NEW(head);
  head.mode := Head; head.a0 := level; head.typ := NIL;
  head.dsc := topScope; head.next := NIL; topScope := head
END OpenScope;

PROCEDURE CloseScope*;
BEGIN topScope := topScope.dsc
END CloseScope;

(*---------------------- import ------------------------*)

PROCEDURE ReadInt(VAR i: INTEGER);
BEGIN Files.ReadBytes(SR, i, 2)
END ReadInt;

PROCEDURE ReadXInt(VAR k: LONGINT);
  VAR i: INTEGER;
BEGIN Files.ReadBytes(SR, i, 2); k := i
END ReadXInt;
```

```
PROCEDURE ReadLInt(VAR k: LONGINT);
BEGIN Files.ReadBytes(SR, k, 4)
END ReadLInt;

PROCEDURE ReadId(VAR id: ARRAY OF CHAR);
  VAR i: INTEGER; ch: CHAR;
BEGIN i := 0;
  REPEAT Files.Read(SR, ch); id[i] := ch; INC(i)
  UNTIL ch = 0X
END ReadId;

PROCEDURE Import*(VAR name, self, FileName: ARRAY OF CHAR);
  VAR i, j, m, s, class: INTEGER; k: LONGINT;
      nofLmod, strno, parlev, fldlev: INTEGER;
      obj, ob0: Object;
      typ: Struct;
      ch, ch1, ch2: CHAR;
      si: SHORTINT;
      xval: REAL; yval: LONGREAL;
      SymFile: Files.File;
      modname: ARRAY 32 OF CHAR;
      LocMod:  ARRAY maxMod OF Object;
      struct:  ARRAY maxStr OF Struct;
      lastpar, lastfld: ARRAY maxParLev OF Object;

  PROCEDURE reversedList(p: Object): Object;
    VAR q, r: Object;
  BEGIN q := NIL;
    WHILE p # NIL DO
      r := p.next; p.next := q; q := p; p := r
    END ;
    RETURN q
  END reversedList;

BEGIN nofLmod := 0; strno := firstStr;
  parlev := -1; fldlev := -1;
  IF FileName = "SYSTEM.Sym" THEN
    Insert(name, obj); obj.mode := Mod; obj.dsc := syslink;
    obj.a0 := 0; obj.typ := notyp
  ELSE SymFile := Files.Old(FileName);
    IF SymFile # NIL THEN
      Files.Set(SR, SymFile, 0); Files.Read(SR, ch);
      IF ch = SFtag THEN
        struct[Undef] := undftyp; struct[Byte] := bytetyp;
        struct[Bool] := booltyp;  struct[Char] := chartyp;
        struct[SInt] := sinttyp;  struct[Int] := inttyp;
        struct[LInt] := linttyp;  struct[Real] := realtyp;
        struct[LReal] := lrltyp;  struct[Set] := settyp;
        struct[String] := stringtyp; struct[NilTyp] := niltyp; struct[NoTyp] := notyp;
        LOOP (*read next item from symbol file*)
          Files.Read(SR, ch); class := ORD(ch);
          IF SR.eof THEN EXIT END ;
          CASE class OF
            0: OCS.Mark(151)
          | 1..7: (*object*) NEW(obj); m := 0;
            Files.Read(SR, ch); s := ORD(ch); obj.typ := struct[s];
            CASE class OF
              1: obj.mode := Con;
            CASE obj.typ.form OF
              2,4: Files.Read(SR, si); obj.a0 := si
            | 1,3: Files.Read(SR, ch); obj.a0 := ORD(ch)
            | 5: ReadXInt(obj.a0)
            | 6,7,9: ReadLInt(obj.a0)
            | 8: ReadLInt(obj.a0); ReadLInt(obj.a1)
            | 10: ReadId(obj.name); OCS.Mark(151)
            | 11: (*NIL*)
            END
        |2,3: obj.mode := Typ; Files.Read(SR, ch); m := ORD(ch);
            IF obj.typ.strobj = NIL THEN obj.typ.strobj := obj END;
            obj.marked := class = 2
        |4: obj.mode := Var; ReadLInt(obj.a0)
        |5,6,7: IF class # 7 THEN obj.mode := XProc; Files.Read(SR, ch)
            ELSE obj.mode := CProc;
              Files.Read(SR, ch); Files.Read(SR, ch); Files.Read(SR, ch)
            END ;
            obj.a0 := ORD(ch); obj.a1 := 0;  (*link adr*)
            obj.dsc := reversedList(lastpar[parlev]); DEC(parlev)
        END ;
        ReadId(obj.name); ob0 := LocMod[m];
        WHILE (ob0.next # NIL)&(ob0.next.name # obj.name) DO
          ob0 := ob0.next
        END ;
        IF ob0.next = NIL THEN ob0.next := obj; obj.next := NIL  (*insert object*)
        ELSIF obj.mode = Typ THEN struct[s] := ob0.next.typ
        END
      | 8..12: (*structure*)
        NEW(typ); typ.strobj := NIL; typ.ref := 0;
        Files.Read(SR, ch); typ.BaseTyp := struct[ORD(ch)];
        Files.Read(SR, ch); typ.mno := SHORT(LocMod[ORD(ch)].a0);
        CASE class OF
            8: typ.form := Pointer; typ.size := PtrSize; typ.n := 0
        |  9: typ.form := ProcTyp; typ.size := ProcSize;
                    typ.link := reversedList(lastpar[parlev]); DEC(parlev)
        | 10: typ.form := Array; ReadLInt(typ.size);
                    ReadXInt(typ.adr); ReadLInt(k); typ.n := SHORT(k)
        | 11: typ.form := DynArr; ReadLInt(typ.size); ReadXInt(typ.adr)
        | 12: typ.form := Record; ReadLInt(typ.size); typ.n := 0;
                    typ.link := reversedList(lastfld[fldlev]); DEC(fldlev);
                    IF typ.BaseTyp = notyp THEN typ.BaseTyp := NIL; typ.n := 0
                    ELSE typ.n := typ.BaseTyp.n + 1
                    END ;
                    ReadXInt(typ.adr) (*of descriptor*)
        END ;
        struct[strno] := typ; INC(strno)
      | 13: (*parameter list start*)
        IF parlev < maxParLev-1 THEN INC(parlev); lastpar[parlev] := NIL
        ELSE OCS.Mark(229)
        END
      | 14, 15: (*parameter*)
        NEW(obj);
        IF class = 14 THEN obj.mode := Var ELSE obj.mode := Ind END ;
        Files.Read(SR, ch); obj.typ := struct[ORD(ch)];
        ReadXInt(obj.a0); ReadId(obj.name);
        obj.dsc := NIL; obj.next := lastpar[parlev]; lastpar[parlev] := obj
```

```
            | 16: (*start field list*)
              IF fldlev < maxParLev-1 THEN INC(fldlev); lastfld[fldlev] := NIL
              ELSE OCS.Mark(229)
              END
            | 17: (*field*)
              NEW(obj); obj.mode := Fld; Files.Read(SR, ch);
              obj.typ := struct[ORD(ch)]; ReadLInt(obj.a0);
              ReadId(obj.name); obj.marked := TRUE;
              obj.dsc := NIL; obj.next := lastfld[fldlev]; lastfld[fldlev] := obj
            | 18: (*hidden pointer field*)
              NEW(obj); obj.mode := Fld; ReadLInt(obj.a0);
              obj.name := ""; obj.typ := notyp; obj.marked := FALSE;
              obj.dsc := NIL; obj.next := lastfld[fldlev]; lastfld[fldlev] := obj
            | 19: (*hidden procedure field*)
              ReadLInt(k)
            | 20: (*fixup pointer typ*)
              Files.Read(SR, ch); typ := struct[ORD(ch)];
              Files.Read(SR, ch1);
              IF typ.BaseTyp = undftyp THEN typ.BaseTyp := struct[ORD(ch1)] END
            | 21, 23, 24: OCS.Mark(151); EXIT
            | 22: (*module anchor*)
              ReadLInt(k); ReadId(modname);
              IF modname = self THEN OCS.Mark(49) END;
              i := 0;
              WHILE (i < nofGmod) & (modname # GlbMod[i].name) DO INC(i) END ;
              IF i < nofGmod THEN (*module already present*)
                IF k # GlbMod[i].a1 THEN OCS.Mark(150) END ;
                obj := GlbMod[i]
              ELSE NEW(obj);
                IF nofGmod < maxImps THEN GlbMod[nofGmod] := obj; INC(nofGmod)
                ELSE OCS.Mark(227)
                END ;
                obj.mode := NotYetExp; COPY(modname, obj.name);
                obj.a1 := k; obj.a0 := nofGmod; obj.next := NIL
              END ;
              IF nofLmod < maxMod THEN LocMod[nofLmod] := obj; INC(nofLmod)
              ELSE OCS.Mark(227)
              END
            END
          END (*LOOP*) ;
          Insert(name, obj);
          obj.mode := Mod; obj.dsc := LocMod[0].next;
          obj.a0  := LocMod[0].a0; obj.typ := notyp
        ELSE OCS.Mark(151)
        END
      ELSE OCS.Mark(152)   (*sym file not found*)
      END
    END
END Import;

(*---------------------- export ------------------------*)
PROCEDURE WriteByte(i: INTEGER);
BEGIN Files.Write(SR, CHR(i))
END WriteByte;
```

```
  PROCEDURE WriteInt(i: LONGINT);
  BEGIN Files.WriteBytes(SR, i, 2)
  END WriteInt;

PROCEDURE WriteLInt(k: LONGINT);
  BEGIN Files.WriteBytes(SR, k, 4)
  END WriteLInt;

  PROCEDURE WriteId(VAR name: ARRAY OF CHAR);
    VAR ch: CHAR; i: INTEGER;
  BEGIN i := 0;
    REPEAT ch := name[i]; Files.Write(SR, ch); INC(i)
    UNTIL ch = 0X
  END WriteId;

  PROCEDURE^ OutStr(typ: Struct);
  PROCEDURE OutPars(par: Object);
  BEGIN WriteByte(13);
    WHILE (par # NIL) & (par.mode <= Ind) & (par.a0 > 0) DO
      OutStr(par.typ);
      IF par.mode = Var THEN WriteByte(14) ELSE WriteByte(15) END ;
      WriteByte(par.typ.ref); WriteInt(par.a0); WriteId(par.name); par := par.next
    END
  END OutPars;

  PROCEDURE OutFlds(fld: Object; adr: LONGINT; visible: BOOLEAN);
  BEGIN
    IF visible THEN WriteByte(16) END ;
    WHILE fld # NIL DO
      IF fld.marked & visible THEN
        OutStr(fld.typ); WriteByte(17); WriteByte(fld.typ.ref);
        WriteLInt(fld.a0); WriteId(fld.name)
      ELSIF fld.typ.form = Record THEN OutFlds(fld.typ.link, fld.a0 + adr, FALSE)
      ELSIF (fld.typ.form = Pointer) OR (fld.name = "") THEN
        WriteByte(18); WriteLInt(fld.a0 + adr)
      END ;
      fld := fld.next
    END
  END OutFlds;

  PROCEDURE OutStr(typ: Struct);
    VAR m, em, r: INTEGER; btyp: Struct; mod: Object;
  BEGIN
    IF typ.ref = 0 THEN
      m := typ.mno; btyp := typ.BaseTyp;
      IF m > 0 THEN mod := GlbMod[m-1]; em := mod.mode;
        IF em = NotYetExp THEN
          GlbMod[m-1].mode := nofExp; m := nofExp; INC(nofExp);
          WriteByte(22); WriteLInt(mod.a1); WriteId(mod.name)
        ELSE m := em
        END
      END;
      CASE typ.form OF
        Undef .. NoTyp:
      | Pointer: WriteByte(8);
        IF btyp.ref > 0 THEN WriteByte(btyp.ref)
        ELSE WriteByte(Undef);
          IF udpinx < maxUDP THEN undPtr[udpinx] := typ; INC(udpinx)
```

```
            ELSE OCS.Mark(224)
            END
          END ;
          WriteByte(m)
        | ProcTyp: OutStr(btyp); OutPars(typ.link);
            WriteByte(9); WriteByte(btyp.ref); WriteByte(m)
        | Array: OutStr(btyp);
            WriteByte(10); WriteByte(btyp.ref); WriteByte(m);
            WriteLInt(typ.size); WriteInt(typ.adr); WriteLInt(typ.n)
        | DynArr: OutStr(btyp);
            WriteByte(11); WriteByte(btyp.ref); WriteByte(m);
            WriteLInt(typ.size); WriteInt(typ.adr)
        | Record:
            IF btyp = NIL THEN r := NoTyp
            ELSE OutStr(btyp); r := btyp.ref
            END ;
            OutFlds(typ.link, 0, TRUE); WriteByte(12); WriteByte(r); WriteByte(m);
            WriteLInt(typ.size); WriteInt(typ.adr)
        END ;
        IF typ.strobj # NIL THEN
          IF typ.strobj.marked THEN WriteByte(2) ELSE WriteByte(3) END;
          WriteByte(strno); WriteByte(m); WriteId(typ.strobj.name)
        END ;
        typ.ref := strno; INC(strno);
        IF strno > maxStr THEN OCS.Mark(228) END
      END
    END OutStr;

    PROCEDURE OutObjs;
      VAR obj: Object;
        f: INTEGER; xval: REAL; yval: LONGREAL;
    BEGIN obj := topScope.next;
      WHILE obj # NIL DO
        IF obj.marked THEN
          IF obj.mode = Con THEN
            WriteByte(1); f := obj.typ.form; WriteByte(f);
             CASE f OF
               Undef:
             | Byte, Bool, Char, SInt: WriteByte(SHORT(obj.a0))
             | Int: WriteInt(SHORT(obj.a0))
             | LInt, Real, Set: WriteLInt(obj.a0)
             | LReal:  WriteLInt(obj.a0); WriteLInt(obj.a1)
             | String: WriteByte(0); OCS.Mark(221)
             | NilTyp:
             END;
            WriteId(obj.name)
          ELSIF obj.mode = Typ THEN
            OutStr(obj.typ);
            IF (obj.typ.strobj # obj) & (obj.typ.strobj # NIL) THEN
              WriteByte(2); WriteByte(obj.typ.ref); WriteByte(0); WriteId(obj.name)
            END
          ELSIF obj.mode = Var THEN
            OutStr(obj.typ); WriteByte(4);
            WriteByte(obj.typ.ref); WriteLInt(obj.a0); WriteId(obj.name)
          ELSIF obj.mode = XProc THEN
            OutStr(obj.typ); OutPars(obj.dsc); WriteByte(5);
        WriteByte(obj.typ.ref); WriteByte(SHORT(obj.a0)); WriteId(obj.name)
      ELSIF obj.mode = CProc THEN
        OutStr(obj.typ); OutPars(obj.dsc); WriteByte(7);
        WriteByte(obj.typ.ref); WriteByte(2); WriteByte(226);
        WriteByte(SHORT(obj.a0)); WriteId(obj.name)
      END
    END ;
    obj := obj.next
  END
END OutObjs;

PROCEDURE Export*(VAR name, FileName: ARRAY OF CHAR;
    VAR newSF: BOOLEAN; VAR key: LONGINT);
  VAR i: INTEGER;
    ch0, ch1: CHAR;
    oldkey: LONGINT;
    typ: Struct;
    oldFile, newFile: Files.File;
    oldSR: Files.Rider;
BEGIN newFile := Files.New(FileName);
  IF newFile # NIL THEN
    Files.Set(SR, newFile, 0); Files.Write(SR, SFtag); strno := firstStr;
    WriteByte(22); WriteLInt(key); WriteId(name); nofExp := 1;
    OutObjs; i := 0;
    WHILE i < udpinx DO
      typ := undPtr[i]; OutStr(typ.BaseTyp); undPtr[i] := NIL; INC(i);
      WriteByte(20); (*fixup*)
      WriteByte(typ.ref); WriteByte(typ.BaseTyp.ref)
    END ;
    IF ~OCS.scanerr THEN
      oldFile := Files.Old(FileName);
      IF oldFile # NIL THEN (*compare*)
        Files.Set(oldSR, oldFile, 2); Files.ReadBytes(oldSR, oldkey, 4);
        Files.Set(SR, newFile, 6);
        REPEAT Files.Read(oldSR, ch0); Files.Read(SR, ch1)
        UNTIL (ch0 # ch1) OR SR.eof;
        IF oldSR.eof & SR.eof THEN (*equal*) newSF := FALSE;  key := oldkey
        ELSIF newSF THEN Files.Register(newFile)
        ELSE OCS.Mark(155)
        END
      ELSE Files.Register(newFile); newSF := TRUE
      END
    ELSE newSF := FALSE
    END
  ELSE OCS.Mark(153)
  END
END Export;

(*------------------------ initialization ------------------------*)
PROCEDURE InitStruct(VAR typ: Struct; f: INTEGER);
BEGIN NEW(typ); typ.form := f; typ.ref := f; typ.size := 1
END InitStruct;

PROCEDURE EnterConst(name: ARRAY OF CHAR; value: INTEGER);
  VAR obj: Object;
BEGIN Insert(name, obj); obj.mode := Con; obj.typ := booltyp; obj.a0 := value
END EnterConst;
```

```
    PROCEDURE EnterTyp(name: ARRAY OF CHAR; form,
          size: INTEGER; VAR res: Struct);
      VAR obj: Object; typ: Struct;
    BEGIN Insert(name, obj);
      NEW(typ); obj.mode := Typ; obj.typ := typ; obj.marked := TRUE;
      typ.form := form; typ.strobj := obj; typ.size := size;
      typ.mno := 0; typ.ref := form; res := typ
    END EnterTyp;

    PROCEDURE EnterProc(name: ARRAY OF CHAR; num: INTEGER);
      VAR obj: Object;
    BEGIN Insert(name, obj); obj.mode := SProc; obj.typ := notyp; obj.a0 := num
    END EnterProc;

  BEGIN topScope := NIL; InitStruct(undftyp, Undef); InitStruct(notyp, NoTyp);
    InitStruct(stringtyp, String); InitStruct(niltyp, NilTyp); OpenScope(0);
    (*initialization of module SYSTEM*)
    EnterProc("LSH", 22); EnterProc("ROT", 23); EnterProc("ADR",  9);EnterProc("OVFL",15);
    EnterProc("GET", 24); EnterProc("PUT", 25); EnterProc("BIT", 26); EnterProc("VAL", 27);
    EnterProc("NEW", 28); EnterProc("MOVE",30); EnterProc("CC",  2);
    EnterTyp("BYTE", Byte, 1, bytetyp);
    syslink := topScope.next; universe := topScope; topScope.next := NIL;

    EnterTyp("CHAR", Char, 1, chartyp); EnterTyp("SET", Set, 4, settyp);
    EnterTyp("REAL", Real, 4, realtyp); EnterTyp("INTEGER", Int, 2, inttyp);
    EnterTyp("LONGINT",  LInt, 4, linttyp); EnterTyp("LONGREAL", LReal, 8, lrltyp);
    EnterTyp("SHORTINT", SInt, 1, sinttyp); EnterTyp("BOOLEAN", Bool, 1, booltyp);
    EnterProc("INC",   16); EnterProc("DEC",   17); EnterConst("FALSE", 0);
    EnterConst("TRUE",  1); EnterProc("HALT",   0); EnterProc("NEW",    1);
    EnterProc("ABS",    3); EnterProc("CAP",    4); EnterProc("ORD",    5);
    EnterProc("ENTIER", 6); EnterProc("SIZE",   7); EnterProc("ODD",    8);
    EnterProc("MIN",   10); EnterProc("MAX",   11); EnterProc("CHR",   12);
    EnterProc("SHORT", 13); EnterProc("LONG",  14); EnterProc("INCL",  18);
    EnterProc("EXCL",  19); EnterProc("LEN",   20); EnterProc("ASH",   21);
  EnterProc("COPY",  29)
  END OCT.
```

12.7. Code Selection

The procedures which determine the selection of instructions corresponding to the various syntactic constructs are contained in modules OCE and OCH. They reflect the two-address nature of the target computer's architecture. If, for example, a simple expression consisting of two terms and an add operator is recognized, procedure Op is invoked, the first parameter specifying addition, and the other two denoting the operands. The sum, representing the simple expression, is assigned to and thereby replaces the first argument (x := x+y), mirroring the computer's two-address instruction (ADDW y, x).

By code selection we understand the determination of operation codes, of operand length codes, and of addressing modes. The actual code generation is delegated to module OCC. For example, the instruction ADDW y, x is selected in procedure OCE.Op which calls the generating procedure OCC.PutF4(0+1, x, y), where 0 is the opcode for ADDi, 1 is the length code for integers, and x and y are parameters of type Item describing the operands. Op would, e.g., select another instruction, if y denoted a small constant, say 3, instead of a variable; its selection would be ADDQW 3, x. Actual generation is then achieved by calling OCC.PutF2(12+1, y.a0, x), where 12 is the opcode of ADDQi and y.a0 has the value 3.

Let us dwell somewhat longer on the above example. As explained before, during the evaluation of an expression no declared variable may change its value. Therefore, the sum cannot be stored in the location of variable x. In order to prevent this from happening, the destination operand is chosen to be a temporary, auxiliary variable allocated in a register. Because the first argument and the result are the same in a two-address instruction, the argument must be transferred into the register before addition. Hence, the resulting code sequence is

```
    MOVW    x, r
    ADDW    y, r
```

where r stands for the mentioned register. Register allocation is done by procedure OCC.GetReg, which selects a free register and returns an Item with mode = Reg, which is one of the intermediate modes generated only during evaluation of expressions.

If the operands of an expression are integer constants, the specified operation is performed by the compiler, the result is represented by the result-item, and no instructions are generated. This feature concerns all arithmetic operations in procedure Op and sign inversion in procedure MOp.

Note: Overflow tests are not included in the program listing, but merely indicated by a comment. They can be programmed in a computer-independent form as shown here for addition:

```
    IF x < 0 THEN
        IF (y < 0) & (x < min-y) THEN overflow ELSE sum := x+y END
    ELSE
        IF (y > 0) & (x > max-y) THEN overflow ELSE sum := x+y END
    END
```

Direct evaluation of expressions is also performed for negation of Boolean operands and for set union. The latter is implicitly invoked in the construction of sets. For instance, the constant set {0, 2} is computed as {0}+{2}. Constant expressions are not evaluated for real values. One reason is that this rare and avoidable case hardly justifies the additional complexity of the compiler, the other that overflow traps for floating-point operations cannot be suppressed.

The principal code selection procedures for expressions are listed below together with an abstract notation for their action.

Index(x, y)	x := x[y]
Field(x, y)	x := x.y
DeRef(x)	x := x^
TypTest(x, y, TRUE)	x := x IS y
TypTest(x, y, FALSE)	x := x(y)
In(x, y)	x := x IN y
Set0(x, y)	x := {y}
Set1(x, y, z)	x := {y .. z}
MOp(op, x)	x := op y
Op(op, x, y)	x := x op y

Some of these procedures generate items with intermediate modes other than the Reg-mode mentioned above. Before we explain the various mode transitions which items may undergo, we list the additional item modes, indicating how the resulting operand address is specified by the item-record's attributes a0, a1, and a2.

mode	resulting address	addressing mode
Var	a0	direct mode
VarX	a0 + s*Reg[a2]	indexed mode
Ind	Mem[a0] + a1	indirect mode
IndX	Mem[a0] + a1 + s*Reg[a2]	indexed indirect mode
RegI	Reg[a0] + a1	register indirect mode
RegX	Reg[a0] + a1 + s*Reg[a2]	indexed register indirect mode

s denotes a scale factor selected according to the type of operands (s = 1, 2, 4, or 8).

It is the goal of a good compiler to make use of all addressing modes offered by the computer, thereby avoiding the emission of unnecessary instructions for address computation. This requires that applicability of complex addressing modes is detected, and that instructions for address computations are not emitted before it is established that the situation cannot be handled with one of the available addressing modes. Procedures *Index, Field*, and *DeRef* contain the necessary case analyses. The mode transitions performed are listed below.

1. Index(x, y), *x* is static array

mode transition of *x*	instruction emitted	construct
Var → VarX		array variable
Ind → IndX		array, VAR-parameter
RegI → RegX		dereferenced array
VarX → VarX	INDEX	indexed array (matrix)
IndX → IndX	INDEX	indexed matrix parameter
RegX → RegX	INDEX	dereferenced array (matrix)

Procedure *Index* also emits an index bound check (CHECKW, FLAG), if the compiler's index checking option is enabled. If the index *y* denotes a constant, the indexed variable's address is computed and no mode transition takes place.

Dynamic array parameters are treated similarly. Indirect addressing via descriptor is necessary even if the array is called by value. Bound checks cannot be performed by the compiler, even if the index is a constant.

2. Index(x, y), *x* is dynamic array

mode transition of *x*	instruction emitted	construct
Var → IndX		dynamic array
Ind → IndX		dynamic array, VAR-parameter
RegI → RegX		dereferenced array
IndX → IndX	INDEX	indexed matrix VAR-parameter
RegX → RegX	INDEX	dereferenced array (matrix)

3. Field(x, y)

mode transition of x	instruction emitted	construct
Var → Var		add field offset to record adr
Ind → Ind		add field offset to record adr
RegI → RegI		increment field offset
others → RegI	ADDR	offset becomes field offset

4. DeRef(x)

mode transition of x	instruction emitted	construct
Var -> Ind		reference via pointer
others -> RegI	ADDR	offset := 0

The *DeRef* procedure is called from *Compiler.selector*. The call may be due to an explicit dereferencing operator (^), or it may be due to a field designator p.f or an array designator *p[i]*, if *p* denotes a pointer. Note that the transition *Var → Ind* is inapplicable in the case of external access, because the processor lacks an indirect external addressing mode.

Boolean expressions, and in particular comparisons, give rise to yet another intermediate item mode: the condition code mode *Coc*. This mode signifies that the operand's value is held in the condition code register in encoded form. Consider, for example, the expression *x* < *y*, which is translated into the single instruction *CMPi y, x*. The resulting Boolean item assumes the Coc-mode, and its attribute *a0* indicates that the value FALSE is obtained by an *Scond* (or *Bcond*) instruction with *a0* as its condition mask. The *a0* attribute depends on the relation (<) specified.

The cases of Boolean conjunction and disjunction are more intricate. As mentioned before, these operations must be represented by conditional jumps rather than explicit AND and OR instructions. For example, the expression

```
(x <= y) & (y < z)
```

yields the instruction sequence

```
    CMPi   y, x
L   BLT    ?
    CMPi   z, y
```

and the result item with Coc-mode and *a0* reflecting the relation < . In addition to the attribute *a0*, the attribute *a1* identifies the location *L* of the BLT instruction, which performs a branch, if *y < x*, i.e. *~(x <= y)*. The first two instructions are emitted by procedure *MOp* called from *Compiler.Term*, the last one by *Op* (also called from *Term*).

Similarly, the expression

```
(x = 1) OR (y = 3)
```

yields the instruction sequence

```
    CMPQi  1, x
L   BEQ    ?
    CMPQi  3, y
```

and the result item with Coc-mode and *a0* reflecting the relation = . The branch location *L* is specified by attribute *a2* (instead of *a1*), because the branch is taken when the first comparison yields TRUE (instead of FALSE).

The more general cases of expressions *p & q & ... & z* and *p OR q OR ... OR z* yield sets of conditional branches that are to be taken, if the expression value is FALSE or TRUE respectively. The locations of these branches are recorded in a list, the so-called *F-list* or *T-list* respectively; its head is recorded by the attribute *a1* (or *a2*), and the links are embedded in the code in place of the branch addresses, which will be inserted when the jump destinations are known.

The most general case requires the presence of both the F-list and the T-list simultaneously. It is exemplified by the following expression:

```
(a < b) & (c < d) OR (e < f) & (g < h)
```

which is represented by the instructions

```
    CMPi   b, a
    BLE    L1
    CMPi   d, c
L0  BGT    ?
L1  CMPi   f, e
L2  BLE    ?
    CMPi   h, g
```

The F-list of the resulting item contains the single element *L2*, and the T-list the single element *L0*. For more details, the reader is referred to the listing of module OCE below; the construction of the lists and the substitution of links by the branch offsets is handled by procedures in module OCC. In passing we note that Boolean expressions also occur in if, while, and repeat statements, where the branch targets are known only after the entire statement has been processed.

A fairly sizeable amount of program is devoted to the seemingly harmless concept of type inclusion. It is a relaxation of the strict requirement of type equality of operands in an expression. Because, however, the computer's instructions strictly require that both operands be of the same type, they have to be preceded by conversion instructions in cases of "mixed expressions". We refrain from going into details and merely mention that implicit conversions of integers are handled by *MOVXij* instructions implying sign extension, and those involving floating-point operands by *MOVif* and *MOVFL* instructions.

An even much larger part of module OCE is devoted to standard procedures and functions. Calls of them do not generate subroutine instructions, but rather in-line code. Therefore, each standard procedure represents an individual case, and they have little in common. Some procedures, namely *SIZE*, *ADR*, *MIN*, *MAX*, *CHR*, *SHORT*, *LEN*, *CC*, and *VAL* may not even generate any instructions. The three procedures *StPar1*, *StPar2*, and *StPar3* are each devoted to the handling of one parameter. Typically, instructions are emitted after the last parameter is recognized.

```
MODULE OCE;  (*NW 7.6.87 / 5.3.91*)
  IMPORT SYSTEM, OCS, OCT, OCC;

  CONST  (*instruction format prefixes*)
      F6 = 4EH; F7 = 0CEH; F9 = 3EH; F11 = 0BEH;
    (*frequent operation codes:   5C, 5D, 5F = MOVQi, 14, 15, 17 = MOVi, 27 = ADDR*)

    (*object and item modes*)
      Var   =  1; VarX  =  2; Ind   =  3; IndX  =  4; RegI  =  5;
      RegX  =  6; Abs   =  7; Con   =  8; Stk   =  9; Coc   = 10;
      Reg   = 11; Fld   = 12; Typ   = 13;

    (*structure forms*)
      Undef = 0; Byte = 1; Bool = 2; Char = 3; SInt = 4; Int = 5; LInt = 6;
      Real = 7; LReal = 8; Set = 9; String = 10; NilTyp = 11; NoTyp = 12;
      Pointer = 13; ProcTyp = 14; Array = 15; DynArr = 16; Record = 17;

  VAR inxchk*: BOOLEAN;
      log: INTEGER;   (*side effect of mant*)
      lengcode: ARRAY 18 OF INTEGER;
      intSet, realSet: SET;

  PROCEDURE inverted(x: LONGINT): LONGINT;
  BEGIN (*inverted sense of condition code*)
    IF ODD(x) THEN RETURN x-1 ELSE RETURN x+1 END
  END inverted;

  PROCEDURE load(VAR x: OCT.Item);
    VAR y: OCT.Item;
  BEGIN
    IF x.mode < Reg THEN
      y := x; OCC.GetReg(x);
      IF (y.mode = Con) & (-8 <= y.a0) & (y.a0 <= 7) THEN
        OCC.PutF2(lengcode[x.typ.form] + 5CH, y.a0, x)
      ELSE OCC.PutF4(lengcode[x.typ.form] + 14H, x, y)
      END
    ELSIF x.mode > Reg THEN OCS.Mark(126)
    END
  END load;

  PROCEDURE loadX(VAR x: OCT.Item);
    VAR y: OCT.Item;
  BEGIN
    IF x.mode <= Reg THEN
      y := x; OCC.GetReg(x);
      IF (y.mode = Con) & (-8 <= y.a0) & (y.a0 <= 7) THEN
        OCC.PutF2(5FH, y.a0, x)
      ELSE OCC.Put(F7, lengcode[x.typ.form] + 1CH, x, y)  (*MOVXiD*)
      END
    ELSIF x.mode > Reg THEN OCS.Mark(126)
    END
  END loadX;

  PROCEDURE loadF(VAR x: OCT.Item);
    VAR y: OCT.Item;
  BEGIN
    IF x.mode < Reg THEN
      y := x; OCC.GetFReg(x); OCC.Put(F11, lengcode[x.typ.form] + 4, x, y)  (*MOVf*)
    ELSIF x.mode > Reg THEN OCS.Mark(126)
    END
  END loadF;

  PROCEDURE loadB(VAR x: OCT.Item);  (*Coc-Mode*)
    VAR L0, L1: LONGINT;
  BEGIN
    IF (x.a1 = 0) & (x.a2 = 0) THEN
      L0 := x.a0; OCC.GetReg(x); OCC.PutF2(3CH, L0, x)
    ELSE OCC.PutF0(inverted(x.a0)); OCC.PutWord(x.a2); L0 := OCC.pc - 2;
      OCC.FixLink(x.a1); OCC.GetReg(x); OCC.PutF2(5CH, 1, x);
      OCC.PutF0(14); L1 := OCC.pc; OCC.PutWord(0);
      OCC.FixLink(L0); OCC.PutF2(5CH, 0, x); OCC.fixup(L1)
    END
  END loadB;

  PROCEDURE loadAdr(VAR x: OCT.Item);
    VAR y: OCT.Item;
  BEGIN
    IF x.mode < Con THEN
      y := x; OCC.GetReg(x);
      IF (y.mode = Ind) & (y.a1 = 0) THEN y.mode := Var; OCC.PutF4(17H, x, y)
      ELSE OCC.PutF4(27H, x, y); x.a1 := 0
      END ;
      x.mode := RegI; x.obj := NIL
    ELSE OCS.Mark(127)
    END
  END loadAdr;

  PROCEDURE setCC(VAR x: OCT.Item; cc: LONGINT);
  BEGIN
    x.typ := OCT.booltyp; x.mode := Coc; x.a0 := cc; x.a1 := 0; x.a2 := 0
  END setCC;

  PROCEDURE cmp(L: INTEGER; VAR x, y: OCT.Item);
  BEGIN
    IF (y.mode = Con) & (y.a0 <= 7) & (y.a0 >= -8) THEN
      OCC.PutF2(L+1CH, y.a0, x)  (*CMPQi*)
    ELSE OCC.PutF4(L+4, x, y)   (*CMPi*)
    END
  END cmp;

  PROCEDURE add(L: INTEGER; VAR x, y: OCT.Item);
  BEGIN
    IF (y.mode = Con) & (y.a0 <= 7) & (y.a0 >= -8) THEN
      OCC.PutF2(L+0CH, y.a0, x)   (*ADDQi*)
    ELSE OCC.PutF4(L, x, y)   (*ADDi*)
    END
  END add;
```

```
PROCEDURE sub(L: INTEGER; VAR x, y: OCT.Item);
BEGIN
  IF (y.mode = Con) & (y.a0 <= 8) & (y.a0 >= -7) THEN
    OCC.PutF2(L+0CH, -y.a0, x)   (*ADDQi*)
  ELSE OCC.PutF4(L+20H, x, y)   (*SUBi*)
  END
END sub;

PROCEDURE mant(x: LONGINT): LONGINT;  (*x DIV 2^log*)
BEGIN log := 0;
  IF x > 0 THEN
    WHILE ~ODD(x) DO x := x DIV 2; INC(log) END
  END ;
  RETURN x
END mant;

PROCEDURE SetIntType*(VAR x: OCT.Item);
  VAR v: LONGINT;
BEGIN v := x.a0;
  IF (-80H <= v) & (v <= 7FH) THEN x.typ := OCT.sinttyp
  ELSIF (-8000H <= v) & (v <= 7FFFH) THEN x.typ := OCT.inttyp
  ELSE x.typ := OCT.linttyp
  END
END SetIntType;

PROCEDURE AssReal*(VAR x: OCT.Item; y: REAL);
BEGIN SYSTEM.PUT(SYSTEM.ADR(x.a0), y)
END AssReal;

PROCEDURE AssLReal*(VAR x: OCT.Item; y: LONGREAL);
BEGIN SYSTEM.PUT(SYSTEM.ADR(x.a0), y)
END AssLReal;

PROCEDURE Index*(VAR x, y: OCT.Item);
  VAR  f, n: INTEGER; i: LONGINT;
    eltyp: OCT.Struct; y1, z: OCT.Item;
BEGIN f := y.typ.form;
  IF ~(f IN intSet) THEN OCS.Mark(80); y.typ := OCT.inttyp END ;
  IF x.typ = NIL THEN HALT(80) END ;
  IF x.typ.form = Array THEN
    eltyp := x.typ.BaseTyp; n := x.typ.n;
    IF eltyp = NIL THEN HALT(81) END ;
    IF y.mode = Con THEN
      IF (0 <= y.a0) & (y.a0 < n) THEN i := y.a0 * eltyp.size
      ELSE OCS.Mark(81); i := 0
      END ;
      IF x.mode = Var THEN INC(x.a0, i)
      ELSIF (x.mode = Ind) OR (x.mode = RegI) THEN INC(x.a1, i); x.obj := NIL
      ELSE loadAdr(x); x.a1 := i
      END
    ELSE
      IF inxchk THEN  (*z = bound descr*)
        z.mode := Var; z.a0 := x.typ.adr; z.lev := -x.typ.mno;
        IF y.mode = Reg THEN y1 := y ELSE OCC.GetReg(y1) END ;
        IF f = SInt THEN OCC.Put(F7, 10H, y1, y); y := y1 END ;  (*MOVXBW*)
        OCC.Put(0EEH, SHORT(y1.a0)*8+1, y, z); OCC.PutF1(0D2H) (*CHECK, FLAG*)
      ELSE
        IF f = LInt THEN load(y) ELSE loadX(y) END ;
```

```
            y1 := y
          END ;
          f := x.mode;
          IF x.mode = Var THEN x.mode := VarX; x.a2 := y1.a0
          ELSIF x.mode = Ind THEN x.mode := IndX; x.a2 := y1.a0
          ELSIF x.mode = RegI THEN x.mode := RegX; x.a2 := y1.a0
          ELSIF x.mode IN {VarX, IndX, RegX} THEN
            z.mode := Con; z.typ := OCT.inttyp;
            z.a0 := (x.typ.size DIV eltyp.size) - 1;
            OCC.Put(2EH, SHORT(x.a2)*8+5, y1, z)  (*INDEX*)
          ELSE loadAdr(x); x.mode := RegX; x.a1 := 0; x.a2 := y1.a0
          END
        END ;
        x.typ := eltyp
      ELSIF x.typ.form = DynArr THEN
        IF inxchk THEN
          z.mode := Var; z.a0 := x.a0 + x.typ.adr; z.lev := x.lev;
          IF y.mode = Reg THEN y1 := y ELSE OCC.GetReg(y1) END ;
          IF f = SInt THEN
            IF y.mode = Con THEN y.typ := OCT.inttyp
            ELSE OCC.Put(F7, 10H, y1, y); y := y1
            END
          END ;
          OCC.Put(0EEH, SHORT(y1.a0)*8+1, y, z); OCC.PutF1(0D2H)  (*CHECK, FLAG*)
        ELSE
          IF f = LInt THEN load(y) ELSE loadX(y) END ;
          y1 := y
        END ;
        IF x.mode IN {Var, Ind} THEN x.mode := IndX; x.a2 := y1.a0
        ELSIF x.mode = RegI THEN x.mode := RegX; x.a2 := y1.a0
        ELSIF x.mode IN {IndX, RegX} THEN
          z.mode := Var; z.a0 := x.a0 + x.typ.adr; z.lev := x.lev;
          OCC.Put(2EH, SHORT(x.a2)*8+5, y1, z)  (*INDEX*)
        ELSE loadAdr(x); x.mode := RegX; x.a1 := 0; x.a2 := y1.a0
        END ;
        x.typ := x.typ.BaseTyp
      ELSE OCS.Mark(82)
      END
    END Index;

    PROCEDURE Field*(VAR x: OCT.Item; y: OCT.Object);
    BEGIN (*x.typ.form = Record*)
      IF (y # NIL) & (y.mode = Fld) THEN
        IF x.mode = Var THEN INC(x.a0, y.a0)
        ELSIF (x.mode = Ind) OR (x.mode = RegI) THEN INC(x.a1, y.a0)
        ELSE loadAdr(x); x.mode := RegI; x.a1 := y.a0
        END ;
        x.typ := y.typ; x.obj := NIL
      ELSE OCS.Mark(83); x.typ := OCT.undftyp; x.mode := Var
      END
    END Field;

    PROCEDURE DeRef*(VAR x: OCT.Item);
    BEGIN
      IF x.typ.form = Pointer THEN
        IF (x.mode = Var) & (x.lev >= 0) THEN x.mode := Ind
        ELSE load(x); x.mode := RegI
        END ;
        x.typ := x.typ.BaseTyp; x.obj := OCC.wasderef
      ELSE OCS.Mark(84)
      END ;
      x.a1 := 0
    END DeRef;

    PROCEDURE TypTest*(VAR x, y: OCT.Item; test: BOOLEAN);

      PROCEDURE GTT(t0, t1: OCT.Struct; varpar: BOOLEAN);
      VAR t: OCT.Struct; xt, tdes, p: OCT.Item;
      BEGIN
        IF t0 # t1 THEN t := t1;
          REPEAT t := t.BaseTyp UNTIL (t = NIL) OR (t = t0);
          IF t # NIL THEN x.typ := y.typ;
            IF OCC.typchk OR test THEN xt := x;
              IF varpar THEN xt.mode := Ind; xt.a0 := x.a0+4
              ELSIF (x.mode = Var) & (x.lev >= 0) THEN
                xt.mode := Ind; xt.a1 := -4; load(xt); xt.mode := RegI
              ELSE load(xt); p := xt; p.mode := RegI; p.a1 := -4;
                OCC.PutF4(17H, xt, p); (*MOVD -4(xt), xt *) xt.mode := RegI
              END ;
              xt.a1 := t1.n * 4; tdes.mode := Var; tdes.lev := -t1.mno; tdes.a0 := t1.adr;
              OCC.PutF4(7, tdes, xt);  (*CMPD*)
              IF ~test THEN
                OCC.PutF0(0); OCC.PutDisp(4); OCC.PutF1(0F2H); OCC.PutByte(18)
              ELSE setCC(x, 0)
              END
            END
          ELSE OCS.Mark(85);
            IF test THEN x.typ := OCT.booltyp END
          END
        ELSIF test THEN setCC(x, 14)
        END
      END GTT;

    BEGIN
      IF x.typ.form = Pointer THEN
        IF y.typ.form = Pointer THEN
          GTT(x.typ.BaseTyp, y.typ.BaseTyp, FALSE)
        ELSE OCS.Mark(86)
        END
      ELSIF (x.typ.form = Record) & (x.mode = Ind) & (x.obj # NIL) &
        (x.obj # OCC.wasderef) & (y.typ.form = Record) THEN
        GTT(x.typ, y.typ, TRUE)
      ELSE OCS.Mark(87)
      END
    END TypTest;

    PROCEDURE In*(VAR x, y: OCT.Item);
      VAR f: INTEGER;
    BEGIN f := x.typ.form;
      IF (f IN intSet) & (y.typ.form = Set) THEN
        IF y.mode = Con THEN load(y) END ;
        OCC.PutF4(lengcode[f]+34H, y, x); setCC(x, 8)   (*TBITi*)
      ELSE OCS.Mark(92); x.mode := Reg
      END ;
      x.typ := OCT.booltyp
    END In;

    PROCEDURE Set0*(VAR x, y: OCT.Item);
      VAR one: LONGINT;
    BEGIN x.mode := Reg; x.a0 := 0; x.typ := OCT.settyp;
      IF y.typ.form IN intSet THEN
        IF y.mode = Con THEN x.mode := Con;
          IF (0 <= y.a0) & (y.a0 < 32) THEN one := 1; x.a0 := SYSTEM.LSH(one, y.a0)
          ELSE OCS.Mark(202)
          END
        ELSE OCC.GetReg(x); OCC.PutF2(5FH, 1, x); OCC.Put(F6, 17H, x, y)  (*LSHD*)
        END
      ELSE OCS.Mark(93)
      END
    END Set0;

