

ELLIOTT 903 ALGOL

OBJECT CODE MANUAL (JUNE 1966)

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1.

INTRODUCTION

The purpose of this manual is to describe the object code of the Elliott 903 Algol system. The elements of this code are called "pords" (parameter words) and are output on to paper tape by the Algol translator while it is reading the source program on an input paper tape. These pords are interpreted one at a time at run time.

The object code is based on one described in the book "Algol 60 Implementation" by Randell and Russell, but is by no means identical to it.

A run time stack is used, somewhat like that in the book, in order to evaluate expressions and to deal with the execution of blocks, procedures and for statements. Although a number of features, for example strings, are handled identically in Randell and Russell and in 903 Algol, it has been possible to introduce certain simplifications because of the restrictions imposed by the IFIP subset. Other changes have also been made and the principal differences are:-

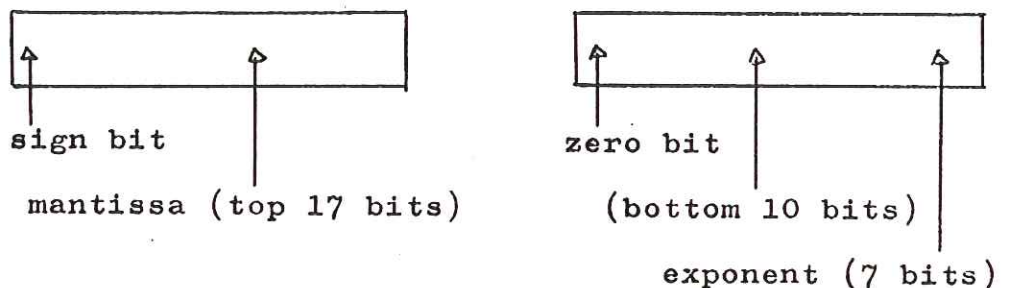
1. The absence of recursion in the subset permits scalars to be given fixed addresses in the store; arrays cannot be treated in this way because their size is not known until run time.
2. The treatment of labels and switches is simplified by the absence of designational expressions from switch lists and by the requirement to declare labels in switch lists; this latter is not an IFIP restriction.
3. The type of an expression, i.e. whether it is real, integer or boolean can be decided at translation time because of the rules of the subset. Unfortunately the parameters to formal procedures form an exception to the rules and it was decided to check at every procedure entry that the actual/formal correspondences are legal; this check extends to include the number of parameters or dimensions of a procedure or array parameter respectively.
4. The restricted call-by-name in the subset removes the need for the "implicit subroutines" described in the book.
5. The addressing of parameters is not as elegant as the method described in the book; although the vector called "display" has been removed, a search down the stack at each parameter reference is sometimes necessary.
6. The object program address increases by one word at a time rather than by one syllable at a time.

7. The object program does not accumulate in the store as translation proceeds but is punched out on paper tape (in relocatable binary form). There is therefore no problem in allocating space to hold the object program, but there is the new problem that one cannot alter something which has already been punched. This is overcome by making use of some facilities of the loader program which performs a second pass as it stores the pords (see 5.2 below).
8. Input and output operations which correspond to all the features of read and print lists have direct counterparts in the pords.
9. An object program block is set up for a procedure body, a for statement, or a block which contains an array or switch declaration.) The case where time is saved is where only local variables are declared and this, unfortunately is rare in practice. *Scalot*

2. FORMAT OF REAL, INTEGER AND BOOLEAN VARIABLES

2.1 Real

In the store a real, or an element of a real array occupies two words with the left (more significant) word at an address one lower than the right hand word. There is no restriction for the left hand word to be at an odd or even address.



With mantissa = a and exponent = b a number of value x is represented as

$$x = a \times 2^b \quad \text{with for } x \neq 0 \quad \begin{aligned} -1 &\leq a < -\frac{1}{2} \\ \frac{1}{2} &\leq a < 1 \\ -64 &\leq b < 63 \end{aligned}$$

for $x = 0$, $a=0$, $b=0$

In this form it is said to be packed. It is to be noted that the most significant digit of the exponent acts as a sign bit so that if $b = -63$ the digits are

1000 001

The largest number which can be held is 9.223×10^{18} approximately and the accuracy is to 8 significant decimal digits (27 bits plus sign bit).

When a real number is brought to the stack it is unpacked into three locations with the exponent occupying the third location and the exponent part of word two cleared to zero. Intermediate results are therefore held to an accuracy of 34 bits plus sign; round off occurs when the result is assigned to a location pair in the store.

