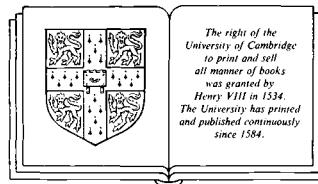


# ILLUSTRATING PASCAL

DONALD ALCOCK



CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE  
NEW YORK PORT CHESTER  
MELBOURNE SYDNEY

CAMBRIDGE UNIVERSITY PRESS

Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press

The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

[www.cambridge.org](http://www.cambridge.org)

Information on this title: [www.cambridge.org/9780521336956](http://www.cambridge.org/9780521336956)

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First published 1987

Reprinted 1990, 1991

Re-issued in this digitally printed version 2008

*A catalogue record for this publication is available from the British Library*

*Library of Congress Cataloguing in Publication data*

Alcock, Donald, 1930—

Illustrating Pascal.

Includes Index.

1. PASCAL (Computer program language) I. Title.

QA76.73.P2A38 1987 005.13'3 87-10369

ISBN 978-0-521-33695-6 paperback

## Acknowledgements

This book was to have been a joint effort, first with Colin Day, then with Richard Kite. But despite all efforts the essentially personal nature of a hand-written book defeated every attempt at co-authorship. Nevertheless the present book is probably better for the experience. My warmest thanks to both of them.

My thanks also to Paul Shearing of *Euro Computer Systems Ltd.* for access to his firm's computers and helping me run my programs using Prospero's Pro Pascal and Borland's Turbo Pascal in addition to the Acorn 150 Pascal under which I had originally developed them.

Finally my thanks to my elder son Andrew for developing the program I employed to assemble and sort the index to this book.

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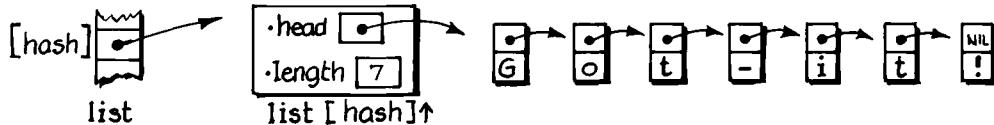
# PREFACE

Pascal is a computer language which was designed by Professor Niklaus Wirth at Eidgossische Technische Hochschule in Zurich. The first draft was completed in 1968. Since that time Pascal has become more and more popular, not only as a language for teaching principles of programming but also as a language in which to write complicated software.

This book introduces and demonstrates the whole of the language defined by BS 6192: *Specification for Computer programming language Pascal*, intended to be compatible with International Standards Institute standard ISO 7185. To keep in touch with reality I have run the programs in this book under three systems:

- ISO Pascal by Acornsoft
- Pro Pascal by Prospero
- Turbo Pascal by Borland International

My style of presentation is pictorial. More can be conveyed by:



than by hundreds of words about hash addresses, pointers, records and linked lists. But I have been careful, too, about wording - aiming at simplicity and conciseness. The page layout has been arranged mainly as double-page spreads, each complete in itself, making it unnecessary to turn pages when referring to diagrams from text. With such layouts - and with diagrams being considered at least as important as text - the wording had to be fitted into place carefully. That is one reason for hand-written text; it is easier to use a pen than a type setter under such constraints. (With word processing and computer type setting making formal composition so easy the modern author is being seduced into thinking "How can I present this concept without a diagram?" when the question ought to be "How can I design a diagram to replace all these boring words?" )

The contents of this book are organized as a programming-language manual. In chapter 1 is an example for the complete beginner, the aim being to demonstrate the concept of a stored program. In chapter 2 there is a quick canter through the rudiments of programming (variables, standard types, expressions, decisions and loops) which should be easy going for those who have written programs in other languages. These two chapters cover enough ground to present each feature of Pascal in the context of a complete program.

Chapter 3 is short but important; it defines the notation used throughout the rest of the book for describing the syntax of Pascal statements and forms. This notation is a blend of Backus-Naur form and railway-track diagrams. It does, I believe, convey structure at a glance – and with no loss of rigour.

From chapter 4 onwards each facility of Pascal is introduced in the context of a working program. The longer programs serve not only to demonstrate facilities of Pascal but also to illustrate fundamental techniques of programming – Quicksort, recursion, rings, binary trees and hashing being among them.

My biggest headache was dealing with interactive input. Pascal was designed in the days of card decks and magnetic tapes; the logic of Pascal's WRITE and READ statements did not allow for programs prompting their users for data from the keyboard. Nowadays such interaction is taken for granted – the reader of this book would probably expect to run the examples interactively – but unfortunately the problem has been solved differently in different versions of Pascal. So I have provided the examples with the simplest possible input statements and noted where the reader who has an interactive system should include prompts for the convenience of the program's user. And I have devoted a short chapter (chapter 11) to the problems one can meet on trying to use Pascal interactively.

If at first you find the punctuation of Pascal programs fussy,  
and  
find

yourself  
lurching  
towards  
the  
right  
margin,

don't despair; you soon grow accustomed to it. When you discover records the sun begins to shine again. When you reach pointers (and can make chains and stacks and rings and trees) you will become addicted. There is no known cure for addiction to Pascal.

REIGATE  
Surrey, U.K.

Donald Alcock  
November 1986



1

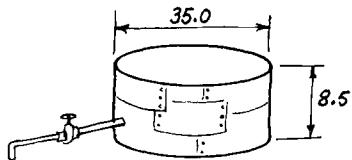
# PRINCIPLES

THE CONCEPT  
INTO PASCAL  
TYPING  
COMPILEATION  
STEPS TO EXECUTION

# THE CONCEPT

OF A "PROGRAM" ~~IS~~ SKIP THIS UNLESS  
YOU ARE COMPLETELY NEW TO COMPUTING

Assume there is no computer to help solve this problem confronting a painter; how many pots of paint are needed to paint the roof and wall of this oil tank?



The paint manufacturer says each pot has enough paint to cover an area of 236.0

Recall that the area of a circle is given by  $\pi r^2$  (where  $r$  is its radius) or  $\pi d^2/4$  (where  $d$  is its diameter). Recall also that the circumference of a circle is given by  $\pi d$  (where  $d$  is its diameter as before). So the painter can work out:

$$\text{AREA OF TOP} = 3.14 \times 35.0^2 \div 4 = 961.63$$

$$\text{AREA OF WALL} = 3.14 \times 35.0 \times 8.5 = 934.15$$

The area to be painted is the sum of the above two areas. Into this area must be divided the coverage of a pot of paint so as to give the number of pots required:

$$\text{POTS} = (961.63 + 934.15) \div 236 = 8.03$$

A number with a fractional part like this is called a *REAL*. Because you cannot readily buy a fraction of a pot of paint the *REAL* must be rounded up to the nearest whole number, or *INTEGER*. To do this truncate the *REAL* and add 1:

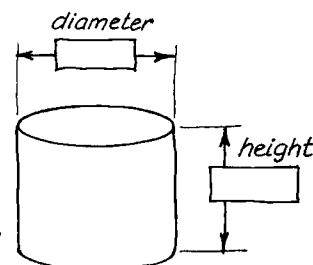
$$\text{FULL POTS} = \cancel{8.03} + 1 = 9$$

*the solution*

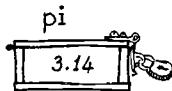
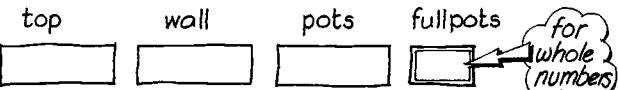
If the dimensions had been such that the number of pots worked out at 8.00 instead of 8.03 the solution would still be 9 pots. This is not arithmetically precise but would make the painter feel happier than an answer of 8.

Now suppose the painter wanted to set down this calculation in a general way such that if the problem arose again he would have only to substitute a few numbers and "turn the handle" for the new result to fall out.

Name some little boxes for holding numbers. The contents of each box will vary from problem to problem.



Don't forget to draw and name the boxes needed to store intermediate results:



read only

Put an approximate value of  $\pi$  into a special box. This value remains constant regardless of oil tank and paint pot  $\approx$  hence the padlock.

A list of instructions  $\approx$  called a program  $\approx$  could be named and written as illustrated below:

PROGRAM painter ( INPUT some data, OUTPUT results);

CONSTANTS       $pi = 3.14 \{ \text{to be used, not changed} \}$ ; declare the  
VARIABLES      diameter, height, coverage, names of all  
                  top, wall, pots, fullpots, boxes to be used,  
                  these boxes are for REALS, but and the types of  
                  fullpots is a box for an INTEGER; value to be  
                  contained

locked boxes      unlocked boxes

BEGINNING OF THE SET OF INSTRUCTIONS

- \* from a waiting line of data, READ numbers into boxes: diameter, height, coverage;
- \* into box top put the result of: the number from box pi times the SQUARE of the number from box diameter, divided by 4.0;
- \* into box wall put the result of: the number from box pi, times the number from box diameter, times the number from box height;
- \* into box pots put the sum of the numbers found in boxes top and wall after dividing this sum by the number found in box coverage;
- \* into box fullpots put the result of TRUNCATING the number from box pots and adding 1;
- \* WRITE a note to the painter ('YOU NEED', write here the number found in box fullpots, 'POTS')

END OF THE SET OF INSTRUCTIONS.

If you had the waiting line of data:

35.0    8.5    236.0

and were to obey the program above (being a human computer) you would go through the calculation set out opposite and end by writing the following note to the painter:

YOU NEED 9 POTS

Of course if you had a different line of data you would get a different result. That is the essence of a "program"  $\approx$  it is a generalized calculation.

# INTO PASCAL

A TRANSLATION OF THE ENGLISH PROGRAM  
ON THE PREVIOUS PAGE

The English instructions on the previous page would be too wordy to be used as computer instructions. Nevertheless the English may be translated into Pascal without losing the original sense.

First of all the recurring phrase "the number from box..." may be treated as understood. For example the third instruction of the program may be shortened to:

★ into box wall put the result of pi times  
diameter times height;

Then do without the phrase "into box such and such put the result of..." by abbreviating to the name of the box followed by a symbol thus:

★ wall :=

where `:=` may be pronounced "becomes" when the statement is read aloud.

Now replace the word "times" by an asterisk. Similarly, replace "add" and "subtract" by plus and minus signs; replace "divide" by a slash (its formal name is *solidus*). Thus the third instruction may be shortened to:

★ wall := pi \* diameter \* height

which reads aloud "wall becomes pi times diameter times height".

There are other abbreviations in Pascal, and some important rules of punctuation to be explained later, but the stage is sufficiently set to illustrate a program in Pascal:

```
PROGRAM painter( INPUT, OUTPUT );
  CONST pi = 3.14;
  VAR diameter, height, coverage, top, wall,
      pots: REAL; fullpots: INTEGER;
  BEGIN
    READ (diameter, height, coverage);
    top := pi * SQR(diameter)/4.0;
    wall := pi * diameter * height;
    pots := ( top + wall ) / coverage;
    fullpots := TRUNC( pots ) + 1;
    WRITE ('YOU NEED', fullpots, ' POTS')
  END.
```

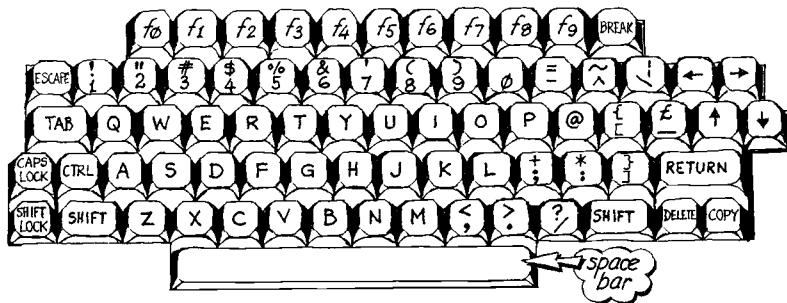
Compare this program with the English one. The declarations and instructions show a one-to-one correspondence.

The mixture of capital letters and small letters is explained later.

# TYPIING

PASCAL IS STANDARDIZED BUT THE COMPUTERS IT RUNS ON ARE NOT; EVERY KEYBOARD IS DIFFERENT

The keyboard of a popular home computer is sketched below; other keyboards are similar.



The keyboard on a VDU connected to a time-sharing computer would look similar to that above. There is always a key at the right, engraved with the word ENTER or RETURN or the symbol ↴. Pressing this key causes a fresh line to be started. Every keyboard has letters A to Z, digits 0 to 9, full stop, comma, colon, semicolon and the arithmetical symbols + - \* / needed for the present example.

Before starting to type you have to "enter the editor" and the way to do this depends on the installation. Using Acornsoft Pascal on the BBC Model B you type EDIT and press RETURN. Using Pro Pascal you use the local editor or a word processor such as Word Star. Using Turbo Pascal you press E.

Once "inside" the editor type fearlessly, taking care over the punctuation which, in Pascal, is pernickety. There is always a way to backspace and re-type a wrong character; on the BBC Model B press DELETE, on some other keyboards press DEL or BACKSPACE.

Other editing facilities differ greatly from installation to installation. The Turbo Pascal editor is modelled on the word processor called Word Star. Every editor is horrible when you first try it but appears to improve as you grow accustomed to it. Patience and perseverance.

Ignore the distinction between capital letters and small letters; type with or without the CAPS LOCK key having been pressed. The only line of the example in which this makes any difference is:

```
write('You need', fullpots, 'pots')
```

where the phrases between apostrophes reappear in the result precisely as typed in the program; upper case, lower case or mixture as above.

Whilst typing the program notice that the computer does not obey any of the instructions. The computer, at this stage, is not even aware that a Pascal program is being typed; it knows only that a file is being typed. You could type Twinkle, twinkle little star in Portuguese and there would be no objection from the computer.

# COMPIRATION

AND, THE PROBLEM OF ENTERING DATA FROM THE KEYBOARD ...

A Pascal program cannot be set to work simply by entering RUN as with many BASIC systems; a Pascal program must first be *compiled*. Compilation means translating the *source program* from Pascal into an *object program* encoded in the computer's own language. When a Pascal program is put to work it is the object program that is obeyed, not the source program.

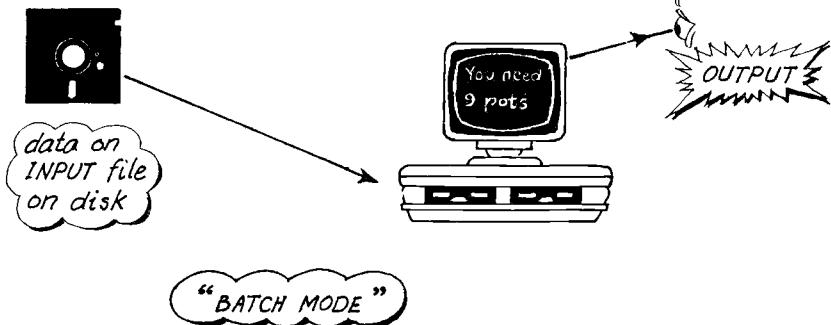
After compilation you have two versions of the same program; one in Pascal and one in machine code (or something close to it). If you were able to display the object program on the screen it would appear to be gibberish.

Pascal runs faster than BASIC because the object program is in machine code which can be obeyed directly or in a code which can be interpreted efficiently. By contrast, statements of a BASIC program are interpreted from source. The price of faster execution is the time and inconvenience of compilation. However, on most installations it is possible to save object programs, hence re-run programs without recompiling them. This course is followed by the steps depicted opposite where a copy of the compiled program is saved on disk.

The steps depicted opposite go from typing a program to running it. Down the left of the page are *commands* typed at the keyboard to initiate each step. The commands are particular to the installation, those shown being imaginary but typical. MYSOURCE and MYOBJECT are assumed to be names invented by the programmer.

The final step depicted opposite assumes INPUT comes from the keyboard and OUTPUT goes to the screen. This arrangement is typical today but is by no means the only way to run Pascal programs. The language was designed at a time when files were saved on magnetic tape, INPUT came from a deck of punched cards, OUTPUT went to a line printer. To make a Pascal program send prompts to a screen and read data from a keyboard requires a suitably modified compiler. If you have such a compiler there should be no difficulty in running the examples in this book. But if prompts and responses get out of sequence (questions following answers) refer to chapter 11 which explains the logical difficulties and their diagnosis. It may be that your compiler cannot compile an interactive program properly - in which case you may still run the examples in this book but with data waiting on a disk file rather than being typed at the keyboard when the program has been set running. This *batch mode* arrangement is depicted below:

GO

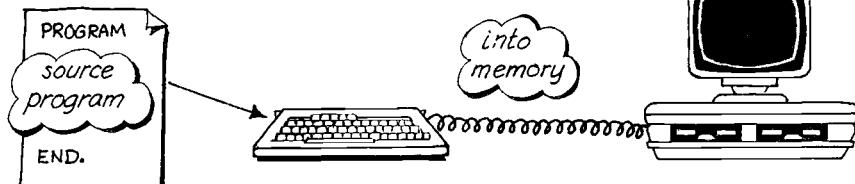


# STEPS TO EXECUTION

BUT THE COMMANDS  
ARE NOT STANDARDIZED

Commands to the operating system vary from one installation to another but the process depicted in steps below is typical:

## EDIT

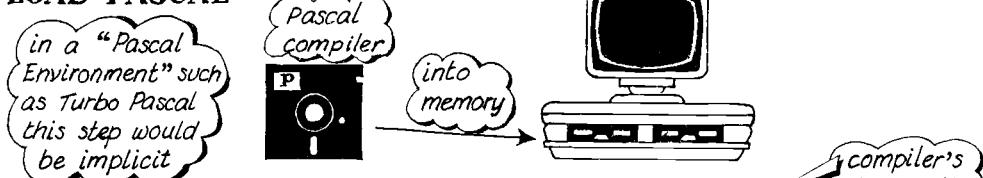


## SAVE MYSOURCE

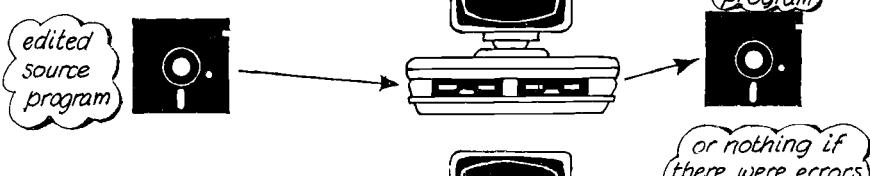


Assume that the program, when run, would expect data from the keyboard. If it expected data from a disk file it would be necessary at this stage to type, edit and save a file of data in the same manner as depicted above for saving the source program.

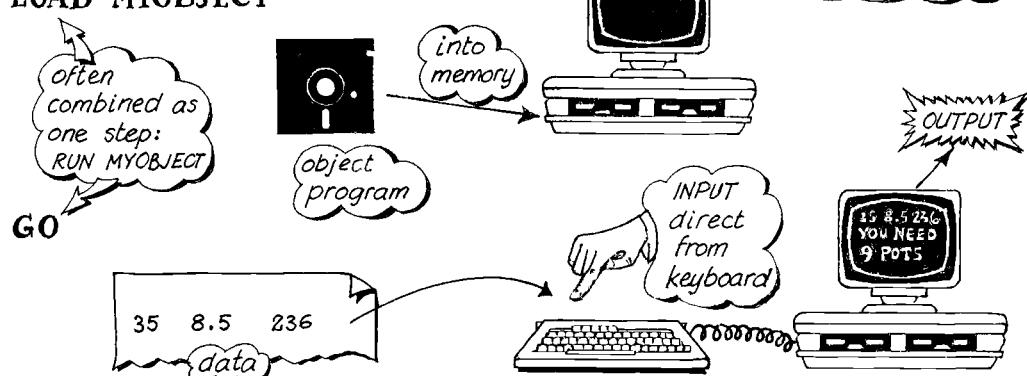
## LOAD PASCAL



## COMPILE MYSOURCE , MYOBJECT



## LOAD MYOBJECT



# EXERCISES

1. Implement the oil-tank program. This exercise demands using the editor and submitting a program for compilation. Getting to grips with a new system is always troublesome; this exercise is probably the most difficult in the whole of this book.

# 2

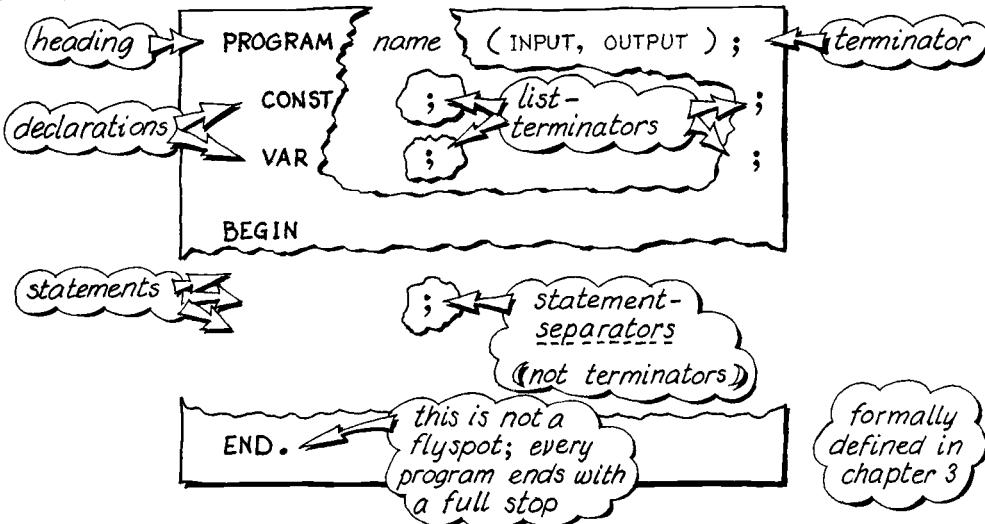
## RUDIMENTS

PUNCTUATION  
VARIABLES  
CONSTANTS  
STANDARD TYPES  
EXPRESSIONS  
LOANS (EXAMPLE)  
DECISIONS  
FIELDS  
SHAPES (EXAMPLE)  
LOOPS  
OLD GLORY (EXAMPLE)  
SINUOUS (EXAMPLE)

# PUNCTUATION

SYNTAX IS DEFINED IN THE NEXT CHAPTER; THE FOLLOWING IS IN GENERAL TERMS

A typical Pascal program has the following skeleton:

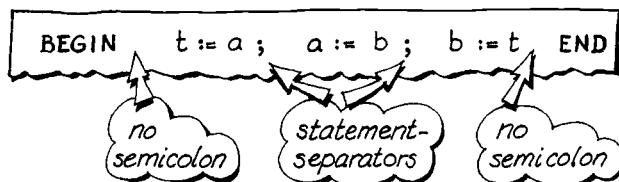


The heading is terminated with a semicolon.

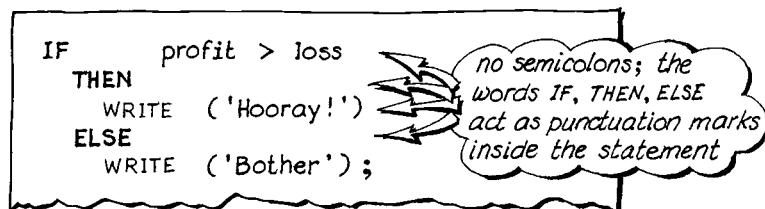
Every list in every declaration is terminated with a semicolon.

Statements are separated from each other by semicolons.

The words BEGIN and END are not statements, they are effectively punctuation marks. BEGIN behaves as a left bracket and END as a right bracket. Because they act as punctuation marks a semicolon after BEGIN or before END would be redundant. BEGIN and END are much used in Pascal programs to make compound statements, where a compound statement (depicted below) is one that may be employed wherever a simple statement would otherwise be allowed. An example is:



Words in other statements act as punctuation marks too. None of these has yet been demonstrated but here is an example:



Because statements are separated by punctuation marks the layout of a program on the page is not important to the compiler. Two rules are enough to satisfy the compiler:

- Don't run words together:

PROGRAM painter( INPUT, OUTPUT )  
CONST pi = 3.14;

- Don't break up a single item with spaces or new lines:

PROGRAM painter ( INPUT, OUT  
PUT); CONST pi = 3.14  
(spaces not marked with bugs are allowable)

Although layout is not important to the compiler it is vital to the programmer's understanding. The introductory example illustrated the use of indentation to clarify the structure of a program. No specific rules for indentation are given in this book; the principles are conveyed by example. But if the examples in this book were to be run on an installation offering automatic indentation the resulting patterns would probably differ from mine. Ideas about the ideal layout differ, but all agree that indentation should make the structure of a program as comprehensible as possible. (Glance forward to page 17 to see a much-indented program.)

The words PROGRAM, CONST, VAR, BEGIN, END (and thirty more, yet to be introduced) are called *reserved words*. Never extend a reserved word:

# CONSTANT VARI



and never try to shorten a reserved word:

PROG. painting( INPUT, OUTPUT);

Use capital letters or lower-case letters or a mixture of both. This book employs a mixture for reasons explained later.

PROGRAM PAINTER(INPUT,OUTPUT); program painter(input,output); Program PAINTER(INPUT,OUTPUT);

But in strings there is a distinction between them:

WRITE( ' YOU NEED', fullpots, ' POTS') → YOU NEED 9 POTS

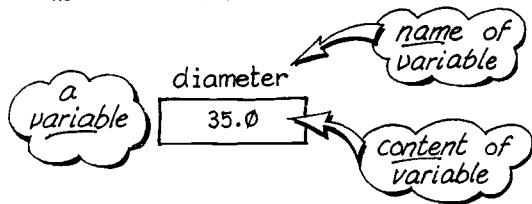
WRITE( 'You need', fullpots, ' Pots') → You need 9 Pots

**M**ake names as long as you like but ensure that every name is unique as far as the first eight characters. Some compilers would treat `NUMBEROFMEN` and `NUMBEROFGWOMEN` as the same name.

# VARIABLES

A SIMPLE VARIABLE TO ILLUSTRATE THE CONCEPT OF VARIABLES GENERALLY

The unlocked little boxes of the introductory example are called **variables**. A simple variable is a conceptual box having a **name** and a **content**.



A variable is created in the computer as a result of declaring it in a VAR statement. The declaration specifies both the name of that variable and the type of its content. Type is further discussed opposite.

```
VAR diameter: REAL;
```

*name* *type*

The symbol compounded of a colon and equals sign  $\coloneqq$  pronounced "becomes"  $\coloneqq$  signifies that a value (typically the result of evaluating an expression) is to be assigned to the box.

```
wall := pi * diameter * height;
```

*"becomes"* *assign*  
*value to variable*

In the introductory example the contents of variables do not change; each has a number assigned to it and there the number stays. But the program could be modified to use fewer variables. In the following version there are several assignments to variable x:

```
PROGRAM painting( INPUT, OUTPUT );
  CONST pi = 3.14;
  VAR diameter, height, coverage, x: REAL;
  fullpots: INTEGER;
  BEGIN
    READ( diameter, height, coverage );
    x := pi*SQR(diameter)/4.0;
    x := x + pi*diameter*height;
    x := x / coverage;
    fullpots := TRUNC(x) + 1;
    WRITE('You need', fullpots, ' pots')
  END.
```

~~x 961.63  
1895.78  
8.03~~

*each new assignment  
obliterates  
what was  
there  
before*

# CONSTANTS

A SIMPLE NAMED CONSTANT TO ILLUSTRATE THE CONCEPT

The locked little box of the introductory example is called a **constant**. Such constants are created as a result of declaring them in a CONST declaration. The type of constant is declared intrinsically from the form of the value put into the box. The decimal point in 3.14, for example, shows that pi names a REAL constant.



```
CONST pi = 3.14;
```

*notice the equals sign; not :=*

# STANDARD TYPES

INTEGER, REAL, CHAR, BOOLEAN

Integers are whole numbers  $\Leftarrow$  negative, zero or positive:

- constants of type INTEGER must all be declared as here  $\Rightarrow$
- variables of type INTEGER must all be declared as here  $\Rightarrow$
- an expression assigned to an integer variable must reduce to an integral value; this precludes divisions of the form  $i/j$  as explained later

CONST dozen = 12, decr = -1;

VAR i, j, k: INTEGER;

i := dozen \* decr + 6  
j := TRUNC (3.14) + 7  
k := i/j  $\approx$  REAL result

no decimal point

no decimal point

Reals are numbers with a fractional part. A real may be negative, zero or positive:

- constants of type REAL must all be declared as here  $\Rightarrow$
- variables of type REAL must all be declared as here  $\Rightarrow$
- an expression assigned to a real variable may reduce to a real or integer value; Integer values are automatically converted to reals before assignment. (Mixtures of real & integer terms in an expression are allowed: implications described overleaf.)

CONST pi=3.1415926, couple=2.0;

VAR x, y, z: REAL;

x := pi / 180.0;  $\Rightarrow$  REAL result  
y := i/j;  $\Rightarrow$  auto. conversion  
z := i + 2  $\Rightarrow$  from int. to real

decimal points essential

or 180

Characters are letters, digits and symbols; type CHAR means single characters:

- constants of type CHAR must all be declared between apostrophes  $\Rightarrow$
- variables of type CHAR must all be declared as here  $\Rightarrow$
- characters may be compared, the result being Boolean, the basis of comparison being ordinal value: 'A' < 'B', 'B' < 'C' etc. and '0' < '1', '1' < '2' etc.

CONST p='A', q='\*', r='6';

VAR a, b, c: CHAR;

IF (p>a) AND (c='X') THEN

FALSE  TRUE

Boolean values are false or true. (In Pascal, false is "less than" true.)

- Boolean constants are supplied, needing no declaration by programmer
- Boolean variables must all be declared as here  $\Rightarrow$
- a Boolean expression must reduce to the value true or false

VAR ok, alive: BOOLEAN;

IF a=b THEN ok := TRUE;  
IF alive AND ok THEN WRITE('Great!')

# EXPRESSIONS

PRECEDENCE  $\approx$  BRACKETS MAY OVERRIDE.  
TYPES: INTEGER, REAL, BOOLEAN

The introductory example illustrates numerical expressions in assignment statements. Here are two of them:

```
pots := ( top + wall ) / coverage;           ← real assignment  
fullpots := TRUNC( pots ) + 1;               ← integer assignment
```

Brackets ensure the desired order of evaluation. If brackets were omitted from the first of the examples above:

```
pots := top + wall / coverage;
```

the division would be done first. Division has higher precedence than addition. In numerical expressions the precedence is:

higher	*	/	* and / have equal precedence
lower	+	-	+ and - have equal precedence

The second of the assignments above illustrates an assignment to an integer variable. The function TRUNC( ) delivers an integer result, the 1 is written without a decimal point, so the two terms sum to an integer value. In general, when all terms have integer values the expression itself reduces to an integer value.

There is an important exception to the rule stated above. A division (using the slash) always delivers a real result:

```
6.5 / 2 → 3.25 ( real )  
6 / 2 → 3.0 ( real: N.B. )
```

Integer division  $\approx$  quotient and remainder  $\approx$  may be achieved using the operators DIV and MOD as explained later.

An expression may comprise a mixture of integer and real terms. The presence of one real term, or of one slash, is enough to make the resulting value real. TRUNC( ) or ROUND( ) may be used to convert a real term to an integer term.

The function SQR( ) raises the value in brackets to the power 2, but there is no operator (such as  $\uparrow$  in BASIC) for raising to any power. This is done by taking logarithms as shown opposite. Non-mathematicians should take it on trust that  $A \uparrow x$  in BASIC may be expressed as EXP(LN(A) \* x) in Pascal.

It may seem strange to some, but  $>$  and  $\leq$  etc. may be used as operators too.  $1 > 2$  has the value false and  $1 + 2 = 3$  true. Expressions which contain such operators reduce to Boolean values and are called Boolean expressions or conditions. Boolean expressions may contain the logical operators NOT, AND, OR, and also terms of type CHAR:

```
ok := ( 1 = 2 ) OR ( ch >= 'A' );  
IF ok THEN
```

# LOANS

AN EXAMPLE TO ILLUSTRATE NUMERICAL EXPRESSIONS,  
RAISING TO A POWER, WRITING A REAL RESULT

The monthly repayment,  $m$ , on a mortgage loan of  $s$  pounds over  $n$  years at  $p$  percent compound interest is given by  $\Rightarrow$

$$m = \frac{sr(1+r)^n}{12((1+r)^n - 1)}$$

where  $r = p \div 100$

Here is a program to work out  $m$ , given values for  $s$ ,  $p$  and  $n$ .

keyboard screen

```

PROGRAM loans( INPUT, OUTPUT );
  VAR
    m, s, p, n, r, a : REAL;
  BEGIN
    READ( s, p, n );
    r := p / 100;
    a := EXP( LN(1+r) * n );
    m := (s * r * a) / (12 * (a - 1));
    m := TRUNC( 100 * m + 0.5 ) / 100;
    WRITELN; WRITELN;
    WRITE( 'Borrowed £', s:4:2 );
    WRITE( ' at', p:5:2, '%' );
    WRITE( ' over', n:5:2, ' years' );
    WRITELN;
    WRITE( 'Monthly repayment is £', m:5:2 );
    WRITELN;
    WRITE( 'Total interest comes to £', m * n * 12 - s:5:2 );
    WRITELN
  END.

```

s [ ] sum borrowed  
 p [ ] percent interest  
 n [ ] years to repay  
 r [ ]  $p \div 100$   
 a [ ]  $(1+r)^n$   
 m [ ] repayment  
 $a = (1+r)^n$   
 by taking logs  
 round to nearest penny  
 each WRITELN starts a new Line  
 :5:2 means a field of 5 with 2 places of decimals  
 1.63  
 1 2 3 4 5

The screen, at the end of a run, should look like this:

99.99 14.5 10

Borrowed £99.99 at 14.5% over 10 years  
 Monthly repayment is £1.63  
 Total interest is £95.61

input

output

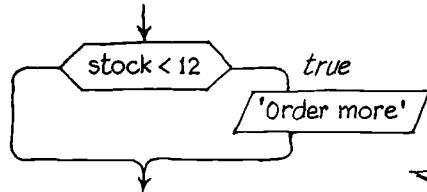
If your version of Pascal permits interactive working, insert a WRITE statement before READ so as to make the screen prompt for the data needed.

The above program does nothing to check data. If the user of the program entered a wrongly-formed number ( perhaps letter 0 in place of digit 0 ) the program would fail. Most programs in this book are equally lax in this respect. The reason for the laxity is that checking data thoroughly would make the programs too long for their purpose  $\Rightarrow$  which is to illustrate succinctly various other aspects of programming. It is left as an exercise to make these programs friendly and "robust".

# DECISIONS

DIFFERENT COURSES OF ACTION ACCORDING TO THE RESULT OF A BOOLEAN EXPRESSION

A program may be made to do different things according to outcome. Here is a trivial example ➡



IF stock < 12 THEN WRITELN ('Order more');

The stock < 12 is a Boolean expression; its value is either true or false. If the value of stock < 12 reduces to false then the WRITELN statement is not obeyed; control would simply pass to the next statement.

In general the IF statement permits any number of statements to be obeyed according to whether the value of a Boolean expression proves to be true or false. ➡

The conditions illustrated here are no more than a comparison of two terms. Conditions may be more complicated, involving the logical operators AND, OR, NOT. For example

(initial) >= 'E') AND (initial) < 'L')

where 'initial' is a variable of type CHAR and holds the initial letter of a surname. A result of true would mean that the surname belonged in the E to K telephone directory.

READ (key);  
IF key = 'y'  
THEN  
BEGIN

these statements obeyed if the response is **Y** RETURN

END  
ELSE  
BEGIN

these statements obeyed if some other response than **Y** RETURN

END;

these statements obeyed subsequently whatever the response was

keen := (x = y) OR (z >= 3);

IF NOT keen THEN

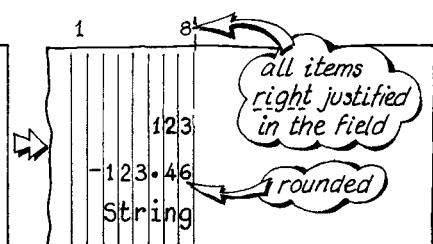
The value of a Boolean expression may be assigned to a Boolean variable and subsequently tested.

# FIELDS

SPECIFY THE FIELDS IN WHICH NUMBERS & STRINGS ARE TO BE PRINTED ➡ ALSO NUMBER OF DECIMAL PLACES

Field width and number of decimal places may be specified after a colon as shown below:

i := 123; r := 123.456;  
WRITELN (i : 8); *field width*  
WRITELN (-r : 8 : 2); *number of places*  
WRITELN ('String': 8) *(for reals only)*

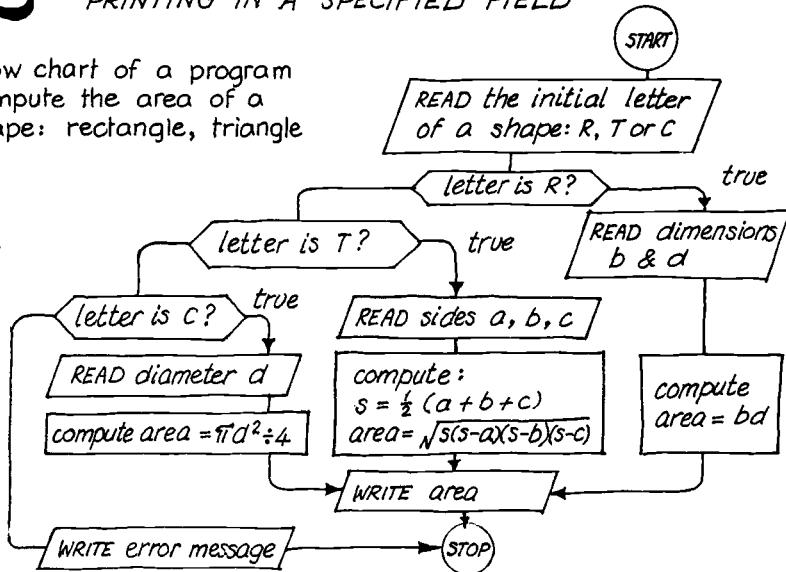
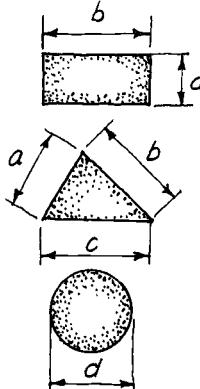


You can plot curves by making field-width an expression as demonstrated later.

# SHAPES

AN EXAMPLE TO ILLUSTRATE DECISIONS AND PRINTING IN A SPECIFIED FIELD

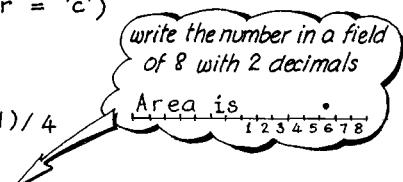
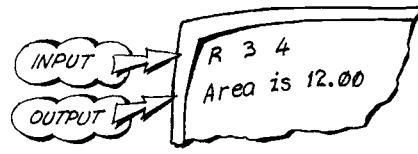
Here is the flow chart of a program designed to compute the area of a geometrical shape: rectangle, triangle or circle.



Here is a program to reflect the flowchart:

```

PROGRAM shapes( INPUT, OUTPUT );
  CONST
    pi = 3.1415926;
  VAR
    letter : CHAR;    s, area, a, b, c, d: REAL; ok: BOOLEAN;
  BEGIN
    ok := TRUE;
    READ( letter );
    IF (letter = 'R') OR (letter = 'r')
    THEN
      BEGIN
        READ( b, d );
        area := b * d
      END
    ELSE IF (letter = 'T') OR (letter = 't')
    THEN
      BEGIN
        READ( a, b, c );
        s := 0.5 * (a + b + c);
        area := SQRT(s*(s-a)*(s-b)*(s-c))
      END
    ELSE IF (letter = 'C') OR (letter = 'c')
    THEN
      BEGIN
        READ( d );
        area := pi * SQR(d)/4
      END
    ELSE ok := FALSE;
    IF ok THEN WRITE('Area is ', area:8:2) ELSE WRITE('Must be R or T or C')
  END.
  
```



# LOOPS

INTRODUCING A CONCEPT WHICH IS FUNDAMENTAL TO PROGRAMMING IN ANY LANGUAGE

A program may be made to go back and obey a sequence of instructions several times over:

```
PROGRAM xmas ( OUTPUT );
  VAR humbug: INTEGER;
  BEGIN
    FOR humbug := 1 TO 3 DO
      WRITELN ('We wish you a merry Christmas');
      WRITELN ('And a happy new year');
    END.
```

this WRITELN  
obeyed once, after  
loop is finished

this statement obeyed  
when humbug contains  
1, when humbug  
contains 2, and when  
humbug contains 3

More usefully:

```
PROGRAM tables ( INPUT, OUTPUT );
  VAR valu, product, multiplier: INTEGER;
  BEGIN
    READ (valu);
    FOR multiplier := 1 TO 10 DO
      BEGIN
        product := multiplier * valu;
        WRITELN (multiplier:2, '*', valu:2, '=', product:4);
      END
    END.
```

Note:  
WRITELN ('something')  
is equivalent to  
WRITE ('something');  
WRITELN

BEGIN and END are  
"brackets" enclosing  
the compound statement  
which follows DO

If the outcome of the above trivial programs is not immediately obvious they should be tried out before reading on. Looping is fundamental to programming.

The FOR loop is called "deterministic" because the number of times round is determined before looping starts. Not so the REPEAT loop. The following fragment could be substituted between the outer BEGIN and END. above:

```
READ (valu);
multiplier := 1;
REPEAT
  product := multiplier * valu;
  WRITELN (multiplier:2, '*', valu:2, '=', product:4);
  multiplier := multiplier + 1
UNTIL multiplier > 10
```

more appropriate  
applications of  
the REPEAT loop  
given later

The FOR loop and REPEAT loop are executed at least once (unless something goes so wrong that they are not executed at all). But there is also a loop for which the test for execution is made at the start, the loop being skipped over if the test fails:

```
READ (valu);
multiplier := 1;
WHILE multiplier <= 10 DO
  BEGIN
    product := multiplier * valu;
    WRITELN (multiplier:2, '*', valu:2, '=', product:4);
    multiplier := multiplier + 1
  END
```

skip over when  
multiplier > 10

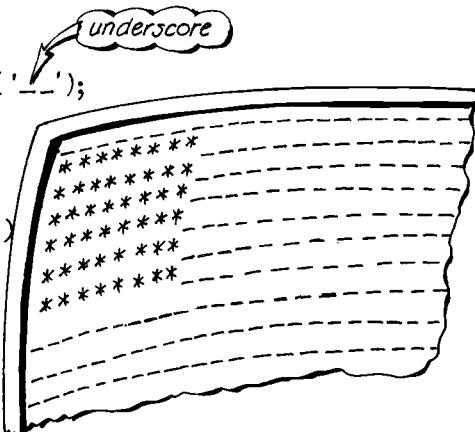
more appropriate  
applications of  
the WHILE loop  
given later

# OLD GLORY

A PROGRAM TO ILLUSTRATE LOOPS BY FLYING THE STARS AND STRIPES (circa 1912)

In 1912 "Old Glory", the American flag, had 48 stars (one per state of the Union) and 13 stripes (one per original Colony). The program below displays a rough approximation to Old Glory c. 1912. Nowadays there are more states, hence more stars.

```
PROGRAM glory(OUTPUT);
  VAR row, col: INTEGER;
  BEGIN
    FOR col := 1 TO 19 DO WRITE('--');
    WRITELN;
    FOR row := 1 TO 13 DO
      BEGIN
        FOR col := 1 TO 19 DO
          IF (col < 9) AND (row < 7)
          THEN
            WRITE('*')
          ELSE
            WRITE('--');
        WRITELN
      END
    END.
  
```



# SINUOUS

A PROGRAM TO PLOT A SINUOUS CURVE USING A LOOP AND A VARIABLE FIELD WIDTH

The following program plots the graph of  $\sin(x)$  scaled and offset from the left margin so that the curve oscillates about the middle of the screen. The trick of this kind of plot is to use an expression for field width. The field width varies from line to line; the asterisk is right-justified in each field.

```
PROGRAM sinuous(OUTPUT);
  CONST
    offset = 20; scale = 18; degreestep = 8;
  VAR
    i: INTEGER; k: REAL;
  BEGIN
    k := degreestep * 3.1415926 / 180;
    FOR i := 0 TO MAXINT DO
      WRITELN ('*': ROUND(offset + scale * SIN(k * i)))
    END.
  
```

three values suitable for a T.V. monitor; adjust to suit your equipment

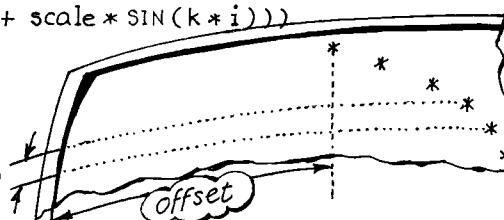
radians from degrees

0, 1, 2, ... degrees

field width as an expression

degreestep

offset



# EXERCISES

1. Implement the *loans* program and experiment with different sets of data. If you enter zero for the percentage rate of interest the program fails. Include a test in the program for this eventuality and make the program print the results for it. If your Pascal permits interactive input make the program prompt its user for the three items of data required.
2. Implement the *shapes* program. Improve the program by making it return for a new problem having displayed a result. Let the program treat the letter Z as a stopping code (i.e. it should recognize R, T, C and Z).
3. Implement the *sinuous* program. Dampen the wave it produces by plotting  $y = \sin x / \exp x$  instead of  $y = \sin x$ .

3

# SYNTAX

TYPESTYLES  
NOTATION  
ELEMENTS  
COMPOUNDS  
SYNTAX OF AN EXPRESSION  
SYNTAX OF A STATEMENT  
SYNTAX OF A PROGRAM  
SYNTAX OF TYPE

# TYPESTYLES

RESERVED WORDS, PREDEFINED NAMES &  
names invented by the programmer

Notice the different styles of writing in the introductory program; here it is again:

```
PROGRAM painting( INPUT, OUTPUT);
CONST pi = 3.14;
VAR diameter, height, coverage, top,
    wall, pots: REAL;
BEGIN
  READ ( diameter, height, coverage );
  top := pi * SQR ( diameter ) / 4.0;
  wall := pi * diameter * height;
  pots := ( top + wall ) / coverage;
  fullpots := TRUNC ( pots ) + 1;
  WRITE ('You need', fullpots, ' pots')
END .
```

When dealing with Pascal programs the computer makes no distinction between capital letters and corresponding lower-case letters except for those between apostrophes. So the program could be typed all in capitals:

```
PROGRAM PAINTING( INPUT, OUTPUT);
CONST PI = 3.14;
```

or all in lower-case letters:

```
var diameter, height, coverage, top,
    wall, pots: real;
```

or in a mixture of capitals and lower-case letters:

```
FullPots := TRUNC ( Pots ) + 1;
```

Only between one apostrophe and the next is case significant:

Write ('You need', FullPots, ' pots')



But in the introductory example and throughout the rest of this book three styles of writing are employed so as to emphasize the three kinds of word in Pascal:

- PROGRAM, CONST, VAR, BEGIN, ... are *reserved words* which behave like punctuation marks, each having a unique meaning in Pascal
- INPUT, REAL, READ, TRUNC, ... are *predefined names*; they nominate facilities offered by Pascal for declaring files (INPUT), types (REAL) or invoking useful functions (WRITE( ), TRUNC( )) but the programmer is free to ignore such facilities and use their names for other purposes
- painting, pi, diameter, height, ... are names composed by the programmer to identify variables, constants, procedures and other things yet to be introduced.

It makes a program easier to understand when the kind of name or word is at once evident from the way it is written.

# NOTATION

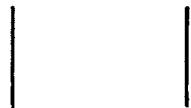
TO DESCRIBE THE WRITTEN FORM OF  
PASCAL'S DECLARATIONS AND STATEMENTS

To define the written form and punctuation of Pascal programs it helps to use a concise notation. The notation described below is a blend of two notations in common use for defining the syntax of Pascal: railway-track diagrams, as used in several books on Pascal, and Backus-Naur Form (BNF) as used in the ISO definition of Pascal. Railway-track diagrams are visually confusing when following all but the simplest layouts; BNF is good for formal definitions but not so good for quick reference or general appraisal of a syntactical structure. The notation described below is intended for quick reference and general appraisal with little (if any) loss of rigour.

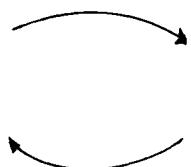
*italics* Italic letters are used to name the entities being defined: *digit*, *operator*, *expression* and so on

**:=** says "is defined to be ..." as in BNF

**ROMANS, & + ( \* / ^ 0!2 etc.** These stand for themselves; copy them from the definitions just as they are. Substitute lowercase letters if preferred: a for A, b for B, c for C etc.



Vertical bars enclosing several rows offer a choice of precisely one row



This arrow says the item(s) over which it is drawn are optional (may be skipped over)



This arrow permits return  $\Rightarrow$  hence offers the choice of another item from vertical bars or the same item as before



A circle (or sausage shape) contains the separator to use when returning for another item. No circle means no separator.