    PROCEDURE Set1*(VAR x, y, z: OCT.Item);
      VAR s: LONGINT;
    BEGIN x.mode := Reg; x.a0 := 0; x.typ := OCT.settyp;
      IF (y.typ.form IN intSet) & (z.typ.form IN intSet) THEN
        IF y.mode = Con THEN
          IF (0 <= y.a0) & (y.a0 < 32) THEN
            y.typ := OCT.settyp; s := -1; y.a0 := SYSTEM.LSH(s, y.a0);
            IF z.mode = Con THEN
              x.mode := Con;
              IF (y.a0 <= z.a0) & (z.a0 < 32) THEN s := -2; x.a0 := y.a0-SYSTEM.LSH(s, z.a0)
              ELSE OCS.Mark(202); x.a0 := 0
              END
            ELSIF y.a0 = -1 THEN
              OCC.GetReg(x); OCC.PutF2(5FH, -2, x); OCC.Put(F6, 17H, x, z);
              OCC.Put(F6, 37H, x, x)   (*LSHD, COMD*)
            ELSE OCC.GetReg(x); OCC.PutF4(17H, x, y); OCC.GetReg(y);
              OCC.PutF2(5FH, -2, y); OCC.Put(F6, 17H, y, z); OCC.PutF4(0BH, x, y)
            END
          ELSE OCS.Mark(202)
          END
        ELSE OCC.GetReg(x); OCC.PutF2(5FH, -1, x); OCC.Put(F6, 17H, x, y);
          IF z.mode = Con THEN
            IF (0 <= z.a0) & (z.a0 < 32) THEN
              y.typ := OCT.settyp; y.mode := Con; s := -2; y.a0 := SYSTEM.LSH(s, z.a0)
            ELSE OCS.Mark(202)
            END
          ELSE OCC.GetReg(y); OCC.PutF2(5FH, -2, y); OCC.Put(F6, 17H, y, z)  (*LSHD*)
          END ;
          OCC.PutF4(0BH, x, y)   (*BICD*)
        END
      ELSE OCS.Mark(93)
      END
    END Set1;

    PROCEDURE MOp*(op: INTEGER; VAR x: OCT.Item);
      VAR f, L: INTEGER; a: LONGINT; y: OCT.Item;
    BEGIN f := x.typ.form;
      CASE op OF
        5: (*&*)
        IF x.mode = Coc THEN
```

```
      OCC.PutF0(inverted(x.a0)); OCC.PutWord(x.a2);
      x.a2 := OCC.pc-2; OCC.FixLink(x.a1)
    ELSIF (x.typ.form = Bool) & (x.mode # Con) THEN
      OCC.PutF2(1CH, 1, x); setCC(x, 0);
      OCC.PutF0(1); OCC.PutWord(x.a2); x.a2 := OCC.pc-2; OCC.FixLink(x.a1)
    ELSIF x.typ.form # Bool THEN
      OCS.Mark(94); x.mode := Con; x.typ := OCT.booltyp; x.a0 := 0
    END
  | 6: (*+*)
    IF ~(f IN intSet + realSet) THEN OCS.Mark(96) END
  | 7: (*-*)
    y := x; L := lengcode[f];
    IF f IN intSet THEN
      IF x.mode = Con THEN x.a0 := -x.a0; SetIntType(x)
      ELSE OCC.GetReg(x); OCC.Put(F6, L+20H, x, y)  (*NEGi*)
      END
    ELSIF f IN realSet THEN
      OCC.GetFReg(x); OCC.Put(F11, L+14H, x, y)  (*NEGf*)
    ELSIF f = Set  THEN OCC.GetReg(x); OCC.Put(F6, 37H, x, y)  (*COMD*)
    ELSE OCS.Mark(97)
    END
  | 8: (*OR*)
    IF x.mode = Coc THEN
      OCC.PutF0(x.a0); OCC.PutWord(x.a1); x.a1 := OCC.pc-2;
      OCC.FixLink(x.a2)
    ELSIF (x.typ.form = Bool) & (x.mode # Con) THEN
      OCC.PutF2(1CH, 1, x); setCC(x, 0);
      OCC.PutF0(0); OCC.PutWord(x.a1); x.a1 := OCC.pc-2; OCC.FixLink(x.a2)
    ELSIF x.typ.form # Bool THEN
      OCS.Mark(95); x.mode := Con; x.typ := OCT.booltyp; x.a0 := 1
    END
  | 9 .. 14: (*relations*)
    IF x.mode = Coc THEN loadB(x) END
  | 32: (*~*)
    IF x.typ.form = Bool THEN
      IF x.mode = Coc THEN x.a0 := inverted(x.a0);
        a := x.a1; x.a1 := x.a2; x.a2 := a
      ELSE OCC.PutF2(1CH, 0, x); setCC(x, 0)
      END
    ELSE OCS.Mark(98)
    END
  END
END MOp;

PROCEDURE convert1(VAR x: OCT.Item; typ: OCT.Struct);
  VAR y: OCT.Item; op: INTEGER;
BEGIN
  IF x.mode # Con THEN
    y := x;
    IF typ.form = Int THEN op := 10H
    ELSE op := lengcode[x.typ.form] + 1CH
    END;
    IF x.mode < Reg THEN OCC.GetReg(x) END ;
    OCC.Put(F7, op, x, y)  (*MOVij*)
  END ;
```

```
   x.typ := typ
END convert1;

PROCEDURE convert2(VAR x: OCT.Item; typ: OCT.Struct);
   VAR y: OCT.Item;
BEGIN y := x; OCC.GetFReg(x);  (*MOVif*)
   OCC.Put(F9, lengcode[typ.form]*4 + lengcode[x.typ.form], x, y); x.typ := typ
END convert2;

PROCEDURE convert3(VAR x: OCT.Item);
   VAR y: OCT.Item;
BEGIN y := x;
   IF x.mode < Reg THEN OCC.GetFReg(x) END ;
   OCC.Put(F9, 1BH, x, y); x.typ := OCT.lrltyp  (*MOVFL*)
END convert3;

PROCEDURE Op*(op: INTEGER; VAR x, y: OCT.Item);
   VAR f, g, L: INTEGER; p, q, r: OCT.Struct;

   PROCEDURE strings(): BOOLEAN;
   BEGIN RETURN
      ((((f=Array) OR (f=DynArr)) & (x.typ.BaseTyp.form=Char)) OR (f=String)) &
      ((((g=Array) OR (g=DynArr)) & (y.typ.BaseTyp.form=Char)) OR (g=String))
   END strings

   PROCEDURE CompStrings(cc: INTEGER; Q: BOOLEAN);
      VAR z: OCT.Item;
   BEGIN z.mode := Reg; z.a0 := 2;
      IF f = DynArr THEN OCC.DynArrAdr(z, x)
      ELSE OCC.PutF4(27H, z, x)
      END ;
      z.a0 := 1;
      IF g = DynArr THEN OCC.DynArrAdr(z, y)
      ELSE OCC.PutF4(27H, z, y)
      END ;
      z.a0 := 0; OCC.PutF2(5FH, -1, z);   (*MOVQD -1, R0*)
      z.a0 := 4; OCC.PutF2(5FH,  0, z);   (*MOVQD  0, R4*)
      OCC.PutF1(14); OCC.PutF1(4); OCC.PutF1(6);  (*CMPSB 6*)
      IF Q THEN (*compare also with zero byte*)
         OCC.PutF0(9); OCC.PutDisp(5);     (*BFC*)
         z.mode := RegI; z.a0 := 2; z.a1 := 0; OCC.PutF2(1CH, 0, z) (*CMPQB*)
      END ;
      setCC(x, cc)
   END CompStrings

   PROCEDURE CompBool(cc: INTEGER);
   BEGIN
      IF y.mode = Coc THEN loadB(y) END ;
      OCC.PutF4(4, x, y); setCC(x, cc)
   END CompBool;

BEGIN
   IF x.typ # y.typ THEN
      g := y.typ.form;
      CASE x.typ.form OF
         Undef:
      | SInt: IF g = Int THEN convert1(x, y.typ)
         ELSIF g = LInt THEN convert1(x, y.typ)
         ELSIF g = Real THEN convert2(x, y.typ)
         ELSIF g = LReal THEN convert2(x, y.typ)
         ELSE OCS.Mark(100)
         END
      | Int:   IF g = SInt THEN convert1(y, x.typ)
         ELSIF g = LInt THEN convert1(x, y.typ)
         ELSIF g = Real THEN convert2(x, y.typ)
         ELSIF g = LReal THEN convert2(x, y.typ)
         ELSE OCS.Mark(100)
         END
      | LInt: IF g = SInt THEN convert1(y, x.typ)
         ELSIF g = Int THEN convert1(y, x.typ)
         ELSIF g = Real THEN convert2(x, y.typ)
         ELSIF g = LReal THEN convert2(x, y.typ)
         ELSE OCS.Mark(100)
         END
      | Real: IF g = SInt THEN convert2(y, x.typ)
         ELSIF g = Int THEN convert2(y, x.typ)
         ELSIF g = LInt THEN convert2(y, x.typ)
         ELSIF g = LReal THEN convert3(x)
         ELSE OCS.Mark(100)
         END
      | LReal:       IF g = SInt THEN convert2(y, x.typ)
         ELSIF g = Int THEN convert2(y, x.typ)
         ELSIF g = LInt THEN convert2(y, x.typ)
         ELSIF g = Real THEN convert3(y)
         ELSE OCS.Mark(100)
         END
      | NilTyp:      IF g # Pointer THEN OCS.Mark(100) END
      | Pointer:     IF g = Pointer THEN
            p := x.typ.BaseTyp; q := y.typ.BaseTyp;
            IF (p.form = Record) & (q.form = Record) THEN
               IF p.n < q.n THEN r := p; p := q; q := r END;
               WHILE (p # q) & (p # NIL) DO p := p.BaseTyp END;
               IF p = NIL THEN OCS.Mark(100) END
            ELSE OCS.Mark(100)
            END
         ELSIF g # NilTyp THEN OCS.Mark(100)
         END
      | ProcTyp:    IF g # NilTyp THEN OCS.Mark(100) END
      | Array, DynArr, String:
      | Byte, Bool, Char, Set, NoTyp, Record: OCS.Mark(100)
      END
   END ;
   f := x.typ.form; g := y.typ.form; L := lengcode[f];

   CASE op OF
      1: IF f IN intSet THEN     (***)
         IF (x.mode = Con) & (y.mode = Con) THEN (*ovfl test missing*)
            x.a0 := x.a0 * y.a0; SetIntType(x)
         ELSIF (x.mode = Con) & (mant(x.a0) = 1) THEN
            x.a0 := log; x.typ := OCT.sinttyp;
            load(y); OCC.Put(F6, L+4, y, x); (*ASHi*) x := y
         ELSIF (y.mode = Con) & (mant(y.a0) = 1) THEN
            y.a0 := log; y.typ := OCT.sinttyp;
            load(x); OCC.Put(F6, L+4, x, y) (*ASHi*)
         ELSE load(x); OCC.Put(F7, L+20H, x, y)  (*MULi*)
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          END
        ELSIF f IN realSet THEN
          loadF(x); OCC.Put(F11, 30H+L, x, y)   (*MULf*)
        ELSIF f = Set THEN
          load(x); OCC.PutF4(2BH, x, y)   (*ANDD*)
        ELSIF f # Undef THEN OCS.Mark(101)
        END
    | 2:  IF f IN realSet THEN  (*/*)
          loadF(x); OCC.Put(F11, 20H+L, x, y)   (*DIVf*)
        ELSIF f IN intSet THEN
          convert2(x, OCT.realtyp); convert2(y, OCT.realtyp);
          OCC.Put(F11, 21H, x, y)   (*DIVF*)
        ELSIF f = Set THEN
          load(x); OCC.PutF4(3BH, x, y)   (*XORD*)
             ELSIF f # Undef THEN OCS.Mark(102)
        END
    | 3:  IF f IN intSet THEN  (*DIV*)
          IF (x.mode = Con) & (y.mode = Con) THEN
            IF y.a0 # 0 THEN x.a0 := x.a0 DIV y.a0; SetIntType(x)
            ELSE OCS.Mark(205)
            END
          ELSIF (y.mode = Con) & (mant(y.a0) = 1) THEN
            y.a0 := -log; y.typ := OCT.sinttyp;
             load(x); OCC.Put(F6, L+4, x, y)   (*ASHi*)
          ELSE load(x); OCC.Put(F7, L+3CH, x, y)   (*DIVi*)
          END
        ELSIF f # Undef THEN OCS.Mark(103)
        END
    | 4:  IF f IN intSet THEN  (*MOD*)
          IF (x.mode = Con) & (y.mode = Con) THEN
            IF y.a0 # 0 THEN x.a0 := x.a0 MOD y.a0; x.typ := y.typ
            ELSE OCS.Mark(205)
             END
          ELSIF (y.mode = Con) & (mant(y.a0) = 1) THEN
            y.a0 := ASH(-1, log); load(x); OCC.PutF4(L+8, x, y)   (*BICi*)
          ELSE load(x); OCC.Put(F7, L+38H, x, y)   (*MODi*)
          END
        ELSIF f # Undef THEN OCS.Mark(104)
        END
    | 5:  IF y.mode # Coc THEN  (*&*)
          IF y.mode = Con THEN
            IF y.a0 = 1 THEN setCC(y, 14) ELSE setCC(y, 15) END
          ELSIF y.mode <= Reg THEN OCC.PutF2(1CH, 1, y); setCC(y, 0)
          ELSE OCS.Mark(94); setCC(y, 0)
          END
        END ;
        IF x.mode = Con THEN
          IF x.a0 = 0 THEN OCC.FixLink(y.a1); OCC.FixLink(y.a2); setCC(y, 15) END ;
          setCC(x, 0)
        END;
        IF y.a2 # 0 THEN x.a2 := OCC.MergedLinks(x.a2, y.a2) END ;
        x.a0 := y.a0; x.a1 := y.a1
    | 6:  IF f IN intSet THEN (*+*)
          IF (x.mode = Con) & (y.mode = Con) THEN
            INC(x.a0, y.a0); SetIntType(x)  (*ovfl test missing*)
          ELSE load(x); add(L, x, y)
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      END
    ELSIF f IN realSet THEN
      loadF(x); OCC.Put(F11, L, x, y)   (*ADDf*)
    ELSIF f = Set THEN
      IF (x.mode = Con) & (y.mode = Con) THEN x.a0 := SYSTEM.VAL
        (LONGINT, SYSTEM.VAL(SET, x.a0) + SYSTEM.VAL(SET, y.a0))
      ELSE load(x); OCC.PutF4(1BH, x, y)   (*ORD*)
      END
    ELSIF f # Undef THEN OCS.Mark(105)
    END
| 7:  IF f IN intSet THEN (*-*)
       IF (x.mode = Con) & (y.mode = Con) THEN
          DEC(x.a0, y.a0); SetIntType(x)  (*ovfl test missing*)
      ELSE load(x); sub(L, x, y)
      END
    ELSIF f IN realSet THEN
      loadF(x); OCC.Put(F11, 10H+L, x, y)   (*SUBf*)
    ELSIF f = Set THEN load(x); OCC.PutF4(0BH, x, y)   (*BICD*)
    ELSIF f # Undef THEN OCS.Mark(106)
    END
| 8:  IF y.mode # Coc THEN  (*OR*)
      IF y.mode = Con THEN
        IF y.a0 = 1 THEN setCC(y, 14) ELSE setCC(y, 15) END
      ELSIF y.mode <= Reg THEN OCC.PutF2(1CH, 1, y); setCC(y, 0)
      ELSE OCS.Mark(95); setCC(y, 0)
      END
    END ;
    IF x.mode = Con THEN
      IF x.a0 = 1 THEN OCC.FixLink(y.a1); OCC.FixLink(y.a2); setCC(y, 14) END ;
      setCC(x, 0)
    END ;
    IF y.a1 # 0 THEN x.a1 := OCC.MergedLinks(x.a1, y.a1) END ;
     x.a0 := y.a0; x.a2 := y.a2
| 9:  IF f IN {Undef, Char..LInt, Set, NilTyp, Pointer, ProcTyp} THEN
      cmp(L, x, y); setCC(x, 0)
    ELSIF f IN realSet THEN OCC.Put(F11, 8+L, x, y); setCC(x, 0)
    ELSIF f = Bool THEN CompBool(0)
    ELSIF strings() THEN CompStrings(0, TRUE)
    ELSE OCS.Mark(107)
    END
|10: IF f IN {Undef, Char..LInt, Set, NilTyp, Pointer, ProcTyp} THEN
      cmp(L, x, y); setCC(x, 1)
    ELSIF f IN realSet THEN OCC.Put(F11, 8+L, x, y); setCC(x, 1)
    ELSIF f = Bool THEN CompBool(1)
    ELSIF strings() THEN CompStrings(1, TRUE)
    ELSE OCS.Mark(107)
    END
|11: IF f IN intSet THEN cmp(L, x, y); setCC(x, 6)
    ELSIF f = Char THEN cmp(0, x, y); setCC(x, 4)
    ELSIF f IN realSet THEN OCC.Put(F11, 8+L, x, y); setCC(x, 6)
    ELSIF strings() THEN CompStrings(4, FALSE)
    ELSE OCS.Mark(108)
    END
|12: IF f IN intSet THEN cmp(L, x, y); setCC(x, 13)
    ELSIF f = Char THEN cmp(0, x, y); setCC(x, 11)
    ELSIF f IN realSet THEN OCC.Put(F11, 8+L, x, y); setCC(x, 13)
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      ELSIF strings() THEN CompStrings(11, TRUE)
      ELSE OCS.Mark(108)
      END
   |13: IF f IN intSet THEN cmp(L, x, y); setCC(x, 12)
      ELSIF f = Char THEN cmp(0, x, y); setCC(x, 10)
      ELSIF f IN realSet THEN OCC.Put(F11, 8+L, x, y); setCC(x, 12)
      ELSIF strings() THEN CompStrings(10, TRUE)
      ELSE OCS.Mark(108)
      END
   |14: IF f IN intSet THEN cmp(L, x, y); setCC(x, 7)
      ELSIF f = Char THEN cmp(0, x, y); setCC(x, 5)
      ELSIF f IN realSet THEN OCC.Put(F11, 8+L, x, y); setCC(x, 7)
      ELSIF strings() THEN CompStrings(5, FALSE)
      ELSE OCS.Mark(108)
      END
   END
END Op;

PROCEDURE StPar1*(VAR x: OCT.Item; fctno: INTEGER);
   VAR f, L: INTEGER; s: LONGINT; y: OCT.Item;
BEGIN f := x.typ.form;
   CASE fctno OF
    0: (*HALT*)
      IF (f = SInt) & (x.mode = Con) THEN
         IF x.a0 >= 20 THEN OCC.PutF1(0F2H); OCC.PutByte(x.a0)  (*BPT*)
         ELSE OCS.Mark(218)
         END
      ELSE OCS.Mark(217)
      END ;
      x.typ := OCT.notyp
   |  1: (*NEW*) y.mode := Reg;
      IF f = Pointer THEN
         y.a0 := 0; OCC.PutF4(27H, y, x);
         x.typ := x.typ.BaseTyp; f := x.typ.form;
         IF x.typ.size > 7FFF80H THEN OCS.Mark(227)
         ELSIF f = Record THEN
            y.a0 := 1; x.mode := Var; x.lev := -x.typ.mno;
            x.a0 := x.typ.adr; OCC.PutF4(17H, y, x);
            OCC.PutF1(0E2H); OCC.PutByte(0)  (*SVC 0*)
         ELSIF f = Array THEN
            y.a0 := 2; x.a0 := x.typ.size; x.mode := Con; x.typ := OCT.linttyp;
            OCC.PutF4(17H, y, x); OCC.PutF1(0E2H); OCC.PutByte(1)  (*SVC 1*)
         ELSE OCS.Mark(111)
         END
      ELSE OCS.Mark(111)
      END ;
      x.typ := OCT.notyp
   |  2: (*CC*)
      IF (f = SInt) & (x.mode = Con) THEN
         IF (0 <= x.a0) & (x.a0 < 16) THEN setCC(x, x.a0) ELSE OCS.Mark(219) END
      ELSE OCS.Mark(217)
      END
   |  3: (*ABS*) y := x; L := lengcode[f];
      IF f IN intSet THEN
         OCC.GetReg(x); OCC.Put(F6, 30H+L, x, y)   (*ABSi*)
      ELSIF f IN realSet THEN
      OCC.GetFReg(x); OCC.Put(F11, 34H+L, x, y)   (*ABSf*)
    ELSE OCS.Mark(111)
    END
  | 4: (*CAP*) y.mode := Con; y.typ := OCT.chartyp; y.a0 := 5FH;
    IF f = Char THEN load(x); OCC.PutF4(28H, x, y)   (*ANDB*)
    ELSE OCS.Mark(111); x.typ := OCT.chartyp
    END
  | 5: (*ORD*)
    IF (f = Char) OR (f = Byte) THEN (*MOVZBW*)
      IF x.mode # Con THEN y := x; OCC.GetReg(x); OCC.Put(F7, 14H, x, y) END
    ELSE OCS.Mark(111)
    END ;
    x.typ := OCT.inttyp
  | 6: (*ENTIER*)
    IF f IN realSet THEN
      y := x; OCC.GetReg(x); OCC.Put(F9, lengcode[f]*4 + 3BH, x, y)  (*FLOORfD*)
    ELSE OCS.Mark(111)
    END ;
    x.typ := OCT.linttyp
  | 7: (*SIZE*)
    IF x.mode = Typ THEN x.a0 := x.typ.size
    ELSE OCS.Mark(110); x.a0 := 1
    END ;
    x.mode := Con; SetIntType(x)
  | 8: (*ODD*)
    IF f IN intSet THEN
      y.mode := Con; y.typ := OCT.sinttyp; y.a0 := 0; OCC.PutF4(34H, x, y)  (*TBITB 0*)
    ELSE OCS.Mark(111)
    END ;
    setCC(x, 8)
  | 9: (*ADR*)
    IF f = DynArr THEN y := x; OCC.GetReg(x); OCC.DynArrAdr(x, y)
    ELSE loadAdr(x); x.mode := Reg
    END ;
    x.typ := OCT.linttyp
  | 10: (*MIN*)
    IF x.mode = Typ THEN x.mode := Con;
      CASE f OF
          Bool, Char:  x.a0 := 0
        | SInt:  x.a0 := -80H
        | Int:   x.a0 := -8000H
        | LInt:  x.a0 := 80000000H
        | Real:  x.a0 := 0FF7FFFFFH
        | LReal: x.a0 := 0FFFFFFFFH; x.a1 := 0FFEFFFFFH
        | Set:   x.a0 := 0; x.typ := OCT.inttyp
        | Undef, NilTyp .. Record: OCS.Mark(111)
      END
    ELSE OCS.Mark(110)
    END
  | 11: (*MAX*)
    IF x.mode = Typ THEN x.mode := Con;
      CASE f OF
          Bool:  x.a0 := 1
        | Char:  x.a0 := 0FFH
        | SInt:  x.a0 := 7FH
        | Int:   x.a0 := 7FFFH
      | LInt:  x.a0 := 7FFFFFFFH
      | Real:  x.a0 := 7F7FFFFFH
      | LReal: x.a0 := 0FFFFFFFFH; x.a1 := 7FEFFFFFH
      | Set:   x.a0 := 31; x.typ := OCT.inttyp
      | Undef, NilTyp .. Record: OCS.Mark(111)
    END
  ELSE OCS.Mark(110)
  END |
| 12: (*CHR*)
  IF ~(f IN {Undef, Byte, SInt, Int, LInt}) THEN OCS.Mark(111) END ;
  IF (x.mode = VarX) OR (x.mode = IndX) THEN load(x) END ;
  x.typ := OCT.chartyp
| 13: (*SHORT*)
  IF f = LInt THEN (*range test missing*)
    IF (x.mode = VarX) OR (x.mode = IndX) THEN load(x)
    ELSIF x.mode = Con THEN SetIntType(x);
      IF x.typ.form = LInt THEN OCS.Mark(203) END
    END ;
    x.typ := OCT.inttyp
  ELSIF f = LReal THEN (*MOVLF*)
    y := x; OCC.GetFReg(x); OCC.Put(F9, 16H, x, y); x.typ := OCT.realtyp
  ELSIF f = Int THEN (*range test missing*)
    IF (x.mode = VarX) OR (x.mode = IndX) THEN load(x)
    ELSIF x.mode = Con THEN SetIntType(x);
      IF x.typ.form # SInt THEN OCS.Mark(203) END
    END ;
    x.typ := OCT.sinttyp
  ELSE OCS.Mark(111)
  END
| 14: (*LONG*)
  IF f = Int THEN convert1(x, OCT.linttyp)
  ELSIF f = Real THEN convert3(x)
  ELSIF f = SInt THEN convert1(x, OCT.inttyp)
  ELSIF f = Char THEN
    y := x; OCC.GetReg(x); OCC.Put(F7, 18H, x, y); x.typ := OCT.linttyp (*MOVZBD*)
  ELSE OCS.Mark(111)
  END
| 15: (*OVFL*)
  IF (f = Bool) & (x.mode = Con) THEN (*BICPSRB 10H*)
    OCC.PutF1(7CH); OCC.PutF1(SHORT(x.a0)*2 + 0A1H); OCC.PutF1(10H)
  ELSE OCS.Mark(111)
  END ;
  x.typ := OCT.notyp
| 16,17: (*INC DEC*)
  IF x.mode >= Con THEN OCS.Mark(112)
  ELSIF ~(f IN intSet) THEN OCS.Mark(111)
  END
| 18,19: (*INCL EXCL*)
  IF x.mode >= Con THEN OCS.Mark(112)
  ELSIF x.typ # OCT.settyp THEN OCS.Mark(111); x.typ := OCT.settyp
  END
| 20: (*LEN*)
  IF (f # DynArr) & (f # Array) THEN OCS.Mark(131) END
| 21: (*ASH*)
  IF f = LInt THEN load(x)
  ELSIF f IN intSet THEN loadX(x); x.typ := OCT.linttyp
```

```
        ELSE OCS.Mark(111)
        END
      | 22, 23: (*LSH ROT*)
        IF f IN {Char, SInt, Int, LInt, Set} THEN load(x) ELSE OCS.Mark(111) END
      | 24,25,26: (*GET, PUT, BIT*)
        IF (f IN intSet) & (x.mode = Con) THEN x.mode := Abs
        ELSIF f = LInt THEN
          IF (x.mode = Var) & (x.lev >= 0) THEN x.mode := Ind; x.a1 := 0
          ELSE load(x); x.mode := RegI; x.a1 := 0
          END
        ELSE OCS.Mark(111)
        END
      | 27: (*VAL*)
        IF x.mode # Typ THEN OCS.Mark(110) END
      | 28: (*SYSTEM.NEW*)
        IF (f = Pointer) & (x.mode < Con) THEN
          y.mode := Reg; y.a0 := 0; OCC.PutF4(27H, y, x);
        ELSE OCS.Mark(111)
        END
      | 29: (*COPY*)
        IF (((f=Array) OR (f=DynArr)) & (x.typ.BaseTyp.form = Char))
           OR (f = String) THEN
          y.mode := Reg; y.a0 := 1;
          IF f = DynArr THEN OCC.DynArrAdr(y, x)
          ELSE OCC.PutF4(27H, y, x)
          END
        ELSE OCS.Mark(111)
        END
      | 30: (*MOVE*)
        IF f = LInt THEN y.mode := Reg; y.a0 := 1; OCC.PutF4(17H, y, x)
        ELSE OCS.Mark(111)
        END
      END
    END StPar1;

  PROCEDURE StPar2*(VAR p, x: OCT.Item; fctno: INTEGER);
      VAR f, L: INTEGER; y, z: OCT.Item; typ: OCT.Struct;
    BEGIN f := x.typ.form;
      IF fctno < 16 THEN OCS.Mark(64); RETURN END ;
      CASE fctno OF
      16, 17: (*INC DEC*)
        IF x.typ # p.typ THEN
          IF (x.mode = Con) & (x.typ.form IN intSet) THEN x.typ := p.typ
          ELSE OCS.Mark(111)
          END
          END ;
        L := lengcode[p.typ.form];
        IF fctno = 16 THEN add(L, p, x) ELSE sub(L, p, x) END ;
        p.typ := OCT.notyp
      | 18: (*INCL*)
        Set0(y, x); OCC.PutF4(1BH, p, y); p.typ := OCT.notyp (*ORD*)
      | 19: (*EXCL*)
        Set0(y, x); OCC.PutF4(0BH, p, y); p.typ := OCT.notyp (*BICD*)
      | 20: (*LEN*)
        IF (x.mode = Con) & (f = SInt) THEN
        L := SHORT(x.a0); typ := p.typ;
        WHILE (L > 0) & (typ.form IN {DynArr, Array}) DO
          typ := typ.BaseTyp; DEC(L)
        END;
        IF (L # 0) OR ~(typ.form IN {DynArr, Array}) THEN OCS.Mark(132)
        ELSE
          IF typ.form = DynArr THEN
            p.mode := Var; p.typ := OCT.linttyp; INC(p.a0, typ.adr);
            load(p); OCC.PutF2(0FH, 1, p)   (* ADDQD 1, p *)
          ELSE p := x; p.a0 := typ.n; SetIntType(p)
          END
        END
      ELSE OCS.Mark(111)
      END
    | 21, 22, 23: (*ASH LSH ROT*)
      IF f IN intSet THEN
        IF fctno = 21 THEN L := 4 ELSIF fctno = 22 THEN L := 14H ELSE L := 0 END ;
        IF (x.mode = VarX) OR (x.mode = IndX) THEN load(x) END ;
        x.typ := OCT.sinttyp; OCC.Put(F6, lengcode[p.typ.form]+L, p, x)
      ELSE OCS.Mark(111)
      END
    | 24: (*GET*)
      IF x.mode >= Con THEN OCS.Mark(112)
      ELSIF f IN {Undef..LInt, Set, Pointer, ProcTyp} THEN
        OCC.PutF4(lengcode[f]+14H, x, p)
      ELSIF f IN realSet THEN OCC.Put(F11, lengcode[f]+4, x, p)   (*MOVf*)
      END ;
      p.typ := OCT.notyp
    | 25: (*PUT*)
      IF f IN {Undef..LInt, Set, Pointer, ProcTyp} THEN OCC.PutF4(lengcode[f]+14H, p, x)
      ELSIF f IN realSet THEN OCC.Put(F11, lengcode[f]+4, p, x)   (*MOVf*)
      END ;
      p.typ := OCT.notyp
    | 26: (*BIT*)
      IF f IN intSet THEN OCC.PutF4(lengcode[f] + 34H, p, x)   (*TBITi*)
      ELSE OCS.Mark(111)
      END ;
      setCC(p, 8)
    | 27: (*VAL*)
      x.typ := p.typ; p := x
    | 28: (*SYSTEM.NEW*)
      y.mode := Reg; y.a0 := 2;
      IF f = LInt THEN OCC.PutF4(17H, y, x)
      ELSIF f = Int THEN OCC.Put(F7, 1DH, y, x)   (*MOVXWD*)
      ELSIF f = SInt THEN OCC.Put(F7, 1CH, y, x)  (*MOVXBD*)
      ELSE OCS.Mark(111)
      END ;
      OCC.PutF1(0E2H); OCC.PutByte(1);  (*SVC 1*)
      p.typ := OCT.notyp
    | 29: (*COPY*)
      IF ((f = Array) OR (f = DynArr)) & (x.typ.BaseTyp.form = Char) THEN
        y.mode := Reg; y.a0 := 2; y.a1 := 0;
        IF f = DynArr THEN p := x; OCC.DynArrAdr(y, x); y.a0 := 0;
          p.mode := Var; INC(p.a0, p.typ.adr); OCC.PutF4(17H, y, p)
        ELSE OCC.PutF4(27H, y, x); y.a0 := 0;
          p.mode := Con; p.typ := OCT.inttyp; p.a0:= x.typ.size-1;
```

```
            OCC.Put(F7, 19H, y, p); (*MOVZWD*)
          END;
          y.a0 := 4; OCC.PutF2(5FH, 0, y);               (*MOVQD*)
          OCC.PutF1(14); OCC.PutF1(0); OCC.PutF1(6);      (*MOVSB*)
          y.mode := RegI; y.a0 := 2; OCC.PutF2(5CH, 0, y) (*MOVQB*)
        ELSE OCS.Mark(111)
        END ;
        p.typ := OCT.notyp
      | 30: (*MOVE*)
        IF f = LInt THEN y.mode := Reg; y.a0 := 2; OCC.PutF4(17H, y, x)
        ELSE OCS.Mark(111)
        END
      END
    END StPar2;

    PROCEDURE StPar3*(VAR p, x: OCT.Item; fctno: INTEGER);
      VAR f: INTEGER; y: OCT.Item;
    BEGIN f := x.typ.form;
      IF fctno = 30 THEN (*MOVE*)
        y.mode := Reg; y.a0 := 0;
        IF f = Int THEN OCC.Put(F7, 1DH, y, x)
        ELSIF f = SInt THEN OCC.Put(F7, 1CH, y, x)
        ELSIF f = LInt THEN OCC.PutF4(17H, y, x)
        ELSE OCS.Mark(111)
        END ;
        OCC.PutF1(14); OCC.PutF1(0); OCC.PutF1(0); p.typ := OCT.notyp  (*MOVSB*)
      ELSE OCS.Mark(64)
      END
    END StPar3;

    PROCEDURE StFct*(VAR p: OCT.Item; fctno, parno: INTEGER);
    BEGIN
      IF fctno >= 16 THEN
        IF (fctno = 16) & (parno = 1) THEN (*INC*)
          OCC.PutF2(lengcode[p.typ.form]+0CH, 1, p); p.typ := OCT.notyp
        ELSIF (fctno = 17) & (parno = 1) THEN (*DEC*)
          OCC.PutF2(lengcode[p.typ.form]+0CH, -1, p); p.typ := OCT.notyp
        ELSIF (fctno = 20) & (parno = 1) THEN (*LEN*)
          IF p.typ.form = DynArr THEN
            p.mode := Var; INC(p.a0, p.typ.adr); p.typ := OCT.linttyp;
            load(p); OCC.PutF2(0FH, 1, p)   (*ADDQD 1 p*)
          ELSE p.mode := Con; p.a0 := p.typ.n; SetIntType(p)
          END
        ELSIF (parno < 2) OR (fctno = 30) & (parno < 3) THEN OCS.Mark(65)
        END
      ELSIF parno < 1 THEN OCS.Mark(65)
      END
    END StFct;

  BEGIN intSet := {SInt, Int, LInt}; realSet := {Real, LReal}; lengcode[Undef] := 0;
    lengcode[Byte] := 0;  lengcode[Bool] := 0; lengcode[Char] := 0; lengcode[SInt] := 0;
    lengcode[Int] := 1; lengcode[LInt] := 3; lengcode[Real] := 1; lengcode[LReal] := 0;
    lengcode[Set] := 3; lengcode[String] := 0; lengcode[NilTyp] := 3; lengcode[ProcTyp] := 3;
    lengcode[Pointer] := 3; lengcode[Array] := 1; lengcode[DynArr] := 1; lengcode[Record] := 1
  END OCE.
```

Module OCH contains the procedures for code selection and type consistency checking corresponding to statements: assignment, procedure calls, and structured control statements. Procedure *Assign* discriminates between the various types of the destination variable with a case statement. It is called both for proper assignments (~*param*) and for the passing of value parameters (*param*). In the latter case, the addressing mode of the destination is TOS; the parameter is pushed onto the stack. Automatic length extension is used, if the operand length is 1 or 2, resulting in proper alignment for all parameters.

Assignments of arrays and records is achieved by a block move instruction (MOVMB, if the size is at most 16, MOVSB otherwise, see procedure *MoveBlock*). If the destination is an indirectly referenced record, i.e. if it is either a VAR-parameter or a dereferenced variable, an implicit type guard is necessary. Consider a record type *R0* and its extension *R1*. Let the destination be either a VAR-parameter *r0* of type *R0*, or *p*^ where *p* is a pointer bound to *R0*, and let variable *r1* be of type *R1*. Then the assignment *r0 := r1* is acceptable only if the *actual* destination is of type *R0*, but not if it happens to be some extension of *R0* (not necessarily *R1*). This condition must be guarded by an implicitly inserted guard. This is an example of a case where an apparently simple and basic concept such as type extension produces unexpected side-effects and complications.

Assignments to dynamic arrays as a whole are not permitted by the rules of the language. However, actual parameters corresponding to a formal parameter declared as a dynamic array called by value may be arrays, dynamic arrays, or strings. Since this implicit assignment is handled by procedure *Assign*, it must handle the case by constructing an appropriate array descriptor. The descriptor consists of the actual parameter's address and its index bounds. The latter is pushed onto the stack first. In the case of a string, its length minus 1 yields the upper bound, and the lower bound of 0 is implied by extending the upper bound to 4 bytes (see procedure *DynArrBnd*).

Assignment of procedures to variables (and parameters) of a procedural type is handled by constructing a procedure descriptor and assigning it to the destination. The descriptor consists of a module descriptor address and an entry offset. Also, the check for type compatibility is fairly complex in this case, because the language admits structural equivalence instead of name equivalence, which is necessary because the type of a declared procedure bears no name. Therefore, both result type and parameter types must be checked for compatibility. This is done by procedure *CompareParameters* and involves the parameters' types and mode. This procedure is also invoked in the case of forward declarations (see *Compiler.ProcedureDeclaration*).

Procedures *PrepCall*, *Param*, and *Call* are used to select code for procedure calls. The first checks that the item properly denotes a procedure and delivers its formal parameter list. *Param* scans the parameters, one per invocation, and delegates its handling to *Assign* in the case of value parameters; otherwise the address of the actual parameter is pushed onto the stack. In the case of dynamic arrays and records, a descriptor is formed containing, in addition to the address, the array's length or the record's base type tag. The latter is used by type guards and type tests. And finally, procedure *Call* selects the appropriate branch instruction, namely BSR for local, CXP for external, CXPD for indirectly called, and SVC for code procedures.

The CXP instruction requires as parameter an index to the module's link table. The indexed entry holds a descriptor identifying the procedure (see Chapter 6). The table entry is established when the compiler encounters a call of the procedure for the first time, and the index is then stored as a1 attribute in the procedure's symbol table entry by procedure *OCC.LinkAdr*.

Procedures *Enter*, *CopyDynArray*, *Result*, and *Return* select the instructions for the prolog and epilog of procedure bodies. The prolog typically consists of an ENTER instruction, the epilog of an EXIT instruction followed by RET for local and RXP for external procedures (see code patterns).

Procedures FJ, CFJ, BJ, CBJ, and LFJ are called for conditional and repetitive constructs and generate jumps. F stands for forward, B for backward, C for conditional, and L for long jump. FJ, CFJ, and LFJ assign the location of the generated branch to their *loc* parameter to be used for a later address fixup.

Procedures *CaseIn* and *CaseOut* process case statements. A case statement represents, in contrast to a cascaded conditional statement, a single, indexed branch. *CaseIn* generates this indexed branch instruction together with an instruction to test the index bounds. *CaseOut* is called when the end of the case statement is reached and the addresses of the individual cases are known and therefore the branch table can be constructed. A fixup of the indexed branch instruction is unavaoidable. The address of the trap instruction is assigned to cases that remained undefined.

