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Notes on IMP Programming

by

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Lecture Notes

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PROGRAMMING IN IMP

These notes started as lecture notes for students of Computer Science 1, using the IMP language on E.M.A.S. (The Edinburgh Multi-Access System), but have been revised slightly in an attempt to make them also of some use to other groups. There are still some references to special facilities provided for the Computer Science 1 class, but the text makes it clear when these occur.

It is particularly important that anyone intending to input IMP programs on cards should look at Appendix A, note (3), and find out what convention they have to observe in regard to the quotation mark character (").

More detailed descriptions of IMP as implemented on any particular Computer Science or E.R.C.C. machine may be obtained from the Computer Science Department or E.R.C.C. respectively.

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SECTION 1 : INTRODUCTION

A complete PROGRAM is used to describe the details of some computation that we wish to have carried out. Programs can be written in a variety of different programming languages, and these notes describe one such language, called IMP. In practically every programming language, there are some details that vary slightly from machine to machine, and also from time to time as improvements are made to the language. These notes refer primarily to the version of Imp available in October 1976 on the I.C.L. 4-75 computers, operating under the Edinburgh Multi-Access System. Users of Imp on other machines will need to note a few minor variations. Also, the method of submitting a program to the machine and having that program run will vary from machine to machine.

A minimum Imp program consists of:

(i) The keyword begin.

(ii) A list, in order, of the instructions we want carried out.

(iii) The keyword end of program.

Of the different types of instruction that may be given under (ii) above, the most important is the call of a ROUTINE. A routine call is an instruction to carry out some standard sequence of operations, achieving some frequently required end. Many routines have been defined as a basic part of Imp, and are permanently available for all to use; later on, we shall see how additional routines can be defined by the programmer (and his colleagues) to suit the needs of their particular field of interest. In the case of students, yet another set of routines is sometimes defined by a lecturer and made available to his class.

To call a routine, we simply write down the NAME of the required routine, followed in most cases by some supplementary information that is placed in brackets after the name. Very often, the name of the routine will give a good idea of what is does. If we are exceptionally fortunate, or our needs are very simple, there is the slight chance that the combination of just one or two of the routines available to us will correspond exactly to the whole computation we require. An example is given on the following page.

```
begin

    PRINT TABLE OF (9)

end of program
```

The routine PRINT TABLE OF, used here to provide an exceptionally brief first example, is clearly of extremely limited value; although it does happen to be in the library of special routines available to Computer Science 1 students in Edinburgh, it is not generally available to, nor likely to be required by others. It causes a simple multiplication table (as met in ones earliest schooldays) to be printed at the appropriate output device (the console, if the program is being run from a console; usually a Line Printer in other cases). The supplementary information given in brackets (officially called a PARAMETER) determines that it will be a 9-times table that is produced, though any other integer (i.e. whole number) could have been given.

To write more useful programs, we shall have to study a list of the more common library routines available, and build up what we require from these. In addition, we shall need to consider:

(i) How to allocate names to storage space (VARIABLES) in which numbers, strings of characters, etc., can be placed by one instruction, ready for subsequent use by a later instruction(s). (Section 2).

(ii) How to cause a choice to be made between two courses of action, depending upon the progress of the program so far. (Section 4).

(iii) How to cause one, or a group, of instructions to be carried out several times. (Section 5).

(iv) How to create new routines of our own, and use them. (Section 10)

Before looking at any of these in detail, let us consider a very slightly more complex program. Suppose that we wish to write a program to print out an N-times table, but do not know at the time of writing what value we shall want for N. The solution is to arrange that before printing the table, our program reads as DATA a number giving the value of N required. This is done by using a standard routine, whose name is READ. This routine will cause data to be taken from whatever is the appropriate source of input (the console, if the program is being run from a console; from an extra card added after end of program if the program

is being submitted on cards). Our program now begins to look like this.

```
READ (N)
PRINT TABLE OF (N)
```

The first routine reads a number as data, and stores it in a place called N; the second uses this value of N to determine what multiplication table to print. But before using the VARIABLE called N, we must DECLARE our wish to have a storage location set up for this purpose. Since, in this example, we shall only store integers in N, we write our declaration:

```
integer N
```

Our whole program then is as follows:

```
begin
integer N
    READ (N)
    PRINT TABLE OF (N)
end of program
```

This is perfectly satisfactory, but let us add 2 more routine calls:

```
begin
    integer N
    READ (N)
    PRINT TABLE OF (N)
    PRINT STRING("THAT CONCLUDES MY FIRST PROGRAM")
    NEWLINE
end of program
```

The PRINT STRING routine causes a string of characters - in this case it is THAT CONCLUDES MY FIRST PROGRAM - to be sent to the output, after the N-times table, of course. When printed on an output device, lines of output are stored until terminated by the character which indicates the end of a line and the start of a new one. This character is sent to the output by calling the standard routine NEWLINE.

Comments

In addition to containing instructions to be obeyed, any worth-while program will always include COMMENTS. These are pieces of program which have NO EFFECT when the program is executed, but are inserted to serve a different but MOST IMPORTANT function - to make the program more legible to human readers, both the author and others. A comment consists of the keyword comment, followed by any sequence of characters. Note that if comments extend over two or more lines, each line will have to start with the keyword comment.

```
begin
    comment   The purpose of this program is to print
    comment   out an N-times multiplication table.
    integer N

    READ (N)
    PRINT TABLE OF (N)
    PRINT STRING ("THAT CONCLUDES MY FIRST PROGRAM.")
    NEWLINE
end of program
```

Since comments are used very widely, it is convenient to have an alternative and shorter way of writing the keyword comment. An exclamation mark is used for this purpose.

```
begin
    !         The purpose of this program is to print
    !         out an N-times multiplication table.
    integer N

    READ (N)
    PRINT TABLE OF (N)
    PRINT STRING ("THAT CONCLUDES MY FIRST PROGRAM.")
    NEWLINE
end of program
```

The structure of a simple program

A program consists of a sequence of STATEMENTS. We may distinguish four main classes of statement:

(i) DECLARATIONS. These are preparatory statements, allocating names to various entities, chiefly variables. (e.g. integer N)

(ii) INSTRUCTIONS. These are the statements that cause things to happen: data to be read in, values to be stored in variables, calculations to take place and results to be output.

(iii) COMMENTS. Statements that are inserted for the benefit of the human reader, but have no effect at run-time.

(iv) BRACKETING STATEMENTS. Statements that mark the beginning and end of certain groups of statements. For example, begin and end of program mark the beginning and end of a whole program. Shortly we shall meet others, such as cycle and repeat, which mark the beginning and end of a group of instructions to be executed several times over.

The correct order of statements in a simple program.

Comments may be placed anywhere. Apart from this, the correct order is:

(i) begin
(ii) The declarations.
(iii) The instructions, interspersed with bracketing statements as necessary.
(iv) end of program.

Two (or more) statements on one line.

In our programs so far, each statement has been written on a separate line. If desired, however, two or more statements may be written on one line, provided they are separated by semi-colons. For example:

```
READ (N) ; PRINT TABLE OF (N)
```

It is often convenient to put one instruction and a short comment upon that instruction on the same line. For example:

```
READ (N) ; comment   N determines which table is to be printed.
```

KEYWORDS, NAMES AND STRINGS

In our first program, we had examples of letters of the alphabet being used in three different contexts:

(a) In Keywords.

In many books on programming languages, our attention is drawn to the keywords of the language by printing them in lower-case letters and either printing them in bold type, or by underlining them. Throughout these notes, underlining will be used (e.g. begin). When we come to input to the computer, however, most devices have neither lower case nor underlining; instead we shall represent keywords with upper case letters and prefixing with a % character (e.g. %BEGIN). See Appendix A for details; and note that if a keyword is broken up into separate words, as it may be for legibility, then a % character is placed in front of each. (e.g. %END %OF %PROGRAM).

(b) In Names.

In our earlier example, we saw that we refer to routines by their NAMES. Shortly we shall also need to allocate names to VARIABLES and, later on, to a few other entities in the language. A name always starts with an upper-case letter of the alphabet (A,B,C.....Z) and may be followed by one or more digits (0,1,2,.....9), or by further letters, or a mixture of the two.

Examples X, SUM, A2B3, PRINTSTRING

Notes (i) There is no limit on the length of a name.

(ii) Note the distinction: keywords consist of underlined letters (marked by %), names consist of non-underlined letters and digits.

(c) In Strings.

In our earlier example, we were concerned with the string of characters:- THAT CONCLUDES MY FIRST PROGRAM. It was not a keyword, nor was it the name of anything; it was simply a sequence of 32 characters (27 letters, 4 spaces and one full stop) which we wanted manipulated as one - in this case it was to be printed out. We mark out the extent of the string by enclosing it between quote characters. A string may consist of anything from 0 to 225 characters. (Some further details are given in the section on string constants).

Note As convenient for legibility, spaces may be freely inserted almost anywhere in a program, without altering the meaning. Hence, the routine name PRINTSTRING, is more legible if written PRINT STRING. Two exceptions to this are:

(i) Spaces within a string count as characters of that string. (as one would wish).

(ii) If spaces are inserted within keywords, additional % characters are required, as above.

SECTION 2 - DECLARATIONS

(i) SCALARS

Before we can use a variable we must specify what sort of variable we want and what its name is to be. The main types of variable are:

(a) numerical (subdivided into real and integer - see below)

(b) string A string variable can store a sequence of characters.

DECLARATION	MEANING
integer A, B3	I intend to use two variables which I will call A and B3. They must be capable of storing integer (whole number) values in the range -2147483648 to +2147483647. (That is -2^{31} to $2^{31}-1$).
real C	I intend to use a variable which I will call C. It must be capable of storing "real" values, that is a number which may be either an integer (e.g. 17) or a number with a fractional part (e.g. 12.261). On many current machines, the range of real numbers that can be stored is (approximately) $\pm$ 7 x 10^{75}; and they are stored to (about) 7 significant decimal digits. (This can be changed to 17 significant digits if long real variables are declared).
string (16) S,T	I intend to use two variables which I will call S and T. They must be capable of storing strings of anything up to 16 characters each. For example: "EDINBURGH" (9 characters) "COMPUTER SCIENCE" (16 characters - the space counts) When declaring a string variable, one gives an upper limit on the length of string that can be stored. (16 in this example). The largest upper limit permitted is 255. Thus, string (256) S would be an illegal declaration.

Notes

(1) The compiler automatically allocates locations to the variables as they are declared. The programmer does not need to concern himself with where the variables are located - he always refers to them by the names he has declared for them.

(2) When the values stored in integer variables are multiplied or added the exact answer is produced. When doing arithmetic on real variables the answers are "rounded off" to (about) 7 significant figures.

(ii) ARRAYS

We can also declare a whole array of variables, all having the same name, but distinguished from one another by means of a "subscript", which is written in brackets after the name of the array.

Examples

```
integer array D(1:4)
real array E(1:9),F,G(-3:2)
string (25) array  P(1:50)
```

These cause the allocation of space to four integer variables D(1), D(2), D(3) and D(4), nine real variables E(1) to E(9), twelve real variables F(-3) to F(2) and G(-3) to G(2), and fifty string variables (each of maximum length 25) P(1) to P(50).

Note the difference between : integer array D(1:4)

and : integer D4

The former creates four variables, of which one is referred to as D(4); the latter creates one variable D4.

UNIQUE USE OF NAMES

Names cannot be used simultaneously for two different purposes. For example:

```
integer A
integer array A(1:10)
```

would be faulted by the compiler.

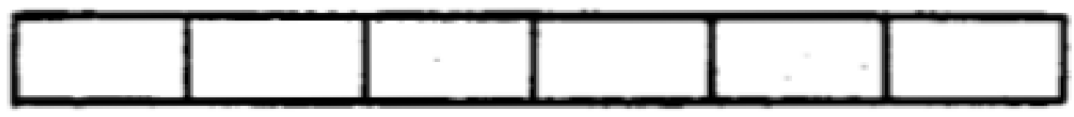
Other types of declaration, associating names with multi-subscript arrays and with the user's own routines, functions and predicates etc. will be explained later. The same prohibition on simultaneous use of a name for two purposes applies to all such declarations. (However, see later section on local and global variables).

(iii) MULTI-SUBSCRIPT ARRAYS

We have already seen how to declare arrays with one subscript. Arrays with two subscripts can also be delcared.

Example	Meaning
real array A(1:2,1:3)	Declare 6 real variables to be known as follows:-

A(1,1) A(1,2) A(1,3) A(2,1) A(2,2) A(2,3)



It is often easier to think of these in two dimensions, and it may be our desire to do so that motivates the declaration of a two-subscript array:-

A(1,1)	A(1,2)	A(1,3)
A(2,1)	A(2,2)	A(2,3)

Arrays with more than two subscripts can be declared in a similar way:-

```
real array B(M:N+1,1:5,-1:3),C,D(-10:10)
integer array F(1:3,1:5,1:20,1:30)
string (20) array G,H(1:3,1:3,1:10)
```

Notes

(1) The maximum number of subscripts is 6.

(2) Any of the array bounds may be given as integer expressions, for example see B above, but in this case we have to ensure that M and N have values assigned before reaching the declaration. (Also see later section on block structure).

(iv) DECLARATION OF CONSTANTS

In general, the declaration of a variable is a preparatory statement, causing a storage location to be allocated and to be given a name. At this stage, no value is stored in this location. Subsequently, instructions will be given (see next section) to store a value, change it, etc.

Sometimes it is convenient to have a storage location allocated and to be given a value which will not be altered during the subsequent stages of the program. In such cases we can make the declaration and assign this fixed value in one statement, by declaring a const integer, real or string. For example:

```
const real          E = 2.7182818, G = 9.80665
const string (25)   VENUE = "LEVEL 3 of APPLETON TOWER"
const integer       CLASS SIZE = 152
```

Arrays of const's can also be useful, and may be declared as follows:-

```
const string (4) array DAY (1:7) = "MON", "TUES", "WED", "THUR",
                                   "FRI", "SAT", "SUN"
const integer array P(11:40) = 3(10), 6, 4 (19)
```

The first sets DAY (1) equal to "MON", DAY (2) equal to "TUES", etc. The second declaration sets the first 10 elements of P (i.e. P(11) to P(20) inclusive) to the value 3, the next one (i.e. P(21))to the value 6 and the remaining 19 to the value 4.

Notes (1) Although two or more const scalars may be declared in one statement (see the two const reals above), a separate declaration is needed for each const array.

(2) Const arrays are limited to one dimension (one subscript).

(3) The bounds of a const array must be constants - thus in the last example, the constant bounds (11:40) could not be replaced by dynamic bounds such as (M:N).

(4) The values assigned to the elements of a const array are separated by commas. If the list spreads over two or more lines, the continuation symbol (c) is not necessary (though permitted), provided the line ends with a comma.