2.2 Integer

An integer occupies a single word of 18 bits and lies between -131072 and +131071.

2.3 Boolean

True is represented by the value +1 and false by the value zero; in either case a whole word is used to hold the value.

3.

THE STACK

The stack is basic to the operation of the system and is used to hold, among other things, the intermediate results formed during the evaluation of an expression.

3.1 Assignment statement

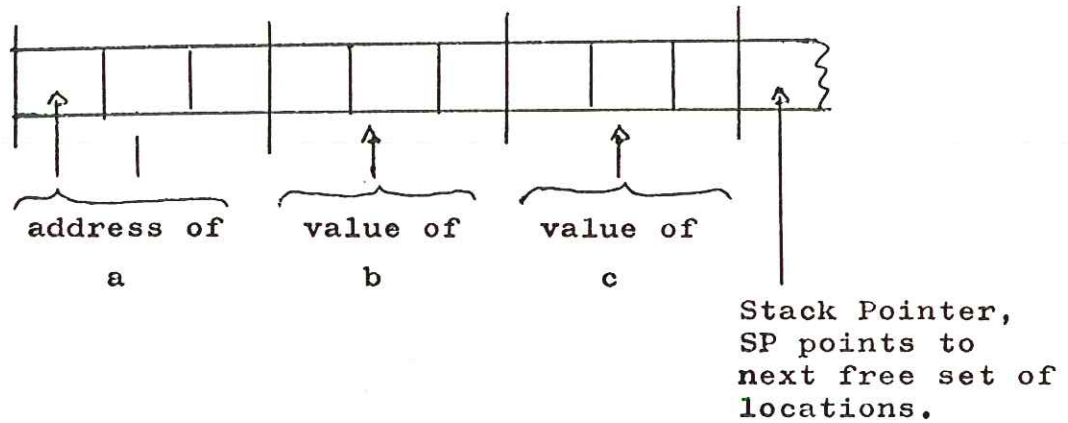
If a, b and c are all real then the Algol text

a := b + c;

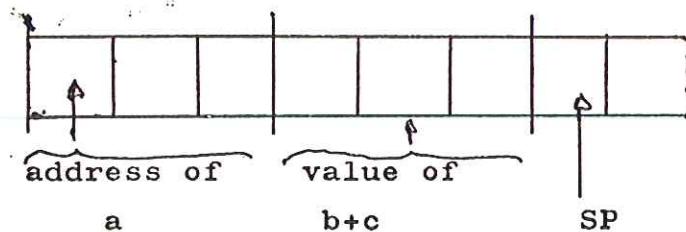
is translated into the pords (for explanation see 6 below):-

```
TRA  "a"
TRR  "b"
TRR  "c"
PRIM R+R→R
PRIM ST
```

The interpreter scans down the pords and, in the case of data references, places the address or the value on the stack; three locations are allotted to each entity in the stack. After scanning the first three pords therefore the stack looks like this:-



A "PRIM" pord defines an operation, in this case the addition of two reals; after this pord the stack looks like this:-



Finally the "PRIM ST" pord assigns the value of $b+c$ to a and moves the stack pointer, SP , back to where it was before the statement began. The stack therefore does not grow continuously but returns to a standard place at the end of each statement.

3.2 Procedure calls

When a procedure is entered in Algol it is necessary to store the return address from which the procedure was called. The address within the pord program is called the pord pointer, PP and this is preserved in the stack at the point of call since it indicates the next pord to be taken after execution of the procedure.

In fact it is necessary to preserve four quantities in the stack in order to enter and leave a procedure correctly; these four are:-

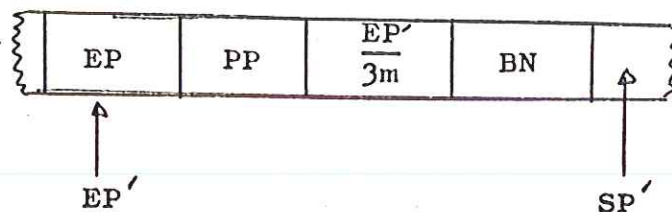
Entry pointer EP Points to the start of the four locations (called a "stack entry") which hold the status of the calling block.

Pord pointer PP Points at next pord for a return address.

$EP' - 3m$ Where there are m parameters, this address is the value to which the stack pointer must return after exit from the procedure.

