University of Edinburgh

PROGRAMMING IN ATLAS AUTOCODE

COMPUTER UNIT REPORT No. 1

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PREFACE

This is a revised version of Computer Unit Report No. 1, which was originally issued on 3rd. Mar. 1964. The revision was undertaken not only to improve the text, but also to take account of such changing circumstances as

(i) Changes in the compilers available on Atlas.

(ii) The writing of the Edinburgh University Atlas Autocode compiler which has made Atlas Autocode available also on the K.D.F.9.

This book is intended to serve as an introduction to the Atlas Autocode programming language. It is based on courses of lectures given at Edinburgh University, and describes a version of the language acceptable to all current Atlas Autocode compilers.

For a complete beginner, the following should prove suitable for a first reading:-

Chapters 1 - 5	(But see note on page 27 and omit any parts of pages 40, 48 which cause the reader trouble).
Chapter 8	(pages 89-91. These may be read any time after page 44).

We should point out that our examples are chosen to illustrate points of the language: we do not claim that the techniques used are in any sense the best possible.

We should be glad to hear from anyone who discovers or suspects any errors.

In making this revision, we have benefitted considerably from discussions with our colleague Mr. Harry Whitfield, who led the team writing the Edinburgh University compiler.

Our thanks are due to Mrs. Jackie Snashall and Miss Isabel Fraser who bore the burden of re-typing and to Mr. Brian Read who compiled the index and produced some of the diagrams.

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28th June 1965.

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CHAPTER 1 : INTRODUCTION

Stages involved in using a Computer.

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PROGRAMMING IN ATLAS AUTOCODE

This book is intended for those who wish to learn to write programs in Atlas Autocode, a language available on both Atlas and KDF9 computers.

A program consists of a detailed set of instructions to the computer, explaining exactly how it is to solve a certain problem. It therefore follows that the programmer must first:-

(a) Formulate the problem and decide on the method to be used to obtain a solution. Only then can he

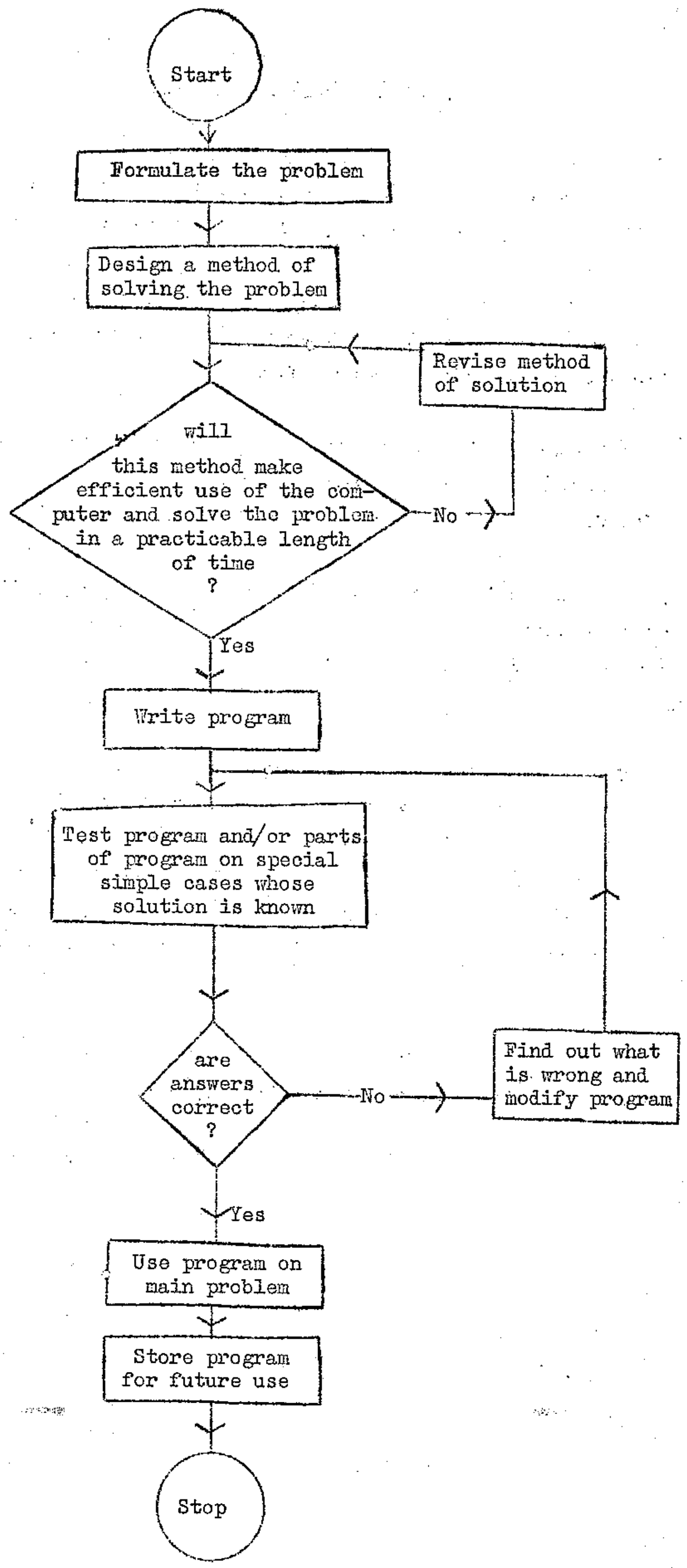
(b) Write a program describing the method already chosen.

Although this book is mostly devoted to describing process (b), it must be emphasised that, in any moderately large problem, it is process (a) which contributes most to the success or failure of a project.

Two general suggestions can be made about this planning stage. Firstly it often pays to draw a 'flow diagram' to help plan the logical connections between different parts of the program. The reader will find many examples of flow diagrams in the subsequent pages. Secondly, considerable effort and money can often be saved by seeking, at the earliest possible stage, the advice of someone who has successfully completed a similar project.

Figure 1 uses the formalism of a flow diagram to indicate the steps involved in using a computer to solve a problem.

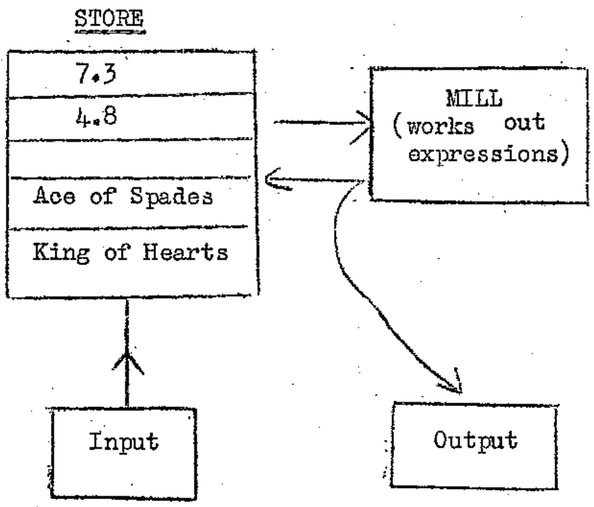
Fig. 1


Start
Formulate the problem
Design a method of solving the problem
Revise method of solution
will this method make efficient use of the computer and solve the problem in a practicable length of time ?
No
Yes
Write program
Test program and/or parts of program on special simple cases whose solution is known
are answers correct ?
No
Find out what is wrong and modify program
Yes
Use program on main problem
Store program for future use
Stop

THE COMPUTER

The basic operation of the computer is most easily understood from the following simplified (and partly fictitious) diagram:-

Fig. 2



The STORE consists of a large number of locations in which information can be deposited. Depending upon the way in which the machine is being used, this information may be thought of as numbers, values of playing cards, letters etc. Some of the store also contains instructions which tell the computer what to do next.

The MILL is a place into which the machine copies pieces of information from the store and works out expressions depending upon this information.

e.g. (1) copy the first two numbers from the store and multiply them.

(2) copy the two cards in locations 4 and 5, and find the higher-ranking.

When an expression has been worked out, it can either be printed out as an answer, or replaced in the store for use later.

Moving information in or out of a location in the store is in some ways similar to the operation of a tape recorder. When withdrawing information ('reading'), we take a copy of the contents of the location. The original information is still there, and can be used again as often as required. When putting information in ('writing') the previous contents of that location are destroyed.

Warning : If we read the contents of a location before putting anything in, we are in danger of obtaining whatever was left behind at the end of the previous program.

INPUT

When we wish to use the computer, we normally need to feed in two 'documents'
(1) Program
(2) Data

The difference between the two is shown by the two examples below:-

Program	Data
Method for solving a set of equations	Set of equations
Method for sorting words into dictionary order	List of words

Most of the program consists of a series of instructions telling the computer to carry out various operations. These are kept in the store in a code or 'language' which is not readily comprehensible to the programmer. It is possible, but tedious, to write programs in this language (in the early days of computers, nothing else was available). Nowadays we can write in a more convenient language, Atlas Autocode for example, and the computer is supplied with a COMPILER which translates the program into its own language.

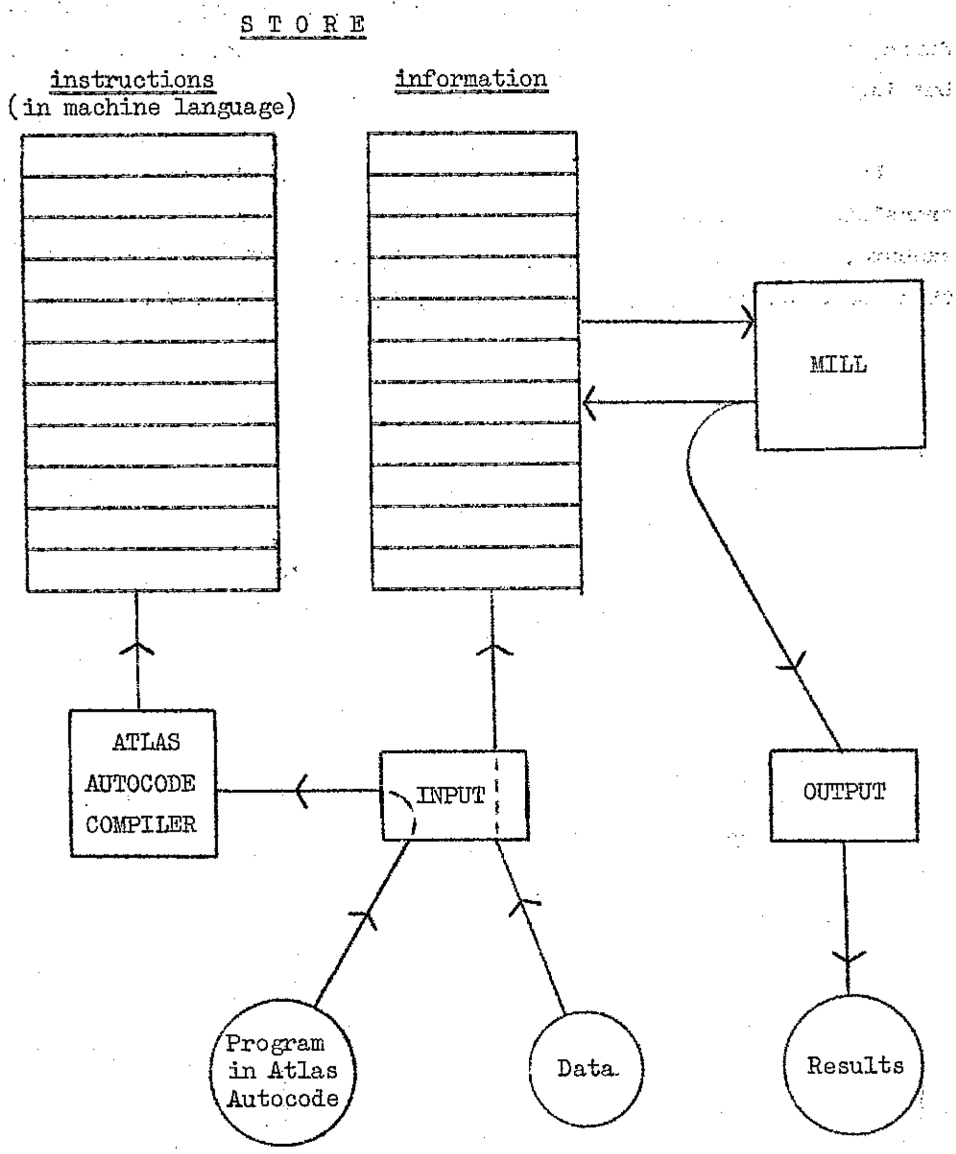
In the first place the program, and often the data as well, will be written down with pencil and paper. After careful checking, this will be converted into suitable form (normally punched paper tape or punched cards) for feeding to an INPUT device.