SECTION 3 - SOME BASIC ROUTINES

Having declared the variables we shall need, we now give a sequence of instructions. A program is normally supplied with a file of DATA upon which to act, and we shall clearly need routines to read information from our data file and place it in our variables. As indicated in section 1, the data file may consist of characters typed in at the console or it may be supplied on punched cards. It may also consist of a file already stored on EMAS (The Edinburgh Multi-Access System).

The data consists of a sequence of characters. These can be read individually, but more often we wish to read a group of characters forming either an integer (e.g. 17), a real number (e.g. 3.1) or a string (e.g. "MORRIS 1300"). Routines to read such sequences and place them in variables of appropriate type are given below.

(i) INPUT ROUTINES

	MEANING
READ (A)	Take the next (unread) number from the data file and place its value in A, which may be an integer or a real variable. If A is an integer variable, then it is essential that the next number occurring in the data is an integer. If A is real, then any number is acceptable.
READ STRING (S)	Take a string of symbols from the data and place it in string variable S. In the data, the beginning and end of the string must be shown by quote marks, although the quote marks themselves do not count as part of the string. (Also see page 8.4). Note It is often inconvenient to have to place quotes around every string in our data, as required by the READ STRING routine. An alternative routine which inputs non-numerical data one character at a time is:-
READ ITEM (S)	Take one character from the data, and place it in the string variable S. The single item read may be a letter, a digit, a punctuation mark, a space (occurring between printing characters) or even the "newline" character which is deemed to exist between the end of one line and the beginning of the next. Since it is known that only one character is to be read, no quotes are used.

Notes (1) Once a character has been read (as part of a string or number), we move forward along the data file and cannot read that character again. (Except by re-running the program.)

(2) When reading a succession of numbers from a data file, the numbers must be separated by spaces, or placed on separate lines. Other characters such as commas or semi-colons between numbers will cause a fault.

(ii) OUTPUT ROUTINES

At some stage of the program we shall need to print out some results of our calculation. These will go to an OUTPUT device (this may be the computer console, or a Line Printer) or an OUTPUT file to be stored on EMAS. Where the results go depends upon the system being used (and can also be affected by instructions described in section 17), but does not affect us here. Irrespective of where they go, we use the same output routines.

	MEANING
WRITE (I*J+3,4)	Evaluate the numerical value of the first INTEGER expression (i.e. I*J+3) and write this value to the output (device or file), using 1 position for the sign and 4 for the digits of the number; that is 5 positions in all. This routine can only deal with integer expressions. (The figure 4 can, of course, be varied).
PRINT (X+Y,3,2)	Evaluate the REAL expression (i.e. X+Y) and print its value, using 1 position for the sign, 3 for the digits before the decimal point and 2 for the digits after the decimal point taking 1+3+1+2=7 positions in all. (The figures 3 and 2 can of course be varied).
PRINT FL (X+Y,3)	Evaluate the expression X+Y and print its value in floating point form, with 3 digits after the decimal point. (In floating point form, 6.321@ -3 means 6.321×10^{-3}).
PRINT STRING ("MORRIS 1300") PRINT STRING (S."AND".T)	Evaluate the expression in brackets (which will be of type string), and print it. In the first example, the expression consists of a constant string of 11 characters (the quotes mark the beginning and end, but are not printed themselves). In the second example, the expression consists of the string presently stored

in S followed by the constant 3-character string AND, followed by the string presently stored in T.

SPACE
SPACES (4)

Write one or more 'space' characters to the output. When a space character is printed, it causes the printer to move 1 column to the right across the page.

NEWLINE
NEWLINES(3)

Write one or more 'newline' characters to the output. When a newline character is printed, it causes the printer to move to the start of a new line.

NEWPAGE

Write a 'newpage' character to the output. When printed, this causes the line printer to move to the top of a new page. At a console, it has no effect.

(iii) ASSIGNMENT INSTRUCTIONS

One operation very frequently required is to work out some expression involving the values currently stored in one or more of our variables, and perhaps also some constant values. Instead of sending the answer to the output device or file (as with WRITE and PRINT STRING), we may wish to place the answer back in a variable for use again later. Since this operation will be required frequently, a special concise notation is used for it:-

INSTRUCTION — **MEANING**

A = B + C

Work out the expression on the right (i.e. the value of B plus the value of C) and then make A have this value. If the contents of A,B and C before carrying out this operation were

A	B	C
5	10	3

then on completion the contents would be

A	B	C
13	10	3

D(1) = D(3) + B - 7

Work out D(3) + B - 7 and then make D(1) have this value.

Note (1) When a value is assigned to a variable, any value previously stored in that variable is lost. (e.g. The value 5 in A in the example above).

(2) The 'equals' sign (=) is used in a slightly unusual way in assignment instructions. In particular, note:

(i) `A = B + C` is a normal assignment.
`B + C = A` is meaningless. (The left-hand side must be the name of a variable previously declared.)

(ii) `B = C` means: put a copy of the value now in C, into B.
`C = B` means: put a copy of the value now in B, into C.

(iii) `A = A + 3` is quite normal, resulting in 3 being added to the value stored in A.

(3) On the right-hand side of an assignment, we may write any expression that will work out to give a value of the correct type, as follows:-

an integer variable can only store integer values.
a real variable can only store real values. (But if the value calculated is an integer (3, say)this will automatically be converted to the corresponding real value 3.000000000 if required for storage in a real variable.)
a string variable can only store string values.

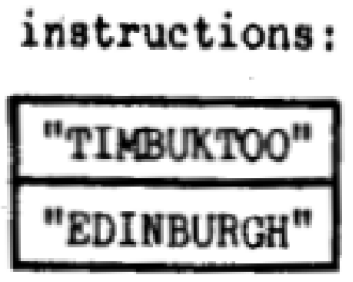
(4) The operations of addition, subtraction, multiplication and division are represented by +, -, * and / (sometimes //) respectively. For fuller details, see Section 8.

(iv) ASSIGNMENT OF STRING EXPRESSIONS. (also see Section 7)

Arithmetic operations are not meaningful to apply to strings. At this stage, we are concerned with only one operation on strings, called CONCATENATION (represented in expressions by a full stop), which places one string immediately after another. For example, the instructions:

```
S = "TIMBUKTOO"
T = "EDINBURGH"
```

will store as follows:



A subsequent instruction

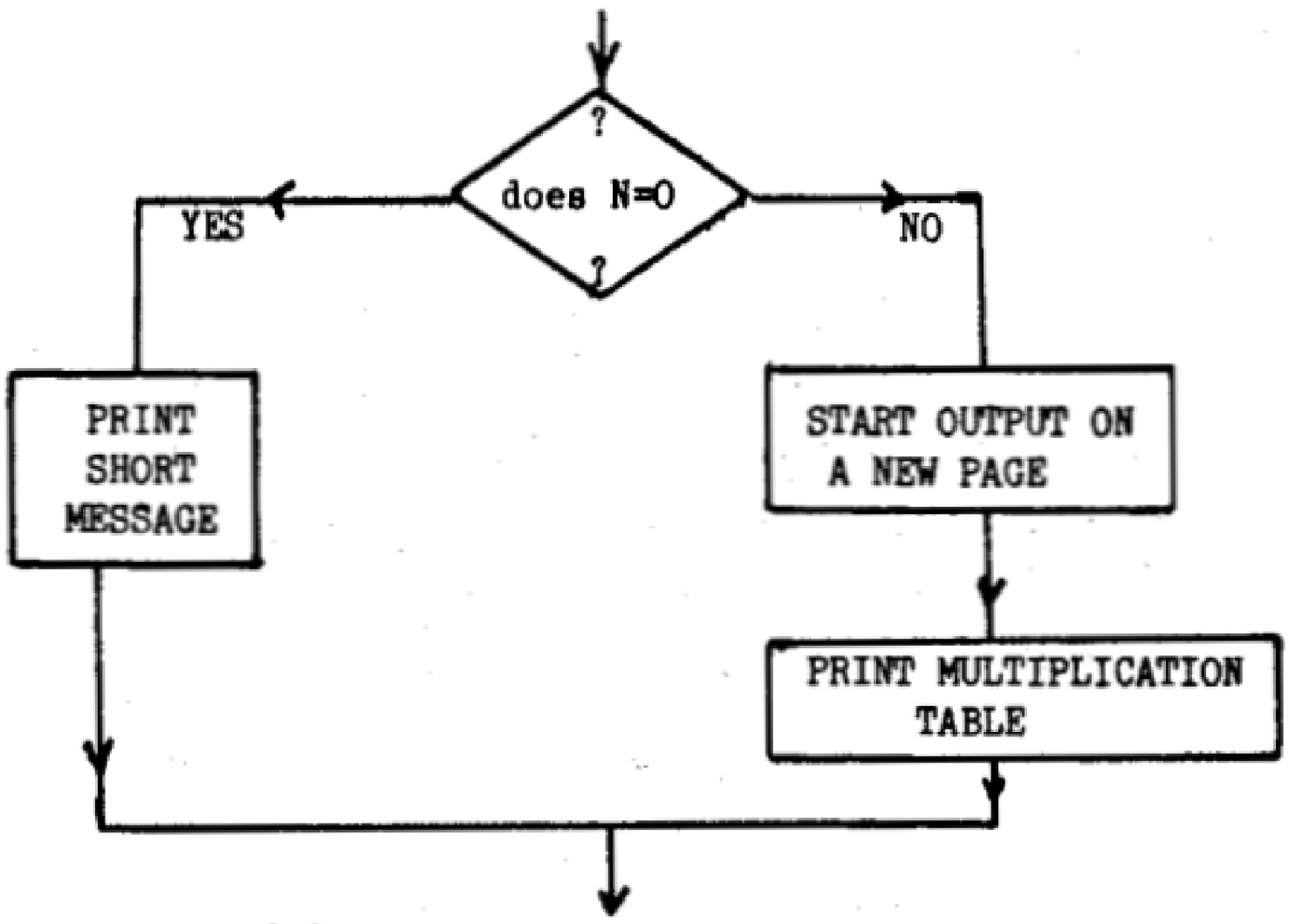
```
T = S." IS FAR FROM ".T
```

will result in this:

SECTION 4 (A) - CONDITIONAL INSTRUCTIONS

(i) if...then...else

Sometimes, at some point in the computation, we shall need to make a choice between two courses of action. In our earlier program to read a number (N) as data and print the corresponding multiplication table, we might feel that if N turns out to be 0, it would not be worth printing a 0-times table, but that instead we should print a brief explanatory message. To achieve this, we should need to arrange that once a value for N has been read, we test to see whether or not N equals 0. The flow of control would be:



and one way of writing the program would be:

```
begin
  comment  This program follows the flow diagram above.
  integer N

  READ (N)
  if  N = 0 then start
      PRINT STRING ("NOT WORTH PRINTING 0-TIMES TABLE")
      NEWLINE
  finish else start
      NEWPAGE
      PRINT TABLE OF (N)
  finish

end of program
```

It is worth noting that the above program would have exactly the same output in all cases if we swopped over the two alternative routes, and at the same time negated the condition; that is wrote: if N ≠ 0 ....

```
begin
   comment  The condition has been negated.
   integer N

   READ (N)
   if N ≠ 0 then start
         NEWPAGE
         PRINT TABLE OF (N)
   finish else start
                  PRINT STRING("NOT WORTH PRINTING 0-TIMES TABLE")
                  NEWLINE
                  finish
   end of program
```

(ii) Omitting else

It quite often happens that one of the two alternative paths involves taking no action. In the above program, for example, we might decide that in the N = 0 case we should refrain from printing anything at all, even the 'NOT WORTH PRINTING' message. If there are no instructions to go between the second start and finish, the whole of this section, including the keyword else, are omitted. This gives:

```
begin
     comment   This program will produce no output if
     comment    N turns out to be 0.
     integer N

     READ (N)
     if N ≠ 0 then start
          NEWPAGE
          PRINT TABLE OF (N)
     finish
end of program
```

(iii) Omitting start and finish

If there is only one simple instruction between the start and finish, then the start and finish can themselves be omitted, and the one instruction is put in place of the start. Thus, if we decide to omit the NEWPAGE instruction, we can use the following very useful and simple form of conditional instructions.

```
if N ≠ 0 then PRINT TABLE OF (N)
```

and another useful abbreviated form permits if.... then .... else in one line.

```
if N = 0 then PRINT STRING ("NOT WORTH IT") else PRINT TABLE OF (N)
```

(iv) Further conditions.

So far, conditional clauses have involved comparison of two numerical quantities either for equality (=) or for non-equality (≠). The four other natural comparisons will be written in normal mathematical notation, namely: > , ≥ , < , ≤ meaning "greater than", "greater than or equal to", "less than" and "less than or equal to" respectively. For input to the computer, however, the non-availability of the characters ≥ and ≤ leads us to represent these by two characters each.
Thus:

Written form	Form for input to computer
if A ≥ B then	$IF A >= B $THEN .....
if P+Q ≤ C-17 then	$IF P+Q <= C-17 $THEN .....

(v) Comparison of strings.

Two strings may be compared in the same six ways. It should be remembered, however, that any spaces present count as part of strings. Hence the 3-letter string "CAT" is NOT equal to the 4-letter string "CAT ", as the latter has an extra space.

In the context of strings, "greater than" is taken to mean "comes LATER IN DICTIONARY ORDER than". Hence

```
if S > "SMITH" then PRINT STRING (S)
```

would cause the string stored in S to be printed only if it came later in dictionary order than "SMITH". A "dictionary order" relationship between strings that contain characters other than letters of the alphabet does exist, but will not be discussed at this stage.