**name**  
**var**  
**const**  
**file**  
**type**  
**fn**  
**proc**

A subscript to *name* tells what that name is naming; whether a *variable*, a *constant*, a *file*, a *type*, a *function*, a *procedure*. (This device goes beyond syntax into the domain of semantics.)



This symbol is put in front of illustrations in place of the words "for example"

Several words used in the definitions below are different from those in standard works on Pascal. In particular, I use *name* in place of *identifier*, *term* in place of *factor*, and have no need of a *word* in place of *term*. I use *comparator* in place of *relational operator*.

# ELEMENTS

OF PASCAL SYNTAX: letter, digit, symbol, space, operator, comparator

letter ::=	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z	digit ::=	0 1 2 3 4 5 6 7 8 9	symbol ::=	+
					-
					*
					/
					=
					<
					>
					[
					.
					,
					:
					;
					↑
					(
					)

except in  
a string  
a lower-case  
letter is  
equivalent  
to the  
corresponding  
upper-case  
letter, e.g.  
 $DIV \equiv div$

Also the lower-case letters if available.

operator ::=	*	high precedence operators
	/	
	DIV	
	MOD	
	AND	
	+	low precedence operators
	-	
	OR	

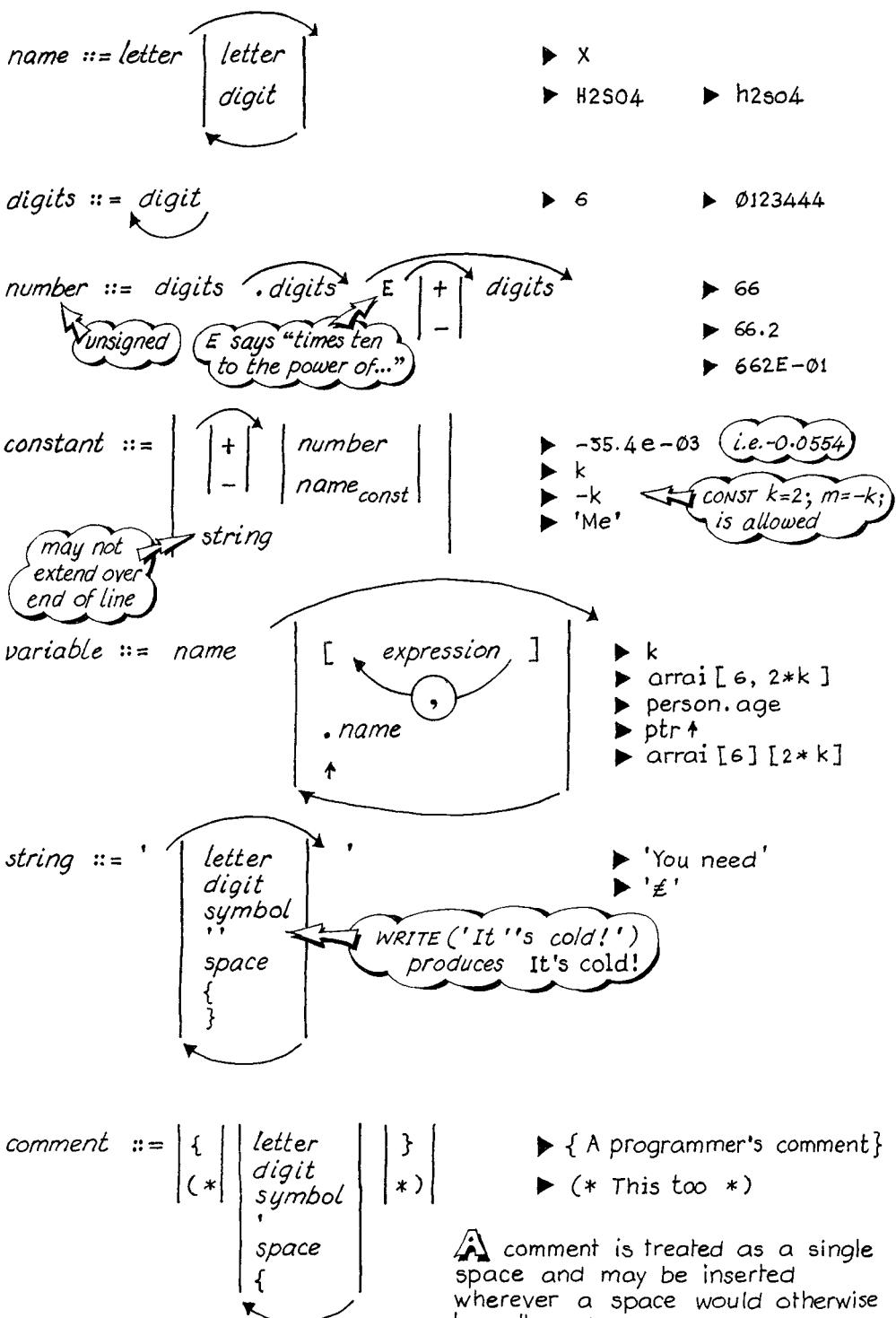
In the expression  $3+4*5$  the  $*$  is applied before  $+$  because it is of higher precedence. Use brackets to override: e.g.  $(3+4)*5$

comparator ::=	<
	$\leq$
	=
	>
	$\geq$
	$\neq$
	IN

The expression  $5-3=2$  is true because it is treated as  $(5-3)=2$ , not as  $5-(3=2)$ . In other words the comparator has lower precedence.

# COMPOUNDS

OF PASCAL SYNTAX: name, digits, number, constant, variable, string, comment

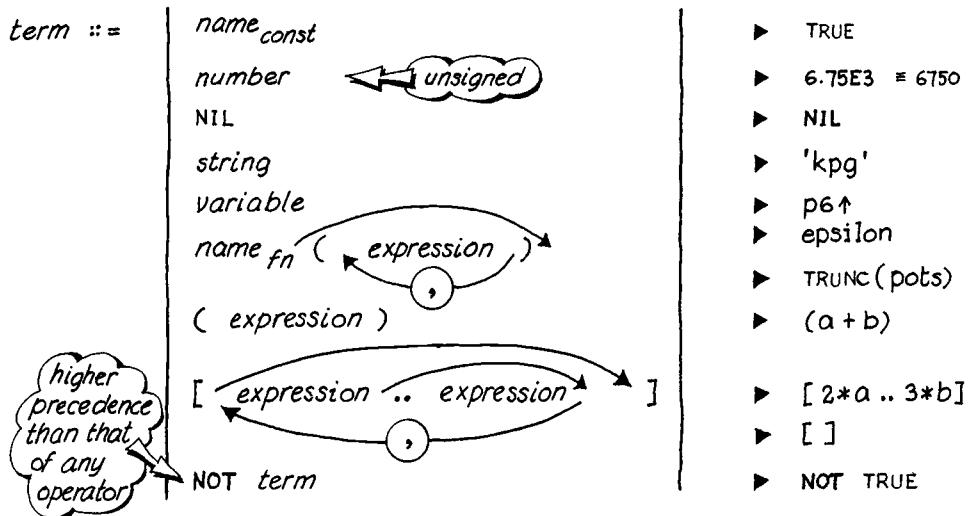


# SYNTAX OF EXPRESSION & BOOLEAN EXPRESSION, ALSO CALLED A CONDITION

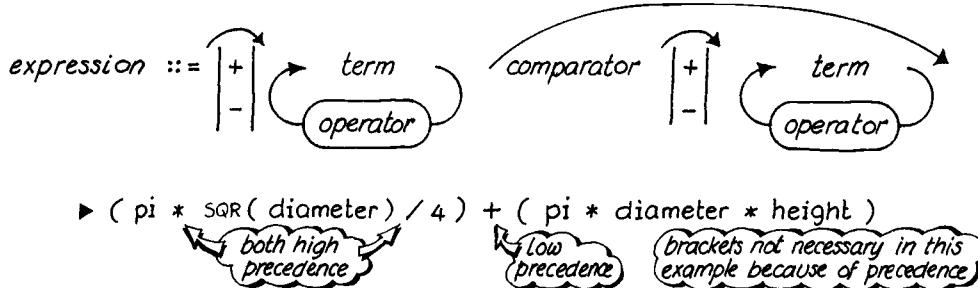
The "elements" and "compounds" of Pascal's syntax may now be combined in the definition of an expression. The introductory example shows several expressions of which the following two are typical:

( top + wall ) / coverage ; pi \* SQR(diameter) / 4.0 ;

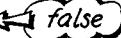
An expression comprises one or more terms. The terms are bound together with brackets and operators. A term may be the name of a variable (e.g. top) or a reference to a function (e.g. TRUNC(pots)) or one of several other forms defined below.



Having defined term, here is the definition of expression which is a collection of terms bound together with operators and comparators :



An expression involving one or more comparators, or a single Boolean term, is called a Boolean expression or condition.

►  $-3 > 1$  

► TRUE 

An exceptional form of expression is allowed in WRITE and WRITELN statements :

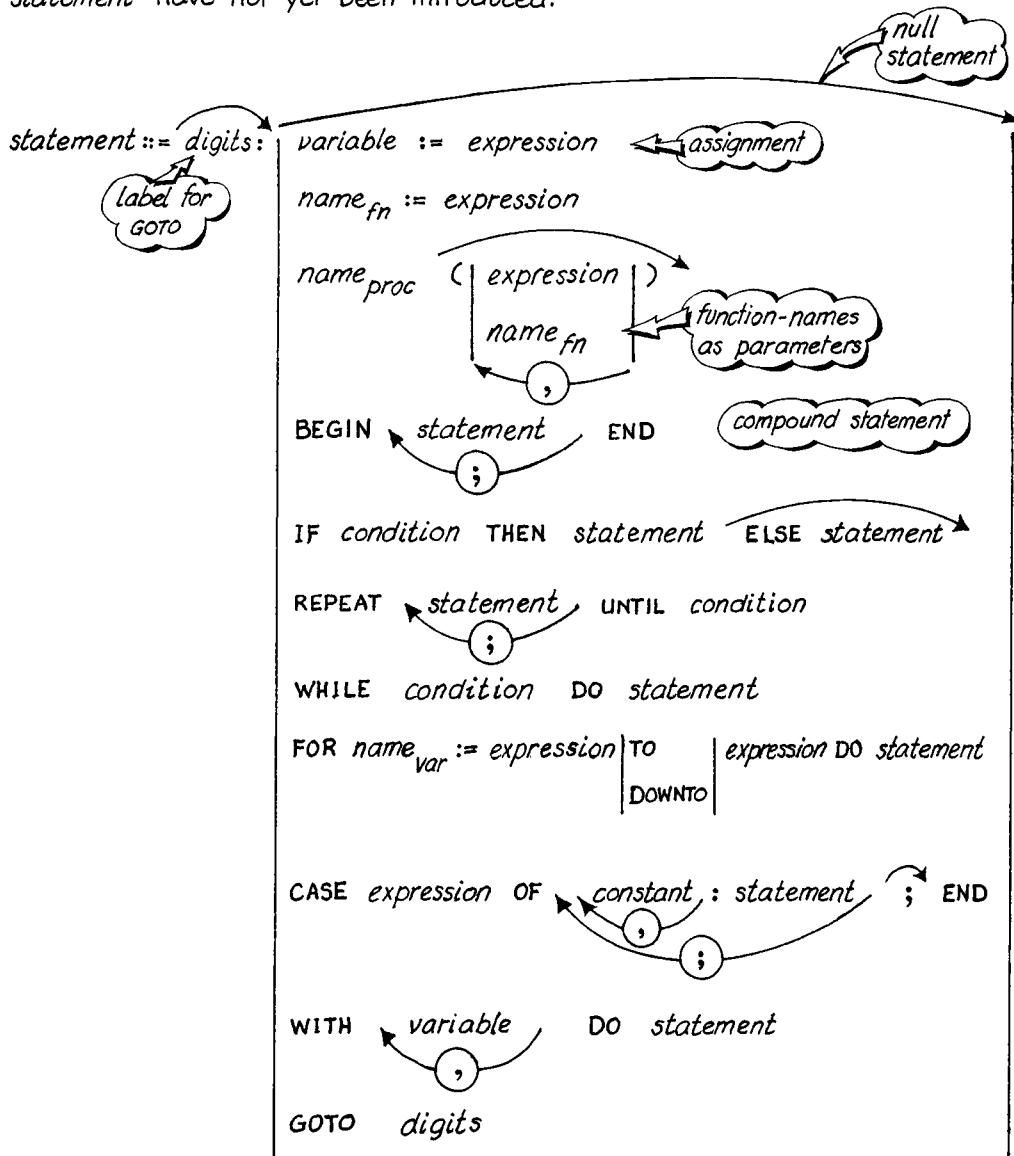
exceptional ::= expression : expression : expression

► WRITE ( x : 8 : 2 )   ► WRITELN ('\*' : ROUND(offset + scale \* SIN(k\*i)))

# SYNTAX OF A STATEMENT

SOME FORMS HAVE NOT  
YET BEEN INTRODUCED

The definition of statement is set out below. Several of these forms of statement have not yet been introduced.



- 100 : area := pi \* SQR( diameter ) / 4 *assignment statement* *labelled*
- BEGIN temp := a; a := b; b := temp END *compound statement*
- IF a > b THEN BEGIN temp := a; a := b; b := temp END *IF statement*
- BEGIN ; t := a; ; a := b; b := t; , END

# SYNTAX OF A PROGRAM

SKIP THIS DOUBLE PAGE ON FIRST READING

Here is a "top-down" definition of program :

program ::= PROGRAM name(  $name_{file}$  ); block . 

Where:

block ::= LABEL  $digits$  ; {continued on next line}

CONST  $name = constant$  ; {continued}

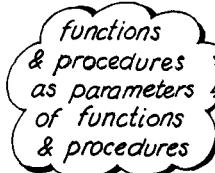
TYPE  $name = type$  ; {continued}

VAR  $name : type$  ; {continued}

FUNCTION name parameters :  $name_{type}$  |  
PROCEDURE name parameters ; block ;  
{continued}

BEGIN statement END

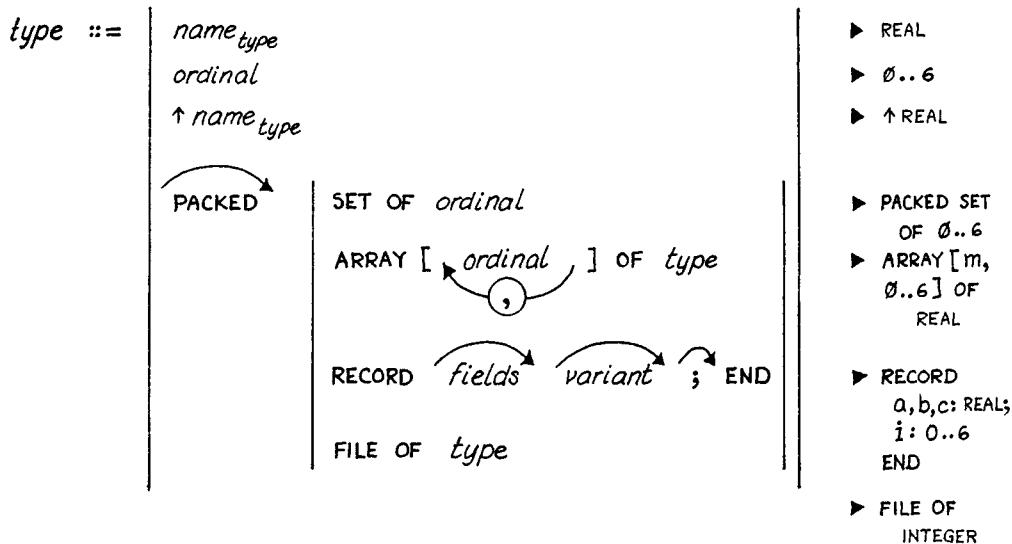
Where:

parameters ::= (  VAR  $name : name_{type}$  ,  
FUNCTION name parameters :  $name_{type}$  |  
PROCEDURE name parameters ; )

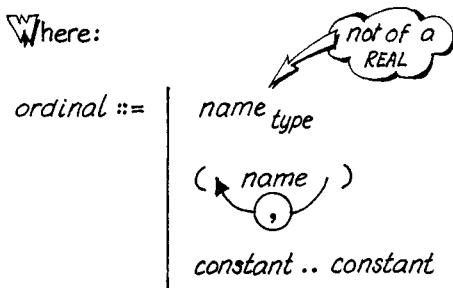
# SYNTAX OF TYPE

TO COMPLETE THE TOP-DOWN DEFINITION OF PROGRAM

Here is a top-down definition of type:



Where:

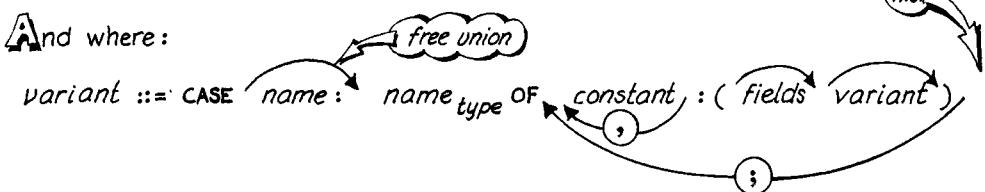


- INTEGER
- ( I, thou, thee, we, you, they )
- $0..6$  ► 'A'..'Z' ► I..we

And where:



And where:



That completes the definition of the syntax of ISO Pascal.



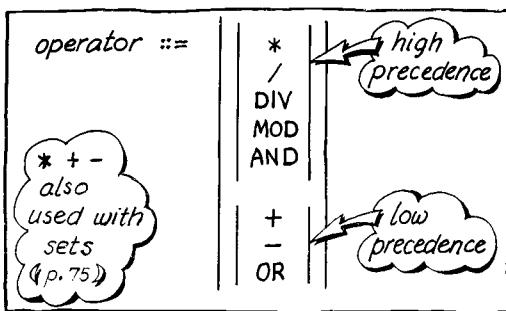
# 4

## ARITHMETIC

OPERATORS  
SIZE AND PRECISION  
COMPARATORS  
ARITHMETICAL FUNCTIONS  
TRIGONOMETRICAL FUNCTIONS  
TRANSFER FUNCTIONS  
BOOLEAN FUNCTIONS  
ORDINAL FUNCTIONS

# OPERATORS

\* / DIV MOD AND  
+ - OR



The syntax of operator is defined again here for convenience.

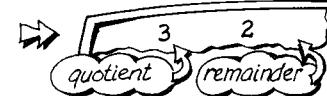
The use of these operators is explained on this double page. The syntax of expression on page 26 should be consulted if the use of brackets in these examples is not immediately clear.

In the absence of brackets an expression is evaluated from left to right, applying high precedence operators before low precedence operators. Brackets may be included to enforce any desired order of evaluation. For example  $a * b / c$  and  $(a * b) / c$  would be evaluated in the same way but  $a * (b / c)$  would enforce a change in the order of operations.

The operators DIV and MOD are for integer division; they yield an integer quotient and remainder respectively:

WRITELN ( 17 DIV 5, 17 MOD 5 )

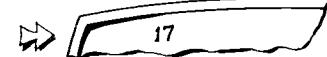
MOD is short for "modulo"



For positive values of i and j the following relationship holds:

$$(i \text{ DIV } j) * j + (i \text{ MOD } j) = i$$

WRITELN ( ( 17 DIV 5 ) \* 5 + ( 17 MOD 5 ) )



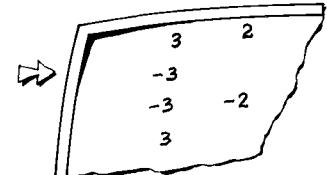
But complications arise with non-positive values. The second operand of MOD is not allowed to be negative:

WRITELN ( 17 MOD -5 )



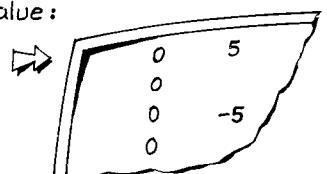
Permissible arrangements are permuted below:

WRITELN ( 17 DIV 5, 17 MOD 5 );  
WRITELN ( 17 DIV (-5) );  
WRITELN ( -17 DIV 5, -17 MOD 5 );  
WRITELN ( -17 DIV (-5) )



and when the first operand is smaller in absolute value:

WRITELN ( 5 DIV 17, 5 MOD 17 );  
WRITELN ( 5 DIV (-17) );  
WRITELN ( -5 DIV 17, -5 MOD 17 );  
WRITELN ( -5 DIV (-17) )



An error is reported if a divisor is zero, or either operand not an integer:

WRITELN ( 17 DIV 0 );  
WRITELN ( 17.0 MOD 5 )



The operators + and - may be used as "monadic" operators (in other words as signs) in front of integer or real expressions:

```
WRITELN ( -2, +2 * 3 );
WRITELN ( -2.0: 4: 1 )
```

The operators \* and + and - produce an integer result when both operands represent integers:

```
WRITELN ( 2*3, 2+3, 2-3 )
```

but produce a real result if either or both operands represent a real:

```
WRITELN ( 2.0*3: 4: 1 );
WRITELN ( 2 + 3.0: 4: 1 )
```

The operator / produces a real result even when both operands represent integers:

```
WRITELN ( 6/2 :4 :1 );
WRITELN ( 6.0/2 :4 :1 )
```

The divisor is not allowed to represent zero:

```
WRITELN ( 6/0 :4 :1 )
```

The operators AND and OR between Boolean operands produce a Boolean result. Errors are reported if the operands are not Boolean:

```
WRITELN ( 1 OR 2 );
WRITELN ( 'A' AND 'B' )
```

only comparators may be used with type CHAR  
e.g. 'A' < 'B'

The following truth tables define the Boolean results obtained when applying AND and OR operators to Boolean operands:

AND		SECOND OPERAND	
		true	false
FIRST OPERAND	true	✓	X
	false	X	X

OR		SECOND OPERAND	
		true	false
FIRST OPERAND	true	✓	✓
	false	✓	X

Here are some examples of Boolean expressions. Notice how the WRITELN statement produces Boolean results as words. Whether these words emerge in capitals or lower-case letters depends on the installation:

```
WRITELN ( TRUE AND TRUE, TRUE AND FALSE );
WRITELN ( FALSE AND TRUE, FALSE AND FALSE );
WRITELN ( TRUE OR TRUE, TRUE OR FALSE );
WRITELN ( FALSE OR TRUE, FALSE OR FALSE );
WRITELN ( (((I=2)OR(I+2=3))OR (I>2)) AND (2+3=5) )
```

# SIZE AND PRECISION

OF INTEGERS & REALS

An integer may be positive or zero or negative. A copy of the biggest allowable integer that can be handled or stored is held as a constant named MAXINT:



The value 32767 is usual for installations in which integers are stored as 16-bit words. A value of 2147483647 is usual where 32-bit words are employed.

If the program tries to evaluate an integer expression for which an intermediate result grows bigger than MAXINT an error message is evoked. It may be possible to avoid this by adding brackets to an expression; for instance changing  $i * j \text{ DIV } k$  to  $i * (j \text{ DIV } k)$ .

Although the allowable range of integer is  $-\text{MAXINT}$  to  $+\text{MAXINT}$  you may discover that a value of  $-(\text{MAXINT} + 1)$  causes no error. This is because a commonly used range of integers stored in  $n$ -bit words runs from  $-2^{n-1}$  to  $(2^{n-1} - 1)$  (asymmetrical about zero).

A real number may be negative, zero or positive. Its maximum absolute value is  $10^{38}$ ; a typical precision is 6 to 7 significant decimal digits. On such an installation the biggest positive or negative number would be about:

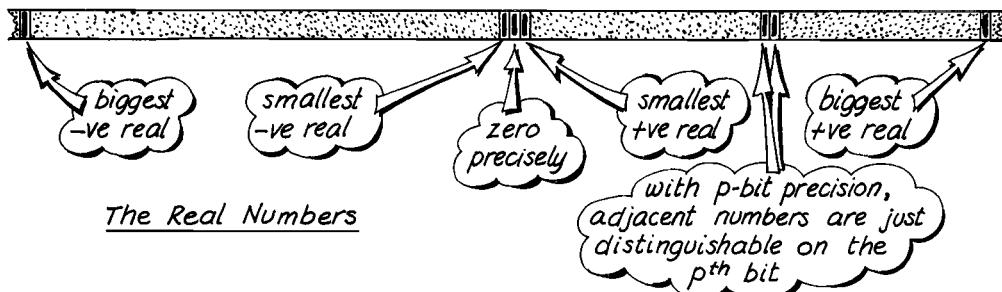
$\pm 100,000,000,000,000,000,000,000,000,000,000,000$

The smallest positive or negative number would be about:

$\pm 0.000,000,000,000,000,000,000,000,000,000,01$

The number 1,000,000 would be just distinguishable (with the above precision) from 1,000,001 but not from 1,000,000.1.

Numbers are stored as binary digits (bits) rather than decimal digits, hence the unavoidable vagueness of the above two paragraphs. The range of real numbers is depicted below:



# COMPARATORS

(OFFICIALLY "RELATIONAL OPERATORS")  
BOOLEAN RESULT FROM COMPATIBLE OPERANDS

comparator ::=	$<$ $\leq$ $=$ $>$ $\geq$ $\neq$ $\text{IN}$

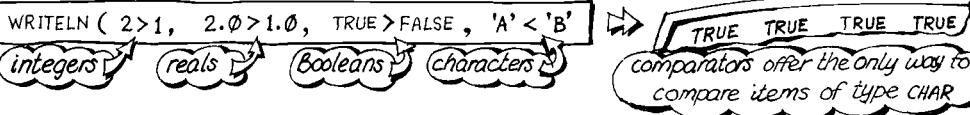
The syntax of comparator is reproduced here for convenience. The symbols have the conventional significance;  $\geq$  for example says "Greater than or equal to".

The precedence of any comparator is lower than that of any operator.

The syntax of expression is also reproduced so as to emphasize the difference in usage between operator and comparator:



Terms of like type may be compared, the result being a Boolean value:



Real and integer terms of like value are interchangeable:



The syntax diagram for expression allows only one comparator. But expression in brackets is a form of term, so a further comparator may then be included to make a more complicated expression thus:



Sets are explained in chapter 7, but the following operations on sets are reproduced below for completeness. The names "friends" and "acquaintances" are names of sets; "ffoulkes" is the name of a single member of a set.

- $\subseteq$  friends = acquaintances  $\Rightarrow$  true if all friends are acquaintances and all acquaintances friends (identical sets)
- $\not\subseteq$  friends  $\neq$  acquaintances  $\Rightarrow$  true if no friend is an acquaintance and no acquaintance is a friend (distinct sets)
- $\subseteq$  friends  $\leq$  acquaintances  $\Rightarrow$  true if all friends are acquaintances
- $\supseteq$  friends  $\geq$  acquaintances  $\Rightarrow$  true if all acquaintances are friends
- $\text{IN}$  ffoulkes IN friends  $\Rightarrow$  true if ffoulkes is a friend
- NOT ( ffoulkes IN friends)  $\Rightarrow$  true if ffoulkes is not a friend

# ARITHMETIC FUNCTIONS

*ABS( ), SQR( ), SQRT( ),  
LN( ), EXP*

For years functions have enjoyed arguments:



but the preferred terminology for argument in Pascal is *parameter*. The parameters described below are *actual parameters*. Later we define *formal parameters* hitherto known as *dummy arguments*.

The following two functions may be given an integer parameter, in which case they return an integer result. These functions may be given a real parameter, in which case they return a real result.

**ABS ( expression )** THE ABSOLUTE ( i.e. POSITIVE ) VALUE OF ITS PARAMETER

```
WRITELN( ABS(-2), ABS(0), ABS(2) );
WRITELN( ABS(-2.0):4:1, ABS(0.0):4:1, ABS(2.0):4:1 )
```

**SQR ( expression )** THE SQUARE OF THE VALUE OF ITS PARAMETER

```
WRITELN( SQR(-2), SQR(0), SQR(2) );
WRITELN( SQR(-2.0):4:1, SQR(0.0):4:1, SQR(2.0):4:1 )
```

The remaining arithmetical functions may be given an integer or real parameter, but return a real value in either case:

**SQRT ( expression )** THE SQUARE ROOT OF ITS PARAMETER WHICH MUST NOT BE NEGATIVE

```
WRITELN( SQRT(16):4:1, SQRT(0.64):4:1, SQRT(0):4:1 );
WRITELN( SQRT(-16) )
```

**LN ( expression )** THE NATURAL LOGARITHM ( BASE e ) OF ITS PARAMETER WHICH MUST BE POSITIVE

```
WRITELN( LN(1):4:1, LN(2.718282):4:1, LN(7.5):4:1 );
WRITELN( LN(0), LN(-1) )
```

**EXP ( expression )** THE NATURAL ANTILOGARITHM ( BASE e ). IN OTHER WORDS EXP(x) SIGNIFIES  $e^x$

```
WRITELN( EXP(0):4:1, EXP(1):8:5, EXP(2.014903):4:1 );
WRITELN( EXP(-1):7:4, EXP(LN(100)):6:1 )
```

$$e^{-1} = \frac{1}{e}$$

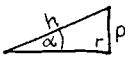
$$e = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \dots$$

# TRIGONOMETRICAL FUNCTIONS

$\sin()$ ,  $\cos()$ ,  
 $\arctan()$

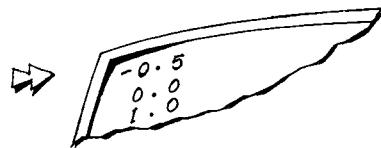
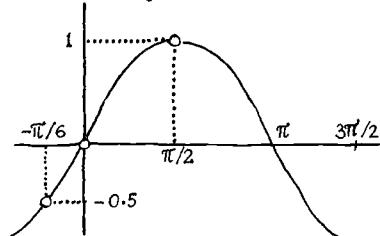
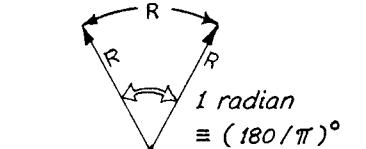
The trigonometrical functions are defined below; each may be given an integer or real parameter but returns a real result in either case.

**SIN ( expression )** THE SINE OF AN ANGLE MEASURED IN RADIANS

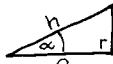
$$\sin \alpha = \frac{p}{h}$$


CONST PI = 3.1415926;

```
WRITELN ( SIN(-PI/6):4:1 );
WRITELN ( SIN(0):4:1 );
WRITELN ( SIN(PI/2):4:1 )
```

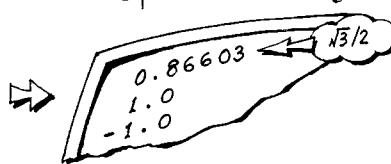
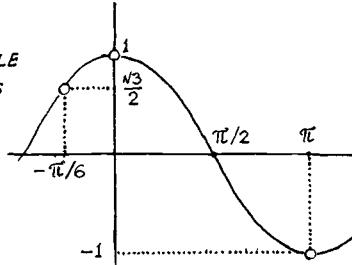


**COS ( expression )** THE COSINE OF AN ANGLE MEASURED IN RADIANS

$$\cos \alpha = \frac{a}{h}$$


CONST PI = 3.1415926;

```
WRITELN ( COS(-PI/6):8:5 );
WRITELN ( COS(0):4:1 );
WRITELN ( COS(PI):4:1 )
```



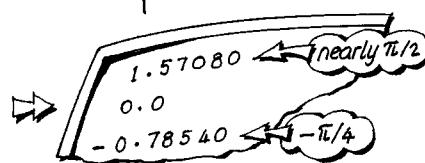
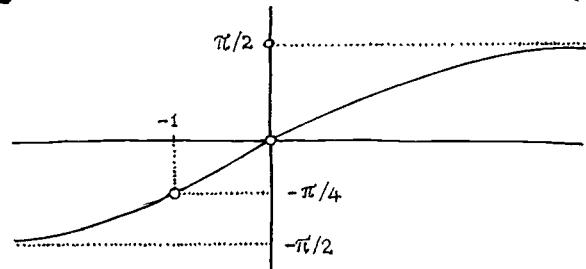
**ARCTAN ( expression )** THE ARCTANGENT { "THE ANGLE, IN RADIANS, WHOSE TANGENT IS..." }

$$\arctan(p/a) = \alpha \text{ radians}$$



effectively infinite

```
WRITELN ( ARCTAN(1E35):8:5 );
WRITELN ( ARCTAN(0):4:1 );
WRITELN ( ARCTAN(-1):8:5 )
```



# TRANSFER FUNCTIONS

FROM REAL TO INTEGER  
TRUNC( ), ROUND( )

When an integer result is assigned to a real variable the result is automatically converted to type real, no function being needed. This facility is called *implicit type conversion*.

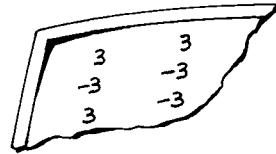
There is no converse of the above; it is wrong to assign a real result to an integer variable.

A real value must either be truncated or rounded before being assigned to an integer variable, the functions TRUNC( ) and ROUND( ) being provided for the purpose.

*real* ↗

**TRUNC( expression )** TRUNCATE ANY FRACTIONAL PART OF THE REAL VALUE AND CONVERT TO TYPE INTEGER

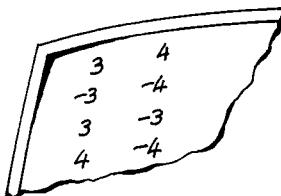
```
WRITELN ( TRUNC (3.1), TRUNC (3.8));
WRITELN ( TRUNC (-3.1), TRUNC (-3.8));
WRITELN ( TRUNC (3.0), TRUNC (-3.0))
```



*real* ↗

**ROUND( expression )** ROUND TO NEAREST WHOLE NUMBER AND CONVERT TO TYPE INTEGER

```
WRITELN ( ROUND (3.1), ROUND (3.8));
WRITELN ( ROUND (-3.1), ROUND (-3.8));
WRITELN ( ROUND (3.0), ROUND (-3.0));
WRITELN ( ROUND (3.5), ROUND (-3.5))
```



There can be surprises. Consider a value of 3.499999 stored in a real variable *x*. If this value were displayed using the statement WRITE( *x*: 8: 5) it would appear as 3.50000, but WRITE( ROUND( *x*)) would yield 3 rather than 4. This problem may be avoided by a "nudge" such as WRITE( ROUND( *x* + 0.000001)) (assuming the value stored in variable *x* is known to be positive).

It is wrong to give an integer parameter to TRUNC( ) or ROUND( ).

```
WRITELN ( TRUNC (3));
WRITELN ( ROUND (3))
```



# BOOLEAN FUNCTIONS

RETURNING TRUE or FALSE  
ODD( ), EOLN( ), EOF( )

The function ODD( ) is for revealing whether the result of an integer expression is odd or even.

**ODD( expression )** *integer* RETURNS TRUE IF PARAMETER REDUCES TO AN ODD INTEGER ≈ OTHERWISE RETURNS FALSE

WRITELN ( ODD(3), ODD(2), ODD(0) );  
WRITELN ( ODD(-3), ODD(-2) ); *even*  
WRITELN ( ODD(3.0) ) *must be integer*



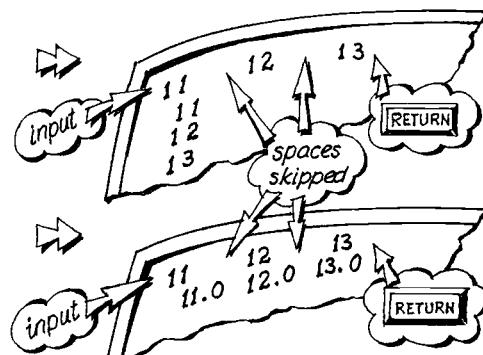
TRUE FALSE FALSE  
TRUE FALSE  
ERROR

The following functions are for detecting the end of a line and the end of a file respectively. EOLN is usable only with text files which are organized as lines of items. Files are described in chapter 10; below is enough information to explain the use of EOLN in the early examples. Do not use EOF if data come from the keyboard; chapter 11 deals with this precaution.

**EOLN( name file )** RETURNS TRUE IF THE FINAL ITEM OF THE CURRENT LINE HAS BEEN READ  
**EOLN** *implies EOLN(INPUT)*

WHILE NOT EOLN DO  
BEGIN  
READ ( i ); *type integer*  
WRITELN ( i: 3 )  
END

WHILE NOT EOLN DO  
BEGIN  
READ ( a ); *type real*  
WRITE ( a: 5: 1 )  
END



**EOF( name file )** RETURNS TRUE IF THE FINAL ITEM ON THE FILE HAS BEEN READ ( OBEDIENCE ANOTHER READ WOULD CAUSE FAILURE )

WHILE NOT EOF( f ) DO  
BEGIN  
WHILE NOT EOLN( f ) DO  
BEGIN  
READ ( ch );  
WRITE( ch )  
END;  
WRITELN  
END

input file, f  
Spaces are significant when reading type CHAR

Spaces are significant when reading type CHAR

WHILE NOT EOF( g ) DO  
BEGIN  
READ ( ch ); WRITE(ch)  
END

The EOLN mark is read as a space

The EOLN mark is read as a space

# ORDINAL FUNCTIONS

POSITION IN ASCENDING ORDER  
ORD(), CHR(), SUCC(), PRED()

The letters 'A' to 'Z' run in ascending order; in other words each letter has an *ordinal value* to establish its relative order in the alphabet. This ordinal value may be obtained from the ORD() function:

**ORD(expression)** RETURNS THE ORDINAL VALUE OF THE CHARACTER OR OTHER ORDERED TYPE EXPRESSED BY THE PARAMETER

WRITELN(ORD('I'), ORD('J'))



The ordinal value of a character depends on the computer installation, the ASCII code being typical on personal and home computers. But whatever the code employed the ordinal values of letters run in ascending order:

ORD('A') < ORD('B') < ORD('C')... < ORD('Z')

but  $\text{ORD('Z')} - \text{ORD('A')}$  is not necessarily 25. Not all computers offer the lower-case letters, but for those that do:

ORD('a') < ORD('b') < ORD('c')... < ORD('z')

There is no defined relationship between upper-case and corresponding lower-case letters but it should be safe to assume that  $\text{ORD('a')} - \text{ORD('A')}$  has the same value through the alphabet to  $\text{ORD('z')} - \text{ORD('Z')}$ .

Whatever the character code employed, the ordinal values of digits run in ascending order:

ORD('0') < ORD('1') < ORD('2')... < ORD('9')

and furthermore there is a difference of 1 between ordinal values of adjacent digits, so  $\text{ORD('9')} - \text{ORD('0')} = 9$ . It follows that the numerical value of digit *d* (type CHAR) may be obtained from:

value := ORD(d) - ORD('0')

(There is probably no Pascal installation at which  $\text{ORD('0')}$  returns zero.)

Types CHAR, INTEGER etc. are provided by Pascal, but the programmer may define other types by enumerating a sequence of constants:

TYPE  
days = (mon, tue, wed, thu, fri, sat, sun);

enumerated types are  
explained on page 72

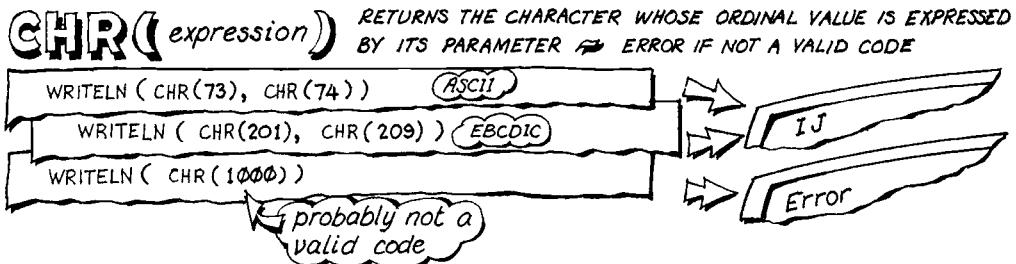
Constants of enumerated type have ordinal values counted from zero. For example  $\text{ORD(mon)}$  returns 0,  $\text{ORD(sun)}$  returns 6;  $\text{mon} < \text{sun}$ .

Type BOOLEAN is an enumerated type which is provided automatically as:

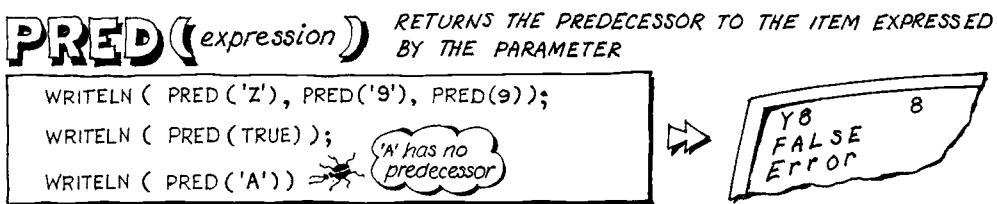
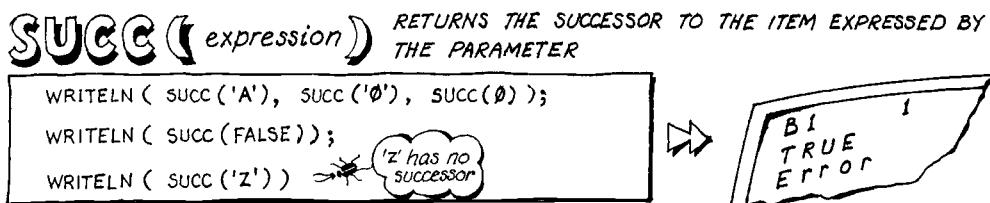
TYPE  
BOOLEAN = ( FALSE, TRUE );

hence  $\text{ORD(FALSE)}$  returns 0,  $\text{ORD(TRUE)}$  returns 1;  $\text{FALSE} < \text{TRUE}$

The converse of `ORD()` is `CHR()`:



If something has an ordinal value it is seldom necessary to know what that value actually is; it is enough to ask for the successor or predecessor in the established order. Functions `SUCC()` and `PRED()` are provided for this purpose:



These two functions may be used to obtain successors and predecessors of enumerated types. Referring to type `days` defined opposite:

`PRED(sun)` returns `sat`, `SUCC(mon)` returns `tue`

but it would be wrong to illustrate this as `WRITELN(PRED(sun))` because enumerated types cannot be read or written  $\approx$  a constraint on their usefulness. The nearest thing to `WRITELN(PRED(sun))` is `WRITELN(ORD(PRED(sun)))` which would cause 5 to be written (the ordinal value of `sat`).

The `SUCC()` function is handy for controlling loops:

```
i := 0;  
REPEAT  
  i := SUCC(i);  
  statements  
UNTIL i = 10
```



# 5

## CONTROL

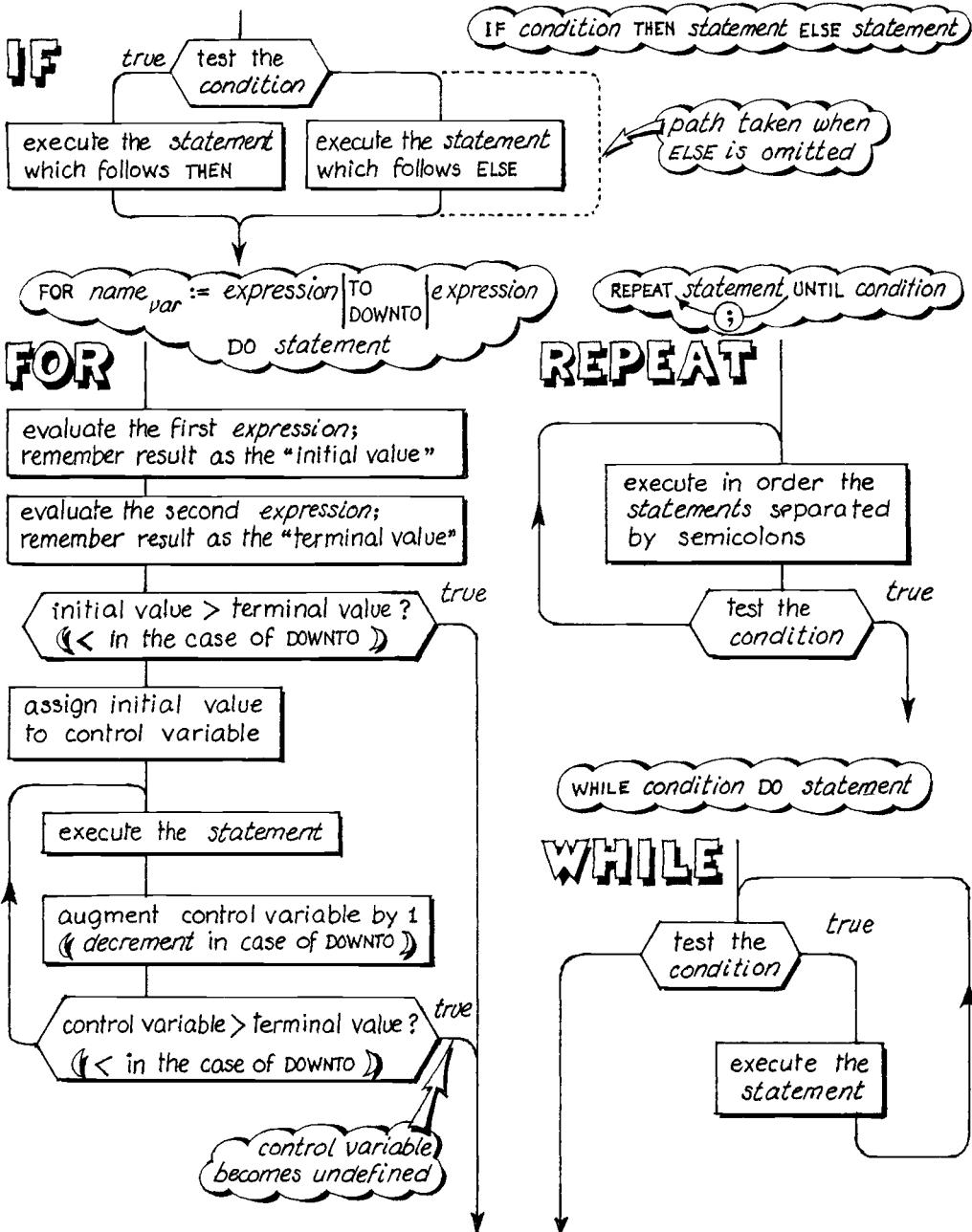
FLOW CHARTS  
IF•THEN•ELSE STATEMENT  
FOR LOOP  
REPEAT LOOP  
WHILE LOOP  
FILTER (EXAMPLE)  
CASE STATEMENT  
SYMBOL-STATE TABLE (EXAMPLE)

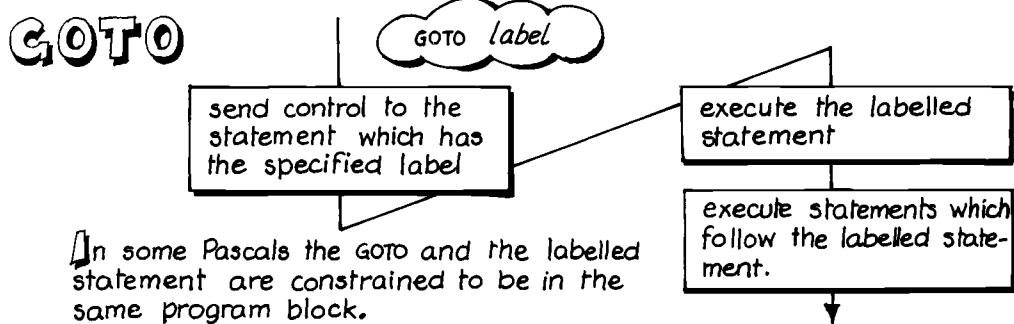
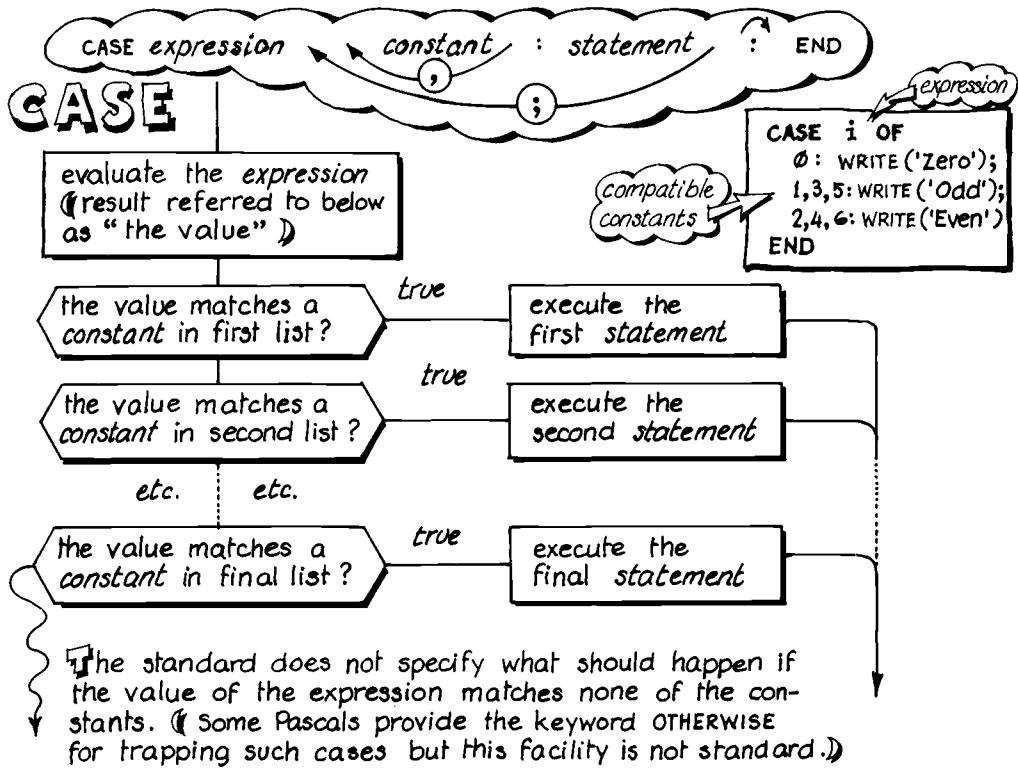
# FLOW CHARTS

IF-THEN-ELSE, FOR LOOP, REPEAT LOOP  
WHILE LOOP, CASE OF, GOTO

Most of the control statements have been introduced by example in earlier chapters; in this chapter they are defined and their characteristics explained. Unless disturbed by one of these statements, control goes from statement to statement sequentially.