OUTPUT

The results of the calculation will come out via an OUTPUT device which either prints out answers directly, or produces punched paper tape or cards for subsequent printing. A device for printing out answers directly is known as a LINE PRINTER.

We can now give an improved version of Fig. 2:-

Fig. 3



The sequence of events should be:-

(1) Read in Program.

(2) Compile (i.e. translate) into machine instructions.

(3) Execute the compiled program which will contain instructions to

 (a) Read in Data

 (b) Carry out Calculation/Processing

 (c) Print out Results

However if any violations of the rules of the language are detected during the compiling stage, no attempt is made to execute the program, but instead a list of faults is printed out.

Even after execution of the program has started, some part of the translated program may turn out to be impossible for the machine to execute. For example, it cannot divide by zero. The execution will then cease and an appropriate fault signal will be printed.

ORDER OF PRESENTATION TO COMPUTER

In a small job, the preliminary information (Job Heading), program and data are usually all supplied to the computer on one piece of tape ordered as follows:-

```
*** A                             )  Job Heading giving title of program
JOB                               )  and stating which compiler is to
BLOGGS' FIRST PROGRAM             )  be used to translate the program
COMPILER AA                       )  following.  (AA=Atlas Autocode)


begin                             )
.....                             )
.....                             )
.....                             )  Program
.....                             )
.....                             )
end of program                    )


.....                             )
.....                             )
.....                             )  Data
.....                             )
.....                             )


*** Z                             )  Marks end of tape
```

NOTES

(1) Programs written in Atlas Autocode can at present be run on either an Atlas or a KDF9 computer. If using an Atlas, we have the choice of two compilers, both written at Manchester University

(a) COMPILER AA

(b) COMPILER AB

The latter is a faster but somewhat restricted version of AA. The Atlas Autocode compiler for KDF9 has been written at Edinburgh University.

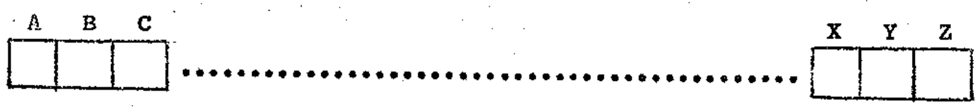
Except where specially indicated, this book describes how to write programs equally acceptable to all three compilers. Precise specifications of each compiler can be obtained from the approprate Computer Unit.

(2) The example of a Job Heading given above is the minimum required. New programmers should consult the Computer Unit of their own University to discover what extra details need be given in any particular case.

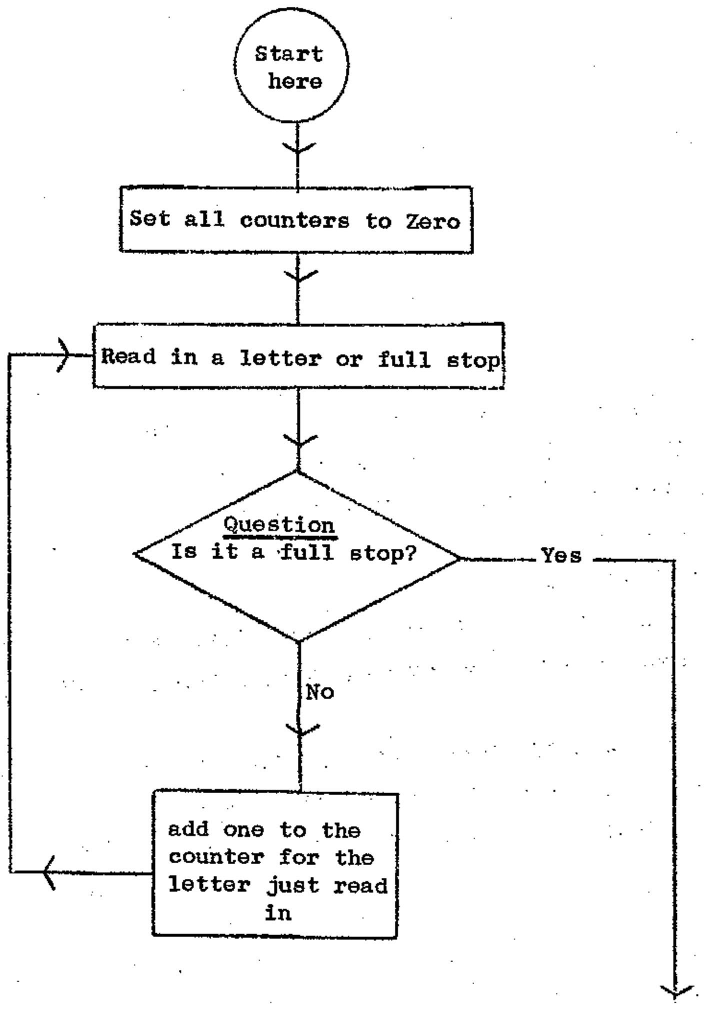
ANALYSIS OF A VERY SIMPLE PROBLEM

Suppose that we wish to read in a string of letters of the alphabet (in any order) and count how many times each letter occurs. To mark the end of the string we shall use a full stop.

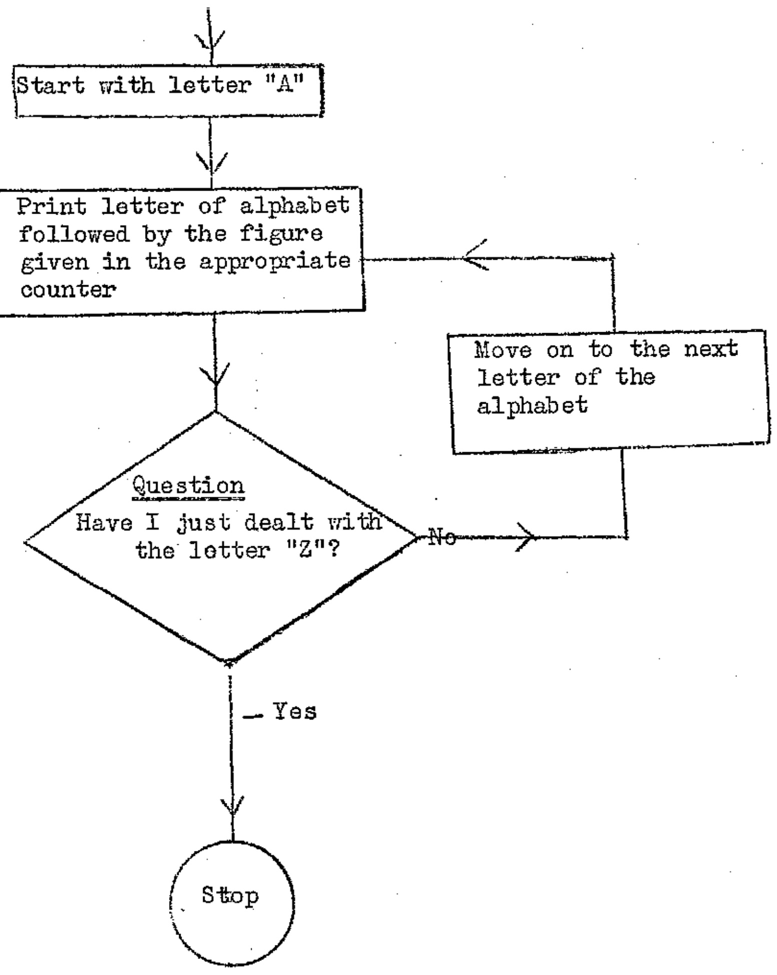
A convenient method of doing this is to set up 26 counters in the machine, one for each letter of the alphabet.



A possible flow diagram is:-


Start here
Set all counters to Zero
Read in a letter or full stop
Question
Is it a full stop?
Yes
No
add one to the counter for the letter just read in

Suppose we now wish to print out the number of times each letter has occurred. The process is:-


Start with letter "A"
Print letter of alphabet followed by the figure given in the appropriate counter
Move on to the next letter of the alphabet
Question
Have I just dealt with the letter "Z"?
No
Yes
Stop

NOTE

An Atlas Autocode program corresponding to these flow diagrams will be given in Chapter 4.

CHAPTER 2 : BASIC NUMERICAL OPERATIONS

Names.

Declarations of variables, including simple arrays.

Basic input, output and assignment instructions.

Separators, Comments.

Blocks.

Labels.

Jump Instructions.

Conditional Instructions.

Example Print the average of a list of numbers.

ATLAS AUTOCODE

The Atlas Autocode language is better equipped for dealing with numbers than with other types of information. For this reason, the basic principles of the language will first be explained in terms of very elementary calculations with numbers. Some equivalent orders for manipulating non - numerical symbols will be given in Chapter 3.

NAMES

Before a number or symbol can be placed in a location of the store, this location must be given a name. A name must start with a letter and consist of

(a) one or more letters (a,b,.....z,A, B, ... Z)

(b) possibly followed by one or more digits (0, 1, 2, ... 9)

(c) possibly followed by one or more primes (', '', ''' etc.)

Examples x, a2'', total 3, SUM', Sum

Notes (1) a2c is not permitted as a letter follows a digit.

(2) The compiler completely disregards all spaces (and underlined spaces) in the program. Spaces may thus be used to improve legibility of program.

LINES

The basic units of a program are

(a) Declarations

(b) Instructions

(c) Separators

These will be described in the following pages. We shall refer to them collectively as 'lines', since they are normally written on distinct lines.** However, two or more 'lines' can be written on the same physical line, provided they are separated by semi-colons.

** What is here called a 'line' is often called a 'source statement' in the literature.

DECLARATIONS

Names are allocated to locations in the store by means of declarations such as:-

Declaration	Meaning
real a	set aside the next unused location, call it a and be prepared to put a 'real' number in it later.
integer b, c3	set aside the next two unused locations, call them b and c3 and be prepared to put integers (whole numbers) in them later.

Note (1) Generally speaking, a name allocated to a location will remain fixed throughout the program. However, the contents will vary whenever new number is placed in it.

(2) The word 'variable' is used to describe locations which have been set aside to contain numbers, either real or integer.

(3) There are three distinctions between real variables and integer variables:-

(a) An integer variable can only contain a whole number. A real variable may contain either an integer or a number such as 73.4827, with up to 11 significant figures.

(b) There are certain purposes for which only integer variables are allowed. (e.g. To give the number of times a group of instructions is to be repeated: repeating 1.7 times would be impossible).

(c) When we do multiplications and additions of integer variables, the machine produces the exact answer. When doing arithmetic on real variables, the answers are 'rounded off' to 11 significant figures.

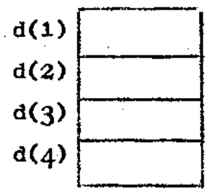
UNDERLINING

Note that the underlining of certain key words (real and integer above, for example) is an integral part of the language. At this stage the reader is advised to accept, as arbitrary rules, that certain words are, and others are not underlined.

DECLARATION OF ARRAYS

We can also declare a whole array of variables, all having the same name, but distinguished from one another by means of a 'suffix' in brackets after it.

real array d(1:4)   set aside 4 locations :-



```
real array e(1:7),f,g (0:4)      set aside (  7 locations for e(1) to e (7)
                                           (
                                           (  5 locations for f(0) to f (4)
                                           (
                                           (  5 locations for g(0) to g (4)
```

Notes (1) Arrays of integer locations are declared in a similar manner by writing integer array ....

(2) In the case of real arrays, it is permissible to omit the word real, simply writing array ....

(3) Note the difference between

```
        real array d(1:4)        which gives four locations
and     real d4                  which gives only one location
```

These four types of declaration are normally written on separate lines, but may instead be separated by a semi-colon.

```
either    real a,b,x3'
          integer array y (1:20)

or        real a,b,x3'  ;  integer array y (1:20)
```

Further types of declaration, allocating names to functions, routines, switches, and multi-suffix arrays will be described later. Declarations are preparatory in nature, and should be contrasted with 'instructions' which, when executed, bring about the transfer of information to locations already prepared.