```
MODULE OCH;    (*NW 7.6.87 / 15.2.91*)
  IMPORT OCS, OCT, OCC;

  CONST  (*instruction format prefixes*)
      F6 = 4EH; F7 = 0CEH; F9 = 3EH; F11 = 0BEH;

    (*object and item modes*)
      Var   =  1; VarX  =  2; Ind   =  3; IndX  =  4; RegI  =  5;
      RegX  =  6; Abs   =  7; Con   =  8; Stk   =  9; Coc   = 10;
      Reg   = 11; Fld   = 12; LProc = 14; XProc = 15;
      CProc = 17; IProc = 18; Mod   = 19;

    (*structure forms*)
      Undef = 0; Byte = 1; Bool = 2; Char = 3; SInt = 4; Int = 5; LInt = 6;
      Real = 7; LReal = 8; Set = 9; String = 10; NilTyp = 11; NoTyp = 12;
      Pointer = 13; ProcTyp = 14; Array = 15; DynArr = 16; Record = 17;

  TYPE LabelRange* = RECORD low*, high*: INTEGER; label*: INTEGER END ;
  VAR lengcode: ARRAY 18 OF INTEGER;

  PROCEDURE setCC(VAR x: OCT.Item; cc: LONGINT);
  BEGIN x.typ := OCT.booltyp; x.mode := Coc; x.a0 := cc; x.a1 := 0; x.a2 := 0
  END setCC;

  PROCEDURE AdjustSP(n: LONGINT);
  BEGIN  (*ADJSPB n*)
    IF n <= 127 THEN OCC.PutF3(-5A84H); OCC.PutByte(n)
    ELSE OCC.PutF3(-5A83H); OCC.PutWord(n)
    END
  END AdjustSP;

  PROCEDURE move(L: INTEGER; VAR x, y: OCT.Item);
  BEGIN
    IF (y.mode = Con) & (y.a0 <= 7) & (y.a0 >= -8) THEN
      OCC.PutF2(L+5CH, y.a0, x)  (*MOVQi*)
    ELSE OCC.PutF4(L+14H, x, y)  (*MOVi*)
    END
  END move;

  PROCEDURE load(VAR x: OCT.Item);
    VAR y: OCT.Item;
  BEGIN
    IF x.mode # Reg THEN
      y := x; OCC.GetReg(x); move(lengcode[x.typ.form], x, y)
    END
  END load;

  PROCEDURE moveBW(VAR x, y: OCT.Item);
  BEGIN
    IF (y.mode = Con) & (y.a0 <= 7) & (y.a0 >= -8) THEN
      OCC.PutF2(5DH, y.a0, x)
    ELSE OCC.Put(F7, 10H, x, y)  (*MOVXBW*)
    END
  END moveBW;

  PROCEDURE moveBD(VAR x, y: OCT.Item);
  BEGIN
    IF (y.mode = Con) & (y.a0 <= 7) & (y.a0 >= -8) THEN
      OCC.PutF2(5FH, y.a0, x)
    ELSE OCC.Put(F7, 1CH, x, y)  (*MOVXBD*)
    END
  END moveBD;

  PROCEDURE moveWD(VAR x, y: OCT.Item);
  BEGIN
    IF (y.mode = Con) & (y.a0 <= 7) & (y.a0 >= -8) THEN
      OCC.PutF2(5FH, y.a0, x)
    ELSE OCC.Put(F7, 1DH, x, y)  (*MOVXWD*)
    END
  END moveWD;

  PROCEDURE Leng(VAR x: OCT.Item; L: LONGINT);
    VAR y: OCT.Item;
  BEGIN
    IF L <= 7 THEN OCC.PutF2(5FH, L, x)      (*MOVQD*)
    ELSE y.mode := Con; y.a0 := L;           (*MOVZBD*)
      IF L <= 255 THEN y.typ := OCT.sinttyp; OCC.Put(F7, 18H, x, y)
      ELSE y.typ := OCT.inttyp; OCC.Put(F7, 19H, x, y)
      END
    END
  END Leng;

  PROCEDURE MoveBlock(VAR x, y: OCT.Item; s: LONGINT; param: BOOLEAN);
    VAR L: INTEGER; z: OCT.Item;
  BEGIN
    IF s > 0 THEN
      IF param THEN
        s := (s+3) DIV 4 * 4; AdjustSP(s)
      END ;
      IF s <= 16 THEN
        OCC.Put(F7, 0, x, y); OCC.PutDisp(s-1)   (*MOVMB*)
      ELSE
        z.mode := Reg; z.a0 := 1; OCC.PutF4(27H, z, y);    (*ADDR y,R1*)
        z.a0 := 2; OCC.PutF4(27H, z, x); z.a0 := 0;        (*ADDR x,R2*)
        IF s MOD 4 = 0 THEN L := 3; s := s DIV 4
        ELSIF s MOD 2 = 0 THEN L := 1; s := s DIV 2
        ELSE L := 0
        END ;
        Leng(z, s);
        OCC.PutF1(14); OCC.PutByte(L); OCC.PutByte(0)      (*MOVS*)
      END
    END
  END MoveBlock;

  PROCEDURE DynArrBnd(ftyp, atyp: OCT.Struct; lev: INTEGER;
        adr: LONGINT; varpar: BOOLEAN);
    VAR f, s: INTEGER; x, y, z: OCT.Item;
  BEGIN (* ftyp.form = DynArr *)
    x.mode := Stk; y.mode := Var;
    IF varpar & (ftyp.BaseTyp = OCT.bytetyp) THEN
      IF atyp.form # DynArr THEN Leng(x, atyp.size-1)
      ELSE y.lev := lev; y.a0 := adr + atyp.adr; y.typ := OCT.linttyp;
        atyp := atyp.BaseTyp;
        IF atyp.form # DynArr THEN
          IF atyp.size > 1 THEN
```

```
                    z.mode := Con; z.typ := OCT.linttyp; z.a0 := atyp.size;
                    load(y); OCC.Put(F7, 23H, y, z);    (* MULD z, Ry *)
                    z.mode := Con; z.typ := OCT.linttyp; z.a0 := atyp.size-1;
                    IF z.a0 < 8 THEN OCC.PutF2(0FH, z.a0, y)            (*  ADDQD  size-1,  Ry
*)
                    ELSE OCC.PutF4(3, y, z) (* ADDD size-1, Ry *)
                    END
                END
              ELSE load(y); OCC.PutF2(0FH, 1, y);
                REPEAT z.mode := Var; z.lev := lev; z.a0 := atyp.adr + adr; z.typ := OCT.linttyp;
                    load(z); OCC.PutF2(0FH, 1, z);      (* ADDQD 1, Rz *)
                    OCC.Put(F7, 23H, y, z);   (* MULD Rz, Ry *)
                    atyp := atyp.BaseTyp
                UNTIL atyp.form # DynArr;
                IF atyp.size > 1 THEN
                    z.mode := Con; z.typ := OCT.linttyp; z.a0 := atyp.size;
                    OCC.Put(F7, 23H, y, z)    (* MULD z, Ry *)
                END ;
                OCC.PutF2(0FH, -1, y)    (* ADDQD -1, Ry *)
              END ;
              OCC.PutF4(17H, x, y)         (* MOVD apdynarrlen-1, TOS *)
            END
          ELSE
            LOOP f := atyp.form;
              IF f = Array THEN y.lev := -atyp.mno; y.a0 := atyp.adr
              ELSIF f = DynArr THEN y.lev := lev; y.a0 := atyp.adr + adr
              ELSE OCS.Mark(66); EXIT
              END ;
              OCC.PutF4(17H, x, y); ftyp := ftyp.BaseTyp; atyp := atyp.BaseTyp;
              IF ftyp.form # DynArr THEN
                IF ftyp # atyp THEN OCS.Mark(67) END ;
                EXIT
              END
            END
          END
        END DynArrBnd;

        PROCEDURE Trap*(n: INTEGER);
        BEGIN OCC.PutF1(0F2H); OCC.PutByte(n)  (*BPT n*)
        END Trap;

        PROCEDURE CompareParLists*(x, y: OCT.Object);
          VAR xt, yt: OCT.Struct;
        BEGIN
          WHILE x # NIL DO
            IF y # NIL THEN
              xt := x.typ; yt := y.typ;
              WHILE (xt.form = DynArr) & (yt.form = DynArr) DO
                xt := xt.BaseTyp; yt := yt.BaseTyp
              END ;
              IF x.mode # y.mode THEN OCS.Mark(115)
              ELSIF xt # yt THEN
                IF (xt.form = ProcTyp) & (yt.form = ProcTyp) THEN
                    CompareParLists(xt.link, yt.link)
                ELSE OCS.Mark(115)
                END
              END ;
              y := y.next
            ELSE OCS.Mark(116)
            END ;
            x := x.next
          END ;
          IF (y # NIL) & (y.mode <= Ind) & (y.a0 > 0) THEN OCS.Mark(117) END
        END CompareParLists;

        PROCEDURE Assign*(VAR x, y: OCT.Item; param: BOOLEAN);
          VAR f, g, L, u: INTEGER; s, vsz: LONGINT;
            p, q: OCT.Struct;
            xp, yp: OCT.Object;
            tag, tdes: OCT.Item;
        BEGIN f := x.typ.form; g := y.typ.form;
          IF x.mode = Con THEN OCS.Mark(56) END ;
          CASE f OF
          Undef, String:
        | Byte:IF g IN {Undef, Byte, Char, SInt} THEN
              IF param THEN moveBD(x, y) ELSE move(0, x, y) END
            ELSE OCS.Mark(113)
            END
        | Bool:IF param THEN u := 3 ELSE u := 0 END ;
            IF y.mode = Coc THEN
              IF (y.a1 = 0) & (y.a2 = 0) THEN OCC.PutF2(u+3CH, y.a0, x)
              ELSE
                IF ODD(y.a0) THEN OCC.PutF0(y.a0-1) ELSE OCC.PutF0(y.a0+1) END ;
                OCC.PutWord(y.a2); y.a2 := OCC.pc-2;
                OCC.FixLink(y.a1); OCC.PutF2(u+5CH, 1, x);
                OCC.PutF0(14); L := OCC.pc; OCC.PutWord(0);
                OCC.FixLink(y.a2); OCC.PutF2(u+5CH, 0, x); OCC.fixup(L)
              END
            ELSIF g = Bool THEN
              IF y.mode = Con THEN OCC.PutF2(u+5CH, y.a0, x)
              ELSIF param THEN OCC.Put(F7, 18H, x, y)  (*MOVZBD*)
              ELSE OCC.PutF4(14H, x, y)
              END
            ELSE OCS.Mark(113)
            END
        | Char, SInt:
            IF g = f THEN
              IF param THEN moveBD(x, y) ELSE move(0, x, y) END
            ELSE OCS.Mark(113)
            END
        | Int:  IF g = Int THEN
              IF param THEN moveWD(x, y) ELSE move(1, x, y) END
            ELSIF g = SInt THEN
              IF param THEN moveBD(x, y) ELSE moveBW(x, y) END
            ELSE OCS.Mark(113)
            END
        | LInt: IF g = LInt THEN move(3, x, y)
            ELSIF g = Int THEN moveWD(x, y)
            ELSIF g = SInt THEN moveBD(x, y)
            ELSE OCS.Mark(113)
            END
        | Real: IF g = Real THEN OCC.Put(F11, 5, x, y)
            ELSIF (SInt <= g) & (g <= LInt) THEN OCC.Put(F9, lengcode[g]+4, x, y)
```

```
        ELSE OCS.Mark(113)
        END
  | LReal: IF g = LReal THEN OCC.Put(F11, 4, x, y)
        ELSIF g = Real THEN OCC.Put(F9, 1BH, x, y)
        ELSIF (SInt <= g) & (g <= LInt) THEN OCC.Put(F9, lengcode[g], x, y)
        ELSE OCS.Mark(113)
        END
  | Set:   IF g = f THEN move(3, x, y) ELSE OCS.Mark(113) END
  | Pointer:
        IF x.typ = y.typ THEN move(3, x, y)
        ELSIF g = NilTyp THEN OCC.PutF2(5FH, 0, x)
        ELSIF g = Pointer THEN
          p := x.typ.BaseTyp; q := y.typ.BaseTyp;
          IF (p.form = Record) & (q.form = Record) THEN
            WHILE (q # p) & (q # NIL) DO q := q.BaseTyp END ;
            IF q # NIL THEN move(3, x, y) ELSE OCS.Mark(113) END
          ELSE OCS.Mark(113)
          END
        ELSE OCS.Mark(113)
        END
  | Array: s := x.typ.size;
        IF x.typ = y.typ THEN MoveBlock(x, y, s, param)
        ELSIF (g = String) & (x.typ.BaseTyp = OCT.chartyp) THEN
          s := y.a1; vsz := x.typ.n;  (*check length of string*)
          IF s > vsz THEN OCS.Mark(114) END ;
            IF param THEN
                    vsz := (vsz+3) DIV 4 - (s+3) DIV 4;
                    IF vsz > 0 THEN AdjustSP(vsz*4) END
            END ;
            MoveBlock(x, y, s, param)
        ELSE OCS.Mark(113)
        END
  | DynArr: s := x.typ.size;
        IF param THEN (*formal parameter is open array*)
          IF (g = String) & (x.typ.BaseTyp.form = Char) THEN Leng(x, y.a1-1)
          ELSIF y.mode >= Abs THEN OCS.Mark(59)
          ELSE DynArrBnd(x.typ, y.typ, y.lev, y.a0, FALSE)
          END ;
          IF g = DynArr THEN OCC.DynArrAdr(x, y)
          ELSE OCC.PutF4(27H, x, y)
          END
        ELSE OCS.Mark(113)
        END
  | Record: s := x.typ.size;
        IF x.typ # y.typ THEN
          IF g = Record THEN
            q := y.typ.BaseTyp;
            WHILE (q # NIL) & (q # x.typ) DO q := q.BaseTyp END ;
            IF q = NIL THEN OCS.Mark(113) END
          ELSE OCS.Mark(113)
          END
        END ;
        IF OCC.typchk & ~param &
          ( ((x.mode = Ind) OR (x.mode = RegI)) & (x.obj = OCC.wasderef)  (* p^ := *)
            OR (x.mode = Ind) & (x.obj # NIL) & (x.obj # OCC.wasderef) ) THEN
          tag := x; tdes.mode := Var; tdes.lev := -x.typ.mno; tdes.a0 := x.typ.adr;
```

```
         IF x.obj = OCC.wasderef THEN tag.a1 := - 4
         ELSE tag.mode := Var; INC(tag.a0, 4)
         END;
         OCC.PutF4(7, tdes, tag);      (* CMPD tag, tdes *)
         OCC.PutF0(0); OCC.PutDisp(4);      (* BEQ continue *)
         OCC.PutF1(0F2H); OCC.PutByte(19)            (* BPT 19 *)
      END ;
      MoveBlock(x, y, s, param)
| ProcTyp:
      IF (x.typ = y.typ) OR (y.typ = OCT.niltyp) THEN OCC.PutF4(17H, x, y)
      ELSIF (y.mode = XProc) OR (y.mode = IProc) THEN
         (*procedure y to proc. variable x; check compatibility*)
         IF x.typ.BaseTyp = y.typ THEN
            CompareParLists(x.typ.link, y.obj.dsc);
            IF y.a1 = 0 THEN
                    y.a1 := OCC.LinkAdr(-y.lev, y.a0); y.obj.a1 := y.a1
            END ;
            y.mode := Var; y.lev := SHORT(-y.a1); y.a0 := 0;
            OCC.PutF4(27H, x, y)   (*LXPD*)
         ELSE OCS.Mark(118)
         END
      ELSIF y.mode = LProc THEN OCS.Mark(119)
      ELSE OCS.Mark(111)
      END
| NoTyp, NilTyp: OCS.Mark(111)
   END
END Assign;

PROCEDURE FJ*(VAR loc: INTEGER);
BEGIN OCC.PutF0(14); OCC.PutWord(loc); loc := OCC.pc-2
END FJ;

PROCEDURE CFJ*(VAR x: OCT.Item; VAR loc: INTEGER);
BEGIN
   IF x.typ.form = Bool THEN
      IF x.mode # Coc THEN OCC.PutF2(1CH, 1, x); setCC(x, 0) END
   ELSE OCS.Mark(120); setCC(x, 0)
   END ;
   IF ODD(x.a0) THEN OCC.PutF0(x.a0-1) ELSE OCC.PutF0(x.a0+1) END ;
   loc := OCC.pc; OCC.PutWord(x.a2); OCC.FixLink(x.a1)
END CFJ;

PROCEDURE BJ*(loc: INTEGER);
BEGIN OCC.PutF0(14); OCC.PutDisp(loc - OCC.pc + 1)
END BJ;

PROCEDURE CBJ*(VAR x: OCT.Item; loc: INTEGER);
BEGIN
   IF x.typ.form = Bool THEN
      IF x.mode # Coc THEN OCC.PutF2(1CH, 1, x); setCC(x,0) END
   ELSE OCS.Mark(120); setCC(x, 0)
   END ;
   IF ODD(x.a0) THEN OCC.PutF0(x.a0-1) ELSE OCC.PutF0(x.a0+1) END ;
   OCC.PutDisp(loc - OCC.pc + 1);
   OCC.FixLinkWith(x.a2, loc); OCC.FixLink(x.a1)
END CBJ;
```

```
PROCEDURE LFJ*(VAR loc: INTEGER);
BEGIN OCC.PutF0(14); OCC.PutWord(-4000H); OCC.PutWord(0); loc := OCC.pc-4
END LFJ;

PROCEDURE PrepCall*(VAR x: OCT.Item; VAR fpar: OCT.Object);
BEGIN
  IF (x.mode = LProc) OR (x.mode = XProc) OR (x.mode = CProc) THEN
    fpar := x.obj.dsc
  ELSIF (x.typ # NIL) & (x.typ.form = ProcTyp) THEN
    fpar := x.typ.link
  ELSE OCS.Mark(121); fpar := NIL; x.typ := OCT.undftyp
  END
END PrepCall;

PROCEDURE Param*(VAR ap: OCT.Item; f: OCT.Object);
  VAR q: OCT.Struct; fp, tag: OCT.Item;
BEGIN fp.mode := Stk; fp.typ := f.typ;
  IF f.mode = Ind THEN (*VAR parameter*)
    IF ap.mode >= Con THEN OCS.Mark(122) END ;
    IF fp.typ.form = DynArr THEN
      DynArrBnd(fp.typ, ap.typ, ap.lev, ap.a0, TRUE);
      IF ap.typ.form = DynArr THEN OCC.DynArrAdr(fp, ap)
      ELSE OCC.PutF4(27H, fp, ap)
      END
    ELSIF (fp.typ.form = Record) & (ap.typ.form = Record) THEN
      q := ap.typ;
      WHILE (q # fp.typ) & (q # NIL) DO q := q.BaseTyp END ;
      IF q # NIL THEN
        IF (ap.mode = Ind) & (ap.obj # NIL) & (ap.obj # OCC.wasderef) THEN
                (*actual par is VAR-par*) ap.mode := Var; ap.a0 := ap.a0 + 4;
                OCC.PutF4(17H, fp, ap); ap.a0 := ap.a0 - 4; OCC.PutF4(17H, fp, ap)
        ELSIF ((ap.mode = Ind) OR (ap.mode = RegI)) & (ap.obj = OCC.wasderef) THEN
                (*actual par is p^*) ap.a1 := - 4; OCC.PutF4(17H, fp, ap);
                IF ap.mode = Ind THEN ap.mode := Var ELSE ap.mode := Reg END;
                OCC.PutF4(17H, fp, ap)
        ELSE
                tag.mode := Var; tag.lev := -ap.typ.mno; tag.a0 := ap.typ.adr;
                OCC.PutF4(17H, fp, tag); OCC.PutF4(27H, fp, ap)
        END
      ELSE OCS.Mark(111)
      END
    ELSIF (ap.typ = fp.typ) OR ((fp.typ.form = Byte)&(ap.typ.form IN {Char, SInt})) THEN
      IF (ap.mode = Ind) & (ap.a1 = 0) THEN (*actual var par*)
        ap.mode := Var; OCC.PutF4(17H, fp, ap)
      ELSE OCC.PutF4(27H, fp, ap)
      END
    ELSE OCS.Mark(123)
    END
  ELSE Assign(fp, ap, TRUE)
  END
END Param;

PROCEDURE Call*(VAR x: OCT.Item);
  VAR stk, sL: OCT.Item;
BEGIN
  IF x.mode = LProc THEN
    IF x.lev > 0 THEN
```

```
        sL.mode := Var; sL.typ := OCT.linttyp; sL.lev := x.lev; sL.a0 := 0;
        stk.mode := Stk; OCC.PutF4(27H, stk, sL)  (*static link*)
      END ;
      OCC.PutF1(2); OCC.PutDisp(x.a0 - OCC.pc + 1)  (*BSR*)
    ELSIF x.mode = XProc THEN
      IF x.a1 = 0 THEN
        x.a1 := OCC.LinkAdr(-x.lev, x.a0); x.obj.a1 := x.a1
      END ;
      OCC.PutF1(22H); OCC.PutDisp(SHORT(x.a1))     (*CXP*)
    ELSIF (x.mode < Con) & (x.typ # OCT.undftyp) THEN   (*CXPD*)
      OCC.PutF2(7FH, 0, x); x.typ := x.typ.BaseTyp
    ELSIF x.mode = CProc THEN
      OCC.PutF1(0E2H); OCC.PutByte(x.a0)           (*SVC n*)
    ELSE OCS.Mark(121)
    END
    (*function result is marked when restoring registers*)
  END Call;

  PROCEDURE Enter*(mode: SHORTINT; pno: LONGINT; VAR L: INTEGER);
  BEGIN
    IF mode # LProc THEN OCC.SetEntry(SHORT(pno)) END ;
    OCC.PutF1(82H);  (*ENTER*)
    IF mode = IProc THEN OCC.PutByte(0C0H) ELSE OCC.PutByte(0) END ;
    IF mode # Mod THEN L := OCC.pc; OCC.PutWord(0) ELSE OCC.PutByte(0) END
  END Enter;

  PROCEDURE CopyDynArray*(adr: LONGINT; typ: OCT.Struct);
    VAR size, ptr, m2, tos: OCT.Item; add: SHORTINT;

    PROCEDURE DynArrSize(typ: OCT.Struct);
      VAR len: OCT.Item;
    BEGIN
      IF typ.form = DynArr THEN DynArrSize(typ.BaseTyp);
        len.mode := Var; len.lev := OCC.level; len.typ := OCT.linttyp;
        len.a0 := adr + typ.adr; load(len);
        IF (size.mode # Con) OR (size.a0 # 1) THEN
          IF add = 4 THEN OCC.PutF2(0FH, 1, size) END; (* ADDQD 1, size *)
          OCC.PutF2(0FH, 1, len); add := 3; (* ADDQD 1, len *)
          OCC.Put(F7, 23H, len, size)          (* MULD size, len *)
        ELSE add := 4
        END;
        size := len
      ELSE size.mode := Con; size.typ := OCT.linttyp; size.a0 := typ.size
      END
    END DynArrSize;

  BEGIN add := 3;
    DynArrSize(typ);          (* load total byte size of dyn array *)
    OCC.PutF2(0FH, add, size);       (* ADDQD 3 or 4, size *)
    m2.mode := Con; m2.typ := OCT.sinttyp;
    m2.a0 := -2; OCC.Put(F6, 7, size, m2);    (* ASHD -2, size *)
    ptr.mode := Var; ptr.lev := OCC.level; ptr.typ := OCT.linttyp;
    ptr.a0 := adr; load(ptr);
    ptr.mode := RegX; ptr.a1 := -4; ptr.a2 := size.a0; tos.mode := Stk;
    OCC.PutF4(17H, tos, ptr);         (* loop:  MOVD -4(ptr)[size:D], TOS *)
    OCC.PutF2(4FH, -1, size); OCC.PutDisp(-4);       (* ACBD -1, size, loop *)
    OCC.PutF3(-31D9H); OCC.PutDisp(0); OCC.PutDisp(adr);             (*      ADDR      0(SP),
adr(FP) *)
```

```
   OCC.FreeRegs({})
END CopyDynArray;

PROCEDURE Result*(VAR x: OCT.Item; typ: OCT.Struct);
   VAR res: OCT.Item;
BEGIN res.mode := Reg; res.typ := typ; res.a0 := 0;
   Assign(res, x, FALSE)
END Result;

PROCEDURE Return*(mode: INTEGER; psize: LONGINT);
BEGIN OCC.PutF1(92H);                              (*EXIT*)
   IF mode = LProc THEN
      OCC.PutByte(0); OCC.PutF1(12H); OCC.PutDisp(psize-8)  (*RET*)
   ELSIF mode = XProc THEN
      OCC.PutByte(0); OCC.PutF1(32H); OCC.PutDisp(psize-12) (*RXP*)
   ELSIF mode = IProc THEN
      OCC.PutByte(3); OCC.PutF1(42H); OCC.PutDisp(0)        (*RETT 0*)
   END
END Return;

PROCEDURE CaseIn*(VAR x: OCT.Item; VAR L0, L1: INTEGER);
   VAR f: INTEGER; r, x0, lim: OCT.Item;
BEGIN f := x.typ.form;
   IF f # Int THEN
      IF f = Char THEN
         x0 := x; OCC.GetReg(x); OCC.Put(F7, 14H, x, x0)  (*MOVZBW*)
      ELSIF f = SInt THEN
         x0 := x; OCC.GetReg(x); OCC.Put(F7, 10H, x, x0)  (*MOVXBW*)
      ELSIF f # LInt THEN OCS.Mark(125)
      END ;
      f := Int
   END ;
   IF (x.mode IN {VarX, IndX, RegX}) OR
         (x.mode # Reg) & (x.lev > 0) & (x.lev < OCC.level) THEN
      x0 := x; OCC.GetReg(x); OCC.PutF4(15H, x, x0)  (*MOVW*)
   END ;
   L0 := OCC.pc+3;   (*fixup loc for bounds adr*)
   lim.mode := Var; lim.typ := OCT.inttyp; lim.lev := 0; lim.a0 := 100H;
   OCC.GetReg(r); OCC.Put(0EEH, SHORT(r.a0)*8 + 1, x, lim);   (*CHECK*)
   OCC.PutF0(8); OCC.PutWord(0); L1 := OCC.pc;         (*BFS*)
   lim.mode := VarX; lim.a2 := r.a0; OCC.PutF2(7DH, 14, lim)  (*CASE*)
END CaseIn;

PROCEDURE CaseOut*(L0, L1, L2, L3, n: INTEGER;
         VAR tab: ARRAY OF LabelRange);
   VAR i, j, lim: INTEGER; k: LONGINT;
BEGIN (*generate jump table*)
   IF n > 0 THEN OCC.AllocBounds(tab[0].low, tab[n-1].high, k)
   ELSE (*no cases*) OCC.AllocBounds(1, 0, k)
   END ;
   j := SHORT(k);
   OCC.FixupWith(L0, j);         (*bounds address in check*)
   OCC.FixupWith(L1-2, L2-L1+3); (*out of bounds jump addr*)
   OCC.FixupWith(L1+3, j+4);     (*jump address to table*)
   i := 0; j := tab[0].low;
   WHILE i < n DO
      lim := tab[i].high;
      WHILE j < tab[i].low DO
```

```
            OCC.AllocInt(L2-L1); INC(j)  (*else*)
          END ;
          WHILE j <= lim DO
            OCC.AllocInt(tab[i].label-L1); INC(j)
          END ;
          INC(i)
        END ;
        OCC.FixLink(L3)
      END CaseOut;

    BEGIN lengcode[Undef] := 0;
      lengcode[Byte] := 0; lengcode[Bool] := 0; lengcode[Char] := 0; lengcode[SInt] := 0;
      lengcode[Int] := 1; lengcode[LInt] := 3; lengcode[Real] := 1; lengcode[LReal] := 0;
      lengcode[Set] := 3; lengcode[String] := 0; lengcode[NilTyp] := 3; lengcode[ProcTyp] := 3;
      lengcode[Pointer] := 3; lengcode[Array] := 1; lengcode[DynArr] := 1; lengcode[Record] := 1
    END OCH.
```

12.8. Code Generation

The subject of this Section is module OCC which generates code in binary form. Its procedures are inherently target architecture dependent. The details are of much less general interest than the parts of the compiler presented so far, and we therefore keep explanations reasonably short. Nevertheless, a brief summary of the NS-32000 architecture's instruction formats will be given below in order to enable the reader to understand the principal routines of OCC. The presented architecture is of the CISC class with a fairly elaborate set of instructions (of which only a part is used by the compiler) and addressing modes. However, it features a commendable regularity. For example, all addressing modes are equally applicable independent of the particular instruction.

The NS-32000 instruction stream is byte-oriented, i.e. every instruction consists of a number of bytes. The first 1, 2, or 3 bytes constitute the instruction code including address mode specifiers. They are followed by additional bytes depending on the addressing modes used. These bytes specify addresses (called displacements, because they are relative to a base address held in a register), constants, or index registers. We first present the various formats of the leading instruction bytes, the so-called basic instruction. The fields dst and src are the address mode specifiers for destination and source operands, and they will be explained below.

Format 0

4	0
cond	1010

Bcond

Format 1

op	0010

0	BSR	3	RXP	7	RESTORE	D	FLAG
1	RET	4	RETT	8	ENTER	E	SVC
2	CXP	6	SAVE	9	EXIT	F	BPT

Format 2

11	7	4	2	0
dst	val	op	11	i

0	ADDQi	3	Scond	5	MOVQi
1	CMPQi	4	ACBi		

Format 3

dst	op	11111 i

0	CXPD	A	ADISPi	E	CASE

Format 4

11	6	2	0
dst	src	op	i

0	ADDi	6	ORi	A	ANDi
1	CMPi	8	SUBi	D	TBITi
2	BICi	9	ADDR	E	XORi
5	MOVi				

Format 6

dst	src	op	i	4E

0	ROTi	8	NEGi
1	ASHi	C	ABSi
5	LSHi	D	COMi

Format 7

dst	src	op	i	CE

0	MOVMi	8	MULi
4	MOVXBW	E	MODi
5	MOVZBW	F	DIVi
7	MOVXiD		

Format 8

dst	src	reg	001	EE	CHECKW
dst	src	reg	101	2E	INDEXW

Format 9

dst	src	op	fi	3E

0	MOVif	3	MOVFL
2	MOVLF	7	FLOORfi

Format 11

dst	src	op	0f	BE

0	ADDf	5	NEGf
1	MOVf	8	DIVf
2	CMPf	C	MULf
4	SUBf	D	ABSf

The *dst* and *src* fields specify an addressing mode *m* as follows; *d*0 and *d1* are displacements:

m	operand address	mode
0 - 7	operand = R[m]	register direct
8 - 15	R[m-8]	register indirect
16	Mem[FP+d0]+d1	indirect, base FP
18	Mem[SB+d0]+d1	indirect, base SB
20		immediate
21	d0	absolute
22	EXT(d0)+d1	external
23	SP	TOS
24	FP+d0	base FP
26	SB+d0	base SB
28 - 31		indexed, scale factor 1, 2, 4, 8

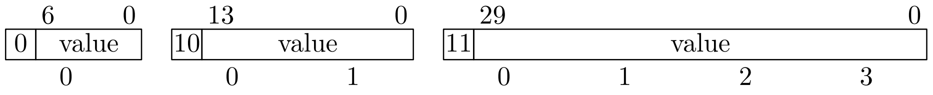
The basic instruction bytes containing the opcode and the address specifiers are followed by the operand bytes in the order shown below from right to left. The operand fields may contain one or two displacement values, or an immediate value, or they may be missing alltogether.

implied	dst disp/imm	src disp/imm	dst index	src index	src	dst	op

Index bytes are present only if an indexed mode is specified. They indicate the register holding the index value, and the mode to be used in the basic address computation. Some instructions contain additional, implied operands.

mode (7–3)	reg (2–0)

Displacements are length-encoded as follows (the values are stored as signed integers in most-significant byte first order, contrary to the little-endian representation of integers used by this processor):



Instructions are generated by procedures *PutF0, PutF1, PutF2, PutF3, PutF4,* and *Put(F),* depending on the format required. Procedures *PutByte* and *PutWord* are used to append immediate operands, and *PutDisp* to encode and insert displacements. Instructions, immediate values, and displacements are inserted in the array code, a global variable. This solution strictly limits the size of modules, but allows for easy fixup of (branch) addresses and is very efficient, because it avoids the use of dynamic allocation.

Similarly, the global arrays *constant*, *entry*, and *link* hold constants, entry addresses of exported procedures, and links for imports. Constants are inserted by procedures *AllocInt*, *AllocString*, *AllocTypDesc*, and *AllocBounds*. Entry addresses are recorded by procedure *SetEntry*, and links are inserted by procedure *LinkAdr*. Various fixup procedures handle the insertion of branch displacements for forward jumps. *SaveRegisters* and *RestoreRegisters* are called for saving and restoring registers (holding intermediate results) before and after a call of a function procedure within an expression.

An object file is generated at the end of a module's compilation by procedure *OutCode*. For a description of the object file format the reader is referred to Chapter 6. First, the symbol table's global scope is scanned for pointer variables and command procedures. Then the header is written and the various tables used by the loader, containing entry addresses, commands, pointers, imports, and links. Then follows the table of global constants, then the code, and finally type descriptor information used by the loader to generate and allocate type descriptors on the heap.

After the actual object file data, a part is appended which is called *reference block*. It is ignored by the loader, but is used in the case of traps during execution of a program for generating a "post-mortem dump" in symbolic form (see Sect. 12.9). For this purpose, the reference block contains the names of variables and procedures together with their addresses. The information is obtained by a full traversal of the symbol table. (Note that only variables of basic, unstructured type and short character arrays are included).

At least one detail about the implementation of module OCC is worth mentioning. It concerns the generation of code for two-address instructions (procedures *PutF4* and *Put*). Due to the rather complicated ordering of operand fields following a basic instruction, it is impossible to first emit an operation code, and then to let it be followed by the two operands. Not only are the address specifiers of both operands contained in the basic instruction bytes, but both index bytes (if any) precede all displacements. Therefore, all parts of both operand's specifications must be available before any emission can take place. The solution chosen is to use two local variables *dst* and *src* of type *Argument* representing the encoded forms of operands, which is computed by procedure *Operand* from a given *Item*. After this computation, the basic instruction bytes are emitted, followed by the operand bytes. The latter is done by procedure *PutArg*. One cannot help but feel that the prescribed instruction format is not exactly the optimal choice.

```
MODULE OCC;  (*NW 30.5.87 / 16.3.91*)
  IMPORT Files, OCS, OCT;

  CONST CodeLength = 18000; LinkLength = 250;
        ConstLength = 3500; EntryLength = 64;
        CodeLim = CodeLength - 100;
        MaxPtrs = 64; MaxRecs = 32; MaxComs = 40; MaxExts = 7;
    (*instruction format prefixes*)
      F6 = 4EH; F7 = 0CEH; F9 = 3EH; F11 = 0BEH;

    (*object and item modes*)
      Var   =  1; VarX  =  2; Ind   =  3; IndX  =  4; RegI  =  5;
      RegX  =  6; Abs   =  7; Con   =  8; Stk   =  9; Coc   = 10;
      Reg   = 11; Fld   = 12; Typ   = 13; LProc = 14; XProc = 15;
      SProc = 16; CProc = 17; IProc = 18; Mod   = 19; Head  = 20;

    (*structure forms*)
      Undef = 0; Byte = 1; Bool = 2; Char = 3; SInt = 4; Int = 5; LInt = 6;
      Real = 7; LReal = 8; Set = 9; String = 10; NilTyp = 11; NoTyp = 12;
      Pointer = 13; ProcTyp = 14; Array = 15; DynArr = 16; Record = 17;

  TYPE Argument =
      RECORD form, gen, inx: INTEGER;
        d1, d2: LONGINT
      END ;
```

```
VAR pc*, level*: INTEGER;
    wasderef*: OCT.Object;
    typchk*: BOOLEAN;
    RegSet*, FRegSet: SET;
    lnkx, conx, nofptrs, nofrec: INTEGER;
    PtrTab: ARRAY MaxPtrs OF LONGINT;
    RecTab: ARRAY MaxRecs OF OCT.Struct;
    constant: ARRAY ConstLength OF CHAR;
    code:  ARRAY CodeLength OF CHAR;
    link:  ARRAY LinkLength OF INTEGER;
    entry: ARRAY EntryLength OF INTEGER;

PROCEDURE GetReg*(VAR x: OCT.Item);
  VAR i: INTEGER;
BEGIN i := 7; x.mode := Reg;
  LOOP IF ~(i IN RegSet) THEN x.a0 := i; INCL(RegSet,i); EXIT END ;
       IF i = 0 THEN x.a0 := 0; OCS.Mark(215); EXIT ELSE DEC(i) END ;
  END
END GetReg;

PROCEDURE GetFReg*(VAR x: OCT.Item);
  VAR i: INTEGER;
BEGIN i := 6; x.mode := Reg;
  LOOP IF ~(i IN FRegSet) THEN x.a0 := i; INCL(FRegSet,i); EXIT END ;
       IF i = 0 THEN x.a0 := 0; OCS.Mark(216); EXIT ELSE i := i-2 END
  END
END GetFReg;

PROCEDURE FreeRegs*(r: SET);
BEGIN RegSet := r; FRegSet := {}
END FreeRegs;

PROCEDURE AllocInt*(k: INTEGER);
BEGIN
  IF conx < ConstLength-1 THEN
    constant[conx] := CHR(k); INC(conx);
    constant[conx] := CHR(k DIV 100H); INC(conx)
  ELSE OCS.Mark(230); conx := 0
  END
END AllocInt;

PROCEDURE AllocString*(VAR s: ARRAY OF CHAR; VAR x: OCT.Item);
  VAR i: INTEGER; ch: CHAR;
BEGIN INC(conx, (-conx) MOD 4); i := 0;
  REPEAT ch := s[i]; INC(i);
    IF conx >= ConstLength THEN OCS.Mark(230); conx := 0 END ;
    constant[conx] := ch; INC(conx)
  UNTIL ch = 0X;
  x.lev := 0; x.a0 := conx - i; x.a1 := i
END AllocString;

PROCEDURE AllocBounds*(min, max: INTEGER; VAR adr: LONGINT);
BEGIN INC(conx, (-conx) MOD 4); adr := conx;
  AllocInt(max); AllocInt(min)
END AllocBounds;

PROCEDURE PutByte*(x: LONGINT);
BEGIN code[pc] := CHR(x); INC(pc)
END PutByte;
```

```
PROCEDURE PutWord*(x: LONGINT);
BEGIN code[pc] := CHR(x DIV 100H); INC(pc); code[pc] := CHR(x); INC(pc)
END PutWord;

PROCEDURE PutDbl(x: LONGINT);
  VAR i: INTEGER;
BEGIN i := -32;
  REPEAT INC(i, 8); code[pc] := CHR(ASH(x, i)); INC(pc) UNTIL i = 0
END PutDbl;

PROCEDURE PutDisp*(x: LONGINT);
BEGIN
  IF x < 0 THEN
    IF x >= -40H THEN code[pc] := CHR(x+80H); INC(pc)
    ELSIF x >= -2000H THEN PutWord(x+0C000H)
    ELSE PutDbl(x)
    END
  ELSIF x < 40H THEN code[pc] := CHR(x); INC(pc)
  ELSIF x < 2000H THEN PutWord(x+8000H)
  ELSE PutDbl(x - 40000000H)
  END
END PutDisp;

PROCEDURE PutArg(VAR z: Argument);
BEGIN
  CASE z.form OF
    0: IF z.inx = 1 THEN code[pc] := CHR(z.d1); INC(pc)
      ELSIF z.inx = 2 THEN PutWord(z.d1)
      ELSIF z.inx = 4 THEN PutDbl(z.d1)
      ELSE PutDbl(z.d2); PutDbl(z.d1)
      END
  | 1:  PutDisp(z.d1)
  | 2, 5:
  | 3, 6:  PutDisp(z.d1)
  | 4, 7:  PutDisp(z.d1); PutDisp(z.d2)
  END
END PutArg;

PROCEDURE PutF3*(op: INTEGER);
BEGIN code[pc] := CHR(op); INC(pc); code[pc] := CHR(op DIV 100H); INC(pc)
END PutF3;

PROCEDURE Operand(VAR x: OCT.Item; VAR z: Argument);
  VAR F: INTEGER;

  PROCEDURE downlevel(VAR gen: INTEGER);
    VAR n, op: INTEGER; b: OCT.Item;
  BEGIN GetReg(b); n := level - x.lev; gen := SHORT(b.a0) + 8;
    op := SHORT(b.a0)*40H - 3FE9H;
    IF n = 1 THEN PutF3(op); PutDisp(8);  (*MOVD 8(FP) Rb*)
    ELSE PutF3(op - 4000H); PutDisp(8); PutDisp(8);  (*MOVD 8(8(FP)) Rb*)
      WHILE n > 2 DO DEC(n);
        PutF3((SHORT(b.a0)*20H + SHORT(b.a0))*40H + 4017H); PutDisp(8)
      END
    END ;
  END downlevel;

  PROCEDURE index;
    VAR s: LONGINT;
  BEGIN s := x.typ.size;
    IF s = 1 THEN z.gen := 1CH
    ELSIF s = 2 THEN z.gen := 1DH
    ELSIF s = 4 THEN z.gen := 1EH
    ELSIF s = 8 THEN z.gen := 1FH
    ELSE z.gen := 1CH; PutByte(F7); PutByte(x.a2 MOD 4 * 40H + 23H);
      PutByte(x.a2 DIV 4 + 0A0H); PutWord(0); PutWord(s)  (*MUL r s*)
   END ;
  END index;

BEGIN F := x.mode;
  CASE x.mode OF
   Var:   IF x.lev = 0 THEN
      z.gen := 1AH; z.d1 := x.a0; z.form := 3
    ELSIF x.lev < 0 THEN (*EXT*)
      z.gen := 16H; z.d1 := -x.lev; z.d2 := x.a0; z.form := 4
    ELSIF x.lev = level THEN
      z.gen := 18H; z.d1 := x.a0; z.form := 3
    ELSIF x.lev+1 = level THEN
      z.gen := 10H; z.d1 := 8; z.d2 := x.a0; z.form := 4
    ELSE downlevel(z.gen); z.d1 := x.a0; z.form := 3
    END
   | Ind:  IF x.lev = 0 THEN
      z.gen := 12H; z.d1 := x.a0; z.d2 := x.a1; z.form := 4
    ELSIF x.lev = level THEN
      z.gen := 10H; z.d1 := x.a0; z.d2 := x.a1; z.form := 4
    ELSE downlevel(z.gen);
      PutF3((z.gen*20H + z.gen-8)*40H + 17H); PutDisp(x.a0);
      z.d1 := x.a1; z.form := 3
    END
   | RegI:            z.gen := SHORT(x.a0)+8; z.d1 := x.a1; z.form := 3
   | VarX:            index;
    IF x.lev = 0 THEN
      z.inx := 1AH; z.d1 := x.a0; z.form := 6
    ELSIF x.lev < 0 THEN (*EXT*)
      z.inx := 16H; z.d1 := -x.lev; z.d2 := x.a0; z.form := 7
    ELSIF x.lev = level THEN
      z.inx := 18H; z.d1 := x.a0; z.form := 6
    ELSIF x.lev+1 = level THEN
      z.inx := 10H;  z.d1 := 8; z.d2 := x.a0; z.form := 7
    ELSE downlevel(z.inx); z.d1 := x.a0; z.form := 6
    END ;
    z.inx := z.inx*8 + SHORT(x.a2)
   | IndX:            index;
    IF x.lev = 0 THEN
      z.inx := 12H; z.d1 := x.a0; z.d2 := x.a1; z.form := 7
    ELSIF x.lev = level THEN
      z.inx := 10H; z.d1 := x.a0; z.d2 := x.a1; z.form := 7
    ELSE downlevel(z.inx);
      PutF3((z.inx*20H + z.inx-8)*40H + 17H); PutDisp(x.a0);
      z.d1 := x.a1; z.form := 6
    END ;
    z.inx := z.inx * 8 + SHORT(x.a2)
   | RegX:            index; z.inx := SHORT((x.a0+8)*8 + x.a2); z.d1 := x.a1; z.form := 6
   | Con:CASE x.typ.form OF
    Undef, Byte, Bool, Char, SInt:
      z.gen := 14H; z.inx := 1; z.d1 := x.a0; z.form := 0
      | Int:         z.gen := 14H; z.inx := 2; z.d1 := x.a0; z.form := 0
      | LInt, Real, Set, Pointer, ProcTyp, NilTyp:
      z.gen := 14H; z.inx := 4; z.d1 := x.a0; z.form := 0
      | LReal:
      z.gen := 14H; z.inx := 8; z.d1 := x.a0; z.d2 := x.a1; z.form := 0
      | String:
      z.gen := 1AH; z.d1 := x.a0; z.form := 3
      END
    | Reg: z.gen := SHORT(x.a0); z.form := 2
    | Stk: z.gen := 17H;  z.form := 2
    | Abs: z.gen := 15H; z.form := 1; z.d1 := x.a0
    | Coc, Fld .. Head: OCS.Mark(126); x.mode := Var; z.form := 0
  END
END Operand;

PROCEDURE PutF0*(cond: LONGINT);
BEGIN code[pc] := CHR(cond*10H + 10); INC(pc)
END PutF0;

PROCEDURE PutF1*(op: INTEGER);
BEGIN code[pc] := CHR(op); INC(pc)
END PutF1;

PROCEDURE PutF2*(op: INTEGER; short: LONGINT; VAR x: OCT.Item);
VAR dst: Argument;
BEGIN Operand(x, dst);
code[pc] := CHR(SHORT(short) MOD 2 * 80H + op); INC(pc);
code[pc] := CHR(dst.gen*8 + SHORT(short) MOD 10H DIV 2);
INC(pc);
IF dst.form > 4 THEN code[pc] := CHR(dst.inx); INC(pc) END ;
PutArg(dst)
END PutF2;

PROCEDURE PutF4*(op: INTEGER; VAR x, y: OCT.Item);
VAR dst, src: Argument;
BEGIN Operand(x, dst); Operand(y, src);
code[pc] := CHR(dst.gen MOD 4 * 40H + op); INC(pc);
code[pc] := CHR(src.gen*8 + dst.gen DIV 4); INC(pc);
IF src.form > 4 THEN code[pc] := CHR(src.inx); INC(pc) END ;
IF dst.form > 4 THEN code[pc] := CHR(dst.inx); INC(pc) END ;
PutArg(src); PutArg(dst)
END PutF4;

PROCEDURE Put*(F, op: INTEGER; VAR x, y: OCT.Item);
VAR dst, src: Argument;
BEGIN Operand(x, dst); Operand(y, src); code[pc] := CHR(F); INC(pc);
code[pc] := CHR(dst.gen MOD 4 * 40H + op); INC(pc);
code[pc] := CHR(src.gen*8 + dst.gen DIV 4); INC(pc);
IF src.form > 4 THEN code[pc] := CHR(src.inx); INC(pc) END ;
IF dst.form > 4 THEN code[pc] := CHR(dst.inx); INC(pc) END ;
PutArg(src); PutArg(dst)
END Put;

PROCEDURE AllocTypDesc*(typ: OCT.Struct);   (* typ.form = Record *)
BEGIN INC(conx, (-conx) MOD 4); typ.mno := 0; typ.adr := conx;
IF typ.n > MaxExts THEN OCS.Mark(233)
ELSIF nofrec < MaxRecs THEN
  PtrTab[nofptrs] := conx; INC(nofptrs);
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      RecTab[nofrec] := typ; INC(nofrec);
      AllocInt(0); AllocInt(0)
    ELSE OCS.Mark(223)
    END
  END AllocTypDesc;

  PROCEDURE InitTypDescs*;
    VAR x, y: OCT.Item; i: INTEGER; typ: OCT.Struct;
  BEGIN
    x.mode := Ind; x.lev := 0; y.mode := Var; i := 0;
    WHILE i < nofrec DO typ := RecTab[i]; INC(i); x.a0 := typ.adr;
      WHILE typ.BaseTyp # NIL DO (*initialization of base tag fields*)
        x.a1 := typ.n * 4; y.lev := -typ.mno; y.a0 := typ.adr; PutF4(17H, x, y);
        typ := typ.BaseTyp
      END
    END
  END InitTypDescs;

  PROCEDURE SaveRegisters*(VAR gR, fR: SET; VAR x: OCT.Item);
    VAR i, r, m: INTEGER; t: SET;
  BEGIN t := RegSet;
    IF x.mode IN {Reg, RegI, RegX} THEN EXCL(RegSet, x.a0) END ;
    IF x.mode IN {VarX, IndX, RegX} THEN EXCL(RegSet, x.a2) END ;
    gR := RegSet; fR := FRegSet;
    IF RegSet # {} THEN
      i := 0; r := 1; m := 0;
      REPEAT
        IF i IN RegSet THEN INC(m, r) END ;
        INC(r, r); INC(i)
      UNTIL i = 8;
      PutF1(62H); PutByte(m)
    END ;
    RegSet := t - RegSet; i := 0;
    WHILE FRegSet # {} DO
      IF i IN FRegSet THEN
        PutF1(F11); PutF3(i*800H + 5C4H); EXCL(FRegSet, i)
      END ;
      INC(i, 2)
    END
  END SaveRegisters;