The behaviour of each control statement is depicted on this double page as a flow chart.

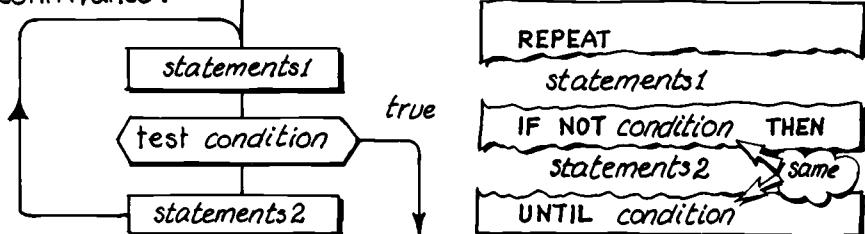




The GOTO is useful for error recovery in interactive systems  $\approx$  a subject beyond the scope of this book.

## EXIT ? PASCAL LACKS AN EXIT STATEMENT

Standard Pascal offers no way to jump out of the middle of a loop.<sup>t</sup> But here is a contrivance :



<sup>t</sup> apart from GOTO

# IF ~ THEN ~ ELSE STATEMENT

The syntax of the IF statement is:

IF condition THEN statement      ELSE statement

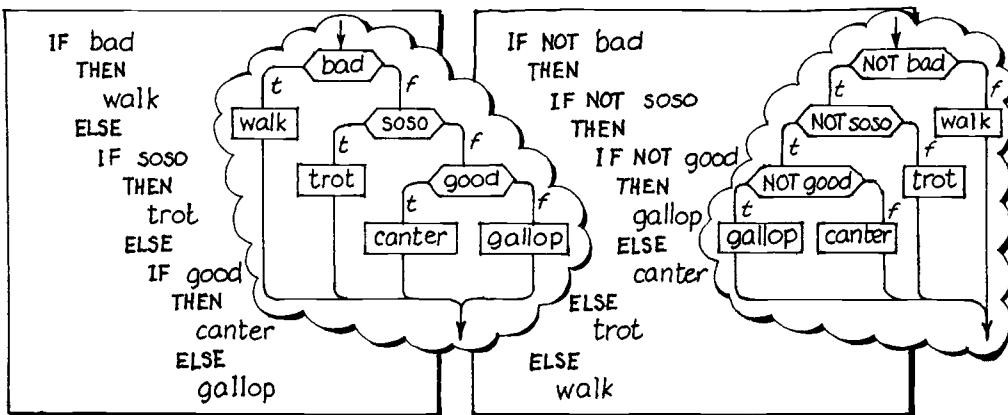
- IF profit > loss THEN WRITE('Hooray!')
- IF profit > loss THEN WRITE('Hooray!') ELSE WRITE('Bother')
- IF initial > 'K' AND initial < 'S' THEN WRITE('See L to R directory')

When condition is evaluated, and its value turns out to be true, the statement following THEN is obeyed  $\leadsto$  the statement following ELSE being ignored. Conversely, if the value turns out to be false, the statement following THEN is ignored  $\leadsto$  the statement following ELSE (if there is one) being obeyed.

If condition does not reduce to true or false an error message is evoked.

The statement following THEN or ELSE may be a compound statement (i.e. BEGIN ... ... END). There is no limit to the number or complexity of statements comprising a compound statement.

Be careful when nesting IF statements. Try to employ the pattern "ELSE IF" rather than "THEN IF" which leaves an "ELSE" dangling in the brain. A sequence of "THEN IF" can conclude in an embarrassing pile-up of ELSE clauses:



In general, ELSE refers to the closest preceding IF which has not yet been paired with an ELSE.

# FOR LOOP

THE LOOP TO USE WHEN YOU CAN SPECIFY THE NUMBER OF CYCLES AT THE OUTSET

The syntax of the FOR statement is:

```
FOR name := expression | TO | expression DO statement  
  ↗ names the control variable
```

- ▶ `FOR humbug := 1 TO 3 DO WRITELN ('We wish you a merry Christmas');  
WRITELN ('And a happy new year')`
- ▶ `FOR m := 12 DOWNTTO 2 DO WRITELN (m:3, ' men');  
WRITELN ('1 man & his dog went to mow a meadow')`

The control variable may be any ordered type (typically INTEGER, never REAL). Both expressions must reduce to the same type of value as that of the control variable.

The flow chart on page 44 should be consulted on the patterns of behaviour illustrated below.

The two expressions are evaluated before any statement of the loop; they are not subsequently re-evaluated. If these expressions define an impossible sequence the loop is not executed at all:

```
FOR i := 2 TO 1 DO WRITE ('shy')
```

nothing written  
≈ no error reported

It is impossible to "run away with the finishing line" which is frozen on entry:

```
finish := 3;  
FOR i := 1 TO finish DO  
  BEGIN  
    finish := finish + 1;  
    WRITELN (finish)  
  END
```

terminal value  
frozen at 3

precisely three  
times round

4  
5  
6

It is wrong to tamper with the control variable. Obvious cases of tampering involve assignment to the control variable and reading values into it:

```
FOR i := 1 TO 3 DO  
  BEGIN  
    i := i - 1;  
    READ(i);  
    FOR i := 1 TO 3 DO WRITE ('Dear me!')  
  END
```



wavy line

It is wrong to assume anything about the value in the control variable on emergence from a FOR loop (unless vacated by GOTO):

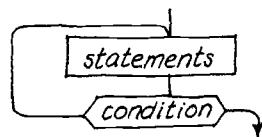
```
FOR i := 1 TO 3 DO  
  WRITE (i:4);  
  WRITELN;  
  WRITE (i:4)
```

could be  
anything

1 2 3

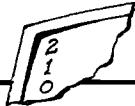
# REPEAT LOOP

The syntax of the REPEAT statement is:



```
REPEAT statement, UNTIL condition  
;
```

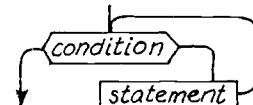
► `n:=3; REPEAT n:=PRED(n); WRITELN(n) UNTIL n=0;` →



As may be verified from the flow chart, the statements are obeyed at least once. A loop that has to be avoided altogether under certain conditions must be specially protected ~ say by an IF statement. In such circumstances it may be better to use a WHILE loop.

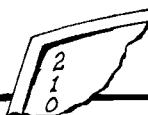
# WHILE LOOP

The syntax of the WHILE statement is:



```
WHILE condition DO statement
```

► `n:=3; WHILE n>0 DO BEGIN n:=PRED(n); WRITELN(n) END;` →

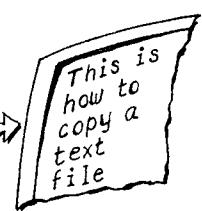
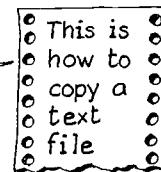


As may be verified from the flow chart, the test for continuance is made before statement is obeyed, permitting the loop to be avoided altogether when conditions are not right (not so with the REPEAT loop).

A typical use of the WHILE loop is for copying text files. A text file is a file of items separated by spaces and organized into lines as explained on page 115.

```
VAR ch: CHAR;
```

```
WHILE NOT EOF(f) DO
  BEGIN
    WHILE NOT EOLN(f)
      BEGIN
        READ(f, ch);
        WRITE(ch)
      END;
    WRITELN
  END;
```



copied to screen  
in this example

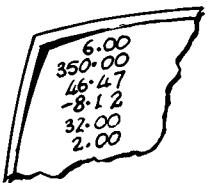
Don't use EOF with keyboard input. Implications of this are explained in chapters 10 and 11.

# FILTER

A PROGRAM TO READ SMALL NUMBERS EMBEDDED IN TEXT AND ILLUSTRATE REPEAT & WHILE LOOPS

The READ statement alone cannot be used to read the numbers from the following file because the words and punctuation marks would get in the way. Program *filter* is designed to filter out the extraneous data and abstract just the numbers.

Here is a file to serve as data. It should be typed without pressing **RETURN** until the final full stop has been typed.



In 6 months, with luck, I shall have £350, +46.47 in interest but -8.12 in bank charges. That should be enough for a 32k home computer Mk2.



Here is the OUTPUT file that the program should create from the INPUT file above.

And here is a program to do the work:

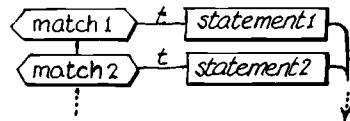
```

PROGRAM filter( INPUT, OUTPUT );
  VAR
    ch, sgn: CHAR; fraction: INTEGER; number: REAL;
  BEGIN
    ch := '.', Space
    WHILE NOT EOLN DO
      BEGIN
        number := 0.0; fraction := 0;
        sgn := ch; READ( ch );
        IF ( ch >= '0' ) AND ( ch <= '9' )
        THEN
          BEGIN { if a digit }
            REPEAT
              REPEAT
                number := 10 * number + ORD(ch) - ORD('0');
                fraction := fraction * 10;
                IF NOT EOLN THEN READ( ch );
              UNTIL ( (ch < '0') OR (ch > '9') ) OR EOLN;
              IF ( ch = '.' ) AND NOT EOLN
              THEN
                BEGIN
                  READ( ch ); fraction := 1
                END
              UNTIL ( (ch < '0') OR (ch > '9') ) OR EOLN;
              IF fraction > 0 THEN number := number / fraction;
              IF sgn = '-' THEN number := -number;
              WRITELN( number: 8:2 )
            END { if a digit }
          END { while not eoln }
      END.
    
```

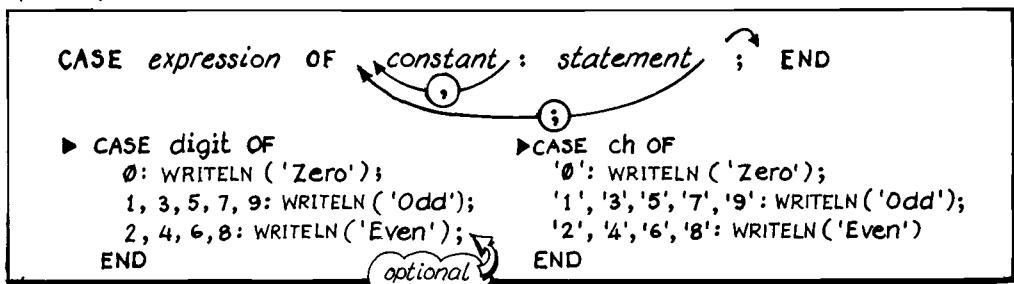
a crudity:   
 if you include more  
 than one decimal point,  
 only the last is acted  
 upon; for example  
 12.3.4 would produce  
 123.40 without an  
 error report

The part of any program concerned with input is difficult to keep tidy because of all the checks that have to be made. The program above is particularly untidy but there is a clearer version on page 76 which exploits features of Pascal not yet introduced.

# CASE STATEMENT



The syntax of the CASE statement is:



The expression may reduce to a value of any ordered type, typically type INTEGER or CHAR but never REAL. The expression and constants must be of the same type as one another.

The behaviour of the CASE statement is defined by the flow chart on page 45. When the first precise match is found the corresponding statement is obeyed, none of the others being obeyed. If there is no match at all the behaviour is undefined, so be careful to allow for every possible value that expression could reduce to (not always easy to achieve).

Nested CASE statements may be used to represent a symbol-state table which is a tidy device for resolving input data. The following table is for decoding Roman numerals with digits X, V and I.

symbol state	'X'	'V'	'I'
→ 1	$n := 10$ ; state := 2	$n := 5$ ; state := 3	$n := 1$ ; state := 6
2	$n := n + 10$ ; state := 2	$n := n + 5$ ; state := 3	$n := n + 1$ ; state := 6
3	ok := FALSE	ok := FALSE	$n := n + 1$ ; state := 4
4	ok := FALSE	ok := FALSE	$n := n + 1$ ; state := 5
5	ok := FALSE	ok := FALSE	$n := n + 1$ ; state := 7
6	$n := n + 8$ ; state := 7	$n := n + 3$ ; state := 7	$n := n + 1$ ; state := 5
7	ok := FALSE	ok := FALSE	ok := FALSE

To decode XIV start in state 1 where the arrow is. The first symbol is 'X' so look down from 'X' and find  $n := 10$ ; state := 2. So set n to 10 and move the arrow to row 2. Now look down from the second symbol, 'I', and find  $n := n + 1$ ; state := 6. The value in n thus becomes  $10 + 1 = 11$ . Move the arrow to row 6. Now look down from the final symbol, 'V', and find  $n := n + 3$ ; state := 7. The value in n then becomes  $11 + 3 = 14$ . Move the arrow to row 7 and notice that any further 'X' or 'V' or 'I' would cause an error (e.g. XIVX).

This table decodes Roman numerals starting with any number of X's and the conventional arrangements of V's and I's :

I, II, III, IV, V, VI, VII, VIII, IX, X, XI etc.

but would treat IIII, for example, as an error by setting ok to FALSE. The table may be extended to cope with M, D, C and L.

# SYMBOL-STATE TABLE

TO ILLUSTRATE NESTED  
CASE STATEMENTS

```

PROGRAM roman ( INPUT, OUTPUT );
  VAR n, state: INTEGER; symbol: CHAR; ok: BOOLEAN;
BEGIN { program }

  state := 1; ok := TRUE; n := 0;
  WHILE NOT EOLN DO
    BEGIN
      READ ( symbol );
      IF ( ( symbol = 'X') OR ( symbol = 'V') ) OR ( symbol = 'I' )
        THEN
          CASE state OF
            1: CASE symbol OF
                'X': BEGIN n := 10; state := 2 END;
                'V': BEGIN n := 5; state := 3 END;
                'I': BEGIN n := 1; state := 6 END
              END;
            2: CASE symbol OF
                'X': BEGIN n := n+10; state := 2 END;
                'V': BEGIN n := n+5; state := 3 END;
                'I': BEGIN n := n+1; state := 6 END
              END;
            3: CASE symbol OF
                'X', 'V': ok := FALSE;
                'I': BEGIN n := n+1; state := 4 END
              END;
            4: CASE symbol OF
                'X', 'V': ok := FALSE;
                'I': BEGIN n := n+1; state := 5 END
              END;
            5: CASE symbol OF
                'X', 'V': ok := FALSE;
                'I': BEGIN n := n+1; state := 7 END
              END;
            6: CASE symbol OF
                'X': BEGIN n := n+8; state := 7 END;
                'V': BEGIN n := n+3; state := 7 END;
                'I': BEGIN n := n+1; state := 5 END
              END;
            7: ok := FALSE
          END { CASE state }
        ELSE
          BEGIN
            IF ok
              THEN WRITELN ( n: 2 )
              ELSE WRITELN ( ' PECCAVISTI' );
            state := 1; ok := TRUE
          END { ELSE }
        END { WHILE NOT }
    END. { program }
  
```

it is nicer to write:  
IF symbol IN ['X', 'V', 'I']  
as explained in chapter 7

decoded number  
in n

Note:  
terminate final item  
with full stop or space  
before pressing RETURN



# **EXERCISES**

**1.** Implement the roman program. Extend it to cope with:

$M = 1000, D = 500, C = 100, L = 50.$

If your Pascal permits interactive working, include prompts for the benefit of the user of the program.

# 6

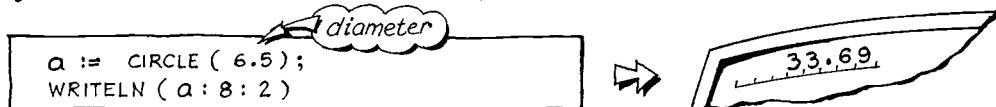
## FUNCTIONS AND PROCEDURES

- FUNCTION DEFINITION
- TYPICAL FUNCTIONS
- RECURSION
- PROCEDURES
- RANDOM NUMBERS
- LOANS AGAIN (EXAMPLE)
- FUNCTION NAMES AS PARAMETERS
- FORWARD REFERENCES
- LOCAL VARIABLES
- SIDE EFFECTS
- SCOPE RULES

# FUNCTION DEFINITION

DEFINE YOUR OWN FUNCTIONS

Pascal does not provide a function for returning the area of a circle given the diameter as its actual parameter:



But it is easy to define such a function:

```

FUNCTION circle( d: REAL ): REAL;
CONST pi = 3.1415926;
BEGIN
  circle := pi * SQR( d )/4.0
END;

```

the function is to return a *REAL* result

the parameter is to be *REAL*

assign the result  $\approx$  a *single* value  $\approx$  to the name of the function: this is a Pascal convention

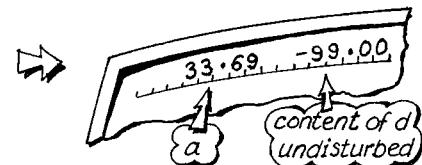
Thereafter, *circle()* (or *CIRCLE()*) may be used in the program just as *SQR()* and *TRUNC()* have been used in earlier examples.

In the top line of the definition, the *d* says "Do what gets done to me, but use whatever value is put in my place." In the example at the top of this page 6.5 is put in place of *d*, and so is duly squared, multiplied by 3.1415926, divided by 4.0. The *d* is a *formal parameter* whereas 6.5 is an *actual parameter*. You could use the name *d* for a variable (or any other named entity) in the program which invokes *area()* without interference from that function:

```

d := -99;
a := circle( 6.5 );
WRITELN( a, d: 8: 2 )

```



The syntax of a function definition (ignoring, for now, parameters which are themselves functions or procedures) is:

```

FUNCTION name( VAR name : name_type ): name_type; block;
  VAR explained later

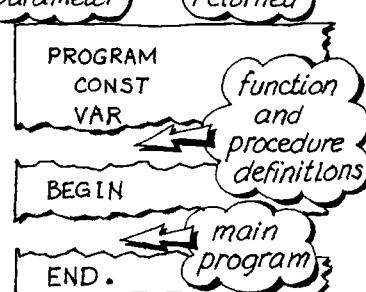
```

type of parameter

type of value to be returned

The item *block* has the structure of a program within a program. The syntax of *block* is properly defined on page 28; this sketch simply illustrates the location of function and procedure definitions in a program.

Function and procedure definitions may have further function and procedure definitions nested within them.



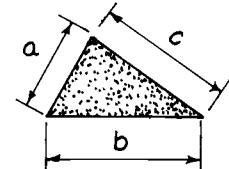
Here is a function for returning the area of a rectangle, given lengths of sides as parameters:

```
FUNCTION rectangle( b, d: REAL ): REAL;
BEGIN rectangle := b * d END;
```



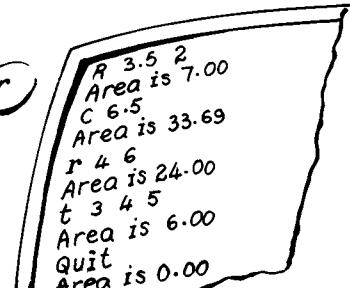
And a similar one for the area of a triangle:

```
FUNCTION triangle( a, b, c: REAL ): REAL;
VAR x: REAL;
BEGIN
  x := (a + b + c) / 2;
  triangle := SQRT( x * (x-a)*(x-b)*(x-c) )
END;
```



These three functions (circle(), rectangle(), triangle()) may be invoked from the following program which is a re-designed version of the program on page 17.

```
PROGRAM shapes2( INPUT, OUTPUT );
VAR letter: CHAR; a, x, y, z: REAL;
put the three functions here in any order
BEGIN
  REPEAT
    READ( letter );
    CASE letter OF
      'q', 'Q': a := 0;
      'r', 'R': BEGIN
        READLN( x, y ); a := rectangle( x, y )
      END;
      't', 'T': BEGIN
        READLN( x, y, z ); a := triangle( x, y, z )
      END;
      'c', 'C': BEGIN
        READLN( x ); a := circle( x )
      END
    END; {CASE letter}
    WRITELN( 'Area is ', a: 8: 2 )
  UNTIL ( letter = 'Q' ) OR ( letter = 'q' )
END.
```



Notice that the functions are invoked with *actual parameters*  $x, y, z$  whereas *formal parameters*  $a, b, c, d$  were used in the definitions. Variable  $a$  in the main program has no connection with formal parameter  $a$  in function triangle(,,). Likewise, variable  $x$  in the main program has no connection with *local variable*  $x$  in function triangle(,,). More about this later.

Each function defined here has a different number of parameters. Any fixed number is permissible, but never a variable number as with READ(a), READ(a,b), READ(a,b,c) etc. This facility is enjoyed by Pascal alone.

In the above examples all types are REAL, but in general any mixture of types is allowed: eg. mixfun( a:REAL; b:INTEGER; c:CHAR ): BOOLEAN;

# TYPICAL FUNCTIONS

EXAMPLES TO ILLUSTRATE  
FUNCTION DEFINITIONS

There is no Pascal function for returning a cube root. Here is one defined:

```
FUNCTION cubrt(x: REAL): REAL;
  VAR old, noo: REAL;
  BEGIN
    IF x = 0 THEN cubrt := 0 ELSE
      BEGIN old := 1;
      REPEAT
        noo := x / SQR(old);
        old := (noo + old) / 2
      UNTIL ABS(x / (noo * noo * noo) - 1) < 1E-6;
      cubrt := noo
    END
  END; { of function }
```

exit when  $\frac{x}{(\text{guess})^3} \approx 1$

cubrt(-27) returns -3  
cubrt(0) returns 0  
cubrt(27) returns 3

Basic programmers regretting the absence of SGN() may define it; either directly:

```
FUNCTION sgn(x: REAL): INTEGER;
  BEGIN
    IF x > 0 THEN sgn := 1 ELSE
    IF x < 0 THEN sgn := -1 ELSE sgn := 0
  END;
```

returns 1 if  $x > 0$   
returns -1 if  $x < 0$   
returns 0 if  $x = 0$

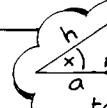
or with cunning:

```
FUNCTION sgn(x: REAL): INTEGER;
  BEGIN sgn := ORD(x > 0) - ORD(x < 0) END;
```

works because:  
 $\text{ORD}(\text{TRUE})=1, \text{ORD}(\text{FALSE})=0$

There is no TAN() function in Pascal (tangent of an angle measured in radians) but here is one defined:

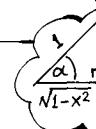
```
FUNCTION tan(x: REAL): REAL;
  BEGIN
    tan := SIN(x) / COS(x)
  END;
```

  $\sin x = p/h$   
 $\cos x = a/h$   
 $\tan x = \frac{p}{a} = \frac{p/h}{a/h} = \frac{\sin x}{\cos x}$

Here are functions for the arcsine (the angle, in radians, whose sine is...) and arccosine:

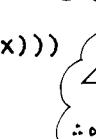
```
FUNCTION arcsin(x: REAL): REAL;
  BEGIN
    IF ABS(x)=1
    THEN arcsin := x * 1.5707963
    ELSE arcsin := ARCTAN(x / SQRT(1-SQR(x)))
  END;
```

$\pm \pi/2$

  $\sin \alpha = x/1$   
 $\tan \alpha = x / \sqrt{1-x^2}$   
 $\therefore \alpha = \arctan(x / \sqrt{1-x^2})$

```
FUNCTION arccos(x: REAL): REAL;
  BEGIN
    IF x = 0
    THEN arccos := 1.5707963
    ELSE arccos := ARCTAN(SQRT(1-SQR(x))/x) + 3.1415926 * ORD(x < 0)
  END;
```

$\pm \pi/2$

  $\cos \alpha = x/1$   
 $\tan \alpha = \sqrt{1-x^2}/x$   
 $\therefore \alpha = \arctan(\sqrt{1-x^2}/x)$

$\pm \pi$  when  $x \geq 0$

There is more about the arcsin() and arccos() functions on page 68.

# RECURSION

## DEFINITION OF A RECURSIVE FUNCTION TO INTRODUCE THE CONCEPT OF RECURSION

The highest common factor (hcf) of 1470 and 693 is 21. In other words 21 is the biggest number that will divide into 1470 and 693 without leaving a remainder in either case. To verify this, factorize both numbers to prime factors:

$$\begin{aligned} 1470 &= 2 \times 3 \times 5 \times 7 \times 7 \\ 693 &= 3 \times 3 \times 7 \times 11 \end{aligned}$$

and pair off any common factors ~~in~~ in this case 3 and 7. The highest common factor (also called gcd, or greatest common divisor) is the product of these; in this case  $3 \times 7 = 21$ .

Euclid's method of finding the hcf is more elegant. Find the remainder when 1470 is divided by 693:

$$1470 \bmod 693 = 84$$

Because this remainder is not zero, repeat the process substituting the second number for the first and the remainder for the second:

$$693 \bmod 84 = 21$$

This remainder is still not zero, so repeat the process:

$$84 \bmod 21 = 0$$

This remainder is zero, so the hcf is 21. Nice.

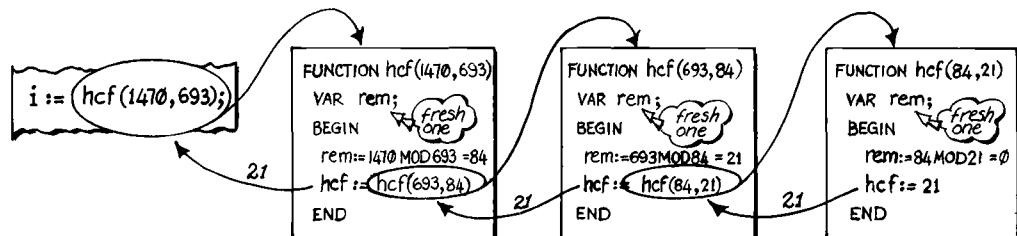
Here is a Pascal function based on Euclid's method:

```
FUNCTION hcf(n, m: INTEGER): INTEGER;
  VAR rem: INTEGER;
  BEGIN
    rem := n MOD m;
    IF rem = 0 THEN hcf := m ELSE hcf := hcf(m, rem)
  END;
```

recursive invocation

this works both for  $n > m$  and  $m < n$

It is easy to see what would happen with  $\text{hcf}(84, 21)$  because rem would become zero making the function return 21. But with  $\text{hcf}(1470, 693)$  rem becomes 84 so the function invokes itself as  $\text{hcf}(693, 84)$ . In so doing rem becomes 21, therefore the function invokes itself as  $\text{hcf}(84, 21)$ . It is as though Pascal provided a fresh copy of the code of the function  $\text{hcf}(,)$  on each invocation:



The ability of a function to invoke itself is called recursion. There is more about recursion in this and subsequent chapters.

# PROCEDURES

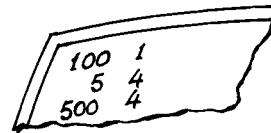
AND THE CONCEPT OF 'VALUE' PARAMETERS  
VERSUS VAR PARAMETERS

When a piece of program is to be used more than once in the same program there is no need for its text to be duplicated; its text may be parcelled as a procedure, given a name, and invoked by that name whenever its text is to be obeyed. Here is a trivial example; a procedure for writing two integers in reverse order of the two parameters:

```
PROCEDURE reverse( a, b: INTEGER );
BEGIN
  WRITELN( b:3 , a:3 )
END;
```

From the main program this procedure could be invoked thus:

```
x := 1; y := 100;
reverse( x, y );
reverse( 4, 5 );
reverse( 4*x, 5*y )
```



The above is silly, but serves to show that the actual parameters may be constants (4, 5) or expressions (4\*x, 5\*y) or names of variables (x, y). Every time reverse() is invoked its actual parameters are evaluated and these values are substituted for the formal parameters a and b. For this reason a and b are called "value" parameters.

Instead of writing values in reverse order suppose it were required to exchange the values stored in a pair of integer variables. The following would be no good at all:

```
PROCEDURE swop( a, b: INTEGER );
VAR
  tempy: INTEGER;
BEGIN
  tempy := a; a := b; b := tempy
END;
```



Suppose it were to be invoked as follows with x containing 1, y containing 100:

```
swop( x, y )
```

The effect would be to store the values 1 in a, 100 in b; then to make the swop in a and b; then to return to the program with x and y unaffected. The procedure is interested only in the values of its parameters; swop(4,5) or swop(4\*x,5\*y) would have the same non-result.

The solution is to make the parameters into VAR parameters. Writing VAR in front of a parameter gives access to a variable in the invoking program:

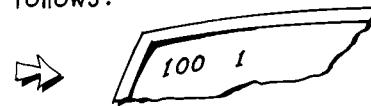
```
PROCEDURE swop( VAR a, b: INTEGER );
VAR
  tempy: INTEGER;
BEGIN
  tempy := a; a := b; b := tempy
END;
```



*you can now change  
the contents of variables  
belonging to the  
invoking program*

Now suppose the procedure were invoked as follows:

```
x:= 1; y := 100;  
swap( x, y )  
WRITELN( x, y )
```



In simple terms: put VAR in front of those parameters whose values are to be changed by the procedure.

A more sophisticated concept is that VAR in the procedure heading signifies direct access to the invoking program. The statement  $a := b$  in the procedure signifies  $x := y$  in the invoking program (when invoked as shown above). In the jargon: VAR parameters are passed by address or passed by reference whereas value parameters are passed by value  $\Rightarrow$  the procedure having to set up a local variable to store each value passed.

The following invocations are meaningless with VAR parameters; invocations

```
swap( 4, 5 );  
swap( 4*x, 5*y )
```

are meaningful if both parameters are names of variables which contain values to be swapped.

A point of possible confusion: the VAR section of a procedure is for declaring variables local to that procedure, whereas VAR in the procedure heading signifies reference to non-local variables:

```
PROCEDURE swap(VAR a,b:INTEGER);  
  VAR tempry:INTEGER;  
  BEGIN  
    tempry:=a; a:=b; b:=tempry  
  END;
```

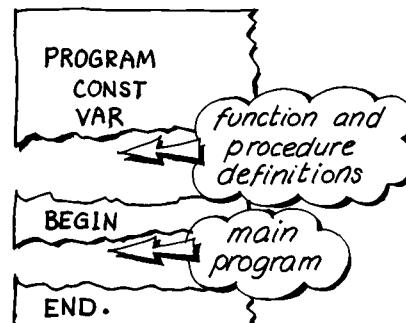
```
PROCEDURE reverse(a,b:INTEGER);  
  BEGIN  
    WRITELN( b, a )  
  END;
```

Here is the syntax of procedure definition (ignoring, for now, parameters which are themselves names of functions).

```
PROCEDURE name( VAR name, : name_type, ) : block;
```

The item block has the structure of a program within a program. The syntax of block is properly defined on page 28.

This diagram shows the location of function and procedure definitions within a program. Each function and procedure definition may have further function and procedure definitions nested within it.



# RANDOM NUMBERS

A FUNCTION WHICH RETURNS A VALUE & CHANGES A PARAMETER

Consider the following function:

```
FUNCTION next ( VAR seed : INTEGER ) : INTEGER ;
  CONST multiplier = 37; increment = 3; cycle = 64;
  BEGIN
    next := seed;
    seed := (multiplier * seed + increment) MOD cycle
  END;
```

notice VAR in the heading; an unusual tactic in a function

Invoked with *s* containing 16 as follows:

```
s := 16; WRITE(next(s))
```



this function must obviously return 16. Furthermore, whenever the function returns 16 it must always change the value stored in *seed* to 19. If the function were again invoked, but with the new setting of *s*, it would return 19 and change the value in *s* to 2. Continually invoking *next()* in this way would produce a predetermined sequence of integers running from the initial value given to *s*:

```
s := 16;
FOR i := 1 TO 64 DO WRITE(next(s): 3)
```

16	19	2	13	36	55	54	17	56	27	42	21	12	63	30	25
32	35	18	29	52	7	6	33	8	43	58	37	28	15	46	41
48	51	34	45	4	23	22	49	24	59	10	53	44	31	62	57
0	3	50	61	20	39	38	1	40	11	26	5	60	47	14	9

A remarkable thing about this sequence is that every value from 0 to 63 occurs precisely once. Furthermore, invoking *next()* for the sixty-fifth time would produce 16, re-starting the identical cycle of integers. In other words the function generates a fixed permutation of the integers 0 to 63, starting from any desired integer.

This technique is much used for generating "random" numbers (strictly pseudo-random in deference to their predictability). A cycle of 64 would be inadequate; Grogono (see Bibliography) gives a set of constants to generate a permutation of integers 0 to 65535:

```
CONST multiplier = 25173; increment = 13849; cycle = 65536;
```

Choosing a set of constants with the necessary properties is not a trivial exercise. To arrive at 37 and 3 for the cycle of 64 numbers shown above I experimented blindly with prime numbers.

The above function returns a value and alters the value of the parameter. The tactic is unusual. Most functions have no need to disturb their parameters, and accordingly make no use of VAR in the headings of their definitions.

In computer simulations and games it is usual to employ random fractions in the range  $0 \leq \text{fraction} \leq 1$  rather than random integers. This requires a few changes to the function defined opposite:

```
FUNCTION rnd (VAR seed: INTEGER): REAL;
  CONST multiplier=25173; increment=13849; cycle=65536;
  BEGIN
    rnd := seed / cycle;
    seed := (multiplier * seed + increment) MOD cycle
  END;
```

name changed to rnd()  
and divisor added

0.0 ≤ rnd < 1.0

formerly INTEGER  
Grogono's constants

This function will not work if MAXINT has a value of less than  $2^{31}-1$ . But here is an ingeniously modified version which generates a cycle of 32768 fractions even if MAXINT has a value as low as  $2^{16}-1$  (32767):

```
FUNCTION rnd (VAR seed: INTEGER): REAL;
  VAR a, b, c, d: INTEGER;
  BEGIN
    rnd := seed / 32767;
    a := seed DIV 256;
    b := seed MOD 256;
    c := ((b*93) MOD 256) + 13;
    d := (b*26) + ((b*93) DIV 256) + (a*93) + (c DIV 256) + 27;
    seed := ((d MOD 128) * 256) + (c MOD 256)
  END;
```

0.0 ≤ rnd < 1.0  
N.B.

Here is a simulation to show how much wiser it is to bet on 7 than any other score if throwing a pair of dice for even money. (An array ≈ see chapter 8 ≈ would make the program simpler.)

```
PROGRAM bones (OUTPUT);
  VAR score, throws, seed, a, b, c, d, e, f, g, h, i, j, k: INTEGER;
  BEGIN
    seed := 0; a := 0; b := 0; c := 0; d := 0; e := 0; f := 0;
    g := 0; h := 0; i := 0; j := 0; k := 0;
    FOR throws := 1 TO 3600 DO
      BEGIN {throws}
        score := ROUND(1+5*rnd(seed)) + ROUND(1+5*rnd(seed));
        CASE score OF
          2: a := a + 1; 12: k := k + 1;
          3: b := b + 1; 11: j := j + 1;
          4: c := c + 1; 10: i := i + 1;
          5: d := d + 1; 9: h := h + 1;
          6: e := e + 1; 8: g := g + 1;
          7: f := f + 1
        END {CASE}
      END; {FOR throws}
    WRITELN (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12);
    WRITELN (a, b, c, d, e, f, g, h, i, j, k)
  END.
```

insert first version of rnd() here

6\*rnd(seed) has range 0.0 to under 6.0

compare the "ideal" scores

choose suitable format for output device; e.g. a:4, b:4, c:4 etc.

2	3	4	5	6	7	8	9	10	11	12
89	194	298	396	523	598	532	418	298	202	92
100	200	300	400	500	600	500	400	300	200	100

The result is roughly symmetrical about 7. Comparison of results with "ideal" scores is encouraging; see page 68 about a much bigger sample.

# LOANS AGAIN

## A PROGRAM TO ILLUSTRATE A PROCEDURE DEFINITION

The program on page 15 computes the monthly repayment,  $m$ , on a mortgage loan of  $s$  at  $p\%$  compound interest over  $n$  years. But here is a more difficult problem; a loan of  $s$  is to be repaid at  $m$  per month over  $n$  years; what rate of interest is being charged?

$$m = \frac{sr(1+r)^n}{12[(1+r)^n - 1]}$$

where  $r = p \div 100$

The equation may be solved by trial and error. Guess  $r$ ; substitute in the formula and compute  $m_1$ . If  $m_1$  is the same as  $m$  the guess was correct. If  $m_1$  was too small it means  $r$  was guessed too low, so multiply  $r$  by  $m/m_1$  to make it bigger and try again. If  $m_1$  is too big it means  $r$  was guessed too high, so multiply  $r$  by  $m/m_1$  to make it smaller and try again. In short; if  $m_1$  is not close enough to  $m$  multiply  $r$  by  $m/m_1$  and try again. Sooner or later  $r$  will get close enough to be acceptable as a solution to the equation.

This method works well as long as an increase in one thing implies a corresponding increase (or decrease) in another. It fails if the other fluctuates or there is a discontinuity such as a bankrupt mortgagee.

Here is the program:

```

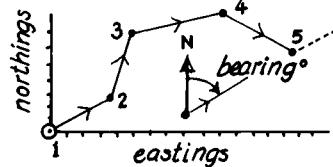
PROGRAM loanrate ( INPUT, OUTPUT );
  VAR
    s, m, m1, r, percent: REAL;
    n: INTEGER;
  PROCEDURE formula ( VAR m: REAL; n: INTEGER; s,r: REAL );
    VAR a: REAL;
    BEGIN
      a := EXP ( LN ( 1 + r ) * n );
      m := ( s * r * a ) / ( 12 * ( a - 1 ) )
    END;
  BEGIN
    if your Pascal is
    interactive insert a
    suitable prompt here
    READ ( s, m, n );
    r := 0.1;           guess initial rate
    REPEAT
      formula ( m1, n, s, r );
      r := r * m / m1
    UNTIL ABS ( m / m1 - 1 ) < 1E-6
    percent := r * 100; leave rounding to WRITELN
    WRITELN ('Sum is £', s:4:2);
    WRITELN ('Monthly repayment £', m:4:2);
    WRITELN ('Number of years', n:4);
    WRITELN;
    WRITELN ('Interest rate', percent:4:2, '%')
  END.
  
```

*rounding to 2 decimals*

# FUNCTION NAMES AS PARAMETERS

DEEP BREATH..IN

Here are the statements of a program to compute northings and eastings of points on the ground, given the compass bearing at each point and the paced distance from the previous point ( a traverse ).



```

BEGIN
  northing := 0; easting := 0; ← origin at point 1
  WHILE NOT EOF(f) ← INPUT file
    BEGIN
      READLN(f, bearing, distance);
      northing := northing + projection(bearing, distance, cosine);
      easting := easting + projection(bearing, distance, sine);
      WRITELN(northing:10:2, easting:10:2)
    END { WHILE }
  END. { program }
  
```

name of a function

name of a function

Here is the definition of projection(,,):

```

FUNCTION projection(bng, dist: REAL; FUNCTION ratio(x: REAL): REAL;
BEGIN
  projection := dist * ratio(bng) ← defines the third
  formal parameter
END;
  
```

may not be a VAR parameter

And here are the definitions of the functions whose names are used as actual parameters of projection(,,):

```

FUNCTION sine(b: REAL): REAL;
BEGIN sine := SIN(3.1415926 * b / 180) END;

FUNCTION cosine(b: REAL): REAL;
BEGIN cosine := COS(3.1415926 * b / 180) END;
  
```

Notice how the third formal parameter of projection(,,) is defined:

FUNCTION ratio(x: REAL): REAL

says the actual parameter is to be the name of a user-defined function

says the user-defined function is to have a REAL parameter

says the user-defined function is to return a REAL result

where x serves only to mark the place of a parameter, keeping the syntax consistent with that of a function definition.

To complete the picture, here is the start of the program:

```

PROGRAM traverse(f, OUTPUT);
  VAR northing, easting: REAL;
  
```

put function definitions here, followed by the main program

The problem is to find a compiler on which this works. Many compilers refuse to allow names of functions to be used as parameters, and I can't say I blame them. The only sensible applications of this facility I have so far seen concern mathematical integration.

...BREATHE OUT!

# FORWARD REFERENCES

DURING COMPILATION

In any block the CONST and VAR declarations precede the BEGIN and END which enclose the statements themselves. This enforced order implies that the compiler never has to handle a statement containing constants or variables it does not know about. The appearance of an undeclared constant or variable would evoke an error message during compilation.

The same logic applies to subprograms (i.e. functions and procedures). An error message is evoked if the compiler meets an invocation of a subprogram it does not know about. It is the programmer's responsibility to see that definitions are properly ordered.

```
PROGRAM demo( INPUT, OUTPUT );
  VAR a, b, c: REAL;
  PROCEDURE ring( VAR area, circumf: REAL; diam:REAL );
    BEGIN
      circumf := 3.14 * diam ;
      area := circle( diam ) 
      the compiler does not know  
about function circle()  
on reaching here
    END
    FUNCTION circle( d: REAL): REAL;
    BEGIN circle:= 3.14 * SQR(d)/4 END;
```

An obvious solution to this problem is to re-order the input so that the function circle( ) is defined before the procedure ring(,,). But there is a less drastic solution (if drastic remembering that real-life programs are longer than the trivial example programs shown here) :

- leave the offending subprogram where it is, but simplify its heading by removing all parameters
- insert the full heading where it ought to be  $\approx$  i.e. before the subprogram that invokes it
- add the predefined word FORWARD after the full heading:

```
PROGRAM demo( INPUT, OUTPUT );
  VAR a, b, c: REAL;
  FUNCTION circle( d: REAL): REAL;
  FORWARD; 
  insert full heading before  
any subprogram that invokes  
this one
  PROCEDURE ring( VAR area, circumf: REAL; diam: REAL );
    BEGIN
      circumf := 3.14 * diam ;
      area := circle( diam )
    END; 
    simplify heading  
to just the name
  FUNCTION circle;
  BEGIN circle:= 3.14 * SQR(d)/4 END; 
  leave the body  
where it was
```

The only other forward reference allowed in Pascal is to do with pointers in linked lists as described in chapter 12.

# LOCAL VARIABLES

FRESH ON EACH INVOCATION,  
EVAPORATING ON RETURN

The following sketches were used on page 59 to distinguish those variables that are *local* to a procedure from those that are not:

```
PROCEDURE swop(VAR a,b:INTEGER);
  VAR tempy
  BEGIN
    tempy:=a; a:=b; b:=tempy
  END;
```

*local*      *non-local variables*

```
PROCEDURE reverse(a,b:INTEGER);
  BEGIN
    WRITELN(b,a)
  END;
```

*local variables*

Local variables are created as a procedure is invoked. Then current values of any *value* parameters are copied into the local variables created for them. For example the invocation:

reverse( 4, 5 );

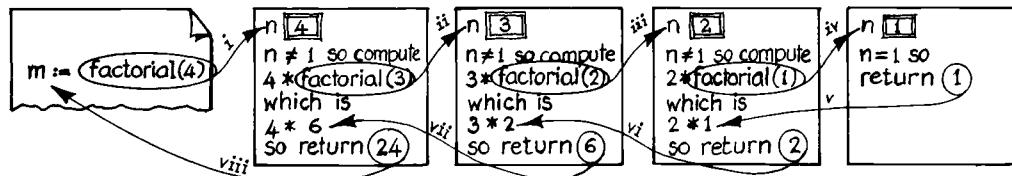
would cause 4 to be copied into local variable *a* and 5 into local variable *b*.

The procedure is then put to work. On completion, when control returns to the invoking program, all local variables are forgotten, their contents being lost forever. *But the local variables do not evaporate until control returns to the invoking program.* This behaviour is essential to recursion as illustrated by this hackneyed example of "factorial" :

```
FUNCTION factorial( number: INTEGER ): INTEGER;
  VAR n: INTEGER;
  BEGIN
    n := number;
    IF n = 1 THEN factorial := 1
    ELSE factorial := n * factorial(n-1)
  END;
```

*local variable n*

Trace the behaviour of the function for the invocation  $m := \text{factorial}(4)$ :



Notice that the first copy of *factorial* remembers the value 4 in local variable *n* until the 24 is returned to *m*. Similarly the second copy remembers the 3 until the 6 is returned to the first copy, and so on. A local variable is local to the current copy; at one instant during the execution depicted above there would be four distinct copies of local variable *n*.

It was not necessary to declare VAR *n* as above; value parameters are automatically declared as local variables:

```
FUNCTION factorial( n: INTEGER ): INTEGER;
  BEGIN
    IF n = 1 THEN fact
    ELSE fact
  END;
```

*value parameters are local variables*

# SIDE EFFECTS

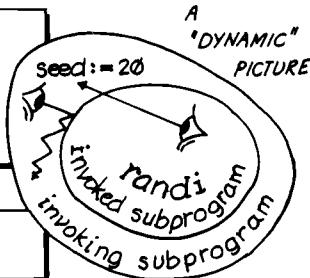
GENERALLY TO BE AVOIDED BUT CAN BE HELPFUL IN PARTICULAR CASES

Here is an alternative to the random number generator on page 61:

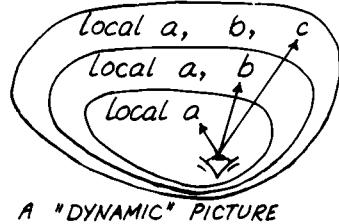
```
FUNCTION randi :  
BEGIN  
  randi := seed / (65536-1);  
  seed := (25173 * seed + 13849) MOD 65536  
END;
```

which could be invoked like this:

```
seed := 20;  
throw := (1+5*randi)+(1+5*randi)
```



The example works because the computer can "see" the variable named *seed* whilst working inside function *randi*. Furthermore *randi* can cause a change in the value stored in the variable named *seed*. An invoked subprogram can see outwards to its invoking program but cannot be seen by it.



When a subprogram refers to variable *a* it means the *local* variable *a*. If there is no local variable *a* the eye looks outwards to the invoking subprogram (possibly a recursive copy of itself) and refers to the *local* variable *a* in that subprogram. If there is no local variable *a* the eye looks outwards...

The same principle applies to all named entities: variables, constants, functions, procedures, files and types.

When a subprogram *changes* the value stored in a variable declared outside itself the subprogram is said to have a *side effect*. Function *randi* has a side effect; it changes the value stored in *seed* which is a variable declared outside *randi*.

Side effects are often caused by accident. Making repeated use of variables with names like *a*, *b*, *c* whilst forgetting to declare them locally is a potential source of trouble; some books on Pascal advocate the use of long names for variables so as to avoid this danger.

When programs are small it may be clearest to make all variables global. When sets are used (sets are described in the next chapter) it may be the only sane approach to make all set variables global. And in long programs it may make sense to define a few global variables to be referred to from inside procedures. But it is bad practice to employ side effects sporadically or carelessly.

Opposite is the skeleton of a typical program. Borders are drawn around subprograms to emphasize the nested structure. The notes explain what variables are available in each layer of nesting, those able to cause side effects being pointed out. Notice how the program itself appears as a subprogram (albeit with a non-standard heading to define the input and output files and a non-standard ending involving a full stop) nested within the "Pascal environment".

# SCOPE RULES

THE "STATIC" PICTURE OF  
A NESTED PROGRAM



PASCAL ENVIRONMENT: standard files ( INPUT, OUTPUT ), types ( REAL etc. ), functions ( SQR( ) etc. ), procedures ( WRITE( ) etc. ), constants ( TRUE, FALSE )

```
PROGRAM twigs( INPUT, OUTPUT );
  VAR a, b, c: REAL;
```

```
PROCEDURE lining( p, q: REAL; VAR x, y : REAL );
  VAR a, b : REAL;
```

```
PROCEDURE chick( p: REAL; VAR x: REAL );
  VAR a, d : REAL;
```

BEGIN *in these statements you may:*

- \* employ *a, d, p* belonging to *chick*
- \* employ *b* belonging to *lining*, *c* belonging to *twigs*
- \* employ *x* to return result via invocation of *chick*
- \* employ *y* " " " " " " " " *lining*
- \* invoke *chick* or *lining* recursively
- \* use all Pascal files, types, functions, procedures, constants

END;

potential  
side effects

```
PROCEDURE egg( p: REAL; VAR x : REAL );
  VAR a, e :
```

BEGIN *in these statements you may:*

- \* employ *a, e, p* belonging to *egg*
- \* employ *b* belonging to *lining*, *c* belonging to *twigs*
- \* employ *x* to return result via invocation of *egg*
- \* employ *y* " " " " " " " " *lining*
- \* invoke *chick* ( for *chick* to invoke *egg* you need FORWARD )
- \* invoke *egg* or *lining* recursively
- \* use all Pascal files, types, functions, procedures, constants

END;

potential  
side effects

BEGIN {*lining*}

*in these statements you may:*

- \* employ *a, b, p, q* belonging to *lining*
- \* employ *c* belonging to *twigs*
- \* employ *x, y* to return results via invocations of *lining*
- \* invoke *chick*, *egg*
- \* invoke *lining* recursively
- \* use all Pascal files, types, functions, procedures, constants

END;

potential  
side effects

BEGIN {*twigs*}

*in the main program you may*

- \* employ *a, b, c* belonging to *twigs*
- \* invoke *lining*
- \* use all Pascal files, types, functions, procedures, constants

END.