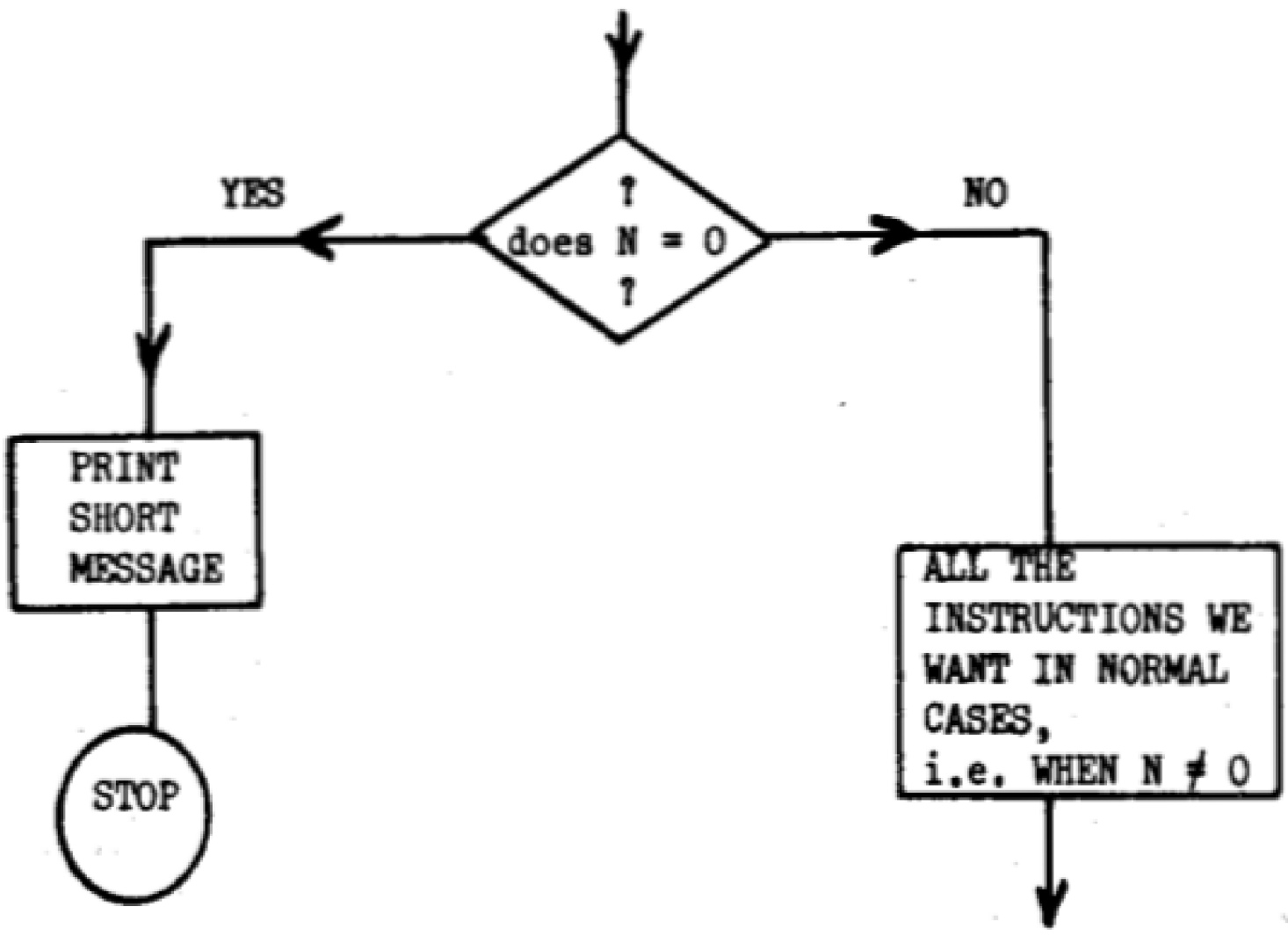
(vi) Use of unless

Any condition written with an if clause may alternatively be expressed in the negative form using an unless clause.

```
if      N ≠ 0 then .....  )
                          )  are exactly equivalent
unless  N = 0 then .....  )

if      A > B then .....  )
                          )  are exactly equivalent
unless  A < B then .....  )  (Note: < NOT ≤ )
```

(vii) The instruction stop

The execution of a program automatically terminates upon reaching end of program. In certain cases it is convenient to terminate prematurely if some special circumstance arises (say, if N = 0), and for this purpose the instruction stop is provided.



At first sight, we might think that this calls for an "if ..... then ..... else" construction, but since execution of a stop instruction causes the program to stop, the following is simpler.

```
begin
  integer N
  READ (N)
  if  N  =  0  then start
      PRINT STRING ("NOT WORTH PROCEEDING")
      NEWLINE
      stop
  finish
  .................     ; !  We only reach this point if N ≠ 0
  .................
  .................
  end of program
```

If we are prepared to omit the warning message when N=0, the whole start/finish group might be contracted to:

```
  if  N = 0  then stop
```

SECTION 4(B) - FURTHER FORMS OF CONDITION

(i) Writing conditions on the right.

In the case of conditional instructions that do not make use of start, finish or else, we may write the instruction first, followed by the condition. Thus the following are exactly equivalent:

```
if N ≠ 0   then WRITE (N,2)

WRITE(N,2)  if  N ≠ 0
```

and, of course, both are also equivalent to the following two:

```
unless N = 0 then  WRITE (N,2)

WRITE(N,2)  unless N = 0
```

The form to be chosen depends upon individual taste and upon which best mirrors the way we wish to think about the condition being tested. Most people would regard the third version above as inelegant, and therefore generally to be avoided.

Remember Those alternative forms with the condition on the right are NOT permitted when start, finish or else is involved.

(ii) Concatenating two instructions

If start/finish brackets enclose a very small (normally no more than two) unconditional instructions, a concise form is permitted.

```
if  N  ≠  0  then start
    READ (X)
    SUM = SUM + X
finish
```

may be written in one statement:

```
if  N ≠  0  then  READ (X) and  SUM = SUM + X
```

Note This is only allowed if both the instructions to be concatenated are unconditional instructions. If one itself involves another condition, we cannot avoid the start/finish . For example:

```
if  N ≠  0  then start
    READ (X)
    if  X > 0 then  SUM = SUM + X
finish
```

(iii) Compound conditions. Examples are:-

```
if  X > Y and Z = 13 then .....
if  X > Y or  Z = 13 then .....

if  X > Y  and  Z = 13  and A + B = C + D  then .....
if (X > Y  and  Z = 13)  or  A + B = C + D  then .....

if  A < B < C  then .....
if  A < B < C  and  C < D then .....
```

Notes

1. The third example gives three simple conditions connected by and. The number of and's is not limited. The same applies to a sequence of or's.

2. Where and and or are both used within the same condition, brackets are required (as in the fourth example) to avoid ambiguity.

3. Following normal mathematical notation, the fifth example is a more compact way of writing:

```
if A < B  and  B < C then .....
```

4. However, this contraction cannot be extended, and the following would be faulted (But see the sixth example above for an acceptable form)

```
if A < B < C < D then .....
```

5. The components of a multiple condition are examined from left to right and testing ceases as soon as sufficient is known to decide whether or not to carry out the main instruction. Thus, supposing in the first example above, that the test for "X > Y" shows this condition to be unsatisfied (i.e. X is not greater than Y) then it is unnecessary to test for Z = 13 and so the value stored in Z will not be examined.

6. or means "inclusive or". Thus the second condition above means:-

"if X > Y or Z=13 OR BOTH"

(iv) Conditions involving string resolution.

See Section 7 .

SECTION 5 (A) - REPEATING GROUPS OF INSTRUCTIONS

(CYCLES)

If a group of instructions is placed between the bracketing keywords cycle and repeat, then as soon as the last instruction of the group is completed, we shall start all over again with the first instruction, and so on .... ..

```
begin
    comment   This first version is unsatisfactory, because
    comment   there is nothing to make it terminate.
    integer N

    cycle
        READ (N)
        PRINT TABLE OF (N)
    repeat
end of program
```

There are many ways of writing in the arrangements to terminate the loop.

(i) Using a control variable

Suppose that we know exactly how many times we wish to go round the loop; let it be 10 times. We must declare an extra integer to be used to count 1,2,3,4.....10. Let us give it the name COUNT.

```
begin
    comment   The meaning of the cycle below is as follows
    comment   "First time round, set COUNT equal to 1,
    comment   Each time round, increase COUNT by 1 and
    comment   Stop the cycle at the end of the time when COUNT = 10"
    integer N, COUNT

    cycle COUNT = 1, 1, 10
        READ (N)
        PRINT TABLE OF (N)
    repeat
end of program
```

The control variable (COUNT in the above case) must be an integer, but there is no need for it to start with the value 1, nor for it to go up in steps of 1. Furthermore, we can use the value of the control variable to make slightly different things happen each time round the cycle.

```
begin
    comment  The control variable, let us call it 'I' this time,
    comment  will take in turn the values 2, 7, 12, 17 and 22.
    comment  Thus we get 2-times, 7-times....22-times tables printed.
    integer I

    cycle I = 2, 5, 22
        PRINT TABLE OF (I)
    repeat
end of program
```

(ii) Using a conditional exit.

Any cycle/repeat loop will be terminated if an exit instruction is obeyed.

```
begin
    comment  Below, when N turns out to be zero, the exit will
    comment  cause the cycle/repeat loop to be terminated.  By
    comment  putting it before the printing instruction, we avoid
    comment  putting out the 0-times table.
    integer N

    cycle
        READ (N)
        if N = 0 then exit
        PRINT TABLE OF (N)
    repeat
    comment  When exit occurs, the program resumes from
    comment  immediately after the repeat (i.e. from here).
    PRINT STRING ("STOPPING NOW BECAUSE N = 0.")
    NEWLINE

end of program
```

Note: The instruction exit is only valid inside a cycle/repeat loop and causes an exit from that loop. If it appears between start/finish brackets (which are themselves necessarily enclosed inside cycle/repeat), it causes an exit from the enclosing cycle/repeat.

(iii) Using an until clause.

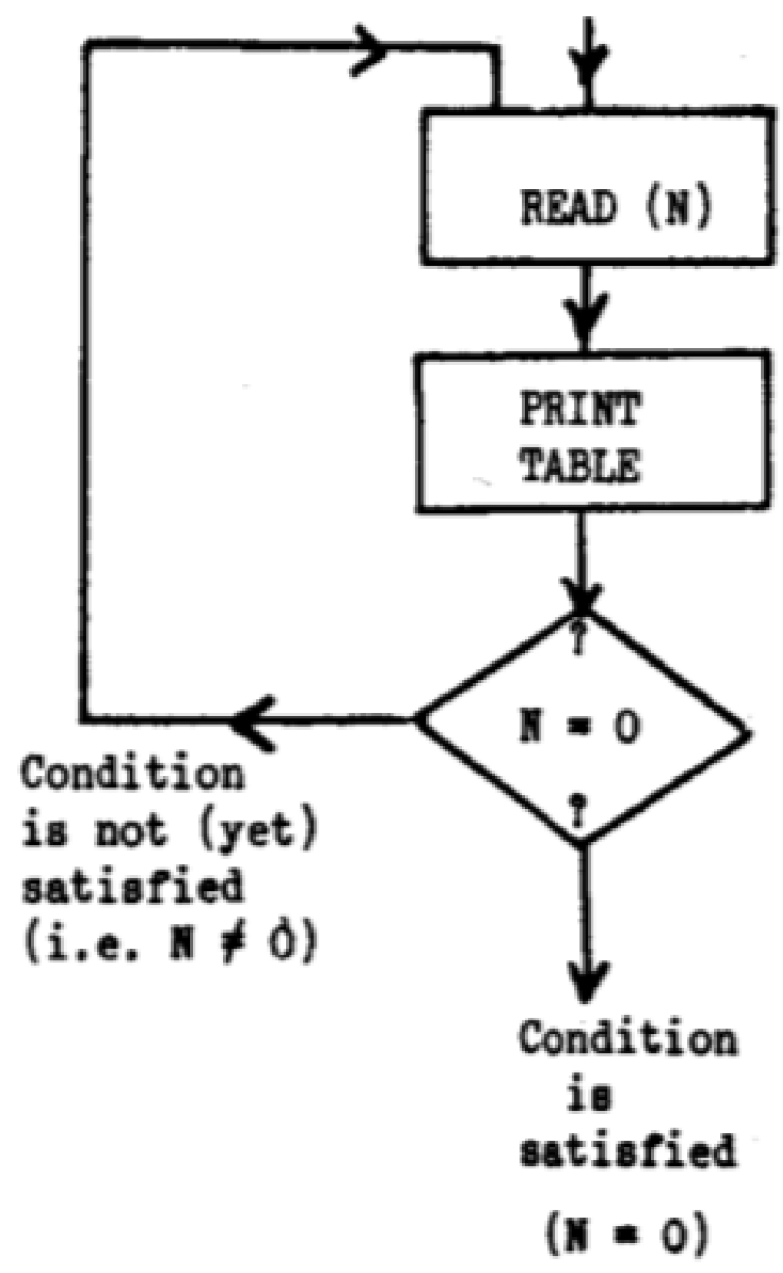
If, in the above, we decided to allow the 0-times table to be printed before exiting from the cycle, we should need to move the line with the conditional exit down one:

```
cycle
    READ (N)
    PRINT TABLE OF (N)
    if N = 0 then exit
repeat
```

In a case like this, where the conditional exit comes immediately before the repeat, we are allowed to write the loop in a slightly more compact form:

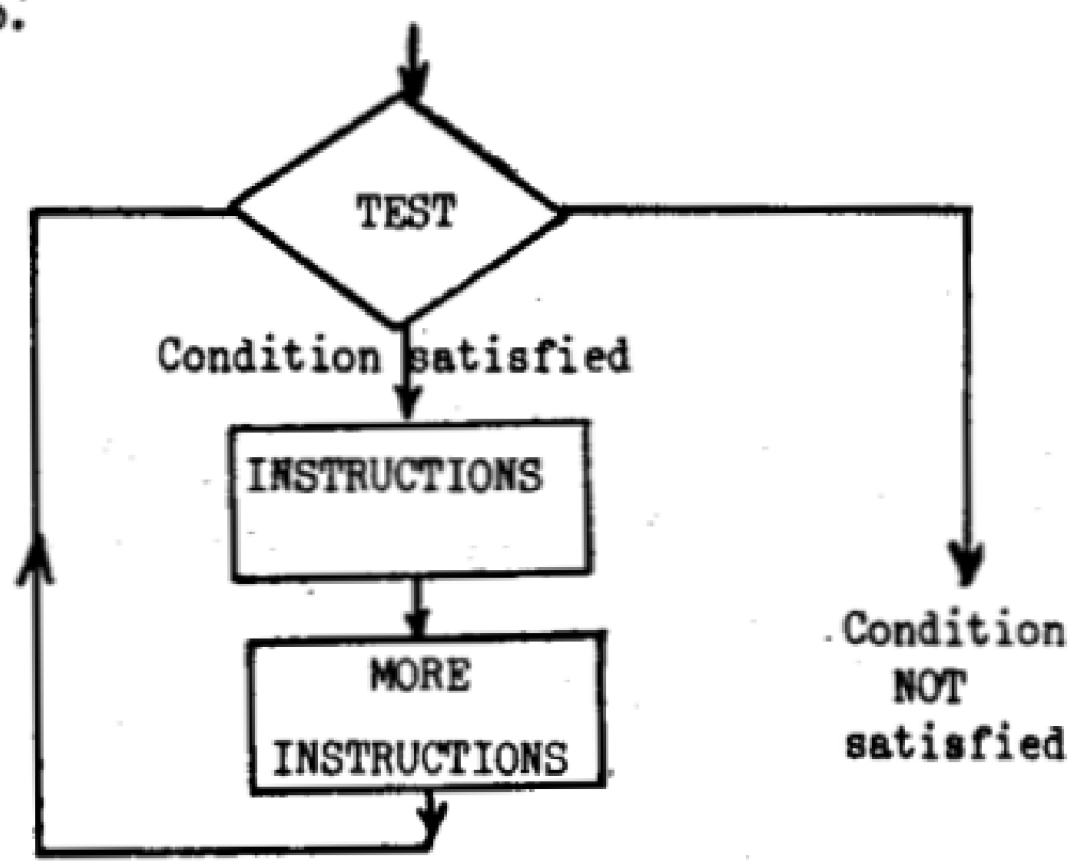
```
until N = 0 cycle
    READ (N)
    PRINT TABLE OF (N)
repeat
```

Note that, although the condition is written on the line with the cycle, the test is actually made at the end of the loop, which will therefore always BE EXECUTED AT LEAST ONCE. The flow diagram looks like this:



(iv) Using a while clause.

while and until clauses are negatives of one another in much the same way as if and unless. (Remember that "if N ≠ 0" and "unless N = 0" are equivalent), but they also differ in the TIME at which the test is carried out. When controlling a cycle with a while clause, the test for existing is made BEFORE carrying out the first instruction of the loop.




```
begin
    comment  This program reads a POSITIVE integer (N), then
    comment  calculates and prints the remainder when N is
    comment  divided by 7.  This is done by repeated subtraction
    comment  of 7, continuing as long as N is ≥ 7.  In case
    comment  N is originally less than 7, we need to test BEFORE
    comment  the first subtraction is carried out.
integer N
    READ (N)
    while N ≥ 7 cycle
        N = N - 7
    repeat
comment  This program assumes POSITIVE input data.
PRINT STRING ("REMAINDER = ")
    WRITE (N, 1)
    NEWLINE
end of program
```

Note The above example is intended to be simple to understand. This is not generally an efficient method of finding a remainder (unless N is known to be small).