  PROCEDURE RestoreRegisters*(gR, fR: SET; VAR x: OCT.Item);
    VAR i, r, m: INTEGER; y: OCT.Item;
  BEGIN RegSet := gR; FRegSet := fR; i := 8;
    (*set result mode*) x.mode := Reg; x.a0 := 0;
    IF (x.typ.form = Real) OR (x.typ.form = LReal) THEN
      IF 0 IN fR THEN GetFReg(y); Put(F11, 4, y, x); x.a0 := y.a0 END ;
      INCL(FRegSet, 0)
    ELSE
      IF 0 IN gR THEN GetReg(y); PutF4(17H, y, x); x.a0 := y.a0 END ;
      INCL(RegSet, 0)
    END ;
    WHILE fR # {} DO
      DEC(i, 2);
      IF i IN fR THEN
        PutF1(F11); PutF3(i*40H - 47FCH); EXCL(fR, i)
      END
    END ;
    IF gR # {} THEN
      i := 8; r := 1; m := 0;
      REPEAT DEC(i);
        IF i IN gR THEN INC(m, r) END ;
        INC(r, r)
      UNTIL i = 0;
      PutF1(72H); PutF1(m)
    END
  END RestoreRegisters;

  PROCEDURE DynArrAdr*(VAR x, y: OCT.Item);  (* x := ADR(y) *)
    VAR l, z: OCT.Item;
  BEGIN
    WHILE y.typ.form = DynArr DO          (* index with 0 *)
      IF y.mode = IndX THEN
        l.mode := Var; l.a0 := y.a0 + y.typ.adr; l.lev := y.lev;
        (* l = actual dimension length - 1 *)
        z.mode := Con; z.a0 := 0; z.typ := OCT.inttyp;
        Put(2EH, SHORT(y.a2)*8+5, z, l)   (* INDEXW inxreg, l, 0 *)
      END;
      y.typ := y.typ.BaseTyp
    END;
    IF (y.mode = Var) OR (y.mode = Ind) & (y.a1 = 0) THEN
      y.mode := Var; PutF4(17H, x, y)     (* MOVD *)
    ELSE PutF4(27H, x, y); x.a1 := 0      (* ADDR *)
    END
  END DynArrAdr;

  PROCEDURE Entry*(i: INTEGER): INTEGER;
  BEGIN RETURN entry[i]
  END Entry;

  PROCEDURE SetEntry*(i: INTEGER);
  BEGIN entry[i] := pc
  END SetEntry;

  PROCEDURE LinkAdr*(m: INTEGER; n: LONGINT): INTEGER;
  BEGIN
    IF lnkx >= LinkLength THEN OCS.Mark(231); lnkx := 0 END ;
    link[lnkx] := m*100H + SHORT(n); INC(lnkx); RETURN lnkx-1
  END LinkAdr;

  PROCEDURE SetLinkTable*(n: INTEGER);
  BEGIN (*base addresses of imported modules*) lnkx := 0;
    WHILE lnkx < n DO link[lnkx] := lnkx*100H + 255; INC(lnkx) END
  END SetLinkTable;

  PROCEDURE fixup*(loc: LONGINT);  (*enter pc at loc*)
    VAR x: LONGINT;
  BEGIN x := pc - loc + 8001H;
    code[loc] := CHR(x DIV 100H); code[loc+1] := CHR(x)
  END fixup;

  PROCEDURE fixupC*(loc: LONGINT);
    VAR x: LONGINT;
  BEGIN x := pc+1 - loc;
    IF x > 3 THEN
      IF x < 2000H THEN
        code[loc] := CHR(x DIV 100H + 80H); code[loc+1] := CHR(x)
      ELSE OCS.Mark(211)
      END
    ELSE DEC(pc, 3)
    END
  END fixupC;

  PROCEDURE fixupL*(loc: LONGINT);
    VAR x: LONGINT;
  BEGIN x := pc+1 - loc;
    IF x > 5 THEN
      code[loc+2] := CHR(x DIV 100H); code[loc+3] := CHR(x)
    ELSE DEC(pc, 5)
    END
  END fixupL;

  PROCEDURE FixLink*(L: LONGINT);
    VAR L1: LONGINT;
  BEGIN
    WHILE L # 0 DO
      L1 := ORD(code[L])*100H + ORD(code[L+1]);
      fixup(L); L := L1
    END
  END FixLink;

  PROCEDURE FixupWith*(L, val: LONGINT);
    VAR x: LONGINT;
  BEGIN x := val MOD 4000H + 8000H;
    IF ABS(val) >= 2000H THEN OCS.Mark(208) END ;
    code[L] := CHR(x DIV 100H); code[L+1] := CHR(x)
  END FixupWith;

  PROCEDURE FixLinkWith*(L, val: LONGINT);
    VAR L1: LONGINT;
  BEGIN
    WHILE L # 0 DO
      L1 := ORD(code[L])*100H + ORD(code[L+1]);
      FixupWith(L, val+1 - L); L := L1
    END
  END FixLinkWith;
  PROCEDURE MergedLinks*(L0, L1: LONGINT): LONGINT;
    VAR L2, L3: LONGINT;
  BEGIN (*merge chains of the two operands of AND and OR *)
    IF L0 # 0 THEN L2 := L0;
      LOOP L3 := ORD(code[L2])*100H + ORD(code[L2+1]);
        IF L3 = 0 THEN EXIT END ;
        L2 := L3
      END ;
      code[L2] := CHR(L1 DIV 100H); code[L2+1] := CHR(L1);
      RETURN L0
    ELSE RETURN L1
    END
  END MergedLinks;

  PROCEDURE Init*;
    VAR i: INTEGER;
  BEGIN pc := 0; level := 0; lnkx := 0; conx := 0; nofptrs := 0; nofrec := 0;
    RegSet := {}; FRegSet := {}; i := 0;
    REPEAT entry[i] := 0; INC(i) UNTIL i = EntryLength
  END Init;

  PROCEDURE OutCode*(VAR name, progid: ARRAY OF CHAR;
                  key: LONGINT; entno: INTEGER; datasize: LONGINT);
    CONST ObjMark = 0F8X;
    VAR ch: CHAR; f, i, m: INTEGER;
        K, s, s0, refpos: LONGINT;
        nofcom, comsize, align: INTEGER;
        obj:    OCT.Object;
        typ:    OCT.Struct;
        ObjFile:   Files.File;
        out:    Files.Rider;
        ComTab: ARRAY MaxComs OF OCT.Object;

    PROCEDURE W(n: INTEGER);
    BEGIN Files.Write(out, CHR(n)); Files.Write(out, CHR(n DIV 100H))
    END W;

    PROCEDURE WriteName(VAR name: ARRAY OF CHAR; n: INTEGER);
      VAR i: INTEGER; ch: CHAR;
    BEGIN i := 0;
      REPEAT ch := name[i]; Files.Write(out, ch); INC(i) UNTIL ch = 0X;
      WHILE i < n DO Files.Write(out, 0X); INC(i) END
    END WriteName;

    PROCEDURE FindPtrs(typ: OCT.Struct; adr: LONGINT);
      VAR fld: OCT.Object; btyp: OCT.Struct;
        i, n, s: LONGINT;
    BEGIN
      IF typ.form = Pointer THEN
        IF nofptrs < MaxPtrs THEN PtrTab[nofptrs] := adr; INC(nofptrs)
        ELSE OCS.Mark(222)
        END
      ELSIF typ.form = Record THEN
        btyp := typ.BaseTyp;
        IF btyp # NIL THEN FindPtrs(btyp, adr) END ;
        fld := typ.link;
        WHILE fld # NIL DO
          IF fld.name # "" THEN FindPtrs(fld.typ, fld.a0 + adr)
          ELSIF nofptrs < MaxPtrs THEN PtrTab[nofptrs] := fld.a0 + adr; INC(nofptrs)
          ELSE OCS.Mark(222)
          END ;
          fld := fld.next
        END
      ELSIF typ.form = Array THEN
        btyp := typ.BaseTyp; n := typ.n;
        WHILE btyp.form = Array DO n := btyp.n * n; btyp := btyp.BaseTyp END ;
        IF (btyp.form = Pointer) OR (btyp.form = Record) THEN
          i := 0; s := btyp.size;
          WHILE i < n DO FindPtrs(btyp, i*s + adr); INC(i) END
        END
      END
    END FindPtrs;

    PROCEDURE PtrsAndComs;
      VAR obj, par: OCT.Object; u: INTEGER;
    BEGIN obj := OCT.topScope.next;
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      WHILE obj # NIL DO
        IF obj.mode = XProc THEN par := obj.dsc;
          IF entry[SHORT(obj.a0)] = 0 THEN OCS.Mark(129)
          ELSIF (obj.marked) & (obj.typ = OCT.notyp) &
                  ((par = NIL) OR (par.mode > 3) OR (par.a0 < 0)) THEN (*command*)
            u := 0;
            WHILE obj.name[u] > 0X DO INC(comsize); INC(u) END ;
            INC(comsize, 3);
            IF nofcom < MaxComs THEN ComTab[nofcom] := obj; INC(nofcom)
            ELSE OCS.Mark(232); nofcom := 0; comsize := 0
            END
          END
        ELSIF obj.mode = Var THEN
          FindPtrs(obj.typ, obj.a0)
        END ;
        obj := obj.next
      END
    END PtrsAndComs;

    PROCEDURE OutRefBlk(first: OCT.Object; pc: INTEGER; name: ARRAY OF CHAR);
      VAR obj: OCT.Object;
    BEGIN obj := first;
      WHILE obj # NIL DO
        IF obj.mode IN {LProc, XProc, IProc} THEN
          OutRefBlk(obj.dsc, obj.a2, obj.name)
        END ;
        obj := obj.next
      END ;
      Files.Write(out, 0F8X); Files.WriteBytes(out, pc, 2); WriteName(name, 0);
      obj := first;
      WHILE obj # NIL DO
        IF (obj.mode = Var) OR (obj.mode = Ind) THEN
          f := obj.typ.form;
          IF (f IN {Byte .. Set, Pointer})
            OR (f = Array) & (obj.typ.BaseTyp.form = Char) THEN
            Files.Write(out, CHR(obj.mode)); Files.Write(out, CHR(f));
            Files.WriteBytes(out, obj.a0, 4); WriteName(obj.name, 0)
          END
        END ;
        obj:= obj.next
      END
    END OutRefBlk;

  BEGIN (*OutCode*) ObjFile := Files.New(name);
    IF ObjFile # NIL THEN
      Files.Set(out, ObjFile, 0);
      WHILE pc MOD 4 # 0 DO PutF1(0A2H) END ; (*NOP*)
      INC(conx, (-conx) MOD 4);
      nofcom := 0; comsize := 1;
      PtrsAndComs; align := comsize MOD 2; INC(comsize, align);
    (*header block*)
      Files.Write(out, ObjMark); Files.Write(out, "6"); W(0); W(0);
      W(entno); W(comsize); W(nofptrs); W(OCT.nofGmod);
      W(lnkx); Files.WriteBytes(out, datasize, 4); W(conx); W(pc);
      Files.WriteBytes(out, key, 4); WriteName(progid, 20);
    (*entry block*)
      Files.Write(out, 82X); Files.WriteBytes(out, entry, 2*entno);
    (*command block*)
      Files.Write(out, 83X);
      i := 0;  (*write command names and entry addresses*)
      WHILE i < nofcom DO
        obj := ComTab[i]; WriteName(obj.name, 0); W(entry[obj.a0]); INC(i)
      END ;
      Files.Write(out, 0X);
      IF align > 0 THEN Files.Write(out, 0FFX) END ;
    (*pointer block*)
      Files.Write(out, 84X); i := 0;
      WHILE i < nofptrs DO
        IF PtrTab[i] < -4000H THEN OCS.Mark(225) END ;
        Files.WriteBytes(out, PtrTab[i], 2); INC(i)
      END ;
    (*import block*)
      Files.Write(out, 85X); i := 0;
      WHILE i < OCT.nofGmod DO
        obj := OCT.GlbMod[i];
        Files.WriteBytes(out, obj.a1, 4); WriteName(obj.name, 0); Files.Write(out, 0X);
        INC(i)
      END ;
    (*link block*)
      Files.Write(out, 86X); Files.WriteBytes(out, link, 2*lnkx);
    (*data block*)
      Files.Write(out, 87X); Files.WriteBytes(out, constant, conx);
    (*code block*)
      Files.Write(out, 88X); Files.WriteBytes(out, code, pc);
    (*type block*)
      Files.Write(out, 89X); i := 0;
      WHILE i < nofrec DO
        typ := RecTab[i]; s := typ.size + 4; m := 4; s0 := 16;
        WHILE (m > 0) & (s > s0) DO INC(s0, s0); DEC(m) END ;
        IF s > s0 THEN s0 := (s+127) DIV 128 * 128 END ;
        nofptrs := 0; FindPtrs(typ, 0);
        s := nofptrs*2 + (MaxExts+1)*4; Files.WriteBytes(out, s, 2);  (*td size*)
        Files.WriteBytes(out, typ.adr, 2);              (*td adr*)
        K := LONG(nofptrs)*1000000H + s0; Files.WriteBytes(out, K, 4);
        K := 0; m := 0;
        REPEAT Files.WriteBytes(out, K, 4); INC(m) UNTIL m = MaxExts;
        m := 0;
        WHILE m < nofptrs DO
          Files.WriteBytes(out, PtrTab[m], 2); INC(m)
        END ;
        INC(i)
      END ;
    (*ref block*)
      refpos := Files.Pos(out); Files.Write(out, 8AX);
      OutRefBlk(OCT.topScope.next, pc, "$$");
      Files.Set(out, ObjFile, 2); Files.WriteBytes(out, refpos, 4);
    IF ~OCS.scanerr THEN Files.Register(ObjFile) END
    ELSE OCS.Mark(153)
    END
  END OutCode;

PROCEDURE Close*;
    VAR i: INTEGER;
  BEGIN i := 0;
    WHILE i < MaxRecs DO RecTab[i] := NIL; INC(i) END
  END Close;

BEGIN NEW(wasderef)
END OCC.
```

12.9. A Facility for Symbolic Debugging

The facility described in this section is in fact not part of the compiler, but it is nevertheless intimately coupled with it through the definition of storage layout. This facility is used in the case of an abnormal command termination to generate a text displaying the state of the computation. The state is represented by the chain of activated procedures and by their local variables at the time of the termination. Because the current values of the variables are displayed in the same form as used in the source program (i.e. in symbolic rather than encoded form), such a facility is usually called a *symbolic debugger*. It is present in the form of a command procedure *Trap* which, however, is not available as a user-activatable command, but rather is invoked by the system whenever an abnormal program condition occurs. Specifically, the procedure is defined in module *System* and is installed in a procedure variable in module *Kernel*.

When a trap occurs, various register values are stored in exported variables of the kernel. *Kernel.err* indicates the trap number (as defined by the processor). Here we list only the more frequently occurring traps:

2	Address trap	typically reference via NIL pointer
3	Floating-point trap	overflow
6	Division by zero	
7	Flag trap	invalid index
13	Integer trap (or invalid index)	overflow
18	Type guard failure	

As an example, let us consider the following command:

```
PROCEDURE Q(multiplier, count: INTEGER);
  VAR sum: LONGINT; ch: CHAR;
BEGIN sum := 1234567; ch := "Q"; Q(multiplier*100, count+1)
END Q;

PROCEDURE Trap*;
  VAR s: ARRAY 32 OF CHAR;
BEGIN s := "This command should never terminate!"); Q(1, 0)
END Trap;
```

The following is the text generated and displayed in a trap viewer after an attempt to multiply caused arithmetic overflow:

```
TRAP 13  FP = 002FFDD0  PC = 00443053
Demo.Q
  multiplier = 10000
  count = 2
  sum = 1234567
  ch = Q
Demo.Q
  multiplier = 100
  count = 1
  sum = 1234567
  ch = Q
Demo.Q
  multiplier = 1
  count = 0
  sum = 1234567
  ch = Q
```

```
Demo.Trap
  msg = "This command never terminates!"
Oberon.Call
TextFrames.Call
TextFrames.Edit
TextFrames.Handle
MenuViewers.Handle
Oberon.Loop
Modules.$$
```

In order to identify the currently activated procedures and to list their local variables and current values, the trap routine must not only have free access to the stack, where these values are allocated, but must be able to rely on information about the mapping of source program to stored code. In fact, this mapping has to be reversed. The relevant information is contained in the *reference part* of each module's object file. It is the last part of an object file and is ignored by the loader. In order to enable quick access, bytes 2-5 indicate the position of the reference part.

The reference part is generated by procedure *OutRefBlk*, which is local to *OCC.OutCode*. It generates an entry in the reference part of the object file for each procedure and some of its local variables. Since procedures may be nested, *OutRefBlk* is recursive. For procedures, their name and offset in the code section of the module's block is indicated, for variables their name, offset address, and type (form). The syntax of the reference part is

```
ReferencePart   = {procedure}.
procedure = 0F8X offset:2 name {procedure | variable}.
variable  = form:1 mode:1 offset:4 name.
name      = {character} 0X.
```

Module bodies are treated like procedures; in place of a name stands "$$". Markers with value F8X serve to distinguish procedure entries from those of variables. *form* stands for one of the following values:

2	BOOLEAN	6	LONGINT	13	POINTER
3	CHAR	7	REAL	14	Procedure type
4	SHORTINT	8	LONGREAL	15	Character array type
5	INTEGER	9	SET		

Structured variables are not included with the exception of short character arrays which take the form of strings. *mode* assumes one of the values:

1	directly addressed	3	indirectly addressed (VAR parameter)

The implementation of the process of generating the desired information can be studied in detail in the subsequent program listing. Procedure *System.Trap* first identifies the head of the dynamic chain of procedure activation records. This value is held in register FP and is now indicated by *Kernel.fp*. The location of the trap is specified by *Kernel.pc,* and the module containing the malfunctioning procedure is specified by *Kernel.mod*. Now this procedure needs to be identified. This is accomplished by accessing the respective module's object file, whose name is found in the module descriptor. The file's reference part is scanned until a procedure is found in whose range the indicated value *pc* (the trap location) lies. If found, the procedure name is listed and its list of local variables is scanned. For each one of them, the name is read from the reference part and listed in the trap text, and its offset is read in order to obtain its current value from the stack and to list it in the format appropriate for the indicated form.

Trap then proceeds through the chain of procedure activation records, and for each record repeats this process. The scanning of local variables is performed by procedure *Locals*, whose parameter specifies the base address of the respective activation record.

```
PROCEDURE Locals(VAR R: Files.Rider; base: LONGINT);
  VAR adr, val: LONGINT;
    sval, form: SHORTINT;
    ch, mode: CHAR;
```

```
      ival, i: INTEGER;
      rval: REAL;
      lrval: LONGREAL;
BEGIN Texts.WriteLn(W); Files.Read(R, mode);
  WHILE ~R.eof & (mode < 0F8X) DO
      Files.Read(R, form); Files.ReadBytes(R,  adr, 4);
      Texts.WriteString(W, "    "); Files.Read(R, ch);
      WHILE ch > 0X DO Texts.Write(W, ch); Files.Read(R, ch) END ;
      Texts.WriteString(W, " = "); INC(adr, base);
      IF mode = 3X THEN SYSTEM.GET(adr, adr) (*indirect*) END ;
      CASE form OF
        2: (*BOOL*) SYSTEM.GET(adr, sval);
         IF sval = 0 THEN Texts.WriteString(W, "FALSE")
            ELSE Texts.WriteString(W, "TRUE")
         END
      | 1,3: (*CHAR*) SYSTEM.GET(adr, ch);
         IF (" " <= ch) & (ch <= "~") THEN Texts.Write(W, ch)
            ELSE Texts.WriteHex(W, ORD(ch)); Texts.Write(W, "X")
         END
      | 4: (*SINT*) SYSTEM.GET(adr, sval); Texts.WriteInt(W, sval, 1)
      | 5: (*INT*) SYSTEM.GET(adr, ival); Texts.WriteInt(W, ival, 1)
      | 6: (*LINT*) SYSTEM.GET(adr, val); Texts.WriteInt(W, val, 1)
      | 7: (*REAL*) SYSTEM.GET(adr, rval); Texts.WriteReal(W, rval, 14)
      | 8: (*LREAL*) SYSTEM.GET(adr, lrval); Texts.WriteLongReal(W, lrval, 21)
      | 9, 13, 14: (*SET, POINTER*)
         SYSTEM.GET(adr, val); Texts.WriteHex(W, val); Texts.Write(W, "H")
      | 15: (*String*) i := 0; Texts.Write(W, 22X);
         LOOP SYSTEM.GET(adr, ch);
            IF (ch < " ") OR (ch >= 90X) OR (i = 32) THEN EXIT END ;
            Texts.Write(W, ch); INC(i); INC(adr)
         END ;
         Texts.Write(W, 22X)
      END;
      Texts.WriteLn(W); Files.Read(R, mode)
  END
END Locals;

PROCEDURE* Trap;
  VAR V: Viewers.Viewer;
      RefFile: Files.File;
      R: Files.Rider;
      fp, pc, refpos, dmy: LONGINT;
      ch, mode: CHAR;
      X, Y, i: INTEGER;
      mod, curmod: Modules.Module;
      name: Modules.ModuleName;
BEGIN
  IF ~trapped THEN  (*global variable as guard against recursive traps*)
      trapped := TRUE; T := TextFrames.Text("");
      Oberon.AllocateSystemViewer(0, X, Y);
      V := MenuViewers.New(TextFrames.NewMenu("System.Trap", StandardMenu),
              TextFrames.NewText(T, 0), TextFrames.menuH, X, Y);
      IF V.state > 0 THEN
         fp := Kernel.fp; pc := Kernel.pc; curmod := NIL;
         mod := SYSTEM.VAL(Modules.Module, Kernel.mod MOD 10000H);
         Texts.WriteString(W, "TRAP "); Texts.WriteInt(W, Kernel.err, 1);
         Texts.WriteString(W, "  FP ="); Texts.WriteHex(W, fp);
         Texts.WriteString(W, "  PC ="); Texts.WriteHex(W, pc);
         IF Kernel.err = 2 THEN
            Texts.WriteString(W, "  EIA ="); Texts.WriteHex(W, Kernel.eia)
         ELSIF Kernel.err = 20 THEN
            Texts.WriteString(W, "  sect ="); Texts.WriteHex(W, Kernel.SectNo)
         END ;
         Texts.WriteLn(W);
         LOOP Texts.WriteString(W, mod.name); Texts.Append(T, W.buf);
            IF mod # curmod THEN
              (*load obj file*) i := 0;
              WHILE mod.name[i] > 0X DO name[i] := mod.name[i]; INC(i) END ;
              name[i] := "."; name[i+1] := "O"; name[i+2] := "b"; name[i+3] := "j";
              name[i+4] := 0X; RefFile := Files.Old(name);
              IF RefFile = NIL THEN curmod := NIL; Texts.WriteLn(W)
              ELSE curmod := mod; Files.Set(R, RefFile, 2);
              Files.ReadBytes(R, refpos, 4); Files.Set(R, RefFile, refpos); Files.Read(R, ch);
              IF ch = 8AX THEN INC(refpos)
              ELSE curmod := NIL; Texts.WriteInt(W, pc - mod.PB, 7); Texts.WriteLn(W)
              END
              END
            END ;
            IF curmod # NIL THEN  (*find procedure*)
              Files.Set(R, RefFile, refpos);
              LOOP Files.Read(R, ch);
              IF R.eof THEN EXIT END ;
              IF ch = 0F8X THEN (*start proc*)
                  Files.ReadBytes(R, i, 2);
                  IF pc < mod.PB + i THEN EXIT END;
                  REPEAT Files.Read(R, ch) UNTIL ch = 0X; (*skip name*)
              ELSIF ch < 0F8X THEN (*skip object*)
                  Files.Read(R, ch); Files.ReadBytes(R, dmy, 4);
                  REPEAT Files.Read(R, ch) UNTIL ch = 0X; (*skip name*)
              END
              END ;
              IF ~R.eof THEN
              Texts.Write(W, "."); Files.Read(R, ch);
              WHILE ch > 0X DO Texts.Write(W, ch); Files.Read(R, ch) END ;
              Texts.Append(T, W.buf); Locals(R, fp)
              END
            END ;
            SYSTEM.GET(fp+4, pc); SYSTEM.GET(fp, fp);
            IF fp >= Kernel.StackOrg THEN EXIT END ;
            mod := SYSTEM.VAL(Modules.Module, Kernel.ModList);
      (*find module of next procedure*)
            WHILE (mod # NIL) &
              ((pc < mod.PB) OR (mod.size + mod.BB <= pc)) DO
              mod := mod.link
            END ;
            IF mod = NIL THEN EXIT END
         END ;
         Texts.Append(T, W.buf)
      END ;
      trapped := FALSE
  END
END Trap;
```

The trap routine is operating in the supervisor mode and uses the supervisor stack. Therefore, it also operates correctly in the case of a stack overflow. We assume that it does itself not cause another trap, except if it causes heap overflow due to its output operations. The global state variable *trapped* prevents the occurrence of a recursive trap. After termination of the trap handler, control returns to the kernel and the stack is reset.

A fringe benefit of having procedure Locals available is that also global variables of a module can be listed in the same way. Command procedure *System.State* serves precisely this purpose. The name of the module to be inspected is provided as parameter, and the relevant module descriptor is obtained by searching the list of module descriptors headed by *Kernel.ModList*. The base address of the area representing the global variables is given by the module's static base *mod.SB*.

```
PROCEDURE OutState (VAR name: ARRAY OF CHAR; t: Texts.Text);
    VAR mod: Modules.Module;
    refpos: LONGINT;
    ch: CHAR; X, Y, i: INTEGER;
    F: Files.File; R: Files.Rider;
BEGIN
  Texts.WriteString(W, name); mod := SYSTEM.VAL(Modules.Module, Kernel.ModList);
  WHILE (mod # NIL) & (mod.name # name) DO mod := mod.link END ;
  IF mod # NIL THEN
    i := 0;
    WHILE (i < 28) & (name[i] > 0X)  DO INC(i) END ;
    name[i] := "."; name[i+1] := "O"; name[i+2] := "b"; name[i+3] := "j"; name[i+4] := 0X;
    F := Files.Old(name);
    IF F # NIL THEN
      Texts.WriteString(W, "  SB ="); Texts.WriteHex(W, mod.SB);
      Files.Set(R, F, 2); Files.ReadBytes(R, refpos, 4); Files.Set(R, F, refpos+1);
      LOOP Files.Read(R, ch);
        IF R.eof THEN EXIT END ;
        IF ch = 0F8X THEN
          Files.ReadBytes(R, i, 2); Files.Read(R, ch);
          IF ch = "$" THEN Files.Read(R, ch); Files.Read(R, ch); EXIT END ;
          REPEAT Files.Read(R, ch) UNTIL ch = 0X  (*skip name*)
        ELSIF ch < 0F8X THEN  (*skip object*)
          Files.Read(R, ch); Files.Read(R, ch); Files.Read(R, ch);
          REPEAT Files.Read(R, ch) UNTIL ch = 0X; (*skip name*)
        END
      END ;
      IF ~R.eof THEN Locals(R, mod.SB) END
    ELSE Texts.WriteString(W, ".Obj  not found")
    END
  ELSE Texts.WriteString(W, " not loaded")
  END ;
  Texts.WriteLn(W); Texts.Append(t, W.buf)
END OutState;

PROCEDURE State*;
  VAR T: Texts.Text;
    S: Texts.Scanner;
    V: Viewers.Viewer;
    beg, end, time: LONGINT;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF S.class = Texts.Name THEN
    Oberon.AllocateSystemViewer(Oberon.Par.vwr.X, X, Y);
    T := TextFrames.Text("");
    V := MenuViewers.New(TextFrames.NewMenu("System.State", StandardMenu),
                        TextFrames.NewText(T, 0), TextFrames.menuH, X, Y);
      OutState(S.s, T)
   END
END State;
```

13. A Graphics Editor

13.1. History and Goal

The origin of graphics systems as they are in use at this time was intimately tied to the advent of the high-resolution bit-mapped display and of the mouse as pointing device. The author's first contact with such equipment dates back to 1976. The Alto computer at the Xerox Palo Alto Research Center is justly termed the first workstation featuring those characteristics. The designer of its first graphics package was Ch. Thacker who perceived the usefulness of the high-resolution screen for drawing and processing schematics of electronic circuits. This system was cleverly tailored to the needs encountered in this activity, and it was remarkable in its compactness and effectiveness due to the lack of unnecessary facilities. Indeed, its acronym was SIL, for Simple ILlustrator.

After careful study of the used techniques, the author designed a variant, programmed in Modula-2 (instead of BCPL) for the PDP-11 Computer, thereby ordering and exhibiting the involved data structures more explicitly. In intervals of about two years, that system was revised and grew gradually into the present Draw system. The general goal remained a simple line drawing system: emphasis was placed on a clear structure and increase of flexibility through generalization of existing rather than indiscriminate addition of new features.

In the history of this evolution, three major transitions can be observed. The first was the move from a single "window", the screen, to multiple windows including windows showing different excerpts of the same graphic. This step was performed on the Lilith computer which resembled the Alto in many ways. The second major transition was the application of the object-oriented style of programming, which allowed the addition of new element types to the basic system, making it extensible. The third step concerned the proper integration of the Draw system with Oberon's text system. The last two steps were performed using Oberon and the Ceres computer.

We refrain from exhibiting this evolution and merely present the outcome, although the history might be an interesting reflection of the evolution of programming techniques in general, containing many useful lessons. We stress the fact, however, that the present system rests on a long history of development, during which many features and techniques were introduced and later discarded or revised. The size of the system's description is a poor measure of the effort that went into its construction; deletion of program text sometimes marks bigger progress than addition.

The goal of the original SIL program was to support the design of electronic circuit diagrams. Primarily, SIL was a line drawing system. This implies that the drawings remain uninterpreted. However, in a properly integrated system, the addition of modules containing operators that interpret the drawings is a reasonably straight-forward proposition. In fact, the Oberon system is ideally suited for such steps, particularly due to its command facility.

At first, we shall ignore features specially tailored to circuit design. The primary one is a macro facility to be discussed in a later chapter.

The basic system consists of the modules *Draw*, *GraphicFrames*, and *Graphics*. These modules contain the facilities to generate and handle horizontal and vertical lines, text captions, and macros. Additional modules serve to introduce other elements, such as rectangles and circles, and the system is extensible, i.e. further modules may be introduced to handle further types of elements.

13.2. A Brief Guide to Oberon's Line Drawing System

In order to provide the necessary background for the subsequent description of the Draw system's implementation, a brief overview is provided in the style of a user's guide. It summarizes the facilities offered by the system and gives an impression of its versatility.

The system called *Draw* serves to prepare line drawings. They contain lines, text captions, and other items, and are displayed in graphic viewers (more precisely: in menu viewers' graphic frames). A graphic viewer shows an excerpt of the drawing plane, and several viewers may show different parts of a drawing. The most frequently used commands are built-in as mouse clicks and combinations of clicks. Additional commands are selectable from texts, either in viewer menus (title bars) or in the text called *Draw.Tool*. Fig. 13.1. shows the display with two graphic viewers at the left and the draw tool text at the right. The mouse buttons have the following principal functions whenever the cursor lies in a graphic frame:

left: draw / set caret	middle: move / copy	right: select

A mouse command is identified (1) by the key k0 pressed initially, (2) by the initial position P0 of the cursor, (3) by the set of pressed keys k1 until the last one is released, and (4) the cursor position P1 at the time of release.

13.2.1. Basic Commands

The command *Draw.Open* opens a new viewer and displays the graph with the name given as parameter. We suggest that file names use the extension *Graph*.

Drawing a line. In order to draw a horizontal or vertical line from P0 to P1, the left key is pressed with the cursor at P0 and, while the key is held, the mouse and cursor is moved to P1. Then the key is released. If P0 and P1 differ in both their x and y coordinates, the end point is adjusted so that the line is either horizontal or vertical.

Writing a caption. First the cursor is positioned where the caption is to appear. Then the left key is clicked, causing a crosshair to appear. It is called the *caret*. Then the text is typed. Only single lines of texts are accepted. The DEL key may be used to retract characters (backspace).

Selecting. Most commands require the specification of operands, and many implicitly assume the previously selected elements - the *selection* - to be their operands. A single element is selected by pointing at it with the cursor and then clicking the right mouse button. This also causes previously selected elements to be deselected. If the left key is also clicked, their selection is retained. This action is called an *interclick*. To select several elements at once, the cursor is moved from *P0* to *P1* while the right key is held. Then all elements lying within the rectangle with diagonally opposite corners at *P0* and *P1* are selected. Selected lines are displayed as dotted lines, selected captions (and macros) by inverse video mode. A macro is selected by pointing at its lower left corner. The corner is called *sensitive area*.

Moving. To move (displace) a set of elements, the elements are first selected and then the cursor is moved from P0 to P1 while the middle key is held. The vector from *P0* to *P1* specifies the movement and is called the *displacement vector*. *P0* and *P1* may lie in different viewers displaying the same graph. Small displacements may be achieved by using the keyboard's cursor keys.

Copying. Similarly, the selected elements may be copied (duplicated). In addition to pressing the middle key while indicating the displacement vector, the left key is interclicked. The copy command may also be used to copy elements from one graph into another graph by moving the cursor from one viewer into another viewer displaying the destination graph. A text caption may be copied from a text frame into a graphic frame and vice-versa. There exist two ways to accomplish this: 1. First the caret is placed at the destination position, then the text is selected and the middle key is interclicked. 2. First the text is selected, then the caret is placed at the destination position and the middle key is interclicked.

Shifting the plane. You may shift the entire drawing plane behind the viewer by specifying a displacement vector pressing the middle button (like in a move command) and interclicking the right button.

The following table shows a summary of the mouse actions:

left	draw line
left (no motion)	set caret
left + middle	copy selected caption to caret
left + right	set secondary caret

middle	move selection
middle + left	copy selection
middle + right	shift drawing plane
right	select area
right (no motion)	select object
right + middle	copy caption to caret
right + left	select without deselection

13.2.2. Menu Commands

The following commands are displayed in the menu (title bar) of every graphic viewer. They are activated by being pointed at and by clicking the middle button.

Draw.Delete	The selected elements are deleted.
Draw.Store	The drawing is written as file with the name shown in the title bar. The original file is renamed by appending ".Bak".

The two viewers in Fig. 13.1. display different parts of the same graphic. The second view was obtained from the generic System.Copy command and a subsequent shift of the drawing plane..

13.2.3. Further Commands

The following commands are listed in the text *Draw.Tool*, but may appear in any text.

Draw.Store *name*	The drawing in the marked viewer is stored as a file with the specified name.
Draw.Print *Server* *	The drawing in the marked viewer is printed by the named print server.
Draw.Print *Server filename1 filename2 ...* ~.	The named files are printed.

The subsequent commands change attributes of drawing elements, such as line width, text font, and color, and they apply to the most recent selection.

Draw.SetWidth *w*	default = 1, $0 < w < 7$.
Draw.ChangeFont *fontname*	
Draw.ChangeColor *c*	
Draw.ChangeWidth *w*	($0 < w < 7$)

The *ChangeColor* command either take a color number in the range 1 .. 15 or a string as parameter. It serves to copy the color from the selected character (see *Draw.Tool*).

A few actions are initiated by control characters from the keyboard. They apply to the focus viewer.

DEL	Selected elements are deleted
Cursor characters	Move selection by 1 unit in the indicated direction
No Scrll	Redraw
Cntl / No Scrll	Reset origin and redra

13.2.4. Macros

A macro is a (small) drawing that can be identified as a whole and be used as an element within a (larger) drawing. Macros are typically stored in collections called *libraries*, from where they can be selected and copied individually.

Draw.Macro *lib mac*	The macro *mac* is selected from the library named *lib* and inserted in the drawing at the caret's position.

An example for the use of macros is drawing electronic circuit diagrams. The basic library file containing frequently used TTL components is called *TTL0.Lib*, and a drawing showing its elements is called *TTL0.Graph*.

13.2.5. Rectangles

Rectangles can be created as individual elements. They are frequently used for framing sets of elements. Rectangles consist of four lines which are selectable as a unit. The attribute commands

Draw.SetWidth, System.SetColor, Draw.ChangeWidth, and *Draw.ChangeColor* also apply to rectangles. Rectangles are selected by pointing at their lower right corner and are created by the following steps:

1. The caret is placed where a corner of the new rectangle is to lie.
2. A secondary caret is placed where the opposite corner is to lie (left + right).
3. The command *Rectangles.Make* is activated.

Rectangles may be filled with a shade pattern. The shade is specified as a number s (0 # s # 9).

Rectangles.SetShade s	default = 0: no shading

By pointing at its lower right corner and clicking the middle button, a rectangle's corner may be dragged, thereby resizing the rectangle

13.2.6. Oblique Lines, Circles, and Ellipse

Further graphic elements are (oblique) lines, circles, and ellipses. The sensitive area of circles and ellipses is at their lowest point. They are created by the following steps:

Lines: 1. The caret is placed where the starting point is to lie.
2. A secondary caret is placed at the position of the end.
3. The command *Curves.MakeLine* is activated.

Circles: 1. The caret is placed where the center is to lie.
2. A secondary caret is placed. Its horizontal distance from the first caret specifies the radius.
3.The command *Curves.MakeCircle* is activated.

Ellipses: 1. The caret is placed where the center is to lie.
2. A second caret is placed. Its horizontal distance from the first caret specifies one axis.
3. A third caret is placed. Its vertical distance from the first caret specifies the other axis.
4. The command *Curves.MakeEllipse* is activated.

13.2.7. Spline Curves

Spline curves are created by the following steps:

1. The caret is placed where the starting point is to lie.
2. Secondary carets are placed at the spline's fixed points (at most 20).
3. The command *Splines.MakeOpen* or *Splines.MakeClosed* is activated.

13.2.8. Constructing New Macros

A new macro is constructed and inserted in the library lib under the name mac as follows:

1. All elements which belong to the new macro are selected.
2. The caret is placed at the lower left corner of the area to be spanned by the macro.
3. A secondary caret is placed at the upper right corner of the area to be spanned by the macro.
4. The command *Draw.MakeMacro lib mac* is activated.

An existing macro can be decomposed (opened) into its parts as follows:

1. The macro is selected.
2. The caret is placed at the position where the decomposition is to appear.
3. The command *Draw.OpenMacro* is activated.

The command *Draw.StoreLibrary lib file* stores the library lib on the specified file. Only the macros presently loaded are considered as belonging to the library. If one wishes to add some macros to an existing library file, all of its elements must first be loaded. This is best done by opening a graph containing all macros of the desired library file.

13.3. The Core and its Structure

Like a text, a graphic consists of elements, subsequently to be called *objects*. Unlike a text, which is a sequence of elements, a graphic is an unordered set of objects. In a text, the position of an element need not be explicitly indicated (stored); it is recomputed from the position of its predecessor each time it is needed, for example for displaying or selecting an element. In a graphic, each object must carry its position explicitly, as it is independent of any other object in the set. This is an essential difference, requiring a different treatment and much more storage space for an equal number of objects.

Although this is an important consideration in the choice of a representation of a data structure, the primary determinants are the kind of objects to be included, and the set of operations to be applied to them. Here SIL set a sensible starting point. To begin with, there exist only two kinds of objects, namely straight, horizontal and vertical lines, and short texts for labelling lines, called *captions*. It is surprising how many useful task can be fulfilled with only these two types of objects.

The typical operations to be performed on objects are creating, drawing, moving, copying, and erasing. Those performed on a graphic are inserting, searching, and deleting an object. For the operations on objects, data indicating an object's position (and possibly color), its length and width in the case of lines, and the character string in the case of captions suffice. For the operations on the graphic, some data structure representing the set of objects must be chosen. Without question, a dynamic structure is most appropriate, and it requires the addition of some linking fields to the record representing an object. Without further deliberation, and with the idea that graphics to be handled with this system contain hundreds rather than tens of thousands of objects, we chose the simplest solution, the linear list. A proper modularization in connection with information hiding will make it possible to alter this choice without affecting client modules.

Although in general the nature of a user interface should not influence the representation chosen for the abstract data structure, we need to take note of the manner in which parameters of certain operations are denoted. It is, for example, customary in interactive graphics systems to select the objects to which an operation is to apply *before* invoking that operation. Their *selection* is reflected in their visual appearance in some way, and gives the user an opportunity to verify the selection (and to change it, if necessary) before applying the operation (such as deletion). For an object to be selectable means that it must record a state (selected/unselected). We note that it is important that this state is reflected by visual appearance.

As a consequence, the property *selected* is added to every object record. We now specify the data types representing lines and captions as follows and note that both types must be extensions of the same base type in order to be members of one and the same data structure.

```
TYPE Object =       POINTER TO ObjectDesc;
  ObjectDesc =      RECORD
                          x, y, w, h, col: INTEGER;
                          selected: BOOLEAN;
                          next: Object
                    END ;

  Line =            POINTER TO LineDesc;
  LineDesc =        RECORD (Object) END ;

  Caption =         POINTER TO CaptionDesc
  CaptionDesc =     RECORD (Object)
                          pos, len: INTEGER
                    END
```

Selection of a single element is typically achieved by pointing at the object with mouse and cursor. Selection of a set of objects is achieved by specifying a rectangular area, implying selection of all objects lying within it. In both cases, the search for selected elements proceeds through the linked list and relies on the position and size stored in each object's descriptor. As a consequence, the rule was adopted that every object not only specify a position through its coordinates *x*, *y*, but also the rectangular area within which it lies (width *w*, height *h*). It is thus easy to determine whether a given point identifies an object, as well as whether an object lies fully within a rectangular area.

In principle, each caption descriptor carries the sequence of characters (string) representing the caption. The simplest realization would be an array structured field, limiting the length of captions to some fixed, predetermined value. First, this is highly undesirable (although used in early versions of the system). And second, texts carry attributes (color, font). It is therefore best to use a global "scratch text", and to record a caption by the position and length of the string in this immutable text.

A procedure *drawGraphic* to draw all objects of a graphic now assumes the following form:

```
PROCEDURE drawObj(obj: Object);
BEGIN
  IF obj IS Line THEN drawLine(obj(Line))
  ELSIF obj IS Caption THEN drawCaption(obj(Caption))
  ELSE (*other object types, if any*)
  END
END drawObj;

PROCEDRE drawGraphic(first: Object);
  VAR obj: Object;
BEGIN obj := first;
  WHILE obj 9 NIL DO drawObj(obj); obj := obj.next END
END drawGraphic
```

The two procedures typically are placed in different modules, one containing operations on objects, the other those on graphics. Here the former is the service module, the latter the former's client. Procedures for, e.g, copying elements, or determining whether an object is selectable, follow the same pattern as *drawGraphic*.

This solution has the unpleasant property that all object types are anchored in the base module. If any new types are to be added, the base module has to be modified (and all clients are to be - at least - recompiled). The object-oriented paradigm eliminates this difficulty by inverting the roles of the two modules. It rests on binding the operations pertaining to an object type to each object individually in the form of procedure-typed record fields as shown in the following sample declaration:

```
ObjectDesc =   RECORD
                   x, y, w, h, col: INTEGER; selected: BOOLEAN;
                   draw: PROCEDURE (obj: Object);
                   write:  PROCEDURE (obj: Object; VAR R: Files.Rider);
                   next: Object
               END
```

The procedure *drawGraphic* is now formulated as follows:

```
PROCEDURE drawGraphic(first: Object);
    VAR obj : Object;
BEGIN obj := first;
    WHILE obj 9 NIL DO obj.draw(obj);  obj := obj.next END
END drawGraphic;
```

The individual procedures - in object-oriented terminology called *methods* - are assigned to the record's fields upon its creation. They need no further discrimination of types, as this role is assumed by the assignment of the procedures upon their installation. We note here that the procedure fields are never changed; they assume the role of *constants* rather than variables associated with each object.

This example exhibits in a nutshell the essence of object-oriented programming, *extensibility* as its purpose and the *procedure-typed* record field as the technique.

The given solution, as it stands, has the drawback that each object (instance, variable) contains several procedures (of which three are listed), and therefore leads to a storage requirement that should be avoided. Furthermore, it defines once and for all the number of operations applicable to objects, and also their parameters and result types. A different approach with the same underlying principle removes these drawbacks. It employs a single installed procedure which itself discriminates among the operations according to different types of parameters. The parameters of the preceding solution are merged into a single record called a *message*. The unified procedure is called a handler, and messages are typically extensions of a single base type (Msg).