Note : A name cannot be used simultaneously for two different purposes. For example:-

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

would cause a fault signal.

INSTRUCTIONS

Some simple types are given below. They are written on separate lines or separated by semi-colons in the same manner as declarations.

Input Instructions (also see p. 85)	Meaning
read (a)	read in the next number in the data and put it in the location whose name is a.
read (b, c3, d(4))	read in the next 3 numbers in the data and put them in b, c3, and d(4)

Assignment Instructions (also see p. 42)

These look like mathematical equations but the meaning is quite different.

Instruction	Meaning
a = b + c	work out the expression on the right (i.e. contents of b plus contents of c) and then put it in the location given on the left (i.e. a) Thus

a	7.32	would	a	13.0
b	10.0	become	b	10.0
c	3.0		c	3.0

a = 2a + 1	copy the contents of a, double it, add 1 and place the answer back in a.

Notes (1) b + c = a is not permitted since b + c is not the name of a variable.

(2) a = b is quite different from b = a.

(3) the use of more complicated expressions on the right will be explained later.

Output Instructions (Also see p. 86)

print (x, 3, 1) print (2x + y + 7, 3, 1)	work out in the Mill the value of the first expression in the brackets (i.e. x or 2x + y + 7) and print the value of the expression with 3 figures before the decimal point and one after. (The figures 3 and 1 can, of course, be varied).
newline	output printer is to go to the start of a fresh line, moving the paper up accordingly.
newlines (2)	equivalent to:- newline ; newline
space	output printer is to leave one blank space (printing takes place from left to right across the page)
spaces (3)	equivalent to:- space; space; space
caption MORRIS1100	output printer is to print out the set of characters MORRIS1100.

Note The instruction *caption* ..... is chiefly used to obtain headings and explanatory notes in the output. These notes may be required to include spaces, newlines, etc.

A special method is provided for outputting the symbols space, newline and semi-colon with a caption, since spaces are ignored by the computer and a semi-colon or newline character marks the end of the *caption* 'line':-

s⃒ or s̸	represents a space
n⃒ or n̸	represents a newline
;⃒ or ;̸	represents a semi-colon.

Either

(a) *caption* n⃒ MORRIS s⃒s⃒ 1100

or (b) newline ; *caption* MORRIS ; spaces (2) ; *caption* 1100

will produce an output (at the beginning of a newline):-

```
MORRIS  1100
```

SEPARATORS

A few lines, neither declarations nor instructions, have to be written into a program, chiefly to mark the begining and end of blocks and routines. Examples are begin end and end of program, described on the next page.

COMMENTS

Any line starting with comment is disregarded by the compiler. This permits the insertion of explanatory notes, which must not contain a semi-colon, for the benefit of the reader. For example:-

```
read (n)
comment n is the number of cases to be solved.
```

For brevity, a single vertical bar can replace comment. For example:-

```
read (n)
| n is the number of cases to be solved.
```

A third equivalent method of writing the above is:-

```
read (n) ; | n is the number of cases to be solved.
```

BLOCKS

A program is normally split up into a number of blocks. In general a block consists of

```
begin
......      )
            )
......      )
            )
......      )     declarations
            )
......      )
            )
......      )


......      )
            )
......      )
            )     instructions
......      )
            )
......      )
end
```

At the end of the last block of a program, end is replaced by end of program.

Example

```
begin
real array a(1:3)
real b

read (a(1),a(2),a(3))
b = a(1)+a(2)+a(3)
print (b,2,3)
end of program
```

This causes the machine to read in three numbers, add them and print out the total.

Note The machine automatically terminates the calculation on reaching end of program. If it is required to stop the calculation at any other point, the instruction stop is used.

LABELS

Any 'line' in the program can be labelled by writing on the left a positive integer, followed by a colon. The label has no effect other than to give the line a reference number.

EXAMPLE

```
     i=i+j
10:  read (x)
     x=x+i
```

JUMP INSTRUCTIONS

Normally, instructions are obeyed in the order in which they are written. In order to make the machine jump, either forwards or backwards, to a labelled line in the program we can use a jump instruction written, for example:-

instruction	meaning
-> 10	the next line to be obeyed is the one labelled 10:

Notes (1) By making the machine jump back to an earlier part of the program we can make it go round a loop of instructions many times.

(2) Although jumps can be either forwards or backwards, we are not allowed to jump from one block to another.

(3) Jump instructions are frequently made conditional, as described in the next section.

CONDITIONAL INSTRUCTIONS

Assignment and jump instructions may be made subject to a condition.

Examples	Meaning
a = b + c if x = 0	Carry out the instruction if
-> 27 unless a > b + 2	(or unless) the condition is
stop if n>100	satisfied. Otherwise skip and
	pass on to the next instruction.

If preferred, instructions may be written with the condition first, followed by then:

```
if x = 0 then a = b + c
unless a > b + 2 then -> 27
if  n > 100 then stop
```

Note (1) Note the different uses of '=' in the first example. In x = 0 it has its normal mathematical significance. In a = b + c it means an assignment.

(2) In the condition we may use any of the relations = ≠ > ≥ < ≤

MORE COMPLICATED CONDITIONS

These may be formed

(1) with a two-sided condition **

e.g. if 0 < x < 1 + y then ......

(2) by writing several conditions separated by and with the obvious significance.

e.g. if x>0 and y = 0 and z ≠ 2 then ....

(3) by a similar use of a succession of or's

e.g. if x>0 or y = 0 or z ≠ 2 then ....

(4) by combining (2) and (3) provided and's or or's are separated by brackets.

e.g. if (x>0 or y = 0) and z ≠ 2 then ....

** This form of condition is not accepted by the Manchester Compiler AB.

EXAMPLE OF A SIMPLE PROGRAM

Suppose we want to read in a list of positive numbers and print out their average. Suppose we do not know in advance how many there will be. In order to inform the computer when we have come to the end of the list, we terminate it with the number -1.

We shall need the following variables:-

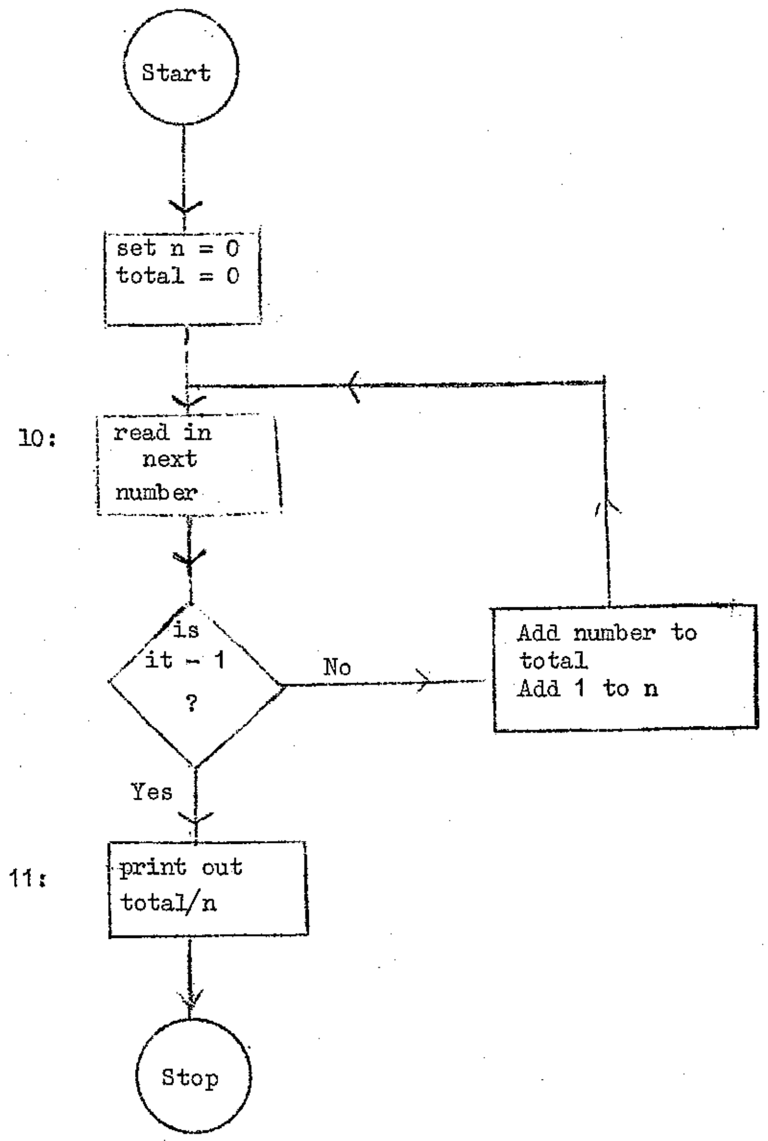
(1) a place in which to put the numbers as they are read in.
(2) a running total.
(3) a count (integer n, say) of how many numbers have been read in.

Note that (2) and (3) must be set to zero before starting.

A possible flow diagram is given on the next page:-

PROGRAM FOR PRINTING AVERAGE

A possible flow diagram is:



and a program to implement this is:-

```
       begin
       integer n
       real total, x
       n = 0;  total = 0
10:    read (x)
       -> 11 if x = -1
       total = total + x
       n = n + 1
       -> 10
11:    newline
       caption Average $ =
       print (total/n,3,5)
       end of program
```

CHAPTER 3 : BASIC SYMBOL OPERATIONS

(NOTE This chapter may be omitted by those solely interested in numerical calculations).

Input of symbols.

Assignment of symbols.

Conditions using symbols.

Output of symbols.

Relationship between symbols and integers.

Example Program to count symbols.

MANIPULATION OF SYMBOLS

INTEGER variables can not only be used to store integer NUMBERS as described in the last chapter, but can also hold SYMBOLS. Possible symbols include

(a) The letters of the alphabet (both upper and lower case).
(b) The numerical digits 0 to 9 (see note 1 below).
(c) ( ) [ ] . , : ; ' ?
(d) + - * / ↑ | = ≠ > ≥ < ≤ α π
(e) space and newline.

Notes
(1) The symbol 9 is NOT the same as the number 9.

(2) Symbols can be stored in integer variables, including elements of integer arrays.

INPUT OF SYMBOLS (See also p. 87)

Input Instruction	Meaning
read symbol (a)	Read the next symbol on the data tape and place it in location a. Move the data tape on by one symbol. Note (1) The instruction read symbol can only read one symbol at a time (unlike the instruction read which may read several numbers). Note (2) a MUST be an integer variable or an element of an integer array.

Important Note When reading numerical data, spaces and newlines simply mark the end of a number. However, both spaces and newlines count as symbols and will be read in by the routine read symbol.

ASSIGNMENT OF SYMBOLS

Instructions to assign symbols to integer variables are written in a form very similar to those which assign numbers, but the symbol concerned is written between a pair of 'quotation marks'. For example:-

```
integer i, j, k
i = '*'
j = 'P'
k = '7'
```

Note that the last two instructions assign the SYMBOLS P and 7 to j and k respectively. On the other hand, the instructions

```
j = P
k = 7
```

assign to j the NUMERICAL value currently stored in the variable named P, and to k the NUMBER 7.

CONDITIONS

Conditions depending upon the equality, inequality, etc. of symbols may be written in a fairly self-evident manner e.g.

```
if i = '*' then stop
-> 9 unless k = '?' or j = 'A'
```

SYMBOLS FOR SPACE, NEWLINE

It was explained on page 19 why it is necessary to write spaces, newlines, etc. in a special manner within a caption. The same problem arises when we wish to write these SYMBOLS in assignment instructions, conditions, etc. and the same special conventions are used. For example,

```
i = '$'
```

assigns the symbol 'space' to the variable i.

A simple method of reading the next 'useful' symbol in data (i.e. disregarding spaces and newlines) would be:-

```
    integer i
1:  read symbol (i)
    -> 1 if i = '$' or i = 'n⃒'
    ..............
    ..............
```

OUTPUT OF SYMBOLS

The instructions

```
(   caption .............   )
(   space                   )
(   spaces   (  )           )
(   newline                 )
(   newlines   (  )         )
```

are available for output of symbols, as described on page 19. There is also an instruction print symbol:-

Instruction	Meaning
print symbol ('*')	print out the symbol *
print symbol (i)	print out the symbol currently held in the integer i

Note (1) The first instruction above could equally well be written:-

```
caption *
```

(2) print symbol (i) is useful when we do not know in advance what symbol is going to be stored in the integer i.