# EXERCISES

1. To appreciate the range of results generated by the `arcsin()` and `arccos()` functions defined on page 56, write a program to tabulate results given parameters from  $-1$  to  $+1$  in increments of  $0.1$ . For example the essence of such a program could be the statement:

```
FOR n := -10 TO 10 DO
  WRITELN ( n/10:6:2, arcsin(n/10):6:2, arccos(n/10):6:2)
```

2. Implement the program named `bones` on page 61. If you have ample computer time to spare increase the number of dice throws from 3600 to 32768 to see if the scores turn out to be closer to the "ideal" ones.

3. Implement the program named `loanrate` on page 62. As with the previous `loans` program this one fails if the rate is zero. Make good this defect. If your Pascal system permits interactive input make the program prompt its user for each item of data required.

# 7

## **TYPES AND SETS**

STANDARD TYPES  
TYPE DEFINITION  
ENUMERATED TYPES  
SUBRANGES  
SET TYPE AND SET VARIABLES  
SET CONSTRUCTORS AND OPERATIONS  
FILTER 2 (EXAMPLE)  
MOOO (EXAMPLE)

# STANDARD TYPES

REAL, INTEGER, CHAR, BOOLEAN  
A SUMMARY

Constants of standard types may be defined in the CONST section of any block. The type of each constant does not have to be declared; it is recognizable by its "literal" form:

CONST pi = 3.14; increment = 1; star = '\*';

decimal point,  
therefore pi is REAL

no decimal point,  
therefore INTEGER

CONST name = constant;

;

apostrophes; therefore  
\* is of type CHAR

or by being set equal to some previously-named constant:

p = pi; stella = star; verily = TRUE; decrement = -increment;

no expressions;  
the limit of complexity is x = -y

The type of each variable must be declared in the VAR section of the block in which it is to be used: ➤

VAR name : type;

;

VAR name : name\_type ) : name\_type

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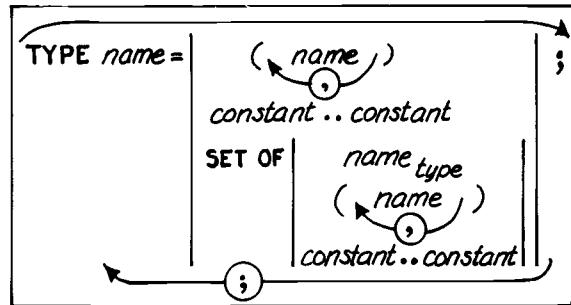
# TYPE DEFINITION

OF ENUMERATIONS, SUBRANGES  
AND SETS OF THESE

The programmer may devise and define simple types other than the four standard types. These definitions may be given in the TYPE section of the relevant block. The TYPE section comes between the CONST and VAR sections as illustrated further down this page.

The syntax of the TYPE section (omitting structured types which are dealt with from the next chapter onwards) is shown here. ➤

The three types are called *enumerated types*, *subrange types* and *set types*.



Here is an example of an enumerated type and two subrange types:

```

PROGRAM dodo( INPUT, OUTPUT );
CONST pi = 3.14;
TYPE daytype = ( mon, tue, wed, thu, fri, sat, sun );
weekdaytype = mon..fri ;
dicetype = 2..12
  
```

enumerated type  
subrange types

Subsequently the names *daytype*, *weekdaytype*, *dicetype* may be used for the definition of variables in the same manner as REAL, INTEGER, CHAR and BOOLEAN. ➤

```

VAR x: REAL;
today: daytype;
throw, score: dicetype;
PROCEDURE egg( VAR d: daytype );
  
```

Alternatively, the definition may be omitted from the TYPE section but included in the VAR section:

```

PROGRAM dodo( INPUT, OUTPUT );
CONST pi = 3.14;
TYPE daytype = ( mon, tue, wed, thu, fri, sat, sun );
VAR x:
today: mon..fri ;
throw, score: 2..12
  
```

type definitions moved  
to the VAR section

but such freedom is not permitted in headings of procedures or functions:

```

PROCEDURE egg( VAR d: daytype );
  
```

type of parameter must have  
been defined in a TYPE  
section

Enumerations and subranges find application in program control, offering an automatic check on range and scope:

```

WHILE throw >= score DO simulate( throw, score );
CASE today OF
  mon, tue, wed, thu, fri: WRITE ('Work');
  sat, sun: WRITE ('Play')
END {CASE}
  
```

error message  
evoked if either  
variable runs  
out of range

# ENUMERATED TYPES

( name )

Here is the definition of two enumerated types and corresponding variables:

```
TYPE days = ( mon, tue, wed, thu, fri, sat, sun );
       status = ( wedded, unwed );
VAR today, tomorrow : days
```

*'wedded' not 'wed' because every name in these enumerations must be unique*

You cannot read or write items of enumerated type:

```
READ ( today, tomorrow );
      WRITE ( fri, today );
```

You can assign values to variables of enumerated type:

```
today := mon;
tomorrow := today;
```

but not if variable and value belong to different enumerations:

```
today := unwed;
```

And you can't do arithmetic on them:

```
today := sat + sun
```

Constants of enumerated type have *ordinal values* counting from zero:

```
WRITELN ( ORD(mon), ORD(tue), ORD(sun) );
```

which implies predecessors and successors:

```
today := PRED ( sun );
tomorrow := SUCC ( today );
WRITELN ( ORD(today), ORD(tomorrow) );
```

→ 0 1 6

→ 5 6

but the first constant has no predecessor and the last has no successor:

```
today := PRED ( mon );
tomorrow := SUCC ( sun );
```

For all items in Pascal which have ordinal values it is allowable to omit the ORD( ) from Boolean expressions:

```
IF ORD(today) > ORD(mon) THEN sayso;
IF today > mon THEN sayso
```

the effect of these two statements is identical

Type BOOLEAN is an enumerated type supplied automatically by the Pascal processor:

```
TYPE
  BOOLEAN = ( FALSE, TRUE )
```

so it follows that ORD(FALSE) is zero, ORD(TRUE) is unity, and FALSE < TRUE .

# SUBRANGES

OF ENUMERATIONS,  
INTEGER & CHAR

constant .. constant  
Lower bound      Upper bound

Here is the definition of variables of several subranges:

```
TYPE daytype = ( mon, tue, wed, thu, fri, sat, sun );
VAR weekday : mon..fri;      subrange of daytype
   throw, score: 2..12;      subranges of INTEGER
   musketeer: 1..3;      subrange of INTEGER
   grade : 'A'..'D'      subrange of CHAR
```

A subrange may be defined comprising any type which has an *ordinal value*. This precludes subranges of type REAL.

```
VAR price = 1.99 .. 5.99      of REAL
```

Subranges of enumerations are subject to the restrictions applying to the enumerated type itself. Thus items of type mon..fri cannot be read or written, cannot have arithmetic done on them, cannot be assigned to variables except those of type mon..fri and daytype (where daytype is the super-range of which mon..fri is the subrange, hence compatible).

Constants of a subrange of any possible type have the same ordinal values as they do in the super-range. Thus in the subrange sat..sun, having daytype as its super-range, the values ORD(sat) and ORD(sun) would be 5 and 6 respectively; not 0 and 1.

When the super-range of a subrange is of type INTEGER, values of the subrange may be treated as integers. Such treatment may include reading, writing and integer arithmetic:

```
READ ( throw );
score := SQR ( throw );
WRITE ( score );
```

Furthermore, values from different subranges are interchangeable:

```
musketeer := score + 2      -MAXINT..MAXINT
                           1..3      2..12
```

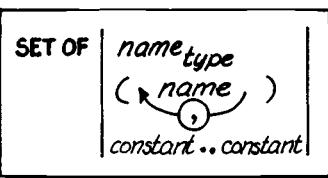
Nevertheless a check is made on the bounds of each variable before its value is updated (by assignment or READ( ) etc.). This automatic restriction to declared bounds is the purpose of subranges. It saves the programmer adding frequent and distracting checks of the form IF ( score > 12) OR (score < 2) THEN WRITE ('Bounds exceeded on SCORE'). In a well-written program you would see VAR score : 2..12 rather than VAR score: INTEGER.

When the super-range of a subrange is of type CHAR, values of the subrange may be treated as characters. This treatment may include reading, writing and employment in Boolean expressions:

```
READ( grade );
IF grade <= 'B'
  THEN WRITE ('Well done!')
  ELSE WRITE ( grade, ' will have to do' )
```

# SET TYPE AND SET VARIABLES

In general terms, a *set* is a collection of items of the same type. In Pascal you may create and name sets for keeping track of the items of any ordered type (not *REAL* or "structured"). "Keeping track" means recording whether each possible item is present or not.



Here is the definition of an enumerated type, followed by a *set type* having *daytype* as its "base type":

TYPE

daytype = (mon, tue, wed, thu, fri, sat, sun);  
dayset = SET OF daytype

and here is the definition of two variables for keeping track of sets of days in the manner depicted below:

VAR

washdays, bathdays: dayset;

At some time or other during execution of the program the two variables might look like this:

washdays      mon    tue    wed    ~~thu~~  
                  fri    sat    sun  
                  i.e. mon wed fri

bathdays      mon    tue    wed    thu  
                  fri    sat    sun  
                  i.e. mon thu fri

showing how the information held by a *set* variable comprises one logical value (present or not) for every possible item of the set.

As when defining enumerations and subranges, it is allowable to abbreviate by moving type definitions to the VAR section:

TYPE

daytype = (mon, tue, wed, thu, fri, sat, sun);

VAR

washdays, bathdays: SET OF daytype

or omit the TYPE section altogether:

VAR

washdays, bathdays: SET OF (mon, tue, wed, thu, fri, sat, sun);

Here is a VAR section which defines several *set* variables:

VAR

washdays, bathdays: SET OF (mon, tue, wed, thu, fri, sat, sun);

teaset: SET OF CHAR;

letters: SET OF 'A'..'Z';

digits: SET OF '0'..'9';

dice: SET OF 2..12;

the full set of CHAR  
depends on the  
installation

SET OF INTEGER  
is too big for some  
installations

dice      2    3    4    5    6    7    8  
            9    10   11   12  
                  i.e. depicted full

digit      \*    \*    \*    \*    \*    \*    \*  
                  \*    \*    \*    \*    \*    \*    \*  
                  i.e. depicted empty

# SET CONSTRUCTORS AND OPERATIONS

A set constructor specifies a set  $\approx$  which may then be assigned to an appropriate variable or manipulated by set operators or both. A set constructor may be considered as a set constant.

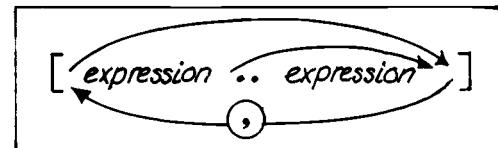
A set may be emptied thus:

`dice := [ ];`

Or assigned to thus:

`dice := [ 2*3..3*3, 5+6, 5 ];`

all these terms are valid in subrange 2..12



- `[ 2*3..3*3, 5+6, 5 ]`
- `[ 5, 6, 7, 8, 9, 11 ]`

identical sets

[ ]

dice

dice

The union of two sets is signified by a plus sign:

`dice := [ 2..5 ] + [ 4..6 ];`

+

The intersection is signified by an asterisk:

`dice := [ 2..5 ] * [ 4..6 ];`

\*

The difference of two sets is signified by a minus sign:

`dice := [ 2..5 ] - [ 4..6 ];`

-

`dice := [ 4..6 ] - [ 2..5 ];`

-

Decisions may be based on sets. The comparator IN or  $\geq$  or  $\leq$  or  $=$  or  $\neq$  in conjunction with set variables or constructors makes a Boolean expression.

Inclusion of a single item in a set may be investigated with IN:

`WRITELN( 6 IN [ 4..6 ], 6 IN [ 2..5 ] );`

IN

TRUE FALSE

One set contains another; use  $\geq$

`WRITELN( [ 2..12 ] \geq [ 3..5 ] );`  
`WRITELN( [ 3..5 ] \geq [ 2..12 ] );`

$\geq$

TRUE FALSE

One set is contained by another; use  $\leq$

`WRITELN( [ 3..5 ] \leq [ 2..12 ] );`  
`WRITELN( [ 2..12 ] \leq [ 3..5 ] );`

$\leq$

TRUE FALSE

One set is identical to another; use  $=$  or  $\neq$

`WRITELN( [ 3..5 ] = [ 5,4,3 ] );`  
`WRITELN( [ 3..5 ] \neq [ 4,5,3 ] );`

$=$

TRUE FALSE

# FILTER2

## ILLUSTRATING PROCEDURES WHICH INVOKE EACH OTHER, ENUMERATED TYPES AND SET CONSTRUCTORS

Program filter on page 49 reads the INPUT file, abstracting and writing on the OUTPUT file any numbers recognized. The version below has the same specification. It is longer than the earlier version but probably easier to follow because it is less tortuous. Procedures are used in the simplest possible way, working only on global variables.

```

PROGRAM filter2( INPUT, OUTPUT );
  VAR state : (ignoring, pending, reading);           ← enumerated type
    fraction : 0..MAXINT;                            ← subrange
    ch: CHAR; positive: BOOLEAN; number: REAL;

```

PROCEDURE initialize;

```

  BEGIN
    state := ignoring; positive := TRUE;
    number := 0; fraction := 0
  END;

```

PROCEDURE display; { then initialize }

```

  BEGIN
    IF fraction > 0 THEN number := number / fraction;
    IF NOT positive THEN number := -number;
    WRITELN ( number : 10:2 );
    initialize
  END;

```

PROCEDURE accumulate; { & set state to reading }

```

  BEGIN
    number := 10 * number + ORD(ch) - ORD('0');
    fraction := 10 * fraction;
    state := reading
  END;

```

PROCEDURE negate; { & set state to pending }

```

  BEGIN
    positive := FALSE; state := pending
  END;

```

```

BEGIN { program }
  initialize;
  WHILE NOT EOLN DO
    BEGIN { WHILE }
      READ( ch );
      CASE state OF
        ignoring: IF ch = '-' THEN negate
                    ELSE IF ch IN ['0'..'9'] THEN accumulate;
        pending: IF ch IN ['0'..'9'] THEN accumulate
                    ELSE initialize;
        reading: IF ch = '.' THEN fraction := 1
                    ELSE IF ch IN ['0'..'9'] THEN accumulate
                    ELSE display
      END { CASE }
    END { WHILE };
    IF state = reading THEN display
  END.

```

try this program with the data shown on page 49

symbol state	IN ['0'..'9']	'.'	'-'	others
ignoring:	accumulate & set to reading	ignore	negate & set pending	ignore
pending:			initialize	
reading:		fraction:=1	display & initialize	

ignoring: IF ch = '-' THEN negate  
ELSE IF ch IN ['0'..'9'] THEN accumulate;

pending: IF ch IN ['0'..'9'] THEN accumulate  
ELSE initialize;

reading: IF ch = '.' THEN fraction := 1  
ELSE IF ch IN ['0'..'9'] THEN accumulate  
ELSE display

crude logic:  
any character acts as terminator  
e.g. \$-8-9\* would produce:  
-8.00  
9.00

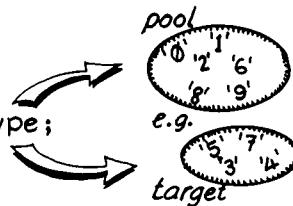
catch number if at very  
end of input file



## A GAME ≈ TO ILLUSTRATE SUBRANGES AND THE MANIPULATION OF SETS

The computer thinks of a four-digit number having no two digits alike. You type a guess and are told the number of bulls (direct hits) and number of cows (digits in the target but not directly hit). For example with a target of 5734 a guess of 0755 scores 1 bull and 2 cows. Keep guessing until you score four bulls.

```
PROGRAM moo00 ( INPUT, OUTPUT );
  TYPE playtype = '0'..'9';
  seedtype = 0..65535;
  scoretype = 0..4;
  VAR pool, target : SET OF playtype;
  a, b, c, d : playtype;
  seed : seedtype;
  bulls, cows : scoretype;
```



```
FUNCTION random: REAL;
BEGIN
  random := seed / 65536;
  seed := (25173 * seed + 13849) MOD 65536;
END; {random}
```

6, not 5, so that  
result is always  
less than 1.0

return a random  
number in range  
0.0 < random < 1.0

```
FUNCTION unique: playtype;
  VAR ch: CHAR;
```

```
BEGIN
```

```
  REPEAT
```

```
    ch := CHR(TRUNC(10 * random) + ORD('0'));
    UNTIL ch IN pool;
    unique := ch;
    pool := pool - [ch];
    target := target + [ch]
```

set  
difference

remove a  
random digit  
from 'pool' &  
put it in  
'target'

```
PROCEDURE try ( thisone: CHAR );
  VAR ch: CHAR;
```

```
BEGIN
```

```
  READ(ch);
```

```
  IF ch IN target
```

```
    THEN IF ch = thisone
```

```
      THEN bulls := SUCC(bulls)
      ELSE cows := SUCC(cows)
```

```
END; {try}
```

read next digit  
and update count  
of bulls or cows  
if appropriate

```
BEGIN { PROGRAM }
```

```
  WRITELN('First enter seed; then keep guessing');
```

```
  READLN(seed);
```

full set

```
  pool := ['0'..'9']; target := [];
```

empty set

```
  a := unique; b := unique; c := unique; d := unique;
```

```
  REPEAT
```

```
    bulls := 0; cows := 0;
```

```
    try(a); try(b); try(c); try(d);
```

```
    WRITELN(bulls:1, 'Bulls &':8, cows:2, 'Cows':5);
```

```
    READLN
```

```
  UNTIL bulls = 4;
```

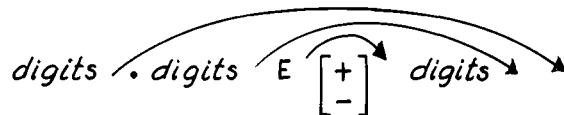
```
END. { PROGRAM }
```

First enter seed;  
35109  
1234  
0 Bulls & 1 Cows  
5678  
1 Bulls & 0 Cows  
5990  
2 Bulls & 0 Cows

4 Bulls & 0 Cows

# EXERCISES

1. Extend program *filter2* on page 76 to cope with numbers expressed in scientific format:



This exercise involves extending the symbol-state table.

2. Implement the game of *mooo* on page 77. Improve the game by making the program:

- offer a new game each time a game has been concluded
- stop the game, and count it as a win for the computer, if the target number has not been guessed correctly after ten tries
- keep separate account of the number of wins by the player and number of wins by computer; display these scores on the screen.

# 8

## ARRAYS AND STRINGS

INTRODUCING ARRAYS  
SYNTAX OF ARRAY DECLARATIONS  
AREA OF A POLYGON (EXAMPLE)  
CABLES (EXAMPLE)  
BUBBLE SORT (EXAMPLE)  
QUICKSORT (EXAMPLE)  
PACKING  
INTRODUCING STRINGS  
PARLOUR TRICK (EXAMPLE)  
NUMBER BASES (EXAMPLE)  
MATRIX MULTIPLICATION (EXAMPLE)  
CONFORMANT ARRAY PARAMETERS

# INTRODUCING ARRAYS

A RECTANGULAR ARRAY OF BOXES OF ANY ONE TYPE

Variables of standard type so far encountered have been independent little boxes:

```
VAR x : REAL; i, j: INTEGER; alive: BOOLEAN; cyfer: CHAR;
```

x  i  j  alive  cyfer

ordinary variables of standard types

and so have variables of *enumerated* and *subrange* type:

```
TYPE daytype = (mon, tue, wed, thu, fri, sat, sun);
```

```
VAR today: daytype; workday: mon..fri; throw: 2..12;
```

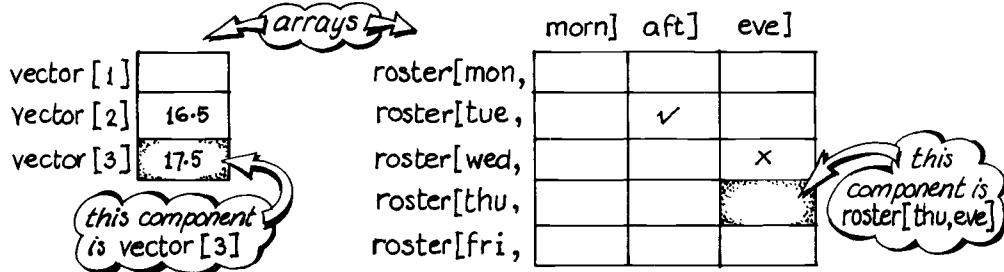
today  workday  throw

ordinary variables of enumerated & subrange types

But it is also possible to declare variables which are *arrays* of such little boxes:

```
TYPE daytype = (mon, tue, wed, thu, fri, sat, sun);  
session = (morn, aft, eve);
```

```
VAR vector: ARRAY [1..3] OF REAL;  
roster: ARRAY [mon..fri, session] OF BOOLEAN;
```



The little boxes of an array are called *components*: the contents of the square brackets are called *subscripts*. The *base type* of an array is the type of little box of which the array is composed (only one type of component in any one array).

Components may be employed in the same way as variables of the base type:

```
vector [2] := 16.5; READ (vector [3]);  
roster [tue, aft] := TRUE; WRITE (roster [tue, aft]);  
roster [wed, eve] := NOT roster [tue, aft];
```

However, there is no merit in using components as though they were ordinary variables; arrays are useful because subscripts may be variables or expressions which indicate successive components. Watch this:

```
FOR day := mon TO fri DO  
  FOR time := morn TO eve DO  
    roster [day, time] := FALSE;  
    FOR i := 1 TO 3 DO vector[i] := 0
```

set all components of roster to FALSE and all components of vector to zero

assuming a preceding VAR section to declare i : 1..3 and day : mon..fri and time : morn..eve

# SYNTAX OF ARRAY DECLARATIONS

The arrays depicted opposite could be declared after first naming and defining their types:

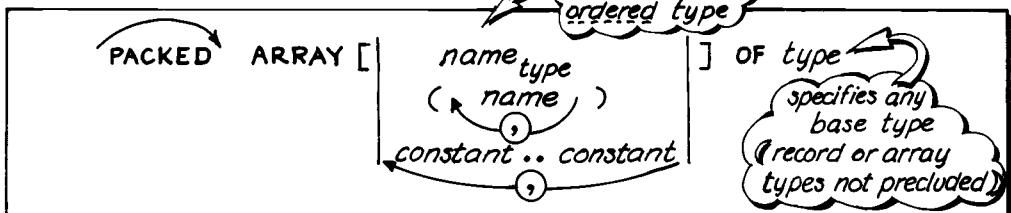
```
TYPE daytype = (mon, tue, wed, thu, fri, sat, sun);  
        session = (morn, aft, eve);  
        vectortype = ARRAY [1..3] OF REAL;  
        rostertype = ARRAY [mon..fri, session] OF BOOLEAN;
```

enumerated types  
array types

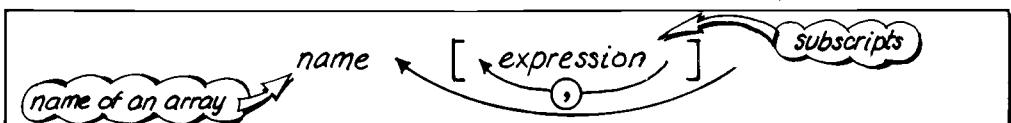
```
VAR vector : vectortype;  
     roster : rostertype;
```

array variables defined in terms of array types

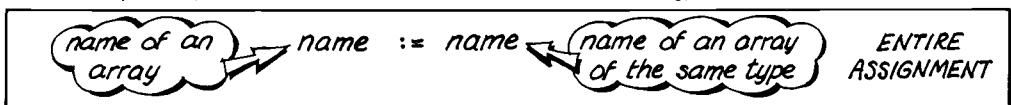
The syntax of array type is:



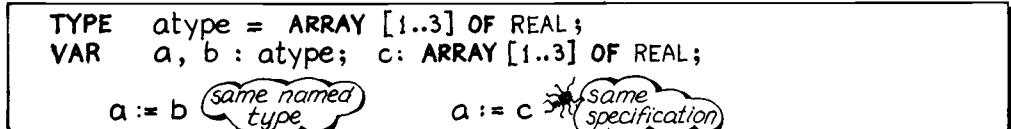
The syntax for referring to a component of an array is:



Arrays are manipulated by altering the subscripts of components as illustrated opposite. But there is an important exception; a copy of the *entire* content of one array may be assigned to another of the *same type* in a single operation:



where "same type" means a type with the *same name*. A type which has the same specification but different name is not equivalent:



An exception to the above is *PACKED ARRAY [ ] OF CHAR* for which, in some Pascals, equivalence is not demanded. Change REAL to CHAR above and *a := c* would be permitted.

A two-dimensional array such as *roster* is really an array of arrays. The following syntax would be allowable but is unnecessarily clumsy:

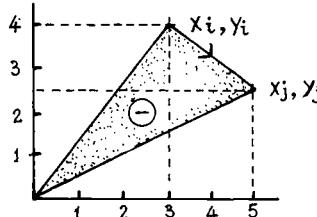
```
TYPE rostertype = ARRAY [mon..fri] OF ARRAY [session] OF BOOLEAN;  
roster [day] [time] := FALSE
```

# AREA OF A POLYCON

## AN EXAMPLE TO ILLUSTRATE ONE-COLUMN ARRAYS

Consider the diagram on the right:  $\Rightarrow$   
The spotted area is given by  $A_{ij}$  where

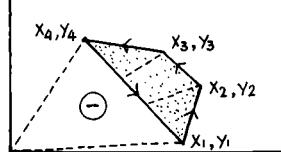
$$A_{ij} = \frac{1}{2} (x_i y_j - x_j y_i) \\ = \frac{1}{2} (2 \times 3 - 2.5 \times 1) = 1.75$$



$\Leftrightarrow$  The same formula may be used for computing the area on the left. But this area turns out to be negative:

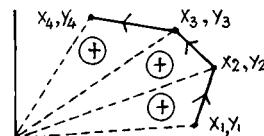
$$A_{ij} = \frac{1}{2} (x_i y_j - x_j y_i) \\ = \frac{1}{2} (3 \times 2.5 - 5 \times 4) = -6.25$$

The formula may be applied to sequential sides of a polygon, and the triangular areas summed to give the area shown here  $\Rightarrow$



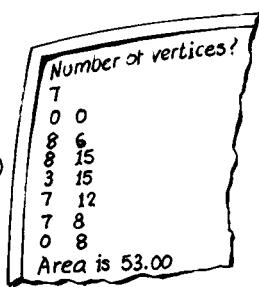
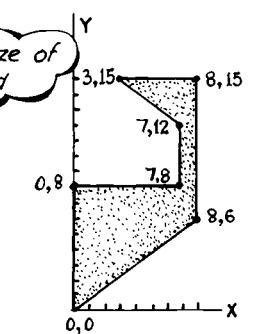
$\Leftrightarrow$  But if the polygon is closed, as shown on the left, the sum of the areas will be the area enclosed.

The bounded surface must be kept to the left of each arrow; the sides of the figure should not cross each other as in a figure of eight.



Here is a program by which to input coordinates of boundary points and compute the area enclosed:

```
PROGRAM polygon ( INPUT, OUTPUT );
TYPE
  spantype = 1..30; set the maximum size of problem as desired
VAR
  i, j, n : spantype; area : REAL;
  x, y: ARRAY [spantype] OF REAL;
BEGIN
  READLN (n); if your Pascal is interactive, insert:
  WRITELN ('Number of vertices?')
  FOR i := 1 TO n DO
    READLN (x[i], y[i]); initialize
  area := 0;
  FOR i := 1 TO n DO
    BEGIN
      j := (i MOD n) + 1; e.g. when i=1 then j=2
      area := area + 0.5*(x[i]*y[j] - x[j]*y[i]); when i=2 then j=3
      etc. but when i=n then j=1
    END;
  WRITELN ('Area is ', area:8:2)
END.
```



# CABLES

AN EXAMPLE TO ILLUSTRATE ARRAYS USED AS VECTORS  
 ≈ FOR THOSE WITH A BIT OF MATHEMATICS ≈

Two power cables  $\vec{a}$  and  $\vec{b}$  look uncomfortably close when you superimpose these sketches; what is the shortest distance between  $\vec{a}$  &  $\vec{b}$ ?

With trigonometry the solution would be messy but with vector algebra it's nice. Express  $\vec{a}$  and  $\vec{b}$  as vectors:

$$\vec{a} = (9-4)\vec{i} + (16-8)\vec{j} + (17-0)\vec{k}$$

$$\vec{b} = (10-6)\vec{i} + (11-3)\vec{j} + (15-5)\vec{k}$$

Their cross product,  $\vec{a} \times \vec{b}$ , is a vector normal to both  $\vec{a}$  and  $\vec{b}$ . Scale this by its own length,  $|\vec{a} \times \vec{b}|$ , and you have a unit vector parallel to  $\vec{a} \times \vec{b}$ :

$$\vec{u} = \vec{a} \times \vec{b} \div |\vec{a} \times \vec{b}|$$

Take a vector  $\vec{c}$  connecting any point on  $\vec{a}$  to any point on  $\vec{b}$ . Here is one of them; it connects the tip of  $\vec{a}$  to the tip of  $\vec{b}$ :

$$\vec{c} = (10-9)\vec{i} + (11-16)\vec{j} + (15-17)\vec{k}$$

Distance  $d$ , the shortest distance between  $\vec{a}$  and  $\vec{b}$ , is given by the projection of  $\vec{c}$  on  $\vec{u}$  (the dot product of  $\vec{c}$  and  $\vec{u}$ ) which is:

$$d = \vec{c} \cdot \vec{u}$$

which works out at 3.52 in this example

<pre> PROGRAM cables( INPUT, OUTPUT );   TYPE vector = ARRAY [1..3] OF REAL;   VAR a, b, c, u : vector; d, length: REAL;   coord: ARRAY [1..12] OF REAL;   i : 1..12; BEGIN   FOR i := 1 TO 12 DO READ(coord[i]);   FOR i := 1 TO 3 DO     BEGIN       a[i] := coord[3+i] - coord[i];       b[i] := coord[9+i] - coord[6+i];       c[i] := coord[9+i] - coord[3+i];     END;   u[1] := a[2] * b[3] - b[2] * a[3];   u[2] := a[3] * b[1] - a[1] * b[3];   u[3] := a[1] * b[2] - b[1] * a[2];   length := SQRT(SQR(u[1]) + SQR(u[2]) + SQR(u[3]));   FOR i := 1 TO 3 DO u[i] := u[i] / length;   d := c[1] * u[1] + c[2] * u[2] + c[3] * u[3];   WRITELN ('Shortest distance is', d:6:2) END. </pre>	<table border="1" style="border-collapse: collapse; width: 100%;"> <tr> <td style="width: 10%;">coord</td> <td style="width: 90%;"></td> </tr> <tr> <td>[1]</td> <td>4</td> </tr> <tr> <td>[2]</td> <td>8</td> </tr> <tr> <td>[3]</td> <td>10</td> </tr> <tr> <td>[4]</td> <td>9</td> </tr> <tr> <td>[5]</td> <td>16</td> </tr> <tr> <td>[6]</td> <td>17</td> </tr> <tr> <td>[7]</td> <td>6</td> </tr> <tr> <td>[8]</td> <td>3</td> </tr> <tr> <td>[9]</td> <td>5</td> </tr> <tr> <td>[10]</td> <td>10</td> </tr> <tr> <td>[11]</td> <td>11</td> </tr> <tr> <td>[12]</td> <td>15</td> </tr> </table> <table border="1" style="border-collapse: collapse; width: 100%;"> <tr> <td style="width: 10%;">a</td> <td style="width: 90%;"></td> </tr> <tr> <td>[1]</td> <td>5</td> </tr> <tr> <td>[2]</td> <td>8</td> </tr> <tr> <td>[3]</td> <td>7</td> </tr> </table> <table border="1" style="border-collapse: collapse; width: 100%;"> <tr> <td style="width: 10%;">b</td> <td style="width: 90%;"></td> </tr> <tr> <td>[1]</td> <td>4</td> </tr> <tr> <td>[2]</td> <td>8</td> </tr> <tr> <td>[3]</td> <td>10</td> </tr> </table> <table border="1" style="border-collapse: collapse; width: 100%;"> <tr> <td style="width: 10%;">c</td> <td style="width: 90%;"></td> </tr> <tr> <td>[1]</td> <td>1</td> </tr> <tr> <td>[2]</td> <td>-5</td> </tr> <tr> <td>[3]</td> <td>-2</td> </tr> </table> <table border="1" style="border-collapse: collapse; width: 100%;"> <tr> <td style="width: 10%;">u</td> <td style="width: 90%;"></td> </tr> <tr> <td>[1]</td> <td>-716</td> </tr> <tr> <td>[2]</td> <td>-656</td> </tr> <tr> <td>[3]</td> <td>239</td> </tr> </table>	coord		[1]	4	[2]	8	[3]	10	[4]	9	[5]	16	[6]	17	[7]	6	[8]	3	[9]	5	[10]	10	[11]	11	[12]	15	a		[1]	5	[2]	8	[3]	7	b		[1]	4	[2]	8	[3]	10	c		[1]	1	[2]	-5	[3]	-2	u		[1]	-716	[2]	-656	[3]	239
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$\vec{u} = \vec{a} \times \vec{b}$   
 $= \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$   
 $= c_1 \vec{i} + c_2 \vec{j} + c_3 \vec{k}$

$\vec{c} = \vec{a} - \vec{b}$   
 $= \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$   
 $= c_1 \vec{i} + c_2 \vec{j} + c_3 \vec{k}$

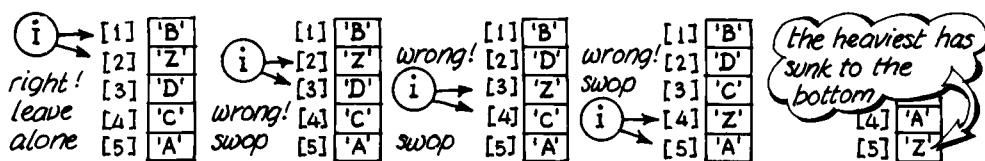
$d = \vec{c} \cdot \vec{u}$

# BUBBLE SORT

DAMNED BY ONE OF MY REVIEWERS AS  
"UNBEATABLE IN ITS INEFFICIENCY"

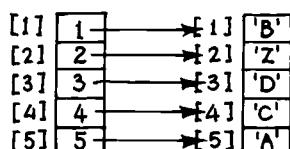
There are many methods of sorting the contents of an array; a simple technique is the *bubble* or *ripple* sort described below.

To demonstrate the method, take a list of letters. "Index" the first letter and the one following. If the letters indexed are in the right order, leave them alone and advance the index one row. If the letters are in the wrong order, swap them and advance the index one row. Stop one row before the end of the list so as to prevent the second index pointing off the end. Here is the method depicted:



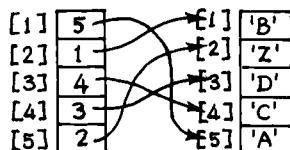
Having sunk the heaviest letter to the bottom it remains to sort the list of letters above it. We set about this precisely as we set about sorting the full list; in other words invoke the same procedure recursively.

The tidiest approach to sorting items is to set up an array of pointers to the items:



pointers      letters

And swap pointers rather than the items themselves. When the sorting is finished the arrays should look like this:



e.g. letters[pointers[4]] is 'D'

pointers      letters

This approach holds no particular merit if the aim is only to sort a few letters. But in the real world there might be a lot of information associated with each of the items to be sorted. There is less work in moving one pointer than moving all the information pointed to.

Here is a complete program to sort letters:

```
PROGRAM bubbles ( INPUT, OUTPUT );
  TYPE sizetype = 0..30;
  VAR pointers : ARRAY [sizetype] OF sizetype;
      letters : ARRAY [sizetype] OF CHAR;
      key: CHAR; n, i : sizetype;
  PROCEDURE swop ( VAR p, q : sizetype );
    VAR tempry : sizetype;
  BEGIN
    tempry := p; p := q; q := tempry
  END;
  PROCEDURE sort ( first, last: sizetype );
    VAR i: sizetype; sorted: BOOLEAN;
  BEGIN { sort }
    IF first < last THEN
      BEGIN
        sorted := TRUE;
        FOR i := first TO last-1 DO
          BEGIN
            IF letters [pointers[i]] > letters [pointers[i+1]] THEN
              BEGIN
                swop ( pointers[i], pointers[i+1] );
                sorted := FALSE
              END { if letters }
            END; { for i }
            IF NOT sorted THEN sort (first, last-1)
          END { if first < last }
      END; { sort }
  BEGIN { bubbles }
    READLN (n); insert: WRITELN('Number of letters?')
    FOR i := 1 TO n DO if your Pascal is interactive
      BEGIN
        READLN (letters[i]);
        pointers[i] := i
      END;
    sort (1, n); sort them
    WRITELN;
    FOR i := 1 TO n DO display them in order
      WRITE (letters [pointers[i]]);
  END. { bubbles }
```

*SORTING PROCEDURE*

*recursive invocation*

*read letters one by one & set up pointers*

*display them in order*

*Number of letters?*

5
B
Z
D
C
A
ABCDZ

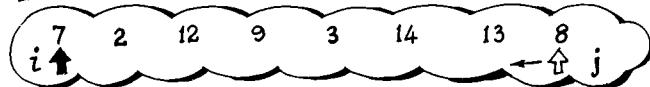
Although the bubble sort is inefficient at sorting a jumbled list, a list in which only one or two items are out of place is sorted very quickly.

# QUICKSORT

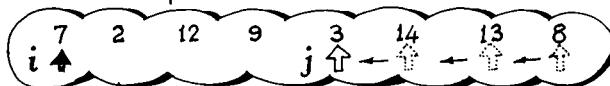
## AN EXAMPLE TO ILLUSTRATE RECURSION AND ANOTHER METHOD OF SORTING

The sorting method called Quicksort was devised by Prof. C.A.R. Hoare. The interpretation below has been formulated to illustrate principles of the method rather than as a practical procedure.

Take some numbers to sort:



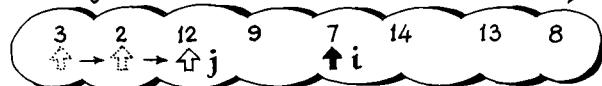
Set pointers  $i$  and  $j$  at each end of the list as shown. Move  $j$  towards  $i$ . If  $j$  points to a bigger number than  $i$  does, move  $j$  another step towards  $i$ .



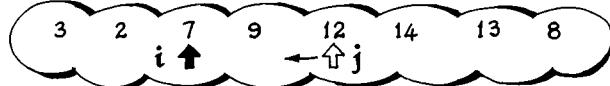
Now  $j$  points to a smaller number than  $i$  does. So swap the two numbers pointed to, and swap the pointers  $i$  and  $j$  as well:



Continue moving  $j$  towards  $i$  (which now means stepping rightwards instead of leftwards). If  $j$  points to a smaller number than  $i$  does, move  $j$  another step towards  $i$ . (Notice that the condition for continuing to move  $j$  towards  $i$  has been reversed.)



Now  $j$  points to a bigger number than  $i$  does. Swap numbers, pointers, direction and condition exactly as before:

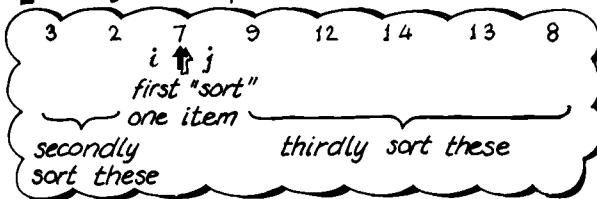


And so on, swopping if necessary (as already illustrated) until  $j$  meets  $i$ :



At which stage it is true to say that every number to the left of  $i$  is at least as small as the number pointed to; every number to the right of  $i$  is at least as big. In other words the number pointed to has found its resting place. The numbers to the left of  $i$  have not, however, been sorted; nor have those to the right of  $i$ . But, having described a procedure for locating a resting place which splits a group into two, it remains only to sort the groups to the left and right of  $i$ , starting out in each case in the manner already described in detail above.

The logic is depicted below:



Recursion is applicable when a problem can be reduced to an identical problem  $\rightsquigarrow$  or identical problems  $\rightsquigarrow$  of smaller size. The recursive procedure must, of course, provide the means of escape when the size of problem has been reduced enough. In the case of sorting this should be when the procedure is called upon to sort a single item.

Here is a Quicksort procedure that may be used in place of the bubble sort procedure described on the previous double page:

```
PROCEDURE sort( first, last : sizetype );
  VAR
    i, j : sizetype; jstep: -1..1; condition: BOOLEAN;
  BEGIN
    IF first < last
    THEN
      BEGIN
        i := first; j := last;
        jstep := -1;
        condition := TRUE;
        REPEAT
          IF condition = (letters[pointers[i]] > letters[pointers[j]]) THEN
            BEGIN
              swop (pointers[i], pointers[j]);
              swop (i, j);
              jstep := -jstep;
              condition := NOT condition
            END;
          j := j + jstep
        UNTIL j = i;
        sort (first, i-1);
        sort (i+1, last)
      END { if first < last }
    END; { sort }
```

Annotations for the Quicksort procedure:

- Cloud: "nothing to sort unless first < last"
- Cloud: "SUBSTITUTE THIS PROCEDURE IN THE PROGRAM ON THE PREVIOUS DOUBLE PAGE"
- Cloud: "effectively swap items"
- Cloud: "swap pointers"
- Cloud: "reverse direction"
- Cloud: "reverse condition"
- Cloud: "recursive invocations"
- Cloud: "escape if nothing to sort"

Notice how the condition is switched between  $\leq$  and  $>$ . The logical expression:  $(\text{letters}[\text{pointers}[i]] \leq \text{letters}[\text{pointers}[j]])$  takes the value *true* or *false*. This value is compared with the Boolean value stored in the variable named *condition* which is made alternately *true* and *false* by *NOT*.

Every time the procedure invokes itself the computer has to store away values of its parameters and local variables for possible re-use on return as illustrated by a simpler example of recursion on page 65. In the above example it would be possible to make *jstep* and *condition* global, and so save storage space. But with problems the size of those illustrated in this book it would be silly to do so.

# PACKING

A BALANCE BETWEEN SPEED AND SPACE  
(SOME COMPILERS PACK AUTOMATICALLY & REGARDLESS)

A Boolean value needs only a single bit (i.e. binary digit) for representation ; a character typically requires four bits ; an integer 16 or 32 bits . But the unit of storage in a computer is its word. The size of this word is dependent on the make and model of computer, 32 bits being typical. It follows that storing Boolean values and characters (perhaps even integers) one per word is wasteful of space.

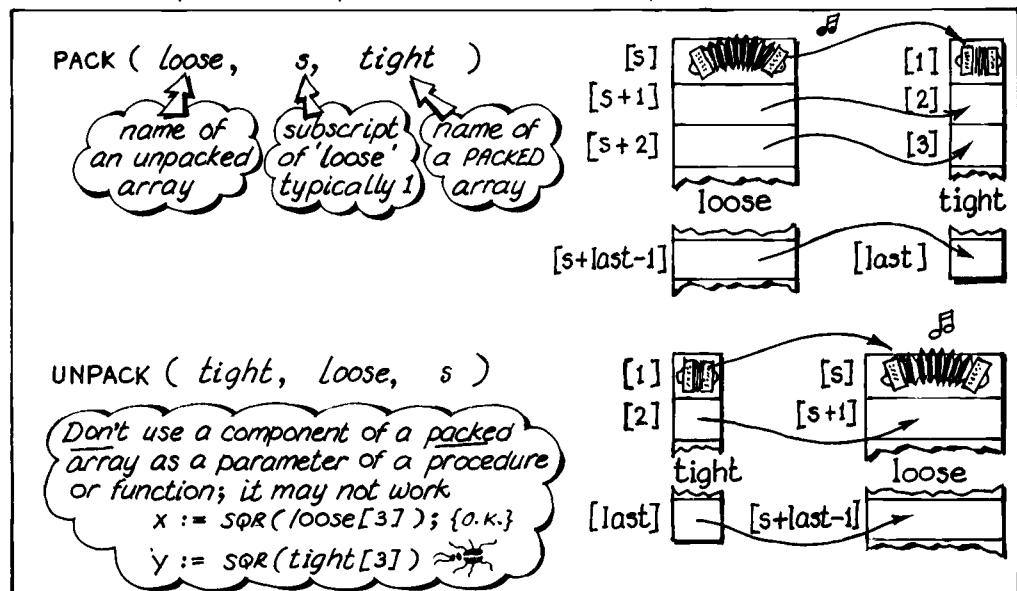
In Pascal the word PACKED in the definition of an array (or record) gives the compiler permission to pack information more tightly than one item per word. For example:

PACKED ARRAY [1..32768] OF BOOLEAN

might result in the compiler packing the components of this array thirty-two to the word, making something feasible that would otherwise be infeasible. (Some modern compilers pack automatically.)

The price to be paid for saving space is slower retrieval during execution.

Space and speed on some systems may be balanced by packing selectively; say by working on an unpacked array, then copying its contents into a packed array for storage. Procedures PACK and UNPACK are provided by Pascal for such purposes.



Below are two typical invocations of these standard procedures:

```
VAR prolix: ARRAY [1..1000] OF CHAR;
      pith: PACKED ARRAY [1..1000] OF CHAR;
```

```
PACK( prolix, 1, pith );
```

```
UNPACK( pith, prolix, 1 );
```

# INTRODUCING STRINGS

SOME PASCALS HAVE A SPECIAL TYPE FOR THIS

A *string constant* comprises characters enclosed between apostrophes. An apostrophe which is to become part of a string must be written as a pair of apostrophes:

WRITELN( 'Ooh!', 'It "s cold!' )



Ooh! It's cold!

For a *string variable* standard Pascal makes do with a **PACKED ARRAY [ ] OF CHAR**:

VAR shiver: PACKED ARRAY [1..10] OF CHAR



shiver

1.....10

String constants may be assigned to string variables:

shiver := 'It "s cold'  
WRITELN( 'Ooh!', shiver )



Ooh! It's cold!

But in standard Pascal the assignment is allowed only if the constant has the same number of characters as the packed array:

shiver := 'Ooh!';   
shiver := 'Ooh!!!!'; { O.K. }

MANY MODERN PASCAL  
COMPILERS RELAX THIS RESTRI-  
CTION OF EQUAL LENGTH

Comparison of strings is allowable provided that the number of characters is the same in each. Any comparator ( $=, <, >, \geq$  etc.) may be applied:

WRITELN( shiver = 'Ooh!!!!');  
WRITELN( shiver > 'Ooh!');



TRUE  
Error

The basis of comparison is *ordinal value*. Characters are compared from the left of each string until a mismatch is found. The string in which this mismatching character has the greater ordinal value is considered the greater string. No mismatching character implies the equality of strings:

'a' < 'b'

'abcz' < 'abda'

'abcdef' = 'abcdef'

true,  
ORD('a') < ORD('b')

true,  
ORD('c') < ORD('d')

true,  
no mismatch

Except for the properties of sequences '0' to '9', 'A' to 'Z' and 'a' to 'z' defined by Pascal the ordinal values of characters depend on the character set on the particular installation; typically ASCII.

Individual characters of a string variable may be manipulated:

FOR i := 1 TO 5 DO  
shiver[i+5] := shiver[i];  
WRITELN( shiver )



OooohOoooh

but not all Pascals allow components of *packed arrays* ( see opposite ) to be used as parameters of procedures: `WRITE(shiver[i])`, for example, might have to be recast as: `ch := shiver[i]; WRITE(ch)`.

These facilities, although limited, are enough for constructing a set of powerful string-handling procedures as demonstrated in chapter 13.

# PARLOUR TRICK

## ILLUSTRATING THE MANIPULATION OF STRINGS AS ARRAYS

**A**maze your friends. Write down a long multiplication such as this; then start writing down the answer, digit by digit, from right to left, carrying all the working in a cool head.

$$\begin{array}{r}
 4675 \\
 \times 389 \\
 \hline
 \end{array}$$

The trick is mentally to reverse the bottom number, mentally shunting it leftwards past the top number. At each shunt multiply only the digits lying beneath one another, summing the products. Write down the last digit of this sum and carry the rest into the next shunt. The entire process is depicted down the right of the page.