Some restrictions in the use of cycles.

(1) In the case of a cycle with a control variable (i.e. cycle I = M,N,P+3) the controlling variable (I) must be an INTEGER variable. The three integer expressions for first value, increment and final value (i.e. M, N and P+3) may contain variables as this example shows, but they must work out so that the cycle terminates. That is, the difference between (P+3) and M must be an exact non-negative multiple of N.

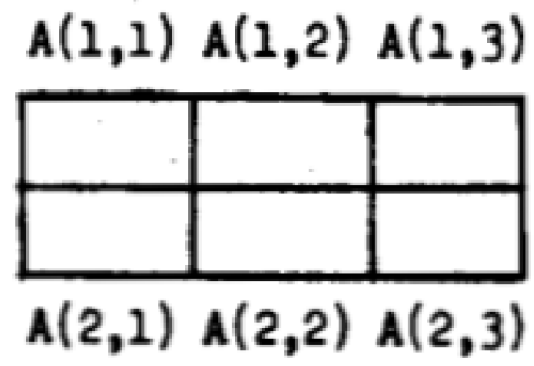
(2) A cycle may be controlled by ONLY ONE of (i) a control variable, (ii) a while clause, (iii) an until clause. In other words it is invalid to write:

```
until X = 0 cycle I = 1,3,N
```

On the other hand, a cycle controlled by any one of the above three may also have an exit instruction within.

NESTING OF CYCLES

A cycle/repeat group may itself be enclosed in a further cycle/repeat. A common need for this arises when operating on 2-subscript arrays.




```
cycle  COL = 1,1,3          ;! This cycle will read three numbers from
   READ (A(1,COL))          ;! the data file into A(1,1), A(1,2) and
repeat                      ;! A(1,3), thus filling the first row.
```

```
cycle  ROW = 1,1,2          ;! These nested cycles will read six numbers
  cycle  COL = 1,1,3        ;! into A(1,1), A(1,2), A(1,3) followed by
     READ (A(ROW,COL))      ;! A(2,1), A(2,2) and A(2,3).
  repeat
repeat
```

```
cycle  COL = 1,1,3          ;! But by reversing the order of the cycles,
  cycle  ROW = 1,1,2        ;! six numbers would be read in, column by
     READ (A(ROW,COL))      ;! column.  That is in the order A(1,1), A(2,1)
  repeat                    ;! followed by A(1,2), A(2,2), followed by
repeat                      ;! A(1,3), A(2,3)
```

SECTION 5(B) - SHORTENED FORMS OF while/until

Cycles controlled by while or until clauses and containing a small number (usually one) of simple unconditional instructions, may be written in abbreviated forms, analagous to those used in place of start/finish groups.

(i) Consider the previous example of taking a remainder when N is divided by 7.

```
while  N ≥ 7  cycle
    N = N - 7
repeat
```

This can be contracted to either of the following equivalent forms:

(a) `while N ≥ 7 then  N = N - 7`

(b) `N = N - 7  while N ≥ 7`

(ii) A cycle to read and sum a set of numbers which are known to be terminated with a zero, is (assuming SUM and X have been declared):

```
SUM = 0
until  X = 0  cycle
    READ (X)
    SUM = SUM + X
repeat
```

Two possible and exactly equivalent contractions are:

(a)
```
SUM = 0
until X = 0 then READ (X) and SUM = SUM + X
```

(b)
```
SUM = 0
READ (X) and SUM = SUM + X until X = 0
```

SECTION 6 : LIBRARY ROUTINES & FUNCTIONS

These may be classified as follows:-

(a) Routines — e.g. READ STRING (S)
NEWLINE
WRITE (I*J,3)
SORT STRING ARRAY (X,1,50)
PRINT STRING (S.T)
READ (I)

(b) Functions (i) integer functions e.g. LENGTH (S)
INT (Y + 3.1)

(ii) real functions e.g. SQ RT (Y*Z)

(iii) string function e.g. DATE

A routine call is a complete instruction. A function, on the other hand, is used as part of an instruction. Its purpose is to generate ONE VALUE. This value must then be used as part (or the whole) of an expression of appropriate type - integer, real or string.

For example, suppose the following declarations had been made:-

integer I,J,K ; real Y,Z ; string (50) S,T,U

Then the following would be possible statements:-

```
I = LENGTH (S) + 17
Z = SQ RT (Y * Z)
PRINT STRING ("TODAY IS ".DATE)
```

Note that we describe a function as an integer function, real function or string function, depending upon the nature of the value it produces as its result; this has nothing to do with the types of the parameters given in brackets. In fact, neither of the examples of integer functions given above takes integer-type parameters. LENGTH takes the name of a string as parameter (but gives as its result an INTEGER giving the number of characters currently stored in that string variable). INT takes a real expression as parameter (but gives as its result the INTEGER value nearest to the real expression.)

SPECIFICATION

Before we are able to use a library routine or function, we need to be told:

(a) Its type: routine, integer function, real function or string function.
(b) Its NAME.
(c) The number and type of parameters required.
(d) What it does.

These first three are sometimes written as a "specification, in the form:-

routine spec SORT STRING ARRAY (string array name X, integer A,B)
integer fn spec LENGTH (string name S)
string fn spec DATE
routine spec PRINT (real EXPR, integer DP1, DP2)
routine spec WRITE (integer EXPR, DP)
routine spec SWOP INTEGERS (integer name I,J)

In this context, the names used for the FORMAL PARAMETERS are of no significance, and only serve to show how many actual parameters of each type are required when we call the routine. We have (so far) nine types of formal parameter:

	Actual Parameter Needed
integer array name) real array name) string array name)	The name of an array of appropriate type (integer, real or string) e.g. A
integer name) real name) string name)	The name of a single variable (or single element of an array) of appropriate type (integer, real or string) e.g. S A(7) B(I,J)
integer) real) string ( ))	An expression of appropriate type (integer, real or string), except that an integer expression may be used in place of a real expression - (but not vice versa). e.g. I*J Y + 3.1 S.T

Note that WRITE takes two integer (i.e. integer expression) parameters, while SWOP INTEGERS takes two integer name parameters. Hence we can use the expression (I*J) in

WRITE (I*J,3)

but NOT as a parameter to the routine READ . In any case, it would be hard to ascribe a meaning if we did write:

READ (I*J)

SUMMARY OF LIBRARY ROUTINES & FUNCTIONS AVAILABLE

(i) Common input and output ROUTINES.

These were described in Section 3:

READ	READ STRING	READ ITEM
WRITE	PRINT	PRINT FL
PRINT STRING		
NEWLINE	NEWLINES	NEWPAGE
SPACE	SPACES	

(ii) STANDARD INTEGER FUNCTIONS

In the tables below, the type of parameters taken by each function will be indicated in brackets after the NAME of the function.

Name	Parameters	The value calculated is:
INT	(real X)	The nearest integer to the real expression given as parameter, X.
INT PT	(real X)	The integral part of X. Note that INT PT(3.73) is 3, but that INT PT(-3.73) is -4.
IMOD	(integer I)	The modulus (absolute value) of I. Hence, IMOD (-3) gives +3.
REM	(integer I,J)	The remainder when I is divided by J. *** Provided for Computer Science 1 students - not in standard IMP. ***
LENGTH	(string name S)	The number of characters in the string variable S.

(iii) Standard STRING FUNCTION

FROM STRING	(string name S, integer I,J)	A copy of the Ith to the Jth characters (inclusive) of S. The string variable S is itself unaltered. Also see section 7.

(iv) Standard REAL FUNCTIONS

Name	Parameters	The value it calculates:
SQ RT	(real X)	The (non-negative) square root of X.
MOD	(real X)	The absolute value of X. e.g. MOD (-3.73) = 3.73
FRAC PT	(real X)	The fractional part of X e.g. FRAC PT (3.73) = 0.73 FRAC PT (-3.73) = 0.27
LOG	(real X)	The logarithm to base e.
EXP	(real X)	e^X.
SIN	(real X)	The usual trigonometric functions, but
COS	(real X)	note that X is in radians.
TAN	(real X)	
ARCSIN	(real X)	$\sin^{-1}x$, where $\lvert X \rvert \leq 1$ and the result is in the range $-\pi/2$ to $\pi/2$.
ARCCOS	(real X)	$\cos^{-1}$, where $\lvert X \rvert \leq 1$ and the result is in the range 0 to π.
ARCTAN	(real X,Y)	$\tan^{-1}$ (Y/X) with the result in the range $-\pi$ to $+\pi$. If X > 0, the result is in the 1st or 4th quadrant. If X < 0, the result is in the 2nd or 3rd quadrant.

(v) TIME, DATE & CPU TIME

Name	Parameters	The value it calculates is:
TIME	NONE	The time of day when the function is called, given as an 8-character STRING. For example: "14:27:31" (24-hour clock)
DATE	NONE	The date when the function is called, given as an 8-character STRING. For example: "27/10/76"
CPU TIME	NONE	This gives a REAL number, for the amount of time in seconds spent by the Central Processing Unit on the execution of this program, up to the time of calling the function. Since the starting time for this "clock" is undefined, this function should always be called TWICE, and the difference between the two values taken. The result is accurate to 0.001 seconds.

***NOTE Users other than Computer Science 1 students will need to give an external specification before using any of the above three functions. This takes the form:

```
external string fn spec  TIME
external string fn spec  DATE
external real   fn spec  CPU TIME
```

(vi) PRIVATE LIBRARIES

Computer Science 1 students should also look in the supplement of additional library routines and functions provided for the class.

(vii) OTHER STANDARD LIBRARIES

Information on these is issued by the ERCC, but will not be required by Computer Science 1 students.

SECTION 7 : MORE OPERATIONS ON STRINGS

STRING RESOLUTION

This is an instruction peculiar to strings and it allows us to search a string for the (first) occurrence of some sequence of characters. For example, suppose we have made the assignment

S = "JOHN SMITH, 8 BLANK TERRACE, EDINBURGH. TEL 668 1212"

then

S → T.(", ").U

will assign to T a copy of the characters found in S before the first occurrence of the expression in brackets (i.e. comma space) and to U a copy of those after it. S will REMAIN UNALTERED. More generally, we have on the right a sequence of alternate string expressions in brackets and string variables. Returning to the above,

S → NAME.(", ").ADDRESS.(" TEL "). PHONE NO

will cause JOHN SMITH to be assigned to string variable NAME,

8 BLANK TERRACE, EDINBURGH. to ADDRESS

and 668 1212 to PHONE NO.

Notes

(a) The expressions in brackets may be general string expressions (variables, constants, functions, etc.) but the string variable names which alternate with them, and appear without brackets, may only be variables since values are to be assigned to them.

(b) If the expression sought does not occur, the program is terminated with a run-time fault.

CONDITIONS INVOLVING STRING RESOLUTION

The condition

if S → P.("**").Q then ....

tests to see if S can be resolved in this way. If it can, copies of the components are assigned to P, Q and, of course, the instruction at ..... is carried out. If not, none of these events takes place.

The resolution operator (→) is not allowed in a two-sided condition. Hence

if T = S → P.("**").Q then ....

is invalid, but could correctly be written

if T = S and S → P.("**").Q then ....

TAKING A FIXED PORTION OF A STRING (FROM STRING)

The string function FROM STRING (parameters: string name S, integer I,J), gives as its result a copy of the Ith to the Jth characters (inclusive) of the string S.. It LEAVES S UNALTERED. For example, if string variable P is currently storing:

MARY QUEEN OF SCOTS

then the instruction: Q = FROM STRING (P,6,10)

will assign to Q the 5-character string: QUEEN

LENGTH OF A STRING (LENGTH)

The integer function LENGTH (parameter: string name S) gives as its result the number of characters in the string currently stored in S. Thus with the value in P as above, an instruction:

I = LENGTH (P)

would result in the value 19 being assigned to I.

LOOK-AHEAD IN THE DATA FILE (NEXT ITEM)

Sometimes we shall wish to 'look ahead' to see what the next character in the data file is, without actually reading it. For example, to find out whether or not it is safe to try to read a number with the READ routine. (If the next character in the data is a letter, then an attempt to use READ will cause the program to be faulted.)

The string function NEXT ITEM gives as its result a 1-character string corresponding to the next character in the data file, BUT LEAVING THAT CHARACTER OFFICIALLY UNREAD, so that it is still there to be used again when we give an instruction to read it officially. This function takes NO PARAMETERS. The value of the function may be assigned to a string variable, but rather more frequently our idea of 'looking ahead' is to decide whether or not it is safe to proceed. For example:

if "0" ≤ NEXT ITEM ≤ "9" then READ (X)

Note that although the above check is sufficient to ensure that it is safe to use "READ", it is not always necessarily what we want - the next item might be a space or newline, and the character AFTER THAT could still be a digit 0-9.

SPECIAL STRING CHARACTERS.