RELATIONSHIP BETWEEN SYMBOLS AND INTEGERS

Symbols are stored in integer variables, and in fact each symbol has a numerical value to which it corresponds. However, since this correspondence may vary between compilers, programmers are advised not to make use of this fact. On the other hand, all the compilers are arranged so that 'A' has a value one less than 'B', which is one less than 'C', etc., thus preserving the natural dictionary ordering. The same is true of 'a', 'b',..... etc. and of '0', '1'..... etc.

Example

To test whether the next symbol on the data tape is a lower case letter in the first half of the alphabet we could write:-

```
read symbol (i)
if 'a' ≤ i ≤ 'm' then ..............
```

EXAMPLE OF A PROGRAM TO COUNT SYMBOLS

Suppose that we wish to read in a sequence of symbols as far as the first full stop, and print out the percentage which are capital E's. The program required is almost identical to that used on page 25 to print the average of a list of numbers.

```
            begin ; comment to give percentage occurrence of letter E
            integer n, Number of Es, x
            n=0 ; Number of Es = 0
10:         read symbol(x)
            ->11 if x = '.'
            if x = 'E' then Number of Es = Number of Es + 1
            n = n +1
            -> 10
11:         newline
--          caption percentage $ of $ E's $ =
            print(100*Number of Es/n,2,1)
            end of program
```

For comparison purposes, the program from page 25 is reprinted below:-

```
            begin ;  comment to give average of a list of numbers
            integer n
            real total, x
            n = 0 ;  total = 0
10:         read (x)
            -> 11 if x = -1
            total = total + x
            n = n + 1
            -> 10
11:         newline
--          caption Average $ =
            print (total/n,3,5)
            end of program
```

CHAPTER 4 : EXPRESSIONS, CYCLES, FURTHER ARRAYS.

ARITHMETIC EXPRESSIONS

There are many places in a program where we have to write an arithmetic expression (e.g. on the right of an assignment instruction or in a print instruction). The simplest form of expression is a single variable or numerical constant. More generally, an expression consists of variables, constants and functions, connected together by mathematical symbols. The method of writing constants is given below; variables have already been described - (pages 16 - 18) and functions will be deferred until page 40.

constant	meaning	note
37) 0.25) 2.374)	obvious	0.25 and .25 are equally valid.
1α3	1000(i.e. 1×10^3)	(i) This is called the 'floating point' form for a constant.
1.732α-2	0.01732 (i.e. 1.732×10^{-2})	(ii)The number after α must be an integer constant.
π	3.14159....	
½	0.5	½ is one symbol. Other fractions must be written as quotients(i.e. 1/3)

Mathematical Symbol	Meaning
+	addition
−	subtraction
*	multiplication
/	division
‡	raise to a power (a‡3 means a^3)
^{2}	squaring
|	used in pairs as modulus signs.

Notes

(1) In normal mathematical notation we often omit the multiplication sign (e.g. ab for a*b). In Atlas Autocode we write the * sign, otherwise the compiler will look for a variable with the name 'ab'. The * can be omitted where a constant is followed by a variable (e.g. 3.5*y and 3.5y are equivalent)

(2) a^2 and a‡2 are equivalent. All other powers must be written with ‡.

(3) In manuscript, the symbol ‡ is usually written ↑.

PRECEDENCE OF OPERATORS (+ - * / ↑)

There may be some uncertainty about the meaning of an expression such as a*b+c. Do we carry out the multiplication first, giving (a*b)+c, or the addition first giving a*(b+c) ?

In the absence of brackets, we have the rule that, of two adjacent operators (like * and + above), the operator of higher precedence in the table below is to be carried out first.

(1)	↑	(highest precedence)
(2)	* or /	
(3)	+ or -	(equal lowest precedence)

Where two adjacent operators are of equal precedence by the above table, the one appearing to the left (in the expression to be evaluated) is carried out first.

<u>Notes</u> (1) The multiplication operator between a constant and a variable has the same precedence whether written explicitly or 'implied' (see note 1 on previous page)

(2) The symbol ^{2} is treated as equivalent to the pair of symbols ↑ 2 and precedence is given accordingly.

(3) If we wish to over-ride the above rules, we must use brackets as in normal mathematical notation.

(4) When in doubt it is wise to insert brackets for safety and clarity.

(5) The 'left-hand precedence' between + and - agrees with normal usage.

e.g. By a-b+c we mean (a-b)+c and not a-(b+c)

Examples	Meaning
a/b*c	$\frac{a}{b} \times c$
a/(b*c)	$\frac{a}{bc}$
a↑b*c	$a^b \times c$
a↑(b*c)	a^{bc}

<u>Note</u> The first two examples show that it is necessary to bracket denominators containing more than one term. A common mistake is to write a/2b when a/(2b) is intended.

FUNCTIONS

In addition to variables and constants, functions may also be included within expressions. The basic functions available are:-

real function	meaning	note
sin(x))	as in	
cos(x))	elementary	x in radians
tan(x))	trigonometry	
sq rt (x)	$+\sqrt{x}$	
log (x)	logarithm of x	to base e
exp (x)	e^{x}	
mod(x)	modulus of x (i.e. Absolute value of x)	mod(-3.7)=3.7;mod(3.7)=3.7 Can be written $\|x\|$, but see note below.
arctan (x,y)	$\tan^{-1}(y/x)$	In radians. Value is in 1st or 4th quadrant if x>0 2nd or 3rd quadrant if x<0
radius (x,y)	$+\sqrt{x^2+y^2}$	
frac pt (x)	fractional part of x	frac pt(3.73)=0.73 frac pt (-3.73)=0.27

integer function	meaning	note
int(x)	nearest integer to x	int (3.73)=4
int pt (x)	integral part of x	int pt (3.73)=3 int pt (-3.73)=-4
parity (n)	+1 if n is even -1 if n is odd	n must be an integer variable.

Notes (1) The first group of functions (down to frac pt) all produce a number of type real, which can only be assigned to a real variable. The last three produce a number of type integer.

(2) In particular, note that the function mod(x) produces a number of type real, irrespective of whether x is of type real or integer. On the other hand, a pair of modulus signs will give the same numerical value as the modulus function, without altering the type. (i.e. integer remains integer). Hence, if n is an integer,

n = |n| is valid

n = mod(n) will be faulted.

(3) The above functions are all understood by the compiler before the program is read in. The method used to define additional functions, if required, will be given later (page. 70)

(4) As the names sin, log etc. are already in use, they should not be used by the programmer in any of his declarations.

INTEGER AND REAL EXPRESSIONS

The differences between integer expressions and real expressions lie not so much in the values of the expressions as in how they are constructed and used.

(1) Any expression consisting entirely of integer variables, integer constants and integer functions is called an INTEGER EXPRESSION. Any other expression is called a REAL EXPRESSION.

(2) We shall meet a number of places where an integer expression is required. In these cases, a real expression is not allowed, not even one whose value may actually work out to be an integer. On the other hand, wherever a real expression is expected, an integer expression will do instead.

Integer Expressions

The main cases where an integer expression is compulsary are:-

(1) When assigning a value to an integer variable.

(2) As the suffix of an array element.

(3) As the power to which a number is to be raised. (Raising to a power is done by repeated multiplication).

(4) In cycle instructions (page 43)

Examples Suppose we have declared

```
integer i
real x,y
real array d(0:10)
```

Example of (1) Although x=i is permitted, i=x will cause a fault signal because x is a real expression.

Example of (2) If we have previously set i=3; x=3 then d(i*i) refers to d(9) but d(i*x) is illegal.

Example of (3) x↑3 and x↑(i+1) are legal expressions but x↑y is not.

Symbols as Integer Expressions

A symbol written between 'quotation marks' is a possible form of integer expression, but should only be used with caution. A simple and safe example of this will be found on Page 47.

FURTHER ASSIGNMENT INSTRUCTIONS

The general form of an assignment is either

(1) assign the value of an INTEGER expression to an INTEGER variable or

(2) assign the value of a REAL or INTEGER expression to a REAL variable.

Examples Suppose we have declared real a,b,c,x
integer i,j,k

then possible instructions are:-

```
x = (-b + sq rt (b*b - 4a*c))/(2a)
i = int(j/k) + j*j
a = log (1 + cos (2π x)) + 3.74b
x = i
```

Notes (1) As already explained i = x will cause a fault signal because x is real. If required, we can write: i = int(x)

(2) On the Atlas versions of the language we can, without a fault signal, assign to an integer variable any integer expression. The responsibililty for ensuring that the expression will work out to be an integer, lies with the programmer. (division or raising to a negative power are possible causes of non-integer results). See the second example above.

(3) When using KDF9 there is the further restriction that, whenever an integer expression is compulsary, each stage in the evaluation of the expression must yield an integer result. Referring to the rules of precedence for operators, we see that, with the previous declarations,

j = i*(i+1)/2 will always work but that
j = (i+1)/2*i , while having the same result as the previous line when (i+1) is even, will be faulted if (i+1) is odd.

(4) It is possible to use expressions inside larger expressions; in particular we can have a function of a function as in the third example.

CYCLES

Suppose that we wish to carry out a certain part of a program 10 times with an integer i taking the values 1,3,5.........,19 on successive occasions.

Clearly it is necessary to indicate

(1) the sequence of values which the integer is to assume, and
(2) the beginning and end of that section of program which is to be repeated.

We achieve this by writing:-

```
        cycle i = 1,2,19
      ( orders making   )
      ( up the section  )
      ( of program      )
      ( to be repeated  )
        repeat
        ......
```

NOTES

(1) The sequence of values i is to assume is indicated by writing '<u>cycle</u> i = ' followed by 3 integer expressions giving the initial value, the increment, and the final value.

(2) The control variable i must have been previously declared to be an integer or an element of an integer array.

(3) The separator <u>repeat</u> is used to indicate the end of the section of program to be repeated.

(4) The expressions for the initial and final values and the increment are evaluated on first reaching the <u>cycle</u>. The number of times the cycle is to be executed is

1 + (final value - initial value)/increment,

and a fault is signalled if this is not a positive integer.

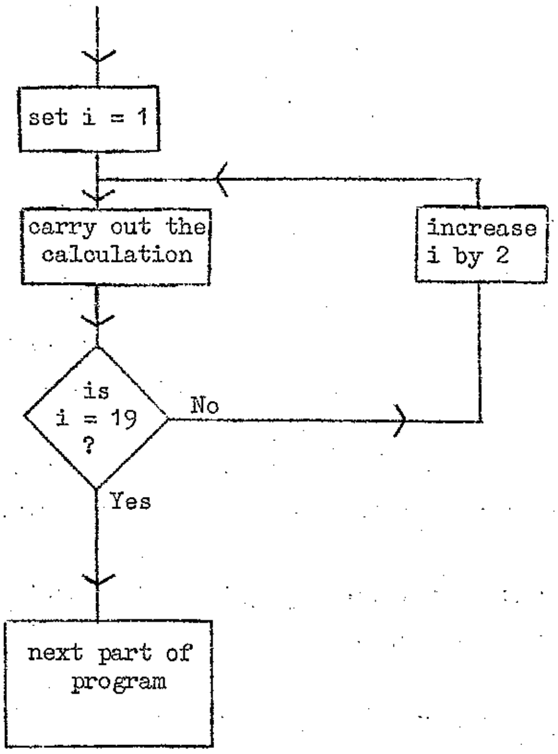
Instead of using cycle and repeat in the above example the same result could have been obtained by using jump instructions. For example:-

```
            i = 1

   1: (     orders making    )
      (     up section       )
      (     of program       )
      (     to be repeated   )

            -> 2 if i = 19
            i = i + 2
            -> 1
   2:       .......
```

The same flow diagram serves for both methods of writing this program:-



NESTING OF CYCLES

Cycles may be nested to any depth. Each cycle must have exactly one associated repeat.