Block number BN This is a unique 9 bit integer for each run time block. Its presence in the stack enables a parameter to be referenced by searching down the stack if necessary. It also allows a "go to" to leave the procedure body.

The stack entry comprises all of these as shown below, primes denote quantities of the current block and unprimed quantities refer to the calling block.



The first two locations are filled in at the point of call and the last two at the procedure's entry point.

The parameters to a procedure and the space for its result, if any, are also held in the stack. Parameters called by value are developed in the stack as values at the point of call and parameters called by name have their addresses in the stack.

Example

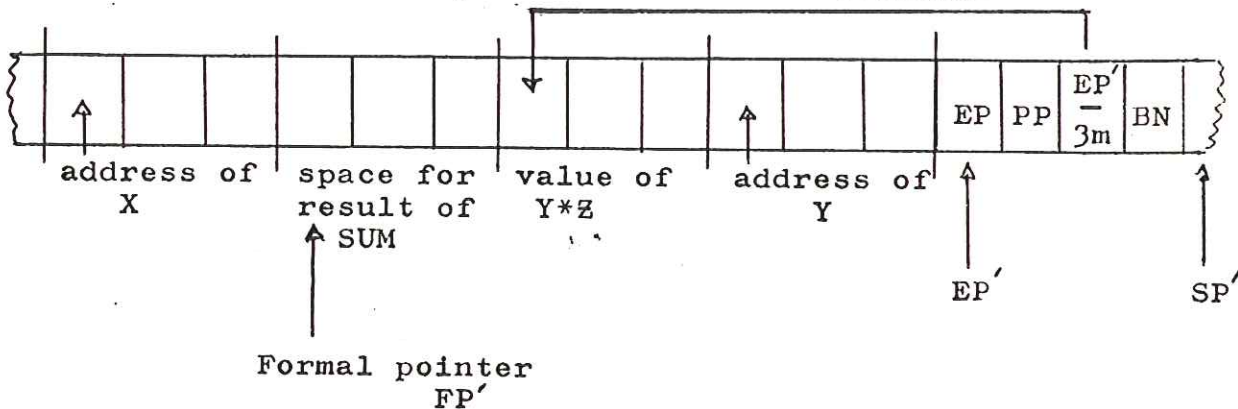
```

begin integer procedure SUM (A,B); value A;
      integer A,B;
      SUM:= A+B;
integer X, Y, Z;
      X:= SUM (Y*Z, Y);

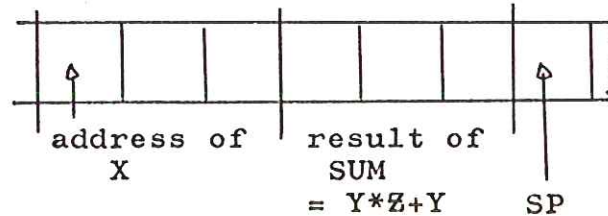
```

*setup
reference*

After the entry to SUM the stack contains



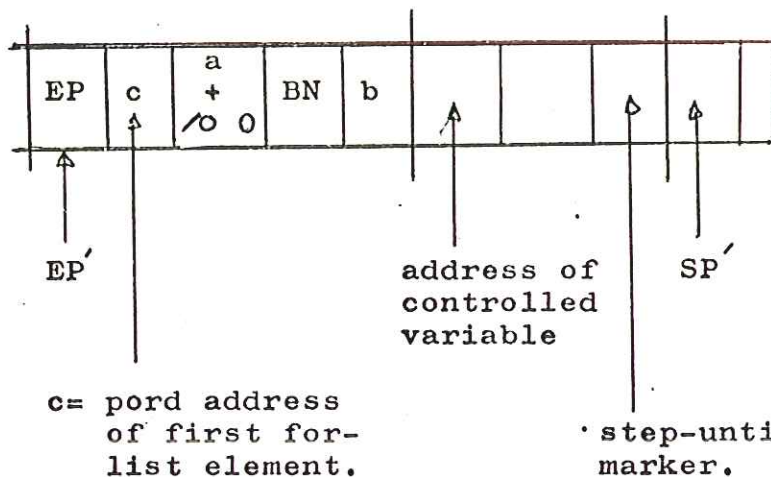
During the body of SUM reference is made to another pointer called the formal pointer FP. This points to the result space if a type procedure is involved and a parameter numbered n is always referenced by the item stored at $FP + 3n$. FP is set up by the pord at the entry to the procedure body. After exit from the body the stack contains



ready for the assignment to X to be made.