To see how it works, consider each number as a polynomial in 10. In every shunted position the products of terms lying one above the other yield the same power of 10. Furthermore these terms are the *only* terms in the same power of 10 (but not forgetting the carry from above).

$$4 \times 10^3 + 6 \times 10^2 + 7 \times 10^1 + 5 \times 10^0$$

$$\underline{9 \times 10^0 + 8 \times 10^1 + 3 \times 10^2}$$

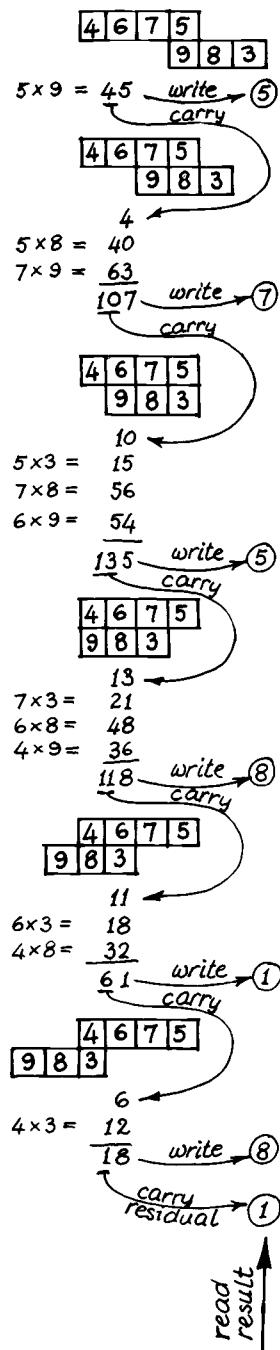
$$54 \times 10^2 + 56 \times 10^2 + 15 \times 10^2$$

e.g. all the terms in  $10^2$

The program opposite automates the method of multiplication described above. It can cope with any reasonable length of multiplication by adjusting the constants *termlimit* and *prodlimit*. As set opposite, the program can multiply terms as long as 20 digits giving a product as long as 40 digits.

To use the program type two terms separated by an asterisk and terminated by an equals sign. Then press **RETURN**.

$$\begin{array}{r} 4675 \times 389 = \\ 1818575 \end{array}$$



```

PROGRAM parlour ( INPUT, OUTPUT );
CONST
  termlimit = 20;  prodlimit = 40;
TYPE
  termspan = 0..termlimit;
  prodspan = 0..prodlimit;
  termtype = PACKED ARRAY [termspan] OF CHAR;
  prodtype = PACKED ARRAY [prodspan] OF CHAR;
VAR
  a, b : termtype;  c: prodtype;  sum, offset: INTEGER;
  na, nb: termspan;  i, k: prodspan;
PROCEDURE backhand ( VAR x:termtype; VAR count:termspan );
  VAR
    i: INTEGER;  buffer: termtype;
  BEGIN
    i := 0;
    REPEAT
      READ( buffer[i] );
      i := SUCC(i);
    UNTIL ( buffer[i-1] = '*' )
      OR ( buffer[i-1] = '=' );
    count := i-2;
    FOR i := 0 TO count DO
      x[i] := buffer[count-i];
  END;  { backhand }

  BEGIN { parlour }

    backhand ( a, na );
    backhand ( b, nb );
    sum := 0;
    offset := ORD('0');

    FOR k := 0 TO na+nb DO
      BEGIN
        FOR i := 0 TO k DO
          IF ( i <= na ) AND ( (k-i) <= nb )
          THEN
            sum := sum + (ORD(a[i])-offset)*(ORD(b[k-i])-offset);
            c[k] := CHR( sum MOD 10 + offset );
            sum := sum DIV 10;
        END;
        residual carry;
      IF sum = 0 THEN i := na+nb ELSE i := na+nb+1;
      FOR k := i DOWNTO 0 DO
        WRITE ( c[k] );
      WRITELN;
    END. { parlour }
  
```

*'backhand' does 3 things*

(i) reads a term into a buffer:

4	6	7	5	*	3
0	1	2	3	4	

count

(ii) counts digits from 0

(iii) reverses digits into x[]

4	6	7	5
3	2	1	0

*"shunts" as explained opposite*

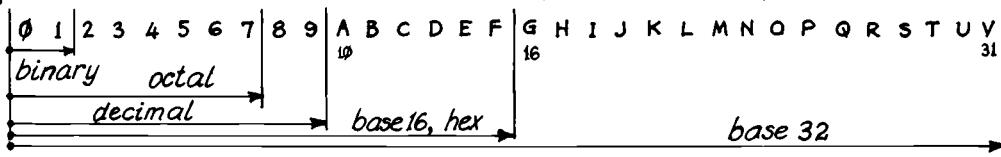
3	2	1	0
a	→	{ 4   6   7   5 }	na
9	8	3	2
0	1	2	nb

but suppress any leading zero

# NUMBER BASES

## MORE MANIPULATION OF STRINGS AS ARRAYS OF CHARACTERS

A decimal (base 10) number is a polynomial in ten as emphasized on the previous page. Similarly a *hex* number (base 16) is a polynomial in sixteen, an *octal* number (base 8) a polynomial in eight, and so on. In general, a number to base  $b$  is a polynomial in  $b$  and  $b$  digits are required to express it. For digits bigger than 9, capital letters are pressed into service; letters A to V cope with bases up to base 32.



In the following program characters '0' to 'V' are held as a string constant (`refconst`) which is assigned to a packed array of characters named `refstring`. This array is used in two ways. Given a character representing a digit (say a hex digit) the corresponding numerical value may be found by matching the digit against each character in turn, the array subscript indicating ordinal value when a match is found. Conversely, by using the ordinal value as an array subscript the corresponding character may be picked out without need of a search.

The above principles are employed in procedures `find` and `outdigit` respectively. Unfortunately some Pascals forbid assignment of a string constant to an array of the type:

PACKED ARRAY [ 0..31 ] OF CHAR

insisting that the lower bound be always unity, e.g. [ 1..32 ]. The array subscript therefore cannot express ordinal value directly but has to be offset by 1. Not nice.

The program is designed to read a number expressed relative to one base and write the same number expressed to another base. For example if the program were given:



it would convert the 112D from hex to octal and display 10455.

The program first looks up the ordinal values of digits D, 2, 1, 1 and evaluates a polynomial in 16:

$$13 \times 16^0 + 2 \times 16^1 + 1 \times 16^2 + 1 \times 16^3 = 4397$$

↳ corresponds to D      ↳ decimal

The looking up is done by procedure `find` and the polynomial is evaluated by procedure `decimal`. Notice that `find` returns -1 if unable to find a match within the range of the current base. If `decimal` receives -1 from `find` it returns a zero result to the main program.

```

PROGRAM bases( INPUT, OUTPUT );
CONST
  stringlength = 32;
  refconst = '0123456789ABCDEFGHIJKLMNPQRSTUVWXYZ';

```

'refconst' is assigned to  
'refstring' in the main program

```

TYPE
  stringrange = 1..stringlength;
  stringtype = PACKED ARRAY [stringrange] OF CHAR;
  basetype = 2..32;
  number = 0..MAXINT;

VAR
  instring, outstring, refstring : stringtype;
  inlength, outlength : stringrange;
  ch: CHAR; dec, i : number;
  basenow, baserequired : basetype;

```

```

FUNCTION find( ch: CHAR; base: basetype ) : INTEGER;

```

```

  VAR
    found: BOOLEAN; i: number;

```

```

  BEGIN

```

```

    i := 1;

```

```

    REPEAT

```

```

    found := ( ch= refstring[i] );

```

```

    IF NOT found THEN i:= SUCC(i)

```

```

    UNTIL found OR ( i > base );

```

```

    IF found

```

```

      THEN find := i-1

```

```

      ELSE find := -1

```

do not search  
beyond range  
of given base

```

  END;

```

```

FUNCTION decimal( string: stringtype; length: stringrange;
  base: basetype ) : INTEGER;

```

```

  VAR

```

```

    digit, power: INTEGER; n: number;

```

```

    i: stringrange; silly: BOOLEAN;

```

```

  BEGIN

```

```

    n := 0; silly := FALSE; power := 1;

```

```

    FOR i:= length DOWNTO 1 DO

```

```

    BEGIN

```

```

      digit := find( string[i], base );

```

```

      IF digit < 0

```

```

        THEN

```

```

        silly := TRUE

```

```

      ELSE

```

```

        BEGIN

```

```

          n := n + digit * power;

```

```

          power := power * base

```

```

        END

```

```

      END;

```

```

      IF silly THEN decimal := 0

```

```

      ELSE decimal := n

```

e.g. if base = 16  
then 'power' goes  
1, 16, 16<sup>2</sup>, 16<sup>3</sup>...

```

    END;

```

continued overleaf

# NUMBER BASES (CONTINUED)

To convert the intermediate decimal value to a number expressed to a new base the program keeps dividing by the new base, taking note of the remainders. The remainders are the ordinal values of the result in reverse order.

$$\begin{array}{r}
 8) 4397 \\
 8) 549 \\
 8) 68 \\
 8) 8 \\
 8) 1 \\
 \hline 0
 \end{array}
 \begin{array}{r}
 \text{rem } 5 \\
 \text{rem } 5 \\
 \text{rem } 4 \\
 \text{rem } 0 \\
 \text{rem } 1
 \end{array}
 \begin{array}{l}
 \uparrow \\
 \uparrow
 \end{array}$$

The ordinal values 10455 are looked up in the array of characters to give the digits of the result. These are 10455 ≈ apparently not worth "looking up". But if the required base were to be 32 the ordinal values would be 4, 9, 13. Looking these up in the array would give 49D.

$$\begin{array}{r}
 32) 4397 \\
 32) 137 \\
 32) 4 \\
 \hline 0
 \end{array}
 \begin{array}{r}
 \text{rem } 13 \\
 \text{rem } 9 \\
 \text{rem } 4
 \end{array}
 \begin{array}{l}
 \uparrow \\
 \uparrow
 \end{array}$$

Conversion to the required base is performed by procedure *outdigit*. Recursion is used to solve the problem of digits being computed in reverse order.

```
PROCEDURE outdigit(n: number; base: basetype);
```

```
VAR
```

```
m: number; c: CHAR;
```

```
BEGIN
```

```
m := n DIV base;
```

```
c := refstring [l + (n MOD base)];
```

```
IF m <> 0
```

```
THEN
```

```
outdigit(m, base);
```

```
WRITE(c)
```

```
END;
```

"look up" digit  
e.g. 8 gives 8  
13 gives D

recursion to write  
digits in reverse order

```
BEGIN { PROGRAM }
```

```
refstring := refconst;
```

```
i := 1;
```

```
REPEAT
```

```
READ(ch);
```

```
instrstring[i] := ch;
```

```
i := SUCC(i);
```

```
UNTIL ch = ',';
```

```
inlength := i - 2;
```

```
READLN(basenow, baserequired);
```

```
dec := decimal(instrstring, inlength, basenow);
```

```
outdigit(dec, baserequired);
```

```
Writeln
```

```
END.
```

INPUT →  
OUTPUT →

112D 16 8  
10455

10455 8 16  
112D

# MATRIX MULTIPLICATION

ILLUSTRATING 2D ARRAYS AS MATRICES

There are three sales people selling four products. Quantities sold are tabulated in table A.

PRODUCT	
1]	2]
1, [1, 1.50 0.20	
2, 2.80 0.40	
3, 5.00 1.00	
4, 2.00 0.50	

PRICE COMMISSION

And the commissions earned as follows:

SALES PERSON [1 5 * 0.20 + 2 * 0.40 + 0 * 1.00 + 10 * 0.50 = 6.80
PERSON [2 3 * 0.20 + 5 * 0.40 + 2 * 1.00 + 5 * 0.50 = 7.10
PERSON [3 20 * 0.20 + 0 * 0.40 + 0 * 1.00 + 0 * 0.50 = 4.00

PRODUCT		1]	2]	3]	4]
SALES PERSON	1,	5	2	0	10
	2,	3	5	2	5
	3,	20	0	0	0

Table B shows the price of each product and the commission earned for selling each item.

The money brought in is calculated as follows:

$$\begin{array}{l} \text{SALES PERSON [1 } 5 * 1.50 + 2 * 2.80 + 0 * 5.00 + 10 * 2.00 = 33.10 \\ \text{PERSON [2 } 3 * 1.50 + 5 * 2.80 + 2 * 5.00 + 5 * 2.00 = 38.50 \\ \text{PERSON [3 } 20 * 1.50 + 0 * 2.80 + 0 * 5.00 + 0 * 2.00 = 30.00 \end{array}$$

This computation is called matrix multiplication and looks best set out thus:

$$\begin{array}{c} 1] 2] 3] 4] \quad 1] 2] \quad 1] 2] \\ A [1, \begin{bmatrix} 5 & 2 & 0 & 10 \end{bmatrix} * B [1, \begin{bmatrix} 1.50 & 0.20 \end{bmatrix} = C [1, \begin{bmatrix} 33.10 & 6.80 \end{bmatrix} \\ A [2, \begin{bmatrix} 3 & 5 & 2 & 5 \end{bmatrix} \quad B [2, \begin{bmatrix} 2.80 & 0.40 \end{bmatrix} = C [2, \begin{bmatrix} 38.50 & 7.10 \end{bmatrix} \\ A [3, \begin{bmatrix} 20 & 0 & 0 & 0 \end{bmatrix} \quad B [3, \begin{bmatrix} 5.00 & 1.00 \end{bmatrix} = C [3, \begin{bmatrix} 30.00 & 4.00 \end{bmatrix} \\ \quad B [4, \begin{bmatrix} 2.00 & 0.50 \end{bmatrix} \end{array}$$

the number of columns of A must be the same as the number of rows of B and the result has as many rows as A & as many columns as B

Here is a program to input data for matrices A & B, multiply them together, then display their product, matrix C:

```
PROGRAM sales ( INPUT, OUTPUT );
TYPE
  atype = ARRAY [ 1..3, 1..4 ] OF INTEGER;
  btype = ARRAY [ 1..4, 1..2 ] OF REAL;
  ctype = ARRAY [ 1..3, 1..2 ] OF REAL;
VAR
  a: atype; b: btype; c: ctype; n,i,j,k: INTEGER;
BEGIN
  FOR n := 1 TO 3 DO
    READLN( a[n,1], a[n,2], a[n,3], a[n,4] );
  FOR n := 1 TO 4 DO
    READLN( b[n,1], b[n,2] );
  FOR i := 1 TO 2 DO
    FOR j := 1 TO 3 DO
      BEGIN
        c [i,j] := 0;
        FOR k := 1 TO 4 DO
          c [j,i] := c [j,i] + a [j,k] * b [k,i];
      END;
    FOR n := 1 TO 3 DO WRITELN( c[n,1]:8:2, c[n,2]:8:2 )
  END.
```

try this with the values in A & B above

# CONFORMANT ARRAY PARAMETERS

DEEP  
BREATH  
IN...

The program on the previous page could be recast by parcelling the matrix multiplication as a procedure:

```
PROCEDURE matmul (VAR p: atype; VAR q: btype; VAR r: ctype);
  VAR
    i, j, k : INTEGER;
  BEGIN
    FOR i := 1 TO 2 DO
      FOR j := 1 TO 3 DO
        BEGIN
          r[j, i] := 0;
          FOR k := 1 TO 4 DO
            r[j, i] := r[j, i] + p[j, k] * q[k, i]
        END
    END;
  END;
```

although p&q are not altered by this procedure, parameters which are names of arrays should always be VAR parameters; otherwise the program has to take copies of the arrays on each invocation. NB!

The main program then simplifies to:

```
BEGIN {PROGRAM}
  FOR n := 1 TO 3 DO
    READLN (a[n,1], a[n,2], a[n,3], a[n,4]);
  FOR n := 1 TO 4 DO
    READLN (b[n,1], b[n,2]);
  matmul (a, b, c); invoke the procedure for arrays a, b, c
  FOR n := 1 TO 3 DO WRITELN (c[n,1]:8:2, c[n,2]:8:2)
END.
```

This is fine provided that the ranges of  $i$ ,  $j$  and  $k$  in the FOR loops of *matmul* conform to the dimensions of arrays of *atype*, *btype* and *ctype* as declared in the TYPE section of the main program:

```
TYPE
  atype = ARRAY [1..3, 1..4] OF INTEGER;
  btype = ARRAY [1..4, 1..2] OF REAL;
  ctype = ARRAY [1..3, 1..2] OF REAL
```

But if circumstances made the programmer expand the dimensions of these array-types then the programmer would have to change the ranges of  $i$ ,  $j$ ,  $k$  in the FOR loops of *matmul*, making them conform to the new dimensions. A potential source of trouble.

A partial solution to the problem has been specified in Pascal to BS6192. When using arrays as parameters (such as  $p$ ,  $q$ ,  $r$  in *matmul*) the idea is to declare them as *conformant arrays*. A conformant array is one that *conforms* in dimensionality and in its type of component with the type of an array declared in an outer block (typically in the TYPE section of the main program). The programmer tells the Pascal compiler that an array is *conformant* by specifying *conformant array parameters*. At the top of the opposite page is the *matmul* procedure rewritten so as to contain conformant array parameters.

```

PROCEDURE matmul( VAR p: ARRAY [1..rp:INTEGER; 1..cp:INTEGER] OF INTEGER;
                   VAR q: ARRAY [1..cp:INTEGER; 1..cq:INTEGER] OF REAL;
                   VAR r: ARRAY [1..rp:INTEGER; 1..cq:INTEGER] OF REAL);
  VAR i, j, k: INTEGER;
BEGIN
  FOR i := 1 TO cq, DO
    FOR j := 1 TO rp DO
      BEGIN
        r[j, i] := 0;
        FOR k := 1 TO cp DO
          r[j, i] := r[j, i] + p[j, k] * q[k, i];
      END;
  END;

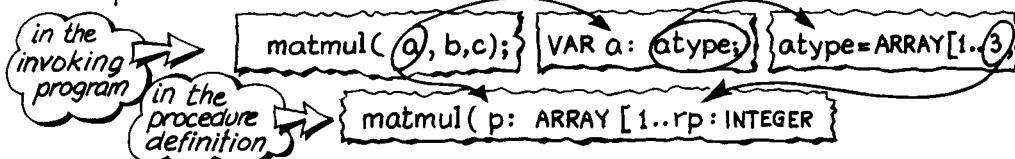
```

this is a conformant array parameter;  $r$  is the conformant array which must "conform" in dimensionality and component-type and state of packing with any array nominated as an actual parameter

The invocation of *matmul* remains exactly as before:

```
matmul( a, b, c );
```

So how is *matmul* to know the values for  $cq$ ,  $rp$  and  $cp$ ? That is the clever bit. Conformant array parameters provide enough information for *matmul* to peep at the declarations of these arrays in the invoking program. Here it is pictorially for array  $p$  when the program invokes *matmul* with actual parameter  $a$ :



Provided that arrays  $p$  and  $a$  are conformant (both two-dimensional; both with components of type INTEGER; both unpacked) each name such as  $rp$  becomes associated with a dimension such as 3.

Conformant array parameters do not provide dynamic array bounds, only the ability to pick up automatically the fixed dimensions declared in the original TYPE declaration. A complicated facility for achieving little. Few Pascals provide conformant array parameters.

Dynamic array bounds of limited scope may be simulated by declaring oversized arrays and making parameters of the current dimensions. The following fragments of program should convey the idea:

```
TYPE atype = ARRAY [1..20, 1..20];
```

oversized declarations

```
PROCEDURE matmul(p:atype; q:btype; r:ctype; i,j,k:INTEGER);
```

```
matmul( a, b, c, 2, 3, 4 );
```

dimensions as parameters

Conformant array parameters would enable *matmul* to tell only that the maximum allowable dimensions were 20.

BREATHE... OUT!

# EXERCISES

1. Implement bubbles with the constant named `sizetype` set to a more challenging size than 30 (say 100 or 150). Then take some timings:

- when the input sequence is made random by stabbing at the keyboard without trying to make a pattern
- when the input sequence is generally sorted:

AAAA BB CCCCCC DDE ...

but with the occasional letter out of sequence:

... EZ FFFF GGGG ...



2. Repeat the exercise using Quicksort (page 87) in place of bubble sort (page 85). What conclusions do you draw from the results?

3. Using program bases as a model, develop specific procedures for:

- converting from hex to decimal
- converting from decimal to hex

By removing the generality from bases you should end up with two short, elegant and useful procedures.

4. If you are familiar with matrix algebra develop a set of procedures like `matmul` for addition, transposition and (a challenge) inversion. Use parameters for current dimensions as described at the bottom of the previous page.

# 9

## RECORDS

INTRODUCING RECORDS  
SYNTAX OF RECORDS  
PERSONNEL RECORDS (EXAMPLE)  
THE *WITH* STATEMENT  
INTRODUCING VARIANTS

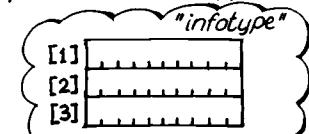
# INTRODUCING RECORDS

ONCE YOU HAVE SEEN  
THE BEAUTY OF A RECORD...

Whereas an array is an arrangement of components of identical type, a record is an arrangement of components generally of different type. Compare the following type of array: ➔

TYPE

```
nametype = PACKED ARRAY [1..10] OF CHAR;
infotype = ARRAY [1..3] OF nametype;
```

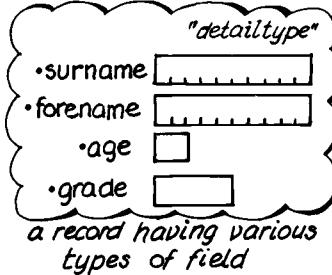


an array of packed arrays

with this type of record: ➔

TYPE

```
nametype = PACKED ARRAY [1..10] OF CHAR;
detailtype =
RECORD
  surname, forename: nametype;
  age : 18 .. 65;
  grade: (jr, sr, exec)
END
```

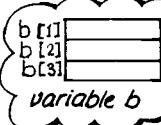
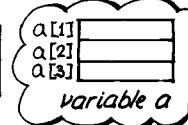


a record having various types of field

Just as variables may be whole arrays:

VAR

```
a, b : infotype;
```



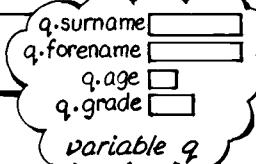
variable a

variable b

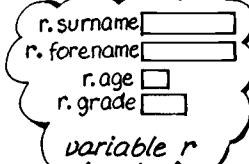
so may variables be whole records:

VAR

```
q, r : detailtype;
```



variable q



variable r

Much as components of arrays are addressed by subscripts (in square brackets):

```
a[1] := 'Wilberforc'; b[2] := a[1];
```

a[1] Wilberforc

b[2] Wilberforc

the components of records are addressed by field name (after a full stop):

```
q.surname := 'Wilberforc';
q.age := 22; q.grade := jr;
r.forename := q.surname;
```

q.surname Wilberforc

q.age 22

q.grade jr

r.forename Wilberforc

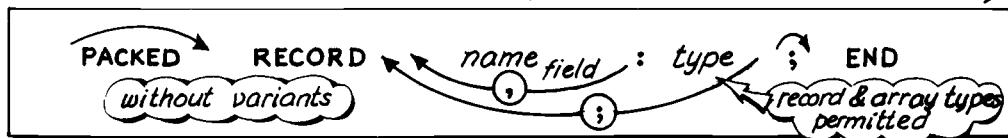
The sketches illustrate records which have components of various types including packed arrays. Conversely, the components of an array may be records. The only restriction to the mixture of types in arrays and records concerns arrays: in any one array all components must be of the same type. An example of an array of records is:

```
VAR people: ARRAY [1..100] OF detailtype
```

'people' is now an array of 100 personnel records

# SYNTAX OF RECORDS

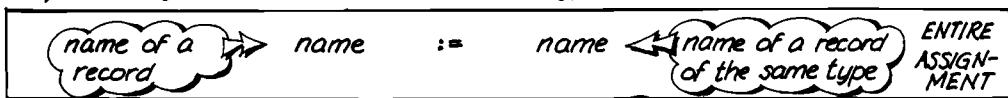
The syntax of record type (excluding variants which are explained later) is:



The syntax for referring to a component of a record is:



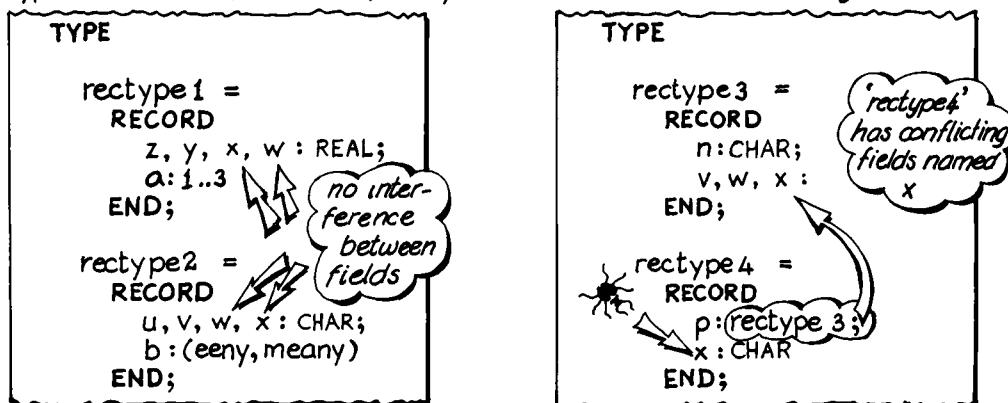
Whereas arrays are manipulated by means of *subscripts*, records are manipulated by means of *field names* which are analogous to subscripts. But there is an important exception; a copy of the *entire* content of one record may be assigned to another of the same type in a single operation:



where "same type" means a type with the same name; a type with the same specification is not enough. A similar requirement applying to the entire assignment of arrays is illustrated on page 81.

The word PACKED in front of RECORD implies the same thing as it does in front of ARRAY. A packed record occupies less space than the corresponding unpacked record at the cost of slower retrieval during execution. The procedures PACK and UNPACK (page 88) are not applicable to records; only to arrays.

In any one type of record  $\rightsquigarrow$  including all records that may be nested within it  $\rightsquigarrow$  every field name must be unique. Field names in different types of record, however, may be identical without causing interference:



# PERSONNEL RECORDS

AN EXAMPLE ILLUSTRATING THE USE OF RECORDS

This program prompts for an employee's surname, forename, age and executive grade. Terminate every answer by pressing the RETURN key. When there are no more records the program sorts all given records by each of four sorting keys :

- surname ( alphabetical order )
- forename ( alphabetical order )
- age ( ascending numerical order )
- grade ( ascending ordinal value : JR, SR, EXEC )

OUTPUT

DAVIS	SAMUEL	64	Junior
HAIG	JOHN	40	Executive
***			
HAIG	JOHN	40	Executive
DAVIS	SAMUEL	64	Junior
***			
HAIG	JOHN	40	Executive
DAVIS	SAMUEL	64	Junior
***			
DAVIS	SAMUEL	64	Junior
HAIG	JOHN	40	Executive

by surname  
by forename  
by age  
by grade

More? (Y/N): Y  
Surname? (<=10chars): HAIG  
Forename? (<=10chars): JOHN  
Age? (18 to 65): 40  
Grade? (JR, SR, EXEC): EXEC  
More? (Y/N): Y  
Surname? (<=10chars): DAVIS  
Forename? (<=10chars): SAMUEL  
Age? (18 to 65): 64  
Grade? (JR, SR, EXEC): JR  
More? (Y/N): N

INPUT

There are minimal checks on data. A grade other than JR, SR or EXEC is treated as JR by default; a response to More? other than Y implies N; other errors (such as a name longer than 10 letters) are trapped by the Pascal processor.

The example shown here assumes a Pascal processor that can be used interactively. Chapter 11 describes some of the potential hiccups caused by interactive input.

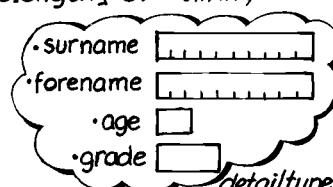
The allowable length of name and allowable number of records are set into constants for ease of adjustment. The type of personnel record is that already illustrated and depicted again below. Associated with its fields ( surname, forename, age and grade ) are elements of an enumerated keytype ( lastname, firstname, decrepitude and clout ). This is used in the sorting procedure for locating the appropriate sorting key. The personnel records are stored in array *a*; associated pointers are stored in array *p*. The pointers are used for sorting as explained on page 84.

Here are the declarations :

```
PROGRAM personnel( INPUT, OUTPUT );

CONST nameLength=10; listLength=30; space=' ';

TYPE nametype= PACKED ARRAY [1..nameLength] OF CHAR;
      detailtype =
      RECORD
        surname, forename: nametype;
        age: 18..65;
        grade: ( jr, sr, exec )
      END;
      indextype = 0..listLength;
      keytype = ( lastname, firstname, decrepitude, clout );
      ordertype = ( gt, eq );
```

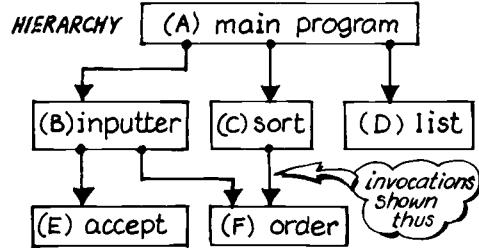


```

VAR a: ARRAY [indextype] OF detailtype;           ↗ array of
                                                ↗ pointers for sorting
p: ARRAY [indextype] OF indextype;               ↗ sorting key
key: keytype;                                     ↗ count of records
count : indextype;

```

The main program is shown overleaf. The main program (A) invokes the input procedure (B), then invokes four times each the sorting procedure (C) and listing procedure (D). The input procedure (B) invokes a special procedure (E) for accepting a string of characters; it also invokes a function (F) for testing the equality of two strings. The sorting procedure (C) also invokes function (F) to test whether one string is "greater" than another. To avoid using the FORWARD directive these subprograms should be arranged such that (E) and (F) precede (B), that (F) also precedes (C). The main program (A) must come last.



This is the procedure (E) for accepting data from the keyboard:

```

PROCEDURE accept(VAR linebuf: nametype);
  VAR i : 0..namelength; ch: CHAR;
  BEGIN
    FOR i := 1 TO namelength DO linebuf[i] := space;
    REPEAT READ(linebuf[1]) UNTIL linebuf[i] <> space;
    i := 1;
    WHILE NOT EOLN DO
      BEGIN
        i := i + 1;
        READ(linebuf[i]);
      END;
    READLN;
  END;

```

fill line buffer with spaces

first character in linebuf[1]

ignore leading spaces

continue from linebuf[2]

Here is the function (F) for comparing strings for equality or relative order:

```

FUNCTION order(c: ordertype; a,b: nametype): BOOLEAN;
  VAR i : 0..namelength; c1, c2, null: CHAR;
  BEGIN
    i := 0; null := CHR(0);
    REPEAT
      i := i + 1;
      IF a[i] = space THEN c1 := null ELSE c1 := a[i];
      IF b[i] = space THEN c2 := null ELSE c2 := b[i];
    UNTIL ((i = namelength) OR (c1 <> c2)) OR ((c1 = null) AND (c2 = null));
    CASE c OF
      gt: order := (c1 > c2);
      eq: order := (c1 = c2)
    END { CASE }
  END;

```

an invisible character with lower ordinal value than any letter or digit

global constant

# PERSONNEL RECORDS (CONTINUED)

The sorting procedure (c) employs the bubble technique explained earlier but adapted to cope with different sorting keys. Each key signifies a different criterion for ordering. Differences are resolved by a CASE statement having a structure similar to that of the personnel record.

```

PROCEDURE sort( n: indextype; k: keytype );
  VAR s, sorted: BOOLEAN; i, tempy: indextype;
  BEGIN
    IF n>1 THEN
      BEGIN
        sorted := TRUE;
        FOR i := 1 TO n-1 DO
          BEGIN
            CASE k OF
              lastname:
                s := order(gt, a[p[i]].surname, a[p[i+1]].surname);
              firstname:
                s := order(gt, a[p[i]].forename, a[p[i+1]].forename);
              decrepitude:
                s := a[p[i]].age > a[p[i+1]].age;
              clout:
                s := ORD(a[p[i]].grade) > ORD(a[p[i+1]].grade)
            END; { CASE }
            IF s THEN
              BEGIN
                sorted := FALSE;
                tempy := p[i];
                p[i] := p[i+1];
                p[i+1] := tempy
              END
            END; { FOR i }
            IF NOT sorted THEN sort( n-1, k )
          END { IF n>1 }
      END;
    
```

signifies which of the four keys is to be sorted

alphabetical keys

numerical key

ordinal key

s signifies TRUE or FALSE

swop pointers if TRUE

recursive invocation

The listing procedure (D) is straightforward:

```

PROCEDURE list( n: indextype );
  VAR i: indextype;
  BEGIN
    FOR i := 1 TO n DO
      BEGIN { FOR i }
        WRITE( a[p[i]].surname, space );
        WRITE( a[p[i]].forename, space );
        WRITE( a[p[i]].age:3, space );
        CASE a[p[i]].grade OF
          jr: WRITELN('Junior');
          sr: WRITELN('Senior');
          exec: WRITELN('Executive')
        END { CASE }
      END { FOR i }
    END;
  
```

].surname CANDLEWICK  
].forename JOSIAH  
].age 19 EXAMPLE  
].grade jr

remember you cannot WRITE a component of enumerated type; hence the CASE statement

Despite a lamentable lack of checks, the input procedure (B) is the most tedious to write. Input procedures in any language become so.

If your program gets the hiccups, asking for data it has already been given (see chapter 11), the remedy is to remove all the prompts and set up a file of input data. Consult your local manual about typing, editing and saving an input file to be read by a Pascal program.

```

PROCEDURE inputter ( VAR n: indextype );
  VAR indicator: CHAR;
  string: nametype;
  buffer: detailtype;
  BEGIN
    n := 0;
  REPEAT
    WRITE ('More? (Y/N): ');
    READLN ( indicator );
    IF indicator = 'Y'
    THEN
      BEGIN
        n := n + 1;
        p[n] := n;
        WRITE('Surname? (<= 10 chars): ');
        accept ( string ); buffer.surname := string;
        WRITE('Forename? (<= 10 chars): ');
        accept ( string ); buffer.forename := string;
        WRITE('Age? (18 to 65): ');
        READLN ( buffer.age );
        WRITE('Grade? (JR, SR, EXEC): ');
        buffer.grade := jr;
        accept ( string );
        IF order(eq, string, 'EXEC')      ' ) THEN buffer.grade := exec;
        IF order(eq, string, 'SR')        ' ) THEN buffer.grade := sr;
        a[n] := buffer
      END
    ELSE
      IF indicator = 'N' THEN WRITELN ('Normal ending')
      ELSE WRITELN ('Abnormal ending');
    UNTIL indicator <> 'Y';
  END; { inputter }

```

The main program (A) is simple:

```

BEGIN
  inputter ( count );
  FOR key := lastname TO clout DO
    BEGIN
      sort ( count, key );
      list ( count );
      WRITELN ('*****')
    END
  END. { PROGRAM }

```

# THE WITH STATEMENT

SAVING TIME AND  
PENCIL ...

Notice the repetition of `a[p[i]].` in the listing procedure on page 104. The thing that most distinguishes one line from the next is the field-name following the full stop.

```
WRITE (a[p[i]].surname;
WRITE (a[p[i]].forename;
WRITE (a[p[i]].age
CASE a[p[i]].grade
```

The WITH statement is designed to supply a single specified record name (as far as the full stop) so that statements such as those shown above may be reduced to their distinguishing features. Here are the statements again, but in full and using WITH.

```
WITH a[p[i]] DO
BEGIN
  WRITE (surname, space);
  WRITE (forename, space);
  WRITE (age:3, space);
CASE (grade) OF
  END {WITH}
```

the WITH applies to  
all field-names  
within the compound  
statement following  
the WITH ... DO

The syntax of the WITH statement is:

WITH *variable* DO *statement*

Note: "DO" does not  
signify "ditto" as  
it does in FOR and  
WHILE loops

where:

*variable* := *name*

[*expression*, ]  
• *name*

e.g. a[p[i]]  
e.g. nest.field1.field2  
also ↑ explained in  
chapter 12

The declarations below are needed by the programs opposite which demonstrate the implications of a WITH statement in the context of a nested record:

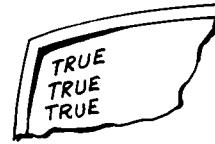
```
TYPE
  nesttype = RECORD
    field1 : RECORD
      field2 : RECORD
        field3 : BOOLEAN
      END
    END;
  VAR
    nest : nesttype;
```

*nest*

field1 field2 field3 TRUE

The first demonstration below shows that the WITH statement may be made to reach any level of nesting (does a nest have "levels"? "Layers" would mix the metaphor less but "levels" is the accepted term):

```
PROGRAM nesting( OUTPUT );
    place TYPE and VAR declarations here
BEGIN
    nest.field1.field2.field3 := TRUE;
    WITH nest.field1.field2 DO WRITELN(field3);
    WITH nest.field1 DO WRITELN(field2.field3);
    WITH nest DO WRITELN(field1.field2.field3)
END.
```



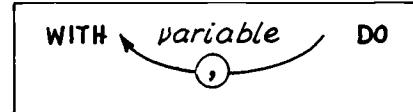
The next demonstration illustrates nested WITH statements reflecting the structure of the nested record:

```
PROGRAM nesting2( OUTPUT );
    place TYPE and VAR declarations here
BEGIN
    nest.field1.field2.field3 := TRUE;
    WITH nest DO
        WITH field1 DO
            WITH field2 DO
                WRITELN(field3)
END.
```



The third demonstration is to illustrate the implication of using commas in place of full stops. This syntax appears to imply the option of nominating more than one type of record. But this would be impossible because the compiler could not then know to which record each field-name belonged (recall that several records may use the same name for distinct fields). The commas are no more than alternatives to full stops. Compare the following program with the program at the top of this page.

```
PROGRAM nesting3( OUTPUT );
    place TYPE and VAR declarations here
BEGIN
    nest.field1.field2.field3 := TRUE;
    WITH nest, field1, field2 DO WRITELN(field3);
    WITH nest, field1 DO WRITELN(field2.field3);
    WITH nest DO WRITELN(field1.field2.field3)
END.
```



The comma notation works only after WITH; do not try:

WITH nest DO WRITELN(field1, field2, field3);

and do not permute:

WITH field2, nest, field1 DO WRITELN(field3);

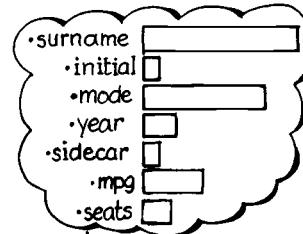


# INTRODUCING VARIANTS

SHARING SPACE ON A FILE

Consider a program for managing a car-sharing scheme devised to soften the impact of a bus or rail strike. The following record might occur:

```
PROGRAM carshare ( INPUT, OUTPUT );
  TYPE
    modetype = ( foot, pushbike, motorbike, car );
    gotype = RECORD
      surname: PACKED ARRAY [1..10] OF CHAR;
      initial: CHAR;
      mode: modetype;
      year: 1900..1990;
      sidecar: BOOLEAN;
      mpg: REAL;
      seats: 1..6
    END;
  VAR
    person: gotype; people: ARRAY [1..100] OF gotype;
    i: 1..100;
```

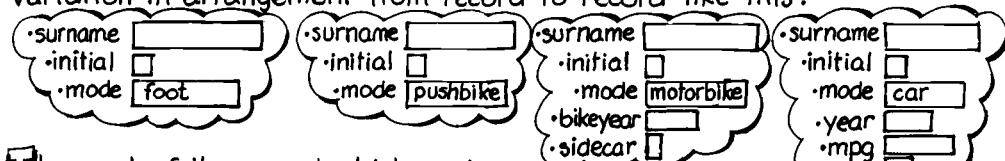


This record must be filled in carefully because not all fields are relevant to every case; a pedestrian, for example, has no mpg or seats. It is the item in the mode field that determines which subsequent fields are relevant to each case. So a CASE statement is appropriate to filling in or printing records. For example:

```
WITH people[i] DO
  BEGIN
    WRITELN (initial, surname: 11);
    CASE mode OF
      foot, pushbike: ; null statement
      motorbike: BEGIN WRITE('Bike made in ', year);
                   IF sidecar THEN WRITELN(' with room for 1')
                   ELSE WRITELN(' pillion only')
                 END; {motorbike}
      car: WRITELN (year:4, mpg:4:1, ' room for ', seats-1:2)
    END; {CASE mode}
  END; {WITH}
```

*this WRITE statement  
is common to all  
modes of transport*

But there are problems; every record has to have the capacity to store every possible arrangement of data. Space is wasted; in a practical program the wastage could be prodigious. So Pascal provides for a variation in arrangement from record to record like this:



The part of the record which varies in arrangement is called the *variant*. The variant always comes last. The field (in this case .mode) which discriminates between variants is called the *tag field*.

To specify a variant a special statement is employed. Its name is CASE but this statement is distinct from the control statement of the same name. Nevertheless, similarities between the two statements are evident. Here is a new definition of *gotype*:

```

TYPE
  modetype = ( foot, pushbike, motorbike, car );
  gotype = RECORD
    surname: PACKED ARRAY [1..10] OF CHAR;
    initial: CHAR;
    CASE mode: modetype OF
      foot, pushbike: ();
      motorbike: (bikeyear: 1900..1990; sidecar: BOOLEAN);
      car: (year: 1900..1990; mpg: REAL; seats: 1..6)
    END { RECORD }
  
```

*CASE has no matching END* *null definition* *note "bikeyear" vs. "year" to make every field-name unique within the record*

The above defines the type of record depicted in all its guises at the foot of the opposite page.

Access to the newly-defined record is no simpler than it was previously; indeed it is more complicated because there are now different components for storing the year of manufacture (change `WRITE('Bike made in', year)` to `WRITE('Bike made in', bikeyear)` to update the fragment of program opposite). The conventional CASE statement is still needed to protect pedestrians and cyclists from being expected to carry passengers.

The syntax of variant is defined recursively as follows:

```

CASE name: name_type OF
  constant: ( fields variant )
  where:
    fields ::= name type
  
```

Notice there is no END to match CASE. Because the variant must come last it is deemed to share its END with the END which matches RECORD.

Notice that ( fields variant ) permits both items to be absent, hence an empty pair of brackets to signify a null definition of fields (as used in the example above). Conversely the presence of a variant introduces a further CASE, causing variants to become nested. And because fields in any variant may be omitted it follows that no restriction on complexity is imposed by the rule that the variant must come last.

Omitting name: implies the absence of a tag field to discriminate between variants. Such a record is called a *free union* (as opposed to a *discriminated union* when there is a tag field). A free union allows an item to be stored under the guise of a character, for example, but retrieved as though it were an integer and similarly for other equivalences of type. A free union designed to peek at pointers (naughty) is given by Grogono along with appropriate warnings about such practice. See bibliography.

# EXERCISES

1. Implement the *personnel* program. Improve the program by defining a more realistic record.
2. Write a Quicksort procedure to replace the bubble-sort procedure on page 104. Does it sort the records any faster?  
(The scale of this exercise is so small that one sorting procedure is as good as another. The simpler the better.)

# 10

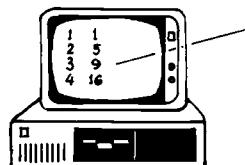
## FILES

INTRODUCING FILES  
OPENING FILES  
TEXT FILES  
*WRITE & WRITELN* WITH TEXT FILES  
*PAGE* WITH TEXT FILES  
*READ & READLN* WITH TEXT FILES  
SAFE READING  
*GRAB* PROCEDURE FOR SAFE READING  
INTRODUCING FILES & *PUT & GET*  
COMPRESSION ((EXAMPLE))  
SUMMARY OF PROPERTIES OF FILES ((TABLE))

# INTRODUCING FILES

THE MEANS OF COMMUNICATION  
BETWEEN PROGRAMS

The file named OUTPUT has already been demonstrated. The name OUTPUT is implied when omitted from a WRITE (or WRITELN) statement but may be included if desired:



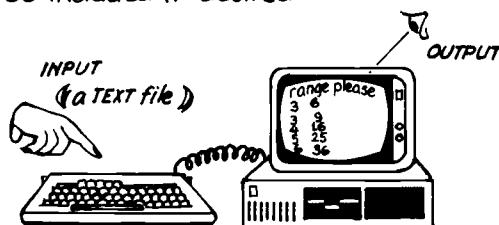
OUTPUT  
(a TEXT file,  
where 'TEXT' is  
defined later)

```
PROGRAM squares(OUTPUT);
VAR i: INTEGER;
BEGIN
  FOR i := 1 TO 4 DO
    WRITELN(OUTPUT, i, SQR(i));
END.
```

file name is  
essential

file name optional

The file named INPUT has also been demonstrated. The name INPUT is implied when omitted from a READ, READLN, EOF or EOLN procedure or function but may be included if desired:



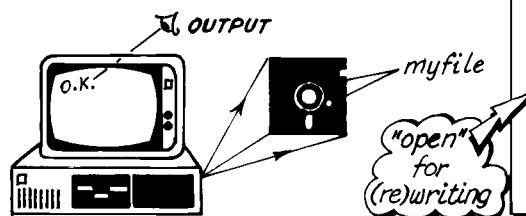
INPUT  
(a TEXT file)

```
PROGRAM anysquares(INPUT, OUTPUT);
VAR i, j, k: INTEGER;
BEGIN
  WRITELN(OUTPUT, 'range please');
  READLN(INPUT, j, k);
  FOR i := j TO k DO
    WRITELN(OUTPUT, i, SQR(i));
END.
```

file names essential

file name optional

Results may be sent to files other than the one named OUTPUT. Each such file must be nominated in the PROGRAM statement and its type declared in the VAR section. But OUTPUT should always be nominated, if only to provide a channel for messages & error messages from the Pascal processor in particular:



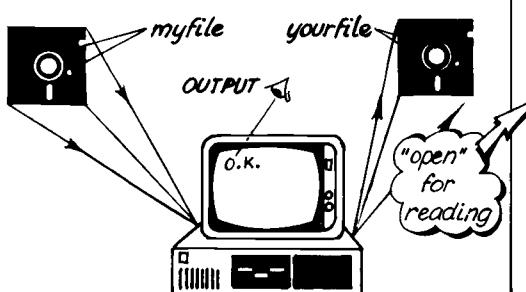
myfile  
"open"  
for  
(re)writing

```
PROGRAM filesquares(OUTPUT, myfile);
VAR i: INTEGER; myfile: TEXT;
BEGIN
  REWRITE(myfile);
  FOR i := 1 TO 4 DO
    WRITELN(myfile, i, SQR(i));
  WRITELN(OUTPUT, 'O.K.');
END.
```

file type

file name  
essential

Files other than the file named INPUT may be nominated as sources of data. Each such file must be nominated in the PROGRAM statement and its type declaration in the VAR section:



yourfile  
"open"  
for  
reading

```
PROGRAM filecubes(OUTPUT, myfile, yourfile);
VAR i, j: INTEGER; myfile, yourfile: TEXT;
BEGIN
  RESET(myfile); REWRITE(yourfile);
  WHILE NOT EOF(myfile) DO
    BEGIN
      READLN(myfile, i, j);
      WRITELN(yourfile, i, i*j);
    END;
  WRITELN(OUTPUT, 'O.K.');
END.
```

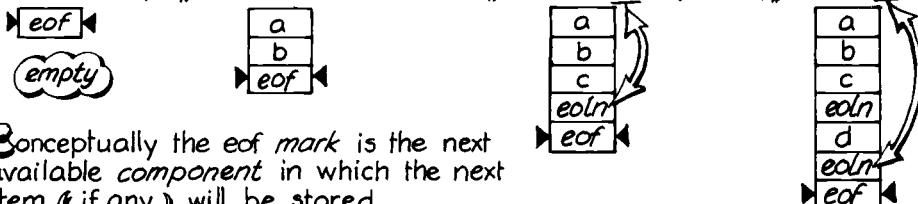
file type

Several files may be open at once; conversely a single file may be opened for writing and subsequently reset for reading all in a single run.

Notice that the files *myfile* and *yourfile* had to be "opened" by REWRITE before writing; by RESET before reading. But REWRITE and RESET may not be employed to open the special files named OUTPUT and INPUT which are opened automatically. It is an error to try to open a file already open.

All files in ISO Pascal are *sequential* files. A file opened for writing is initially empty, comprising just an end-of-file mark. Each WRITE or WRITELN causes new information to be appended, then the end-of-file mark to be moved to the new end of file. WRITELN (as distinct from WRITE) causes an end-of-line character to be appended before control moves on.