Example

```
cycle i = 1,1,4
read (A(i))
newline
  cycle j = 1,1,i
  print (A(i)↑j,2,0)
  spaces (2)
  repeat ; comment this refers to cycle j =
repeat   ; comment this refers to cycle i =
```

Supplied with the data

```
0   1   2   3
```

the output would be

```
0
1    1
2    4    8
3    9    27   81
```

NOTE

Within cycles, either single or nested, the control variable(s) may be used for two distinct purposes:-

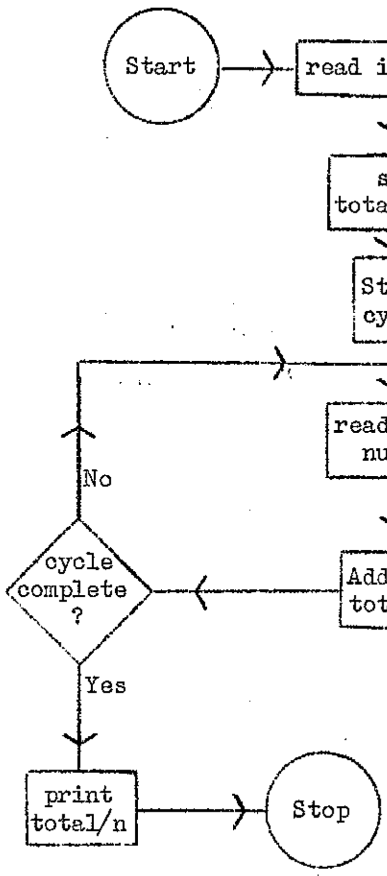
(a) to count the number of times the cycle has been executed, and

(b) to vary systematically quantities occurring in arithemetic expressions. (e.g. the integer i in the above example both counts the number of times the outer cycle is executed, and also enables us to operate on different array elements on each occasion).

Example

Use a cycle to simplify the program on pages 24-25 for giving the average of a list of numbers.

Instead of using the special number -1 to terminate the data, we head the list with an integer indicating how many numbers there are to follow.



and the program is:-

```
begin
integer i,n
real total,x
read(n)
total=0

cycle i=1,1,n
read(x)
total=total + x
repeat

caption $ Average $ =
print (total/n,3,5)
end of program
```

EXAMPLE OF A CYCLE TO COUNT SYMBOLS

We can now program the flow diagram given at the end of the introductory Chapter 1. The following program will only count capital letters, and will disregard all other symbols except the terminating full stop.

```
   begin
   integer array Counter ('A':'Z'); comment 'A' and 'Z' are integer constants
   integer i, j
   cycle i = 'A', 1,'Z'
   Counter (i) = 0
   repeat

1: read symbol (j)
   -> 2 if j = '.'
   Counter(j) = Counter(j) + 1  if 'A'≤ j ≤ 'Z'; | disregard all other symbols
   -> 1

2: cycle i = 'A',1,'Z'
   newline
   print symbol (i)
   print (Counter (i),4,0)
   repeat

   end of program
```

SWITCH LABELS

It is sometimes required to jump to one of several points of a program, depending upon the value of some (integer) expression. One method is given below on the left, with the equivalent and more compact use of a switch given on the right:-

```
                                    switch A(0:3)
                                    ......
21: read (i)                  A(3): read (i)

    -> 22 if i = 0                  -> A(i)
    -> 21 if i = 3
    -> 23 if i = 2

22: a = b + c                 A(0): a = b + c
23: a = 2a                    A(2): a = 2a
```

NOTES

(1) As with ordinary labels, jumps can be either forwards or backwards, but cannot go outside the current block.

(2) Switch declarations appear among the other declarations at the head of the block, and hence the name is declared before being used for either a label or a jump instruction.

(3) The name of the switch must not be used for any other purpose at the same level.

(4) It is not necessary to use all the labels in the range declared (note A(1) missing above), but a fault would be signalled if i had the value 1 on reaching the instruction -> A(i).

(5) The bounds given when declaring a switch must be integer constants, although the jump instruction can use integer expressions such as -> A(i+2j).

(6) The symbol -> can only be followed by a constant (ordinary label) or an element of a switch.

MULTI-SUFFIX ARRAYS

On page 17, we introduced declarations of arrays with one suffix. In a similar manner we can declare arrays with two or more suffices.

declaration	meaning
real array A(1:2, 1:3)	set aside 6 locations for 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)
integer array A(1:2, 1:3)	as above, but giving integer variables.

Arrays with more than two suffices may be declared in a similar fashion. For example:-

```
real array B(0:4, 0:4, 0:4)
integer array C(1:5, 1:5, 1:20, 1:30)
```

Example

Suppose we wish to form a table giving the number of successes in 'A' level Mathematics, Physics, Latin and French, sub-divided into boys and girls. Let us store the numbers in integer variables A(i,j) as follows:-

	Maths	Physics	Latin	French
Boys	A(1,1)	A(1,2)	A(1,3)	A(1,4)
Girls	A(2,1)	A(2,2)	A(2,3)	A(2,4)

Here the first suffix gives the sex and the second the subject.

To set all the first row to zero initially, we could write:

```
cycle j = 1,1,4
A(1,j) = 0
repeat
```

and then for the second row

```
cycle j = 1,1,4
A(2,j) = 0
repeat
```

It is easier to combine these two processes by means of a cycle within a cycle

```
cycle  i = 1,1,2
   cycle j = 1,1,4
   A(i,j) = 0
   repeat
repeat
```

The same method will be used to print out the results in a rectangular table.

Data Suppose the data is supplied as follows:-

(1) An integer giving the number of results to analyse.

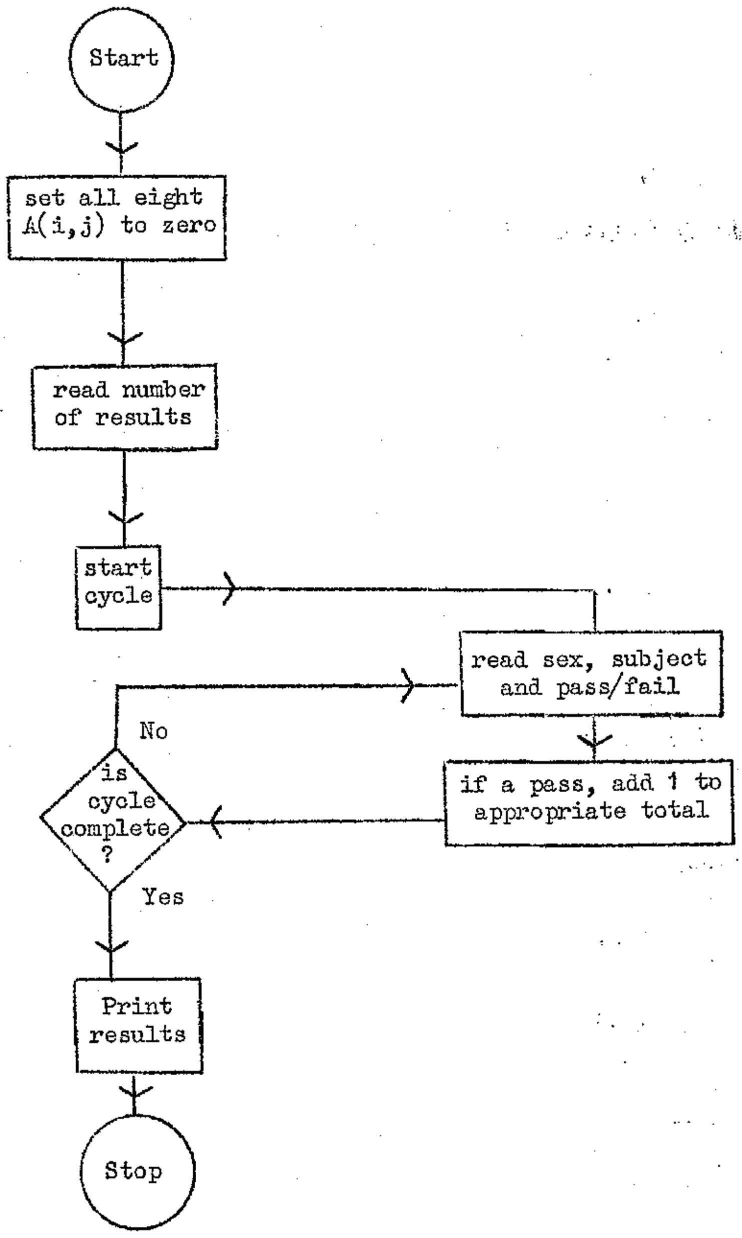
(2) Groups of three integers in which

the first indicates sex	(1 for boy, 2 for girl)
the second indicates subject	(1,2,3,4 as before)
the third indicates success	(0 for fail, 1 for pass)

for example:-

data	meaning
999	999 results to follow
1 1 0	A boy has taken Maths and failed.
1 4 1	A boy has taken French and passed.
2 3 1	A girl has taken Latin and passed.
etc.	

A possible flow diagram and program are given on the following pages.



Start
set all eight A(i,j) to zero
read number of results
start cycle
read sex, subject and pass/fail
if a pass, add 1 to appropriate total
is cycle complete ?
No
Yes
Print results
Stop

```
begin
integer i,j,k,l,n
integer array A(1:2,  1:4)

cycle i = 1,1,2
    cycle j = 1,1,4
    A(i,j) = 0
    repeat
repeat

read (n)

cycle i = 1,1,n
read (i,j,k,)
if k = 1 then A(i,j) = A(i,j) + 1
repeat

newline

cycle i = 1,1,2
    cycle j = 1,1,4
    Print (A(i,j), 3,0)
    spaces (5)
    repo t
newline
repeat

end of program
```

Notes: (1) The inner cycles have been indented on the pages for clarity. This is quite permissible as spaces in the program are disregarded by the compiler.

(2) In order to achieve a rectangular layout of results, spaces (5) are put in the inner cycle, and the newline in the outer cycle.

CHAPTER 5 : BLOCK STRUCTURE

Block structure.

Local and Global variables.

Example Ordering of lists of integers.

<u>Block Structure</u>

The basic layout of a block was described on page 21. It has the form of <u>begin</u> followed by the appropriate declarations, then by the instructions, and terminated by <u>end</u>. It is permissable to nest blocks as in the following diagram

```
begin                                       )
.....                           )           )
.....                           ) declarations )
.....                           )           )
                                            )
                                            )
                                            )
.....                           )           )
.....                           )           )
.....                           )           )
                                )           )  outer block
                                )           )
                                )           )
  begin          )              )           )
  .....          )              ) instructions )
  .....          ) inner block  )           )
  .....          )              )           )
  end            )              )           )
                                )           )
.....                           )           )
.....                           )           )
.....                           )           )
end                                         )
```

<u>Note</u> (1) It is sometimes convenient to regard a whole block as one compound instruction. With this view of the inner block, the outer block has the structure given on page 21.

(2) Blocks may be nested within one another to any depth.

(3) Blocks may not be made conditional.

Among the reasons for nesting blocks of program one inside another are the following.

(a) It may be required to declare an array whose suffix bounds are not known until some stage in the execution of the program. This is illustrated in the following example where the first number read indicates how many more are to follow

```
begin
integer n
read (n)
     begin
     real array A(1:n)
     cycle i = 1,1,n
     read (A(i))
     repeat
     .....
     end
.....
end
```

(b) The declarations made at the head of a block are cancelled on reaching the end which terminates the block. Thus if a program requires large amounts of working space for each one of several distinct jobs, then storage space can be economised if each job is written as a distinct block. For example:-

```
begin
.....
.....
    begin
    real array A(1:10000)
    ...........
    end
.....
.....
    begin
    real array B(1:20,1:500)
    .............
    end
......
.....
end
```

Note Storage limitations are particularly important on K.D.F.9 as none of those supplied to the Universities can hold more than 16000 numbers in the main store. The appropriate operating manual should be consulted for further details.

(c) In developing a complicated program it is often a great advantage that each sub-block can be developed seperately. A program is generally much clearer if its sub-blocks are related to the blocks of its flow diagram. Another and closely related method of breaking a program down into sub-units is by the use of routines: see pages 63-69.

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 the term local variable is used when referring to variables declared in this block, and the term global variables when referring to variables declared in any exterior block. These points are illustrated by the following example.

(i)

```
begin
real A
.......
A = 1
  begin
  real A, B, C
  ............
   B = 1
   C = 4
   A = B+C
   end
 print (A,2,2)
 end
```

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

(ii)

```
begin
real A
.......
A = 1
  begin
  real B,C
  ........
  B = 1
  C = 4
  A = B+C
  end
 print (A,2,2)
 end
```

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

Notes (1) To communicate between blocks, global variables must be used, since local variables are cancelled upon exit from a block.