3.3 For-statements

A for-statement is made into a run time block with the help of a stack entry involving five quantities and this is always followed by the address of the controlled variable:-



The address 'a' is the address of the controlled statement and the address b is that of the next statement. The sign bit of the word containing 'a' is set equal to one to mark the entry as a for-block in case a go to causes an exit from the block.

A while or step-until element continually executes the statement beginning at 'a' which eventually returns control to 'c' the for-list element in question where evaluation of the condition begins again; during this evaluation the stack is used as workspace in the normal way with the help of SP. When the element is exhausted the address c gets overwritten with that of the next for-list element and so the process goes on.

A simple for-list element merely overwrites c before execution of the controlled statement.

The last for-list element is followed by a special pord which causes exit from the entire for-block and execution resumes at pord address b.

The location at EP+7 is the step-until marker used to prevent the incrementing of the controlled variable at the first iteration. It is important that BN is stored in the same relative position to EP for a procedure and a for-block stack entry because of parameter references and go to.

3.4 Arrays

An array has space set aside for it in the stack just after a block entry in which it has been declared. For the details of this action see MAMPS in 6.4 below. An array parameter called by value causes all the elements of an array to be copied from one part of the stack to another (see 8 below).

4.

STORAGE ALLOCATION

For a basic machine there are alternative ways of dividing up the store depending on whether the library of Algol procedures is held after the end of the interpreter or is held as a relocatable binary paper tape.

With a multi module machine it would appear reasonable to confine the interpreter, library and special machine code to module 1 and to place the object code etc in module 2 onwards. The only restriction is that the length of the object code, constants and scalars must not individually exceed 8191 words.

Figure 1 shows the case of a basic machine containing the whole of the library in the store. Dealing with the areas in turn:-

4.1 Interpreter

This part is a machine code program which contains the subroutines for input/output, the simpler Algol standard procedures, floating point arithmetic, interpretation of the pord code and management of the run time stack. The interpreter is aware of the starting address of the pord program even if the library changes size because the pord program is loaded by entry at a special address.

4.2 The library

This consists of the machine coded Algol procedures:-

arctan	}	under library name "qatrig"
cos		
sin		
sqrt		
instring	}	under library name "qastri"
outstring		
lowbound		
range		

The linking of these procedures to their calls from within the object code is done by the loader program which acts in a similar manner to that of the SIR loader. It follows therefore that all the above names including qatrig and qastri are held in the loader's dictionary before the relocatable Algol object code tape is fed in.

If the library gets deliberately overwritten by input of an object program it can be re-established by a start at 12; this also resets the name into the loader's dictionary.

4.3 The pord code

This is described in detail in the rest of this manual. Each word has, like machine code, a function part of 5 bits and an address part of 13 bits and these words are examined in turn by the interpreter. All the operations required by the Algol source text are done by interpreter subroutines which are reached from the pords.

4.4 Constants

Each constant mentioned in the Algol text is stored here (once only) as a positive integer or a positive floating point number. Information relating to switches and labels is also held here and the contents of the whole area are punched out at the end of a translation.

This part of the output tape is preceded by the left hand global name "qacod1" (Algol Constants Object Data Load) and this is noted by the loader. All references to constants, labels or switches at run time require the interpreter to refer to the address of qacod1.

4.5 Scalars

Each integer, boolean or real variable declared in the source text has space reserved for it here. The area is labelled globally by the name "qavnda" (Algol Variables Notional Data Area) and this is also noted by the loader. All references to these variables at run time require the interpreter to refer to the address of qavnda.

The space is reserved by using a SIR skip code and hence the area is not cleared to zero during input, nor is it cleared to zero at the start.

This scheme is not so efficient as one which places all scalars on the stack, but the loss of space is never serious in practice and there is a slight gain in speed.

4.6 Machine code

A User may wish to have special procedures written in machine code and these can be input by a start at 11 after input of the Algol pord program.

4.7 Stack

As described in section 3.

4.8 Loader names

This is a list of names and addresses which is used by the loader to link procedures to their calls.

4.9 Loader

This loads relocatable binary paper tape.

4.10 Systems area

No use is made of this area at present. It could be used for transferring the Algol translator or interpreter from magnetic tape or disc into the store.

4.11 Summary

There is better use of available storage if the Algol is translated in "library mode" (start at 12). Figure 2 shows the layout. In the first place it is likely that the program does not need all the library and only the part which is needed is present; in the second place the space needed for scalars can overlap the loader but to take advantage of this the scalar space must come last. This is what happens when a translation is done in library mode. Figure 3 shows a suggested use of store in a multi module machine.