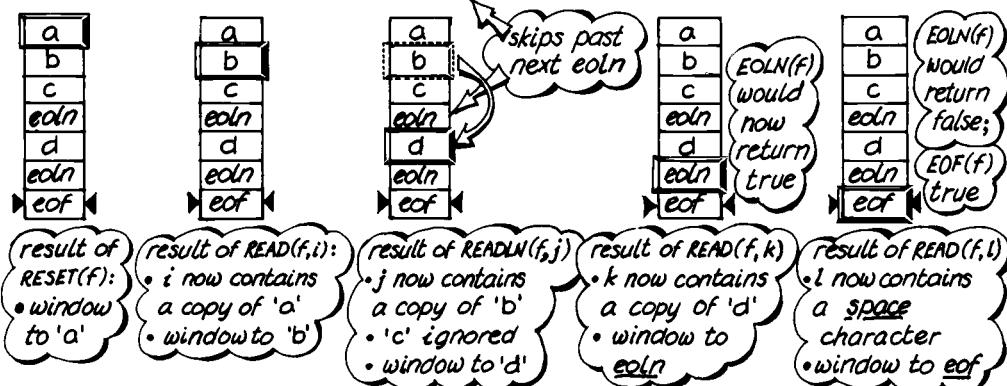
REWRITE(f);  $\Rightarrow$  WRITE(f, 'a', 'b');  $\Rightarrow$  WRITELN(f, 'c');  $\Rightarrow$  WRITELN(f, 'd')



Conceptually the eof mark is the next available component in which the next item (if any) will be stored.

A file opened for reading has a "window" placed over its first component. The first READ to be obeyed causes the item in the window to be read, then the window to be moved to the next component, and so on. READLN (as distinct from READ) causes the window to be moved *past the next end-of-line character* before control moves on. If there is no such character the window ends up at the end-of-file mark.

RESET(f);  $\Rightarrow$  READ(f, i);  $\Rightarrow$  READLN(f, j);  $\Rightarrow$  READ(f, k);  $\Rightarrow$  READ(f, l)



The READ(f, i); READLN(f, j) above could be combined as READLN(f, i, j). In general:

READLN(f, p, q, r, ...)  $\equiv$  READ(f, p); READ(f, q); READ(f, r); ... READLN(f)  
 WRITELN(f, p, q, r, ...)  $\equiv$  WRITE(f, p); WRITE(f, q); WRITE(f, r); ... WRITELN(f)

The behaviour of the end-of-line character is relevant only to *TEXT* files such as those depicted opposite. A *TEXT* file comprises rows of words and numbers separated by spaces as the name suggests. *Binary* files are explained later.

With *interactive* input the above logic is modified as explained in the next chapter.

# OPENING FILES

EXPLAINING REWRITE AND RESET  
SHOWN ON PREVIOUS DOUBLE PAGE

Every file written or read by a Pascal program should be nominated in the PROGRAM statement:

```
PROGRAM nameprog ( namefile );
```

```
► PROGRAM myprog( OUTPUT, mydata, mydump );
```

always to be nominated

The type of each file should be declared in the VAR section of the main program. The syntax is given below, where FILE OF REAL anticipates the subject of *binary files* dealt with later:

```
VAR namefile : type;
```

do not include the files named  
INPUT or OUTPUT which are  
implicitly declared as files  
of type TEXT

```
► VAR mydata: TEXT; mydump: FILE OF REAL
```

A file other than the file named OUTPUT may be written only when it has been opened by invoking the REWRITE procedure:

```
REWRITE( namefile )
```

possibly some  
local extensions

```
► REWRITE( mydump )
```

do not  
REWRITE  
the file named  
OUTPUT

A file other than the file named INPUT may be read by READ or READLN only when it has been opened by invoking the RESET procedure.

```
RESET( namefile )
```

possibly some  
local extensions

```
► RESET( mydata )
```

do not  
RESET the  
file named  
INPUT

The WRITE, WRITELN, READ, READLN procedures are elaborated on the next double page.

The above definitions apply both to TEXT files and binary files. Binary files are introduced later.

# TEXT FILES

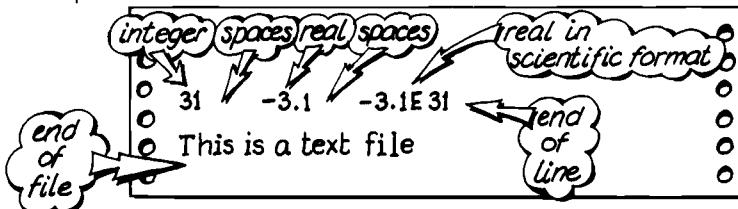
CONSULT YOUR LOCAL MANUAL ABOUT TYPING,  
EDITING AND SAVING FILES

The files named INPUT and OUTPUT are of type TEXT. Files nominated by the programmer may also be declared as files of type TEXT.

```
PROGRAM ( INPUT, OUTPUT, hisfile, herfile );  
  VAR hisfile, herfile: TEXT;
```

TEXT files declared  
by programmer

A text file consists of ASCII characters or characters of whatever code the computer uses so a text file is intelligible to the human eye when printed:



A text file is organized as rows of items, the items separated by spaces. A Pascal program designed to read such a file may do so one character at a time, using only `READ(file, ch)` (where `ch` is of type `CHAR`). Alternatively the program may employ several parameters in its `READ` statements, each parameter of the same type as that of the corresponding item expected in the text file. For example `READLN(file, i, x, y)` would correctly read the top line of the text file above (where `i` is of type `INTEGER` and `x` and `y` of type `REAL`).

It is the unique property of text files that items are automatically converted from internal form to character form by `WRITE`, from character form to internal form by `READ`, as indicated by the types of parameters involved. A reading program stops if types fail to match, so it is safer to read data one character at a time and forgo automatic conversion. An input procedure like this is given on pages 118 to 123.

Text files may be created by `WRITE` statements as illustrated on page 112. Text files may also be typed at the keyboard and stored on disk. The way to do this depends on your installation; consult your local manuals. Typically the file is typed under control of a "line editor" or "screen editor". Such an editor provides facilities for typing, amending, inserting and erasing text. When a file has been typed and corrected it may be saved on disk for subsequent use as the INPUT file for a Pascal program. The command is typically:

SAVE 'INPUT' *perhaps without the quotes*

With many compilers it is not enough to nominate files in the `PROGRAM` statement; you have also to associate those names with file names recognized by the operating system. *Pro Pascal* and *Turbo Pascal* provide the `ASSIGN` procedure for this; *Acornsoft 150 Pascal* extends the `RESET` and `REWRITE` procedures:

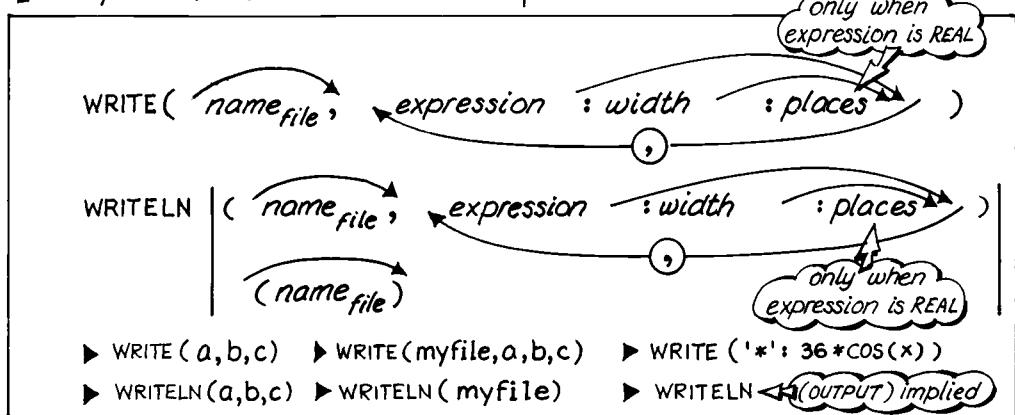
file name for  
Pascal

ASSIGN( mydata2, 'MYDAT2.TX' )  
RESET( mydata2, 'MYDAT2.TX' )

file name for  
operating system

# WRITE AND WRITELN WITH TEXT FILES IN MORE DETAIL

The syntax of the WRITE and WRITELN procedures is:



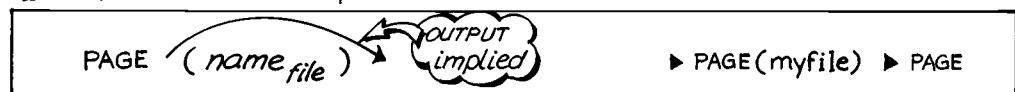
The first WRITE or WRITELN to be obeyed locates the first output field at the start of the output file. ( A field is a contiguous sequence of character positions in which an item of output is written  $\approx$  right justified. ) Subsequent fields, and fields generated by subsequent WRITE and WRITELN procedures, are appended sequentially and contiguously as each, in its turn, is written to the output file.

An unspecified width for a field of type REAL or INTEGER implies a default width which is installation dependent ( 14 is typical ). An unspecified number of places for a field of type REAL implies output in "scientific" form ( E-format ); for example -1.23456E-04 to express the value -0.000123456. The number of significant digits printed before the E is installation dependent ( 6 or 9 is typical ). An unspecified width for a string implies the number of characters in the string excluding opening and closing apostrophes ( 'abc' implies 3 ). An unspecified width for an item of type PACKED ARRAY [ 1 .. *n* ] OF CHAR implies *n*. An unspecified width for a Boolean item implies a width which is installation dependent ( typically 4 for TRUE, 5 for FALSE ). A field is extended rightwards if a given value for width is too small to accommodate the corresponding item.

When the final parameter of a WRITELN ( as distinct from a WRITE ) procedure has been written, an end-of-line character is automatically appended. WRITELN without a parameter also causes an end-of-line character to be appended.

# PAGE WITH TEXT FILES AND ONLY WITH TEXT FILES

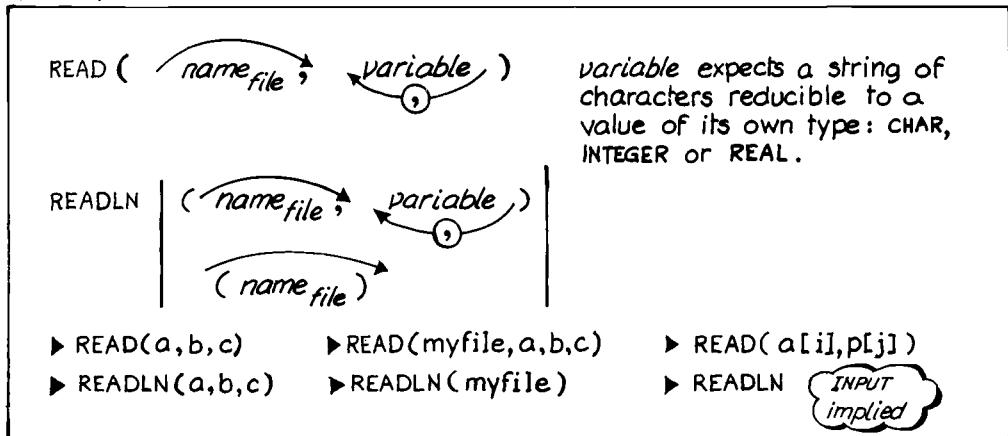
The syntax of the PAGE procedure is:



When this standard procedure is invoked a page-throw code is sent to the nominated or implied output file. ( Applicable only if the local equipment can respond to such a signal. )

# READ AND READLN WITH TEXT FILES IN MORE DETAIL

The syntax of the READ and READLN procedures is:



When the current parameter is of type CHAR the character in the window is read. If this is an end-of-line character it is read as though it were a space. It is nevertheless distinguishable from a space because whenever there is an end-of-line character in the window  $\Rightarrow$  and at no other time  $\Rightarrow$  the EOLN function for that file would return true if invoked. After the character in the window has been read successfully, the window moves on to frame the very next character. If this character happens to be the end-of-file mark then the EOF function for that file would return true if invoked. The EOF function returns true only when the window is framing the end-of-file mark. Trying to read the end-of-file mark is an error.

When the current parameter is of type INTEGER or REAL the window skips over spaces and new lines until the first significant character of a new string is encountered ( $\Rightarrow$  if the search ends abortively at the end-of-file mark). A string is converted ( $\Rightarrow$  if correctly formed) to an item of standard type consistent with its corresponding parameter. (The instruction `READ(x)`, for example, would fail if the string were 1.5 and `x` of type INTEGER.) After successful reading of a string the window is made to frame the character immediately following that string. This following character could be a space. Or it could be a new-line character in which case EOLN, if invoked, would return true ( $\Rightarrow$  and EOLN false).

When the final parameter of READLN ( $\Rightarrow$  as distinct from READ) has been satisfied the window skips over everything remaining on the current line. It then rests, framing the first character of the next line. This first character could be the end-of-file mark in which case the EOF function, if invoked, would return true. The same applies to READLN when used without parameters.

With text files this conceptual window has an elastic frame. Much of the time it frames only single characters, but when a string of characters denoting a number is encountered the frame "stretches" to encompass all characters in that string. This is in contrast to the windows used for reading binary files; such windows may be complicated in structure but not elastic. Binary files are described later.

# SAFE READING

THIS IS A PROBLEM IN MOST POPULAR LANGUAGES

We have all had to complete a "formated" data form from time to time. It has advantages, if only in making life easier for the programmer:

But when the data are complicated it is sensible to make the arrangement of data more flexible. The programmer may devise a "problem-oriented language" in which a keyword tells the program what the next number, or group of numbers, describes:



In a program designed to read "formated" data it is conceivable that the programmer would leave verification of data to Pascal; for example by employing `READ(INPUT, weight)` to read the first item in the top data sheet above. But if the user of such a program erroneously entered 16.75, say, instead of 16.75 there would be a message from Pascal about a bad number and the program would stop. For a program that reads more than a few items of data such an approach is unthinkable.

The only way for a program to stay in control is to read data one character at a time, building up the number or keyword and discovering the user's errors for itself. The only pre-defined Pascal procedure safe to employ is `READ(file, ch)` preceded by a check on end-of-file.

If this conclusion shows Pascal in a bad light be assured that several other established languages are no better in their handling of input. Fortran offers a tempting range of input descriptors (see my *Illustrating Fortran, C.U.P, 1982, ch 10*) but the only usable one is that which reads a single character. Those versions of BASIC that have "ON ERROR ..." are a little more helpful because this statement makes it possible to win back control when a bad item has been read; a clumsy approach.

The procedure described below is designed to stay in control whatever nonsense has been encountered on the input file. The procedure is called `grab`.

To use `grab` simply invoke it whenever the next item is needed; there is no need to check the end-of-file before invocation. Each item is deemed to be terminated by a space, newline or end-of-file. The procedure returns with a record describing every aspect of the item just read. The four kinds of item distinguished by `grab` are:

- `name`; a name begins with a letter and comprises only letters and digits. Only the first four characters are significant (RADII=RADIUSES)
- `number`; a number may be written with or without a decimal point; the procedure distinguishes one form of number from the other
- `nogood`; a string of characters which is neither name or number (for example +PG)
- `isn't`; a null item implying end-of-file (any subsequent invocation of `grab` would then cause the same result).

The record with which the procedure returns is depicted here. It looks complicated but is very simple to use. Suppose, for example, the programmer expects the next item from the input file to be a number. The invocation might be:

```
grab(it);
IF it.tisnumber
  THEN remember := it.nr
ELSE complain(it);
```

where we assume that *complain* is a diagnostic procedure. So if the item

proved to be something other than a number the diagnostic procedure could discover precisely what went wrong ( IF it.tisnt THEN... IF it.tisnogood THEN... ) and might investigate precisely what the user typed by consulting the component *it.string*.

The programmer would probably employ: WITH it DO... and so simplify references to the record thus: IF *tisnumber* THEN... IF *tisnogood* THEN...

A number such as 12345 on the input file causes both the flag *tisnumber* and the flag *tisinteger* to be set true; a value of 12345.0 would then be found in field *.nr* and a value of 12345 in field *.int*. But 12345000000 on the input file would cause only *tisnumber* to be set true because ( on a typical computer ) this value would be greater than MAXINT.

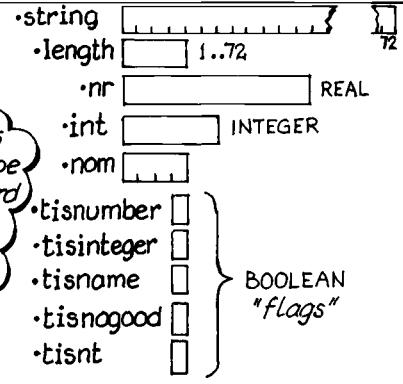
Here is the essential logic of the *grab* procedure expressed as a state table. Use of such a table is explained on page 50.

symbol state	$\oplus$ 1]	$\ominus$ 2]	'0'..'9' 3]	'A'..'Z' 'a'..'z' 4]	$\odot$ 5]	other 6]	$\odot$ , space, newline 7]
$\Rightarrow$ [1, $\Rightarrow$ 2, sign:=-1	$\Rightarrow$ 2, $\Rightarrow$ 3, 1	$\Rightarrow$ 3, $\Rightarrow$ 4, 2	$\Rightarrow$ 4, $\Rightarrow$ 5, 3	$\Rightarrow$ 5, $\Rightarrow$ 6, 4	$\Rightarrow$ 6, 10, 5	$\Rightarrow$ 7, $\Rightarrow$ 7, 6	$\Rightarrow$ 1, 7
[2, $\Rightarrow$ 7, $\Rightarrow$ 7, 2				$\Rightarrow$ 7, 3	$\Rightarrow$ 7, 7, 4	$\Rightarrow$ 7, 7, 5	$\Rightarrow$ 3, 7
[3, $\Rightarrow$ 7, $\Rightarrow$ 7, 4			$\Rightarrow$ 7, 5, 3	$\Rightarrow$ 7, 7, 6	$\Rightarrow$ 7, 7, 8	$\Rightarrow$ 7, 7, 9	$\Rightarrow$ 7, 7, 10
[4, $\Rightarrow$ 7, $\Rightarrow$ 7, 6			$\Rightarrow$ 7, 7, 5	$\Rightarrow$ 7, 7, 7	$\Rightarrow$ 7, 7, 8	$\Rightarrow$ 7, 7, 9	$\Rightarrow$ 7, 7, 10
[5, $\Rightarrow$ 7, $\Rightarrow$ 7, 6			$\Rightarrow$ 7, 7, 7	$\Rightarrow$ 7, 7, 8	$\Rightarrow$ 7, 7, 9	$\Rightarrow$ 7, 7, 10	$\Rightarrow$ 7, 7, 11
[6, $\Rightarrow$ 7, $\Rightarrow$ 7, 7			$\Rightarrow$ 7, 7, 7	$\Rightarrow$ 7, 7, 8	$\Rightarrow$ 7, 7, 9	$\Rightarrow$ 7, 7, 10	$\Rightarrow$ 7, 7, 11
[7, $\Rightarrow$ 7, $\Rightarrow$ 7, 7				$\Rightarrow$ 7, 7, 7	$\Rightarrow$ 7, 7, 8	$\Rightarrow$ 7, 7, 9	$\Rightarrow$ 7, 7, 10

In this table the various actions are numbered in little clouds thus 7. Changes of state are indicated by broad arrows thus  $\Rightarrow$  7. The table itself is stored as array table [ 1..7, 1..7 ] ( overleaf ) and the number in each component is encoded as:

100 \* action + state

This table is created in the computer with the help of a file.



# GRAB(*record*) PROCEDURE FOR SAFE READING

The main program begins by setting constants. *Stringlength* should be as long as the longest possible line of input (in case the user forgets to type any spaces or commas). *NameLength* should be set to the number of significant characters in a name, four being typical. *Minord* and *maxord* are the ordinal values of the first and last character in the available character set. 32 and 127 are for ASCII code; change these if you are using EBCDIC or other code.

```

PROGRAM saferead( INPUT, OUTPUT, f );
CONST
  stringlength = 72; nameLength = 4; minord = 32; maxord = 127;
TYPE
  stringtype = PACKED ARRAY [1.. stringlength] OF CHAR;
  nametype = PACKED ARRAY [1.. nameLength] OF CHAR;
  lookuptype = ARRAY [minord.. maxord] OF 1..7;
  tabletype = ARRAY [1..7, 1..7] OF 1..1200;

  intype = RECORD
    string: stringtype;
    length: 0.. stringlength;
    nr: REAL;
    int: INTEGER;
    nom: nametype;
    tisnumber, tisinteger, tisname,
    tisnogood, tisnt: BOOLEAN
  END;

  VAR
    it: intype; lookup: lookuptype; table: tabletype;
    i: INTEGER; f: TEXT; TEXT file

```

lookup[32]	6
lookup[33]	6
lookup[34]	6
lookup[46]	5
lookup[57]	4 "9"
lookup[66]	4 "B"

*examples*

The arrays named *lookup* and *table* have to be initialized. The purpose of *lookup* is to provide the column number of *table* corresponding to the character just read. For example, if the character stored in *ch* were "9" then *lookup[ORD(ch)]* would return 4 directly. Similarly if *ch* contained "." then *lookup[ORD(ch)]* would return 5. Initialization is performed by a special procedure which should be invoked precisely once before subsequent invocations of *grab*. Here is the procedure:

```

PROCEDURE initialization( VAR I: lookuptype; VAR t: tabletype);
  VAR
    c: CHAR; i, j: 1..7; k: minord.. maxord;
  BEGIN
    FOR k := minord TO maxord DO I[k]:= 6;
    I[ORD('+')]:= 1; I[ORD('-')]:= 2;
    FOR c := '0' TO '9' DO I[ORD(c)]:= 3;
    FOR c := 'A' TO 'Z' DO I[ORD(c)]:= 4;
    FOR c := 'a' TO 'z' DO I[ORD(c)]:= 4;
    I[ORD('.')] := 5;
    I[ORD(' ,')] := 7;
    I[ORD(' ')] := 7;

```

*Fill with sixes, then  
overwrite some of them*

*READ(ch) reads the e.o.l  
character as a space*

The VAR declaration in the main program contains "f: TEXT" declaring a file of type TEXT. Writing this file and reading it back again avoids the need for forty-nine individual assignments:

t[1,1] := 002; t[1,2] := 102; t[1,3] := 203; etc.

(If your Pascal compiler permits "temporary" files it may be possible to remove all references to f from the main program and put them in the VAR section of this initialization procedure ~ the only place where f is used.)

```

REWRITE (f); ← open for writing to file f
WRITE (f, 002, 102, 203, 1006, 007, 007, 001 );
WRITE (f, 007, 007, 203, 007, 007, 007, 300 );
WRITE (f, 007, 007, 403, 007, 504, 007, 300 );
WRITE (f, 007, 007, 605, 007, 007, 007, 700 );
WRITE (f, 007, 007, 605, 007, 007, 007, 800 );
WRITE (f, 007, 007, 1106, 1106, 007, 007, 900 );
WRITE (f, 007, 007, 007, 007, 007, 007, 700 );

RESET (f); ← reset for reading
FOR i := 1 TO 7 DO
  FOR j := 1 TO 7 DO
    READ (f, t[i,j]);
  END;
{initialization}

```

compare this table with that on page 119

key: 504  
action 5  
new state 14, [0, implies exit]

The start of the grab procedure is shown below. This includes the definition of a local function for returning the integer value of a character; for example `digit('6')` would return 6.

```

PROCEDURE grab( VAR rec: intype );
  VAR
    i: 1..stringlength; sign: -1..1; state: 0..7;
    ch: CHAR; action: 0..11; frac: INTEGER;

  FUNCTION digit(c: CHAR ): INTEGER;
  BEGIN
    digit := ORD(ch) - ORD('0')
  END;

  BEGIN {grab}
    WITH rec DO
      BEGIN { WITH rec }
        tisnumber := FALSE; tisinteger := FALSE;
        tisname := FALSE; tisnogood := FALSE; tisnt := FALSE;
        length := 0; state := 1; sign := 1;
        FOR i := 1 TO stringlength DO string[i] := ' ';
        FOR i := 1 TO namelength DO nom[i] := ' ';
        i := 1; ← re-initialize
      END { WITH rec }
    END {grab}
  
```

set all flags false

blank out the receiving string

continued overleaf

# GRAB (record) continued

Here is the logic of the grab procedure:

```

REPEAT { for each digit }
  check →
  IF EOF ( INPUT )
  THEN
    BEGIN
      action := table [ state, 7 ] DIV 100;
      tisnt := ( state = 1 )
    END
  ELSE
    BEGIN
      READ ( INPUT, ch );
      length := length + 1; string [ length ] := ch;
      action := table [ state, lookup [ ORD ( ch ) ] ] DIV 100;
      state := table [ state, lookup [ ORD ( ch ) ] ] MOD 100
    END; { END of IF }
  CASE action OF
    0: ; → do nothing
    1: sign := -1; → was pre-set to +1
    2: nr := digit ( ch ); → first digit
    3: BEGIN
        IF nr <= MAXINT ← nr can be converted to an
        THEN → integer by TRUNC( ) only if
        BEGIN → in range of MAXINT
          tisinteger := TRUE;
          int := sign * TRUNC ( nr )
        END;
        tisnumber := TRUE;
        nr := sign * nr
      END;
    4: nr := 10 * nr + digit ( ch ); → build integer
    5: frac := 1; → in nr
    6: BEGIN
        frac := 10 * frac;
        nr := nr + digit ( ch ) / frac → after the decimal point
      END; → divide successive digits
    7: tisnogood := TRUE;
    8: BEGIN
        tisnumber := TRUE;
        nr := sign * nr
      END;
    9: tisname := TRUE;
    10: nom [ 1 ] := ch; → first character
    11: BEGIN
        i := i + 1;
        IF i <= namelength THEN nom [ i ] := ch.
      END
    END { CASE } → usual ending
  UNTIL ( state = 0 ) OR tisnt → build nom as far
  END → as namelength
END; { procedure grab} → the e.o.f was met
                                before any item

```

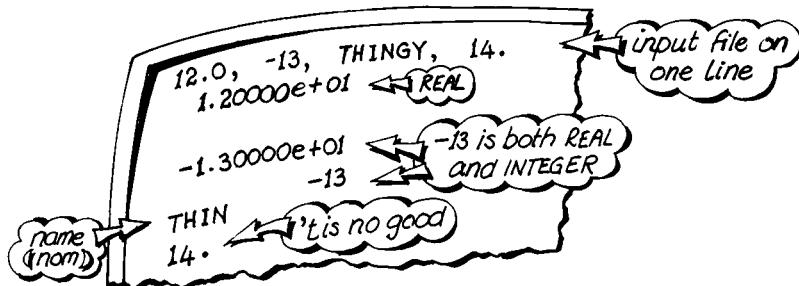
Annotations and notes:

- check →
- 17 heads the column of terminators
- e.o.f when in state 1 means that grab grabbed nothing ... a null item
- store the string
- action and new state
- do nothing
- was pre-set to +1
- first digit
- build integer in nr
- after the decimal point divide successive digits by 10, 100, 1000 etc.
- first character of nom
- usual ending
- build nom as far as namelength
- the e.o.f was met before any item

The following main program is just for demonstrating the procedure named *grab*:

```
BEGIN { main program }
  initialization (lookup, table);
  REPEAT
    grab(it);
    WITH it Do
      BEGIN
        IF tisnumber THEN WRITELN (nr);
        IF tisinteger THEN WRITELN (int);
        IF tisname THEN WRITELN (nom);
        IF tisnogood THEN
          FOR i := 1 TO length DO
            WRITE (string[i]);
        WRITELN;
      END { WITH it }
    UNTIL it.tisnt
  END. { program }
```

Experiment with the program as suggested below:



Binary files are introduced on the next page. The file named *f* in the above example would be better as a binary file. To make the alteration change *f:TEXT* in the main *VAR* section to *f: FILE OF INTEGER*.

The check for EOF at the top of the opposite page is there for non-interactive applications but should cause no trouble when *grab* is used interactively. EOF should return *false* unless some special signal (e.g. **CTRL-Z** in Turbo Pascal) is sent from the keyboard. If you do have trouble with *grab* consult chapter 11 for inspiration.

# INTRODUCING BINARY FILES AND PUT( ) AND GET( )

An item on a *text* file is converted from a character string to internal form by `READ`; from internal form to a character string by `WRITE`. By contrast a *binary* file holds data in internal (binary) form. Binary files have several advantages over text files. They are faster to read and write because there is no need for conversion; they are also more compact than text files and suffer none of the rounding errors associated with conversion to and from internal form. A disadvantage of binary files (with the exception of `FILE OF CHAR`) is that they would be incomprehensible to the human eye if printed.

Binary files are useful as backing storage during computations. Usually such files may be deleted at the end of a run, having served their purpose. But in some applications huge files of intermediate data have to be saved between runs. Binary files, being compact and accurate, are ideal for this purpose.

In Pascal a file is a *variable*. Notice the last line of the `VAR` section on page 120, reproduced below:

```
i : INTEGER; f: TEXT;
```

variable of  
type TEXT

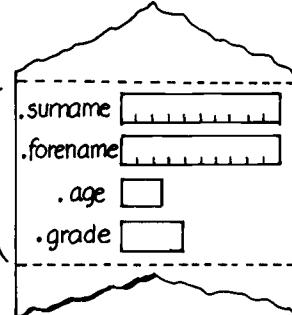
which shows `f` declared as a variable of type `TEXT` in precisely the same way as `i` is declared a variable of type `INTEGER`. In general, files may be of any type; those not of type `TEXT` being *binary* files.

Here is a file named `binfile`. Each component is a record of the shape used in the program of personnel records on page 102.

```
TYPE
  nametype = PACKED ARRAY [1..10] OF CHAR;
  detailtype =
    RECORD
      surname, forename : nametype;
      age : 18..65;
      grade: (jr, sr, exec)
    END;
  VAR
    binfile: FILE OF detailtype;
```

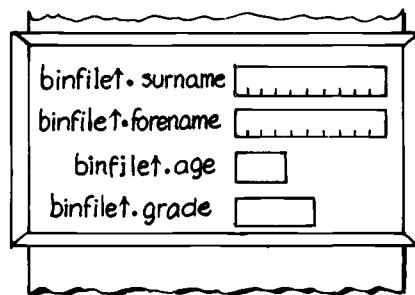
Note: "FILE OF"

one component

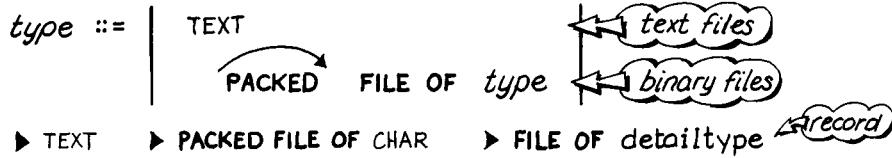


A single empty component of `binfile` is sketched above. The file comprises many such records as needed during the course of a run.

Declaration of any file has the additional effect of declaring a *window variable* associated with that file. The name of the window is the name of the file, but with `↑` appended as illustrated here:  $\Rightarrow$   
All communication with the file named `binfile` is through the window named `binfile↑` which you pronounce as "binfile-window".

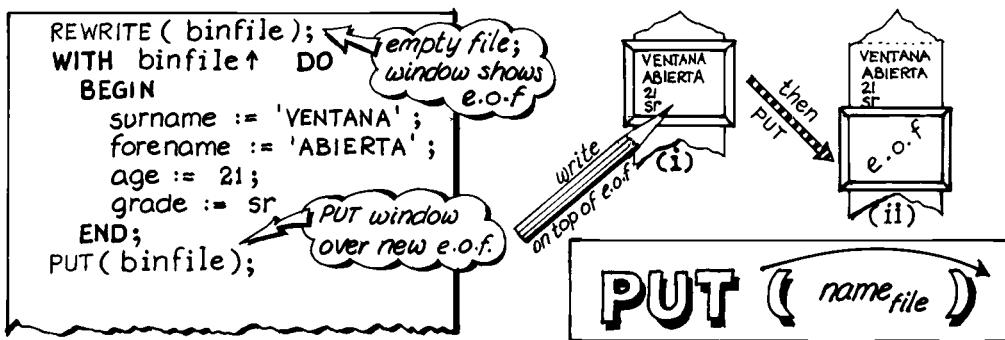


The syntax for type of file is defined as follows:

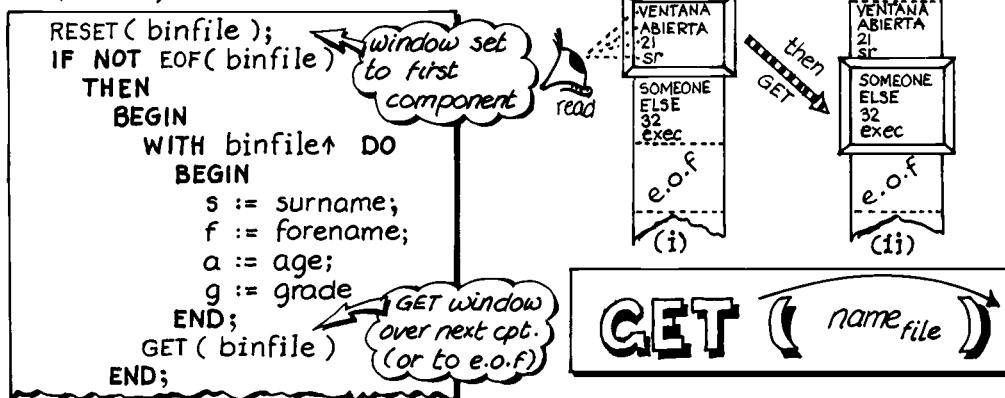


Do not confuse FILE OF CHAR with TEXT. Automatic conversions to and from character strings  $\approx$  and detection of end-of-line  $\approx$  are properties exclusively of TEXT files. WRITELN and READLN work only with TEXT files.

Writing a binary file is, in general, a two-stage process: (i) assign to the window-variable whatever is to be written (ii) invoke PUT to move the window frame onwards and establish a new end-of-file:



Having checked for end-of-file, reading is also a two-stage process: (i) read what is in the window (ii) use GET to move the window frame onwards to the next component (or to the end-of-file if there is no next component) :



Procedures PUT and GET are "low level" procedures. WRITE and READ may be described in terms of PUT and GET  $\approx$  and the window variables  $\approx$  as follows:

WRITE( filename, item )  $\equiv$  filename  $\uparrow$  := item; PUT( filename )  
 READ ( filename, item )  $\equiv$  item := filename  $\uparrow$ ; GET( filename )

Turbo Pascal does not define PUT or GET; it has extended WRITE & READ instead.

# COMPRESSION

## AN EXAMPLE TO ILLUSTRATE HANDLING BOTH TEXT AND BINARY FILES

This program is designed to read a text file and write a corresponding binary file, so compressing the information held.

Assume the text file has already been verified by another program so that no checks on form or completeness need be made on input; the file is known to be strictly of the form illustrated ➔

SUN-ROOM temperature log			
Day No.	Month	Noon temp	Remarks
2	FEB	2.5	COLD
4	FEB	-10	BITTER
17	FEB	-15.5	MONKEYS

```
PROGRAM compressor( textin, binaryout, OUTPUT );
```

CONST

monthchars = 3;  
remchars = 8;

TYPE

monthtype = PACKED ARRAY [1..monthchars] OF CHAR;  
remtype = PACKED ARRAY [1..remchars] OF CHAR;

groupstype = RECORD

day: 1..31;  
month: monthtype;  
temp: REAL;  
remark: remtype

END;

VAR

textin: TEXT;  
binaryout: FILE OF groupstype;  
count: INTEGER; i: 1..monthchars; j: 1..remchars;

BEGIN

count := 0;

RESET( textin );

REWRITE( binaryout );

WITH binaryout↑ DO

WHILE NOT EOF( textin ) DO

BEGIN

READ( textin, day );

FOR i := 1 TO monthchars DO

READ( textin, month[i] );

READ( textin, temp );

FOR j := 1 TO remchars DO

READ( textin, remark[j] );

count := count + 1;

READLN( textin );

PUT( binaryout )

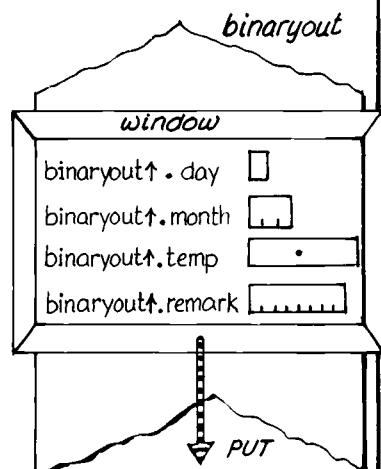
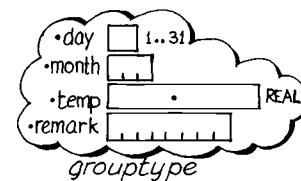
END { WHILE }

{ end of WITH }

WRITELN( OUTPUT, count, ' lines of data transferred' )

END.

messages



# SUMMARY OF PROPERTIES OF FILES

PROPERTY	TEXT FILES		PACKED FILE OF CHAR (not TEXT files)	Other types (e.g. files of ARRAYS; files of RECORDS of mixed type)		
	The standard TEXT files: INPUT and OUTPUT	Names given by the programmer				
Inclusion of file names in the PROGRAM statement	INPUT is optional but OUTPUT must be included if only to give a destination for error reports	In general the file should be nominated in the PROGRAM statement.  (Some compilers permit "temporary" files, these not being nominated in the PROGRAM statement)				
Definition of file variable in VAR section	Implicitly of type TEXT	In general the file variable should be declared in the main VAR section (a local VAR section if the compiler allows "temporary" files)				
RESET and REWRITE	Implicit: do not use RESET or REWRITE	Files to be read must be opened using RESET(filename). Files to be written must first be opened using REWRITE (filename)				
Input statements available	READ, READLN and GET: Omitting first parameter implies INPUT	READ, READLN and GET: No default parameter	READ and GET but not READLN			
Conversions on input	Each character-string encoded automatically as CHAR, INTEGER, or REAL to match the basic type of the receiving parameter		Binary code on file converted to items of type CHAR only	Binary code on file converted to INTEGER, REAL or CHAR according to type of file variable		
Output statements available	WRITE, WRITELN, PUT and PAGE (but some Pascal compilers do not offer PUT)		WRITE and PUT but not WRITELN			
Conversions on output	Items of type CHAR, INTEGER, BOOLEAN - also PACKED ARRAY OF CHAR - are converted to printable character strings		Items of type CHAR converted to binary code on output file	Items of all types converted to binary code on output file		
EOLN	The end-of-line character is read as a space but causes EOLN( ) to return TRUE whilst the end-of-line character is in the file window		End of line is not detectable; the EOLN( ) function is relevant only to TEXT files			
	EOLN implies EOLN( INPUT )	No default parameter				
EOF	The EOF function returns TRUE if invoked whilst the end-of-file "mark" is in the file window, otherwise it returns FALSE		No default parameter for EOF( )	Interactive input is infeasible		
	EOF implies EOF( INPUT )					
	With interactive input the EOF signal is installation dependent					

# EXERCISES

1. Implement the *saferead* program. Experiment by trying to "break" it from the keyboard. It should be found impossible to make the program lose control; on each attempt the erroneous string would be displayed for inspection
2. Make the *personnel* program on page 102 file the array of personnel records (array *a*) as a binary file. The file should be written when all the data have been read and before they have been sorted. Similarly make the program start by reading such a file before the input of each new batch of records. With these facilities the program begins to look like a rudimentary management system.
3. Take any of the programs in earlier chapters (for example the *loanrate* program on page 62) and replace its primitive input statements with invocations of the *grab* procedure. If your Pascal permits interactive programs add suitable prompts and error diagnostics to make the resulting program reasonably friendly towards its intended user.

11

# INTERACTIVE INPUT

INTERACTION  
PEEP-AHEAD PROBLEM  
BUFFER PROBLEM  
*EOF* PROBLEM

# INTERACTION

## PASCAL WAS NOT DESIGNED AS AN INTERACTIVE LANGUAGE

A user of many modern programs takes part in a dialogue, the program displaying questions or prompts on the screen, the user responding by typing at the keyboard. Each response is made in the light of results so far displayed on the screen. There might be a different result if the user had to supply all information in advance. In other words the user and the program "interact" to achieve a result. The concept of interaction is commonplace now but its achievement is comparatively recent in the history of computing.

Pascal was designed before interaction became commonplace. It was designed in the days when programmers punched programs into cards, surrendering a "program deck" to computer operators for loading into the card reader. The data were also punched into cards and handed to the operators as a "data deck". Both decks were later returned to the programmer wrapped in "music paper" with results ( or woeful diagnostics ) from the line printer. Because it was usual for the operators to wait until they had acquired several such programs before loading them, this mode of operation was called "batch mode".

The READ procedure of Pascal was designed for the convenience of programmers working in batch mode. The logic of the READ procedure in the context of punched cards is: (i) read the specified item or items from the current card, then (ii) peep ahead to see if there is a further character position on the current card; make EOLN true if not. This logic enables the programmer to precede each READ with:

IF NOT EOLN THEN ...

The logic for reading a whole line ( READLN ) is similar: (i) read the specified item or items from the current card, ignoring any remaining character positions, then (ii) peep ahead to see if there is a further card; make EOF true if not. This logic enabled the programmer to precede each READLN with:

IF NOT EOF THEN ...

But when input is interactive, peeping ahead is nonsense; a program can't know what its user intends to type next. So the logic of READ and READLN has to be modified wherever the source of input is to be a human being responding to prompts.

A popular modification ( Acornsoft: ISO Pascal, Prospero: Pro Pascal ) is "lazy i/o" which means delaying the peep ahead until the program makes a further reference  $\approx$  e.g. by READ or EOF  $\approx$  to the keyboard. Another technique ( Borland: Turbo Pascal ) is to treat the current character from a keyboard as the result of the peep ahead. Both methods solve the peep ahead problem demonstrated opposite. Other problems follow.

# PEEP-AHEAD PROBLEM

THIS PROBLEM PRECLUDES  
INTERACTIVE WORKING

Interactive hiccups are caused by the logic of peeping ahead as discussed in general opposite. The RESET procedure (implicit in the case of INPUT) places a window over the first item of the file; the subsequent READ or READLN procedure copies what is in the window then moves the window to the next character or past the next end-of-line respectively. This logic is so fundamental to Pascal that it is worth exploring what would happen if an attempt were made to run this little program ~ if compiled by a traditional Pascal compiler ~ interactively.

```
PROGRAM hiccups(INPUT, OUTPUT);
  VAR a, b: CHAR;
BEGIN
  WRITELN('first please');
  READLN(a);
  WRITELN('second please');
  READLN(b);
  WRITELN(a, b, '!')
END.
```

Control begins at WRITELN('first please') and goes straight on to READLN(a), making the program wait for something to be typed and entered.



Type U and press the RETURN key.

U RETURN

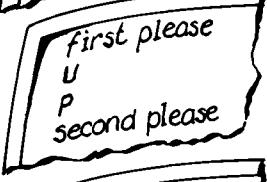
READLN(a) picks up the U but is not satisfied until it has peeped ahead at the first character of the next line. So we are hung up. The obvious thing to do is offer the first character of the next line.



Still hanging! In most systems the program receives no data until the RETURN key is pressed. Press it.

P

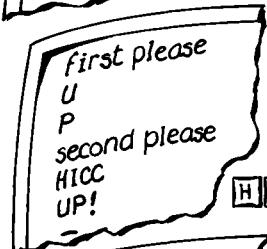
That satisfied READLN(a) so control went on to WRITELN('second please') and so to READLN(b). READLN(b) picked up the P but won't be satisfied until it has peeped ahead to the first character of the next line. Hung up again!



There is no next line. Nevertheless enter something. Anything!

RETURN

That satisfied READLN(b) so control went on to WRITELN(a,b,'!') and so to the end of the program. Messy result.



HICC RETURN

Pascal compilers such as those quoted opposite do not cause hiccups; the result would be as one would expect from reading the text of the program. In other words as illustrated here.

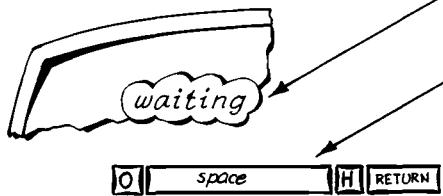


# BUFFER PROBLEM

IF YOUR PASCAL HAS THIS TROUBLE  
DON'T WRITE INTERACTIVE PROGRAMS

In the days when the word "file" implied "magnetic-tape file" it was customary for the Pascal processor to employ *buffers* for input and output. A buffer is an area of memory. Characters to be sent to the output file would be sent as far as the buffer; only when the buffer was full would its contents be copied to the magnetic tape. The same idea was employed for input. Such buffering is essential when filing on magnetic tapes, useful when filing on disks, but if the "file" is a person typing at a keyboard buffering is disastrous. The following analysis illustrates such a disaster.

```
PROGRAM flush( INPUT, OUTPUT );
  VAR a, b : CHAR;
BEGIN
  WRITELN ('first please');
  READ(a);
  WRITELN ('second please');
  READ(b);
  WRITELN (a, b, '!');
END.
```



Control starts at WRITELN('first please'). The words 'first please' are faithfully written, but written to the output buffer  $\approx$  which has plenty of room so its contents are not yet copied to the screen. The screen reveals nothing. But the program is waiting.

Type a line of data and press the RETURN key. The data are "echoed" to the screen, but this does not mean the program has received them.

If nothing else happens it means the data have gone to the input buffer and won't come out until the buffer is full or until you send an e.o.f. from the keyboard. (The e.o.f. signal is installation dependent.)

Assume there is just a line buffer for input and that the RETURN key activates it. That means READ(a) is satisfied; WRITELN('second please') sends the words 'second please' to the output buffer; READ(b) is satisfied; WRITELN(a, b, '!') sends the word 'OH!' to the output buffer.

Finally control reaches END. at which stage the output buffer is copied to the screen.

If your programs behave like this it means your Pascal compiler was not designed to compile interactive programs. Programs to be compiled by such a compiler should be designed to read data from a disk file.

Pro Pascal, Turbo Pascal and Acornsoft ISO Pascal do not exhibit the difficulties described above; interactive programs may be compiled by them.

# EOF PROBLEM

DON'T USE THE STATEMENT WHILE NOT EOF IN INTERACTIVE PROGRAMS

This is the standard Pascal model for non-interactive input. But what does EOF mean in an interactive program? Typically end-of-file is signalled from the keyboard by a special character particular to each installation. An example end-of-file signal is pressing **CTRL** and **Z** together.

WHILE NOT EOF(f) THEN  
BEGIN

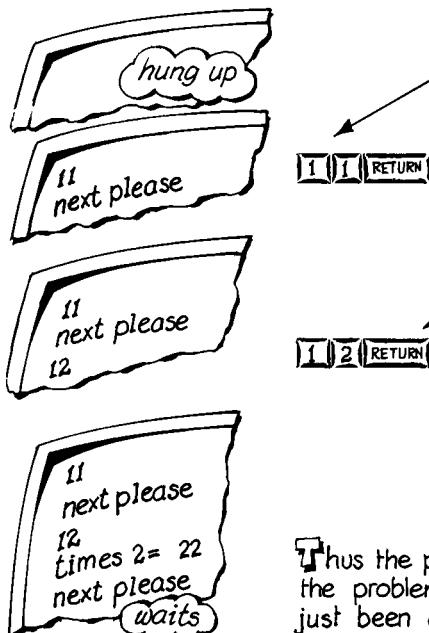
- read & process what is in the window, then
- move the window to next item

END

```
PROGRAM pardon (INPUT, OUTPUT);
  VAR i: INTEGER;
BEGIN
  WHILE NOT EOF(INPUT) DO
    BEGIN
      WRITELN ('next please');
      READLN (INPUT, i);
      WRITELN ('times 2= ', 2*i)
    END
END.
```

Here is what happens if you write an interactive program using this model.

Control begins at WHILE NOT EOF(INPUT) where it hangs. Nothing has yet been typed so there is nothing for EOF to test. (The READLN statement is not to blame because control has not reached a READLN statement yet.) Help the program by entering the first number.



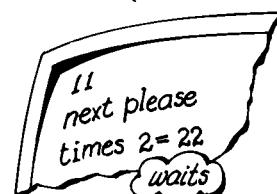
The '11' satisfied the EOF test, EOF(INPUT) returned *false* so control went to WRITELN('next please') and so to the READLN(INPUT, i). The READLN(INPUT, i) picked up the '11' but won't be satisfied until it has peeped ahead (more about this at the bottom of the page).

That satisfied READLN(INPUT, i) for the first number 11 so control went to WRITELN ('times 2= ', 2\*i) which wrote 22, then back round the loop to WRITELN('next please'), and so to READLN(INPUT, i). The READLN(INPUT, i) picks up the '12' and waits for the next chance to peep ahead.

Thus the program would continue to print the solution to the problem-before-last, then ask for the number it has just been given.

Until you press the combination of keys that signals end-of-file on your particular installation (shown here as **Z**).

With "lazy input" the results look a little less silly but remain out of phase



Don't use WHILE NOT EOF in interactive programs.