**** The facilities on this page are not part of standard IMP ****

(i) NEWLINE CHARACTERS. (SNL)

If we wish to write down the string constant consisting of one newline character, this can look a bit awkward and inelegant.

```
READ ITEM (S)
if  S = "
" then  COUNT = COUNT + 1
```

To avoid this inelegance, we can write SNL (standing for STRING NEW LINE) instead. Thus the above becomes:

```
READ ITEM (S)
if  S = SNL  then  COUNT = COUNT + 1
```

(ii) SKIPPING ITEMS IN THE DATA FILE (SKIP ITEM)

The routine SKIP ITEM (parameters NONE) simply reads a character from the data file but makes no use of it ('throws it away') so that the next character after it in the file is now next in line to be read.

```
while NEXT ITEM = " " or  NEXT ITEM = SNL  then  SKIP ITEM
```

SECTION 8 : NUMERICAL AND STRING EXPRESSIONS

We have alread seen any places where integer, real and string expressions are written in IMP programs - on the right-hand side of assignment instructions, in conditions and as actual parameters to routines (when parameters are called by value). Integer expressions are also used as bounds in array declarations, as array subscripts and as bounds for cycles. String expressions can also be used between the brackets of string resolution instructions such as: S -> T.(.....).U

While noting that in all the above cases we can use any expression of the correct type, there some cases in the language where we are constrained to write a constant, rather than an expression. Such places are indicated by .... in the following:

(a) As the maximum length in string declarations.

```
string (....) array  PETE (M : N+1)
```

(b) In the bounds for CONST arrays (also OWN arrays, described later).
In the list of initial values given to CONST and OWN arrays.

```
const integer array  TABLE (.... : ....) = .... , .... , .... ,
```

INTEGER EXPRESSIONS Consist of:

Integer variables Integer constants (e.g. 45) Integer functions	connected by the operators: + - * // ** , where * is multiplication, // division and ** is for exponentiation (raising to a power).

NOTE The result of integer division (using the operator //) is rounded down. The result of 7//2 is the integer 3.

REAL EXPRESSIONS Consist of:

Real OR integer variables Real OR integer constants Real OR integer functions	connected by any of the operators: + - * / or **.

NOTES (1) Real division (using /) involves no more rounding than is necessary to match the precision available in real variables.

(2) Integer operands (variables, constants and functions) may be used in real expressions, but not vice versa.

NOTE (3) The exponentiation operator (**) raises operands to a power, but this power must be an integer (positive or negative). Thus X**3 represents X^3.

(4) Apart from an initial + or - sign, all arithmetic operators must appear directly between a pair of operands; two adjacent operators are not allowed. Thus X^{-3} will have to be written as X ** (-3) and not as X ** -3.

(5) Real constants may be in either fixed point form: 3.725

or in floating point form: 1.732@3 meaning 1.732×10^3

1.732@-3 meaning 1.732×10^{-3}

The constant π (i.e. 3.14159265.....) may be written in IMP programs as PI (or π or £ or $, depending upon the particular compiler and input device in use).

STRING EXPRESSIONS Consist of:

String variables
String constants (e.g. "MORRIS 1300")
String functions

} connected by the operator for concatenating, which is a full stop (.)

NOTE ON STRING CONSTANTS.

String constants are written between quotes, and may consist of up to 255 characters. The quotes marking the begining and end of the string do not form part of the string. Hence

"THE CAT"

is a string of length 7 (6 letters and 1 space).

The empty or NULL string (of length 0) is of course represented by two quotes with nothing between them, i.e. ""

This should not be confused with a string consisting of one or more spaces, which might be " " one space

or " " two spaces, etc.

Newline characters can appear in strings like this:

"THIS STRING IS SPREAD
OVER TWO LINES"

If a quote character is required in a string, it is immediately followed by another, to show it is not a terminating marker.

"WHO SAID ""NO""?" is the way to write the string: WHO SAID "NO"?

PRECEDENCE OF ARITHMETIC OPERATORS.

If we consider the expression A+B*C we might think of evaluating it in two ways, i.e. as (A+B)*C or as A+(B*C). It is easily seen that these do not in general give the same value. So we have precedence rules which define the order of evaluation in the absence of brackets. For two adjacent operators (like * and + above), the operation of the higher precedence in the table below is carried out first.

```
**                  (highest precedence)
* or / or //
+ or -              (lowest precedence)
```

Where two adjacent operators are of equal precedence according to the table the one appearing to the left in the expression to be evaluated takes precedence.

We can always use brackets to over-ride the above rules of precedence. When in doubt it is wise to insert brackets for safety and clarity. Extra brackets do no harm.

The 'left-hand precedence' between + and - agrees with normal (mathematical) usage,

e.g. By A-B+C we mean (A-B)+C and not A-(B+C)

EXAMPLE	MEANING
A/B*C	(A/B)*C
A/(B*C)	(A)/(B*C)
A**B*C	(A**B)*C
A**(B*C)	(A)**(B*C)

Note that it is necessary to bracket denominators containing more than one term. A common mistake is to write A/2*B when A/(2*B) is intended.

MODULUS SIGNS *** WARNING - SEE BELOW ***

If we wish to take the absolute value of an expression, we enclose the expression between exclamation marks. Thus

```
!X-Y!
```

yields the (positive) difference between X and Y. This operation may be applied to either integer or real expressions, and gives a result of the same type as the original expression.

*** WARNING *** This modulus operator may soon be removed from some IMP compilers. Use MOD and IMOD instead. (See section 6.)

SECTION 9 : INNER BLOCKS - LOCAL AND GLOBAL VARIABLES.

Inside a program we may use an inner block. Its structure, with its local declarations at the head, and its instructions following, is identical to that of the main program, except that it is terminated by end instead of end of program. An inner block may be regarded as a compound instruction.

```
begin                                                          )
.....                                                          )
.....                                                          )
                                                               )
.....                                                          )
.....                                                          )
  begin                                                        )
   .....   )                                                   )
   .....   )   declarations                                    )
                                                               )
   .....   )   instructions                                    )
   .....   )                                                   )
  end                                                          )
.....                                                          )
.....                                                          )
end of program                                                 )
```

One case where this is useful is when we require to declare an array whose bound is not known until some part of the calculation has been completed. For example:-

```
begin
  integer N
  READ(N)              ;!  N is the size of array required

  begin
  integer array  A (1:N)
  ......
  ......
  ......
  end
end of program
```

LOCAL AND GLOBAL VARIABLES

It is important to appreciate the sphere of influence of the declarations made in the inner and outer blocks.

A declaration appears at the head of a block and normally remains valid throughout that block until cancelled by the end terminating the block. It also remains in force upon descent to an inner block, UNLESS the same name is declared in the inner block. In the latter case, the variable is held in abeyance while the machine is executing the inner block, coming into force again when the end of the inner block is reached.

Within any particular block, we call a variable declared within that block a LOCAL VARIABLE while one declared in any exterior block is called a GLOBAL VARIABLE.

These points are illustrated in the following example:

(i)
```
begin
integer A
.....
A = 1
   begin
   integer A,B,C
   .....
   B = 1
   C = 4
   A = B + C
   end
WRITE (A,2)
end of program
```

Here the name A refers to quite distinct variables in the inner block and the outer block. The WRITE instruction will print the value 1.

(ii)
```
begin
integer A
.....
A = 1
   begin
   integer B,C
   .....
   B = 1
   C = 4
   A = B + C
   end
WRITE (A,2)
end of program
```

Here A is global to the inner block since this time A has not been re-declared. In this case the WRITE instruction will print the value 5.

SCOPE OF VARIABLES.

It is important to realise that on leaving a block, all local variables declared within that block are lost. Thus in the examples above, if the WRITE instruction on the penultimate line had attempted to write B or C, the program would have been faulted.

Although inner blocks will not be needed very often, the idea of local and global variables and their scope, is most important. In the next section on defining our own ROUTINES and FUNCTIONS, the same principle applies.

SECTION 10 ; DEFINING OUR OWN ROUTINES & FUNCTIONS

(A) ROUTINES

When designing a program to solve a problem, we first try to decompose the problem into smaller elements. This enables us to view the structure of the program as a whole, without initially having to bother about the fine detail of all the steps. Also, it often turns out that essentially the same sequence of instructions is required in several places in the program. We may also recognise that particular sequences may be of use in the future for similar programs. It is therefore very convenient to be able to define our own routines, which may then be used in our program in the same way as the library routines.

Before we can call one of our own routines in a program, we must make sure its name, and the number and type of parameters required, is declared. This may be done by placing a specification (spec)among the declarations at the head of the program. The form of the spec is exactly as used in the discussion on library routines, and indicates that the details of the routine will be given in a routine block later on in the program. Alternatively, we can, in all but exceptional cases described later, place the whole body of the routine at the head of the program, where it may be thought of as a declaration of name, parameters and what the routine does. The body of the routine has a structure similar to that of a main program except that in place of begin and end of program, we have routine ..... and end. Between these we put the local declarations (if required), followed by the instructions. For example, anyone not having access to the Computer Science 1 library routine "SWOP INTEGERS" could add it for himself by inserting four lines as follows:-

```
begin
    routine  SWOP INTEGERS (integer name I,J)
       integer  K                          ;!  local variable for a copy of I
       K = I  ;  I = J  ;  J = K           ;!  while value of J is moved to I
    end

    comment  The above routine for swopping any two integers is now
    comment  available throughout the program to follow

    integer P,Q
    integer array A (1:10)
    .........
    .........
    SWOP INTEGERS (P,Q)                    ;!  this first routine call causes
    SWOP INTEGERS (A(1),A(10))             ;!  the routine above to be carried out
    ........                               ;!  but with P and Q in place of the
    ........                               ;!  dummy names I and J, respectively.
end of program                             ;!  second time: A(1) and A(10).
```

Note that the positioning of the routine body at the head of the program has nothing to do with the time the routine will be executed - the routine will be executed when it is CALLED, that is at the line "SWOP INTEGERS (P,Q)". In the call, we are told that the ACTUAL PARAMETERS P & Q are to be used in place of the dummy FORMAL PARAMETERS (I and J).

Another example:

```
begin
    routine READ REAL ARRAY (real array name X, integer A,B)
    !  This routine reads real numbers from the data file into
    !  the real array X, from X(A) to X(B) inclusive.
       integer I
       cycle  I = A, 1, B
          READ (X(I))
       repeat
    end

 real array  A,B (1:100), C (0:20)
    READ REAL ARRAY (B, 1, 100)          ;!  read 100 numbers into array B.
    READ REAL ARRAY (A,51, 100)          ;!  read 50 numbers into array A.
    READ REAL ARRAY (C, 0, 20)           ;!  read 21 numbers into array C.
    ..................
    ..................
    ..................

end of program
```

Note This routine is defined with a formal parameter real array name. This means that it can only be used to act upon a real array, and furthermore only upon a 1-dimensional real array. Unfortunately, separate routines will have to be defined if we wish to read a sequence of integers into an integer array, or real numbers into a 2- or 3-dimensional array.

RETURNING FROM ROUTINES

See notes two pages on for the use of the instruction return

(B) FUNCTIONS

These may be added at the head of the program in a manner almost identical to that for a routine. The first line of the function indicates the type of function it is (integer, real or string) and since the purpose of a function is to produce ONE VALUE to be used (e.g. in an expression), we need a special form of instruction to indicate when the result has been calculated. This takes the form:

```
result = .....
```

```
begin

   integer fn LARGER OF (integer P,Q)
   !  this function finds the larger of two integer values.

      if  P>Q  then result = P else result = Q
   end



   real fn  LARGEST IN  (real array name X, integer A,B)
   !  This function finds the largest member of X from X(A) to X(B), inclusive
      integer  I  ;  real  LARGEST
      LARGEST = X(A)                          ;!  Try this, compare all others with it
      cycle  I = A+1, 1, B                    ;!  This assumes A< B.  See note over page.
        if  X(I)>LARGEST then  LARGEST = X(I);!  On finding bigger one, take it.
      repeat
result = LARGEST
end



      integer I,J,K,L, M; real Y,Z        ;!  MAIN PROGRAM STARTS HERE
      real array A(1:100)
      .....
      .....
      I =  LARGER OF (J,K) + LARGER OF (L-1,M)
      Z = LARGEST IN (A,51,100)
      .....
      .....
end of program
```

NOTES ON FUNCTIONS

(a) On reaching "result = ..." in a function, this result is accepted as the value, and no further instructions in the function are performed. Hence the first function above could equally well be written:-

```
integer fn LARGER OF(integer P,Q)
    if P > Q then result = P
    result = Q
end
```

since the line "result = Q" is only reached if the condition "P > Q" has failed.

(b) In the second example, it is for the same reason that we must defer giving "result = " until after completing the cycle/repeat.

(c) The second example assumes that B is strictly greater than A. If we wish to allow for the possibility of them being equal, we could add, as the first instruction of the function:-

```
if A = B then result = X(A)
```

(d) Since the purpose of a function is to produce ONE VALUE, we should not want to assign new values to any of the parameters during the course of executing the function. For this reason, we should expect to call all parameters by value. In fact, Imp only allows arrays to be called by name. This forces us to call X as a real array name in the second function above.

RETURNING FROM ROUTINES

We have seen above that we leave a function on executing the instruction result = ... , and that this need not necessarily arise at the textual end of the function.

The event that causes the program to leave a routine may be
either reaching the textual end of the routine
or executing the instruction return. This instruction may, like the result = of a function, be made conditional. For example, if we have a routine to sort an array into some order from X(A) to X(B), say, we may wish to insert a conditional return at the begining to deal with the possibility that the array has only one (or even less) elements:

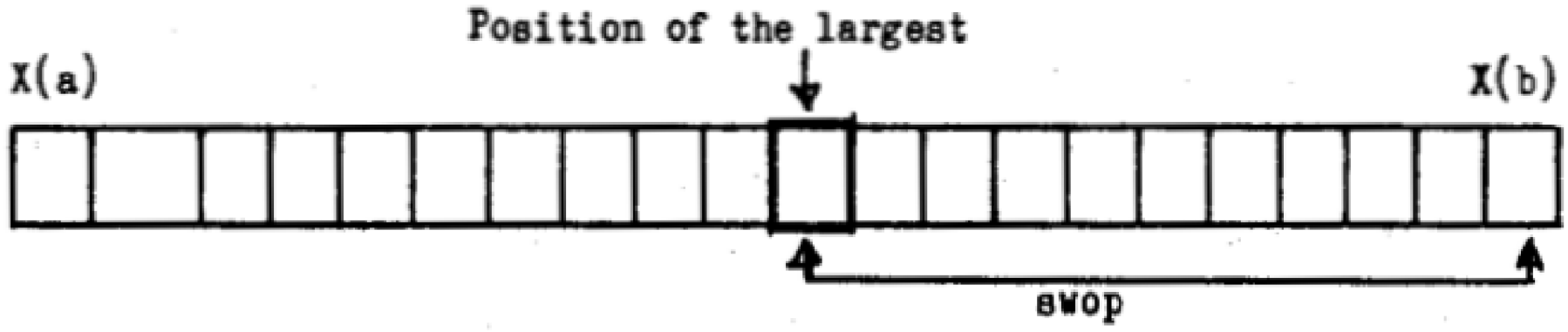
```
if A > B then return
```

SECTION 11 : RECURSIVE ROUTINES AND FUNCTIONS.