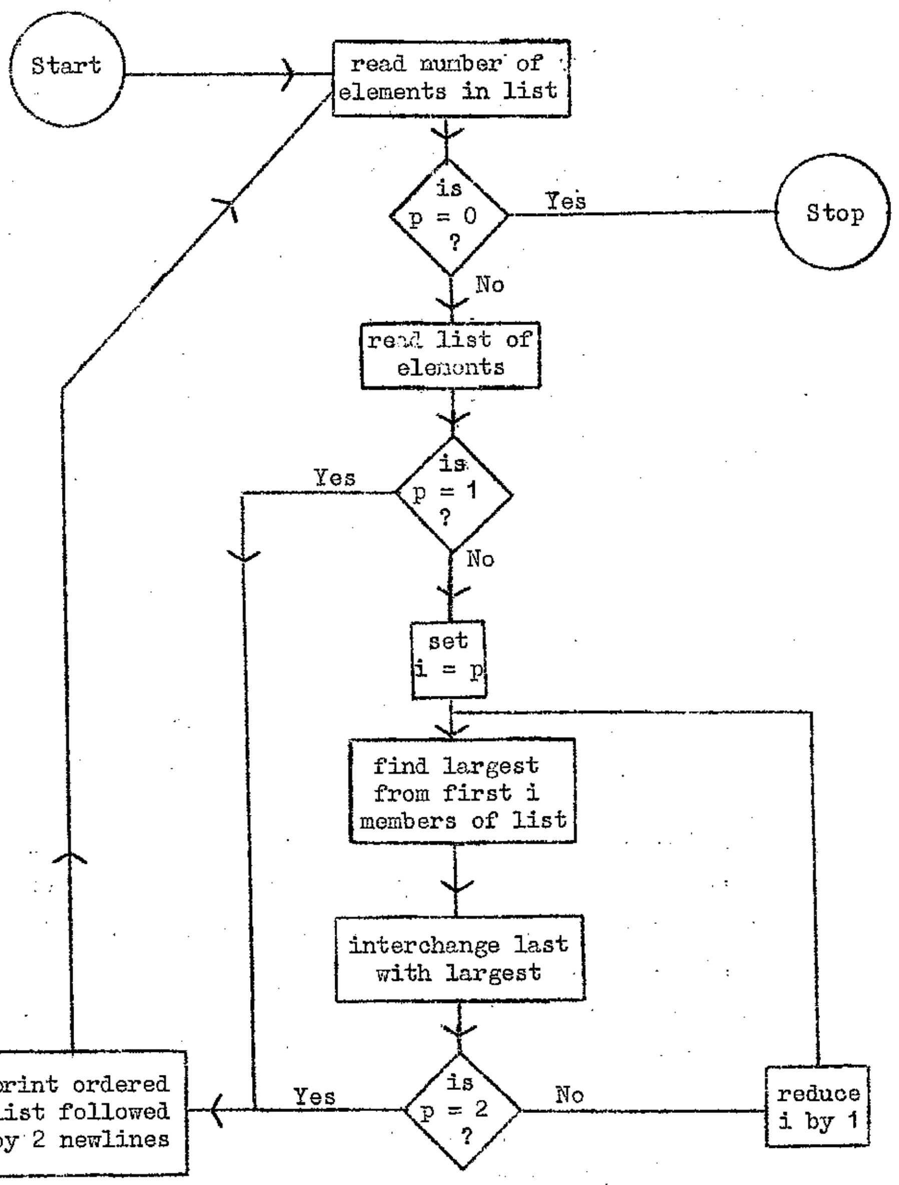
(2) Labels and switch labels, unlike variables, are always local to a block. It is thus impossible to enter a block except through the head of the block (which is just as well as the local declarations are written there). It is impossible to jump from one block to another.

(3) Similarly each repeat must be in the same block as the cycle to which it refers.

EXAMPLE OF A COMPLETE PROGRAM

Read in lists of positive integers and print them out with each list sorted into increasing order of magnitude. Insert 2 blank lines to separate one list from the next.

On input of data, each list will be headed by an integer giving the number of elements in the list. After the last list, a single zero will be fed in, indicating an imaginary list of zero length.


Start
read number of elements in list
is p = 0 ?
Yes
Stop
No
read list of elements
is p = 1 ?
Yes
No
set i = p
find largest from first i members of list
interchange last with largest
is p = 2 ?
Yes
No
reduce i by 1
print ordered list followed by 2 newlines

EXAMPLE OF A PROGRAM

```
   begin
   comment to arrange lists of positive integers in
   comment increasing order of magnitude
   integer p
 1:read(p)
   if p<0 then stop
       begin
       integer i,j,AMAX,jMAX
       integer array A(1:p)
       cycle i=1,1,p
       read(A(i))
       repeat
       -> 3 if p=1
       cycle i=p,-1,2
       AMAX=0
           cycle j= 1,1,i
           if  AMAX ≥ A(j) then -> 2
           AMAX= A(j) ; jMAX=j
         2:   repeat
       A(jMAX)=A(i)
       A(i)=AMAX
       repeat
     3:cycle i=1,1,p
       newline
       print(A(i),5,0)
       repeat
       end
    newline
    newline
    -> 1
    end of program
```

Notes (1) p is declared in the outer block, but can still be used in the inner block where it is a global variable. (Lines 8,9,12,13,22).

(2) The label 1 is in the outer block, so the instruction '-> 1' must also be in the outer block.

(3) The line numbers given on the left are not printed with a normal program, and should not appear on the program sheet, but the compiler does in fact count physical lines in this way and will print out the line number of any fault found in a program. In this connection, note that a physical line may contain more than one declaration or instruction, that is more than one 'line' as defined on Page 15. (e.g. line 17).

(4) The sorting technique used in the above program has been chosen because it is a convenient example. It is not an efficient procedure and should not be used to sort large quantities of data. A more efficient technique is given on Page 77.

CHAPTER 6 : ROUTINES AND FUNCTIONS

ROUTINES AND FUNCTIONS

There are many occasions on which it is necessary to perform an operation several times in different contexts within a program, or even in different programs (perhaps written by different people). A possible method of programming this operation as a unit is to write it as a routine.

ROUTINES WITHOUT PARAMETERS

On page 55 we explained that a block can be regarded as one compound instruction. Instead of writing out this block in full every time it is required, we can give it a name which is then written (as a single instruction) every time we wish the block to be carried out. Such a named block is called a ROUTINE.

There are three operations involved in incorporating a routine into a program (1) Declaration
(2) Calling
(3) Description

As an example, we use a routine to interchange the values of two variables x and y.

(1)	<u>declaration</u>	<u>meaning</u>
	<u>routine spec</u> interchange	the name interchange is to be the short title for a routine (a block of declarations and instructions) which will be described later.
(2)	<u>call</u>	<u>meaning</u>
	interchange	carry out the routine which has the short title interchange
(3)	<u>description</u>	<u>meaning</u>

	<u>routine</u> interchange
	<u>integer</u> z
	z = x
	x = y
	y = z
	
	<u>end</u>
		the routine interchange consists of the one declaration and three instructions given opposite.

Notes (1) A routine description has the same structure as a block except that begin is replaced by routine followed by its name.

(2) In the routine description given above, x and y are global variables.

(3) The first line of the description is always the same as the declaration, but with spec omitted.

(4) A routine may be called in any block interior to the one in which it is declared (and described). In this way we can think of local and global routines, in just the same way as local and global variables.

(5) A routine call is an instruction and may be made conditional:

e.g. if p ≠ 10 then interchange

(6) Normally, instructions in the routine are obeyed in sequence until reaching end. If it is desired to stop the routine at some other point, the instruction return may be used. This is equivalent to a jump to end and hence cannot be used in an inner block of the routine. return may be made conditonal.

Example Interchange x and y, and square them if they are both positive.

```
routine interchange and square
integer z
z = x; x = y; y = z
if x≤0 or y≤0 then return
x = x*x; y = y*y
end
```

Note A second return could be written immediately before end, but would be redundant.

STRUCTURE OF BLOCKS CONTAINING ROUTINES

Routine descriptions are placed at the end of the block in which they are declared. The general structure of a block can now be extended to :-

```
begin

   integer ......                      )
   real...........                     ) declarations, including
   routine spec interchange            ) declarations of routines.
   routine spec .......                )

   ...........                         ) instructions including
   interchange                         ) routine calls.
   ...........                         )

   routine interchange        )        )
   ........                   )        )
   end                        )        ) routine descriptions, each
                                       ) having a block-like
   routine ......             )        ) stucture of its own.
   ........                   )        )
   end                        )        )

end
```

ROUTINES WITH PARAMETERS

The previously described routine 'interchange' will exchange the values of x and y, but will be of no use if we wish to interchange any other pair of variables.

In Atlas Autocode, to facilitate the use of the same routine in different contexts within a program, the user is permitted to write the routine using formal (or dummy) names for some or all of the variables global to it. In each call of the routine, these formal names are replaced by the appropriate actual names.

If formal names are used in the writing of a routine, then the following modifications must be made to the procedures for declaring, describing, and calling the routine.

(a) In declaring and in describing the routine its name must be followed by a bracketed list of the formal parameters used, together with a statement of their type.

(b) In calling the routine the name must be followed by a bracketed list of the actual parameters which are to replace the formal parameters on this occasion.

The designation 'parameter' has been used above in anticipation of facilities which permit quantities other than names (for example elements of arrays and arithmetic expressions) to be passed on to routines.

Example 1

```
        integer a,b,i
        integer array A(1:10)
        routine spec interchange (integer name x,y)      Declaration
        .............
        .............
        interchange (a,b)                                Call 1
        cycle i = 1,1,9
        interchange (A(i) , A(10))                       Call 2
        repeat
        .............
        routine interchange (integer name x,y)           Description
        integer z
        z = x;  x = y; y = z

        end
```

Notes (1) Here x and y are the formal parameters.

(2) The actual parameters must be placed in the same order as the formal parameters to which they correspond.
In call 1, x is replaced by a and y by b. In call 2, x is replaced by A(1) and y by A(2).

(3) The statement of parameter type is omitted in calling the routine, but the compiler checks to see that the actual parameters listed are of the type indicated in the declaration.

PARAMETERS CALLED BY VALUE Parameter n in the example below illustrates the use of a different type of formal parameter.

```
.............
integer shriek
routine spec FACT (integer name y, integer n)
.............
.............
FACT (shriek, 10)
.............
.............
routine FACT (integer name y, integer n)
integer i
y = 1
cycle i = 1,1,n
y = i*y
repeat
end
```

The difference between the formal parameter types integer and integer name is important and must be carefully noted.

(a) integer name. When a routine call is made the first action is to replace the formal integer name parameter at every place where it occurs within the routine body by the corresponding actual parameter given at the time of the call. This must have been declared in the usual way either as an integer variable or as an element of an integer array (see the two routine calls in the example on page 66).

(b) integer In this case the first action is the declaration of a variable of type integer local to the routine. This variable is now filled with the value of the actual parameter which may be any integer expression.

Note The integers n and i are both variables local to the routine FACT. They are brought into existence upon entry to the routine and their contents are lost upon exit. They differ in that n has an initial value assigned, which varies from occasion to occasion depending upon the value of the expression given as the actual parameter on that occasion of call. In the call above, n is initially set to 10.

The parameter types real name and real are used in a similar manner. The actual parameter corresponding to the parameter type real name must have been declared as a real variable or as an element of an array. The actual parameter corresponding to the parameter type real may be a general (i.e. integer or real) arithmetic expression.

Parameters of type integer name and real name are said to be CALLED BY NAME.

Parameters of type integer or real are said to be CALLED BY VALUE.

In Atlas Autocode parameters called by name are completely determined by the actual values of all relevant quantities (including global variables) of the time of call. For example it may happen that a routine with a parameter list containing say

```
.........(real name x, integer name i, .......)
```

is called with the actual parameters

```
.........(A(j), j, ..........)
```

where A is the name of a previously declared real array. If the value of j at the time of the call is, say, 10 then in the execution of the routine the formal parameter x is replaced everywhere by A(10) no matter how j varies.

The reader is warned that the alternative convention (whereby, in the above example, the array element replacing x would be determined by the current value of j during the execution of the routine) is used in some other programming languages (e.g. Algol).