# 12

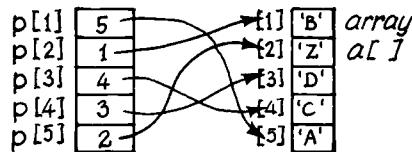
## DYNAMIC STORAGE

DYNAMIC STORAGE  
NEW AND DISPOSE  
STACKS (STACKS AND QUEUES)  
REVERSE POLISH NOTATION  
H21J09 (EXAMPLE)  
SIMPLE CHAINS  
SHORTEST ROUTE (EXAMPLE)  
INTRODUCING RINGS  
ROSES (EXAMPLE)  
INTRODUCING BINARY TREES  
MONKEY-PUZZLE SORT (EXAMPLE)

# DYNAMIC STORAGE

## INTRODUCING POINTERS AND DYNAMIC RECORDS

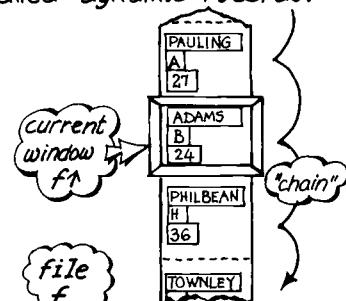
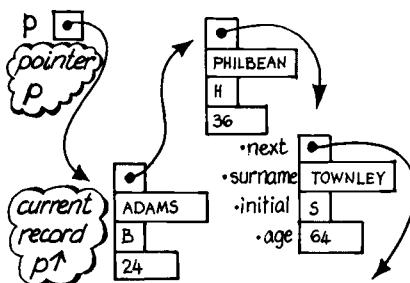
The concept of a pointer has already been introduced in the context of sorting an array. The pointers are exchanged rather than the components they point to. In this context the pointers are integers confined to the subrange of the array subscripts.



`FOR i := 1 TO 5 DO WRITELN(a[p[i]])`

Wherever the things to be sorted may be held in a simple array the pointers to those things may be integers as demonstrated above. But the use of arrays is not always convenient because the array structure is too rigid. Moss Bros does not stock a morning suit and a dinner jacket for hire to every customer on its books because it is unusual for them all to wed on the same day or dine extravagantly on the same evening. By analogy it is not practicable to declare an array of maximum possible size for every array variable. On the hypothesis of the more sheep the less goats Pascal provides a "heap" of storage boxes. As data arrive, boxes may be taken from the heap and assembled into records. If the first item of data is a temperature reading, for example, a container of type REAL is assembled for storing the value. If the next item comprises a complicated personnel record then boxes from the heap are assembled into a container of corresponding TYPE. When a record is no longer wanted its container may be disposed of by throwing its component storage boxes back on the heap. Such records, because they come and go, are called *dynamic records*.

Dynamic records are now introduced by analogy with a *file*. Recall that every file is associated with a *file variable* in the form of a *window*. If the file is named *f* then the window is referred to as *f1*. In other words a window has no name of its own; it is referred to by the name of the file which comprises a "chain" of such windows  $\Rightarrow$



Similarly a *pointer* is associated with every *dynamic record*. If the pointer is named *p* the dynamic record is referred to as *p1*. In other words a dynamic record has no name of its own; it may be referred to by the name of any pointer which points directly to it. A "chain" may be constructed by giving each record a component for containing the pointer to another.

Items in the current record are referred to in the same way as those in the current window:

`WRITELN(f1.initial);`

$\equiv$

`WRITELN(p1.initial);`



The pointers illustrated here are *not* of type INTEGER, they are items of a special *pointer type* (you can't WRITE a pointer to see what it looks like). The syntax for declaring pointers of pointer type is now defined:

optional spaces  $\uparrow$  name type      **POINTER TYPE**      ▶ **TYPE**      **POINTER TO**  
pointertype =  $\uparrow$  persontype

Compare the above syntax of *pointer* type with that of *file* type:

► TYPE  
filetype = **FILE OF** persontype

Notice that the words FILE OF are matched *not* by the words POINTER TO (as one might expect) but by an upward arrow. In this context the upward arrow should be pronounced "pointer to" and thought of as shorthand for POINTER TO.

Comparing syntax, the words FILE OF may be followed by the *name* of a type or by the *full definition* of a type. In this example the name *persontype* could be eliminated by placing the RECORD definition directly after FILE OF. But this short cut is *not* allowed with pointers; the item after the upward arrow must be the *name* of a type previously defined.

```

TYPE
  persontype = RECORD
    surname : PACKED ARRAY [1..10] OF CHAR;
    initial : CHAR;
    age : 18..65
  END;
  filetype = FILE OF persontype
  pointertype = ↑ persontype
  name essential

```

A pointer to a record is of most use if the record itself contains a pointer pointing to another record. The simplest data structure linked by such pointers is the "chain" illustrated opposite. It needs the following pair of declarations:

persontype = RECORD  
 next: pointertype;  
 surname: PACKED ARRAY [1..10] OF CHAR;  
 initial: CHAR;  
 age: 18..65  
 END;  
 pointertype = ↑ persontype;  
 Which should come first? If we declared persontype first it would refer forward to pointertype; conversely pointertype declared first would refer forward to persontype. But no Catch 22; declare first the one with the upward arrow. A forward reference from a **POINTER TO** is permitted as a necessary exception to the rule forbidding references to things yet to be defined.

Having named one or more pointer types, pointer variables may be declared in the VAR section in the usual way. The example on the next double page shows the declaration of pointer variables named *head* and *p*; both are of the pointer type named *pointertype*.

A standard pointer constant is provided, needing no declaration (there is no way to declare pointer constants of one's own). The standard pointer constant is named NIL and is defined below. It is analogous to zero when manipulating pointers and is useful for marking the end of a chain as illustrated on the next double page.

**NIL**  *standard constant of pointer type*

# NEW AND DISPOSE

INTRODUCED IN THE CONTEXT OF  
A LINKED LIST (A CHAIN)

To explain what the program on the opposite page does it is easiest to start the explanation part way through. The user entered an 'A', then a 'B' and the program did this:



The user now plans to enter a 'C' for linking to the chain illustrated. The four steps for linking (already employed to link A and B) are:

(i) create a new record pointed to by  $p$ . This is achieved by invoking a standard procedure named NEW:

NEW( $p$ );

(ii) put data in the record; e.g.

READLN( $p^.data$ );

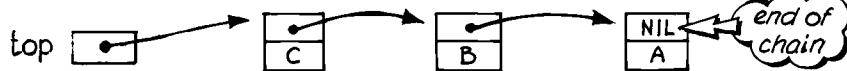
(iii) copy the pointer from  $top$  into the new record, causing the new record (as well as  $top$ ) to head the old chain:

$p^.next := top$ ;

(iv) copy the pointer from  $p$  into  $top$  causing  $top$  (as well as  $p$ ) to head the augmented chain:

$top := p$ ;

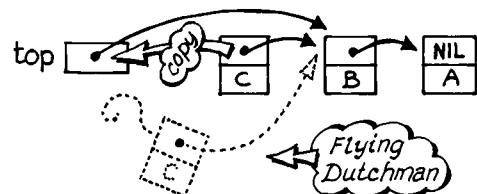
The result is:



To unlink the record currently at the head of the chain requires only one step if a bit of memory may be wasted (as often it may):

(i) copy the pointer of the doomed record into  $top$ , causing  $top$  to point to the subsequent record:

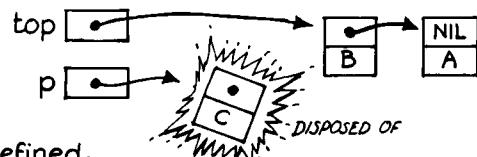
$top := top^.next$ ;



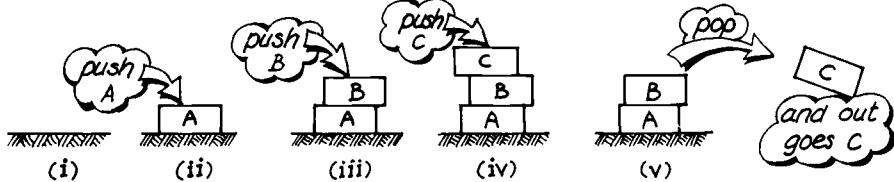
But if Flying Dutchmen cannot be afforded, their hulks may be returned to the heap for re-use. To do this (i) point to the doomed record, (ii) unlink as above, (iii) invoke the standard procedure named DISPOSE. Three steps instead of one:

$p := top$ ;  
 $top := top^.next$ ;  
DISPOSE( $p$ )

The 'C' has now vanished;  $p$  is undefined.



From the explanation opposite it is evident that the last record to be linked is the first to be unlinked. So we can change the metaphor from linking and unlinking a chain to "pushing and popping a stack".



To operate the program below: Enter +L (or plus any letter) to push that letter onto the stack; enter a lone minus sign (- at the start of a line) to pop the stack. Enter a lone asterisk (\*) at the start of a line to stop.

```

PROGRAM stack ( INPUT, OUTPUT );
TYPE
  pointertype = ^ recordtype;
  recordtype = RECORD
    next: pointertype;
    letter: CHAR
  END;
VAR
  top, p: pointertype;  ch: CHAR;
BEGIN
  top := NIL;           initialize an empty stack
  REPEAT
    READ( ch );
    IF ch IN ['+', '-'] THEN
      CASE ch OF
        '+': BEGIN { PUSH }
          NEW( p );
          READLN( p^.letter );
          p^.next := top;
          top := p
        END
        '-': BEGIN { POP }
          IF top <> NIL THEN
            BEGIN
              WRITELN( top^.letter, ' popped' );
              p := top;
              top := top^.next;
              DISPOSE( p )
            END
          ELSE
            WRITELN( 'nothing to pop' )
        END
      END { CASE }
    UNTIL ch = '*'
  END.

```

+L  
+T  
-  
T popped  
-  
L popped  
-  
nothing to pop  
+Q  
etc.

standard procedure  
NEW( name<sub>pointer</sub> )

test for an empty stack  
disposal  
standard procedure  
DISPOSE( name<sub>pointer</sub> )

# STAQUES

## STACKS AND QUEUES ~ INTRODUCING RECUSION TO TRAVERSE A LINKED LIST

The program on the previous page was kept as simple as possible to show without distraction the mechanism of linking and unlinking a record to the head of a chain. The program below employs the same techniques but parcelled as functions and procedures to be invoked as follows:

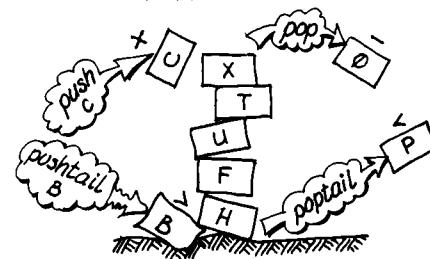
`push( ptr, ch)` and `ch := pop( ptr)`

Without altering the simple chain structure of the stack, two further utilities are added:

`pushtail( ptr, ch)` and `ch := poptail( ptr)`

for pushing an item on the *bottom* of a stack and popping an item from the *bottom* of a stack respectively.

Using only *push* and *poptail* means using a chain as a *queue*. Items are pushed on at one end, wait in the queue, get popped from the other end for service. Using only *pushtail* and *pop* implies a similar queue in the opposite direction.



Recursion is employed to reach the bottom of the stack. When *pushtail* is invoked the current link of the chain appears in one of two states:

`ptr NIL` or else `ptr [ ] → [ ] ptr↑.next`

If `ptr = NIL` we are at the end of a chain, so the `NIL` has to be replaced by a pointer to a new record. If `ptr <> NIL` we are *not* at the end of a chain so we invoke *pushtail( ptr↑.next, ch )* to do the work.

Recursion is also used in *poptail*, but here there are *three* possible states:

`ptr NIL` or `ptr [ ] → [ ] NIL ptr↑.next` or `ptr [ ] → [ ] [ ] → [ ]`

If `ptr = NIL` the queue is empty. If `ptr↑.next = NIL` there is a solitary item which may be popped as though the queue were a stack. If `ptr↑.next <> NIL` we invoke *poptail( ptr↑.next )* to do the work.

```
PROGRAM staque( INPUT, OUTPUT );
TYPE
  pointertype = ^ recordtype;
  recordtype = RECORD
    next: pointertype;
    data: CHAR
  END;
VAR
  top: pointertype;
  ch: CHAR;
```

First set up the data structure

```

PROCEDURE push(VAR ptr: pointertype; c: CHAR);
  VAR
    p: pointertype;
  BEGIN
    NEW(p);
    p^.data := c;
    p^.next := ptr;
    ptr := p
  END;

```

Where are the four utilities; they are used to good effect in the program on page 144.

```

FUNCTION pop(VAR ptr: pointertype): CHAR;
  BEGIN
    pop := CHR(0);
    IF ptr <> NIL
    THEN
      BEGIN
        pop := ptr^.data;
        ptr := ptr^.next
      END
    END;

```

'pop' returns this invisible character if stack is empty

dispose of the Flying Dutchman if you wish

```

PROCEDURE pushtail(VAR ptr: pointertype; c: CHAR);
  BEGIN

```

```

    IF ptr = NIL
    THEN
      BEGIN
        NEW(ptr);
        ptr^.data := c;
        ptr^.next := NIL
      END
    ELSE
      pushtail(ptr^.next, c)
  END;

```

recursion

```

FUNCTION poptail(VAR ptr: pointertype): CHAR;
  BEGIN
    poptail := CHR(0);
    IF ptr <> NIL
    THEN
      IF ptr^.next = NIL
      THEN
        poptail := pop(ptr)
      ELSE
        poptail := poptail(ptr^.next)
    END;

```

empty: see above

recursion

```

BEGIN { stack }
  top := NIL;
  REPEAT
    READ(ch);
    IF ch IN ['+', '-', '>', '<']
    THEN
      CASE ch OF
        '+': BEGIN
          READLN(ch);
          push(top, ch)
        END;
        '-': WRITELN( pop(top) );
        '>': BEGIN
          READLN(ch);
          pushtail( top, ch )
        END;
        '<': WRITELN( poptail(top) )
      END
    UNTIL ch = '*'
  END.

```

use this program in the same way as that on page 139 ~ but enjoy two extra facilities:

→ to push 'L' (or any letter) on the stack

→ to push letter on the bottom of the stack

- to pop the stack

< to pop the bottom of the stack

\* to stop

# REVERSE POLISH NOTATION

ILLUSTRATING THE USE OF STACKS

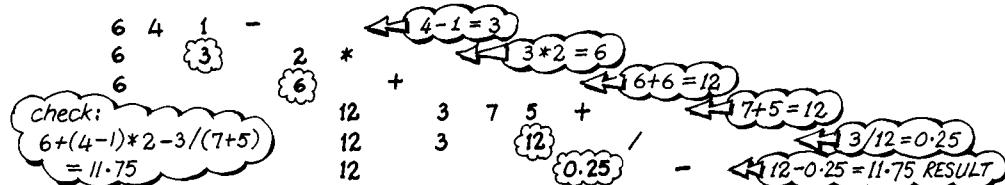
Algebraic expressions in conventional form may be expressed in Reverse Polish Notation which has no parentheses ("Polish" because the notation was devised by the Polish logician Jan Lukaciewicz which only Poles can pronounce; "Reverse" because his original order of operators and operands has been reversed). As an example of reverse Polish notation:

$A + (B - C) * D - F / (G + H)$  transforms to  $ABC - D * + FGH + / -$

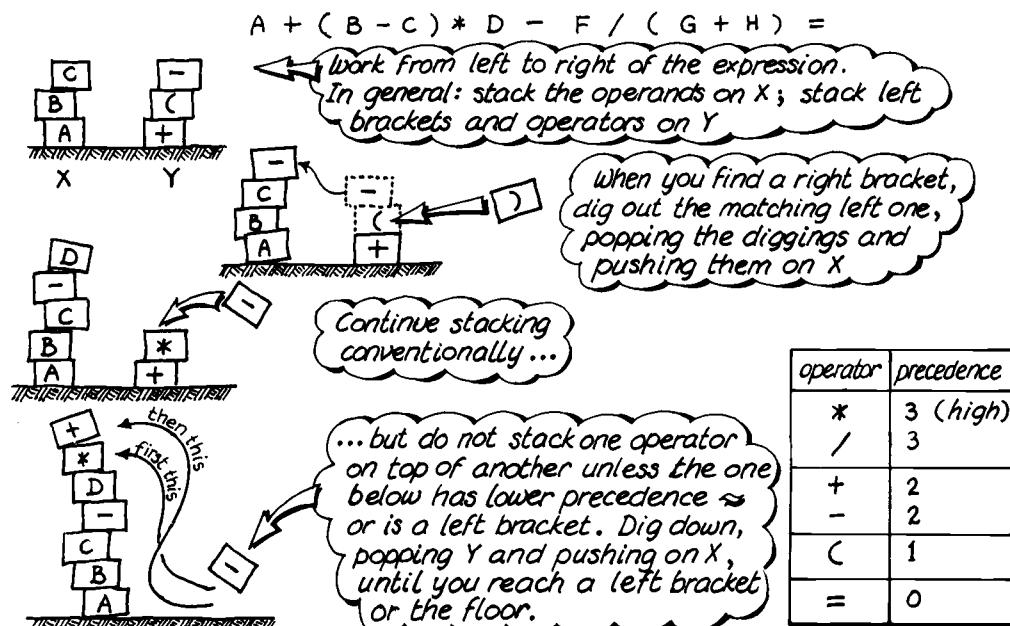
The reverse Polish expression is easier to evaluate than might appear. For example let  $A = 6$ ,  $B = 4$ ,  $C = 1$ ,  $D = 2$ ,  $F = 3$ ,  $G = 7$ ,  $H = 5$ . With these values the expression to be evaluated is:

6 4 1 - 2 \* + 3 7 5 + / -

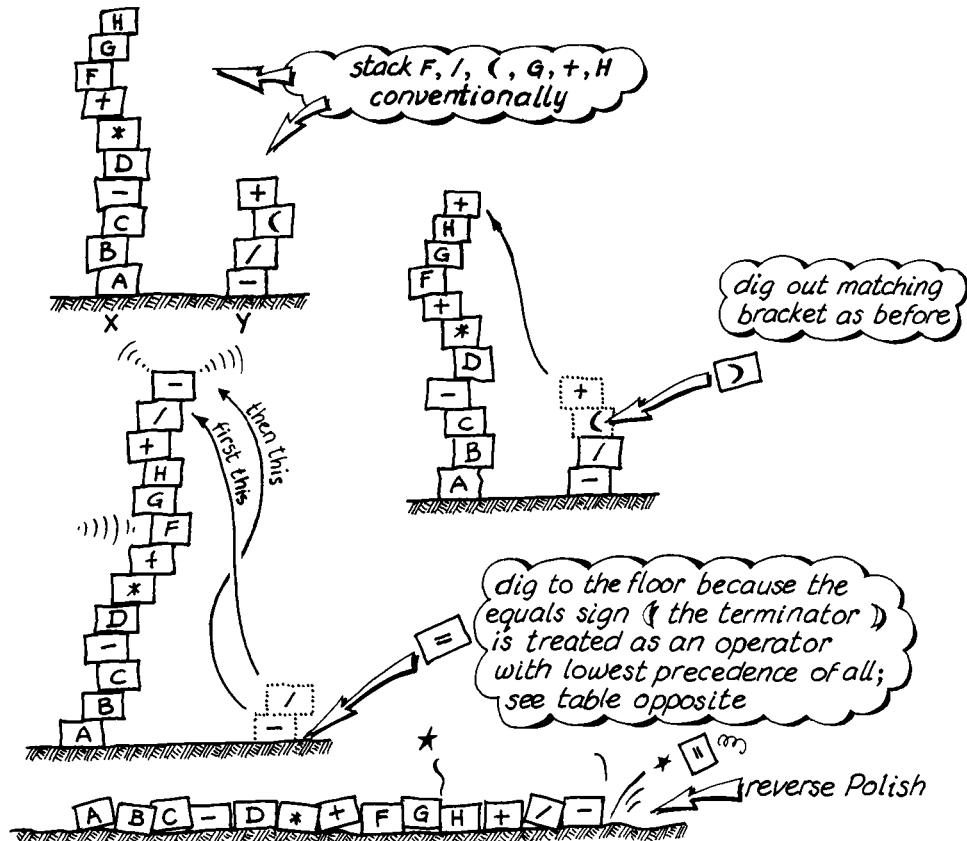
Work from left to right taking each item in turn. Whenever you come to an operator apply it to the previous two terms, reducing two terms to one:



The above should demonstrate that reverse Polish notation would be useful for evaluating expressions by computer. So how do you transform an expression such as  $A + (B - C) * D - F / (G + H)$  in the first place? The process employs two stacks; the steps are explained below.



Notice that the left bracket is included in the precedence table and allocated low precedence. This is a trick to avoid having to treat explicitly the condition " $\simeq$  or is a left bracket". Clever.



In addition to the procedure `push(stack, ch)` and the functions `pop(stack)` and `poptail(stack)` a function is needed to return the precedence of an operator. The function shown below is given a character as its parameter and returns the corresponding integer from the little table opposite:

```
FUNCTION prec( c : CHAR ) : INTEGER;
BEGIN
  CASE c OF
    '*', '/': prec := 3;
    '+', '-': prec := 2;
    '(': prec := 1;
    '=': prec := 0
  END
END;
```

see little table opposite

On the next page is a program to transform conventional expressions to reverse Polish. To use the program type the expression and terminate with an equals sign:

A+(B-C)\*D-F/(G+H)=  
ABC-D\*+FGH+/-

enter this

get result

# HELLOP

AN EXAMPLE TO ILLUSTRATE THE USE OF STACKS  
(operating instructions at foot of previous page)

```

PROGRAM hsilop( INPUT, OUTPUT);
TYPE
  pointertype = ^recordtype;
  recordtype = RECORD
    next: pointertype;
    data: CHAR
  END;
VAR
  x, y: pointertype;
  ch: CHAR; i: 0..40; exit: BOOLEAN;
  insert procedures and functions here: use
  push, pop, poptail, prec from previous pages
BEGIN {hsilop}
  x := NIL; y := NIL; initialize stacks
  REPEAT
    READ( ch );
    IF ch IN ['A'..'Z'] THEN push( x, ch );
    IF ch = '(' THEN push( y, ch );
    IF ch = ')'
    THEN
      BEGIN
        WHILE y^.data <> '('
        DO
          push( x, pop( y ) );
          ch := pop( y );
        END;
        dig out the matching
        left bracket
        then throw it away
    IF ch IN ['+', '- ', '*', '/', '=' ]
    THEN
      BEGIN
        REPEAT
          exit := TRUE;
          IF y <> NIL
          THEN
            IF prec( ch ) <= prec( y^.data )
            THEN
              BEGIN
                push( x, pop( y ) );
                exit := FALSE;
              END;
            UNTIL exit;
            push( y, ch );
          END;
        if the precedence of the
        operator on top...
        ... <= precedence
        of the operator
        or left bracket
        beneath
      END;
      only then is it
      right to push
      the new operator
    UNTIL ch = '=' ;
    WHILE x <> NIL DO WRITE( poptail( x ) );
    WRITELN
  END.

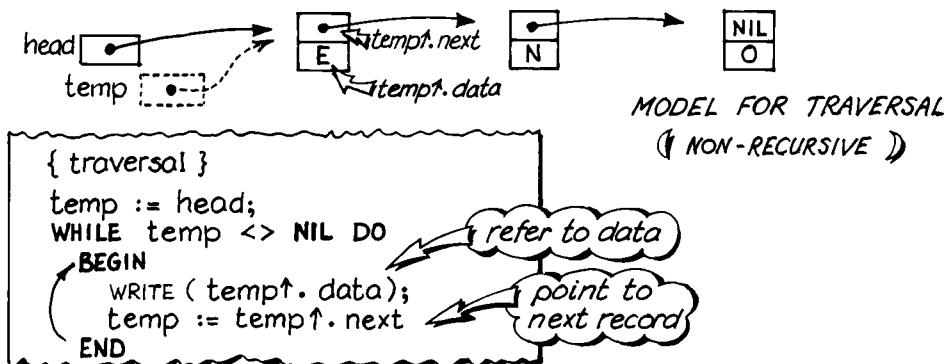
```

# SIMPLE CHAINS

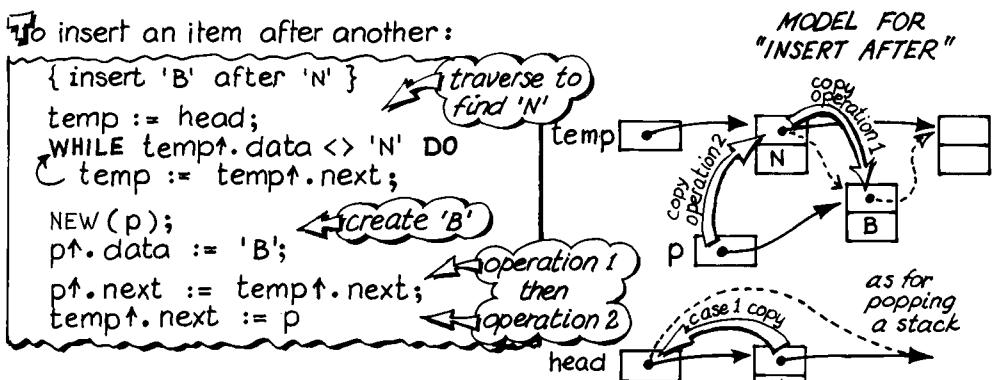
MODELS FOR "TRAVERSAL" AND "INSERT AFTER"

The essence of a *stack* or *queue* is that referring to a record means *removing* that record. (There is cheating in the previous example where the program *peeps* at the record on top of the stack before deciding to *pop* it.) But there are many applications in which sequential records of a chain are referred to without removing them. Referring to sequential records in this way is called *traversal*.

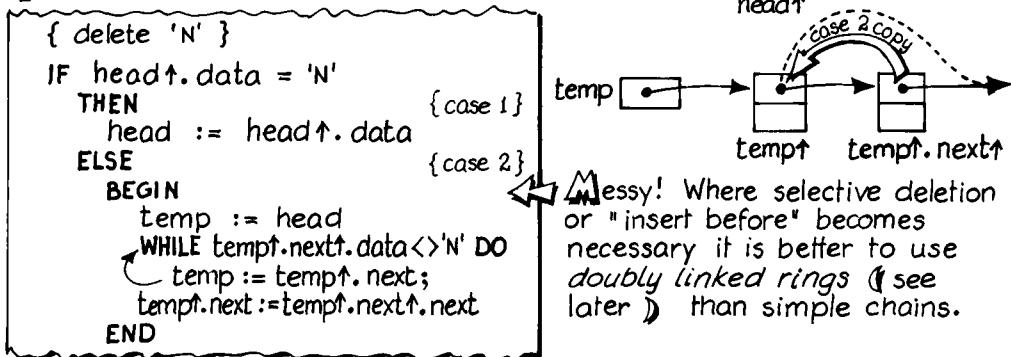
Below are shown a conventional chain and a fragment of program for its traversal. "Referring to a record" in this example involves no more than printing an item from one of its components but would, in general, be a more complicated procedure.



To insert an item after another:



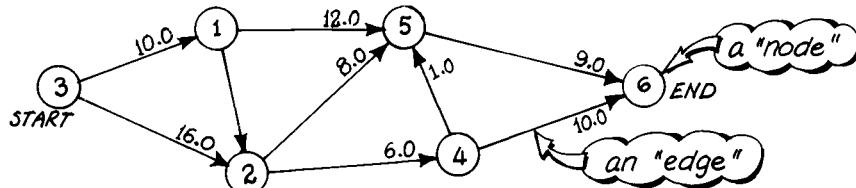
To delete an item:



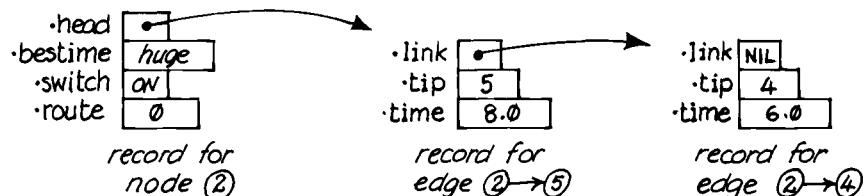
# SHORTEST ROUTE

AN EXAMPLE TO ILLUSTRATE  
THE USE OF CHAINS

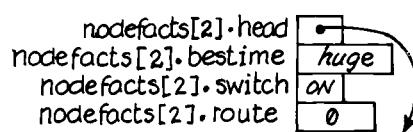
Finding the shortest (or longest) route through a network is a problem that crops up in various disciplines  $\hookrightarrow$  one of which is *critical path scheduling* for the control and monitoring of construction projects. Given a network such as that below, the problem is to find the shortest route from the node marked *START* to that marked *END*. The journey must follow the direction of the arrow. The number against each arrow shows the journey time.



The data structure needed for a shortest-route program is depicted below. There is a record for each node and a chain runs from each such record. Each chain comprises edge records which store data describing all the edges which run out of that node.



Records for all nodes are held in an array named *nodefacts*. The record for node 2 is annotated more fully below. In the component named *bestime* is the value *huge* (a constant set to  $10^{20}$ ). In the component named *switch* is a Boolean value, initially switched to *on*. Use of these items is explained later.



*nodefacts[2].head*  
*nodefacts[2].bestime*  
*nodefacts[2].switch*  
*nodefacts[2].route*

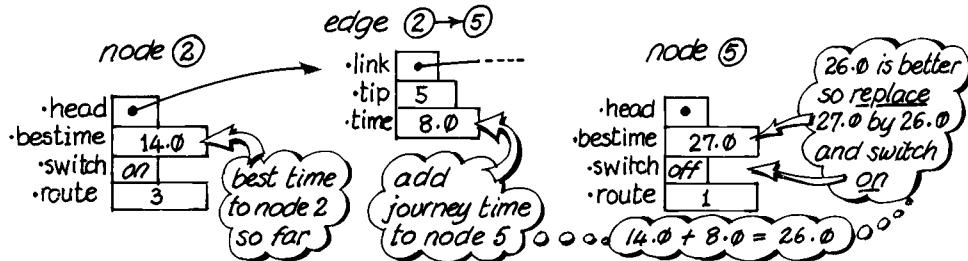
The records for edges running out of a node are created dynamically. Each record has a component for storing the link, another for storing the node number at the tip, another for storing the journey time along the particular edge. This example is for edge  $② \rightarrow ⑤$ .

The shortest route is found by an iterative process. Before the process can start the chains must be formed and initial values placed in the components that will eventually hold changing values. The component named *bestime* is to hold the best time so far achieved to this node by different trial routes; the initial time in this component is set so high that the first feasible route, however slow, has to be an improvement. An exception is the starting node; the best time to the starting node is, by definition, nothing.

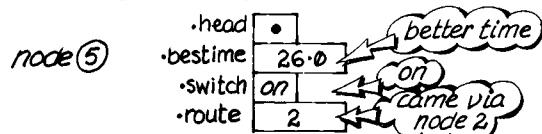
All switches are turned *on* initially. A switch that is *on* implies that the edges leading out of that node must be explored (or re-explored).

The iterative process starts at the starting node, then cycles the array of node records until terminated. The process terminates on detection of all switches being off.

At each node the chain of edge records is traversed. For each edge in the chain the time to reach its tip is found by adding the best time so far achieved at the tail to the journey time for that edge. The result is compared with the best time so far recorded in the node record for the tip. If the new time is better, several things must be recorded. These are depicted below:



Whenever a better route to a node is found, the faster time is substituted and the node switched on as depicted for node 5 above. To be able to trace this improved route subsequently, the route component is made to contain the number of the node through which the route came. So the outcome of dealing with the edge from ② to ⑤ is:



After traversing the chain of edges from node 2 the switch at node 2 is turned off. However, the action at node 2 included turning on the switch at node 5 so the iteration is not yet finished. The process continues until all switches are off in other words until a complete cycle through the nodes fails to make a single improvement to the route.

The node-records are assembled as an array rather than being created dynamically and linked as a chain. The array structure was chosen because node-records are accessed in a "random" way (e.g. when dealing with node 2 you have to refer to nodes 5 and 4). Using an array such references are resolved quickly by a simple change of subscript.

Tried with the network sketched opposite, data and results (assuming interactive use) would be as shown here. ↗

No. nodes	No. edges	Startnode	Endnode
9	9	3	6
6	1	10.0	
3	2	16.0	
3	2	5.0	
1	2	12.0	
1	5	6.0	
2	4	8.0	
2	5	9.0	
5	6	10.0	
4	6	1.0	
4	5	3.0	
Route from 6 to 3			
6...4...2...1...3			
Time taken is 31.0			

# SHORTEST ROUTE

( THE FULL PROGRAM )

```

PROGRAM network ( INPUT, OUTPUT );
CONST
  on = TRUE;    off = FALSE;
  huge = 1E20;  nothing = 0.0;
  maxnodes = 30; maxedges = 50;

TYPE
  nodetype = 0..maxnodes; edgetype = 0..maxedges;
  pointertype = ^chaintype;
  chaintype = RECORD
    link: pointertype;
    tip: nodetype;
    time: REAL
  END;
  rectype = RECORD
    head: pointertype;
    bestime: REAL;
    switch: BOOLEAN;
    route: nodetype
  END;
  arraytype = ARRAY [nodetype] OF rectype;

VAR
  nodes, startnode, endnode, i, n, tail: nodetype;
  edges, j: edgetype;
  edge, p: pointertype;
  nodefacts: arraytype; array of node records
  cycles: 0..2; try: REAL;

BEGIN
  WRITELN ('No.nodes, No.edges, Startnode, Endnode');
  READLN (nodes, edges, startnode, endnode);

  FOR i := 1 TO nodes DO
    WITH nodefacts[i] DO
      BEGIN
        head := NIL;
        bestime := huge;
        switch := on;
        route := 0
      END; { WITH }
    nodefacts[startnode].bestime := nothing;

  FOR j := 1 TO edges DO
    BEGIN
      NEW (p);
      READLN (tail, p^.tip, p^.time);
      p^.link := nodefacts[tail].head;
      nodefacts[tail].head := p
    END;

```

*initialize*

*replace time at start node*

*form all chains*

*read data*

*link new record to chain*

```
cycles := 0;  
n := startnode - 1;
```

*n is augmented by +1 before use, hence -1 in preparation*

```
WHILE cycles < 2 DO  
BEGIN  
  cycles := SUCC(cycles);  
  n := n MOD nodes + 1  
  IF nodefacts[n].switch = on  
  THEN  
    BEGIN { IF switch }  
    cycles := 0;  
    edge := nodefacts[n].head;  
  
    WHILE edge <> NIL DO  
    BEGIN { WHILE edge }  
    try := nodefacts[n].bestime + edge^.time;  
    IF try < nodefacts[edge^.tip].bestime  
    THEN  
      WITH nodefacts[edge^.tip] DO  
      BEGIN  
        bestime := try;  
        route := n;  
        switch := on  
      END  
      edge := edge^.link  
    END; { WHILE edge }  
    nodefacts[n].switch := off  
  END { IF switch }  
END; { WHILE cycles }
```

```
WITH nodefacts[endnode] DO  
IF (bestime <> huge) AND (bestime <> nothing)  
THEN  
BEGIN  
  WRITELN('Route from', endnode:3, ' to', startnode:3);  
  n := endnode;  
  
  WHILE n <> 0 DO  
  BEGIN  
    WRITE(n:1);  
    n := nodefacts[n].route;  
    IF n <> 0 THEN WRITE('...')  
  END;  
  WRITELN;  
  WRITELN('Time taken is', bestime:6:2)  
END  
  
ELSE  
  WRITELN('No way through - or going nowhere')  
END.
```

*keep looking back to previous node*

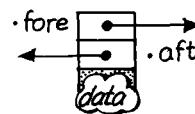
*field width expands to 2 if node number has 2 digits*

*e.g. 6...4...2...1...3*

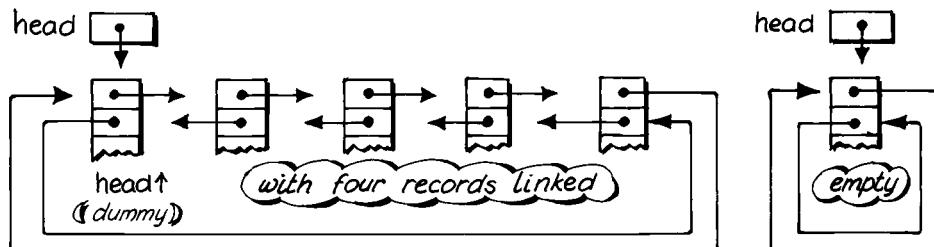
# INTRODUCING RINGS

AN ELEGANT DATA STRUCTURE

The fundamental record of a doubly linked ring has pointers pointing fore and aft thus: ➤



Access to records in a ring is simplified by employing one record as a dummy head as illustrated below. This device makes it unnecessary to check whether the record to be added or deleted is next to the fixed head, taking special action accordingly. Very messy.



A ring is depicted above with four records; it is also depicted empty.

Here is the definition of a record suitable for constructing a ring. To keep everything simple this record is made capable of storing just a single character. ➤

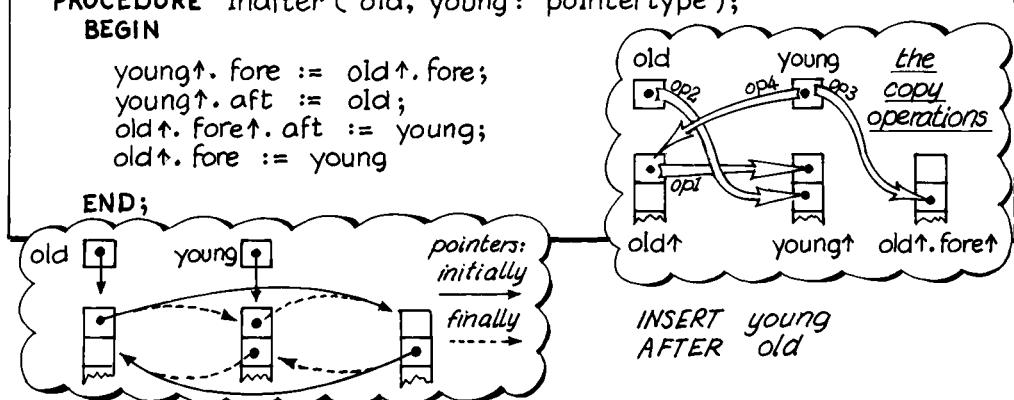
In the main program an empty ring may be set up as follows.

```
NEW ( head );
head↑.fore := head;
head↑.aft := head;
```

```
TYPE
  pointertype = ↑ recordtype;
  recordtype = RECORD
    fore,aft: pointertype;
    data: CHAR
  END;
  VAR
    head, temp : pointertype;
```

A new record may be inserted before or after the record currently pointed to. Procedures for both these operations are given below:

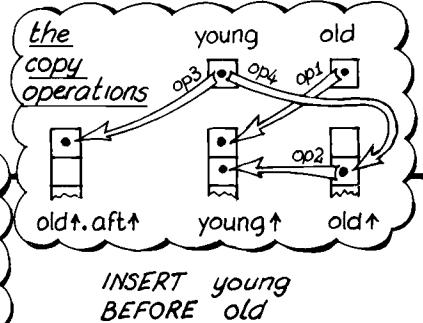
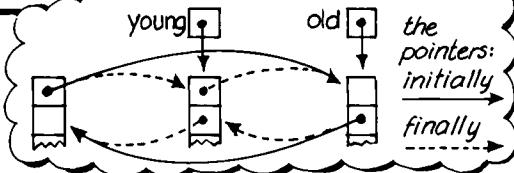
```
PROCEDURE inafter ( old, young: pointertype );
BEGIN
  young↑.fore := old↑.fore;
  young↑.aft := old;
  old↑.fore↑.aft := young;
  old↑.fore := young
END;
```



```

PROCEDURE inbefore (VAR old, young: pointertype);
BEGIN
  young↑. fore := old;
  young↑. aft := old↑. aft;
  old↑. aft↑. fore := young;
  old↑. aft := young
END;

```

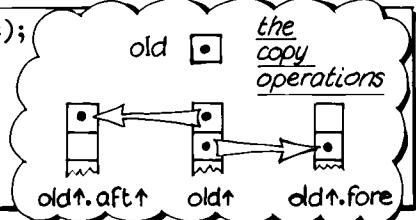


Deletion is simple and elegant:

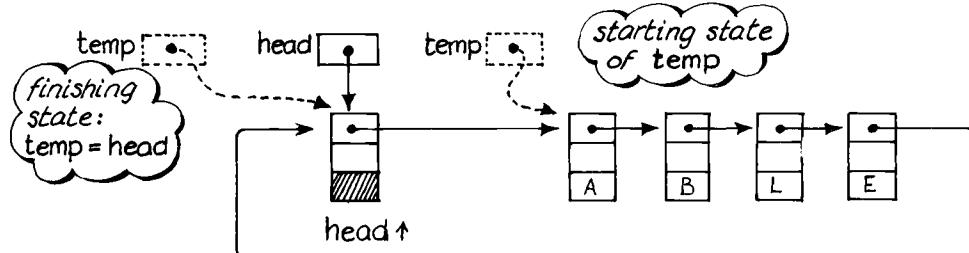
```

PROCEDURE delete ( VAR old: pointertype);
BEGIN
  old↑. fore↑. aft := old↑. aft;
  old↑. aft↑. fore := old↑. fore
END;

```



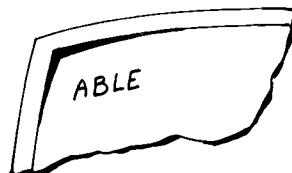
Traversal is simple in either direction; the only difficulty is stopping in time. If the aim is to traverse the ring precisely once, start by pointing to the first record and arrange to stop as soon as the pointer points to the dummy head (if before trying to refer to data in the dummy head).



```

temp := head↑. fore;
WHILE temp <> head DO
  BEGIN
    WRITE temp↑. data;
    temp := temp↑. fore
  END;
  WRITELN

```



If both occurrences of "fore" were changed to "aft" the result of the above piece of program would be ELBA rather than ABLE.

Overleaf is a demonstration program designed to exercise the principles and procedures introduced on this double page.

# ROSES

## AN EXAMPLE PROGRAM TO DEMONSTRATE THE WORKING OF A DOUBLY-LINKED RING

The following program maintains a doubly-linked ring organized alphabetically. To introduce a letter enter +L ( or + any other letter ) at the start of a line. To remove a letter enter -L ( or - whatever the letter ). To display the stored data in alphabetical order enter > at the start of a line. To display in reverse order enter <. To stop enter \* at the start of a line.

```

PROGRAM roses( INPUT, OUTPUT );
TYPE
  pointertype = ^recordtype;
  recordtype = RECORD
    fore, aft: pointertype;
    data: CHAR
  END;
VAR
  ch: CHAR;
  head, p, temp: pointertype;
  caps, operators : SET OF CHAR;
PROCEDURE inbefore( VAR old, young: pointertype );
BEGIN
  young^.fore := old;
  young^.aft := old^.aft;
  old^.aft^.fore := young;
  old^.aft := young
END;
PROCEDURE delete( VAR old: pointertype );
BEGIN
  old^.fore^.aft := old^.aft;
  old^.aft^.fore := old^.fore
END;
BEGIN
  caps := ['A'..'Z'];
  operators := ['+', '-', '>', '<'];
  NEW( head );
  head^.fore := head;
  head^.aft := head;
  head^.data := CHR( 0 );
  REPEAT
    READ( ch );
    IF ch IN operators
      THEN

```

+R  
 +O  
 >  
 OR  
 +S  
 +E  
 +S  
 >  
 EORSS  
 -S  
 <  
 SROE  
 \*

procedures  
 inbefore and  
 delete as on  
 previous page

set up an empty ring.  
 put a dummy character  
 CHR(0) into dummy head  
 to avoid the crash warned  
 about on the next page

CASE ch OF

'+' : BEGIN

  READ ( ch );  
  IF ch IN caps

  THEN

    BEGIN

      NEW ( p );

      pt. data := ch;

      temp := head↑. fore;

      WHILE ( temp <> head ) AND ( temp↑. data < ch ) DO

        temp := temp↑. fore;

      inbefore ( temp, p )

    END

  END;

Beware of a potential crash.  
The condition temp↑. data < ch  
will be evaluated even when the  
condition temp <> head is false.  
So temp↑. data must not be left  
undefined in the dummy head.  
Hence the CHR(0)

← insert

'-' : BEGIN

  READ ( ch );  
  IF ch IN caps

  THEN

    BEGIN

      temp := head↑. fore;

      WHILE ( temp <> head ) AND ( temp↑. data < ch ) DO

        temp := temp↑. fore;

      IF temp <> head

        THEN

          delete ( temp )

delete

    END

  END;

'>' : BEGIN

  temp := head↑. fore;  
  WHILE temp <> head DO

    BEGIN

      WRITE ( temp↑. data );

      temp := temp↑. fore

    END;

  WRITELN

END;

display in  
ascending  
order

'<' : BEGIN

  temp := head↑. aft;  
  WHILE temp <> head DO

    BEGIN

      WRITE ( temp↑. data );

      temp := temp↑. aft

    END;

  WRITELN

END

END { CASE }

UNTIL ch = '\*'

END. { roses }

display in  
descending  
order

stop work  
on \*

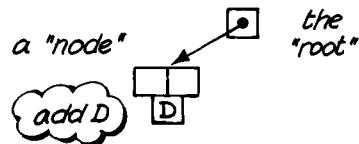
# INTRODUCING BINARY TREES

ANOTHER ELEGANCE

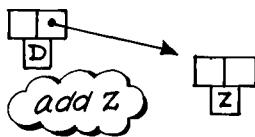
Take some letters to sort:

D, Z, B, E, A, F, C

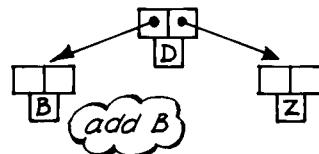
Bring the first letter, D, to the root of a tree and store it in a node. (Trees grow upside down as do several metaphors in computer science.)



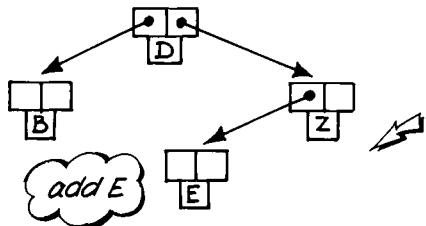
Now take the next letter, Z, and bring it to the root node. It is "bigger" than D so go right and make a new node to contain Z as shown here.



Now the third letter, B. It is smaller than D so go left and make a new node.

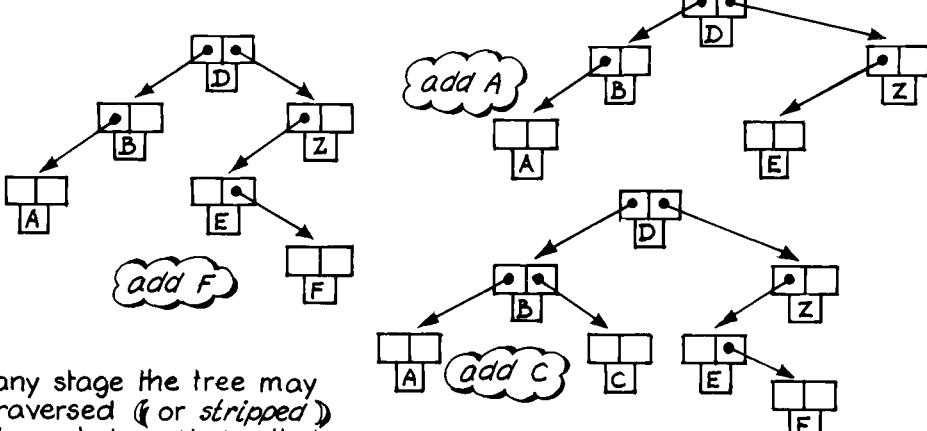


The next letter, E, is bigger than D so go right. It is smaller than Z so go left. Then make a new node to contain E as shown here.

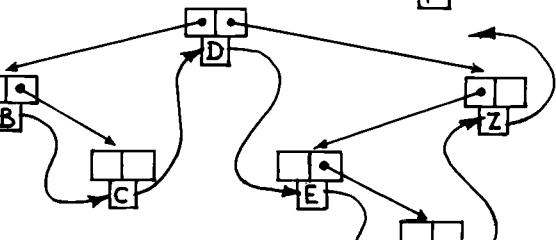


In general; bring the next letter to the root node and compare. If the new letter is smaller go left, if bigger go right. Do the same thing as you reach each node until there are no more nodes to supply letters for comparison. Then make a new node to contain the new letter.

the same thing as you reach each node until there are no more nodes to supply letters for comparison. Then make a new node to contain the new letter.



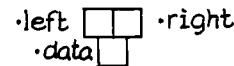
At any stage the tree may be traversed (or stripped) as shown below. Notice that the arrow runs through the letters in alphabetical order.



The order may be reversed by traversing the other way.