To write a routine to sort an array (say, an integer array) into ascending order by the method of 'selecting the largest', we might start planning as follows:

(i) Find the position of the largest member of the array.

(ii) Swop this largest member with the right-hand member.



We now have one element (the right-hand one) in its final resting place; it can now be disregarded and the rest of the problem is simply to sort the remaining members of the array. Now, this is exactly the same in nature as the original problem, but one smaller, so that step (iii) is:

(iii) Sort an array one smaller than the original one.

The Computer Science 1 library contains a function and a routine to carry out steps (i) and (ii) above. Step (iii) can be carried out by calling our main sorting routine from within itself, a process known as RECURSION.

```
routine  SELECT SORT  (integer array name X, integer A,B)
   integer P
                                          ;! Using C.S.1 special routines.
   P = POS BIG INTEGER (X,A,B)            ;! Find posn. of largest.
   SWOP INTEGERS ( X(P),X(B) )            ;! Swop it with the end one.
   SELECT SORT (X,A,B-1) if A < B-1       ;! Leaving the end one
end                                       ;! alone, sort the rest.
```

NOTES (1) It is important to make sure that a routine or function written recursively will not carry on calling itself indefinately. In this case, each call on SELECT SORT acts on an array of one less elements than in the previous call, so that it will suffice to insert a simple condition to miss out the recursive call when the array consists of one element (which, of course, cannot help but be in the correct order).

NOTE (2) In this case, the recursion can, if we wish, easily be avoided by using a simple cycle instead. In more complex situations, this may not be so easy, and recursion can provide a great simplification in our thinking.

(3) The above version of the routine will fail if called with A and B initially 'inside out', that is A > B. It is instructive to re-write it as follows:

```
routine SELECT SORT  (integer array name X, integer A,B)
  integer P

  return if A ≥ B                    ;!  Nothing needs to be done.
  P = POS BIG INTEGER (X, A, B)      ;!  Find largest.
  SWOP INTEGERS (X(P), X(B))         ;!  Swop it with the end one.
  SELECT SORT (X, A, B-1)            ;!  Sort the remainder.
end
```

RECURSIVE FUNCTIONS.

Similarly, functions may be written recursively. Consider the problem of finding the Highest Common Factor of two integers, P and Q, say, using the Euclinean algorithm.

(i) Find the remainder (R), when P is divided by Q.
(ii) If R = 0, then the H.C.F. is Q.
(iii) Otherwise, we need to find the H.C.F. of Q and R.

```
integer fn HCF (integer P, Q)
  integer R

  R = P - P//Q * Q                   ;!  Same as the CSl function REM
  if R = 0 then result = Q           ;!  The HCF required.
  result = HCF (Q, R)                ;!  We only reach here if R ≠ 0
end
```

NOTE Once again, our recursive function has an escape clause (if R = 0) to ensure that it does not call itself indefinately.

SECTION 12 : EXTERNAL ROUTINES AND FUNCTIONS

DEFINING EXTERNAL ROUTINES AND FUNCTIONS.

A file of external routines and/or functions takes the following form:

```
external routine A(integer array name X)
. . . .
end
external routine PRINT DECODED (string(31) S)
. . . .
. . . .
end
external real fn CUBE ROOT (real x)
. . . .
   result = . . . . .
end
end of file
```

This file is compiled in the normal way. After this, the routines A and PRINT DECODED, and the real function CUBE ROOT may be used in any program, provided that program contains an appropriate "external spec" (see next page).

** WARNING When stored by EMAS, the names of your external routines and functions are TRUNCATED to the first 8 characters. You must take care, therefore, to avoid using two names with the same first 8 characters.

Notes (1) Unlike a main program, a file of external routines has no begin statement. Instead of end of program , it terminates with end of file .

(2) If we require any global variables, accessible from two or more of the routines or functions, these have to be declared as own or const variables (see next section). (There is a third possibility, external variables, described in the IMP language manual, but these are not normally to be recommended).

CALLING AN EXTERNAL ROUTINE OR FUNCTION.

To use an external routine or function in a program, we give an "external spec" - this is the same as the first line of the routine (or function), with the keyword spec added.

```
begin

    external routine spec PRINT DECODED(string(31) S)

    external real fn spec CUBE ROOT (real X)

    real X,Y

    . . . . .

    READ (X)

    Y = CUBE ROOT (X)

    PRINT DECODED ('*A23B!PZ7R')

    . . . . .

    . . . . .

end of program
```

** WARNING Be very careful that the parameters you give for your external spec are identical to those given for your external routine (or function). NO CHECK is made when the program is run, and if the parameter lists differ, then chaos will usually result. ("ADDRESS ERROR" at run-time is a likely consequence).

GLOBAL VARIABLES FOR A FILE OF EXTERNAL ROUTINES.

If we require some global variables accessible from several external routines in one file, it is no good declaring an ordinary variable at the head of the file - being outside of a program or external routine, this would be illegal. We are, however, allowed to declare either CONST or OWN variables at this point. See section 2(iv) for CONST and section 13 for OWN variables. Note that it is also permissible to put a record format statement at the head of a file of external routines in the same way, and the format will apply to all the external routines.

SECTION 13 : OWN VARIABLES.

OWN variables are almost the same as CONST variables (which were described in section 2(iv) - but avoiding the word 'variables' because we were describing things that could not be varied). Storage space for both OWN and CONST variables is allocated and initial values are assigned when the program starts execution; the difference is that OWN variables can subsequently be altered by the program.

On leaving a routine (or function or inner block), all variables declared locally within that routine become inaccessible. However, whereas ordinary variables then cease to exist (the space allocated to them is normally re-used for some other purpose), OWN and CONST variables continue in existance "behind the scenes". Thus if and when the program returns to execute this routine on a later occasion within the same run of the program, OWN and CONST variables will once again become accessible and will contain the values left there at the end of the previous visit to the routine. Note that the initial value given with the declaration of OWN variables is assigned once, and once only, each time the program is run.

```
routine ANYTHING
  own integer  I = 0
  I = I + 1
  . . . . . .
  . . . . . .
end
```

Like any other local variable, I is of course only accessible from within the routine (or from within any routine/function/block embedded within the routine). When the program starts, I takes the initial value 0, as in the declaration. On reaching the instruction I = I + 1 for the first time, I will increase to 1. Assuming that none of the later instructions within the routine alters I, it will still be 1 on leaving the routine; thus on entering the routine the next time, I will start with the value 1 and immediately be increased by 1 to 2. Thus I will always be storing an integer corresponding to the number of times the routine has been entered. (Note that it will be the number of times the routine has been entered since we started this present run of the program - the fact that we ran it several times earlier to-day has no bearing.)

Note An OWN variable declared at the head of a file of external routines may be accessed from within any of them.

SECTION 14 : BYTE INTEGERS, SHORT INTEGERS, LONG REALS

BYTE INTEGERS, SHORT INTEGERS

To economise in storage it is sometimes convenient to declare:

```
short integer  I      ;!  occupies 2 bytes (16 bits).
                      ;!  range of values stored: -32768 to +32767.

byte integer   J      ;!  occupies 1 byte (8 bits).
                      ;!  range of values stored: 0 to 255.
```

Notes (1) Although short integers are seldom used, byte integers are useful for storing symbols. See section 18.

(2) Short integers and byte integers may be used in any integer expression.

(3) The value of an integer expression (including normal integer variables) may be assigned to a short or byte integer, provided the value obtained lies in the ranges given above.

(4) ** WARNING. Short or byte integer variables may not be used as the control variable for cycles.

(5) Arrays may be declared in the obvious way:

```
short integer array   A(0:999)

byte integer array    B(1:2000)
```

(6) Name-type or value-type parameters to routines may be of type short integer or byte integer.

LONG REALS

```
long real X,Y                      ;!  each occupies 8 bytes (64 bits).

long real array Z(-1000:1000)
```

Long real variables can store the same range of values as real variables, but to a greater precision (between 14 and 15 decimal digits instead of between 6 and 7).

Note If the special statement reals long is placed at the head of a program:

```
reals long
begin
```

this has the effect of turning all declarations and parameters of type real into the corresponding ones of type long real. (Computer Science 1 students need not do this, as it is inserted for them automatically.)

SECTION 15 : RECORD VARIABLES.

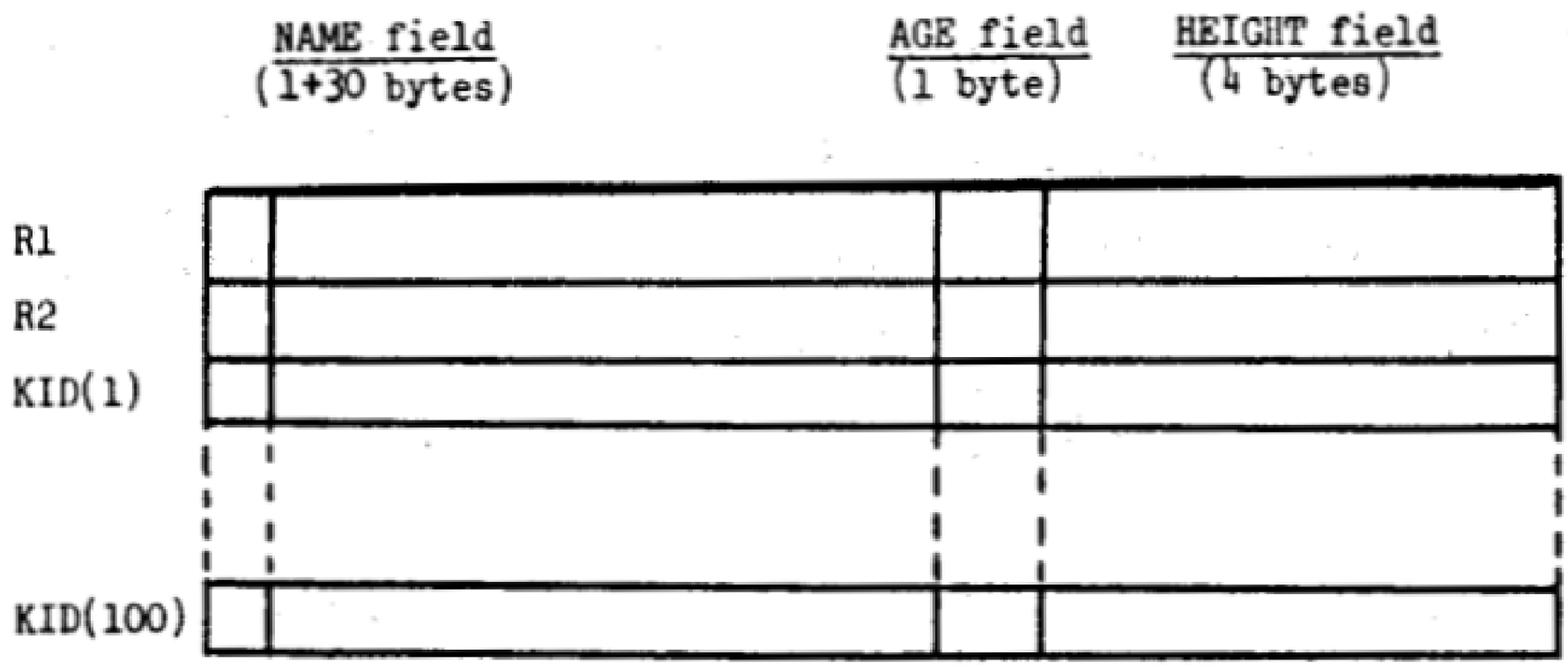
Suppose that we wish to store the following data about some children:

(a) Name - Up to 30 characters. Use a string(30).
(b) Age in months - A byte integer will serve (Max. value = 255).
(c) Height in inches - Kept to nearest 0.1". We need a real.

It will be convenient if we can store these three pieces of information in one variable, which can be manipulated as a whole. For this we need to define a new type of variable, known as a record. To define a new type of variable, we first give a record format ; having done that, we are able to declare scalars and arrays as follows:-

```
record format BABY (string(30) NAME, byte integer AGE, real HEIGHT)

record  R1, R2 (BABY)
record array KID (1:100) (BABY)
```

Because they have been declared as of type BABY, records R1, R2 and all elements of record array KID consist of 36 bytes, like this:



A complete record is referred to by its name (e.g. R2 or KID(12)). Assignments to complete records must have on the right-hand side either another record of the same format, or 0. For example:

```
R2 = KID(13)        ;! All fields of KID(13) are copied to R2.
R1 = 0              ;! All fields of R1 are set to 0 (for numerical
                    ;! fields) or to the null string (string fields).
```

Individual fields may be referred to separately, as shown on the next page.

FIELDS WITHIN RECORDS.

To refer to an individual field, we give the name of the whole record, followed by the underline character (_) and the name of the field required.

R1_NAME is the NAME field of record R1. It can be treated as any other string variable. For example:

```
PRINT STRING (R1_NAME)
R1_NAME = "A.B. SMITH"
```

R2_HEIGHT is the HEIGHT field of record R2. It can be treated as any other real variable. For example:

```
R2_HEIGHT = R2_HEIGHT + 2.5
```

KID(3)_AGE is the AGE field of record KID(3). It can be treated as any other byte integer variable. For example:

```
KID(3)_AGE = R2_AGE
WRITE(KID(3)_AGE,3)
```

ARRAY FIELDS WITHIN RECORDS.

Suppose that we wish to store records, each containing (a) the name of a student and (b) an array of his marks in each of 12 examinations. A suitable set of declarations might be:

```
begin
  record format STUDENT (string(30) NAME, integer array MARK(1:12))
  record array CS1 (1:200) (STUDENT)
  record  A,B (STUDENT)
```

We can now refer either to a whole record (e.g. A or CS1(34)), or to the MARK field (which is an integer array) or to an individual element of of a MARK array.

A_MARK is an integer array, giving the twelve marks stored in record A. It can be treated as any other integer array, for example, it can be passed as a parameter to a sorting routine:

```
SORT INTEGER ARRAY (A_MARK,1,12)
```

CS1(I)_MARK(J) is an integer variable, giving the mark in the Jth exam of the student whose record is in CS1(I).

RECORDS AS PARAMETERS PASSED TO ROUTINES/FUNCTIONS.