PASSING ON ARRAYS TO ROUTINES

A parameter of type real array name or integer array name is used in the same manner as those of type real name and integer name. We can describe a routine in terms of elements of an array with a formal (or dummy) name. In each call, we give the actual name of the array which is to be used in place of the dummy array on that particular occasion.

Example The following routine will double the first 10 elements of any one-suffix array (provided it starts with suffix 1 and has at least 10 elements).

```
routine double (real array name X)
integer i
cycle i = 1,1,10
X(i) = 2X(i)
repeat
end
```

The routine is called by instructions such as:-

```
double (A)
double (B)
```

which will double A(1), A(2).....A(10) and B(1) ....B(10).

Note The routine and the two arrays would, of course, have been previously declared in the usual manner.

Example In the next example it is assumed that a number of square arrays have been declared and a routine is required to print out certain sums of consecutive diagonal elements such as A(5,5) + A(6,6) + ... + A(10,10).

```
routine trace (real array name X, integer m,n)
integer i
real z
z = 0
cycle i = m,1,n
z = z + X(i,i)
repeat
newline
print (z,5,5)
end
```

and instructions to call this routine might be

```
trace (A,5,10)
trace (B,1,50)
```

Note On all the Atlas Autocode compilers, there are four types of parameters called by NAME:-

integer name
real name
integer array name
real array name

and two by value:-

integer
real

On the Manchester COMPILER AA only, there are two extra types called by value:-

integer array
real array

For further details, see the appropriate reference manual. These 'array by value' facilities should be used with caution, not only because of incompatability with other compilers, but also because they can use large amounts of storage space and because of the time taken to copy all the elements of a large array.

FUNCTIONS

The function facilities are closely related to the routine facilites. However, the result of a function call is a number (real or integer) and function calls occur in arithmetic expressions. The declaration, call and description of routines and functions are compared in the following table:-

	Routine	Function
Declaration	routine spec..	a. real fn spec....... b. integer fn spec ......
Result of call	execution of an instruction	a. real number b. integer
Description	routine	a. real fn ... b. integer fn ...

In place of return, the instruction result = is used to terminate the evaluation of a function. However, the use of result is obligatory. Like return, result must not occur in an inner block of a function.

Example The routine FACT can be rewritten as an integer function which we rename FACT'

```
integer shriek
integer fn spec FACT' (integer n)
...............
shriek = FACT' (10)
...............
integer fn FACT' (integer n)
integer prod,i
if n = 1 then result = 1    ; comment see note 1 below
prod = 1
cycle i = 2,1,n             ; comment see note 1 below
prod = i* prod
repeat
result = prod
end
```

Note (1) the assignment of the value of the function to result. The reader should study carefully the two occurrences of result : depending on the value of n, either is a possible exit point. The two lines marked with a comment could be combined as in the routine FACT, but the similarity to the example to follow on page 77 would be lost.

(2) Both the routine call FACT (shriek, 10) and the assignment shriek = FACT' (10) produce identical results.

Like routines, functions have the property of being global to any block interior to the one in which they have been declared and described. In particular, the functions listed on page 40 have the property of being global to the user's program so that neither declaration nor description is required.

Example

The specimen program for ordering lists of positive integers can be rewritten to illustrate the use of the routine and function facilities. A function MAX will be defined which finds the suffix of the largest element in the list. In terms of these, the cycle which achieves the ordering is written

```
cycle i = p, -1,2
j = MAX (A,i)
interchange (A(j), A(i))
repeat
```

with a considerable gain in legibility.

The full program is given on the next page.

Note (1) The integer array A is passed on to the function MAX in exactly the same manner as was indicated previously for routines.

(2) The function MAX could have been written in terms of elements of the global array A. To give the function a more general application, we write it in terms of a (formal) array with name V. When calling the function, we pass on the name A as the actual parameter to replace V.

(3) The instruction -> 1 in the outer block refers to label 1 of the outer block. The same instruction in the integer function MAX refers to label 1 of that function.

```
begin

comment to order lists of positive integers

integer p

1: read(p)

if p<0 then stop

        begin

        integer i,j

        integer array A(1:p)

        integer fn spec MAX(integer array name V, integer k)

        routine spec interchange (integer name a,b)

        cycle i = 1,1,p

        read (A(i))

        repeat

        -> 2 if p = 1

        cycle i = p,-1,2

        j = MAX(A,i)

        interchange (A(j), A(i))

        repeat

     2: cycle i = 1,1,p

        newline ; print (A(i),5,0)

        repeat


        integer fn  MAX(integer array name V, integer k)
        integer p,q,r
        r = 0
        cycle p = 1,1,k
        if r ≥ V(p) then -> 1
        r = V(p) ; q = p
     1: repeat
        result = q
        end

        routine interchange (integer name a,b)
         integer z
         z=a ; a=b ; b=z
         end

         end ; comment end of inner block

 newlines (2) ; -> 1


 end of program
```

CHAPTER 7 : MORE ADVANCED FACILITIES

(NOTE Readers inexperienced in programming will probably prefer to pass straight on to Chapter 8).

Routines and functions as parameters.

Example Numerical integration by trapezoidal rule.

Recursive use of routines and functions.

Examples (i) Calculation of factorials.

(ii) Quicksort.

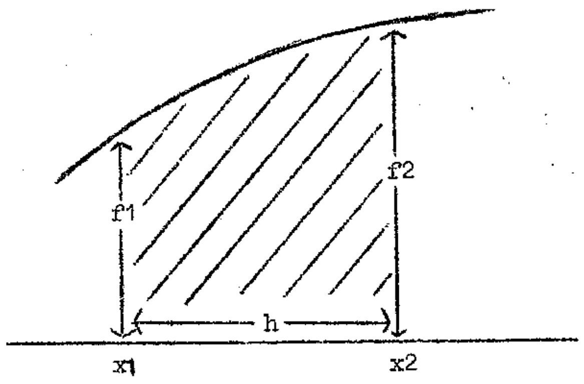
(iii) The game of Hanoi.

Store mapping functions.

ROUTINES AND FUNCTIONS AS PARAMETERS

It is possible to include routines and functions among the formal parameters of a routine or function by means of the type statements routine, real fn, and integer fn. When calling the routine or function the actual parameters must be the names of routines or functions declared either at the head of the block in which the call is made or in any exterior block. Note, however, that all quantities, other than the formal parameters, used in a routine or function description must be global to this description. It is not sufficient for them to be global at the time of call.

Example



Calculate approximately the area under the graph of y=f(x) between x = x1 and x = x2 using the trapezoidal rule. This is illustrated in the accompanying diagram. The area of the shaded part of the panel is ½h*(f1 + f2). The calcuation is performed by dividing the area under the graph into a number of such panels, applying the formula to each panel and summing the results.

The program on the next page carries out the approximate calculation five times, with the area divided into, 10, 20, 30, 40, and 50 panels. The curve used is a quarter circle given by y = $\sqrt{1 -x^2}$, from x = 0 to x = 1. The exact area is $\pi/4$ = 0.785398163.

```
begin
integer i
real fn spec TRAP SUM(real x1,x2, integer n, real fn f)
real fn spec circle(real x)

cycle i=10,10,50
newline
print(i,2,0); spaces(2)
print(TRAP SUM(0,1,i,circle),1,9)
repeat

     real fn TRAP SUM(real x1,x2, integer n, real fn f)
     real fn spec f(real y)
     real h,SUM
     integer i
     h=(x2-x1)/n; SUM=f(x1)
     cycle i=1,1,n-1
     SUM=SUM+2f(x1+i*h)
     repeat
     SUM=SUM+f(x2)
     result =h*SUM/2
     end

     real fn circle(real x)
     result =sq rt(1-x²)
     end
end of program
```

notes (1) The print-out from the program was:-

```
10    0.776129582
20    0.782116220
30    0.783610789
40    0.784236934
50    0.784567128
```

(slowly approaching the true value of 0.785398163).

(2) The formal function parameter f is declared a second time on line 2 of routine TRAPSUM. This serves not as a declaration of the name (this is made on the line above) but of the parameter list.

REMARK

There are certain difficulties in the use of functions and routines as parameters in all the existing compilers. The user should consult the appropriate reference manuals for further details.

RECURSIVE USE OF ROUTINES AND FUNCTIONS

Routines and functions have the property of being global to any block interior to the one in which they are declared. In particular, a routine or function can be used within the description of that routine or function itself. This process is called RECURSION.

Example A function RECFACT equivalent to the function FACT' of page 00 can be defined recursively as follows:-

RECFACT(1) = 1
RECFACT(n) = n * RECFACT(n-1)

This is easily programmed:-

```
integer fn RECFACT (integer n)
if n = 1 then result = 1
result = n * RECFACT (n-1)
end
```

Example QUICKSORT. Quicksort is a method of sorting numbers (or any other quantities) into order. It is generally far more efficient than the techniques described earlier in this book. (For further details of this method, see C. Hoare, The Computer Journal, April 1962)

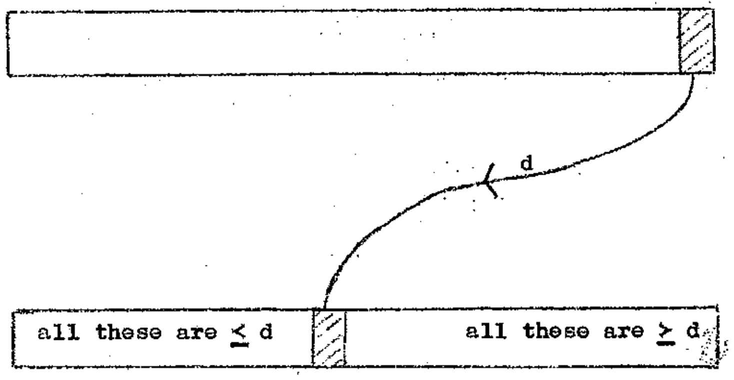
The basic routine

(a) Selects some member of the set to be sorted, and uses this as the 'partition bound'.

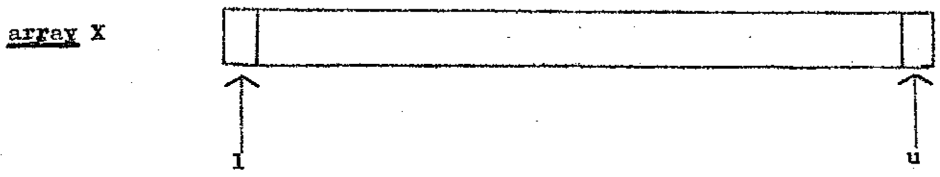
(b) Partitions the remainder of the set into two groups, one containing members not greater than the partition bound, and the other containing members not less than it. These groups are positioned to the left and right of the bound as in the diagram on the next page.

(c) Calls itself recursively to sort each of these two groups.

In the diagram and routine below, the partitioning bound, d, has been chosen arbitrarily to be the right-hand member.



The partitioning is carried out as follows:-



(a) Set pointers l and u to the lower and upper ends of the array to be sorted.

(b) Dump the partitioning bound, leaving a location X(u) which can be over-written when required.

(c) Move pointer l forward until we find a member > d. Put this member into location X(u), leaving X(l) free to be overwritten when required.

(d) Move pointer u backwards until we find a member < d. Put this into X(l).

....

....

(e) Steps (c) and (d) are continued alternately until pointers l and u meet. The bound, d, is then placed in X(u).

A possible description of this routine is:-

```
          routine real quicksort(real array name X, integer a,b)
          comment sorts elements of real array X from X(a) to X(b)
          integer l,u
          real d

          return if a ≥ b

          l=a ; u=b                     ; | set pointers
          d=X(u)                        ; | dump partition bound
          -> 2

1:        l=l+1                         ; | this section moves
          -> 4 if l= u                  ; | l forward until
2:        -> 1 unless X(l) > d          ; | we find a member > d
          X(u) = X(l)

3:        u=u-1                         ; | this section moves
          -> 4 if l = u                 ; | u back until we
          -> 3 unless X(u)<d            ; | find a member < d
          X(l)=X(u)
          -> 1

4:        X(u)=d                        ; | partitioning complete

          real quicksort(X,a,l-1)       ; | sort from X(a) to X(l-1)
          real quicksort(X,u+1,b)       ; | sort from X(u+1) to X(b)
          end
```

<u>Note</u> Although, as we have seen, our first example of recursion can equally easily be written using a cycle, this is not true of quicksort.