FIGURE 1.

Basic machine; library entirely stored

u.mop apisdh

	<u>Address</u>	<u>Remarks</u>
	8	
INTERPRETER		
LIBRARY	4200	
PORD OBJECT CODE	4900	
CONSTANTS	6000	Labelled QACODL
SCALARS	6200	Labelled QAVNDA
MACHINE CODE	6400	If any is present
↓ STACK ↓ ↑ LOADER NAMES ↑	6800	
LOADER	7500	
SYSTEMS AREA	8000	

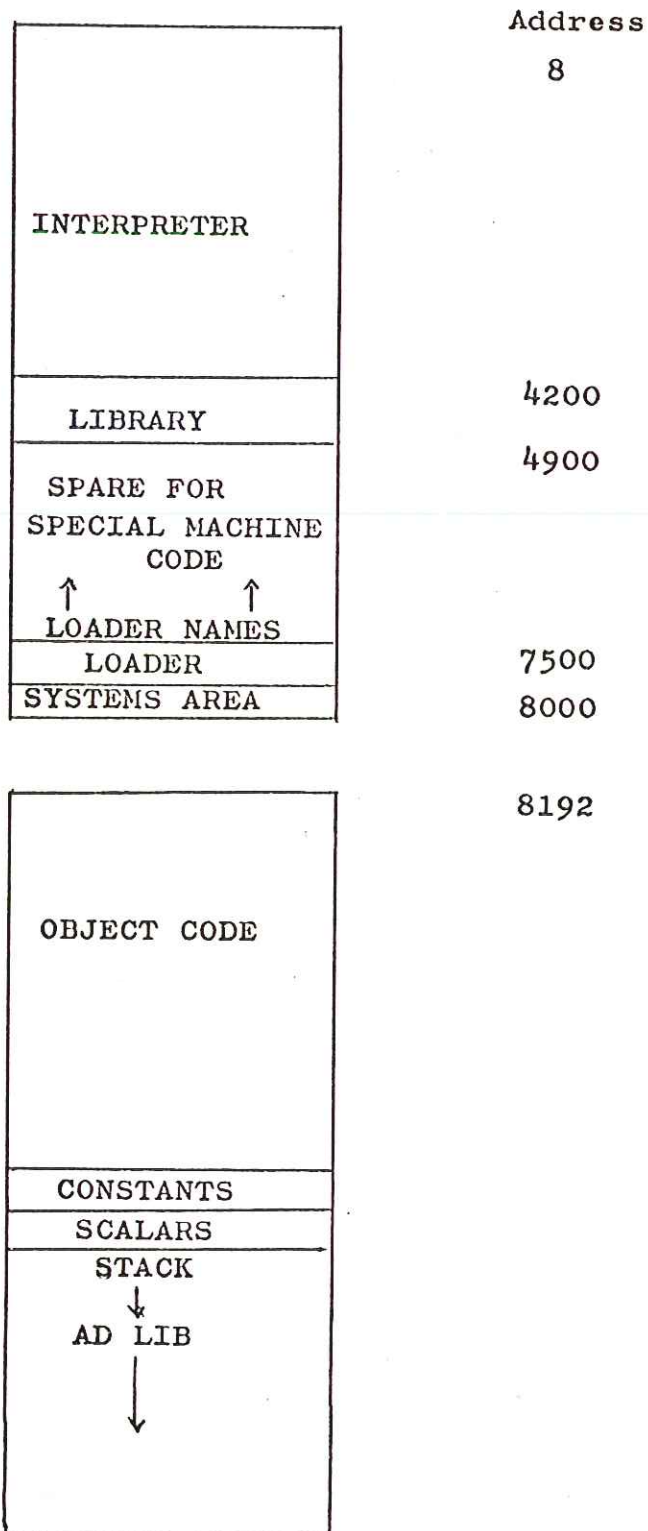
FIGURE 2.

Basic machine; library detached

	<u>Address</u>	<u>Remarks</u>
	8	
INTERPRETER		
OBJECT CODE	4200	
CONSTANTS	5300	Labelled QACODL
DETACHED LIBRARY	5500	
MACHINE CODE	5700	If any is present
SCALARS	6100	Labelled QAVNDA
↓ STACK ↓	6300	
↑ LOADER NAMES		
↑	7500	
LOADER		
SYSTEMS AREA	8000	

FIGURE 3.