Records and record arrays passed as parameters to routines or functions may only be passed by name. In addition, each such parameter must be followed by a record spec statement, indicating what type of record it is. In the following example, note that the one record format statement at the begining of the program is valid within both the routines that follow it, in accordance with the normal scope rules. It is also valid for the declaration at the start of the main program.

```
begin
record format BABY (string(30) NAME, byte integer AGE, real HEIGHT)

  routine SWOP RECORDS (record name X,Y)

    record spec  X  (BABY)   ;!  Note that unfortunately, a separate spec
    record spec  Y  (BABY)   ;!  statement is needed for each parameter.
    record       Z  (BABY)   ;!  A dump variable, needed as usual.

    Z = X  ;  X = Y  ;  Y = Z

  end


  routine SORT RECORD ARRAY (record array name R, integer A,B)

    record spec R (BABY)     ;!  Takes same form as for scalars above.
    integer I

    cycle  I = A,1,B-1
      if R(I)_HEIGHT > R(I+1)_HEIGHT then SWOP RECORDS (R(I),R(I+1))
    repeat

  SORT RECORD ARRAY (R,A,B-1) if B-1 > A
  end

                    MAIN PROGRAM STARTS HERE

  record array KID (1:1000)  (BABY)
  record P,Q (BABY)

     etc.   etc.
```

SECTION 16.

ROUTINES/FUNCTIONS AS PARAMETERS

Suppose that we wish to have one routine that will print a table of square roots, cube roots or cosines, etc. as required. We clearly need the name of the required function to be passed as a parameter, for example:-

```
TABULATE (SQ RT)
TABULATE (CUBE RT)
TABULATE (COS)
```

In another case, we might wish to write a routine that would see how long some nominated sorting routine took to sort an array of 100 random numbers. In this case, a routine would need to be passed as a parameter. For example:-

```
TIME SORTING BY (QUICKSORT)
TIME SORTING BY (BUBBLESORT)
```

In a realistic example we should almost certainly need some further parameters (e.g. a string to be printed as a heading for the table, the size of the table to be printed, or of the array to be sorted, etc., etc.). For clarity, however, these will be omitted in the examples below.

The routine/function is passed as a parameter in a fairly natural way, except that one extra statement is needed: if the function or routine being passed as parameter has the formal name F, we need a "spec" statement to say what parameter(s) F itself takes. And, of course, the actual functions used (e.g. SQ,RT, CUBE RT COS in the above) will have to conform.

```
routine  TABULATE  (real fn  F)
  spec F (real X)              ;!  The actual function passed as
                               ;!  parameter must conform to this and
  integer  I                   ;!  take just one real value parameter.
  cycle  I = 0, 1, 10
    NEWLINE                    ;!  Tabulates the function F(I) for
    WRITE (I,2)                ;!  I = 0, 1, 2, ........10.
    PRINT (F(I),4,4)
  repeat
NEWLINES(2)
end
```

An example of a ROUTINE passed as a parameter to a routine:-

```
routine  TIME SORTING BY (routine ANYSORT)

  spec  ANYSORT (integer array name X, integer A,B)
  integer array P (1:100)      ;!  Stores the numbers to be sorted.
  integer I
  real T                       ;!  To measure the time taken.

  cycle I = 1, 1, 100          ;!  Fill an array with 100 random
    P(I) = RANDOM INTEGER      ;!  numbers, using the function from
  repeat                       ;!  the CS1 library.

  T = CPU TIME
  ANYSORT (P, 1, 100)          ;!  ANYSORT is the dummy name for any
  PRINT (CPU TIME - T, 3, 3)   ;!  sorting routine, whose actual name
end                            ;!  will be given when the routine is called.
```

MINOR NOTE.

In the example on the previous page, the routine TABULATE requires as actual parameter a real function. In fact, the standard functions SQ RT and COS are defined as long real functions. Although this distinction has been irrelevant to us so far, it is significant when a function is passed as a parameter. If we require to pass any of the long real standard functions to our TABULATE routine, a simple way to reconcile the parameters is to place the special statement reals long at the head of each program or file of external routines concerned. This has the effect of turning all declarations and parameters of type real into the corresponding long real types. In fact, this is done automatically for Computer Science 1 students.

SECTION 17 : INPUT AND OUTPUT STREAMS.

In all our discussion so far, we have assumed that all the data being read by our input routines (READ, READ STRING, etc.) comes in one STREAM from just one file (or input device); and similarly that all our output is sent in one stream to just one file (or output device). Depending upon the computer we are using and the operating mode, there will be DEFAULT OPTIONS which, in the absence of instructions to the contrary from the program, determine the devices to be used for the input and output streams. These, and the methods of over-riding them, are not part of our IMP program and do not concern us here. However, we may wish to include instructions in our program to arrange for input data to be taken from two or more different streams (coming from different files/devices), or to send our output to two or more streams (being stored or printed on different files/devices). To arrange for this, we use the routines SELECT INPUT and SELECT OUTPUT, which both take an integer value as parameter.

```
begin
  real X
  READ (X)              ;!  This comes from the default input
  ........              ;!  stream, as no instructions to the
  ........              ;!  contrary have been given.
  SELECT INPUT(2)       ;!  From now on, until changed again,
  READ (X)              ;!  input comes from STREAM 2.
  ........
end of program
```

NOTES (1) Output streams are selected in just the same way with the routine SELECT OUTPUT.

(2) Computer Science 1 students can choose stream as follows:

For input: Input stream 1, 2, 3 or 0. (Input 0 is the console).
For output: Output stream 1, 2, 3 or 0. (Output 0 is the console).

(3) Other users will have to use one set of numbers for input streams and a different set for output streams.

(4) ** WARNING ** Both input and output streams are buffered line by line. Unfortunately, when we select a new stream we lose any data remaining in any half-read line on the old input stream. A subsequent re-selection of the old stream will resume reading at the beginning of the following line. On calling SELECT OUTPUT, any half-complete line on the old stream is terminated with a newline.

SECTION 18 : SYMBOLS

String variables, functions, etc., are designed to facilitate operations upon non-numerical quantities. However, they suffer from the inconvenient limitation of having a maximum length of 255 characters. Moreover, to access an individual character (say the 7th) of string S, we have to use the unweildy function

```
T = FROM STRING (S, 7, 7)
```

We can, of course, store information in an array of 1-character strings:

```
string (1) array  S(1:1000)
```

but if we are going to have to store our non-numerical characters in one-character units anyway, there is the alternative of storing them as what are known as SYMBOLS. This is more economical in storage than using one-character strings, but denies the facilities of concatenation and resolution. Each symbol is regarded as equivalent to an integer in the range 0 - 127, and thus symbols can be stored in integer or, for economy of storage, byte integer variables. Corresponding to the routines and functions so far considered for input and output of strings, we have equivalent ones for operating on symbols being stored as integers.

```
     string (1) S, T, U                    integer I, J, K

     READ ITEM (S)                         READ SYMBOL (I)
     T = NEXT ITEM                         J = NEXT SYMBOL
**   U = NEXT SIG ITEM                **   K = NEXT SIG SYMBOL
**   SKIP ITEM                             SKIP SYMBOL
     PRINT STRING (S)                      PRINT SYMBOL (I)
     PRINT STRING ("Q")                    PRINT SYMBOL ('Q')
     U = "A"                               K = 'A'
     if  "A" ≤ S ≤ "Z" then ...            if  'A' ≤ I ≤ 'Z' then ...
**   if  S = SNL then ...                  if  I = NL then ...
**   if  S ≠ SEM then ...             **   if  I ≠ EM then ...
```

Notes (1) ** indicates facilities that are not part of standard IMP.

(2) Constant symbols are written single primes; constant strings are written between double primes (quotation marks) as shown in the examples above.

(3) The integers I,J,K above could , for economy of storage, have been declared as byte integers.

CONVERSION BETWEEN ONE-CHARACTER STRINGS AND SYMBOLS.

```
string fn spec TO STRING (integer N)

integer fn spec  CHAR  NO (string name S, integer I)
```

TO STRING takes the symbol whose equivalent numerical value is N, and gives as its result the same character, in the form of a 1-character string.

CHAR NO does the inverse: it takes the Ith character of string S and gives as its result the same character as a symbol.

Examples of use.

```
integer I,J    ;   string (1) S   ;   string(10) T

I = CHAR NO (T,3)        : !  I now stores a symbol

S = TO STRING (J)        ; !  S now stores a 1-character string
```

Note

From its name, one might expect that FROM STRING would be the inverse of TO STRING , but it is in fact a quite different thing. (FROM STRING copies a part of a string to form another string).

ARITHMETIC RELATIONSHIPS BETWEEN SYMBOLS.

Although we do not normally need to know what numerical values correspond to different symbols, it is useful to know that successive letters of the alphabet correspond to successive integers. Since symbols are stored in integer, or byte integer, variables, we can carry out addition and subtraction operations to convert from one letter to another. Thus:

```
the expression    'A' + 1    gives   'B'
the expression    'Y' + 1    gives   'Z'
```

One case where this property is useful is in the declaration of an array whose subscripts can be written as symbols.

```
integer array COUNTER ('A':'Z')
```

This would be the natural declaration if we wished to count the frequency of occurrence of the different letters of the alphabet in a piece of text. Another natural use would be to cycle from 'A' to 'Z' setting these counters to 0.

```
cycle i = 'A',1,'Z'
     COUNTER (i) = 0
repeat
```

LOWER CASE LETTERS

Lower case letters (a,b,....z) can also appear as symbols. They have different numerical values from those of upper case letters, but are themselves ordered in the natural way. Thus:

the expression 'a' + 1 gives 'b'

the expression 'w' + 1 gives 'x'

CONVERSION BETWEEN UPPER AND LOWER CASE

Because of the above relationships, it is clear that:

the difference between 'A' and 'a'
is the same as the difference between 'B' and 'b'
and as the difference between 'Z' and 'z'.

If, therefore, an integer I stores an upper case letter as a symbol, then the corresponding lower case symbol is given by:

I + 'a' - 'A'.

For example, we might write:

```
if 'A' < I < 'Z' then I = I + 'a' - 'A'
```

EXAMPLE Counting the letter frequency in one sentence of text. In order to count upper and lower case letters together, we first convert all lower case letters into corresponding upper case letters.

```
begin
   integer array COUNT ('A':'Z')                    ;! for counting letters
   integer I
   cycle I = 'A', 1, 'Z'                            ;! initialise counters
      COUNT(I) = 0
repeat
cycle
   READ SYMBOL (I)
   if I = '.' then exit                             ;! sentence ends on a full stop
   if 'a' ≤ I ≤ 'z' then I = I + 'A' - 'a'          ;! convert lower case to upper
   if 'A' ≤ I ≤ 'Z' then COUNT(I)=COUNT(I)+1        ;! increment corresponding
repeat                                              ;! counters.
                                                    ;! tabulate results.
cycle I = 'A', 1, 'Z'
      NEWLINE
      PRINT SYMBOL(I)
      WRITE (COUNT(I), 6)
   repeat
   NEWLINE
end of program
```

NUMERICAL VALUE OF THE DIGITS 0-9

Rather unfortunately, the "numerical value" of the symbol '2' is not the decimal integer 2. However, the usual relationship holds:-

the expression '0' + 1 gives the symbol '1'

the expression '0' + 9 gives the symbol '9'

Thus if we have an integer variable holding an integer known to lie in the range 0-9, we can get the corresponding symbol by adding '0'.

```
integer I,J
I = 7                ;! I stores the integer 7.
J = I + '0'          ;! J stores the symbol 7.
```

SECTION 19 : POINTER VARIABLES.

Suppose that we have a routine

routine A (integer P, integer name Q)

then on entry to the routine, we assign to P the value of the actual parameter given, but place in Q a POINTER to the actual parameter corresponding. Whenever the routine refers to Q, we actually use the location to which Q is pointing. In a rather similar way, we can declare POINTER variables (integer name, real name, record name, etc., and also integer array name, string array name etc.).

```
begin
  integer array A (1:100,1:100)
  integer name  Q                ;! a POINTER variable
```

Q can now be made to point to any integer variable (say, A(I,J+3)) by

```
Q = =  A(I, J+3)
```

Q is now synonymous with A(I, J+3), and provides a concise may of writing it.

```
Q = Q + 1  unless  Q = 0
```

is a more concise way of writing the same instruction with A(I, J+3) and it also saves the program from having to evaluate the address of the same two-dimensional array element three times in rapid succession.

NOTES (1) It is clearly necessary to make Q point to an integer location (using Q = = ...) before it is meaningful to make an ordinary assignment (Q = ...).

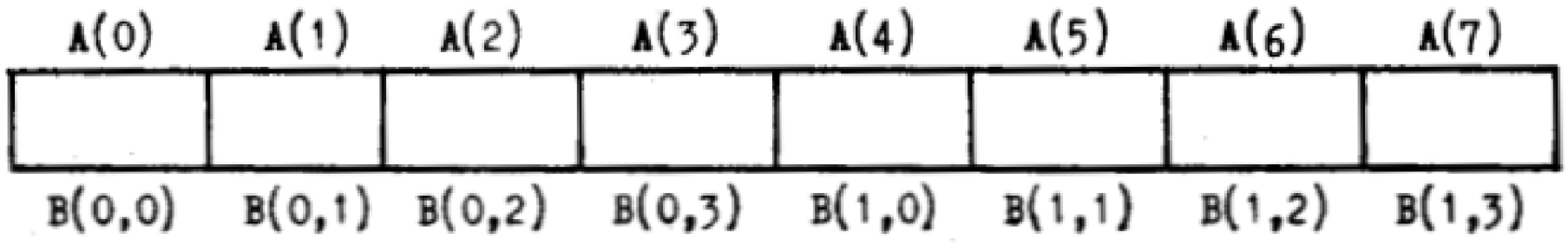
(2) An example of both a record name and an array name is:

```
begin
record format STUDENT(string(30) NAME, integer array MARK(1:1
record array  CS1 (1:200)  (STUDENT)

record name  R (STUDENT)
integer array name M

R = = CS1 (14)            ;!  R is short for the 14th record.
M = = CS1 (I) _ MARK      ;!  M is an integer array
                          ;!  M(6) is an integer
```

SECTION 20 : MAPPING FUNCTIONS.

Mapping functions have some features similar to those of pointer variables, in that they allow us to define how a whole set of "alternative names" are to be allocated to certain variables.

As a practical example, note that some IMP compilers only allow us to declare 1-dimensional arrays. In such cases, we are generally able to obtain the convenience of 2-dimensional arrays by declaring a 1-dimensional array and allocating second names by means of a mapping function.




```
real array A(0:7)
real map B(integer I,J)
     result = = A (4*I + J)          ;! NOTE: use the = = sign, as
end                                  ;! with pointer variables.  ***
```

Any reference to B(1,3), for example, will cause an entry to the mapping function B; this will evaluate the resulting address you want to use, namely "the same as the address of A(4*1+3)", which is A(7).

Notes (1) Other types of map (string map, integer map, etc.) are written in a similar fashion.

(2) A map has the same structure as a function, except that the instruction that causes the calculation to cease is result = = , rather than result = . The right-hand side of this result instruction must be something that gives the address of a variable of the correct type. (i.e. a string variable for a string map, etc.)