```
TYPE Msg =          RECORD END;
    DrawMsg =       RECORD (Msg) END;
    WriteMsg =      RECORD (Msg) R: Files.Rider END ;

    ObjectDesc =    RECORD
                        x, y, w, h, col: INTEGER; selected: BOOLEAN;
                        handle: PROCEDURE (obj: Object; VAR M: Msg);
                        next: Object
                    END ;

PROCEDURE  Handler (obj: Object; VAR M: Msg);
    (*this procedure is assigned to the handle field of every line object*)
BEGIN
    IF M IS DrawMsg THEN drawLine(obj(Line))
    ELSIF M IS WriteMsg THEN writeLine(obj(Line), M(WriteMsg).R)
    ELSE ...
    END
END ;

PROCEDURE drawGraphic(first: Objec; VAR M: Msg);
    VAR obj: Object;
BEGIN obj := first;
    WHILE obj 9 NIL DO obj.handle(obj, M);  obj := obj.next END
END drawGraphics
```

In the present system, a combination of the two schemes presented so far is used. It eliminates the need for individual method fields in each object record as well as the cascaded IF statement for discriminating among the message types. Yet it allows further addition of new methods for later extensions without the need to change the object's declaration. The technique used is to include a single field (called *do*) in each record (analogous to the handler). This field is a pointer to a method record containing the procedures declared for the base type. At least one of them uses a message parameter, i.e. a parameter of record structure that is extensible.

```
TYPE Method =  POINTER TO MethodDesc;
  Msg =        RECORD END;
  Context =    RECORD END;

  Object =     POINTER TO ObjectDesc;
  ObjectDesc = RECORD
                   x, y, w, h, col: INTEGER; selected: BOOLEAN;
                   do: Method; next: Object
               END;

MethodDesc =   RECORD
                 new: Modules.Command;
                 copy: PROCEDURE (obj, to: Object);
                 draw, handle: PROCEDURE (obj: Object; VAR M: Msg);
                 selectable: PROCEDURE (obj: Object; x, y: INTEGER): BOOLEAN;
                 read: PROCEDURE (obj: Object; VAR R: Files.Rider; VAR C: Context);
                 write: PROCEDURE (obj: Object; cno: SHORTINT;
                   VAR R: Files.Rider; VAR C: Context);
                 print: PROCEDURE (obj: Object; x, y: INTEGER)
               END
```

A single method instance is generated when a new object type is created, typically in the initialization sequence of the concerned module. When a new object is created, a pointer to this record is assigned to the do field of the new object descriptor. A call then has the form *obj.do.write(obj, R).* This example exhibits the versatility of Oberon's type extension and procedure variable features very well, and it does so without hiding the data structures involved in a dispensible, built-in run-time mechanism.

The foregoing deliberations suggest the system's modular structure shown in Fig. 13.3.:

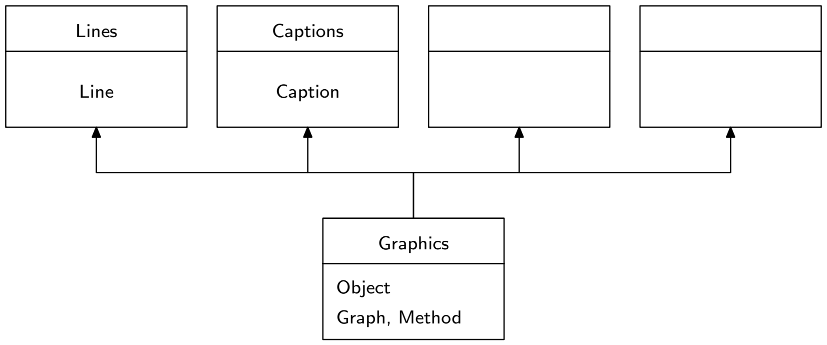


Fig. 13.3. Clients of module *Graphics*

The modules in the top row implement the individual object types' methods, and additionally provide commands, in particular *Make* for creating new objects. The base module specifies the base types and procedures operating on graphics as a whole.

Our system, however, deviates from this scheme somewhat for several reasons:

1. Implementation of the few methods requires relatively short programs for the basic objects. Although a sensible modularization is desirable, we wish to avoid an atomization, and therefore merge parts that would result in tiny modules with the base module.

2. The elements of a graphic refer to fonts used in captions and to libraries used in macros. The writing and reading procedures therefore carry a context constisting of fonts and libraries as an additional parameter. Routines for mapping a font (library) to a number according to a given context on output, and a number to a font (library) on input are contained in module *Graphics*.

3. In the design of the Oberon System, a hierarchy of four modules has proven to be most appropriate:

   0. Module with base type handling the abstract data structure.
   1. Module containing procedures for the representation of objects in frames (display handling).
   2. Module containing the primary command interpreter and connecting frames with a viewer.
   3. A command module scanning command lines and invoking the appropriate interpreters.

The module hierarchy of the Draw System is here shown together with its analogy of the Text System:

3. Command Scanner	Draw	Edit
2. Viewer Handler	MenuViewers	MenuViewers
1. Frame Handler	GraphicFrames	TextFrames
0. Base	Graphics	Texts

As a result, module *Graphics* does not only contain the base type *Object*, but also its extensions *Line* and *Caption*. Their methods, however, are defined in *GraphicFrames*, if they refer to frames (e.g. draw), and in *Graphics* otherwise.

So far, we have discussed operations on individual objects and the structure resulting from the desire to be able to add new object types without affecting the base module. We now turn our attention briefly to operations on graphics as a whole. They can be grouped into two kinds, namely operations involving a graphic as a set, and those applying to the selection, i.e. to a subset only.

The former kind consists of procedures Add, which inserts a new object, *Draw*, which traverses the set of objects and invokes their drawing methods, *ThisObj*, which searches for an object at a given position, *SelectObj*, which marks an object to be selected, *SelectArea*, which identifies all objects lying within a given rectangular area and marks them, *Selectable*, a Boolean function, and *Enumerate*, which applies the parametric procedure handle to all objects of a graphic. Furthermore, the procedures *Load*, *Store*, *Print*, and *WriteFile* belong to this kind.

The set of operations applying to selected objects only consist of the following procedures: *Deselect*, *DrawSel* (drawing the selection according to a specified mode), *Change* (changing certain attributes of selected objects like width, font, color), *Move*, *Copy*, *CopyOver* (copying from one graphic into another), and finally *Delete*. Also, there exists the important procedure *Open* which creates a new graphic, either loading a graphic stored as a file, or generating an empty graphic.

The declaration of types and procedures that have emerged so far are summarized in the following excerpt of the module's interface definition.

```
DEFINITION Graphics;  (*excerpt*)
    IMPORT Files, Fonts, Texts, Modules, Display;

    CONST NameLen = 16;

    TYPE Graph = POINTER TO GraphDesc;
        GraphDesc = RECORD sel: Object; time: LONGINT END ;

        Object = POINTER TO ObjectDesc;
        Method = POINTER TO MethodDesc;

        ObjectDesc = RECORD
            x, y, w, h, col: INTEGER;
            selected, marked: BOOLEAN;
            do: Method
        END ;

        Name = ARRAY NameLen OF CHAR;
        Msg = RECORD END ;
        Context = RECORD END ;

        MethodDesc = RECORD module, allocator: Name;
            new: Modules.Command;
            copy: PROCEDURE (obj, to: Object);
            draw, handle: PROCEDURE (obj: Object; VAR msg: Msg);
            selectable: PROCEDURE (obj: Object; x, y: INTEGER): BOOLEAN;
            raed: PROCEDURE (obj: Object; VAR R: Files.Rider; VAR C: Context);
            write: PROCEDURE (obj: Object; cno: SHORTINT;
                VAR R: Files.Rider; VAR C: Context);
            print: PROCEDURE (obj: Object; x, y: INTEGER);
        END ;

        Line = POINTER TO LineDesc;
        LineDesc = RECORD (ObjectDesc) END ;

        Caption = POINTER TO CaptionDesc;
        CaptionDesc = RECORD (ObjectDesc) pos, len: INTEGER END ;

        WidMsg =        RECORD (Msg) w: INTEGER END ;
        ColorMsg =      RECORD (Msg) col: INTEGER END ;
        FontMsg =       RECORD (Msg) fnt: Fonts.Font END ;

    VAR new: Object;
        width, res: INTEGER;
        T: Texts.Text;
        LineMethod, CapMethod, MacMethod: Method;

    PROCEDURE Add (G: Graph; obj: Object);
    PROCEDURE Draw (G: Graph; VAR M: Msg);
    PROCEDURE ThisObj (G: Graph; x, y: INTEGER): Object;
    PROCEDURE SelectObj (G: Graph; obj: Object);
    PROCEDURE SelectArea (G: Graph; x0, y0, x1, y1: INTEGER);
    PROCEDURE Enumerate (G: Graph; handle:
    PROCEDURE (obj: Object; VAR done: BOOLEAN));

    PROCEDURE Deselect (G: Graph);
    PROCEDURE DrawSel (G: Graph; VAR M: Msg);
    PROCEDURE Change (G: Graph; VAR M: Msg);
    PROCEDURE Move (G: Graph; dx, dy: INTEGER);
    PROCEDURE Copy (Gs, Gd: Graph; dx, dy: INTEGER);
    PROCEDURE Delete (G: Graph);

    PROCEDURE FontNo (VAR W: Files.Rider; VAR C: Context; fnt: Fonts.Font): SHORTINT;
    PROCEDURE WriteObj (VAR W: Files.Rider; cno: SHORTINT; obj: Object);
    PROCEDURE Store (G: Graph; VAR W: Files.Rider);
    PROCEDURE WriteFile (G: Graph; name: ARRAY OF CHAR);
    PROCEDURE Print (G: Graph; x0, y0: INTEGER);
    PROCEDURE Font (VAR R: Files.Rider; VAR C: Context): Fonts.Font;
    PROCEDURE Load (G: Graph; VAR R: Files.Rider);
    PROCEDURE Open (G: Graph; name: ARRAY OF CHAR);
END Graphics.
```

13.4. Displaying Graphics

The base module *Graphics* defines the representation of a set of objects in terms of a data structure. The particulars are hidden and allow the change of structural representation by an exchange of this module without affecting its clients. The problems of displaying a graphic on a screen or a printed page are not handled by this module; they are delegated to the client module *GraphicFrames*, which defines a frame type for graphics which is an extension of *Display.Frame*, just like *TextFrames.Frame* is an extension of *Display.Frame*. In contrast to text frames, however, a graphic instead of a text is associate with it.

```
FrameDesc = RECORD (Display.Frame)
            graph: Graphics.Graph;
            Xg, Yg, X1, Y1, x, y, col: INTEGER;
            marked, ticked: BOOLEAN;
            mark: LocDesc
  END
```

Every frame specifies its coordinates *X, Y* within the display area, its size by the attributes *W* (width) and *H* (height), and its background color *col*. Just as a frame represents a (rectangular) section of the entire screen, it also shows an excerpt of the drawing plane of the graphic. The coordinate origin need coincide with neither the frame origin nor the display origin. The frame's position relative to the graphic plane's origin is recorded in the frame descriptor by the coordinates *Xg, Yg*.

The additional, redundant attributes *x, y, X1, Y1* are given by the following invariants, and they are recorded in order to avoid their frequent recomputation.

```
X1  =  X + W,          Y1  =  Y + H
x   =  X + Xg,         y   =  Y1 + Yg
```

X and *Y* (and hence also *X1* and *Y1*) are changed when a viewer is modified, i.e. when the frame is moved or resized. *Xg* and *Yg* are changed when the graph's origin is moved within a frame. The meaning of the various values is illustrated in Fig. 13.4.

As a consequence, the display coordinates *u, v* of an object *z* of a graph displayed in a frame *f* are computed as

```
u = z.x + f.x,          v = z.y + f.y
```

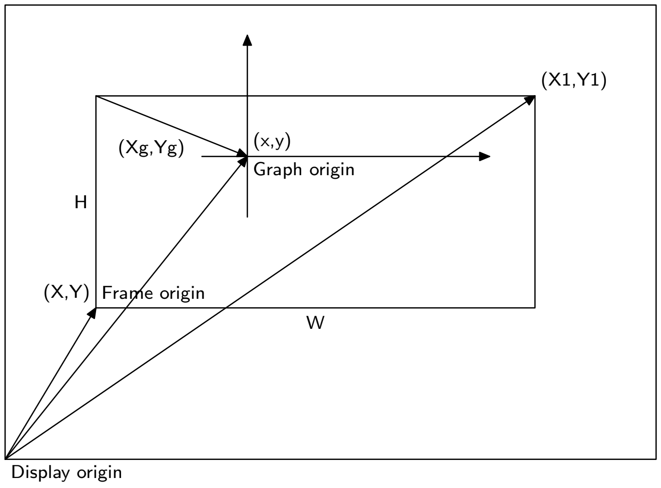


Fig. 13.4. Frame and graph coordinates

In order to determine whether an object *z* lies within a frame *f*, the following expression must hold:

(f.X <= u) & (u + z.w <= f.X1) & (f.Y <= v) & (v + z.h <= f.Y1)

The record field *marked* indicates whether or not the frame contains a caret. Its display position is recorded in the field called *mark*. A frame may contain several (secondary) carets; they form a list of location descriptors.

When an object is displayed (drawn), its state must be taken into consideration in order to provide visible user feedback. The manner in which selection is indicated, however, may vary among different object types. This can easily be realized, because every object (type) is associated with an individual drawing procedure. The following visualizations of selection have been chosen:

Selected lines are shown in a grey tone (raster pattern).
Selected captions are shown with "inverse video".

Change of state is a relatively frequent operation, and if possible a complete repainting of the involved objects should be avoided for reasons of efficiency. Therefore, procedures for drawing an object are given a mode parameter, in addition to the obvious object and frame parameters. The parameters are combined into the message record of type *DrawMsg*.

```
DrawMsg = RECORD (Graphics.Msg)
            f: Frame;
            mode, x, y, col: INTEGER
  END
```

The meaning of the mode parameter's four possible values are the following:

mode = 0: draw object according to its state,
mode = 1: draw reflecting a transition from normal to selected state,
mode = 2: draw reflecting a transition from selected to normal state,
mode = 3: erase.

In the case of captions, for instance, the transitions are indicated by simply inverting the rectangular area covered by the caption. No rewriting of the captions' character patterns is required.

A mode parameter is also necessary for reflecting object deletion. First, the selected objects are drawn with *mode* indicating erasure. Only afterwards are they removed from the graphic's linked list.

Furthermore, the message parameter of the drawing procedure contains two offsets *x* and *y*. They are added to the object's coordinates, and their significance will become apparent in connection with macros. The same holds for the color parameter.

The drawing procedures are fairly straight-forward and use the four basic raster operations of module *Display*. The only complication arises from the need to clip the drawing at the frame boundaries. In the case of captions, a character is drawn only if it fits into the frame in its entirety. The raster operations do not test (again) whether the indicated position is valid.

At this point we recall that copies of a viewer (and its frames) can be generated by the *System.Copy* command. Such copies display the same graphic, but possibly different excerpts of them. When a graphic is changed by an insertion, deletion, or any other operation, at a place that is visible in several frames, all affected views must reflect the change. A direct call to a drawing procedure indicating a frame and the change does therefore not suffice. Here again, the object-oriented style solves the problem neatly: In place of a direct call a message is broadcast to all frames, the message specifying the nature of the required updates.

The broadcast is performed by the general procedure *Viewers.Broadcast(M)*. It invokes the handlers of all viewers with the parameter *M*. The viewer handlers either interpret the message or propagate it to the handlers of their subframes. Procedure *obj.handle* is called with a control message as parameter when pointing at the object and clicking the middle mouse button. This allows control to be passed to the handler of an individual object.

The definition of module *GraphicFrames* is summarized by the following interface:

```
DEFINITION GraphicFrames;
    IMPORT Display, Graphics;

    TYPE Frame = POINTER TO FrameDesc;

        Location = POINTER TO LocDesc;
        LocDesc = RECORD
            x, y: INTEGER;
            next: Location
        END ;

        FrameDesc = RECORD (Display.FrameDesc)
            graph: Graphics.Graph;
            Xg, Yg, X1, Y1, x, y, col: INTEGER;
            marked, ticked: BOOLEAN;
            mark: LocDesc
        END ;

        (*mode = 0: draw according to selected, 1: normal -> selected,
            2: selected -> normal, 3: erase*)

        DrawMsg = RECORD (Graphics.Msg)
            f: Frame;
            x, y, col, mode: INTEGER
        END ;

        CtrlMsg = RECORD (Graphics.Msg)
            f: Frame; res: INTEGER
        END

    PROCEDURE Restore (F: Frame);
    PROCEDURE Focus (): Frame;
    PROCEDURE Selected (): Frame;
    PROCEDURE This(x, y: INTEGER): Frame;
    PROCEDURE Draw (F: Frame);
    PROCEDURE Erase (F: Frame);
    PROCEDURE DrawObj (F: Frame; obj: Graphics.Object);
    PROCEDURE EraseObj (F: Frame; obj: Graphics.Object);
    PROCEDURE Handle (F: Frame; VAR msg: Graphics.Msg);
    PROCEDURE Defocus (F: Frame);
    PROCEDURE Deselect (F: Frame);
    PROCEDURE Macro (VAR Lname, Mname: ARRAY OF CHAR);
    PROCEDURE New (graph: Graphics.Graph; X, Y, col: INTEGER; ticked: BOOLEAN): Frame;
END GraphicFrames.
```

Focus and *Selected* identify the graphic frame containing the caret, or containing the latest selection. *Draw*, *Erase*, and *Handle* apply to the selection of the specified frame's graphic. And *New* generates a frame displaying the specified graphic with an origin given by coordinates *X* and *Y*.

13.5. The User Interface

Although the display is the prime constituent of the interface between the computer and its user, we chose the title of this chapter for a presentation primarily focussed on the computer's input, i.e. on its actions instigated by the user's handling of keyboard and mouse, the editing operations. The design of the user interface plays a decisive role in a system's acceptance by users. There is no fixed set of rules which determine the optimal choice of an interface. Many issues are a matter of subjective judgement, and all too often convention is being mixed up with convenience. Nevertheless, a few criteria have emerged as fairly generally accepted.

We base our discussion on the premise that input is provided by a keyboard and a mouse, and that keyboard input is essentially to be reserved for textual input. The critical issue is that a mouse - apart from providing a cursor position - allows to signal actions by the state of its keys. Typically, there are far more actions than there are keys. Some mice feature a single key only, a situation that we deem highly unfortunate. There are, however, several ways to "enrich" key states:

1. Position. Key states are interpreted depending on the current position of the mouse represented by the cursor. Typically, interpretation occurs by the handler installed in the viewer covering the cursor position, and different handlers are associated with different viewer types. The handler chosen for interpretation may even be associated with an individual (graphic) object and depend on that object's type.

2. Multiple clicks. Interpretation may depend on the number of repeated clicks (of the same key), and/or on the duration of clicks.

3. Interclicks. Interpretation may depend on the combination of keys depressed until the last one is released. This method is obviously inapplicable for single-key mice.

Apart from position dependence, we have quite successfully used interclicks. A ground rule to be observed is that frequent actions should be triggered by single-key clicks, and only variants of them should be signalled by interclicks. The essential art is to avoid overloading this method.

Less frequent operations may as well be triggered by textual commands, i.e. by pointing at the command word and clicking the middle button. Even for this kind of activation, Oberon offers two variations:

1. The command is listed in a menu (title bar). This solution is favoured when the respective viewer is itself a parameter to the command, and it is recommended when the command is reasonably frequent, because the necessary mouse movement is relatively short.

2. The command lies elsewhere, typically in a viewer containing a tool text.

Lastly, we note that any package such as *Draw* is integrated within an entire system together with other packages. Hence it is important that the rules governing the user interfaces of the various packages do not differ unnecessarily, but that they display common ground rules and a common design "philosophy". *Draw*'s conventions were, as far as possible and sensible, adapted to those of the text system. The right key serves for selection, the left for setting the caret, and the middle key for activating general commands, in this case moving and copying the entire graphic. Inherently, drawing involves certain commands that cannot be dealt with in the same way as for texts. A character is created by typing on the keyboard; a line is created by dragging the mouse while holding the left key. Interclicks left-middle and right-middle are treated in the same way as in the text system (copying a caption from the selection to the caret), and this is not surprising, because text and graphics are properly integrated, i.e. captions can be copied from texts into graphics and vice-versa. Using different conventions depending on whether the command was activated by pointing at the caption within a text frame or within a graphics frame would be confusing indeed.

13.6. Macros

For many applications it is indispensible that certain sets of objects may be named and used as objects themselves. Such a named subgraph is called a *macro*. A macro thus closely mirrors the sequence of statements in a program text that is given a name and can be referenced from within other statements: the procedure. The notion of a graphic object becomes recursive, too. The facility of recursive objects is so fundamental that it was incorporated in the base module *Graphics* as the third class of objects.

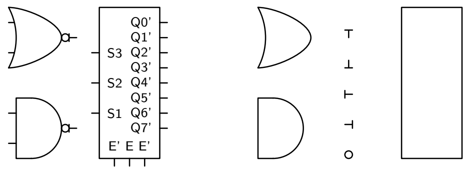


Fig. 13.5. Macros and their components

Its representation is straight-forward: in addition to the attributes common to all objects, a field is provided storing the head of the list of elements which constitute the macro. In the present system, a special node is introduced representing the head of the element list. It is of type *MacHeadDesc* and carries also the name of the macro and the width and height of the rectangle covering all elements. These values serve to speed up the selection process, avoiding their recomputation by scanning the entire element list.

The recursive nature of macros manifests itself in recursive calls of display procedures. In order to draw a macro, drawing procedures of the macro's element types are called (which may be macros again). The coordinates of the macro are added to the coordinates of each element, which function as offsets. The color value of the macro, also a field of the parameter of type *DrawMsg*, overrides the colors of the elements. This implies that macros always appear monochrome.

An application of the macro facility is the design of schematics of electronic circuits. Circuit components correspond to macros. Most components are represented by a rectangular frame and by labelled connectors (pins). Some of the most elementary components, such as gates, diodes, transistors, resistors, and capacitors are represented by standardized symbols. Such symbols, which may be regarded as forming an alphabet of electronic circuit diagrams, are appropriately provided in the form of a special font, i.e. a collection of raster patterns. Three such macros are shown in Fig. 13.5, together with the components from which they are assembled. The definitions of the data types involved are:

```
Macro =           POINTER TO MacroDesc;
MacroDesc =       RECORD (ObjectDesc) mac: MacHead END ;

MacHead =         POINTER TO MacHeadDesc;
MacHeadDesc =     RECORD name: Name;
                      w, h: INTEGER; lib: Library
                  END ;
  Library =       POINTER TO LibraryDesc;
LibraryDesc =     RECORD name: Name END
```

Procedure *DrawMac(mh, M)* displays the macro with head *mh* according to the draw message parameter *M* which specifies a frame, a position within the frame, a display mode, and an overriding color.

In the great majority of applications, macros are not created by their user, but are rather provided from another source, in the case of electronic circuits typically by the manufacturer of the components represented by the macros. As a consequence, macros are taken from a collection (inappropriately) called a *library*. In our system, a macro is picked from such a collection by a call to procedure

ThisMac, which takes a library and a macro name as parameters. The command *Draw.Macro* inserts the specified macro at the place of the caret, as is to be expected.

At last, we mention that selection of a macro is visualized by inverting the color over the entire rectangular area covered by the macro. This emphasizes the fact that the macro constitutes an object as a whole.

The design of new macros is a relatively rare activity. They are used rather like characters of a font; the design of new macros and fonts is left to the specialist. Nevertheless, it was decided to incorporate the tools necessary for macro design in the basic system. These tools consist of a few procedures only: *MakeMac* integrates all elements lying within a specified rectangular area into a new macro. *OpenMac* reverses this process by disintegrating the macro into its parts. *InsertMac* inserts a specified macro into a library. *NewLib* creates a new, empty library, and *StoreLib* generates a library file containing all macros currently loaded into the specified library. The details of these operations may be examined in the program listings provided later in this Chapter.

13. 7. Object Classes

Although surprisingly many applications can be covered satisfactorily with the few types of objects and the few facilities described so far, it is nevertheless expected that a modern graphics system allow the addition of further types of objects. The emphasis lies here on the word addition instead of change. New facilities are to be providable by the inclusion of new modules without requiring any kind of adjustment, not even recompilation of the existing modules. In practice, their source code would quite likely not be available. It is the triumph of the object-oriented programming technique that this is elegantly possible. The means are the extensible record type and the procedure variable, features of the programming language, and the possibility to load modules on demand from statements within a program, a facility provided by the operating environment.

We call, informally, any extension of the type *Object* a *class*. Hence, the types *Line, Caption,* and *Macro* constitute classes. Additional classes can be defined in other modules importing the type *Object*. In every such case, a set of methods must be declared and assigned to a variable of type *MethodDesc*. They form a so-called *method suite*. Every such module must also contain a procedure, typically a command, to generate a new instance of the new class. This command, likely to be called *Make*, assigns the method suite to the *do* field of the new object.

This successful decoupling of additions from the system's base suffices, almost. Only one further link is unavoidable: When a new graphic, containing objects of a class not defined in the system's core, is loaded from a file, then that class must be identified, the corresponding module with its handlers must be loaded - this is called *dynamic loading* - and the object must be generated (allocated). Because the object in question does not already exist at the time when reading the object's attribute values, the generating procedure cannot possibly be installed in the very same object, i.e. it cannot be a member of the method suite. We have chosen the following solution to this problem:

1. Every new class is implemented in the form of a module, and every class is identified by the module name. Every such module contains a command whose effect is to allocate an object of the class, to assign the message suite to it, and to assign the object to the global variable *Graphics.new*.
2. When a graphics file is read, the class of each object is identified and a call to the respective module's allocation procedure delivers the desired object. The call consists of two parts: a call to *Modules.ThisMod*, which may cause the loading of the respctive class module *M*, and a call of *Modules.ThisCommand*. Then the data of the base type *Object* are read, and lastly the data of the extension are read by a call to the class method *read*.

The following may serve as a template for any module defining a new object class *X*:

```
MODULE Xs;
    IMPORT Files, Printer, Oberon, Graphics, GraphicFrames;

    TYPE X* = POINTER TO XDesc;
        XDesc = RECORD (Graphics.ObjectDesc)
```

```
                (*additional data fields*)
            END ;

    VAR method: Graphics.Method;

    PROCEDURE New*;
        VAR x: X;
    BEGIN NEW(x); x.do := method; Graphics.new := x
    END New;

    PROCEDURE* Copy(obj, to: Graphics.Object);
    BEGIN to(X)^ := obj(X)^
    END Copy;

    PROCEDURE* Draw(obj: Graphics.Object; VAR msg: Graphics.Msg);
    BEGIN ...
    END Draw;

    PROCEDURE* Selectable(obj: Graphics.Object; x, y: INTEGER): BOOLEAN;
    BEGIN ...
    END Selectable;

    PROCEDURE* Handle(obj: Graphics.Object; VAR msg: Graphics.Msg);
    BEGIN
        IF msg IS Graphics.ColorMsg THEN obj.col := msg(Graphics.ColorMsg).col
        ELSIF msg IS ... THEN ...
        END
    END Handle;

    PROCEDURE* Read(obj: Graphics.Object; VAR W: Files.Rider; VAR C: Context);
    BEGIN (*read X-specific data*)
    END Write;

    PROCEDURE* Write(obj: Graphics.Object; cno: SHORTINT;
        VAR W: Files.Rider; VAR C: Context);
    BEGIN Graphics.WriteObj(W, cno, obj); (*write X-specific data*)
    END Write;

    PROCEDURE* Print(obj: Graphics.Object; x, y: INTEGER);
    BEGIN (*output object using routines of module Printer*)
    END Print;

    PROCEDURE Make*;   (*command*)
        VAR x: X;  F: GraphicFrames.Frame;
    BEGIN F := GraphicFrames.Focus();
        IF F # NIL THEN
            GraphicFrames.Deselect(F);
            NEW(x); x.x := F.mark.x - F.x; x.y := F.mark.y - F.y; x.w := ... ; x.h := ... ;
            x.col := Oberon.CurCol; x.do := method;
            GraphicFrames.Defocus(F); Graphics.Add(F.graph, x); GraphicFrames.DrawObj(F, x)
        END
    END Make;

BEGIN NEW(method); method.module := "Xs"; method.allocator := "New";
    method.copy := Copy; method.draw := Draw; method.selectable := Selectable;
    method.handle := Handle; method.read := Read; method.write := Write; method.print := Print
END Xs.
```

We wish to point out that also the macro and library facilities are capable of integrating objects of new classes, i.e. of types not occurring in the declarations of macro and library facilities. The complete interface definition of module *Graphics* is obtained from its excerpt given in Sect. 13.3, augmented by the declarations of types and procedures in Sect. 13.6. and 13.7.

13.8. The Implementation

13.8.1. Module *Draw*

Module *Draw* is a typical command module whose exported procedures are listed in a tool text. Its task is to scan the text containing the command for parameters, to check their validity, and to activate the corresponding procedures, which primarily are contained in modules *Graphics* and *GraphicFrames*. The most prominent among them is the *Open* command. It generates a new viewer containing two frames, namely a text frame serving as menu, and a graphic frame.

We emphasize at this point that graphic frames may be opened and manipulated also by other modules apart from *Draw*. In particular, document editors that integrate texts and graphics - and perhaps also other entities - would refer to *Graphics* and *GraphicFrames* directly, but not make use of *Draw* which, as a command module, should not have clients.

```
MODULE Draw; (*NW 29.6.88 / 22.11.91*)
    IMPORT Files, Fonts, Viewers, Printer, Texts, Oberon,
        TextFrames, MenuViewers, Graphics, GraphicFrames;

    VAR W: Texts.Writer;

    (*Exported commands:
        Open, Delete,
        SetWidth, ChangeColor, ChangeWidth, ChangeFont,
        Store, Print
        Macro, OpenMacro, MakeMacro, LoadLibrary, StoreLibrary*)

    PROCEDURE Open*;
        VAR X, Y: INTEGER;
            beg, end, t: LONGINT;
            G: Graphics.Graph;
            V: Viewers.Viewer;
            text: Texts.Text;
            S: Texts.Scanner;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
        IF (S.class = Texts.Char) & (S.c = "^") THEN
            Oberon.GetSelection(text, beg, end, t);
            IF t >= 0 THEN Texts.OpenScanner(S, text, beg); Texts.Scan(S) END
        END ;
        IF S.class = Texts.Name THEN
            NEW(G); Graphics.Open(G, S.s);
            Oberon.AllocateUserViewer(Oberon.Par.vwr.X, X, Y);
            V := MenuViewers.New(
                TextFrames.NewMenu(S.s,
                        "System.Close  System.Copy  System.Grow  Draw.Delete  Draw.Store"),
                GraphicFrames.New(G, 0, 0, 0, TRUE), TextFrames.menuH, X, Y)
        END
    END Open;

    PROCEDURE Delete*;
        VAR F: GraphicFrames.Frame;
    BEGIN
        IF Oberon.Par.frame = Oberon.Par.vwr.dsc THEN
            F := Oberon.Par.vwr.dsc.next(GraphicFrames.Frame);
            GraphicFrames.Erase(F); Graphics.Delete(F.graph)
```

```
  END
END Delete;

PROCEDURE SetWidth*;
  VAR S: Texts.Scanner;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF (S.class = Texts.Int) & (S.i > 0) & (S.i < 7) THEN Graphics.width := SHORT(S.i) END
END SetWidth;

PROCEDURE ChangeColor*;
  VAR ch: CHAR;
    CM: Graphics.ColorMsg;
    S: Texts.Scanner;
BEGIN
  IF Oberon.Par.frame(TextFrames.Frame).sel > 0 THEN
    Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.frame(TextFrames.Frame).selbeg.pos);
    Texts.Read(S, ch); CM.col := S.col
  ELSE Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
    IF S.class = Texts.Int THEN CM.col := SHORT(S.i) ELSE CM.col := S.col END
  END ;
  GraphicFrames.Change(GraphicFrames.Selected(), CM)
END ChangeColor;

PROCEDURE ChangeWidth*;
  VAR WM: Graphics.WidMsg;
    S: Texts.Scanner;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF S.class = Texts.Int THEN
    WM.w := SHORT(S.i); GraphicFrames.Change(GraphicFrames.Selected(), WM)
  END
END ChangeWidth;
PROCEDURE ChangeFont*;
  VAR FM: Graphics.FontMsg;
    S: Texts.Scanner;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF S.class = Texts.Name THEN
    FM.fnt := Fonts.This(S.s);
    IF FM.fnt # NIL THEN GraphicFrames.Change(GraphicFrames.Selected(), FM) END
  END
END ChangeFont;

PROCEDURE Backup (VAR name: ARRAY OF CHAR);
  VAR res, i: INTEGER; ch: CHAR;
    bak: ARRAY 32 OF CHAR;
BEGIN i := 0; ch := name[0];
  WHILE ch > 0X DO bak[i] := ch; INC(i); ch := name[i] END ;
  IF i < 28 THEN
    bak[i] := "."; bak[i+1] := "B"; bak[i+2] := "a"; bak[i+3] := "k"; bak[i+4] := 0X;
    Files.Rename(name, bak, res)
  END
END Backup;

PROCEDURE Store*;
  VAR par: Oberon.ParList; S: Texts.Scanner;
    Menu: TextFrames.Frame; G: GraphicFrames.Frame;
    v: Viewers.Viewer;
BEGIN par := Oberon.Par;
  IF par.frame = par.vwr. dsc THEN
```

```
      Menu := par.vwr.dsc(TextFrames.Frame); G := Menu.next(GraphicFrames.Frame);
      Texts.OpenScanner(S, Menu.text, 0); Texts.Scan(S);
      IF S.class = Texts.Name THEN
        Texts.WriteString(W, S.s); Texts.WriteString(W, " storing");
        Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf);
        Backup(S.s); Graphics.WriteFile(G.graph, S.s)
      END
    ELSE
      Texts.OpenScanner(S, par.text, par.pos); Texts.Scan(S);
      IF S.class = Texts.Name THEN
        v := Oberon.MarkedViewer();
        IF (v.dsc # NIL) & (v.dsc.next IS GraphicFrames.Frame) THEN
          G := v.dsc.next(GraphicFrames.Frame);
          Texts.WriteString(W, S.s); Texts.WriteString(W, " storing");
          Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf);
          Backup(S.s); Graphics.WriteFile(G.graph, S.s)
        END
      END
    END
  END Store;

  PROCEDURE Print*;
    VAR nofcopies: INTEGER;
      S: Texts.Scanner;
      G: Graphics.Graph;
      V: Viewers.Viewer;

    PROCEDURE Copies;
      VAR ch: CHAR;
    BEGIN nofcopies := 1;
      IF S.nextCh = "/" THEN
        Texts.Read(S, ch);
        IF (ch >= "0") & (ch <= "9") THEN nofcopies := ORD(ch) - 30H END ;
        WHILE ch > " " DO Texts.Read(S, ch) END ;
        S.nextCh := ch
      END
    END Copies;

  BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
    IF S.class = Texts.Name THEN
      Printer.Open(S.s, Oberon.User, Oberon.Password);
      IF Printer.res = 0 THEN
        Texts.Scan(S);
        WHILE S.class = Texts.Name DO
          Texts.WriteString(W, S.s); Copies; Graphics.Open(G, S.s);
          IF Graphics.res = 0 THEN
            Texts.WriteString(W, " printing");
            Texts.WriteInt(W, nofcopies, 3); Texts.Append(Oberon.Log, W.buf);
            Graphics.Print(G, 0, Printer.PageHeight-128); Printer.Page(nofcopies)
          ELSE Texts.WriteString(W, " not found")
          END ;
          Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf); Texts.Scan(S)
        END ;
        IF (S.class = Texts.Char) & (S.c = "*") THEN
          Copies; V := Oberon.MarkedViewer();
          IF (V.dsc # NIL) & (V.dsc.next IS GraphicFrames.Frame) THEN
            Texts.OpenScanner(S, V.dsc(TextFrames.Frame).text, 0);
          Texts.Scan(S);
          IF S.class = Texts.Name THEN
            Texts.WriteString(W, S.s); Texts.WriteString(W, " printing");
            Texts.WriteInt(W, nofcopies, 3); Texts.Append(Oberon.Log, W.buf);
            Graphics.Print(V.dsc.next(GraphicFrames.Frame).graph, 0, Printer.PageHeight-128);
            Printer.Page(nofcopies)
          END
        END
      END ;
      Printer.Close
    ELSIF Printer.res = 1 THEN Texts.WriteString(W, " no printer")
    ELSIF Printer.res = 2 THEN Texts.WriteString(W, " no link")
    ELSIF Printer.res = 3 THEN Texts.WriteString(W, " bad response")
    ELSIF Printer.res = 4 THEN Texts.WriteString(W, " no permission")
    END
  END ;
  Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
END Print;

PROCEDURE Macro*;
  VAR S: Texts.Scanner;
    T: Texts.Text;
    time, beg, end: LONGINT;
    Lname: ARRAY 32 OF CHAR;
BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
  IF S.class = Texts.Name THEN
    COPY(S.s, Lname); Texts.Scan(S);
    IF (S.class = Texts.Char) & (S.c = "^") THEN
      Oberon.GetSelection(T, beg, end, time);
      IF time >= 0 THEN Texts.OpenScanner(S, T, beg); Texts.Scan(S) END
    END ;
    IF (S.class = Texts.Name) OR (S.class = Texts.String) THEN
      GraphicFrames.Macro(Lname, S.s)
    END
  END
END Macro;

PROCEDURE OpenMacro*;
  VAR F: GraphicFrames.Frame; sel: Graphics.Object;
BEGIN F := GraphicFrames.Selected();
  IF F # NIL THEN
    sel := F.graph.sel;
    IF (sel # NIL) & (sel IS Graphics.Macro) THEN
      GraphicFrames.Deselect(F);
      Graphics.OpenMac(sel(Graphics.Macro).mac, F.graph, F.mark.x - F.x, F.mark.y - F.y);
      GraphicFrames.Draw(F)
    END
  END
END OpenMacro;

PROCEDURE MakeMacro*;
  VAR new: BOOLEAN;
    F: GraphicFrames.Frame;
    S: Texts.Scanner;
    Lname: ARRAY 32 OF CHAR;

  PROCEDURE MakeMac;
    VAR x0, y0, x1, y1, w, h: INTEGER;
```

```
          mh: Graphics.MacHead;
          L: Graphics.Library;
      BEGIN
        L := Graphics.ThisLib(Lname, FALSE);
        IF L = NIL THEN L := Graphics.NewLib(Lname) END ;
        x0 := F.mark.x; y0 := F.mark.y; x1 := F.mark.next.x; y1 := F.mark.next.y;
        w := ABS(x1-x0); h := ABS(y1-y0);
        IF x0 < x1 THEN x0 := x0 - F.x ELSE x0 := x1 - F.x END ;
        IF y0 < y1 THEN y0 := y0 - F.y ELSE y0 := y1 - F.y END ;
        mh := Graphics.MakeMac(F.graph, x0, y0, w, h, S.s);
        Graphics.InsertMac(mh, L, new)
      END MakeMac;

    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
      IF S.class = Texts.Name THEN
        COPY(S.s, Lname); Texts.Scan(S);
        IF (S.class  = Texts.Name) OR (S.class = Texts.String) & (S.len <= 8) THEN
          F := GraphicFrames.Focus();
          IF (F # NIL) & (F.graph.sel # NIL) THEN
            MakeMac; Texts.WriteString(W, S.s);
            IF new THEN Texts.WriteString(W, " inserted in ")
            ELSE Texts.WriteString(W, " replaced in ")
            END ;
            Texts.WriteString(W, Lname); Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
          END
        END
      END
    END MakeMacro;

    PROCEDURE LoadLibrary*;
      VAR S: Texts.Scanner; L: Graphics.Library;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
      IF S.class = Texts.Name THEN
        L := Graphics.ThisLib(S.s, TRUE);
        Texts.WriteString(W, S.s); Texts.WriteString(W, " loaded");
        Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
      END
    END LoadLibrary;

    PROCEDURE StoreLibrary*;
      VAR i: INTEGER; S: Texts.Scanner; L: Graphics.Library;
        Lname: ARRAY 32 OF CHAR;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
      IF S.class = Texts.Name THEN i := 0;
        WHILE S.s[i] >= "0" DO Lname[i] := S.s[i]; INC(i) END ;
        Lname[i] := 0X;
        L := Graphics.ThisLib(Lname, FALSE);
        IF L # NIL THEN
          Texts.WriteString(W, S.s); Texts.WriteString(W, " storing");
          Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf); Graphics.StoreLib(L, S.s)
        END
      END
    END StoreLibrary;

BEGIN Texts.OpenWriter(W)
END Draw.
```

13.8.2. Module *GraphicFrames*

Module *GraphicFrames* contains all routines concerned with displaying, visualizing graphic frames and their contents, i.e. graphics. It also contains the routines for creating new objects of the base classes, i.e. lines, captions, and macros. And most importantly, it specifies the appropriate frame handler which interprets input actions and thereby defines the user interface. The handler discriminates among the following message types:

1. Update messages. According to the *id* field of the message record, either a specific object or the entire selection of a graphic are drawn according to a mode. The case *id = 0* signifies a restoration of the entire frame including all objects of the graphic.
2. Selection, focus, and position queries. They serve for the identification of the graphic frame containing the latest selection, containing the caret (mark) or the indicated position. In order to identify the latest selection, the time is recorded in the graph descriptor whenever a new selection is made or when new objects are inserted.
3. Input messages. They originate from the central loop of module *Oberon* and indicate either a mouse action (track message) or a keyboard event (consume message).
4. Control messages from *Oberon*. They indicate that all marks (selection, caret, star) are to be removed (neutralize), or that the focus has to be relinquished (defocus).
5. Selection, copy, and copy-over messages from *Oberon*. They constitute the interface between the graphics and the text system, and make possible identification and copying of captions between graphic and text frames.
6. Modify messages from *MenuViewers*. They indicate that a frame has to be adjusted in size and position because a neighbouring viewer has been reshaped, or because its own viewer has been repositioned
7. Display messages. They originate from procedure *InsertChar* and handle the displaying of single characters when a caption is composed (see below).

The frame handler receiving a consume message interprets the request through procedure *InsertChar* (except for cursor and restore characters), and receiving a track message through procedure *Edit*. If no mouse key is depressed, the cursor is simply drawn, and thereby the mouse is tracked. Instead of the regular arrow, a crosshair is used as cursor pattern. Thereby immediate visual feedback is provided to indicate that now mouse actions are interpreted by the graphics handler (instead of, e.g., a text handler). Such feedback is helpful when graphic frames appear not only in a menuviewer, but as subframes of a more highly structured document frame.

Procedure *Edit* first tracks the mouse while recording further key activities (interclicks) until all keys are released. The subsequent action is determined by the perceived key clicks. The actions are (the second key denotes the interclick):

keys = left	set caret, if mouse was not moved, draw new line otherwise,
keys = left, middle	copy text selection to caret position
keys = left, right	set secondary caret (mark)
keys = middle	move selection
keys = middle, left	copy selection
keys = middle, right	shift origin of graph
keys = right	select (either object, or objects in area)
keys = right, middle	copy selected caption to caret position

When copying or moving a set of selected objects, it must be distinguished between the cases where the source and the destination graphics are the same or are distinct. In the former case, source and destination positions may lie in the same or in different frames.

Procedure *InsertChar* handles the creation of new captions. The actual character string is appended to the global text *T*, and the new object records its position within *T* and its length.

A complication arises because the input process consists of as many user actions as there are characters, and because other actions may possibly intervene between the typing. It is therefore unavoidable to record an insertion state, which is embodied by the global variable *newcap*. When a character is typed, and *newcap = NIL*, then a new caption is created consisting of the single typed character. Subsequent typing results in appending characters to the string (and *newcap*). The variable is reset to NIL, when the caret is repositioned. The DEL character is interpreted as a backspace by procedure *DeleteChar*.

Since the caption being generated may be visible simultaneously in several frames, its display must be handled by a message. For this reason, the special message *DispMsg* is introduced, and as a result, the process of character insertion turns out to be a rather complex action. To avoid even further complexity, the restriction is adopted that all characters of a caption must use the same attributes (font, color).