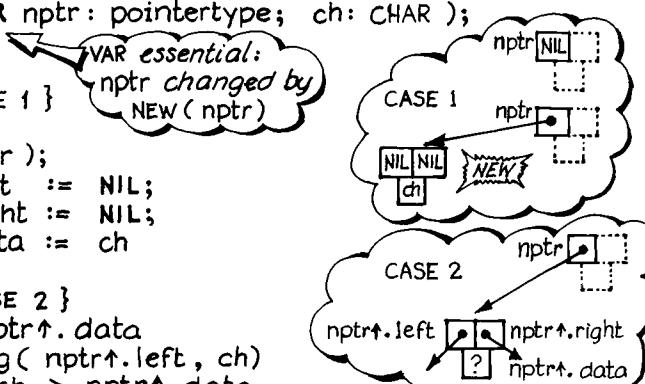
The type of node record depicted opposite is easily defined:

```
TYPE
  pointertype = ^ nodetype;
  nodetype = RECORD
    left, right : pointertype;
    data: CHAR
  END;
```



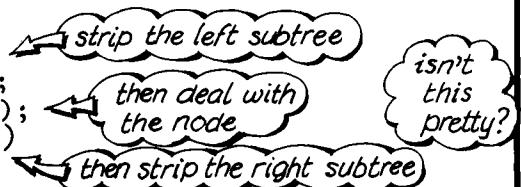
Hanging letters on a tree  $\approx$  depicted in stages opposite  $\approx$  is best done recursively. If the current node is NIL make a new node to contain the new letter; otherwise invoke the "hang" procedure with the parameter specifying the left or right pointer according to how the new letter compares with that pointed to:

```
PROCEDURE hang( VAR nptr: pointertype; ch: CHAR );
BEGIN
  IF nptr = NIL
  THEN { CASE 1 }
    BEGIN
      NEW( nptr );
      nptr^.left := NIL;
      nptr^.right := NIL;
      nptr^.data := ch
    END
  ELSE { CASE 2 }
    IF ch < nptr^.data
    THEN hang( nptr^.left, ch )
    ELSE IF ch > nptr^.data
    THEN hang( nptr^.right, ch )
    ELSE WRITELN( 'Duplicate entry' )
  END;
```



The tree may be traversed recursively:

```
PROCEDURE strip( VAR nptr : pointertype );
BEGIN
  IF nptr <> NIL
  THEN
    BEGIN
      strip( nptr^.left );
      WRITE( nptr^.data );
      strip( nptr^.right )
    END
  END;
```



In both the above procedures "WITH nptr↑ DO" could be used to reduce the number of occurrences of "nptr↑" at the cost of extra lines and less clarity. The VAR in the traversal procedure, though not logically necessary, prevents the processor taking a copy of the data structure on each invocation. Ouch!

Over the page is a program based on a binary tree. It reads letters typed in any order and displays them in alphabetical order. It is left as an exercise to add a facility for display in reverse order.

Binary trees are useful for all sorts of things besides sorting.

# MONKEY~PUZZLE SORT

ANOTHER NAME FOR  
BINARY-TREE SORT

This program maintains a binary tree in much the same way as Roses maintains a doubly-linked ring. To hang a new letter on the tree enter +L ( + or + any letter ). To remove a letter enter -L ( - or minus whatever the letter ). To display the letters on the tree in alphabetical order enter > at the start of a line. Enter \* at the start of a line to stop.

Adding to the tree is elegantly simple but deleting a node which is not a "leaf" ↗ especially when duplicated items are allowed on the tree ↗ is not easy at all. This program simply keeps a count of like items, reducing the count when an item is deleted.

```

PROGRAM monkey( INPUT, OUTPUT );

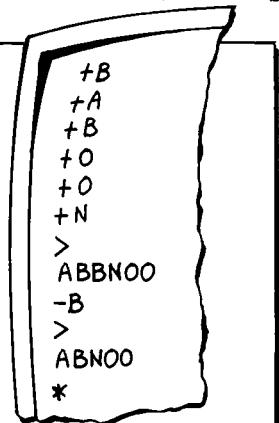
TYPE
  pointertype = ^ nodetype;

  nodetype = RECORD
    left, right: pointertype;
    data: CHAR;
    count: INTEGER
  END;

VAR
  root, p: pointertype;
  ch: CHAR;

PROCEDURE hang( VAR nptr: pointertype; ch: CHAR );
BEGIN
  IF nptr = NIL
  THEN
    BEGIN
      NEW( nptr );
      nptr^.left := NIL;
      nptr^.right := NIL;
      nptr^.data := ch;
      nptr^.count := 1
    END
  ELSE
    IF ch < nptr^.data
    THEN
      hang( nptr^.left, ch )
    ELSE IF ch > nptr^.data
    THEN
      hang( nptr^.right, ch )
    ELSE
      nptr^.count := nptr^.count + 1
  END;

```



augment the  
count if a  
duplicate

The following function is for finding a letter to be deleted. The function is written recursively using the same logic as in *hang*.

```

FUNCTION find(VAR nptr: pointertype; ch: CHAR): pointertype;
BEGIN
  IF nptr = NIL
  THEN find := NIL
  ELSE IF ch < nptr^.data
  THEN find := find(nptr^.left, ch)
  ELSE IF ch > nptr^.data
  THEN find := find(nptr^.right, ch)
  ELSE find := nptr
END;

PROCEDURE strip(VAR nptr: pointertype);
VAR
  i: 0..MAXINT;
BEGIN
  IF nptr <> NIL
  THEN
    BEGIN
      strip(nptr^.left);
      FOR i := 1 TO nptr^.count DO
        WRITE(nptr^.data);
      strip(nptr^.right)
    END
  END;

BEGIN { monkey }
  root := NIL;
  REPEAT
    READ(ch);
    IF ch IN ['+', '-', '>']
    THEN
      CASE ch OF
        '+': BEGIN
          READ(ch);
          IF ch IN ['A'..'Z']
          THEN
            hang(root, ch)
        END;

        '-': BEGIN
          READ(ch);
          p := find(root, ch);
          IF p <> NIL
          THEN IF p^.count > 0
          THEN p^.count := p^.count - 1
        END;

        '>': BEGIN
          strip(root);
          WRITELN
        END
      END { CASE }
    UNTIL ch = '*'
  END.

```

return NIL if not found

found it

e.g. if the count is 2 write the letter twice; if the count is 0 don't write anything

effectively delete one copy of letter

# EXERCISES

1. Write a program to read an arithmetic expression such as:

$$3.5 * (7 + (4 - 6.2) / 32)$$

and display the answer. Use an input procedure such as *grab* (pages 118-23) to read the numbers and operators which comprise the expression. Employ the logic of the reverse Polish program (pages 142-4) but with an important difference; when you are about to transfer an operator from stack Y to stack X do the following instead:

- pop two numbers from stack X
- apply the operator to them
- push the result on stack X

By this device you should end up with a single number in stack X; this is the value of the expression.

2. Write an adventure game. The player explores a mystic palace or smelly dungeon, walking from room to room, picking things up, putting things down, whilst contending with monsters. To write such a program you need the string-handling facilities developed in the next chapter because the player expects to type:

TAKE POISON  
or

GO WEST

and have the computer respond intelligently. There is a simple but complete adventure game described in my book:

*Illustrating Super-BASIC* C.U.P. 1985

which exploits ring structures for picking things up in one room and dropping them in another, state matrices for mapping the topology of rooms and doors, and symbol-state tables for encoding the rules of play. Enough techniques are described for constructing a complete and worthwhile adventure game.

13

## DYNAMIC STRINGS

### STRING UTILITIES

- READSTRING
- WRITESTRING
- MIDDLE
- CONCAT
- COMPARE
- INSTR
- PEEK
- POKE

BACKSLANG (EXAMPLE)

HASHING TECHNIQUE

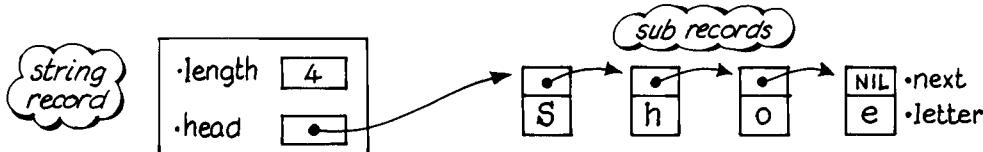
HASHER (EXAMPLE)

# STRING UTILITIES

MAY BE USEFUL EVEN IF YOU HAVE PASCAL WITH 'TYPE STRING'

Standard Pascal defines few string-handling facilities; as a consequence modern compilers offer non-standard ones. The disadvantage of using non-standard facilities is loss of portability. One way round the portability problem is to define one's own set of utilities built strictly from standard parts. This course is followed below. Its purpose is to suggest and illustrate a methodical approach rather than attempt the standardization of string utilities; the reader is sure to want different facilities and better written procedures than those to be found here.

The utilities are based on a record of the form depicted below:



Because dynamic storage is employed every string may have a different length and there is no arbitrary limit placed on length. Here is the type definition. (Also included is a definition of enumerated type for later use in the comparison of strings.)

```
PROGRAM strings ( INPUT, OUTPUT );  
  
TYPE  
  stringrange = 0..MAXINT; // constrained to be non-negative  
  pointertype = ↑ lettertype;  
  
  lettertype = RECORD  
    next: pointertype; // letter may contain any character not just alphabetic ones  
    letter: CHAR  
  END;  
  
  stringtype = RECORD  
    length: stringrange;  
    head: pointertype  
  END;  
  
  relation = ( eq, ne, gt, ge, lt, le );  
 // equivalent to: (=, <>, >, >=, <, <=)
```

The first two procedures are recursive. *Append* is for appending a new character to the end of a string; *reclaim* is for disposing of subrecords when a record is to store a new string. These are "low-level" procedures used by the main string utilities. The programmer who uses the main string utilities need not know about the low-level ones.

Throughout all procedures the parameters which nominate string records are made VAR parameters. The idea is to prevent the processor having to make copies of strings which could be very long.

```

PROCEDURE append(VAR p: pointertype; c: CHAR );
BEGIN
  IF p = NIL
  THEN
    BEGIN
      NEW( p );
      p^.letter := c;
      p^.next := NIL
    END
  ELSE
    append( p^.next, c )
END;

```

recursion

```

PROCEDURE reclaim(VAR p: pointertype );
BEGIN
  IF p <> NIL
  THEN
    BEGIN
      IF p^.next <> NIL
      THEN
        reclaim( p^.next );
      DISPOSE( p );
      p := NIL
    END
  END;

```

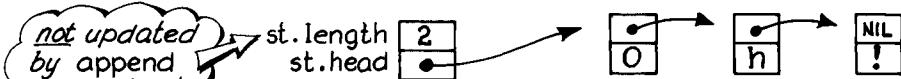
recursion

Assume a string named st :

VAR st : stringtype;



The effect of `append(st.head, '!')` would be:



The effect of `reclaim(st.head)` would be:



The following depicts an empty string. Before any string is used by name in the procedures that follow, that string must be initialized. You could write a formal procedure to do this but it's not worth the effort and complication.

st.head := NIL;  
st.length := 0

THIS IS HOW TO INITIALIZE

st.length 0  
st.head NIL

THIS IS THE EMPTY STRING DEPICTED

## READSTRING ( name<sub>string</sub> ) CHECK EOLN BEFORE INVOCATION

The following procedure reads a string and stores it under the specified name. The specified name may be the name of an empty string or of a non-empty string, the previous content being lost. It is an error to invoke the procedure with the name of a string not yet initialized. A string is considered terminated by a space or EOLN (i.e. the RETURN key pressed). Leading spaces are ignored by this procedure.

```
PROCEDURE readstring ( VAR newstring: stringtype );
  CONST
    space = ' ';
  VAR
    ch: CHAR;
  BEGIN
    reclaim( newstring.head );
    newstring.length := 0;
    REPEAT
      READ( ch )
    UNTIL ( ch <> space ) OR EOLN;
    IF ch <> space
    THEN
      REPEAT
        append( newstring.head, ch );
        newstring.length := newstring.length + 1;
        ch := space;
        IF NOT EOLN THEN READ( ch )
      UNTIL ch = space
    END;
```

reclaim does nothing  
if newstring is already  
empty

ignore leading  
spaces

count  
characters

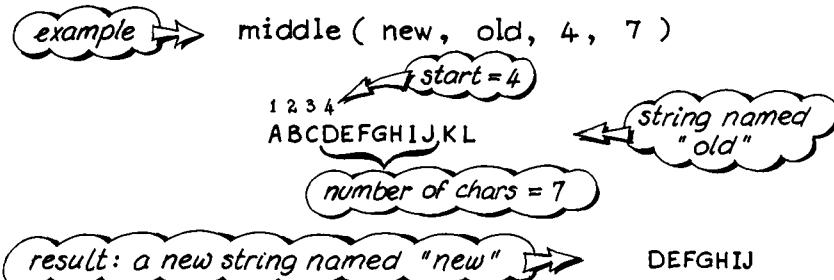
## WRITESTRING ( name<sub>string</sub> ) DOES NOTHING WITH AN EMPTY STRING

The following procedure writes a copy of the nominated string with no leading spaces and no trailing spaces or new-line characters. If the nominated string is empty the procedure does nothing.

```
PROCEDURE writestring ( VAR oldstring: stringtype );
  VAR
    p: pointertype;
  BEGIN
    p := oldstring.head;
    WHILE p <> NIL DO
      BEGIN
        WRITE ( p^.letter );
        p := p^.next
      END
    END;
```

## MIDDLE ( *name<sub>newstring</sub>*, *name<sub>oldstring</sub>*, *start<sub>position</sub>*, *span<sub>no. of chars</sub>* )

This procedure creates a string by copying part of another. The new string is made a copy of the "middle" of the old string starting at a specified position and having a specified number of characters. Use of parameters is best explained pictorially:



This procedure is modelled on the popular *BASIC* command *MID\$( , , , )*.

The fourth parameter may specify an impossibly high value, in which case the new string is truncated where the old string ends. The procedure may be used to copy a complete string. A new string may be made to overwrite the old string.

```

PROCEDURE middle( VAR newstring,oldstring: stringtype;
                   start, span : stringrange );
  VAR
    i: stringrange;  p, temp: pointertype;

  BEGIN
    IF (start > 0) AND (start <= oldstring.length)
    THEN
      BEGIN
        temp := NIL;
        p := oldstring.head;
        i := 1;
        WHILE i < start DO
          BEGIN
            p := p^.next;
            i := SUCC( i );
          END;
        i := 1;
        WHILE ( p <> NIL) AND (i <= span) DO
          BEGIN
            append( temp, p^.letter );
            p := p^.next;
            i := i + 1
          END;
        newstring.length := i - 1;
        reclaim( newstring.head );
        newstring.head := temp
      END;
    END;
  END;

```

run as far as "start"

truncate if "span" is too big

build result as a temporary string

reclaim space, then point to "temporary" string

## CONCAT( name<sub>newstring</sub>, name<sub>leftstring</sub>, name<sub>rightstring</sub> )

This procedure creates a new string as a copy of two nominated strings joined end to end in other words concatenated. The left and right strings nominated for concatenation remain undisturbed unless the new string is to overwrite one of them.

```
PROCEDURE concat( VAR newstring, left, right: stringtype );
  VAR
    p, temp: pointertype;
  BEGIN
    temp := NIL;
    p := left.head;
    WHILE p <> NIL DO
      BEGIN
        append( temp, p^.letter );
        p := p^.next
      END;

    p := right.head;
    WHILE p <> NIL DO
      BEGIN
        append( temp, p^.letter );
        p := p^.next
      END;
    newstring.length := left.length + right.length;
    reclaim( newstring.head );
    newstring.head := temp
  END;
```

The next function is for comparing strings. The criteria for equality and relative size are those commonly used for alphabetical directories. Upper case letters are considered "equal" to corresponding lower-case letters. Strings are "equal" if they have identical length and all characters match in pairs from left to right:

AbCd is considered "equal" to aBCd

When strings are unequal their relative order in a directory is determined by the first mismatching character from the left. The one with the higher ordinal value indicates the greater string:

AbCdg is considered "greater than" aBCdefg  
first mismatching character

When one string is shorter than another imagine a "null" character of zero ordinal value appended to the shorter. The rule above then still applies:

AbCde is considered "greater than" aBC<sub>ll</sub> imaginary  
first mismatching character null

**COMPARE** ( *name<sub>string</sub>*, *cr*, *name<sub>string</sub>* ) FUNCTION RETURNS BOOLEAN VALUE, TRUE OR FALSE

criterion for returning true:  
*eq, ne, gt, ge, lt, le*  
*=, <>, >, >=, <, <=*

examples: IF compare(response, eq, affirm) THEN...  
 IF compare(left, ge, right) THEN...

enumerated  
 on page 160

FUNCTION compare ( VAR left: stringtype; r: relation;  
 VAR right: stringtype ): BOOLEAN;

VAR

cp, cq: CHAR;  
 same, pmore, qmore : BOOLEAN;  
 p, q: pointertype;

FUNCTION upper( c: CHAR ): CHAR;

BEGIN

IF c IN [ 'a' .. 'z' ]

THEN

upper := CHR( ORD(c) - ORD('a') + ORD('A') )

ELSE

upper := c

END;

when comparing  
 strings any lower-  
 case letter is treated  
 as a capital letter

BEGIN { compare }

p := left.head; q := right.head;

pmore := p <> NIL; qmore := q <> NIL;

same := TRUE;

WHILE ( pmore AND qmore ) AND same DO

BEGIN

cp := upper( p^.letter );

cq := upper( q^.letter );

same := cp = cq;

p := p^.next; pmore := p <> NIL;

q := q^.next; qmore := q <> NIL

END;

assume this offset  
 is constant:  
 from a → z  
 A → Z

IF ( same AND qmore ) AND ( NOT pmore )

THEN cp := CHR( 0 );

IF ( same AND pmore ) AND ( NOT qmore )

THEN cq := CHR( 0 );

CASE r OF

eq : compare := cp = cq;

ne : compare := cp <> cq;

gt : compare := cp > cq;

ge : compare := cp >= cq;

lt : compare := cp < cq;

le : compare := cp <= cq;

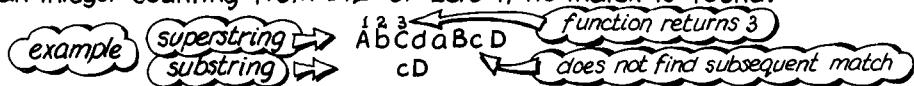
END { CASE }

END; { compare }

CHR(0) is bound  
 to be less  
 than any  
 character it  
 is compared  
 with

## INSTR ( $\text{name}_{\text{superstring}}, \text{name}_{\text{substring}}$ ) FUNCTION RETURNS POSITION OF MATCH OR ZERO FOR NO MATCH

This function is modelled on a popular function of BASIC. It seeks the first occurrence of *substring* within *superstring*, returning its position as an integer counting from 1 or zero if no match is found.



```
FUNCTION instr( VAR super, sub: stringtype ): stringrange;
```

```
VAR
  tempstring: stringtype;
  i, j: stringrange;
  match: BOOLEAN
BEGIN
  instr := 0;
  tempstring.head := NIL;
  i := 0;
  j := super.length - sub.length + 1;
  IF j >= 1
  THEN
    BEGIN
      REPEAT
        i := SUCC( i );
        middle( tempstring, super, i, sub.length );
        match := compare( tempstring, eq, sub )
      UNTIL match OR ( i = j );
      IF match THEN instr := i;
      reclaim( tempstring.head )
    END
  END;
END;
```

*take a short temporary string from successive positions in super*

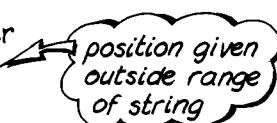
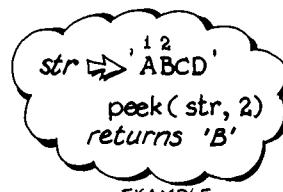
*compare the temporary string with sub*

## PEEK ( $\text{name}_{\text{string}}, n_{\text{position}}$ ) FUNCTION RETURNS $n^{\text{th}}$ CHARACTER

This function returns the character at position  $n$  of the nominated string, or  $\text{CHR}(0)$  if  $n$  is beyond the range of that string.

```
FUNCTION peek( VAR old: stringtype; n: stringrange ): CHAR;
```

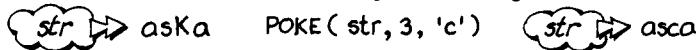
```
VAR
  i: stringrange; p: pointertype;
BEGIN
  p := old.head;
  i := 1;
  WHILE ( i < n ) AND ( p <> NIL ) DO
    BEGIN
      i := SUCC( i );
      p := p^.next
    END;
  IF p <> NIL
  THEN
    peek := p^.letter
  ELSE
    peek := CHR( 0 )
  END;
```



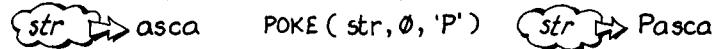
**POKE (** name string,  $n_{position}$ ,  $c_{character}$  **)** *REPLACES  $n^{th}$  CHARACTER WITH  $c$*

This procedure is versatile:

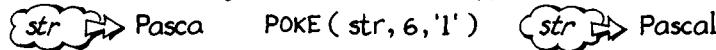
- when  $1 \leq n \leq length$  the procedure replaces the  $n^{th}$  character of the nominated string with the given character:



- when  $n = \emptyset$  the given character is pushed on the front:



- when  $n > length$  the given character is appended:



String "constants" may be built from empty strings in this manner. For long string constants it would be better to write a procedure to build strings from Pascal string constants assigned to packed arrays of characters.

```
PROCEDURE poke( VAR old: stringtype; n: stringrange; c: CHAR;
  VAR
    p: pointertype;
    i : stringrange;
  BEGIN
    IF n > old.length
    THEN
      BEGIN
        append( old.head, c );
        old.length := old.length + 1
      END
    ELSE IF n = 0
    THEN
      BEGIN
        NEW( p );
        p^.next := old.head;
        p^.letter := c;
        old.head := p;
        old.length := old.length + 1
      END
    ELSE
      BEGIN
        p := old.head;
        i := 1;
        WHILE (i < n) AND (p <> NIL) DO
          BEGIN
            i := SUCC( i );
            p := p^.next
          END;
        IF p <> NIL
        THEN
          p^.letter := c
      END
    END;
```

$n > length$  ;  
append

$n = \emptyset$  ;  
push on front

$1 \leq n \leq length$  ;  
replace  $n^{th}$  character

# BACK-SLANGE

Isthay isay Ackslangbay! Ançay ouyay eadray itay? Erhapspay otnay atay irstfay.

**B**ackslang is a secret language spoken in boarding schools. It is suitably incomprehensible when heard for the first time but easy to master once you know the grammatical rules. There are probably many dialects of backslang (also called *pig Latin*); this one is remembered from school days. Each English word is folded about its first vowel and *ay* is appended (tea → eatay, tomato → omatotay). If a word begins with a vowel, the second vowel becomes the pivot (item → emitay) unless there is no second vowel in which case there is no fold (itch → itchay). A diphthong at the beginning of a word is treated as a single vowel (oil → oilay not iloay; earwig → igearway not arwigeay).

**A** capital letter at the beginning of a word has to be transformed (Godfather → Odfathergay not odfatherGay). The *u* after *q* demands special treatment (Queen → Eenquay not ueenQay). A trailing punctuation mark has to remain trailing (Crumbs! → Umbscray! not Umbs!cray).

**T**o make all this work properly the input file for the following program should be typed without pressing the RETURN key until the end. Type in lower-case but capitalize words wherever appropriate. There should be a space after ↗ and not before ↗ each punctuation mark. Quotation marks, double or single, are not catered for so should be omitted; embedded punctuation marks such as apostrophes are treated as consonants.

**T**ry the following input file which should make the program encipher and display the text shown at the very top of this page:

This is Backslang! Can you read it? Perhaps not at first.

```
PROCEDURE colossus;
  VAR
    puncmark: CHAR;
    recap: BOOLEAN;
    btm: 2..3;
    fold, k, quin: stringrange;
    offset: INTEGER;
    word, fore, aft, qu, ay,: stringtype;
```

BEGIN

```
  word.head := NIL; word.length := Ø;
  fore.head := NIL; fore.length := Ø;
  aft.head := NIL; aft.length := Ø;
  ay.head := NIL; ay.length := Ø;
  qu.head := NIL; qu.length := Ø;
```

```
  offset := ORD('a') - ORD('A');
```

```
  poke(ay,1,'a'); poke(ay,2,'y'); poke(ay,3,' ');
  poke(qu,0,'u'); poke(qu,0,'q');
```

the real purpose of this example is to show how to apply the string facilities developed on earlier pages

initialize all string variables

"string constants"  
'ay' and 'qu'

space

```

WHILE NOT EOLN DO
BEGIN
  readstring( word );
  recap := peek( word, 1 ) IN [ 'A'..'Z' ];
  IF recap
    THEN
      poke( word, 1, CHR( ORD( peek( word, 1 ) ) + offset ) );
  IF NOT ( peek( word, word.length ) IN [ 'A'..'Z', 'a'..'z' ] )
    THEN
      BEGIN
        punctmark := peek( word, word.length );
        IF word.length = 1
          THEN
            poke( word, 0, ' ' );
            middle( word, word, 1, word.length - 1 )
        END
      ELSE
        punctmark := CHR( 0 );
        quin := instr( word, qu );
        IF quin > 0
          THEN
            poke( word, quin+1, '*' );
        IF peek( word, 1 ) IN [ 'A','a','E','e','I','i','O','o','U','u' ]
          THEN btm := 3
        ELSE btm := 2;
        fold := 1;
        FOR k := word.length DOWNTO btm DO
          IF peek( word, k ) IN [ 'A','a','E','e','I','i','O','o','U','u' ]
            THEN
              fold := k;
        IF quin > 0
          THEN
            poke( word, quin+1, 'u' );
            middle( fore, word, fold, word.length-fold+1 );
            middle( aft, word, 1, fold-1 );
            concat( word, fore, aft );
            concat( word, word, ay );
        IF punctmark <> CHR( 0 )
          THEN
            BEGIN
              poke( word, word.length, punctmark );
              poke( word, 1 + word.length, ' ' );
            END;
        IF recap AND ( peek( word, 1 ) IN [ 'a'..'z' ] )
          THEN
            poke( word, 1, CHR( ORD( peek( word, 1 ) ) - offset ) );
            writestring( word )
        END; { WHILE }
        WRITELN
      END; { colossus }

BEGIN { strings }
  colossus
END. { strings }

  if initial letter is a capital, reduce to l/c
  if last character is not a letter remember it as a punctuation mark
  if word contains 'qu' change to 'q*'
  restore 'u' after 'q'
  append punctuation mark if there was one
  recapitalize if necessary
  the main program

```

# HASHING TECHNIQUE

FOR LOOKING THINGS UP  
QUICKLY

How do you locate a word in a list of words? The simplest solution is to scan the list from top to bottom, arranging to do something when a match is found. Here is a trivial piece of program to locate the letter 'C' in a list of letters. There is nothing wrong with such an approach provided that the list of words is short.

```
FOR i:=1 TO 9 DO
  BEGIN
    IF list[i] = 'C'
    THEN
      WRITELN('Cat',i);
      lastposition := i
    END
```

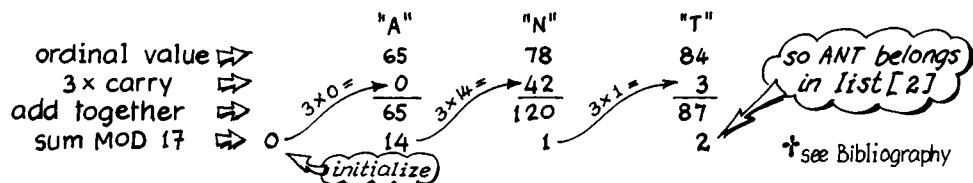
list[1]	'P'
list[2]	'O'
list[3]	'L'
list[4]	'I'
list[5]	'C'
list[6]	'E'
list[7]	'M'
list[8]	'A'
list[9]	'N'

In long lists the trick is to go straight to the place where the match ought to be found. In a list of letters having a length of 26 the technique would be perfect; such a list would be arranged in alphabetical order, so to find if 'C' is there you would look in list[3]. To find any letter  $x$  you would look in list[ $\text{ORD}(x) - \text{ORD}('A') + 1$ ]. The expression  $\text{ORD}(x) - \text{ORD}('A') + 1$  in mathematical terminology is a function of  $x$ . This function returns the correct address for any letter  $x$ .

But it would be impractical to provide a list of words in which every conceivable word had an exclusive address. The practical solution is to set a limit to the length of list and devise a function (similar to the one illustrated above) to give the probable address of the word sought. Such a function is called a *hash function*.

A hash function looks and behaves like a function for generating random numbers. Just as a random-number function involves the use of MOD to constrain the result to a particular range, so does a hash function employ MOD to constrain the address to lie within the length of list. The hash function shown below is based on one given by Kernighan and Plauger<sup>†</sup>.

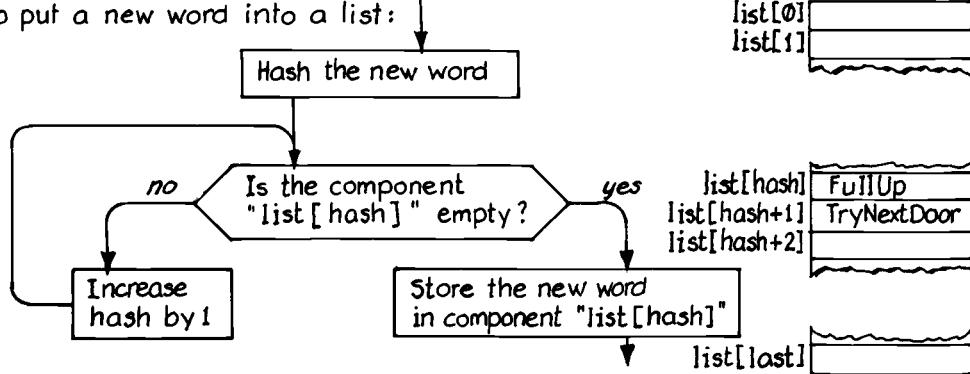
Take the word ANT which is to find its place in a list of 17 components, 0 to 16. Ordinal values of the letters are used in the hash function; those below are in ASCII code but the method would work on computers with other codes.



By the same algorithm AARDVARK would generate a hash code of 7 and so belong in list[7]. From the addresses of ANT and AARDVARK it is evident that hash codes do not arrange words in alphabetical order. Hashing STOAT yields a hash code of 2 in competition with ANT. Clashes such as this are resolved by the logic explained opposite.

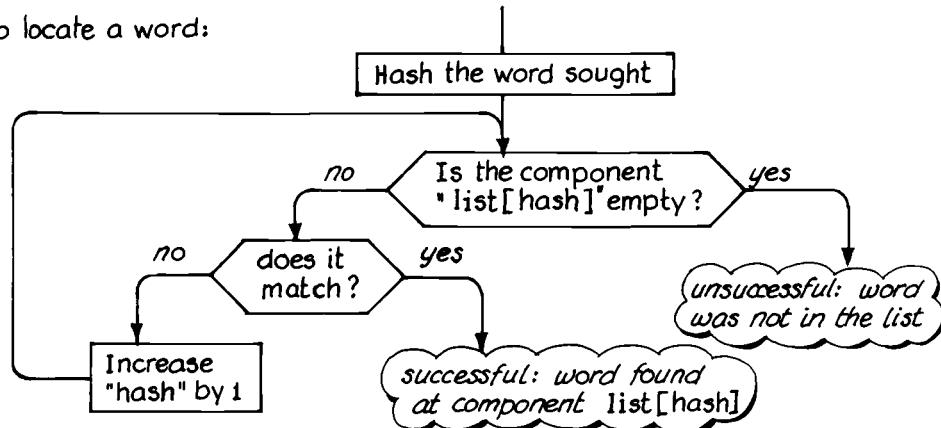
The 3 is a "magic number"; you could try 5 or 7 or other small prime. The length of list (17 in the example) should also be a prime number for best effect. "Best" means distributing the hash codes evenly over the list so that it is not filled in clumps. On page 172 is a program to demonstrate the hash function described above; try it to see if you get clumping (I don't).

To put a new word into a list:



The list should be made "circular" so that when *hash* reaches *last* an increase of 1 makes *hash* revert to zero. There should also be a mechanism to stop the search going round indefinitely when the list is full.

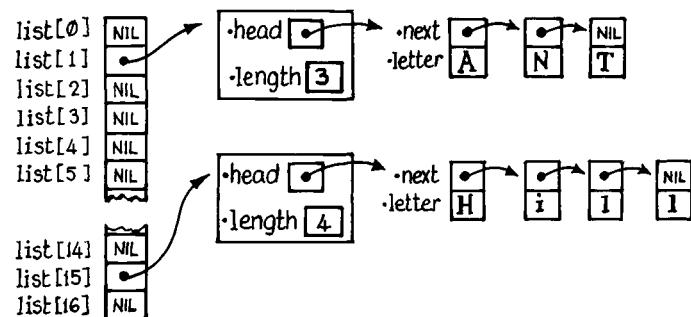
To locate a word:



The program over the page is designed to demonstrate the effect of hashing. To use it, simply enter words. Each "new" word is stored in the list and the list displayed in full, showing where the word is stored. When an "old" word is found its location is reported. The program initially assumes that a given word is "old" and goes searching for it. If the search proves unsuccessful the program stores the given word as a "new" one.

The program relies upon the string utilities developed earlier  $\Rightarrow$  thus capital letters are treated as equal to corresponding lower-case letters: ANT  $\equiv$  Ant.

The data structure comprises an array of pointers pointing to records of *stringtype*. The array of pointers has to be dimensioned and initialized but the rest of the data are created dynamically.



# HASHER

## AN EXAMPLE PROGRAM TO DEMONSTRATE HASHING

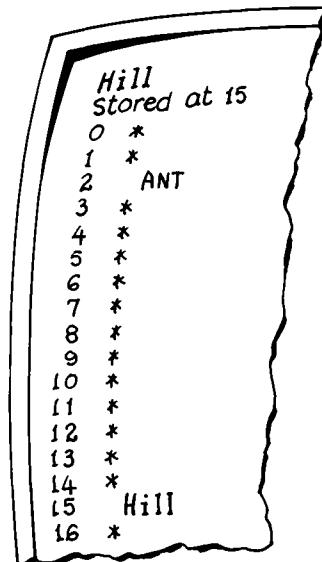
Here is the program based on the principles introduced on the previous double page. To use the program simply enter words and watch the screen to see where the words are stored. Enter some words previously entered and notice that duplicate copies are not stored; their location is reported instead.

```
PROGRAM hasher ( INPUT, OUTPUT );
```

include here the declarations and utilities employed in the strings program on pages 160-7 (i.e. omit procedure colossus and the main program on pages 168-9). Procedures middle, concat, instr and poke are not invoked by the hashing procedure so may also be omitted if desired.

```
PROCEDURE hashplay;
CONST
  size = 17;    siz = 16;    keep one less than size
TYPE
  sizerange = 0..siz;
  nametype = ^ stringtype;
  arraytype = ARRAY [sizerange] OF nametype;
VAR
  name: stringtype;
  i, hash, recall: sizerange;
  full, found, ahole: BOOLEAN;
  list: arraytype;
  n: INTEGER;

PROCEDURE show; show on screen
  VAR
    i: sizerange;
  BEGIN
    FOR i := 0 TO siz DO
      IF list[i] <> NIL
      THEN
        BEGIN
          WRITE ( i, ' ' );
          writestring ( list[i] );
          WRITELN
        END
      ELSE
        WRITELN ( i, '*' )
    END;
  BEGIN { hashplay }
    name.head := NIL;
    full := FALSE;
    FOR i := 0 TO siz DO
      list[i] := NIL;
```



```

REPEAT
  readstring( name );
  hash := 0;
  FOR i := 1 TO name.length DO
    BEGIN
      n := ORD( peek( name, i ) );
      IF n IN [ ORD('a').. ORD('z') ]
      THEN
        n := n - ORD('a') + ORD('A');
      hash := ( 3 * hash + n ) MOD size
    END;
    ahole := list[hash] = NIL;
    IF NOT ahole
    THEN
      BEGIN
        recall := hash;
        REPEAT
          found := compare( name, eq, list[hash] );
        IF found
        THEN
          WRITELN( 'Found at', hash:4 )
        ELSE
          BEGIN
            hash := ( 1 + hash ) MOD size;
            ahole := list[hash] = NIL;
            full := hash = recall
          END
        UNTIL ( ahole OR found ) OR full
      END;
    IF ahole
    THEN
      BEGIN
        NEW( list[hash] );
        list[hash] := name;
        WRITELN( 'Stored at', hash:3 );
        WRITELN;
        show;
        name.head := NIL
      END
    ELSE IF full
    THEN
      BEGIN
        WRITELN( 'List full' );
        show
      END
    UNTIL full
  END; { hashplay }

BEGIN {main program}
  hashplay
END. {main program}

```

change lower-case to capital for comparing

the hashing function

augment hash by 1

copy

important! failure to do this would allow readstring to dispose of the word that name still points to



## BIBLIOGRAPHY

BSI Specification for *Computer programming language Pascal* BS6192: 1982

The British Standard defines the dialect of Pascal presented in my book. BS6192 is not bed-time reading but if you are looking for precise syntax or the defined behaviour of a Pascal processor under rare circumstances then BS6192 is what you need. Its preface tries to explain a complicated relationship between BS6192 and ISO 7185 but I have not yet deciphered it. Apparently BS6192 and ISO 7185 were supposed to be the same but aren't quite.

Jensen, K. & Wirth, N. (1975). *Pascal user manual and report*. (Springer-Verlag)

This was the first book on Pascal; this book's co-author, Niklaus Wirth, being the inventor of the language. The user manual by Kathleen Jensen is a model of conciseness and makes fine historical reading.

Grogono, Peter (1980). *Programming in PASCAL* (Addison-Wesley)

This is the classic; first published in 1978 with word-processed text but now nicely type-set. It is still the best book I have seen for a full course on programming in Pascal. The writing is clear and the examples imaginative. To get the best from the book you have to work hard and get stuck into the long examples. Grogono gives a long and authoritative bibliography for the reader who wants to dig deeper still.

Brown, P. J. (1982). *Pascal from BASIC* (Addison-Wesley)

A good self-teach book, easy to understand yet does not dodge awkward issues. Strange characters like Prof. Primple (archetypal academic) and Bill Mudd (enthusiastic bodger) keep appearing to emphasize different attitudes to programming but one learns to forgive their intrusion. Advanced data structures and dynamic storage are dealt with briefly. This book should help the erstwhile BASIC enthusiast to switch allegiance to Pascal and clean habits.

Kernighan, B.W. & Plauger, P.J. (1981). *Software tools in Pascal* (Addison-Wesley)

A book full of tested and practical applications of Pascal. The sentence: "A picture is worth about a thousand words" appears next to one of only two pictures in the whole book; the rest is 95,000 words of text. The prose, to me, reads awkwardly but perseverance is rewarded with lots and lots of information.



# QUICK REFERENCE

A SUMMARY OF STANDARD PROCEDURES, FUNCTIONS & SYNTAX

The summaries of standard procedures and standard functions are each in alphabetical order. A page reference is given on the right of the page for every procedure and function summarized. The summary of syntax is "top down".

## STANDARD PROCEDURES AN UNSPECIFIED FILE NAME IMPLIES INPUT OR OUTPUT

DISPOSE (name <sub>pointer</sub> )	● return an unwanted record to the heap	139
GET (name <sub>file</sub> )	● advance the window on the nominated input file	125
NEW (name <sub>pointer</sub> )	● create a new and empty record	139
PACK (name <sub>loose</sub> , subscript <sub>loose</sub> , name <sub>tight</sub> )	● pack the contents of one array in another	88
PAGE (name <sub>file</sub> )	● write a form-feed character to nominated output file (if printer can respond to it)	116
PUT (name <sub>file</sub> )	● advance the window on the nominated output file	125
READ (name <sub>file</sub> , variable, )	● read from nominated file; items on TEXT files are separated by spaces or newlines or both	117
READLN (name <sub>file</sub> , variable, )	● as READ but only for TEXT files: skip to next line of input when the final parameter has been satisfied	117
RESET (name <sub>file</sub> )	● prepare the nominated file for reading (never reset INPUT or rewrite OUTPUT)	114
REWRITE (name <sub>file</sub> )	● prepare the nominated file for writing	114
UNPACK (name <sub>tight</sub> , name <sub>loose</sub> , subscript <sub>loose</sub> )	● the converse of PACK	88
WRITE (name <sub>file</sub> , expression : width : places )		116
WRITELN (name <sub>file</sub> , expression : width : places )		116

● width and places are integer expressions. places is applicable only if the expression whose value is to be written is of type REAL.

# STANDARD FUNCTIONS

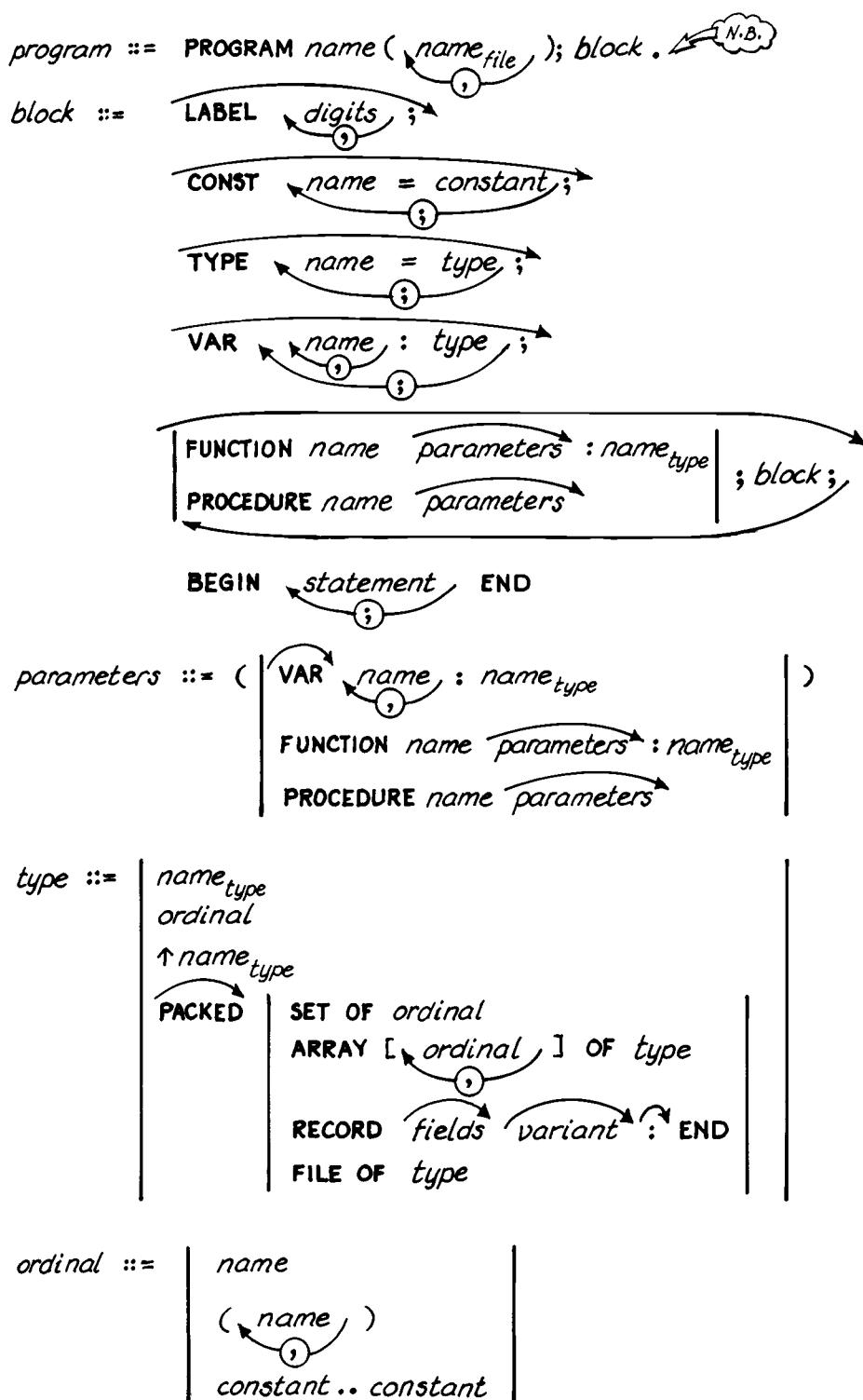
YOUR PASCAL PROBABLY HAS  
MORE FUNCTIONS THAN THESE

*i* denotes an expression that reduces to an integer value, *r* denotes an expression reducing to a *real* value, *m* denotes a parameter which has an ordinal value: e.g. integer, character or member of enumerated type.

ABS( <i>i</i> )	● <i>absolute value</i> : ABS(-6) returns 6 (an integer)	36
ABS( <i>r</i> )	● <i>absolute value</i> : ABS(-6.5) returns 6.5 (a real)	36
ARCTAN( <i>r</i> )	● <i>arctangent</i> : ARCTAN(1.0) returns 0.785398 ( $\pi/4$ )	37
CHR( <i>i</i> )	● <i>character</i> : CHR(65) returns 'A' if code is ASCII	41
COS( <i>r</i> )	● <i>cosine</i> : COS(3.141593 / 3) returns 0.5	37
EOF ( <i>name file</i> )	● returns TRUE if READ would fail on its next attempt because of meeting end-of-file	39
EOLN ( <i>name file</i> )	● returns TRUE if READ would next read the space signifying an end of line	39
EXP( <i>r</i> )	● <i>exponent, or natural antilogarithm</i> : EXP(1) returns 2.7182818 (i.e. $e^1$ )	36
LN( <i>r</i> )	● <i>natural logarithm</i> : LN(2.7182818) returns 1 (i.e. $\ln(e)$ )	36
ODD( <i>i</i> )	● <i>odd</i> : ODD(-3) returns TRUE ; ODD(0) returns TRUE	39
ORD( <i>m</i> )	● <i>ordinal value</i> : ORD('A') returns 65 if ASCII code; ORD(TRUE) returns 1 ; ORD(FALSE) returns 0	40
PRED( <i>m</i> )	● <i>predecessor</i> : PRED('B') returns 'A' ; PRED(6) returns 5 ; PRED(TRUE) returns FALSE	41
ROUND( <i>r</i> )	● <i>round to nearest integer</i> : ROUND(3.5) returns 4; ROUND(-3.8) returns -4	38
SIN( <i>r</i> )	● <i>sine</i> : SIN(3.141593 / 6) returns 0.5	37
SQR( <i>i</i> )	● <i>square</i> : SQR(-3) returns 9 (an integer)	36
SQR( <i>r</i> )	● <i>square</i> : SQR(-3.0) returns 9.0 (a real)	36
SQRT( <i>r</i> )	● <i>square root</i> : SQRT(81) returns 9.0 (a real)	36
SUCC( <i>m</i> )	● <i>successor</i> : SUCC('A') returns B; SUCC(5) returns 6; SUCC(FALSE) returns TRUE	41
TRUNC( <i>r</i> )	● <i>truncate to integer</i> : TRUNC(-3.8) returns -3 (an integer)	38

# SYNTAX

CHAPTER 3 DEFINES THE NOTATION USED IN THE FOLLOWING TOP-DOWN SUMMARY OF SYNTAX DIAGRAMS



# SYNTAX ( SUMMARY CONTINUED )

Fields ::=  $\text{name} : \text{type}$

variant ::= CASE  $\text{name} : \text{name}_\text{type}$  OF constant, : ( fields variant ), ;

statement ::= digits :

variable := expression

$\text{name}_\text{fn} := \text{expression}$

$\text{name}_\text{proc} ( \text{expression} )$

BEGIN statement END ;

IF condition THEN statement ELSE statement

REPEAT statement UNTIL condition ;

WHILE condition DO statement

FOR  $\text{name}_\text{var} := \text{expression}$  DOWN TO expression  
DO statement

CASE expression OF constant, : statement,  
; END ;

WITH variable, DO statement ;

GOTO digits

expression ::=  $\begin{cases} + \\ - \end{cases}$  term comparator  $\begin{cases} + \\ - \end{cases}$  term

condition ::= expression  $\xrightarrow{\text{reducing to Boolean value}}$

~~exception~~ in WRITE and WRITELN, expression may be expression ;

term ::=	name <sub>const</sub> number NIL string variable name <sub>fn</sub> ( expression ) ( expression ) [ expression .. expression ] NOT term
	  

# LIST OF RESERVED WORDS

AND	END	NIL	SET
ARRAY	FILE	NOT	THEN
BEGIN	FOR	OF	TO
CASE	FUNCTION	OR	TYPE
CONST	GOTO	PACKED	UNTIL
DIV	IF	PROCEDURE	VAR
DO	IN	PROGRAM	WHILE
DOWNTO	LABEL	RECORD	WITH
ELSE	MOD	REPEAT	

operator ::= \* / DIV MOD AND + - OR

<i>comparator ::=</i>	<i>&lt;</i>
	<i>&lt;=</i>
	<i>=</i>
	<i>&gt;</i>
	<i>&gt;=</i>
	<i>&lt;&gt;</i>
	<b>IN</b>

string ::=	letter
	digit
	symbol
	"
	space
	{
	}

variable ::= name [ expression, ]  
 • name

name ::= letter | letter  
                  | digit

constant ::= 

*digits* ::=  $\text{digit}^*$

number ::= digits . digits E [ + ] digits

~~~~~end of syntax summary~~~~~

# INDEX

FOR QUICK REFERENCE TO STANDARD PROCEDURES,  
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