(3) Since the result of a map is the address of the variable you want, the map may (unlike a function) be used on the left as well as the right-hand side of an assignment. For example:

```
B(1,0) = B(1,0) + 3
```

(4) Since each reference to B involves executing the body of the mapping function, it is somewhat slow.

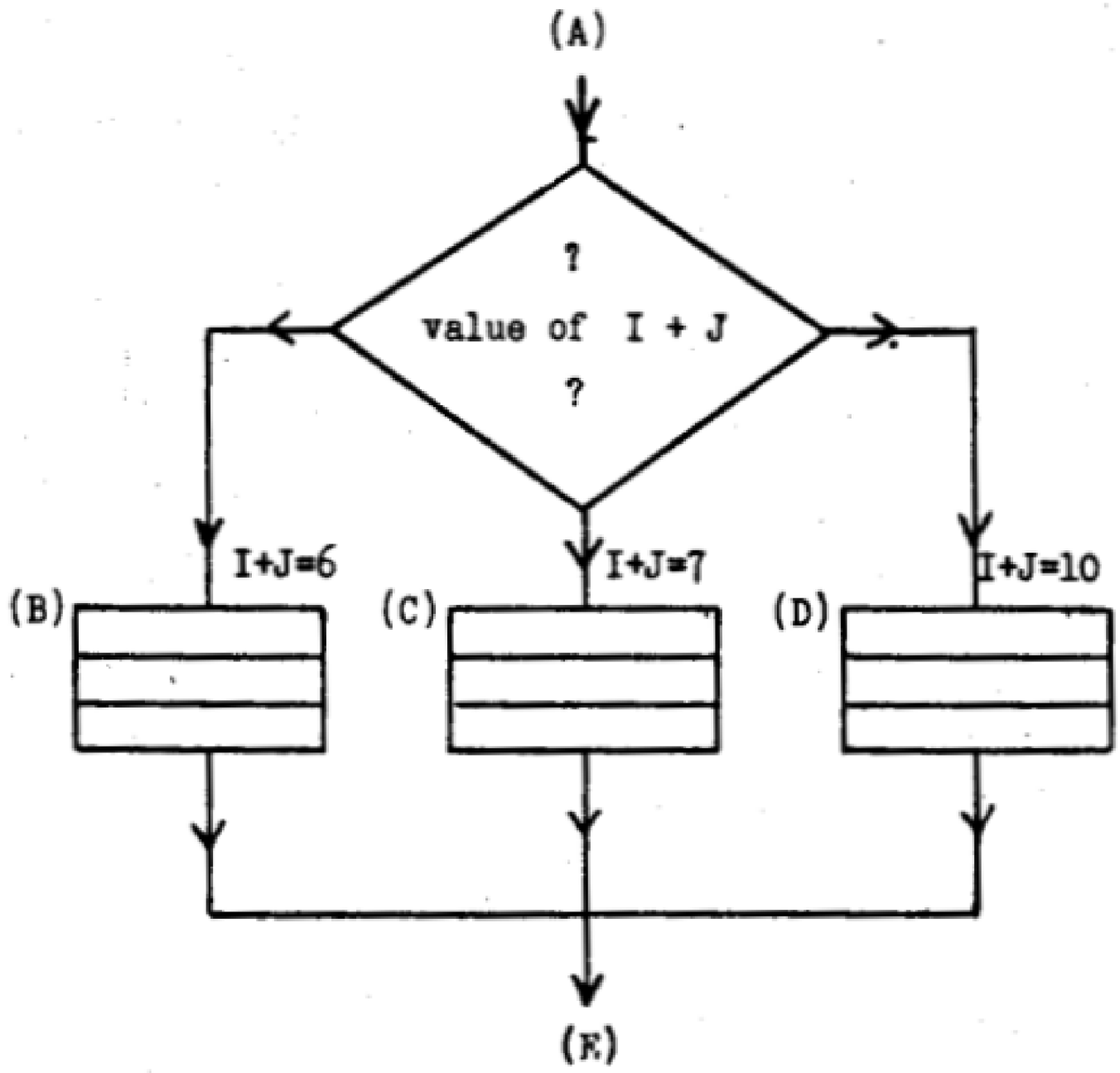
SECTION 21 : JUMPS, LABELS AND SWITCHES

In earlier sections, a number of methods have been described for controlling the order in which instructions are executed. These have involved:

(i) *if* ..... *then* ..... *else* .....
(ii) *start* & *finish*
(iii) *while* .....
(iv) *until* .....
(v) *cycle* & *repeat*
(vi) *exit*, *stop*, *return*, *result* =

In a well-structured program, these will suffice for nearly all purposes. If we wish to make a test to determine which of two alternative paths is to be followed, then "*if* .... *then* .... *else* ....", together with "*start* & *finish*" will be quite convenient. If we have more than two possible routes, however, we can be forced into testing on a succession of conditions. To avoid great inefficiency, we shall probably need nested *start* / *finish* groups, and this can soon become cumbersome.

Suppose the following program structure is required. (Only three possible routes are shown, for simplicity, but there could of course be many more.)



To meet this requirement, we need the following:-

(i) At point (A), to be able to choose between going to one of points (B), (C) or (D). If the choice involves testing for the value of an integer expression, one convenient way of doing this is to use a SWITCH JUMP.

(ii) Having divided into three (or more) paths, a properly structured program will normally require to merge again, to point (E), say. This can be achieved with SIMPLE JUMP instructions. Being simpler, these will be described first.

JUMPS TO SIMPLE LABELS

Jump instructions	meaning
-> L2	JUMP TO the label L2. That is, instead of going on to the next instruction in sequence, break off from here and resume from the statement labelled L2.

Simple labels

L2: NEWPAGE PRINT STRING(" ... ") etc.	The simple label, L2 say, is followed by a colon and placed on the left of the statement from which we wish to resume execution.

Notes (1) A simple label can be any legal Imp name. Such names do NOT have to be declared. (But see next paragraph for switch label names that do.)

(2) The label can come either earlier or later in the program text than the corresponding jump instruction (i.e. we can jump either forwards or backwards), but both must be within the same routine, function or block.

(3) Owing to the high risk of introducing errors that can be very hard to locate, jump instructions should NEVER be used when any of the methods listed at the top of the page would be applicable in a convenient way.

(4) As an alternative to a name, it is possible with some Imp compilers to use a positive integer as a label.

(5) The arrow (→) is printed with a "minus" and "greater than" sign.

SIMPLE JUMP INSTRUCTIONS (WITH CONDITION)

```
if N = 0 then  ->  L2
READ (X)
```

This is exactly the same as the previous example, except that the jump only takes place if N = 0. Otherwise the program naturally continues with the next instruction, say READ (X).

JUMPS TO SWITCH LABELS

If we wish to be able to jump to one of many points in the current block, depending upon the value of an integer expression (I+J, say), then we must DECLARE (in the usual place at the head of the routine, function or block) an array of labels. For example:

```
switch S(6:10)
```

and the jump is written

```
-> S (I+J)
```

and the labels are

```
S(6):  ......
```

The structure of the program to implement the flow diagram given earlier would now be like this:

```
begin
     switch S (6:10)                ;!  a declaration of labels S(6) to S(10)
     .....
     .....
     -> S (I+J)                     ;!  evaluate I+J and jump to correct label

S(6): .....                         ;!  start here if I+J=6
     .....
     -> L99                         ;!  NOTE THIS IS USUALLY WANTED *****

S(7): .....                         ;!  start here if I+J=7
     .....
     -> L99

S(10):.....                         ;!  and here if I+J=10
     .....
     .....
L99:  .....                         ;!  all routes meet together again here
     .....
```

Some notes on SWITCH LABELS

(1) As with simple jumps, the jump instruction and all the corresponding labels must be inside the same block, routine or function. In addition, the switch declaration must also be in the same block, routine or function. That is, there is no possibility of using a "global" switch name.

(2) The bounds of the switch declaration must be CONSTANTS. Hence

switch S (M:N)

would be invalid.

(3) It is not necessary for all the labels in the range declared to appear in the program. For example, S(8) and S(9) do not appear in our example above. On the other hand, if, in that example, I+J were to evaluate to 8 or 9 upon reaching the switch jump, then a run-time fault would naturally occur.

(4) Without the -> L99 jumps, our example would have resulted in the program running on from the instructions at S(6) to continue with those that follow labels S(7) and S(10). This is not the structure normally required. No such jump was needed at the end of the instructions at S(10), since label L99: was on the next line anyway.

APPENDIX A

Preparing IMP Programs on Card Punches and On-Line Consoles

Certain symbols used in the written version of the language are not available on card punches and On-Line Consoles. Special conventions must be adopted as follows:

(1) Keywords

(a) Keywords (begin, end, etc) are punched with a % character immediately preceding the letters. The word must then be separated from other symbols by something other than a letter.

No spaces are permitted within one keyword, but, integer array name may for example be regarded as one or three keywords and hence may be punched

as %INTEGER %ARRAY %NAME

or %INTEGERARRAYNAME

(b) The % symbol acts as a shift character denoting that the sequence of letters immediately following are to be interpreted as keyword letters. It is cancelled by anything which is not a letter.

(2) Use of Spaces

Within the program (but not always within Job Control or data) spaces may be inserted anywhere on a line to improve legibility. Such spaces are disregarded by the compiler except that

(a) A space marks the end of the 'underlining' in keywords.

(b) Certain sequences of characters, known as STRINGS, are indicated by placing them between quote characters ("). Between quotes, spaces DO count, so that

"THE CAT"

is a string of length 7 (six letters and one space).

(3) String conventions on card input.

Anyone inputting IMP programs on cards should check on the current conventions regarding quotation marks. In many cases, the quote character on cards is taken to mean that the previous character is to be disregarded. If such a convention is still in force, quote marks must obviously not be used to delimit strings. In these cases, the single prime (') is used instead. Example:

'THE CAT'

(4) Maximum length of line

Lines of program and data should be limited to 72 characters, as the 73rd and later characters will be disregarded. Most consoles only print 72 characters on a line, so you normally see when information is going to be lost. Beware, however, when using cards as they can take up to 80 characters - although the card punches can and should be set to prevent you going beyond column 72.

(5) Continuation onto a further line (program only)

Normally, each instruction in a program will be written on a separate line. However, long instructions or declarations may be continued onto a second (or further) line by punching %C before reaching the 72nd position on the line. This facility is available in program only, not within Job Control cards, nor data. Its chief use is for punching long instructions of more than 72 characters.

(6) Composite characters

Certain composite characters have to be represented by a pair of characters as follows:-

≥	is represented by the two characters	> =
≤	is represented by the two characters	< =
→	is represented by the two characters	- >
←	is represented by the two characters	<-

(7) Characters not available on card punches and some consoles

If the input keyboard does not have the following characters, they are represented as follows:-

≠	is input as	#	
¬	is input as	£	or $
~	is input as	¬	

APPENDIX B - Notes on Fault Finding.

1. COMPILE TIME FAULTS.

(a) Recognised (numbered) Faults.

If the compiler recognises what appears to be the intended syntactical structure of a statement, but detects a violation of some rule of the language, a fault number and a short message describing the nature of the violation will be printed out. The message normally gives enough information for us to identify the fault. There are two possible messages that are worthy of further comment here.

(i) FAULT 108 (EM CHAR IN STMNT) DISASTER

This means "End-of-message character in statement", and arises when the compiler reaches the end of the source file without recognising our end of program. We may have mis-spelt it, omitted it. This fault can also arise if we try to compile an empty or non-existent file.

(ii) FAULT 19 (WRONG NUMBER OF PARAMETERS)

This can mean either the wrong number of parameters given for a routine
or the wrong number of subscripts given for an array access.
Either of these can sometimes occur through the omission of a comma in, for example, PRINT (X+Y, 3 5) since spaces do not count in program, and the 3 5 will be mistaken for 35 decimal digits being demanded before the decimal point.

(b) Syntax Faults.

This means that the compiler has encountered a statement which does not conform to any of the acceptable syntactical structures. To the human, the fault often appears ridiculously trivial. For example:-

too few closing brackets:	READ (A(N)
excess of commas:	real X,Y,Z,

(c) Side-effects of carlier faults.

Example 1: cyclee I= 1, 1, 10
.....
repeat

Here the first line will be faulted for syntax (faulty spelling of cycle). As a consequence, the compiler will be unaware of our intention to start a cycle and will find a spurious fault:

FAULT 1 (REPEAT TOO MANY)

Example 2: reall TOTAL

```
TOTAL = 0
.....
TOTAL = 0.7
```

Here the first line has a syntax fault and so the declaration will not be acknowledged. Hence the second line will be faulted for "name not declared". In in attempt to avoid the same fault message each subsequent time you use TOTAL, the compiler will declare "TOTAL" for you. Unfortunately it will guess you intended it as an integer and subsequent attempt to assign a real value (0.7) to a supposedly integer variable will cause yet another spurious fault (Real quantity used in integer expression.).

2. RUN TIME FAULTS.

If your program fails at run time, you will receive the message

MONITOR ENTERED FROM IMP

The MONITOR will then proceed to give you several valuable items of diagnostic information, as follows

(i) A message briefly describing the type of fault. Some notes on interpreting these messages is given on the next page. (B.3)

(ii) The line number in your program where the failure occurred. ALWAYS IDENTIFY THIS ON YOUR PROGRAM LISTING.

(iii) A list of the scalar variables in force at the time of failure, and the values stored in them, if any. (Arrays are not printed, as they are liable to be large, and hence time-consuming to print.)

DO NOT RUSH to alter your program until you have made use of the above information to discover why it went wrong. If the cause of the failure does not come easily, it often helps to work through part of the program with pencil and paper, writing down the values you would expect to be stored in the different variables at each stage of the computation.

RUN-TIME FAULTS (continued)

It may be useful to give the following few notes in explanation of the run-time fault messages. For further details, see the "Edinburgh IMP Language Manual", section 13.

(i) ARRAY BOUND FAULT 21

Attempt to use A(21) when array A was declared only (1:20), for example.

(ii) INPUT ENDED

You have tried to read more data (using READ, READ STRING, etc) than you provided in the data file. This is often caused by getting the program into an unintentional loop.

(iii) UNASSIGNED VARIABLE

You have tried to use the contents of a variable which has had nothing put in it.

(iv) SYMBOL IN DATA 'R'

While trying to read a number, you have come across a symbol which cannot form part of a number, for example: R.

(v) ILLEGAL CYCLE

You have tried to start a cycle with control variable which will never terminate e.g.

cycle I = 2,K,10

where K = 3.

(vi) CAPACITY EXCEEDED

The string you are trying to assign is longer than the maximum length declared for this variable.

(vii) NOT ENOUGH STORE

You are trying to use more of the store than is available to you. Note that multi-dimensional arrays run away with a lot of space.

(viii) DIVIDE ERROR

Usually a division by zero.