```
MODULE GraphicFrames; (*NW 18.4.88 / 22.11.91*)
    IMPORT Display, Viewers, Input, Fonts, Texts, Graphics, Oberon, MenuViewers;

    CONST (*update message ids*)
        restore = 0;
        drawobj = 1; drawobjs = 2; drawobjd = 3;
        drawnorm = 4; drawsel = 5; drawdel = 6;

        markW = 5;

    TYPE
        Frame* = POINTER TO FrameDesc;
        Location* = POINTER TO LocDesc;

        LocDesc* = RECORD
                x*, y*: INTEGER;
                next*: Location
            END ;

        FrameDesc* = RECORD (Display.FrameDesc)
                graph*: Graphics.Graph;
                Xg*, Yg*: INTEGER;  (*pos rel to graph origin*)
                X1*, Y1*: INTEGER;  (*right and upper margins*)
                x*, y*, col*: INTEGER;  (*x = X + Xg, y = Y + Yg*)
                marked*, ticked*: BOOLEAN;
                mark*: LocDesc
            END ;

        DrawMsg* = RECORD (Graphics.Msg)
                f*: Frame;
                x*, y*, col*, mode*: INTEGER
            END ;

        CtrlMsg* = RECORD (Graphics.Msg)
                f*: Frame; res*: INTEGER
            END ;

        UpdateMsg = RECORD (Display.FrameMsg)
                id: INTEGER;
                graph: Graphics.Graph;
                obj: Graphics.Object
            END ;

        SelQuery = RECORD (Display.FrameMsg)
                f: Frame; time: LONGINT
            END ;

        FocusQuery = RECORD (Display.FrameMsg)
                f: Frame
            END ;
```

```
  PosQuery = RECORD (Display.FrameMsg)
      f: Frame; x, y: INTEGER
    END ;

  DispMsg = RECORD (Display.FrameMsg)
      x1, y1, w: INTEGER;
      pat: Display.Pattern;
      graph: Graphics.Graph
    END ;

VAR Crosshair*: Oberon.Marker;
  newcap: Graphics.Caption;
  DW, DH, CL: INTEGER;
  W: Texts.Writer;

(*Exported procedures:
  Restore, Focus, Selected, This, Draw, Erase,
  DrawObj, EraseObj, Change, Defocus, Deselect, Macro, New*)

PROCEDURE Restore*(F: Frame);
  VAR M: DrawMsg; x, y, col: INTEGER;
BEGIN F.X1 := F.X + F.W; F.Y1 := F.Y + F.H;
  F.x := F.X + F.Xg; F.y := F.Y1 + F.Yg; F.marked := FALSE; F.mark.next := NIL;
  IF F.X < CL THEN col := Display.black ELSE col := F.col END ;
  Oberon.RemoveMarks(F.X, F.Y, F.W, F.H);
  Display.ReplConst(col, F.X, F.Y, F.W, F.H, 0);
  IF F.ticked THEN
    y := F.Yg MOD 16 + F.Y1 - 16;
    WHILE y >= F.Y DO (*draw ticks*)
      x := F.Xg MOD 16 + F.X;
      WHILE x < F.X1 DO Display.Dot(Display.white, x, y, 0); INC(x, 16) END ;
      DEC(y, 16)
    END
  END ;
  M.f := F; M.x := F.x; M.y := F.y; M.col := 0; M.mode := 0; Graphics.Draw(F.graph, M)
END Restore;

PROCEDURE Focus*(): Frame;
  VAR FQ: FocusQuery;
BEGIN FQ.f := NIL; Viewers.Broadcast(FQ); RETURN FQ.f
END Focus;

PROCEDURE Selected*(): Frame;
  VAR SQ: SelQuery;
BEGIN SQ.f := NIL; SQ.time := 0; Viewers.Broadcast(SQ); RETURN SQ.f
END Selected;

PROCEDURE This*(x, y: INTEGER): Frame;
  VAR PQ: PosQuery;
BEGIN PQ.f := NIL; PQ.x := x; PQ.y := y; Viewers.Broadcast(PQ); RETURN PQ.f
END This;

PROCEDURE Draw*(F: Frame);
  VAR UM: UpdateMsg;
BEGIN UM.id := drawsel; UM.graph := F.graph; Viewers.Broadcast(UM)
END Draw;

PROCEDURE DrawNorm(F: Frame);
  VAR UM: UpdateMsg;
```

```
BEGIN UM.id := drawnorm; UM.graph := F.graph; Viewers.Broadcast(UM)
END DrawNorm;

PROCEDURE Erase*(F: Frame);
  VAR UM: UpdateMsg;
BEGIN UM.id := drawdel; UM.graph := F.graph; Viewers.Broadcast(UM)
END Erase;

PROCEDURE DrawObj*(F: Frame; obj: Graphics.Object);
  VAR UM: UpdateMsg;
BEGIN UM.id := drawobj; UM.graph := F.graph; UM.obj := obj; Viewers.Broadcast(UM)
END DrawObj;

PROCEDURE EraseObj*(F: Frame; obj: Graphics.Object);
  VAR UM: UpdateMsg;
BEGIN UM.id := drawobjd; UM.graph := F.graph; UM.obj := obj; Viewers.Broadcast(UM)
END EraseObj;

PROCEDURE Change*(F: Frame; VAR msg: Graphics.Msg);
BEGIN
  IF F # NIL THEN Erase(F); Graphics.Handle(F.graph, msg); Draw(F) END
END Change;

PROCEDURE FlipMark(x, y: INTEGER);
BEGIN
  Display.ReplConst(Display.white, x-7, y, 15, 1, 2);
  Display.ReplConst(Display.white, x, y-7, 1, 15, 2)
END FlipMark;

PROCEDURE Defocus*(F: Frame);
  VAR m: Location;
BEGIN newcap := NIL;
  IF F.marked THEN
    FlipMark(F.mark.x, F.mark.y); m := F.mark.next;
    WHILE m # NIL DO FlipMark(m.x, m.y); m := m.next END ;
    F.marked := FALSE; F.mark.next := NIL
  END
END Defocus;

PROCEDURE Deselect*(F: Frame);
  VAR UM: UpdateMsg;
BEGIN
  IF F # NIL THEN
    UM.id := drawnorm; UM.graph := F.graph; Viewers.Broadcast(UM);
    Graphics.Deselect(F.graph)
  END
END Deselect;

PROCEDURE Macro*(VAR Lname, Mname: ARRAY OF CHAR);
  VAR x, y: INTEGER;
    F: Frame;
    mac: Graphics.Macro; mh: Graphics.MacHead;
    L: Graphics.Library;
BEGIN F := Focus();
  IF F # NIL THEN
    x := F.mark.x - F.x; y := F.mark.y - F.y;
    L := Graphics.ThisLib(Lname, FALSE);
    IF L # NIL THEN
      mh := Graphics.ThisMac(L, Mname);
      IF mh # NIL THEN
```

```
            Deselect(F); Defocus(F);
            NEW(mac); mac.x := x; mac.y := y; mac.w := mh.w; mac.h := mh.h;
            mac.mac := mh; mac.do := Graphics.MacMethod; mac.col := Oberon.CurCol;
            Graphics.Add(F.graph, mac); DrawObj(F, mac)
          END
        END
      END
    END Macro;

    PROCEDURE CaptionCopy(F: Frame;
        x1, y1: INTEGER; T: Texts.Text; beg, end: LONGINT): Graphics.Caption;
      VAR ch: CHAR;
        dx, w, x2, y2, w1, h1: INTEGER;
        cap: Graphics.Caption;
        pat: Display.Pattern;
        R: Texts.Reader;
    BEGIN Texts.Write(W, 0DX);
      NEW(cap); cap.len := SHORT(end - beg);
      cap.pos := SHORT(Graphics.T.len)+1; cap.do := Graphics.CapMethod;
      Texts.OpenReader(R, T, beg); Texts.Read(R, ch); W.fnt := R.fnt; W.col := R.col; w := 0;
      cap.x := x1 - F.x; cap.y := y1 - F.y + R.fnt.minY;
      WHILE beg < end DO
        Display.GetChar(R.fnt.raster, ch, dx, x2, y2, w1, h1, pat);
        INC(w, dx); INC(beg); Texts.Write(W, ch); Texts.Read(R, ch)
      END ;
      cap.w := w; cap.h := W.fnt.height; cap.col := W.col;
      Texts.Append(Graphics.T, W.buf); Graphics.Add(F.graph, cap); RETURN cap
    END CaptionCopy;

    PROCEDURE SendCaption(cap: Graphics.Caption);
      VAR M: Oberon.CopyOverMsg;
    BEGIN
      M. text := Graphics.T; M.beg := cap.pos; M.end := M.beg + cap.len; Viewers.Broadcast(M)
    END SendCaption;

    PROCEDURE Edit(F: Frame; x0, y0: INTEGER; k0: SET);
      VAR obj: Graphics.Object;
        x1, y1, w, h, t, pos: INTEGER;
        beg, end, time: LONGINT;
        k1, k2: SET; ch: CHAR;
        mark, newmark: Location;
        T: Texts.Text;
        Fd: Frame;
        G: Graphics.Graph;
        CM: CtrlMsg;
        name: ARRAY 32 OF CHAR;

      PROCEDURE NewLine(x, y, w, h: INTEGER);
        VAR line: Graphics.Line;
      BEGIN NEW(line); line.col := Oberon.CurCol; line.x := x - F.x; line.y := y - F.y;
        line.w := w; line.h := h; line.do := Graphics.LineMethod; Graphics.Add(G, line)
      END NewLine;

    BEGIN k1 := k0; G := F.graph;
      IF k0 = {1} THEN
        obj := Graphics.ThisObj(G, x0 - F.x, y0 - F.y);
        IF (obj # NIL) & ~obj.selected THEN
          CM.f := F; CM.res := 0; obj.do.handle(obj, CM);
          IF CM.res # 0 THEN (*done*) k0 := {} END
        END
      END ;
      REPEAT Input.Mouse(k2, x1, y1); k1 := k1 + k2;
        DEC(x1, (x1-F.x) MOD 4); DEC(y1, (y1-F.y) MOD 4);
        Oberon.DrawCursor(Oberon.Mouse, Crosshair, x1, y1)
      UNTIL  k2 = {};
      Oberon.FadeCursor(Oberon.Mouse);
      IF k0 = {2} THEN (*left key*)
        w := ABS(x1-x0); h := ABS(y1-y0);
        IF k1 = {2} THEN
          IF (w < 7) & (h < 7) THEN (*set mark*)
            IF (x1 - markW >= F.X) & (x1 + markW < F.X1) &
              (y1 - markW >= F.Y) & (y1 + markW < F.Y1) THEN
              Defocus(F); Oberon.PassFocus(Viewers.This(F.X, F.Y));
              F.mark.x := x1; F.mark.y := y1; F.marked := TRUE; FlipMark(x1, y1)
            END
          ELSE (*draw line*) Deselect(F);
            IF w < h THEN
              IF y1 < y0 THEN y0 := y1 END ;
              NewLine(x0, y0, Graphics.width, h)
            ELSE
              IF x1 < x0 THEN x0 := x1 END ;
              NewLine(x0, y0, w, Graphics.width)
            END ;
            Draw(F)
          END
        ELSIF k1 = {2, 1} THEN (*copy selection to caret mark*)
          Deselect(F); Oberon.GetSelection(T, beg, end, time);
          IF time >= 0 THEN DrawObj(F, CaptionCopy(F, x1, y1, T, beg, end)) END
        ELSIF k1 = {2, 0} THEN
          IF F.marked THEN (*set secondary mark*)
              NEW(newmark); newmark.x := x1; newmark.y := y1; newmark.next := NIL;
            FlipMark(x1, y1); mark := F.mark.next;
            IF mark = NIL THEN F.mark.next := newmark ELSE
              WHILE mark.next # NIL DO mark := mark.next END ;
              mark.next := newmark
            END
          END
        END
      ELSIF k0 = {1} THEN (*middle key*)
        IF k1 = {1} THEN (*move*)
          IF (x0 # x1) OR (y0 # y1) THEN
            Fd := This(x1, y1); Erase(F);
            IF Fd = F THEN Graphics.Move(G, x1-x0, y1-y0)
            ELSIF (Fd # NIL) & (Fd.graph = G) THEN
              Graphics.Move(G, (x1-Fd.x-x0+F.x) DIV 4 * 4, (y1-Fd.y-y0+F.y) DIV 4 * 4)
            END ;
            Draw(F)
          END
        ELSIF k1 = {1, 2} THEN (*copy*)
          Fd := This(x1, y1);
          IF Fd # NIL THEN DrawNorm(F);
            IF Fd = F THEN Graphics.Copy(G, G, x1-x0, y1-y0)
            ELSE Deselect(Fd);
              Graphics.Copy(G, Fd.graph, (x1-Fd.x-x0+F.x) DIV 4 * 4, (y1-Fd.y-y0+F.y) DIV 4 * 4)
```

```
            END ;
            Draw(Fd)
          END
        ELSIF k1 = {1, 0} THEN (*shift graph origin*)
          INC(F.Xg, x1-x0); INC(F.Yg, y1-y0); Restore(F)
        END
      ELSIF k0 = {0} THEN (*right key: select*)
        newcap := NIL;
        IF (ABS(x0-x1) < 7) & (ABS(y0-y1) < 7) THEN
          IF ~(2 IN k1) THEN Deselect(F) END ;
          obj := Graphics.ThisObj(G, x1 - F.x, y1 - F.y);
          IF obj # NIL THEN
            Graphics.SelectObj(G, obj); DrawObj(F, obj);
            IF (k1 = {0, 1}) & (obj IS Graphics.Caption) THEN
              SendCaption(obj(Graphics.Caption))
            END
          END
        ELSE Deselect(F);
          IF x1 < x0 THEN t := x0; x0 := x1; x1 := t END ;
          IF y1 < y0 THEN t := y0; y0 := y1; y1 := t END ;
          Graphics.SelectArea(G, x0 - F.x, y0 - F.y, x1 - F.x, y1 - F.y); Draw(F)
        END
      END
    END Edit;

    PROCEDURE NewCaption(F: Frame; col: INTEGER; font: Fonts.Font);
    BEGIN Texts.Write(W, 0DX);
      NEW(newcap); newcap.x := F.mark.x - F.x; newcap.y := F.mark.y - F.y + font.minY;
      newcap.w := 0; newcap.h := font.height; newcap.col := col;
      newcap.pos := SHORT(Graphics.T.len + 1); newcap.len := 0;
      newcap.do := Graphics.CapMethod; Graphics.Add(F.graph, newcap); W.fnt := font
    END NewCaption;

    PROCEDURE InsertChar(F: Frame; ch: CHAR);
      VAR w1, h1: INTEGER; DM: DispMsg;
    BEGIN DM.graph := F.graph;
      Display.GetChar(W.fnt.raster, ch, DM.w, DM.x1, DM.y1, w1, h1, DM.pat);
      DEC(DM.y1, W.fnt.minY);
      IF newcap.x + newcap.w + DM.w + F.x < F.X1 THEN
        Viewers.Broadcast(DM); INC(newcap.w, DM.w); INC(newcap.len); Texts.Write(W, ch)
      END ;
      Texts.Append(Graphics.T, W.buf)
    END InsertChar;

    PROCEDURE DeleteChar(F: Frame);
      VAR w1, h1: INTEGER; ch: CHAR; pos: LONGINT;
        DM: DispMsg; R: Texts.Reader;
    BEGIN DM.graph := F.graph;
      IF newcap.len > 0 THEN
        pos := Graphics.T.len; Texts.OpenReader(R, Graphics.T, pos-1);  (*backspace*)
        Texts.Read(R, ch);
        IF ch >= " " THEN
          Display.GetChar(R.fnt.raster, ch, DM.w, DM.x1, DM.y1, w1, h1, DM.pat);
          DEC(newcap.w, DM.w); DEC(newcap.len); DEC(DM.y1, R.fnt.minY);
          Viewers.Broadcast(DM); Texts.Delete(Graphics.T, pos-1, pos)
        END
```

```
   END
END DeleteChar;

PROCEDURE GetSelection(F: Frame; VAR text: Texts.Text; VAR beg, end, time: LONGINT);
   VAR obj: Graphics.Object;
BEGIN obj := F.graph.sel;
   IF (obj # NIL) & (obj IS Graphics.Caption) & (F.graph.time >= time) THEN
      WITH obj: Graphics.Caption DO beg := obj.pos; end := obj.pos + obj.len END ;
      text := Graphics.T; time := F.graph.time
   END
END GetSelection;

PROCEDURE* Handle(G: Display.Frame; VAR M: Display.FrameMsg);
   VAR i: LONGINT; ch: CHAR;
      x, y: INTEGER;
      DM: DispMsg; dM: DrawMsg;
      G1: Frame;

   PROCEDURE move(G: Frame; dx, dy: INTEGER);
      VAR M: UpdateMsg;
   BEGIN Defocus(G); Oberon.FadeCursor(Oberon.Mouse);
      M.id := drawdel; M.graph := G.graph;  Viewers.Broadcast(M);
      Graphics.Move(G.graph, dx, dy); M.id := drawsel; Viewers.Broadcast(M)
   END move;

BEGIN
   WITH G: Frame DO
      IF M IS Oberon.InputMsg THEN
         WITH M: Oberon.InputMsg DO
            IF M.id = Oberon.track THEN
               x := M.X - (M.X - G.x) MOD 4; y := M.Y - (M.Y - G.y) MOD 4;
               IF M.keys # {} THEN Edit(G, x, y, M.keys)
               ELSE Oberon.DrawCursor(Oberon.Mouse, Crosshair, x, y)
               END
            ELSIF M.id = Oberon.consume THEN
               IF M.ch = 7FX THEN
                  IF newcap # NIL THEN DeleteChar(G)
                  ELSE Oberon.FadeCursor(Oberon.Mouse);
                    Defocus(G); Erase(G); Graphics.Delete(G.graph)
                  END
               ELSIF M.ch = 91X THEN Restore(G)
               ELSIF M.ch = 93X THEN G.Xg := -1; G.Yg := 0; Restore(G)  (*reset*)
               ELSIF M.ch = 0C1X THEN move(G, 0, 1)
               ELSIF M.ch = 0C2X THEN move(G, 0, -1)
               ELSIF M.ch = 0C3X THEN move(G, 1, 0)
               ELSIF M.ch = 0C4X THEN move(G, -1, 0)
               ELSIF (M.ch >= 20X) & (M.ch <= 86X) THEN
                  IF newcap # NIL THEN InsertChar(G, M.ch)
                  ELSIF G.marked THEN
                              Defocus(G); Deselect(G);
                              NewCaption(G, M.col, M.fnt); InsertChar(G, M.ch)
                   END
               END
            END
         END
      ELSIF M IS UpdateMsg THEN
         WITH M: UpdateMsg DO
            IF M.graph = G.graph THEN
```

```
        dM.f := G; dM.x := G.x; dM.y := G.y; dM.col := 0;
        CASE M.id OF
          restore: Restore(G)
        | drawobj:  dM.mode := 0; M.obj.do.draw(M.obj, dM)
        | drawobjs: dM.mode := 1; M.obj.do.draw(M.obj, dM)
        | drawobjd: dM.mode := 3; M.obj.do.draw(M.obj, dM)
        | drawsel:  dM.mode := 0; Graphics.DrawSel(G.graph, dM)
        | drawnorm: dM.mode := 2; Graphics.DrawSel(G.graph, dM)
        | drawdel:  dM.mode := 3; Graphics.DrawSel(G.graph, dM)
        END
      END
    END
  ELSIF M IS SelQuery THEN
    WITH M: SelQuery DO
      IF (G.graph.sel # NIL) & (M.time < G.graph.time) THEN
        M.f := G; M.time := G.graph.time
      END
    END
  ELSIF M IS FocusQuery THEN
    IF G.marked THEN M(FocusQuery).f := G END
  ELSIF M IS PosQuery THEN
    WITH M: PosQuery DO
      IF (G.X <= M.x) & (M.x < G.X1) & (G.Y <= M.y) & (M.y < G.Y1) THEN
        M.f := G
      END
    END
  ELSIF M IS DispMsg THEN
    DM := M(DispMsg);
    x := G.x + newcap.x + newcap.w; y := G.y + newcap.y;
    IF (DM.graph = G.graph) & (x >= G.X) & (x + DM.w < G.X1)
        & (y >= G.Y) & (y < G.Y1) THEN
      Display.CopyPattern(Oberon.CurCol, DM.pat, x + DM.x1, y + DM.y1, 2);
      Display.ReplConst(Display.white, x, y, DM.w, newcap.h, 2)
    END
  ELSIF M IS Oberon.ControlMsg THEN
    WITH M: Oberon.ControlMsg DO
      IF M.id = Oberon.neutralize THEN
        Oberon.RemoveMarks(G.X, G.Y, G.W, G.H); Defocus(G);
        DrawNorm(G); Graphics.Deselect(G.graph)
      ELSIF M.id = Oberon.defocus THEN Defocus(G)
      END
    END
  ELSIF M IS Oberon.SelectionMsg THEN
    WITH M: Oberon.SelectionMsg DO GetSelection(G, M.text, M.beg, M.end, M.time) END
  ELSIF M IS Oberon.CopyMsg THEN
    Oberon.RemoveMarks(G.X, G.Y, G.W, G.H); Defocus(G);
    NEW(G1); G1^ := G^; M(Oberon.CopyMsg).F := G1
  ELSIF M IS MenuViewers.ModifyMsg THEN
    WITH M: MenuViewers.ModifyMsg DO G.Y := M.Y; G.H := M.H; Restore(G) END
  ELSIF M IS Oberon.CopyOverMsg THEN
    WITH M: Oberon.CopyOverMsg DO
      IF G.marked THEN
        DrawObj(G, CaptionCopy(G, G.mark.x, G.mark.y, M.text, M.beg, M.end))
      END
    END
  END
  END
END Handle;

(*------------------- Methods -----------------------*)

PROCEDURE* DrawLine(obj: Graphics.Object; VAR M: Graphics.Msg);
  (*M.mode = 0: draw according to state,
      = 1: normal -> selected,
      = 2: selected -> normal,
      = 3: erase*)
  VAR x, y, w, h, col: INTEGER; f: Frame;
BEGIN
  WITH M: DrawMsg DO
    x := obj.x + M.x; y := obj.y + M.y; w := obj.w; h := obj.h; f := M.f;
    IF (x+w > f.X) & (x < f.X1) & (y+h > f.Y) & (y < f.Y1) THEN
      IF x < f.X THEN DEC(w, f.X-x); x := f.X END ;
      IF x+w > f.X1 THEN w := f.X1-x END ;
      IF y < f.Y THEN DEC(h, f.Y-y); y := f.Y END ;
      IF y+h > f.Y1 THEN h := f.Y1-y END ;
      IF M.col = Display.black THEN col := obj.col ELSE col := M.col (*macro*) END ;
      IF (M.mode = 0) & obj.selected OR (M.mode = 1) THEN
        Display.ReplPattern(col, Display.grey2, x, y, w, h, 0)
      ELSIF M.mode = 3 THEN Display.ReplConst(Display.black, x, y, w, h, 0)  (*erase*)
      ELSE Display.ReplConst(col, x, y, w, h, 0)
      END
    END
  END
END DrawLine;

PROCEDURE* DrawCaption(obj: Graphics.Object; VAR M: Graphics.Msg);
  VAR x, y, dx, x0, x1, y0, y1, w, h, w1, h1, col: INTEGER;
    f: Frame;
    ch: CHAR; pat: Display.Pattern; fnt: Fonts.Font;
    R: Texts.Reader;
BEGIN
  WITH M: DrawMsg DO
    x := obj.x + M.x; y := obj.y + M.y; w := obj.w; h := obj.h; f := M.f;
    IF (f.X <= x) & (x <= f.X1) & (f.Y <= y) & (y+h <= f.Y1) THEN
      IF x+w > f.X1 THEN w := f.X1-x END ;
      Texts.OpenReader(R, Graphics.T, obj(Graphics.Caption).pos); Texts.Read(R, ch);
      IF M.mode = 0 THEN
        IF ch >= " " THEN
          IF M.col = Display.black THEN col := obj.col ELSE col := M.col (*macro*) END ;
          fnt := R.fnt; x0 := x; y0 := y - fnt.minY;
          LOOP
            Display.GetChar(fnt.raster, ch, dx, x1, y1, w1, h1, pat);
            IF x0+x1+w1 <= f.X1 THEN Display.CopyPattern(col, pat, x0+x1, y0+y1, 1)
            ELSE EXIT
            END ;
            INC(x0, dx); Texts.Read(R, ch);
            IF ch < " " THEN EXIT END
          END ;
          IF obj.selected THEN Display.ReplConst(Display.white, x, y, w, h, 2) END
        END
      ELSIF M.mode < 3 THEN Display.ReplConst(Display.white, x, y, w, h, 2)
      ELSE Display.ReplConst(Display.black, x, y, w, h, 0)
      END
      END
    END
  END DrawCaption;

  PROCEDURE* DrawMacro(obj: Graphics.Object; VAR M: Graphics.Msg);
    VAR x, y, w, h: INTEGER;
      f: Frame; M1: DrawMsg;
  BEGIN
    WITH M: DrawMsg DO
      x := obj.x + M.x; y := obj.y + M.y; w := obj.w; h := obj.h; f := M.f;
      IF (x+w > f.X) & (x < f.X1) & (y+h > f.Y) & (y < f.Y1) THEN
        M1.x := x; M1.y := y;
        IF x < f.X THEN DEC(w, f.X-x); x := f.X END ;
        IF x+w > f.X1 THEN w := f.X1-x END ;
        IF y < f.Y THEN DEC(h, f.Y-y); y := f.Y END ;
        IF y+h > f.Y1 THEN h := f.Y1-y END ;
        IF M.mode = 0 THEN
          M1.f := f; M1.col := obj.col; M1.mode := 0;
          Graphics.DrawMac(obj(Graphics.Macro).mac, M1);
          IF obj.selected THEN Display.ReplConst(Display.white, x, y, w, h, 2) END
        ELSIF M.mode < 3 THEN Display.ReplConst(Display.white, x, y, w, h, 2)
        ELSE Display.ReplConst(Display.black, x, y, w, h, 0)
        END
      END
    END
  END DrawMacro;

  PROCEDURE New*(graph: Graphics.Graph; X, Y, col: INTEGER; ticked: BOOLEAN): Frame;
    VAR G: Frame;
  BEGIN NEW(G); G.graph := graph; G.Xg := X; G.Yg := Y; G.col := col; G.marked := FALSE;
    G.mark.next := NIL; G.ticked := ticked; G.handle := Handle; RETURN G
  END New;

  PROCEDURE* DrawCrosshair(x, y: INTEGER);
  BEGIN
    IF x < CL THEN
      IF x < markW THEN x := markW ELSIF x > DW THEN x := DW - markW END
    ELSE
      IF x < CL + markW THEN x := CL + markW
      ELSIF x > CL + DW THEN x := CL + DW - markW
      END
    END ;
    IF y < markW THEN y := markW ELSIF y > DH THEN y := DH - markW END ;
    Display.CopyPattern(Display.white, Display.cross, x - markW, y - markW, 2)
  END DrawCrosshair;

BEGIN DW := Display.Width - 8; DH := Display.Height - 8; CL := Display.ColLeft;
  Crosshair.Draw := DrawCrosshair; Crosshair.Fade := DrawCrosshair; Texts.OpenWriter(W);
  Graphics.LineMethod.draw := DrawLine; Graphics.CapMethod.draw := DrawCaption;
  Graphics.MacMethod.draw := DrawMacro
END GraphicFrames.
```

13.8.3. Module *Graphics*

The preceding presentations of the interface definitions have explained the framework of the graphics system and set the goals for their implementation. We recall that the core module *Graphics* handles the data structures representing sets of objects without reliance on the specifications of individual objects.

Even the structural aspects of the object sets are not fixed by the interface. Several solutions, and hence several implementations are imaginable.

Here we present the simplest solution for representing an abstract, unordered set: the linear, linked list. It is embodied in the object record's additional, hidden field *next*. Consequently, a graphic is represented by the head of the list, and the type *GraphDesc* obtains the hidden field *first* (see listing of *Graphics*). In addition, the descriptor contains the exported field sel denoting a selected element, and the field *time* indicating the time of its selection. The latter is used to determine the most recent selection in various viewers.

Additional data structures become necessary through the presence of macros and classes. Macros are represented by the list of their elements, like graphics. Their header is of type *MacHeadDesc* in analogy to *GraphDesc*. In addition to a macro's name, width, and height, it contains the field *first*, pointing to the list's first element, and the field *lib*, referring to the library from which the macro stems.

A library descriptor is similarly structured: In addition to its name, the field *first* points to the list of elements (macros) of the library, which are themselves linked through the field *next*. Fig. 15.6. shows the data structure containing two libraries. It is anchored in the global variable *FirstLib*.

Libraries are permanently stored as files. It is evidently unacceptable that file access be required upon every reference to a macro, e.g. each time a macro is redrawn. Therefore a library is loaded into primary store, when one of its elements is referenced for the first time. Procedure *ThisMac* searches the data structure representing the specified library and locates the header of the requested macro.

We emphasize that the structures employed for macro and library representation remain hidden from clients, just like the structure of graphics remains hidden within module *Graphics*. Thus, none of the linkage fields of records (*first*, *next*, *sel*) are exported from the base module. This measure retains the possibility to change the structural design decisions without affecting the client modules. But partly it is also responsible for the necessity to include macros in the base module.

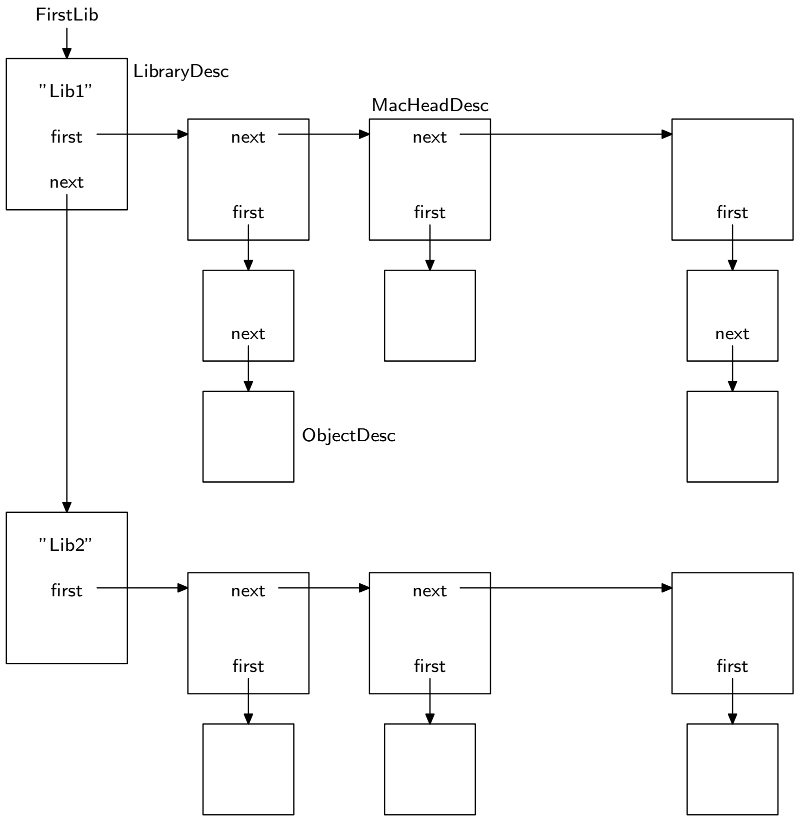


Fig. 13.6. Data structure for libraries and macros

A large fraction of module *Graphics* is taken up by procedures for reading and writing files representing graphics and libraries. They convert their internal data structure into a sequential form and vice-versa. This would be a rather trivial task, were it not for the presence of pointers referring to macros and classes. These pointers must be converted into descriptions that are position-independent, such as names. The same problem is posed by fonts (which are also represented by pointers).

Evidently, the replacement of every pointer by an explicit name would be an uneconomical solution with respect to storage space as well as speed of reading and writing. Therefore, pointers to fonts and libraries - themselves represented as files - are replaced by indices to font and library dictionaries. These dictionaries establish a context and are constructed while a file is read. They are used only during this process and hence are local to procedure *Load* (or *Open*). For classes, a dictionary listing the respective allocation procedures is constructed in order to avoid repeated calls to determine the pertinent allocator.

When a graphics file is generated by procedure *Store*, local dictionaries are constructed of fonts, libraries, and classes of objects that have been written onto the file. Upon encountering a caption, a macro, or any element whose font, library, or class is not contained in the respective dictionary, a pair consisting of index and name is emitted to the file, thereby assigning a number to each name. These pairs are interspersed within the sequence of object descriptions.

When the graphic file is read, these pairs trigger insertion of the font, library, or class in the respective dictionary, whereby the name is converted into a pointer to the entity, which is obtained by a loading process embodied by procedures *Fonts.This, ThisLib,* and *ThisClass*. Both the *Load* and *Store* procedures traverse the file only once. The files are self-contained in the sense that all external quantities are represented by their names. The format of a graphics file is defined in Extended BNF syntax as follows:

```
file =      tag stretch.
stretch =   {item} -1.
item =      0 0 fontno fontname | 0 1 libno libname | 0 2 classno classname allocname |
            1 data |  2 data fontno string |  3 data libno macname |  classno data extension.
data =      x  y  w  h  color.
```

All class numbers are at least 4; the values 1, 2, and 3 are assigned to lines, captions, and macros. *x, y, w, h,* and *color* are two-byte integer attributes of the base type *Object*.

The same procedures are used for loading and storing a library file. In fact, *Load* and *Store* read and write a file stretch representing a sequence of elements which is terminated by a special value (-1). In a library file each macro corresponds to a stretch, and the terminator is followed by values specifying the macro's overall width, height, and its name. The structure of library files is defined by the following syntax:

```
libfile =   libtag {macro}.
macro =     stretch w h name.
```

The first byte of each element is a class number within the context of the file and identifies the class to which the element belongs. An object of the given class is allocated by calling the class' allocation procedure, which is obtained from the class dictionary in the given context. The class number is used as dictionary index. The presence of the required allocation procedure in the dictionary is guaranteed by the fact that a corresponding index/name pair had preceded the element in the file.

The encounter of such a pair triggers the loading of the module specifying the class and its methods. The name of the pair consists of two parts: the first specifies the module in which the class is defined, and it is taken as the parameter of the call to the loader (see procedure *ThisClass*). The second part is the name of the relevant allocation procedure which returns a fresh object to variable *Graphics.new*. Thereafter, the data defined in the base type *Object* are read.

Data belonging to an extension follow those of the base type, and they are read by the extension's *read* method. This part must always be headed by a byte specifying the number of bytes which follow. This information is used in the case where a requested module is not present; it indicates the number of bytes to be skipped in order to continue reading further elements.

A last noteworthy detail concerns the *Move* operation which appears as surprisingly complicated, particularly in comparison with the related copy operation. The reason is our deviation from the principle that a graphics editor must refrain from an interpretation of drawings. Responsible for this deviation was the circumstance that the editor was at first primarily used for the preparation of circuit diagrams. They suggested the view that adjoining, perpendicular lines be connected. Consequently, the horizontal or vertical displacement of a line was to preserve connections. Procedure *Move* must therefore identify all connected lines, and subsequently extend or shorten them.

```
MODULE Graphics;   (*NW 21.12.89 / 3.2.92*)
    IMPORT Files, Modules, Display, Fonts, Printer, Texts, Oberon;

    CONST NameLen* = 16; GraphFileId = 0F9X; LibFileId = 0FDX;

    TYPE
      Graph* = POINTER TO GraphDesc;
      Object* = POINTER TO ObjectDesc;
      Method* = POINTER TO MethodDesc;

      Line* = POINTER TO LineDesc;
      Caption* = POINTER TO CaptionDesc;
      Macro* = POINTER TO MacroDesc;

      ObjectDesc* = RECORD
          x*, y*, w*, h*, col*: INTEGER;
          selected*, marked*: BOOLEAN;
          do*: Method;
          next, dmy: Object
        END ;

      Msg* = RECORD END ;
      WidMsg* = RECORD (Msg) w*: INTEGER END ;
      ColorMsg* = RECORD (Msg) col*: INTEGER END ;
      FontMsg* = RECORD (Msg) fnt*: Fonts.Font END ;
      Name* = ARRAY NameLen OF CHAR;

      GraphDesc* = RECORD
          time*: LONGINT;
          sel*, first: Object
        END ;

      MacHead* = POINTER TO MacHeadDesc;
      MacExt* = POINTER TO MacExtDesc;
      Library* = POINTER TO LibraryDesc;

      MacHeadDesc* = RECORD
          name*: Name;
          w*, h*: INTEGER;
          ext*: MacExt;
          lib*: Library;
          first: Object;
          next: MacHead
        END ;

      LibraryDesc* = RECORD
          name*: Name;
          first: MacHead;
          next: Library
        END ;

      MacExtDesc* = RECORD END ;
```

```
  Context* = RECORD
      nofonts, noflibs, nofclasses: INTEGER;
      font: ARRAY 10 OF Fonts.Font;
      lib: ARRAY 4 OF Library;
      class: ARRAY 10 OF Modules.Command
    END;

    MethodDesc* = RECORD
        module*, allocator*: Name;
        new*: Modules.Command;
        copy*: PROCEDURE (from, to: Object);
        draw*, handle*: PROCEDURE (obj: Object; VAR msg: Msg);
        selectable*: PROCEDURE (obj: Object; x, y: INTEGER): BOOLEAN;
        read*: PROCEDURE (obj: Object; VAR R: Files.Rider; VAR C: Context);
        write*: PROCEDURE (obj: Object; cno: SHORTINT;
            VAR R: Files.Rider; VAR C: Context);
      print*: PROCEDURE (obj: Object; x, y: INTEGER)
    END ;

  LineDesc* = RECORD (ObjectDesc)
    END ;

  CaptionDesc* = RECORD (ObjectDesc)
      pos*, len*: INTEGER
    END ;

  MacroDesc* = RECORD (ObjectDesc)
      mac*: MacHead
    END ;

VAR new*: Object;
  width*, res*: INTEGER;
  T*: Texts.Text;  (*captions*)
  LineMethod*, CapMethod*, MacMethod* : Method;

  FirstLib: Library;
  W, TW: Texts.Writer;

PROCEDURE Add*(G: Graph; obj: Object);
BEGIN obj.marked := FALSE; obj.selected := TRUE; obj.next := G.first;
  G.first := obj; G.sel := obj; G.time := Oberon.Time()
END Add;

PROCEDURE Draw*(G: Graph; VAR M: Msg);
  VAR obj: Object;
BEGIN obj := G.first;
  WHILE obj # NIL DO obj.do.draw(obj, M); obj := obj.next END
END Draw;

PROCEDURE ThisObj*(G: Graph; x, y: INTEGER): Object;
  VAR obj: Object;
BEGIN obj := G.first;
  WHILE (obj # NIL) & ~obj.do.selectable(obj, x ,y) DO obj := obj.next END ;
  RETURN obj
END ThisObj;

PROCEDURE SelectObj*(G: Graph; obj: Object);
BEGIN
  IF obj # NIL THEN obj.selected := TRUE; G.sel := obj; G.time := Oberon.Time() END
END SelectObj;
```

```
PROCEDURE SelectArea*(G: Graph; x0, y0, x1, y1: INTEGER);
  VAR obj: Object; t: INTEGER;
BEGIN obj := G.first;
  IF x1 < x0 THEN t := x0; x0 := x1; x1 := t END ;
  IF y1 < y0 THEN t := y0; y0 := y1; y1 := t END ;
  WHILE obj # NIL DO
    IF (x0 <= obj.x) & (obj.x + obj.w <= x1) & (y0 <= obj.y) & (obj.y + obj.h <= y1) THEN
      obj.selected := TRUE; G.sel := obj
    END ;
    obj := obj.next
  END ;
  IF G.sel # NIL THEN G.time := Oberon.Time() END
END SelectArea;

PROCEDURE Enumerate*(G: Graph;
    handle: PROCEDURE (obj: Object; VAR done: BOOLEAN));
  VAR obj: Object; done: BOOLEAN;
BEGIN done := FALSE; obj := G.first;
  WHILE (obj # NIL) & ~done DO handle(obj, done); obj := obj.next END
END Enumerate;

(*----------------procedures operating on selection -------------------*)

PROCEDURE Deselect*(G: Graph);
  VAR obj: Object;
BEGIN obj := G.first; G.sel := NIL; G.time := 0;
  WHILE obj # NIL DO obj.selected := FALSE; obj := obj.next END
END Deselect;

PROCEDURE DrawSel*(G: Graph; VAR M: Msg);
  VAR obj: Object;
BEGIN obj := G.first;
  WHILE obj # NIL DO
    IF obj.selected THEN obj.do.draw(obj, M) END ;
    obj := obj.next
  END
END DrawSel;

PROCEDURE Handle*(G: Graph; VAR M: Msg);
  VAR obj: Object;
BEGIN obj := G.first;
  WHILE obj # NIL DO
    IF obj.selected THEN obj.do.handle(obj, M) END ;
    obj := obj.next
  END
END Handle;

PROCEDURE Move*(G: Graph; dx, dy: INTEGER);
  VAR obj, ob0: Object; x0, x1, y0, y1: INTEGER;
BEGIN obj := G.first;
  WHILE obj # NIL DO
    IF obj.selected & ~(obj IS Caption) THEN
      x0 := obj.x; x1 := obj.w + x0; y0 := obj.y; y1 := obj.h + y0;
      IF dx = 0 THEN (*vertical move*)
        ob0 := G.first;
        WHILE ob0 # NIL DO
          IF ~ob0.selected & (ob0 IS Line) & (x0 <= ob0.x)
                   & (ob0.x <= x1) & (ob0.w < ob0.h) THEN
            IF (y0 <= ob0.y) & (ob0.y <= y1) THEN
```

```
                    INC(ob0.y, dy); DEC(ob0.h, dy); ob0.marked := TRUE
                ELSIF (y0 <= ob0.y + ob0.h) & (ob0.y + ob0.h <= y1) THEN
                    INC(ob0.h, dy); ob0.marked := TRUE
                END
              END ;
              ob0 := ob0.next
            END
          ELSIF dy = 0 THEN (*horizontal move*)
            ob0 := G.first;
            WHILE ob0 # NIL DO
              IF ~ob0.selected & (ob0 IS Line) & (y0 <= ob0.y)
                    & (ob0.y <= y1) & (ob0.h < ob0.w) THEN
                IF (x0 <= ob0.x) & (ob0.x <= x1) THEN
                    INC(ob0.x, dx); DEC(ob0.w, dx); ob0.marked := TRUE
                ELSIF (x0 <= ob0.x + ob0.w) & (ob0.x + ob0.w <= x1) THEN
                    INC(ob0.w, dx); ob0.marked := TRUE
                END
              END ;
              ob0 := ob0.next
            END
          END
        END ;
        obj := obj.next
      END ;
      obj := G.first; (*now move*)
      WHILE obj # NIL DO
        IF obj.selected THEN INC(obj.x, dx); INC(obj.y, dy) END ;
        obj.marked := FALSE; obj := obj.next
      END
    END Move;

    PROCEDURE Copy*(Gs, Gd: Graph; dx, dy: INTEGER);
      VAR obj: Object;
    BEGIN obj := Gs.first;
      WHILE obj # NIL DO
        IF obj.selected THEN
          obj.do.new; obj.do.copy(obj, new); INC(new.x, dx); INC(new.y, dy);
          obj.selected := FALSE; Add(Gd, new)
        END ;
        obj := obj.next
      END ;
      new := NIL
    END Copy;

    PROCEDURE Delete*(G: Graph);
      VAR obj, pred: Object;
    BEGIN G.sel := NIL; obj := G.first;
      WHILE (obj # NIL) & obj.selected DO obj := obj.next END ;
      G.first := obj;
      IF obj # NIL THEN
        pred := obj; obj := obj.next;
        WHILE obj # NIL DO
          IF obj.selected THEN pred.next := obj.next ELSE pred := obj END ;
          obj := obj.next
        END
      END
    END Delete;
```