<u>Example</u> The game of HANOI.

This is another example where recursion greatly simplifies the writing of a program.

In this game one is given three pegs, and on one of these pegs are a number of circular discs of different sizes, graded so that the largest is at the bottom and the smallest at the top. The aim of the game is to transfer the discs to one of the other pegs (making use of the third as required) in such a way that there is never a larger disc on a smaller one. Only one disc at a time may be moved.

If the solution to the game for (n-1) discs is known, then the solution for n can readily be obtained. Let the pegs be numbered 1, 2 and 3, and let it be required that the n discs on 1 be transferred to 3. This can be done by transferring the first (n-1) to 2, the last to 3, and then the first (n-1) from 2 to 3. In the following program n is the number of discs which have to be moved from peg i to peg j.

<u>PROGRAM FOR GAME OF HANOI</u>

```
begin
integer n,i,j
routine spec hanoi (integer m,p,q)
read (n,i,j)
hanoi (n,i,j)

  routine hanoi (integer m,p,q)
  if m=0 then return
  hanoi (m-1,p,6-p-q)    ; | if p,q are two pegs, other is 6-p-q
  newline
  print (p,1,0); caption $ -> $ ; print (q,1,0)
  hanoi (m-1,6-p-q,q)
  end

end of program
```

The output for the case n=2,i=1,j=3 is:-

```
1 -> 2
1 -> 3
2 -> 3
```

STORE MAPPING FUNCTIONS

The store mapping function provides the user with the possibility of renaming storage locations which have previously been named by a declaration of type real array or integer array. The method of use of a mapping function is almost identical to that of a function. For example it is declared either by real map spec or integer map spec depending on the nature of the variables to be renamed.

Like integer and real functions, mapping functions can appear in arithmetic expression. However as the result of the store map is a variable, it can also be written on the left hand side of an assignment.

Example

```
real x
real map spec W(integer i,j)
..............
X = W(2,3)
W(1,2) = 1 + x † 3
..............
```

Note This illustrates the use of the store map both on the left and on the right hand sides of an assignment.

The description of the store mapping function has the form

```
real map W(integer i,j,.....)
result = addr (A(integer expression, integer expression,..))
end
```

Notes (1) A is the name of the array to be renamed.

(2) Here it is assumed that A is global to the description of the mapping function. However A could have been included in the function heading as a formal parameter of type array name.

(3) There is no restriction on the number of suffices that can be associated with either A or W.

(4) The integer expressions that determine the values of the suffices of the array A can be general integer expressions involving the formal parameters i,j,..... .

Example

```
real array A(1:1000)
real map spec W(integer i)
.............
real map  W(integer i)
result = addr (A (i*i))
end
```

Note In the example W(i) and A(i*i) are equivalent. For example W(10) and A(100) are both valid titles for the same storage location.

Store maps have the great advantage that they permit economical use of storage on a computer. For example if a two dimensional array is symmetric (so that X(i,j) = X(j,i)) then it is completely specified by the values X(i,j) with i ≥ j. It is therefore necessary to store only this (lower) triangular array with a saving in storage space of nearly 50 per cent. An appropriate description of the mapping function might be

```
real map X (integer i, j)
result = addr (A(i*(i - 1)/2 + j)) if i ≥ j
result = addr (A(j*(j - 1)/2 + i))
end
```

Note The saving in storage space gained by using mapping functions is obtained by sacrificing speed in the execution of the compiled program. For this reason mapping functions are not recommended for general use.

CHAPTER 8 : GENERAL TOPICS

Input and output of numbers.

Query printing.

Input and output of symbols.

List of instructions which can be made conditional.

Library routines.

Efficiency.

Checking of programs.

INPUT AND OUTPUT

Input and output of numbers and symbols is achieved by permanent routines whose descriptions are held in the machine. These routines are global to the whole program and may therefore be called without further declaration and description. Although some of these routines have already been explained, they are included here for the sake of completeness.

INPUT OF NUMBERS

read (a)	Read the next number on the data tape into location a, and move the tape on, ready for the next number. (Parameter called by name).
read (a,b,c,d)	Read the next four numbers into a,b,c and d respectively. There is no limit to the number of parameters allowed and each one may be either real or integer, or an element of either an array or an integer array.
Notes	(1) Although spaces in a program are disregarded, this is not true on a data tape, where spaces can be used to separate numbers from one another. Numbers written in floating point form (Page 37) may have spaces between α and the exponent, but in all other cases a space or a newline character indicates the end of a number. (2) In the case of the instruction read (i,x(i)), the first number is assigned to i. The second number is then read into x(i) where i takes the value just assigned.

OUTPUT OF NUMBERS

print ((a+b+c)/n, i+1, j)	Print out the value of the first expression with (i+1) figures before and j figures after the decimal point. If the expression works out to contain less than (i+1) figures before the decimal point, extra spaces will be inserted. If it has more, the extra figures will be printed, but the vertical alignment of a column of results will be spoilt. Parameters are called by VALUE, and so may be expressions. The last two must be integer expressions.
print fl ((a+b+c)/n,j)	Print out the value of the first expression in floating point form. One figure is printed before and j after the decimal point, additional powers of 10 being indicated by the symbol α, as on Page 37.

Note. When using the print and print fl routines, a negative number is preceded by - and a positive number by a space (to give correct vertical alignment of a column).

QUERY PRINTING

On occasions it is convenient to print out the result of some intermediate calculation. For example, this is often a help in locating programming errors. A simple method of doing this is 'query printing'. If an assignment to any variable (but not to result in a function) is followed by a question mark e.g.

```
a = b + c ?
```

the effect is

(i) if a is real	a = b + c ; print fl(a,10)
(ii) if a is integer	a = b + c ; print(a,1,0)

Notes (1) In the case of the Edinburgh compiler, newline is inserted before the printing instruction.

(2) The 'line' ignore queries added immediately before the first begin of the program cancels query printing when it is no longer required.

INPUT OF SYMBOLS

read symbol(a)	Read the next symbol on the data tape and place it in location a. Move the data tape on by one symbol. <u>Note</u> (1). This routine can only read one symbol at a time, unlike the read routine which can have any number of parameters. <u>Note</u> (2). a must be an integer variable or an element of an integer array.
skip symbol	Move the data tape on one symbol, without reading anything into the machine.
a = next symbol	Read the next symbol into integer location a, without moving the data tape. (So the same symbol can be read in a second time) <u>Note</u> next symbol is a permanent integer function, and can thus be used in integer expressions and conditions. For example:-

```
-> 7 if next symbol = '*'
```

<u>REMEMBER</u> When reading symbols, both spaces and newlines count as symbols, whereas, when reading numerical data they simply mark the end of a number.

OUTPUT OF SYMBOLS

<u>caption</u>.........	)	
print symbol( )	)	Have already been adequately
space, spaces	)	discussed on Pages 19 and 31.
newline, newlines	)	

CONDITIONAL INSTRUCTIONS

It is convenient to collecttogether a list of all types of instruction which can be made conditional (by means of an if or an unless clause).

Type	Example with condition
(a) Assignment instructions	$a=b+c^2$ if $x=0$
(b) Jump instructions	->7 if $x \neq 1$ ->Sw(i) unless $j = 3$
(c) Routine calls (including permanent routines)	interchange(a,b) if $a > b$ print(a,1,0) unless $a = 0$
(d) caption.........	if $x \neq 0$ then caption O.K.
(e) result = ...	if $a \geq b$ then result = 17
(f) stop, return	stop if $n < 0$ or $m = 2$ return if i = '*'

Notes (1) cycle..... , and repeat do not appear on the list. They are not Instructions, but Separators (see classification on page 15).

(2) The if or unless clause has the same effect whether written before or after the instruction, except in the case of caption ...... If the example at (d) above had been written

caption O.K. if $x \neq 0$

the if clause would have been treated as part of the text of the caption, giving an output, irrespective of the value of x:-

```
O.K.ifx≠0
```

LIBRARY ROUTINES

Routines to carry out many of the standard computational processes have been written in Atlas Autocode. Using these within one's own program saves considerable programming effort. The reader should obtain details from his Computer Unit.

EFFICIENCY

We give below some suggestions which may assist the reader to write his programs in a form which will make efficient use of machine time. He should, however, keep a sense of proportion, remembering that his own time is also valuable and that the first objective should be to make his program work successfully.

(1). The parts of a program in which efficiency is important are those which are executed many times. For example, any minor improvement made in the area (A) below will cause a saving on each of the 10,000 times this section is executed.

```
cycle i=1,1,100
cycle j=1,1,100
...............               )
...............               )   (A)
...............               )
repeat
repeat
```

(2). Division takes longer than multiplication, so that 0.1*x is computed more quickly than x/10.

(3). Whenever some part of an expression is required many times, it should be evaluated once and stored, as in the right-hand version below.

```
                           d=x*π/180
cycle i=1,1,100            cycle i=1,1,100
A(i)=A(i)*x*π/180          A(i)=A(i)*d
repeat                     repeat
```

(4). It takes longer to move numbers in and out of array elements than simple variables. Again, the right-hand version below is the more efficient.

```
X(i,j)=0                   d=0
cycle k=1,1,15             cycle k=1,1,15
X(i,j)=X(i,j) + Y(k)       d=d +Y(k)
repeat                     repeat
                           X(i,j)=d
```

(5). It is far quicker to calculate numbers inside the machine than to read data in or print answers out. Given some reading taken during an experiment every 1/10 sec

time	reading
12.0	2.137
12.1	3.657
12.2	6.678
.....	.....
.....	.....
.....	.....
59.9	7.547
60.0	2.652

it is wasteful to read in the left-hand column at all. We can read the first and last times (12.0 and 60.0), together with the interval (0.1) and compute the intervening times.

Similarly, output should be reduced to the minimum that the programmer really wishes to read. Apart from the saving of machine time and money, the computer can disregard all uninteresting results (which have to be adequately defined) far more quickly than we can tear up unwanted sheets of paper and assign them to the waste paper basket.

(6). When available, a Line Printer is a more efficient method of output than punched paper tape. With the Line Printer, answers should be printed right across the page, as the cost is proportional to the number of lines printed. (A line of output is limited to 120 characters).

(7). When fault finding, use 'query printing' with discretion. Query printing within program loops is a common cause of large quantities of output which are never read.

CHECKING OF PROGRAMS

The need for checking of programs cannot be overemphasised. A check sheet to assist the reader to avoid some of the more common errors is given on the next page.

PROGRAM CHECK SHEET

1. General details Are all the special words of the language correctly underlined ?

2. Have I a corresponding number of
   (a) begin / end (also routine..../ end, etc) ?
   (b) cycle / repeat (and at corresponding levels) ?

3. Declarations (a) Have I used the same name before at this level ?
   (b) Have I got my commas and colons correctly written in my array declarations ?
   (c) Have I assigned values to the variables used in the calculation of array bounds ?

4. Names Have they been declared (at an appropriate level) ?

5. Labels Have they been used before at this level ?

6. Jump instructions Has the label been set at this level ? If a switch label, has it also been declared (at this level) ?

7. Expressions (a) Do left and right brackets correspond ?
   (b) Have I any real quantities or functions being assigned to integer variables or used as an exponent ?
   (c) Can the expression get too large at any intermediate stage or in the final value ?

8. Array elements Are the suffices all integer expressions, and CAN THEY EVER TAKE VALUES OUTSIDE THE DECLARED BOUNDS ?

9. Cycles (a) Is the control variable an integer ?
   (b) Are the 3 expressions all integer expressions ?
   (c) Is expr(3)-expr(1) a non-negative multiple of expr(2) ?

10. Routine and function calls Has the routine/function been declared and described at an appropriate level, and are the actual parameters of legitimate type and correct in number ?

11. Functions Have I given a result ?

12. Division (a) Am I sure the denominator can never be zero or dangerously close to zero ?
    (b) In integer expressions on KDF 9, will all intermediate results be integral ?

13. Square Roots Can the argument ever be negative ?

14. Logarithms Can the argument ever be negative or dangerously small ?

15. Stopping Have I arranged for the program to stop ?

16. General (a) Have I supplied a valid Job Heading ?
    (b) Have I supplied data, and the right amount ?

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