```
(* ---------------------- File I/O ------------------------ *)

PROCEDURE ReadInt*(VAR R: Files.Rider; VAR x: INTEGER);
   VAR c0: CHAR; s1: SHORTINT;
BEGIN Files.Read(R, c0); Files.Read(R, s1); x := s1; x := x * 100H + ORD(c0)
END ReadInt;

PROCEDURE ReadLInt*(VAR R: Files.Rider; VAR x: LONGINT);
   VAR c0, c1, c2: CHAR; s3: SHORTINT;
BEGIN Files.Read(R, c0); Files.Read(R, c1); Files.Read(R, c2); Files.Read(R, s3);
   x := s3; x := ((x * 100H + LONG(c2)) * 100H + LONG(c1)) * 100H + LONG(c0)
END ReadLInt;

PROCEDURE ReadString*(VAR R: Files.Rider; VAR s: ARRAY OF CHAR);
   VAR i: INTEGER; ch: CHAR;
BEGIN i := 0;
   REPEAT Files.Read(R, ch); s[i] := ch; INC(i) UNTIL ch = 0X
END ReadString;

PROCEDURE ReadObj(VAR R: Files.Rider; obj: Object);
BEGIN ReadInt(R, obj.x); ReadInt(R, obj.y);
   ReadInt(R, obj.w); ReadInt(R, obj.h); ReadInt(R, obj.col)
END ReadObj;

PROCEDURE WriteInt*(VAR W: Files.Rider; x: INTEGER);
BEGIN Files.Write(W, CHR(x)); Files.Write(W, CHR(x DIV 100H))
END WriteInt;

PROCEDURE WriteLInt*(VAR W: Files.Rider; x: LONGINT);
BEGIN Files.Write(W, CHR(x)); Files.Write(W, CHR(x DIV 100H));
   Files.Write(W, CHR(x DIV 10000H)); Files.Write(W, CHR(x DIV 1000000H))
END WriteLInt;

PROCEDURE WriteString*(VAR W: Files.Rider; VAR s: ARRAY OF CHAR);
   VAR i: INTEGER; ch: CHAR;
BEGIN i := 0;
   REPEAT ch := s[i]; INC(i); Files.Write(W, ch) UNTIL ch = 0X
END WriteString;

PROCEDURE WriteObj*(VAR W: Files.Rider; cno: SHORTINT; obj: Object);
BEGIN Files.Write(W, cno); WriteInt(W, obj.x); WriteInt(W, obj.y);
   WriteInt(W, obj.w); WriteInt(W, obj.h); WriteInt(W, obj.col)
END WriteObj;

(* ---------------------- Storing ----------------------- *)

PROCEDURE WMsg(s0, s1: ARRAY OF CHAR);
BEGIN Texts.WriteString(W, s0); Texts.WriteString(W, s1);
   Texts.WriteLn(W); Texts.Append(Oberon.Log, W.buf)
END WMsg;

PROCEDURE InitContext(VAR C: Context);
BEGIN C.nofonts := 0; C.noflibs := 0; C.nofclasses := 4;
   C.class[1] := LineMethod.new; C.class[2] := CapMethod.new; C.class[3] := MacMethod.new
END InitContext;

PROCEDURE FontNo*(VAR W: Files.Rider; VAR C: Context; fnt: Fonts.Font): SHORTINT;
   VAR fno: SHORTINT;
BEGIN fno := 0;
   WHILE (fno < C.nofonts) & (C.font[fno] # fnt) DO INC(fno) END ;
   IF fno = C.nofonts THEN
      Files.Write(W, 0); Files.Write(W, 0); Files.Write(W, fno);
      WriteString(W, fnt.name); C.font[fno] := fnt; INC(C.nofonts)
    END ;
    RETURN fno
  END FontNo;

  PROCEDURE StoreElems(VAR W: Files.Rider; VAR C: Context; obj: Object);
    VAR cno: INTEGER;
  BEGIN
    WHILE obj # NIL DO
      cno := 1;
      WHILE (cno < C.nofclasses) & (obj.do.new # C.class[cno]) DO INC(cno) END ;
      IF cno = C.nofclasses THEN
        Files.Write(W, 0); Files.Write(W, 2); Files.Write(W, SHORT(cno));
        WriteString(W, obj.do.module); WriteString(W, obj.do.allocator);
        C.class[cno] := obj.do.new; INC(C.nofclasses)
      END ;
      obj.do.write(obj, SHORT(cno), W, C); obj := obj.next
    END ;
    Files.Write(W, -1)
  END StoreElems;

  PROCEDURE Store*(G: Graph; VAR W: Files.Rider);
    VAR C: Context;
  BEGIN InitContext(C); StoreElems(W, C, G.first)
  END Store;

  PROCEDURE WriteFile*(G: Graph; name: ARRAY OF CHAR);
    VAR F: Files.File; W: Files.Rider; C: Context;
  BEGIN F := Files.New(name); Files.Set(W, F, 0); Files.Write(W, GraphFileId);
    InitContext(C); StoreElems(W, C, G.first); Files.Register(F)
  END WriteFile;

  PROCEDURE Print*(G: Graph; x0, y0: INTEGER);
    VAR obj: Object;
  BEGIN obj := G.first;
    WHILE obj # NIL DO obj.do.print(obj, x0, y0); obj := obj.next END
  END Print;

  (* ---------------------- Loading ------------------------ *)

  PROCEDURE ThisClass*(VAR module, allocator: ARRAY OF CHAR): Modules.Command;
    VAR mod: Modules.Module; com: Modules.Command;
  BEGIN mod := Modules.ThisMod(module);
    IF mod # NIL THEN
      com := Modules.ThisCommand(mod, allocator);
      IF com = NIL THEN WMsg(allocator, " unknown") END
    ELSE WMsg(module, " not available"); com := NIL
    END ;
    RETURN com
  END ThisClass;

  PROCEDURE Font*(VAR R: Files.Rider; VAR C: Context): Fonts.Font;
    VAR fno: SHORTINT;
  BEGIN Files.Read(R, fno); RETURN C.font[fno]
  END Font;

  PROCEDURE^ ThisLib*(VAR name: ARRAY OF CHAR; replace: BOOLEAN): Library;

  PROCEDURE LoadElems(VAR R: Files.Rider; VAR C: Context; VAR obj: Object);
    VAR cno, len, k: SHORTINT;
```

```
      name, name1: ARRAY 32 OF CHAR;
BEGIN obj := NIL; Files.Read(R, cno);
   WHILE ~R.eof & (cno >= 0) DO
      IF cno = 0 THEN
         Files.Read(R, cno); Files.Read(R, k); ReadString(R, name);
         IF cno = 0 THEN C.font[k] := Fonts.This(name)
         ELSIF cno = 1 THEN C.lib[k] := ThisLib(name, FALSE)
         ELSE ReadString(R, name1); C.class[k] := ThisClass(name, name1)
         END
      ELSIF C.class[cno] # NIL THEN
         C.class[cno]; ReadObj(R, new);
         new.selected := FALSE; new.marked := FALSE; new.next := obj; obj := new;
         new.do.read(new, R, C)
      ELSE Files.Set(R, Files.Base(R), Files.Pos(R) + 10);
         Files.Read(R, len); Files.Set(R, Files.Base(R), Files.Pos(R) + len)
      END ;
      Files.Read(R, cno)
   END ;
   new := NIL
END LoadElems;

PROCEDURE Load*(G: Graph; VAR R: Files.Rider);
   VAR C: Context;
BEGIN G.sel := NIL; InitContext(C); LoadElems(R, C, G.first)
END Load;

PROCEDURE Open*(G: Graph; name: ARRAY OF CHAR);
   VAR tag: CHAR;
      F: Files.File; R: Files.Rider; C: Context;
BEGIN G.first := NIL; G.sel := NIL; G.time := 0; F := Files.Old(name);
   IF F # NIL THEN
      Files.Set(R, F, 0); Files.Read(R, tag);
      IF tag = GraphFileId THEN InitContext(C); LoadElems(R, C, G.first); res := 0
      ELSE res := 1
      END
   ELSE res := 2
   END
END Open;

(* --------------------- Macros / Libraries ----------------------- *)

PROCEDURE ThisLib*(VAR name: ARRAY OF CHAR; replace: BOOLEAN): Library;
   VAR i, j: INTEGER; ch: CHAR;
      L: Library; mh: MacHead;
      F: Files.File; R: Files.Rider; C: Context;
      Lname, Fname: ARRAY 32 OF CHAR;
BEGIN L := FirstLib; i := 0;
   WHILE name[i] >= "0" DO Lname[i] := name[i]; INC(i) END ;
   Lname[i] := 0X;
   WHILE (L # NIL) & (L.name # Lname) DO L := L.next END ;
   IF (L = NIL) OR replace THEN
      (*load library*) j := 0;
      WHILE name[j] > 0X DO Fname[j] := name[j]; INC(j) END ;
      IF i = j THEN
         Fname[j] := "."; Fname[j+1] := "L"; Fname[j+2] := "i"; Fname[j+3] := "b"; INC(j, 4)
      END ;
      Fname[j] := 0X; F := Files.Old(Fname);
      IF F # NIL THEN
      WMsg("loading ", name); Files.Set(R, F, 0); Files.Read(R, ch);
      IF ch = LibFileId THEN
        IF L = NIL THEN
          NEW(L); COPY(Lname, L.name); L.next := FirstLib; FirstLib := L
        END ;
        L.first := NIL; InitContext(C);
        WHILE ~R.eof DO
          NEW(mh); LoadElems(R, C, mh.first);
          ReadInt(R, mh.w); ReadInt(R, mh.h); ReadString(R, mh.name);
          mh.lib := L; mh.next := L.first; L.first := mh;
        END
      ELSE L := NIL; WMsg(name, " bad library")
      END
    ELSE WMsg(name, " not found")
    END
  END ;
  RETURN L
END ThisLib;

PROCEDURE NewLib*(VAR Lname: ARRAY OF CHAR): Library;
  VAR L: Library;
BEGIN NEW(L); COPY(Lname, L.name); L.first := NIL;
  L.next := FirstLib; FirstLib := L; RETURN L
END NewLib;

PROCEDURE StoreLib*(L: Library; VAR Fname: ARRAY OF CHAR);
  VAR mh: MacHead;
    F: Files.File; W: Files.Rider;
    C: Context;
BEGIN F := Files.New(Fname); Files.Set(W, F, 0); Files.Write(W, LibFileId);
  InitContext(C); mh := L.first;
  WHILE mh # NIL DO
    WriteInt(W, mh.w); WriteInt(W, mh.h); WriteString(W, mh.name);
    StoreElems(W, C, mh.first); mh := mh.next
  END
END StoreLib;

PROCEDURE RemoveLibraries*;
BEGIN FirstLib := NIL
END RemoveLibraries;

PROCEDURE ThisMac*(L: Library; VAR Mname: ARRAY OF CHAR): MacHead;
  VAR mh: MacHead;
BEGIN mh := L.first;
  WHILE (mh # NIL) & (mh.name # Mname) DO mh := mh.next END ;
  RETURN mh
END ThisMac;

PROCEDURE OpenMac*(mh: MacHead; G: Graph; x, y: INTEGER);
  VAR obj: Object;
BEGIN obj := mh.first;
  WHILE obj # NIL DO
    obj.do.new; obj.do.copy(obj, new); INC(new.x, x); INC(new.y, y); new.selected := TRUE;
    Add(G, new); obj := obj.next
  END ;
  new := NIL
END OpenMac;
```

```
PROCEDURE DrawMac*(mh: MacHead; VAR M: Msg);
  VAR elem: Object;
BEGIN elem := mh.first;
  WHILE elem # NIL DO elem.do.draw(elem, M); elem := elem.next END
END DrawMac;

PROCEDURE MakeMac*(G: Graph; x, y, w, h: INTEGER;
    VAR Mname: ARRAY OF CHAR): MacHead;
  VAR obj, last: Object; mh: MacHead;
BEGIN obj := G.first; last := NIL;
  WHILE obj # NIL DO
    IF obj.selected THEN
      obj.do.new; obj.do.copy(obj, new); new.next := last; new.selected := FALSE;
      DEC(new.x, x); DEC(new.y, y); last := new
    END ;
    obj := obj.next
  END ;
  NEW(mh); mh.w := w; mh.h := h; mh.first := last; mh.ext := NIL;
  COPY(Mname, mh.name); new := NIL; RETURN mh
END MakeMac;

PROCEDURE InsertMac*(mh: MacHead; L: Library; VAR new: BOOLEAN);
  VAR mh1: MacHead;
BEGIN mh.lib := L; mh1 := L.first;
  WHILE (mh1 # NIL) & (mh1.name # mh.name) DO mh1 := mh1.next END ;
  IF mh1 = NIL THEN
    new := TRUE; mh.next := L.first; L.first := mh
  ELSE
    new := FALSE; mh1.w := mh.w; mh1.h := mh.h; mh1.first := mh.first
  END
END InsertMac;

(* ---------------------------- Line Methods -----------------------------*)

PROCEDURE* NewLine;
  VAR line: Line;
BEGIN NEW(line); new := line; line.do := LineMethod
END NewLine;

PROCEDURE* CopyLine(src, dst: Object);
BEGIN dst.x := src.x; dst.y := src.y; dst.w := src.w; dst.h := src.h; dst.col := src.col
END CopyLine;

PROCEDURE* HandleLine(obj: Object; VAR M: Msg);
BEGIN
  IF M IS WidMsg THEN
    IF obj.w < obj.h THEN
      IF obj.w <= 7 THEN obj.w := M(WidMsg).w END
    ELSIF obj.h <= 7 THEN obj.h := M(WidMsg).w
    END
  ELSIF M IS ColorMsg THEN obj.col := M(ColorMsg).col
  END
END HandleLine;

PROCEDURE* LineSelectable(obj: Object; x, y: INTEGER): BOOLEAN;
BEGIN
  RETURN (obj.x <= x) & (x < obj.x + obj.w) & (obj.y <= y) & (y < obj.y + obj.h)
END LineSelectable;
```

```
PROCEDURE* ReadLine(obj: Object; VAR R: Files.Rider; VAR C: Context);
BEGIN
END ReadLine;

PROCEDURE* WriteLine(obj: Object; cno: SHORTINT;
    VAR W: Files.Rider; VAR C: Context);
BEGIN WriteObj(W, cno, obj)
END WriteLine;

PROCEDURE* PrintLine(obj: Object; x, y: INTEGER);
  VAR w, h: INTEGER;
BEGIN w := obj.w * 2; h := obj.h * 2;
  IF w < h THEN h := 2*h ELSE w := 2*w END ;
  Printer.ReplConst(obj.x * 4 + x, obj.y *4 + y, w, h)
END PrintLine;

(* ---------------------- Caption Methods ------------------------ *)

PROCEDURE* NewCaption;
  VAR cap: Caption;
BEGIN NEW(cap); new := cap; cap.do := CapMethod
END NewCaption;

PROCEDURE* CopyCaption(src, dst: Object);
  VAR ch: CHAR; R: Texts.Reader;
BEGIN
  WITH src: Caption DO
    WITH dst: Caption DO
      dst.x := src.x; dst.y := src.y; dst.w := src.w; dst.h := src.h; dst.col := src.col;
      dst.pos := SHORT(T.len + 1); dst.len := src.len;
      Texts.Write(TW, 0DX); Texts.OpenReader(R, T, src.pos);
      Texts.Read(R, ch); TW.fnt := R.fnt;
      WHILE ch > 0DX DO Texts.Write(TW, ch); Texts.Read(R, ch) END
    END
  END ;
  Texts.Append(T, TW.buf)
END CopyCaption;

PROCEDURE* HandleCaption(obj: Object; VAR M: Msg);
  VAR dx, x1, dy, y1, w, w1, h1, len: INTEGER;
    pos: LONGINT;
    ch: CHAR; pat: Display.Pattern; fnt: Fonts.Font;
    R: Texts.Reader;
BEGIN
  IF M IS FontMsg THEN
    fnt := M(FontMsg).fnt; w := 0; len := 0; pos := obj(Caption).pos;
    Texts.OpenReader(R, T, pos); Texts.Read(R, ch); dy := R.fnt.minY;
    WHILE ch > 0DX DO
      Display.GetChar(fnt.raster, ch, dx, x1, y1, w1, h1, pat);
      INC(w, dx); INC(len); Texts.Read(R, ch)
    END ;
    INC(obj.y, fnt.minY-dy); obj.w := w; obj.h := fnt.height;
    Texts.ChangeLooks(T, pos, pos+len, {0}, fnt, 0 , 0)
  ELSIF M IS ColorMsg THEN obj.col := M(ColorMsg).col
  END
END HandleCaption;

PROCEDURE* CaptionSelectable(obj: Object; x, y: INTEGER): BOOLEAN;
BEGIN
```

```
   RETURN (obj.x <= x) & (x < obj.x + obj.w) & (obj.y <= y) & (y < obj.y + obj.h)
END CaptionSelectable;

PROCEDURE* ReadCaption(obj: Object; VAR R: Files.Rider; VAR C: Context);
   VAR ch: CHAR; fno: SHORTINT; len: INTEGER;
BEGIN obj(Caption).pos := SHORT(T.len + 1); Texts.Write(TW, 0DX);
   Files.Read(R, fno); TW.fnt := C.font[fno]; len := 0; Files.Read(R, ch);
   WHILE ch > 0DX DO Texts.Write(TW, ch); INC(len); Files.Read(R, ch) END ;
   obj(Caption).len := len; Texts.Append(T, TW.buf)
END ReadCaption;

PROCEDURE* WriteCaption(obj: Object; cno: SHORTINT;
      VAR W: Files.Rider; VAR C: Context);
   VAR ch: CHAR; fno: SHORTINT;
      TR: Texts.Reader;
BEGIN Texts.OpenReader(TR, T, obj(Caption).pos); Texts.Read(TR, ch);
   fno := FontNo(W, C, TR.fnt);
   WriteObj(W, cno, obj); Files.Write(W, fno);
   WHILE ch > 0DX DO  Files.Write(W, ch); Texts.Read(TR, ch) END ;
   Files.Write(W, 0X)
END WriteCaption;

PROCEDURE* PrintCaption(obj: Object; x, y: INTEGER);
   VAR fnt: Fonts.Font;
      i: INTEGER; ch: CHAR;
      R: Texts.Reader;
      s: ARRAY 128 OF CHAR;
BEGIN Texts.OpenReader(R, T, obj(Caption).pos); Texts.Read(R, ch);
   fnt := R.fnt; DEC(y, fnt.minY*4); i := 0;
   WHILE ch >= " " DO s[i] := ch; INC(i); Texts.Read(R, ch) END ;
   s[i] := 0X;
   IF i > 0 THEN Printer.String(obj.x*4 + x, obj.y*4 + y, s, fnt.name) END
END PrintCaption;

(* ---------------------- Macro Methods ------------------------ *)

PROCEDURE* NewMacro;
   VAR mac: Macro;
BEGIN NEW(mac); new := mac; mac.do := MacMethod
END NewMacro;

PROCEDURE* CopyMacro(src, dst: Object);
BEGIN dst.x := src.x; dst.y := src.y; dst.w := src.w; dst.h := src.h;
   dst.col := src.col; dst(Macro).mac := src(Macro).mac
END CopyMacro;

PROCEDURE* HandleMacro(obj: Object; VAR M: Msg);
BEGIN
   IF M IS ColorMsg THEN obj.col := M(ColorMsg).col END
END HandleMacro;

PROCEDURE* MacroSelectable(obj: Object; x, y: INTEGER): BOOLEAN;
BEGIN
   RETURN (obj.x <= x) & (x <= obj.x + 8) & (obj.y <= y) & (y <= obj.y + 8)
END MacroSelectable;

PROCEDURE* ReadMacro(obj: Object; VAR R: Files.Rider; VAR C: Context);
   VAR lno: SHORTINT; name: ARRAY 32 OF CHAR;
BEGIN Files.Read(R, lno);
```

```
      ReadString(R, name); obj(Macro).mac := ThisMac(C.lib[lno], name)
    END ReadMacro;

    PROCEDURE* WriteMacro(obj: Object; cno: SHORTINT;
        VAR W1: Files.Rider; VAR C: Context);
      VAR ch: CHAR; lno: SHORTINT; TR: Texts.Reader;
    BEGIN lno := 0;
      WITH obj: Macro DO
        WHILE (lno < C.noflibs) & (obj.mac.lib # C.lib[lno]) DO INC(lno) END ;
        IF lno = C.noflibs THEN
          Files.Write(W1, 0); Files.Write(W1, 1); Files.Write(W1, lno);
          WriteString(W1, obj.mac.lib.name); C.lib[lno] := obj.mac.lib; INC(C.noflibs)
        END ;
        WriteObj(W1, cno, obj); Files.Write(W1, lno); WriteString(W1, obj.mac.name)
      END
    END WriteMacro;

    PROCEDURE* PrintMacro(obj: Object; x, y: INTEGER);
      VAR elem: Object; mh: MacHead;
    BEGIN mh := obj(Macro).mac;
      IF mh # NIL THEN elem := mh.first;
        WHILE elem # NIL DO
          elem.do.print(elem, obj.x*4 + x, obj.y*4 + y); elem := elem.next
        END
      END
    END PrintMacro;

    PROCEDURE* Notify(T: Texts.Text; op: INTEGER; beg, end: LONGINT);
    BEGIN
    END Notify;

BEGIN Texts.OpenWriter(W); Texts.OpenWriter(TW); width := 1;
    NEW(T); Texts.Open(T, ""); T.notify := Notify;
    NEW(LineMethod); LineMethod.new := NewLine; LineMethod.copy := CopyLine;
    LineMethod.selectable := LineSelectable; LineMethod.handle := HandleLine;
    LineMethod.read := ReadLine; LineMethod.write := WriteLine; LineMethod.print := PrintLine;
    NEW(CapMethod); CapMethod.new := NewCaption; CapMethod.copy := CopyCaption;
    CapMethod.selectable := CaptionSelectable; CapMethod.handle := HandleCaption;
    CapMethod.read := ReadCaption; CapMethod.write := WriteCaption; CapMethod.print :=
PrintCaption;
    NEW(MacMethod); MacMethod.new := NewMacro; MacMethod.copy := CopyMacro;
    MacMethod.selectable := MacroSelectable; MacMethod.handle := HandleMacro;
    MacMethod.read := ReadMacro; MacMethod.write := WriteMacro; MacMethod.print :=
PrintMacro
END Graphics.
```

13.9. Rectangles and Curves

13.9.1. Rectangles

In this section, we present two extensions of the basic graphics system which introduce new classes of objects. The first implements rectangles which are typically used for framing a set of objects. They are, for example, used in the representation of electronic components (macros, see Fig. 15.2). Their implementation follows the scheme presented at the end of chapter 15.7 and is reasonably straight-forward, considering that each rectangle merely consists of four lines. Additionally, a background raster may be specified.

One of the design decisions occurring for every new class concerns the way to display the selection. In this case we chose, in contrast to the cases of captions and macros, not inverse video, but a small square dot in the lower right corner of the rectangle.

The data type *Rectangle* contains two additional fields: *lw* indicates the line width, and *vers* specifies the background pattern.

In spite of the simplicity of the notion of rectangles, their drawing method is more complex than might be expected. The reason is that drawing methods are responsible for appropriate clipping at frame boundaries. In this case, some of the component lines may have to be shortened, and some may disappear altogether.

Procedure *Handle* provides an example of a receiver of a control message. It is activated as soon as the middle mouse button is pressed, in contrast to other actions, which are initiated after the release of all buttons. Therefore, this message allows for the implementation of actions under control of individual handlers interpreting further mouse movements. In this example, the action serves to change the size of the rectangle, namely by moving its lower left corner.

```
MODULE Rectangles;  (*NW 25.2.90 / 1.2.92*)
    IMPORT Display, Files, Input, Printer, Texts, Oberon, Graphics, GraphicFrames;

    TYPE Rectangle* = POINTER TO RectDesc;

      RectDesc* = RECORD (Graphics.ObjectDesc)
          lw*, vers*: INTEGER
        END ;

    VAR method*: Graphics.Method;
      shade: INTEGER;

    PROCEDURE New*;
      VAR r: Rectangle;
    BEGIN NEW(r); r.do := method; Graphics.new := r
    END New;

    PROCEDURE* Copy(src, dst: Graphics.Object);
    BEGIN dst(Rectangle)^ := src(Rectangle)^
    END Copy;

    PROCEDURE mark(col, x, y: INTEGER);
    BEGIN Display.ReplConst(col, x-4, y, 4, 4, 0)
    END mark;

    PROCEDURE* Draw(obj: Graphics.Object; VAR M: Graphics.Msg);
      VAR x, y, w, h, lw, col: INTEGER; s: SET; f: GraphicFrames.Frame;

      PROCEDURE draw(col: INTEGER);
      BEGIN
        IF 0 IN s THEN Display.ReplConst(col, x, y, w, lw, 0) END ;
        IF 1 IN s THEN Display.ReplConst(col, x+w-lw, y, lw, h, 0) END ;
        IF 2 IN s THEN Display.ReplConst(col, x, y+h-lw, w, lw, 0) END ;
        IF 3 IN s THEN Display.ReplConst(col, x, y, lw, h, 0) END
      END draw;

    BEGIN
      WITH M: GraphicFrames.DrawMsg DO
        x := obj.x + M.x; y := obj.y + M.y; w := obj.w; h := obj.h; f := M.f;
        lw := obj(Rectangle).lw; s := {0..3};
        IF x+w < f.X THEN s := {}
        ELSIF x < f.X THEN DEC(w, f.X-x); x := f.X; EXCL(s, 3)
        END ;
        IF x >= f.X1 THEN s := {}
        ELSIF x+w > f.X1 THEN w := f.X1-x; EXCL(s, 1)
        END ;
        IF y+h < f.Y THEN s := {}
        ELSIF y < f.Y THEN DEC(h, f.Y-y); y := f.Y; EXCL(s, 0)
        END ;
        IF y >= f.Y1 THEN s := {}
        ELSIF y+h > f.Y1 THEN h := f.Y1-y; EXCL(s, 2)
        END ;
        IF s # {} THEN
          IF M.col = Display.black THEN col := obj.col ELSE col := M.col END ;
          IF M.mode = 0 THEN
            draw(col);
            IF obj.selected THEN mark(Display.white, x+w-lw, y+lw) END ;
            IF obj(Rectangle).vers # 0 THEN
                Display.ReplPattern(col, Display.grey0, x, y, w, h, 1)
            END
          ELSIF M.mode = 1 THEN mark(Display.white, x+w-lw, y+lw)
          ELSIF M.mode = 2 THEN mark(Display.black, x+w-lw, y+lw)
          ELSIF obj(Rectangle).vers = 0 THEN
            draw(Display.black); mark(Display.black, x+w-lw, y+lw)
          ELSE Display.ReplConst(Display.black, x, y, w, h, 0)
          END
        END
      END
    END Draw;

    PROCEDURE* Selectable(obj: Graphics.Object; x, y: INTEGER): BOOLEAN;
    BEGIN
      RETURN (obj.x + obj.w - 4 <= x) & (x <= obj.x + obj.w) & (obj.y <= y) & (y <= obj.y + 4)
    END Selectable;

    PROCEDURE* Handle(obj: Graphics.Object; VAR M: Graphics.Msg);
      VAR x0, y0, x1, y1, dx, dy: INTEGER; k: SET;
    BEGIN
      IF M IS Graphics.WidMsg THEN obj(Rectangle).lw := M(Graphics.WidMsg).w
      ELSIF M IS Graphics.ColorMsg THEN obj.col := M(Graphics.ColorMsg).col
      ELSIF M IS GraphicFrames.CtrlMsg THEN
        WITH M: GraphicFrames.CtrlMsg DO
          WITH obj: Rectangle DO
            M.res := 1; x0 := obj.x + obj.w + M.f.x; y0 := obj.y + M.f.y;
            mark(Display.white, x0 - obj.lw, y0 + obj.lw);
            REPEAT Input.Mouse(k, x1, y1);
                DEC(x1, (x1-M.f.x) MOD 4); DEC(y1, (y1-M.f.y) MOD 4);
                Oberon.DrawCursor(Oberon.Mouse, GraphicFrames.Crosshair, x1, y1)
            UNTIL k = {};
            mark(Display.black, x0 - obj.lw, y0 + obj.lw);
            IF (x0 - obj.w < x1) & (y1 < y0+ obj.h) THEN
                GraphicFrames.EraseObj(M.f, obj);
                dx := x1 - x0; dy := y1 - y0;
                INC(obj.y, dy); INC(obj.w, dx); DEC(obj.h, dy);
                GraphicFrames.DrawObj(M.f, obj)
            END
          END
        END
      END
    END Handle;
    PROCEDURE* Read(obj: Graphics.Object; VAR R: Files.Rider; VAR C: Graphics.Context);
      VAR w, v, len: SHORTINT;
    BEGIN Files.Read(R, len); Files.Read(R, w); Files.Read(R, v);
      obj(Rectangle).lw := w; obj(Rectangle).vers := v
    END Read;

    PROCEDURE* Write(obj: Graphics.Object; cno: SHORTINT;
        VAR W: Files.Rider; VAR C: Graphics.Context);
    BEGIN Graphics.WriteObj(W, cno, obj); Files.Write(W, 2);
      Files.Write(W, SHORT(obj(Rectangle).lw)); Files.Write(W, SHORT(obj(Rectangle).vers))
    END Write;

    PROCEDURE* Print(obj: Graphics.Object; x, y: INTEGER);
      VAR w, h, lw, s: INTEGER;
    BEGIN INC(x, obj.x * 4); INC(y, obj.y * 4); w := obj.w * 4; h := obj.h * 4;
      lw := obj(Rectangle).lw * 2; s := obj(Rectangle).vers;
      Printer.ReplConst(x, y, w, lw);
      Printer.ReplConst(x+w-lw, y, lw, h);
      Printer.ReplConst(x, y+h-lw, w, lw);
      Printer.ReplConst(x, y, lw, h);
      IF s > 0 THEN Printer.ReplPattern(x, y, w, h, s) END
    END Print;

    PROCEDURE Make*;  (*command*)
      VAR x0, x1, y0, y1: INTEGER;
        R: Rectangle;
        G: GraphicFrames.Frame;
    BEGIN G := GraphicFrames.Focus();
      IF (G # NIL) & (G.mark.next # NIL) THEN
        GraphicFrames.Deselect(G);
        x0 := G.mark.x; y0 := G.mark.y; x1 := G.mark.next.x; y1 := G.mark.next.y;
        NEW(R); R.col := Oberon.CurCol;
        R.w := ABS(x1-x0); R.h := ABS(y1-y0);
        IF x1 < x0 THEN x0 := x1 END ;
        IF y1 < y0 THEN y0 := y1 END ;
        R.x := x0 - G.x; R.y := y0 - G.y;
        R.lw := Graphics.width; R.vers := shade; R.do := method;
        Graphics.Add(G.graph, R);
        GraphicFrames.Defocus(G); GraphicFrames.DrawObj(G, R)
      END
    END Make;

    PROCEDURE SetShade*;
      VAR S: Texts.Scanner;
    BEGIN Texts.OpenScanner(S, Oberon.Par.text, Oberon.Par.pos); Texts.Scan(S);
      IF S.class = Texts.Int THEN shade := SHORT(S.i) END
    END SetShade;

BEGIN shade := 0; NEW(method);
    method.module := "Rectangles"; method.allocator := "New";
    method.new := New; method.copy := Copy; method.draw := Draw;
    method.selectable := Selectable; method.handle := Handle;
    method.read := Read; method.write := Write; method.print := Print
END Rectangles.
```

13.9.2. Oblique Lines, Circles, and Ellipses

The second extension is module *Curves*. It introduces three new kinds of objects: lines which are not necessarily horizontal or vertical, circles, and ellipses (with horizontal and vertical axes). All are considered to be variants of the same type Curve, the variant being specified by the field *kind* of the object record. Selection is again indicated by a small, square dot at the end of a line and at the lowest point of a circle or an ellipse.

In order to avoid computations involving floating-point numbers and to increase efficiency, Bresenham algorithms are used. The algorithm for a line defined by $bx - ay = 0$ (for $b \leq a$) is summarized by the following statements:

```
x := 0; y := 0; h := (b – a) DIV 2;
WHILE x <= a DO Dot(x, y);
  IF h <= 0 THEN INC(h, b) ELSE INC(h, b-a); INC(y) END ;
  INC(x)
END
```

The Bresenham algorithm for a circle given by the equation $x^2 + y^2 = r^2$ is:

```
x := r; y := 0; h := 1-r;
WHILE y <= x DO Dot(x, y);
  IF h < 0 THEN INC(h, 2*y + 3) ELSE INC(h, 2*(y-x)+5); DEC(x) END ;
  INC(y)
END
```

```
MODULE Curves;  (*NW 8.11.90 / 1.2.91*)
    IMPORT Display, Files, Printer, Oberon, Graphics, GraphicFrames;

    TYPE Curve* = POINTER TO CurveDesc;

      CurveDesc* = RECORD (Graphics.ObjectDesc)
          kind*, lw*: INTEGER
        END ;

    (*kind: 0 = up-line, 1 = down-line, 2 = circle, 3 = ellipse*)

    VAR method*: Graphics.Method;

    PROCEDURE dot(f: GraphicFrames.Frame; col: INTEGER; x, y: LONGINT);
    BEGIN
      IF (f.X <= x) & (x < f.X1) & (f.Y <= y) & (y < f.Y1) THEN Display.Dot(col, x, y, 0) END
    END dot;

    PROCEDURE mark(f: GraphicFrames.Frame; col, x, y: INTEGER);
    BEGIN
      IF (f.X <= x) & (x+4 < f.X1) & (f.Y <= y) & (y+4 < f.Y1) THEN
        Display.ReplConst(col, x, y, 4, 4, 0)
      END
    END mark;

    PROCEDURE line(f: GraphicFrames.Frame; col: INTEGER; x, y, w, h, d: LONGINT);
      VAR x1, y1, u: LONGINT;
    BEGIN
      IF h < w THEN
        x1 := x+w; u := (h-w) DIV 2;
        IF d = -1 THEN INC(y, h) END ;
        WHILE x < x1 DO
          dot(f, col, x, y); INC(x);
          IF u < 0 THEN INC(u, h) ELSE INC(u, h-w); INC(y, d) END
        END
      ELSE y1 := y+h; u := (w-h) DIV 2;
        IF d = -1 THEN INC(x, w) END ;
        WHILE y < y1 DO
          dot(f, col, x, y); INC(y);
          IF u < 0 THEN INC(u, w) ELSE INC(u, w-h); INC(x, d) END
        END
      END
    END line;

    PROCEDURE circle(f: GraphicFrames.Frame; col: INTEGER; x0, y0, r: LONGINT);
      VAR x, y, u: LONGINT;
    BEGIN u := 1 - r; x := r; y := 0;
      WHILE y <= x DO
        dot(f, col, x0+x, y0+y); dot(f, col, x0+y, y0+x); dot(f, col, x0-y, y0+x);
        dot(f, col, x0-x, y0+y);
        dot(f, col, x0-x, y0-y); dot(f, col, x0-y, y0-x); dot(f, col, x0+y, y0-x); dot(f, col, x0+x, y0-y);
        IF u < 0 THEN INC(u, 2*y+3) ELSE INC(u, 2*(y-x)+5); DEC(x) END ;
        INC(y)
      END
    END circle;

    PROCEDURE ellipse(f: GraphicFrames.Frame; col: INTEGER; x0, y0, a, b: LONGINT);
      VAR x, y, y1, aa, bb, d, g, h: LONGINT;
    BEGIN aa := a*a; bb := b*b;
      h := (aa DIV 4) - b*aa + bb; g := (9*aa DIV 4) - 3*b*aa + bb; x := 0; y := b;
      WHILE g < 0 DO
        dot(f, col, x0+x, y0+y); dot(f, col, x0-x, y0+y); dot(f, col, x0-x, y0-y); dot(f, col, x0+x, y0-y);
        IF h < 0 THEN d := (2*x+3)*bb; INC(g, d)
        ELSE d := (2*x+3)*bb - 2*(y-1)*aa; INC(g, d + 2*aa); DEC(y)
        END ;
        INC(h, d); INC(x)
      END ;
      y1 := y; h := (bb DIV 4) - a*bb + aa; x := a; y := 0;
      WHILE y <= y1 DO
        dot(f, col, x0+x, y0+y); dot(f, col, x0-x, y0+y); dot(f, col, x0-x, y0-y); dot(f, col, x0+x, y0-y);
        IF h < 0 THEN INC(h, (2*y+3)*aa) ELSE INC(h, (2*y+3)*aa - 2*(x-1)*bb); DEC(x) END ;
        INC(y)
      END
    END ellipse;

    PROCEDURE New*;
      VAR c: Curve;
    BEGIN NEW(c); c.do := method; Graphics.new := c
    END New;

    PROCEDURE* Copy(src, dst: Graphics.Object);
    BEGIN dst(Curve)^ := src(Curve)^
    END Copy;

    PROCEDURE* Draw(obj: Graphics.Object; VAR M: Graphics.Msg);
      VAR x, y, w, h, col: INTEGER; f: GraphicFrames.Frame;
    BEGIN
      WITH M: GraphicFrames.DrawMsg DO
        x := obj.x + M.x; y := obj.y + M.y; w := obj.w; h := obj.h; f := M.f;
        IF M.col = Display.black THEN col := obj.col ELSE col := M.col END ;
        IF (x < f.X1) & (f.X <= x+w) & (y < f.Y1) & (f.Y <= y+h) THEN
          IF obj(Curve).kind = 0 THEN  (*up-line*)
            IF M.mode = 0 THEN
              IF obj.selected THEN mark(f, Display.white, x, y) END ;
              line(f, col, x, y, w, h, 1)
            ELSIF M.mode = 1 THEN mark(f, Display.white, x, y)
            ELSIF M.mode = 2 THEN mark(f, Display.black, x, y)
          ELSE mark(f, Display.black, x, y); line(f, Display.black, x, y, w, h, 1)
          END
        ELSIF obj(Curve).kind = 1 THEN  (*down-line*)
          IF M.mode = 0 THEN
            IF obj.selected THEN mark(f, Display.white, x, y+h) END ;
            line(f, col, x, y, w, h, -1)
          ELSIF M.mode = 1 THEN mark(f, Display.white, x, y+h)
          ELSIF M.mode = 2 THEN mark(f, Display.black, x, y+h)
          ELSE mark(f, Display.black, x, y+h); line(f, Display.black, x, y, w, h, -1)
          END
        ELSIF obj(Curve).kind = 2 THEN  (*circle*)
          w := w DIV 2;
          IF M.mode = 0 THEN
            IF obj.selected THEN mark(f, Display.white, x+w, y-4) END ;
            circle(f, col, x+w, y+w, w)
          ELSIF M.mode = 1 THEN mark(f, Display.white, x+w, y-4)
          ELSIF M.mode = 2 THEN mark(f, Display.black, x+w, y-4)
          ELSE mark(f, Display.black, x+w, y-4); circle(f, Display.black, x+w, y+w, w)
          END
        ELSIF obj(Curve).kind = 3 THEN  (*ellipse*)
          w := w DIV 2; h := h DIV 2;
          IF M.mode = 0 THEN
            IF obj.selected THEN mark(f, Display.white, x+w, y-4) END ;
            ellipse(f, col, x+w, y+h, w, h)
          ELSIF M.mode = 1 THEN mark(f, Display.white, x+w, y-4)
          ELSIF M.mode = 2 THEN mark(f, Display.black, x+w, y-4)
          ELSE mark(f, Display.black, x+w, y-4); ellipse(f, Display.black, x+w, y+h, w, h)
          END
        END
      END
    END
    END Draw;

    PROCEDURE* Selectable(obj: Graphics.Object; x, y: INTEGER): BOOLEAN;
    VAR xm, y0, w, h: INTEGER;
    BEGIN
    IF obj(Curve).kind <= 1 THEN  (*line*)
      w := obj.w; h := obj.h;
      IF obj(Curve).kind = 1 THEN y0 := obj.y + h; h := -h ELSE y0 := obj.y END ;
      RETURN
        (obj.x <= x) & (x < obj.x + w) & (ABS(LONG(y-y0)*w - LONG(x-obj.x)*h) < w*4)
    ELSE (*circle or ellipse*)
      xm := obj.w DIV 2 + obj.x;
      RETURN (xm - 4 <= x) & (x <= xm + 4) & (obj.y - 4 <= y) & (y <= obj.y + 4)
    END
    END Selectable;

    PROCEDURE* Handle(obj: Graphics.Object; VAR M: Graphics.Msg);
    BEGIN
    IF M IS Graphics.ColorMsg THEN obj.col := M(Graphics.ColorMsg).col END
    END Handle;

    PROCEDURE* Read(obj: Graphics.Object; VAR R: Files.Rider; VAR C: Graphics.Context);
    VAR len: SHORTINT;
    BEGIN Files.Read(R, len); Graphics.ReadInt(R, obj(Curve).kind);
    Graphics.ReadInt(R, obj(Curve).lw)
    END Read;
```

```
PROCEDURE* Write(obj: Graphics.Object; cno: SHORTINT;
      VAR W: Files.Rider; VAR C: Graphics.Context);
BEGIN Graphics.WriteObj(W, cno, obj);
   Files.Write(W, 4); Graphics.WriteInt(W, obj(Curve).kind);
   Graphics.WriteInt(W, obj(Curve).lw)
END Write;

PROCEDURE* Print(obj: Graphics.Object; x, y: INTEGER);
   VAR x0, y0: INTEGER;
BEGIN
   IF obj(Curve).kind = 0 THEN
      x0 := obj.x * 4 + x; y0 := obj.y * 4 + y;
      Printer.Line(x0, y0, obj.w * 4 + x0, obj.h * 4 + y0)
   ELSIF obj(Curve).kind = 1 THEN
      x0 := obj.x * 4 + x; y0 := obj.y * 4 + y;
      Printer.Line(x0, obj.h * 4 + y0, obj.w * 4 + x0, y0)
   ELSIF obj(Curve).kind = 2 THEN
      Printer.Circle((obj.x*2 + obj.w)*2 + x, (obj.y*2 + obj.h)*2 + y, obj.w*2)
   ELSE
      Printer.Ellipse((obj.x*2 + obj.w)*2 + x, (obj.y*2 + obj.h)*2 + y, obj.w*2, obj.h*2)
   END
END Print;

PROCEDURE MakeLine*;  (*command*)
   VAR x0, x1, y0, y1: INTEGER;
      c: Curve;
      G: GraphicFrames.Frame;
BEGIN G := GraphicFrames.Focus();
   IF (G # NIL) & (G.mark.next # NIL) THEN
      GraphicFrames.Deselect(G);
      x0 := G.mark.x; y0 := G.mark.y; x1 := G.mark.next.x; y1 := G.mark.next.y;
      NEW(c); c.col := Oberon.CurCol;
      c.w := ABS(x1-x0); c.h := ABS(y1-y0); c.lw := Graphics.width;
      IF x0 <= x1 THEN c.x := x0;
         IF y0 <= y1 THEN c.kind := 0; c.y := y0 ELSE c.kind := 1; c.y := y1 END
      ELSE c.x := x1;
         IF y1 < y0 THEN c.kind := 0; c.y := y1 ELSE c.kind := 1; c.y := y0 END
      END ;
      DEC(c.x, G.x); DEC(c.y, G.y); c.do := method;
      Graphics.Add(G.graph, c);
      GraphicFrames.Defocus(G); GraphicFrames.DrawObj(G, c)
   END
END MakeLine;

PROCEDURE MakeCircle*;  (*command*)
   VAR x0, y0, r: INTEGER;
      c: Curve;
      G: GraphicFrames.Frame;
BEGIN G := GraphicFrames.Focus();
   IF (G # NIL) & (G.mark.next # NIL) THEN
      GraphicFrames.Deselect(G);
      x0 := G.mark.x; y0 := G.mark.y; r := ABS(G.mark.next.x-x0);
      IF r > 4 THEN
         NEW(c); c.x := x0 - r - G.x; c.y := y0 - r - G.y; c.w := 2*r+1; c.h := c.w;
         c.kind := 2; c.col := Oberon.CurCol;
         c.lw := Graphics.width; c.do := method;
         Graphics.Add(G.graph, c);
```

```
                GraphicFrames.Defocus(G); GraphicFrames.DrawObj(G, c)
            END
        END
    END MakeCircle;

    PROCEDURE MakeEllipse*;  (*command*)
        VAR x0, y0, a, b: INTEGER;
            c: Curve;
            G: GraphicFrames.Frame;
    BEGIN G := GraphicFrames.Focus();
        IF (G # NIL) & (G.mark.next # NIL) & (G.mark.next.next # NIL) THEN
            GraphicFrames.Deselect(G);
            x0 := G.mark.x; y0 := G.mark.y;
            a := ABS(G.mark.next.x-x0); b := ABS(G.mark.next.next.y - y0);
            IF (a > 4) & (b > 4) THEN
                NEW(c); c.x := x0 - a - G.x; c.y := y0 - b - G.y; c.w := 2*a+1; c.h := 2*b+1;
                c.kind := 3; c.col := Oberon.CurCol;
                c.lw := Graphics.width; c.do := method;
                Graphics.Add(G.graph, c);
                GraphicFrames.Defocus(G); GraphicFrames.DrawObj(G, c)
            END
        END
    END MakeEllipse;

BEGIN NEW(method); method.module := "Curves"; method.allocator := "New";
    method.new := New; method.copy := Copy; method.draw := Draw;
    method.selectable := Selectable; method.handle := Handle;
    method.read := Read; method.write := Write; method.print := Print
END Curves.
```

14. Building and Maintenance Tools

14.1 The Startup Process

An aspect usually given little attention in system descriptions is the process of how a system is started. Its choice, however, is itself an interesting and far from trivial design consideration and will be described here in some detail. Moreover, it directly determines the steps in which a system is developed from scratch, mirroring the steps in which it builds itself up from a bare store to an operating body.

The startup process typically proceeds in several stages, each of them bringing further facilities into play, raising the system to a higher level towards completion. The term for this strategy is *bootstrapping* or, in modern computer jargon, *booting*.

Stage 1 is initiated when power is switched on or when the reset button is pressed and released. To be precise, power-on issues a reset signal to all parts of the computer and holds it for a certain time. Pushing the reset button therefore appears like a power-on without power having been switched off. Release of the reset signal causes the processor to start the so-called *boot loader*. This program resides in a read-only store (ROM) and hence is always present, even on a "bare" machine. It loads data into memory, which are interpreted as code in Stage 2. In order to keep the boot loader as simple as possible - remember that it is burnt into ROM on every workstation and therefore cannot be changed without considerable effort - the format of its data must be simple. We have chosen the following structure, which had never to be changed during the entire development effort of the Oberon System because of both its simplicity and generality:

```
BootFile   = {block}.
block      = size:4 address:4 {byte}.
```

The address of the last block, distinguished by *size* = 0, is interpreted as the address of the starting point of Stage 2. The size of the boot loader on Ceres is about 250 bytes.

The source of the boot data is typically a fixed location on the disk. In our case, the data occupy less than a single track, which is therefore called the *boot track* and remains permanently reserved.

The data loaded in Stage 1 are interpreted as code in Stage 2, representing modules *Kernel, FileDir, Files,* and *Modules,* which are said to constitute the *inner core* of the system. Control is transferred to module *Kernel*'s initialization part. First, the processor's base address registers are initialized, then the chain of free module descriptors is formed. This is followed by the initialization of the required virtual address pages on machines which feature a memory management unit. Interrupt table and interrupt control unit (ICU) are initialized, and finally the initialization parts of the remaining three modules are executed, the last one being *Modules*. Note that only a single device driver is contained in the inner core: the disk driver in module *Kernel.*

The presence of *Modules* implies that the regular loader is available for the further build-up of the system. Module *Files* is present in the inner core, because it is imported by *Modules,* and *FileDir* because it is imported by *Files*. The initialization of module *FileDir* constructs the sector reservation table by recording all files registered in the file directory. This process requires the traversal of the entire directory and the reading of all file headers. It can be regarded as the garbage collection process of disk sectors. The initialization part of *Modules* contains the statement

```
M := ThisMod("Oberon")
```

which causes loading of module *Oberon* and with it automatically of all modules imported by *Oberon*. This constitutes Stage 3 of the boot process. In particular, Stage 3 loads and initializes the display, keyboard and mouse drivers, as well as the display, text, and font machinery. It terminates with the initialization of module *Oberon* itself, which contains the statement

```
M := Modules.ThisMod("System")
```

It initiates Stage 4 of the boot process and completes the system by loading the first tool module. The initialization of *System* opens a viewer for the log and one for a tool text. In addition to *System*, modules *MenuViewers* and *TextFrames* are loaded, because they are imported by System. The modules loaded so far form the outer core. In passing we note that also the default font and the text *System.Tool* are needed in Stage 4. After completion of Stage 4, control returns to the statements

```
P := ThisCommand(M, "Loop"); P
```

in the initialization part of *Modules*. Thereby control enters the central loop of the Oberon System for polling input events. Normal operation has begun.

Let us summarize the prerequisites for the four stages:

0. The bootloader must reside in the ROM
1. The boot file must reside on the boot track of the disk.
2. The modules of the outer core must reside in the file system.

These conditions are usually met. But they are not satisfied, if either a new, bare machine is present, or if the disk store is defective. In these cases, the prerequisites must be established with, of course, the aid of suitable tools. The tools needed for the case of the bare machine or the incomplete file store are called *building tools*, those required in the case of defects are called *maintenance tools*.

14.2. Building Tools

Building Tools allow to establish the three preconditions for the boot process on a bare machine. Condition 0 requires an assembler for programming the boot loader, and a so-called ROM-programmer, typically an external device connected by an RS-232 (V24) link. We will not discuss these tools any further. Condition 1 requires a tool to compose the boot file, and one to load it onto the boot track. Condition 2 requires a tool which establishes a file directory and is able to load files. The tool which creates the boot file is called a *boot linker*; this module was given the name *Boot*. The tool which has the capability to load the boot track and to load files is module *Oberon0*.

There remains the important question of how *Oberon0* is loaded onto a bare machine. A partial answer is: by a boot process consisting of Stages 1 and 2 only, using a boot file in which module *Modules* is replaced by *Oberon0*. But this does not suffice. The key facility is a boot loader that admits an external source as alternative to the disk's boot track. As alternative source we use (the boot track of) the diskette. The selection of the source is determined by a switch. It makes the use of I/O devices apart from the diskette driver during the boot phase avoidable. The initiation rite for a bare machine then consists of the following steps:

1. Select the alternative boot source by the appropriate switch setting.
2. Reset. The boot file is read and *Oberon0* is started.
3. Invoke the command which reads all files from the diskette, (which supposedly holds all files needed for the outer core).
4. Reset the switch and boot again. This initiates the regular boot process.

A more modern solution would be to select the network as alternate boot file source. We rejected this option in order to keep net access routines outside the ROM, in order to keep the startup of a computer independent of the presence of a server, and also in consideration of the fact that there exist machines which operate in a stand-alone mode. As it turns out, the need for the alternative boot file source arises very rarely.

The boot linker is almost identical to the module loader, with the exception that object code is not deposited in newly allocated blocks, but in a fixed buffer which is finally output to form the boot file. Its name is supplied as second parameter to the command *Boot.Link*. The first parameter specifies the module which is the top of the hierarchy forming the inner core

```
Boot.Link Modules Ceres2.Boot
Boot.Link Oberon0 Ceres2.Boot0
```

The boot file consists of four blocks (see Section 14.1.). The first block contains the module descriptors (see Chapter 6) for the modules of the inner core. The second block consists of their code and global data sections. The third block contains the lengths of the first two blocks. The fourth block specifies the start address of *Kernel*. The load addresses of the first three blocks are fixed constants in the Boot program (4000H, 8000H, 0).

From the description of the start-up process for a bare machine given above, module *Oberon0* must first initialize the file directory and then load all files contained on a boot diskette. We have chosen to extend *Oberon0* into a much more versatile tool. This was not merely clever foresight, but is due to *Oberon0*'s emergence from the development process of the Oberon System which, naturally, included a considerable amount of error detection and correction [1]. *Oberon0* therefore contains a genuine command interpreter. There exist commands for inspecting memory areas, disk sectors, for inspecting the file directory, and even for loading modules. The presence of a command interpreter requires input (keyboard) and output (display) facilities. They were kept to a bare minimum and encapsulated in module IO.

```
DEFINITION IO;
  PROCEDURE Read (VAR ch: CHAR);
  PROCEDURE WriteLn;
  PROCEDURE Write (ch: CHAR);
  PROCEDURE WriteString (s: ARRAY OF CHAR);
  PROCEDURE WriteHex (x: LONGINT);
  PROCEDURE WriteInt (x, n: LONGINT);
END IO.
```

The command interpreter is a simple loop, accepting commands specified by a single letter followed by parameters which are either hexadecimal numbers or names. User-friedliness was not attributed any importance at this point, and it would indeed be unjustified. We refrain from elaborating on further details and concentrate on providing a list of available commands. This should give the reader an impression of the capabilities of this tool module for system initiation and for error searching.

r	name	read file from diskette
w	name	write file to diskette
d	name	delete file from diskette
z		read all files contained on diskette
e		ennumerate diskette files
!i		initialize diskette directory
!f		format diskette
E		enumerate file directory
D	name	delete file
N	name0 name1	rename file
M	name	load and initialize module
C	name	call command
O		load Oberon and call Loop
a	address	display memory block (256 bytes) in hex
A	address	display memory block (256 bytes) as characters
k	number	display disk sector in hex
K	number	display disk sector as characters
l		clear display
?		list available commands
t		get time and date from real time clock
T	time date	set real time clock
!B	name	load file onto boot track
!Y		initialize bad sector file
!1		initialize file directory

All these additional commands give *Oberon0* the character of a maintenance tool. In particular, the possibility to read individual files from the diskette allows recovery when a file required in stages 3 or 4 of the boot process has been corrupted. The O-command allows to detect at which point the process fails. Nevertheless, the original purpose of *Oberon0* is to initiate a bare machine through commands *!1, !B,* and *z*.

14.3. Maintenance Tools

An important prerequisite for Stage 2 (and the following stages) in the boot process has not been mentioned above. Recall that the initialization of module *FileDir* constructs the disk sector reservation table in the *Kernel* from information contained on the disk. Obviously, its prerequisite is an intact, consistent file directory. A single unreadable, corrupted file directory or file header sector lets this process fail, and booting becomes impossible. To cope with this (fortunately rare) situation, a maintenance tool has been designed: module *DiskCheck*. It is included in a special boot file generated by the command

```
Boot.Link DiskCheck Ceres2.CheckBoot
```

DiskCheck is organized similarly to *Oberon0* as a simple command interpreter, but it imports only *Kernel* and *IO*. Hence, booting involves only Stages 1 and 2 without any access to the disk. Operating *DiskCheck* requires care and knowledge of the structure of the file system (Chapter 7). The available commands are the following; those that write on the disk are guarded by an exclamation mark.

r	n	read sector n into sector buffer, display hex
R	n	read sector n into sector buffer, display as characters
e	n	read extended index sector n into sector buffer
!W		write sector buffer
d	n	read directory sector n into dir buffer
!D		write dir buffer
h	n	read header sector into Header buffer
!H		write header buffer
x	n	read track containing sector n into track buffer
!Y		format track
!Z		write track buffer
S	m, n	insert sector n as header address of entry m in dir buffer
s	m, n	insert sector n in entry m of sector table in header buffer
L	n	set file length in header buffer to n
i	adr val	insert val at adr in sector buffer
f	name	read header sector of named file into header buffer
q	n	find all files of which sector n is part
c		check consistency of files and directory
b	n	add faulty sector to bad sector table
l		clear display
Q		reset disk drive
?		list available commands
!0	n	clear sector n (write zeroes)
!1		initialize file directory
!2		initialize bad sector table
!?		read all disk sectors and record faulty sectors
!*		format disk

Sectors are always read into a buffer, namely the sector buffer, the directory buffer, the header buffer, or the track buffer, and the number of the sector in the respective buffer is retained. Changes are made on the data stored in the respective buffer, which is displayed after each reading or change in an appropriately decoded format. Every change must be confirmed, because only a writing command transfers the buffered data to the disk.

The typical handling of the occurence of a corrupted sector in a file consists of the following steps:

1. The track containing the unreadable sector is read (x).
2. The track is reformatted (!Y).
3. The track is restored (!Z). (the faulty sector data are lost)
4. The track is reread (x) and the steps are repeated, if the condition persists.
5. If, after several tries, the sector cannot be corrected, the file must be removed. In order to make a directory traversal possible without changing the directory data, the corresponding entry is changed (S). The simplest way is to set it equal to its neighbouring entry, thereby introducing an inconsistency (double reference) which must be corrected by deleting the file as soon as the Oberon System is operational.
6. An unrecoverably faulty sector must be made unreferenceable. This is done by appending it to a file called *BadSectors*, which is inherently unreadable, but which lets its sectors be marked as used in the initialization process of the sector reservation table in Boot Stage 2. A sector is appended to this file by command b.
7. When the Oberon System is available again, the recovered files must be either deleted or inspected and, if possible, corrected.

Program *DiskCheck* must be extremely robust. No data read can be assumed to be correct, no index can be assumed to lie within its declared bounds, no sector number can be assumed to be valid, and no directory or header page may be assumed to have the expected format. Guards and error diagnostics take a prominent place. Because any program failure must be prevented, no use is made of disk procedures provided by the *Kernel*. They are reprogrammed with additional guards and status reporting.

Whereas a faulty, unreadable sector in a file in the worst case leads to the loss of that file, a fault in a sector carrying a directory page is quite disastrous. Not only because the files referenced from that page, but also those referenced from descendant pages become inaccessible. A fault in the root page even causes the loss of all files. The catastrophe is of such proportions, that measures should be taken even if the case is very unlikely. After all, it may happen, and it indeed has occurred.

The only way to recover files that are no longer accessible from the directory is by scanning the entire disk. In order to make a search at all possible, every file header carries a mark field that is given a fixed, constant value. It is very unlikely, but not entirely impossible, that data sectors which happen to have the same value at the location corresponding to that of the mark, may be mistaken to be headers.

The tool performing such a scan is called *Scavenger*. It is, like *DiskCheck* a simple command interpreter, and a boot file is created by

```
Boot.Link Scavenger Ceres2.ScavBoot
```

The available commands are

s n	Scan the first n sectors and collect headers
d	Display names of collected files
W	Build new directory
l	Clear display
?	Show available commands

During the scan, a new directory is gradually built up in primary store. Sectors marked as headers are recorded by their name and creation date. The scavenger is the reason for recording the file name in the header, although it remains unused there by the Oberon System. Recovery of the date is essential, because several files with the same name may be found. If one is found with a newer creation date, the older entry is overwritten.

Command *W* transfers the new directory to the disk. For this purpose, it is necessary to have free sectors available. These have been collected during the scan: both old directory sectors (identified by a directory mark similar to the header mark) and overwritten headers are used as free locations.

The scavenger has proven its worth on more than one occasion. Its main drawback is that it may rediscover files that had been deleted. The deletion operation by definition affects only the directory, but not the file. Therefore, the header carrying the name remains unchanged and is discovered by the scan. All in all, however, it is a small deficiency.

Reference

1. N. Wirth. Designing a System from Scratch. *Structured Programming*, *1*, (1989), 11-19.

A. Ten Years After: From Objects to Components

In practice, the design of the Oberon runtime model as described in Chapters 3, 4 and 5 proved to be basically flawless and sustainable. However, later developments gradually revealed some unused potential. The main shortcoming was the absence of a *generic object type* that would serve as an abstract root of the entire Oberon object hierarchy. As a remedy, we later added a module called *Objects* and two abstract types *Object* and *Library*, from that we then derived some previously independent types via type extension. Figure A.1 depicts the resulting type hierarchy. This simple extension of the Oberon kernel had an amazingly beneficial effect, and it allowed us to develop a substantial evolution of the original Oberon system, including

- A generic persistence mechanism for objects
- A generalized notion of text as sequence of arbitrary objects
- A fully hierarchic component framework
- An advanced graphical user interface (GUI) called *Gadgets*

Figure A.5 at the end of this Chapter shows the modular structure of the evolutionary *Oberon* system. In the following Sections we briefly discuss the rationale behind it and illustrate its use.

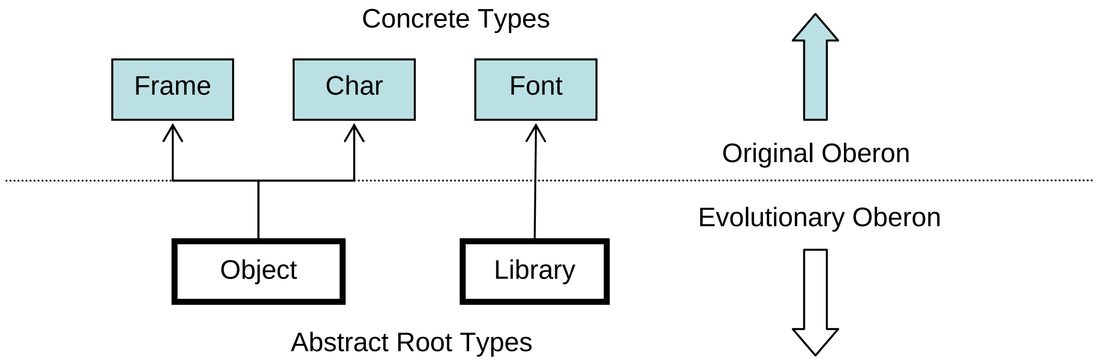


Figure A1 The Oberon Type Hierarchy

A.1. Object Libraries

In Oberon, the model of *persistent objects* is defined by a single module called *Objects* that exports two abstract concepts represented by the types *Objec*t and *Library*.

An *object library* is an indexed collection of objects (instances of objects to be precise). A library is either *public* or *private* (to some host). *Public libraries* are named and accessible from any authority in the system. For example, the member object *O* of the public library *L* can be referenced invariantly by its qualified name *L.O*. Figure A.2 further shows that object libraries can refer to each other. In their entirety, they build a hierarchy that, in a sense, is dual to the system's module hierarchy. *Private libraries* are anonymous and encapsulated in some higher authority, typically in a document. This case is also depicted in Figure A.2.

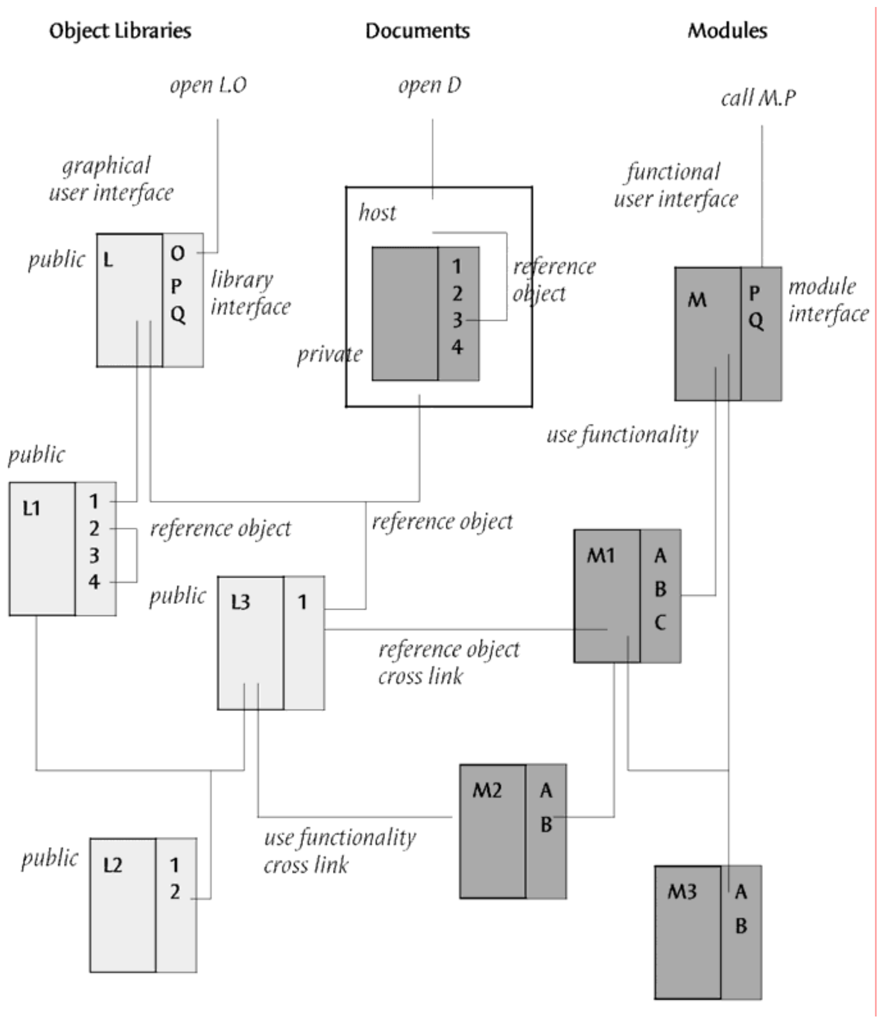


Figure A.2 The Dual Hierarchies of Object Libraries and Modules

Object libraries are used in Oberon to manage persistent objects. Essentially they serve two different purposes:

- Presenting logically connected groups of objects as *indexed collections*
- Providing generic support for *serialization* and *de-serialization* of object representations. Serialization/ de-serialization are used to *externalize* and *internalize* persistent objects to and from persistent store or the network.

The functional interface of object libraries comprises a variety of operations for retrieving, adding and removing objects (at runtime) and for storing and loading the contents of the library to and from a sequential file.

Objects are typically (recursively) composed of components and represented internally as a graph of linked nodes. From this it follows that the algorithms for externalizing and internalizing objects must be generic enough to serialize and de-serialize any arbitrary dynamically linked heterogeneous data structure. It is therefore interesting to study these algorithms in some detail.

For the sake of simplicity, we assume a simple, all-or-nothing storing/ loading scheme. Notice, however, that the definition of type *Library* allows different implementations of its functional interface such as, for example, a smart partial storing/ loading strategy in combination with buffering.

The Generic Externalization Algorithm

This is a two-pass process that relies on a (recursive) binding phase followed by the actual storing phase:

```
Bind (object) = begin
  for all components of object do Bind(component) end;
  if object unbound then assign index to object end
end

Store (library) = begin
  for all objects in library do Bind(current object) end;
  for all indexes in library do
    with object for this index do
      store generator;
      (*) store main node where pointers are replaced with indexes
    end
  end
end
```

The statement marked (*) cannot be executed by a universal library method, because the internal structure of an object is unknown to the library. Instead, an instance method call is needed.

The Generic Internalization Algorithm

This is again a two-pass process:

```
Load (library) = begin
  for index := 0 to max do load generator; generate main node end;
  for index := 0 to max do
    (*) load main node where indexes are replaced with pointers
  end
end
```

The marked statement must again be implemented as an instance method call. Further notice that indexes in object nodes might refer to different libraries and therefore might lead to a recursive loading process.

Let us now leave the discussion of libraries for a moment and turn to objects. On the level of definition, objects are abstract (or ”virtual”) and have no concrete functionality. However, any participating object is expected to implement a basic predefined *message protocol* that, in a sense, defines the framework of persistent objects in Oberon. In analogy with the familiar concept of a hardware bus, we could call this architecture a *software bus*: Participating components simply plug in by implementing the predefined message protocol.

This is a short overview of the set of predefined message types:

- *Bind Message:* Used to bind objects to a given library. More precisely, if we call *loose* any object that is either unbound or bound to an anonymous library, the *Bind* message requires the recipient and all its loose components to bind themselves.
- *File Message:* Used to externalize and internalize objects to and from a sequential file.
- *Attribute Message:* Object attributes are specified by their name and their value (typically a string or a number). Using the Attribute Message, attributes can be added, and their value can be retrieved or changed. *Gen* and *Name* are predefined attributes. They specify the object's generator (a procedure) and its intrinsic identifier respectively.
- *Link Message:* Used to create and retrieve named links to other objects. Allows “wiring” of components at run time.
- *Find Message:* Used to locate and retrieve a component by its name within the scope of the recipient.
- *Copy Message:* Used to create an exact copy (*clone*) of the recipient. In the case of a composite original object, we distinguish between *shallow* copies and *deep* copies. While shallow copies still refer to the components of the original object, deep copies consist of fresh copies of the components of the original object.

A.2. Frames as Visual Objects

From Chapter 4 we know a very important concrete class of objects: *Frames* on the display screen. Frames are *visual objects* because they are assumed to provide functionality for some visual representation within a rectangular area on the screen (or printer). Typically, a frame represents a *view* of some *model* object and comes with a built-in controller, typically an interpreter for interactions. In other words, a typical frame combines the *VC* components of the *MVC* scheme.

From a technical point of view, frames are instances of type *Frame* that in turn is an extension of the base type *Object*. In summary, frames in Oberon are visual persistent objects that are expected to obey the basic message protocol plus a set of special *frame messages* controlling their display. The set of frame messages comprises requests to display oneself, to change one's state (*visible* or *invisible*), size or location, to consume an other object or some text caption, to return selected contents, to mark itself as selected and to update consistency with the underlying model.

In a sense, it is natural to regard the display area itself as a global visual container that is hierarchically composed of smaller containers or objects. This view has some interesting consequences. First, as depicted in Figure A.3, it leads to a coherent extension of the hierarchical structure of the tiling Oberon display screen whose first two levels represent (vertical) tracks and (horizontal) viewers respectively.

A second consequence of the hierarchical structure of the display space is the option of a message passing scheme that obeys strict *parental control*. Because every visual object is a possibly indirect component of the display space, messages directed to any visual object can simply be sent to the global display space, with an implicit forwarding obligation to its components. The exact forwarding strategy depends on the kind of message. A *target-oriented* strategy is used if the message is directed to some specific object in the display space (the target), while *a broadcast* strategy is used in cases of an unknown final recipient or an unknown set of final recipients. A typical application of the broadcast strategy is *update view* requests sent by model objects, with the substantial benefit of dispensing models from the burden of keeping track of their views (for example in the form of call-back lists).

The two forwarding strategies are similar in the sense that both are context-oriented. However, they are different in detail. While the broadcast strategy simply spreads the message in the display space, the target-oriented forwarding strategy aims at passing down the message along the path leading to the desired target object. We should clarify that the strategy of forwarding messages down the display hierarchy is part of the extended message protocol that is compulsory for all members of the display space.

Let us now track a message that is traveling through the display space and finally arriving at its destination. We know that, in the moment of its arrival, the message has passed the entire context, step by step. We can draw benefits of this fact in two respects: (a) Any context-oriented processing can be done incrementally and (b) context-dependent message handling is possible. Typical uses of (a) are accumulation of relative coordinates and computation of overlapping masks in the context of a visual object. A typical use of (b) is visual objects showing a different behavior in a developer context and in a user context.

A possible complication arises from the fact that we allow views of views, so-called *camera views*, see again Figure A.3. As a consequence, paths may join in the display space, and we can no longer assert its tree-structure. In combination with a context-oriented forwarding strategy, this may lead to errors due to possibly undetected multiple arrivals of a message at the same object. For example, a *copy* message arriving twice at a shared component of a composite object could lead to the creation of two different copies of this component. In order to avoid problems of this kind, messages are *time-stamped* in Oberon, and recipients in the display space are requested to detect multiple arrivals of one and the same message by comparing time-stamps.

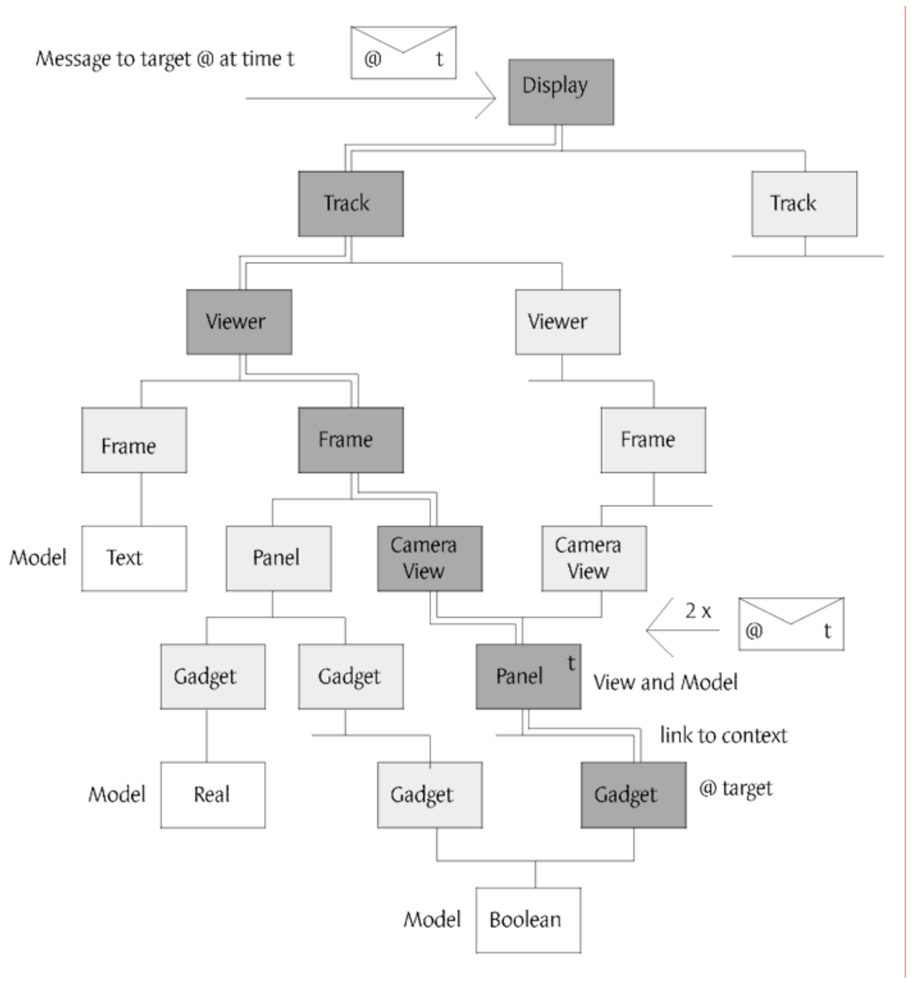


Figure A.3 The Oberon Display Space Hierarchy

We can best summarize the comprehensive rules of message handling and message passing in the display space by presenting a rough sketch of a message handler:

```
Handle message M received by frame F =
  save pointer to context in F; update context pointer in M;
  if timestamp of M then backup timestamp in F then
    save timestamp in F;
    accumulate coordinates in M;
    if target frame of M = F then (*target frame is me*) handle M
    else
      if target frame of M = NIL then (*broadcast*) handle M end;
      while more descendants do
         pass M to next descendant
      end
    end
  else special handling in new context
  end
end
```

In reality, message handling is slightly more intricate because (for the sake of optimization) recipients may decide to (early) terminate the handling of a message and to stop any further propagation.

We now briefly come back to a remark that we made in an earlier Chapter on the value of open object interfaces. As we can easily see, any context-oriented forwarding strategy in fact requires open object interfaces. The reason is that intermediate stations on the message paths must be able to pass through (and even to preprocess) messages of a possibly unknown type such as, for example, update-view requests for exotic components.

A.3. Embedded Objects

We can distinguish two kinds of containers for objects: (a) Container objects and (b) text. Obviously, case (a) is subsumed under the hierarchical concept of composite objects that culminates in the construct of the global display space. For case (b), a different but no less elegant solution exists. Let us first recall Oberon's original text model. An Oberon text is a sequence of attributed characters or, slightly simplified, a sequence of pairs *(character code, font).*

The key idea of our solution is now a shift of emphasis in the interpretation of the *font* attribute. By simply reinterpreting *font* as a collection of characters, we arrive at a view of text as a sequence of pairs *(character code, collection of characters).* It is now a small step from “collection of characters” to “collection of objects” or “object library”. With this, our generalized texts are now sequences of pairs *(index, object library),* that is sequences of general objects. Depending on the kind of library, an embedded object is either *public* (and possibly contained in other documents as well) or *private* to the containing text. Typical examples of non-character objects are pictures, formulae and arbitrary visual objects. However, completely other kinds of non-visual embedded objects are conceivable, for example formatting controls and links.

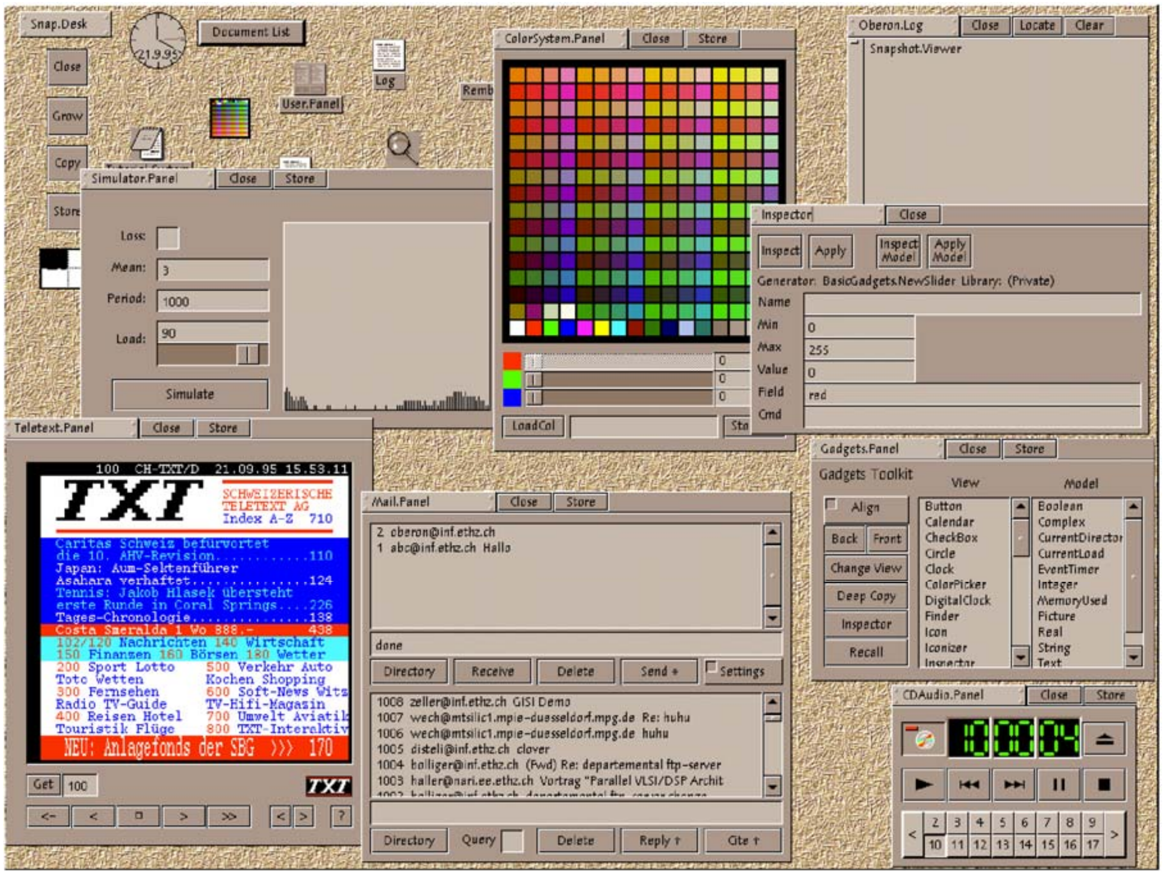
A.4. Gadgets

Gadgets in Oberon are objects that serve as elements of a *graphical user interface* (GUI). *Visual gadgets* come in great variety, ranging from simple buttons, checkboxes, sliders, text fields, lists, icons etc. to more complex elements such as pictures, line graphics, control panels, texts and entire desktops. In addition, there exist non-visual *model gadgets* like *Boolean, Integer*, *Rea*l etc. Some gadgets feature a title bar with an integrated name plate and a number of buttons. They are called *documents* and are considered autonomous entities that can be stored under their name and reloaded in an arbitrary context. The desktop itself is a document, which demonstrates that documents may (recursively) contain other documents as elements. Figure A.4 shows a snapshot of a *Gadgets* desktop.

The set of built-in gadgets may easily be extended by programming *custom gadgets*. The complexity of custom gadgets is quite essentially determined by their structure. *Container-gadgets* like panels are an order of magnitude more complex than *atomic gadgets* like buttons, lists and bar diagrams. This is not surprising, because container gadgets must be able to manage content objects of any arbitrary type. Their message handlers must properly implement parental control including message propagation to contents and, in addition, they must be prepared for feedback requests by contents (for example, if a content object is requested to expand).

The *Gadgets tool* is used to create and compose gadgets interactively. It is itself a gadget (a document) that contains two lists and some buttons. The lists expose an extensive collection of predefined visual gadgets and model gadgets respectively. In addition, the *Gadgets* tool provides other useful support for the interactive construction such as automatic alignment in regularly laid-out panels and view-model connections with built-in consistency. For example, a text field and a slider could be connected to one and the same *Real* type model, or three sliders *red*, *green*, *blue* could be connected to a *Color* model.

The *Inspector tool* is a very versatile instrument that can be applied to any gadget (visual or model) for an inspection of its identity, attributes and properties. When applied to a specific gadget, the tool immediately adjusts its shape, so to represent an attribute form for this gadget. Note that attribute forms are again documents, this time created programmatically, however.



Mean: 3
Period: 1000
Load: 90

Generator: BasicGadgets.NewSlider Library: (Private)
Name
Min 0
Max 255
Value 0
Field red
Cmd

```
100  CH-TXT/D  21.09.95 15.53.11
TXT           SCHWEIZERISCHE
              TELETEXT AG
              Index A-Z  710
Caritas Schweiz befürvortet
die 10. AHV-Revision...........110
Japan: Aum-Sektenführer
Asahara verhaftet..............124
Tennis: Jakob Hlasek übersteht
erste Runde in Coral Springs....226
Tages-Chronologie..............138
Costa Smeralda 1 Wo 888.-      438
102/120 Nachrichten 140 Wirtschaft
150 Finanzen 160 Börsen 180 Wetter
200 Sport Lotto     500 Verkehr Auto
Toto Wetten         Kochen Shopping
300 Fernsehen       600 Soft-News Witz
Radio TV-Guide      TV-Hifi-Magazin
400 Reisen Hotel    700 Umwelt Aviatik
Touristik Flüge     800 TXT-Interaktiv
NEU: Anlagefonds der SBG  >>>  170
```

Get 100

```
2  oberon@inf.ethz.ch
1  abc@inf.ethz.ch  Hallo
```

done

```
1008  zeller@inf.ethz.ch  GISI Demo
1007  wech@mtsilic1.mpie-duesseldorf.mpg.de  Re: huhu
1006  wech@mtsilic1.mpie-duesseldorf.mpg.de  huhu
1005  disteli@inf.ethz.ch  clover
1004  bolliger@inf.ethz.ch  (Fwd) Re: departemental ftp-server
1003  haller@nari.ee.ethz.ch  Vortrag "Parallel VLSI/DSP Archit
```

Figure A.4 The Oberon Gadgets GUI Desktop

In some cases (such as in the case of adaptive attribute forms just discussed), the interactive method for the construction of gadgets is inapplicable or at least inappropriate, and a *descriptive* approach would be preferable. Construction by programming is possible but is not particularly convenient. A much better solution consists of a suitable layout scripting language and a corresponding interpreter.

Here is an example of a scripted composition in functional programming style:

```
(LIB GUI
   (FRAME MediaPanel (OBJ Panels.NewPanel)
      (Volume (OBJ BasicGadgets.NewInteger (Value 100)))
      (Brightness (OBJ BasicGadgets.NewInteger (Value 200)))
      (GRID 2:50 1:* @ 1:25% 1:50% 1:25%) (PAD 2 @ 2)
         (FRAME (POS 1 @ 1) (OBJ TextFields.NewCaption) (Value "Brightness"))
         (FRAME (POS 1 @ 2) (OBJ BasicGadgets.NewSlider)
            (Max 255) (Model Brightness) (Cmd "Movie.SetBright #Value Movie")
         )
        (FRAME (POS 1 @ 3) (OBJ TextFields.NewTextField)
     )
   )
)
```

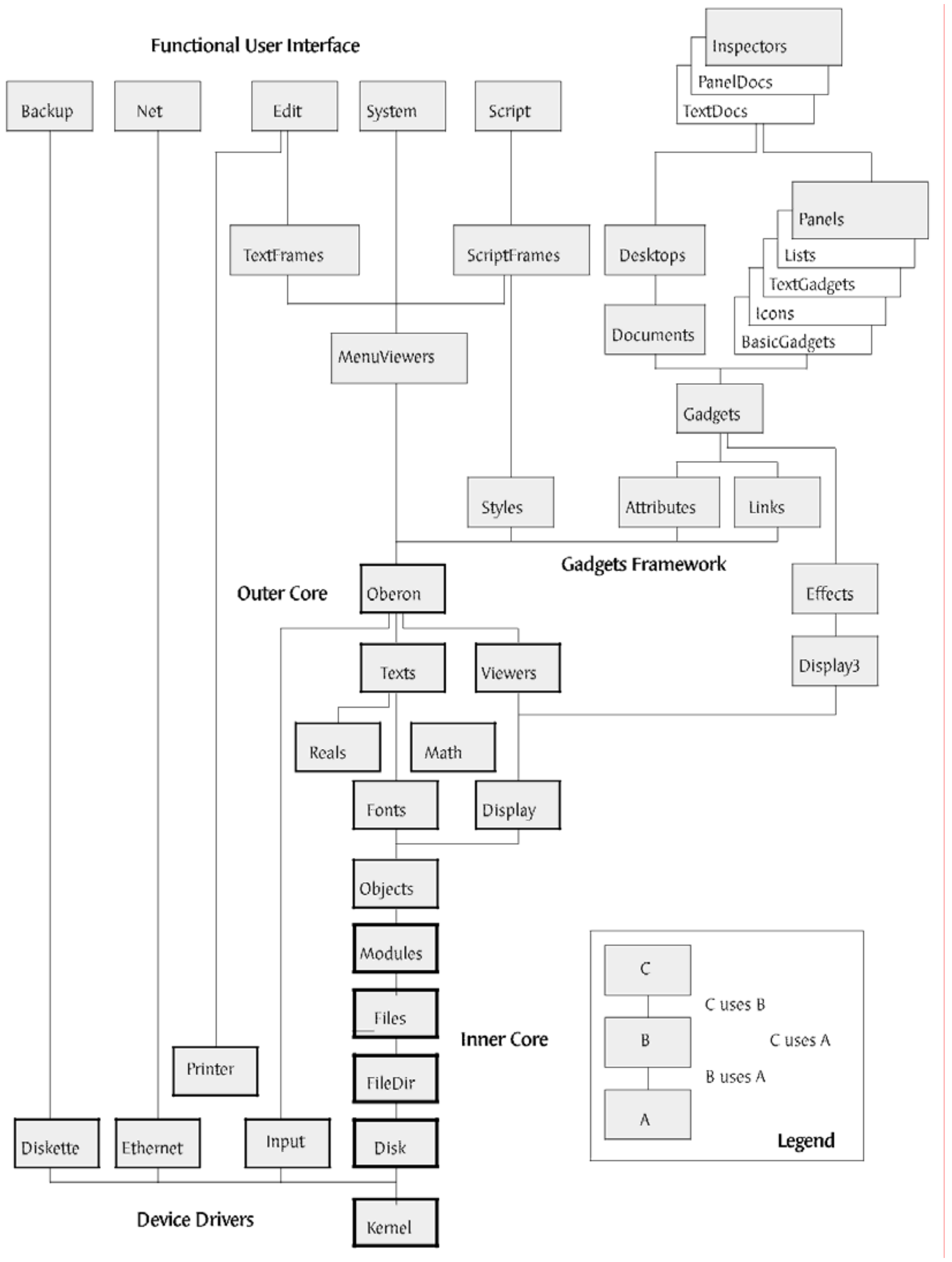


Figure A5 The Oberon Module Hierarchy