Multi module machine; suggested scheme



5.1 As held in the store

The object code consists of 18 bit words which are interpreted at run time. Like machine code each word has a 5 bit (mnemonic) function part and a 13 bit address which is often a data reference:-

TIR N "Take Integer Result from location N in the Notional Data Area and store it in the stack; advance the stack pointer by three".

When the address is not a data reference then it is either a small integer:-

INDR 3n "Store in the stack an element from an n dimensional array".

or it is the address of part of the object program being executed:-

IFJ N "If False Jump. The top-most stack location is regarded as a boolean result; reduce the stack pointer by three and, if false, jump to address N from the beginning of the object code".

or it is some miscellaneous quantity, sometimes a packed pair of items.

Of the 32 possible functions there are about 30 which are described below; one of these, called PRIM, is used to reach one of about 60 further subroutines and the entire collection of 90-odd subroutines forms the bulk of the interpreter.

Example, if a and b are integers, the Algol text:-

b: = a+5;

is translated into the following object code:-

TIA	"b"	Take Integer Address of b
TIR	"a"	Take Integer Result a
TIC	"5"	Take Integer Constant 5
PRIM	I+I	Add Integers
PRIM	ST	Store result in b.

The references to b, a, 5, I+I and ST are all small integers in the actual code.

5.2 As punched on paper tape

There are two formats on the paper tape corresponding to the two input modes for the 920 and 903.

920 mode (7 bits in)		903 mode (8 bits in)
A B C D E . F G H		A B C D E . F G H
I J K L M . N O P		I J K L M . N O P
Q R S T U . V W X	↑	Q R S T U . V W X

direction
of motion

A B C ← Loader code → B C D
D L T ← Parity bits → A I Q and are all zero.
EFGHIJKMNOPQRSUVWX ← Word → EFGHJKLMNOPRSTUVWX
itself

It will be noted that in 903 mode the parity bits are all zero; in 920 mode the parity bits are correct on tape, but ignored by the hardware. However there is a checksum accumulated for every row of tape for protection against faulty punching.

The following loader facilities are used:

- code 1 Load as it stands
- code 2 Load after adding base address
- code 3 Update an implicit jump such as is needed around a procedure body or along a conditional expression.
Code 3 accompanies the word containing the address of the word to be updated. For such an update the following word is zero and is accompanied by loader code zero and this is followed by three blanks.
Code 3 followed by a non zero word is used to update an array or procedure checking word (see 8 below).
- code 4 With subcode 1 for the left hand global labels "qacod1 and "qavnda"; with subcode 2 for punching the call of library procedure names. These names are never accompanied by an increment.
- code 5 Skip n locations. This is used to reserve data space at the end of the program.
- code 6 This is a checksum.
- code 7 Stop loading and print "FIRST NEXT" message.

Generally speaking the chaining facility of the loader is only used for multiple calls on a library procedure where this latter is attached to the end of the pord tape.

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Addition to Pord Manual December 1966

Section 6

The code number 5 has been allotted to a new function, INDFS, Index Formal Switch. It is punched with loader code 1 and has BN, n as its address part.

Action

"Find FP using BN; address := contents of (3n + FP); subtract 3 from SP; get integer from stack;

If integer is zero or negative or greater than contents of address then FAIL;

store 2 * integer - 1 + address at SP; add 3 to SP; "

Purpose

INDFS is needed at the call of P in the program below.

TEST;

begin

switch S := L1, L2, L3;

procedure P (A); value A; label A; goto A;

procedure Q (B); switch B; P (B [2]) ;

comment start of program;

Q (S);

L1 : L3 : print "L\ BAD\ ; stop;

L2 : print "L\ GOOD\ ;

end;

D. Hunter

6.

FUNCTION CODES

6.1 Glossary

PP	Pord Pointer value	13 bits	
SP	Stack Pointer "	16 "	
EP	Entry Pointer "	16 "	
FP	Formal " "	16 "	
BN	Block Number	9 " stored	
		in bits 6-14 inc.	
N	A relative address	13 bits	
n	A parameter number	4 " stored	
		in bits 15-18 inc.	
m	The number of parameters	"	?
d	The number of dimensions	6 bits stored	
		in bits 6-12 inc.	
a	The number of arrays	6 bits stored	
		in bits 13-18 inc.	
PBA	Primitive Base Address (= address of beginning of a table of subroutine entry addresses	13 bits	
QACODL	Address of start of Object Data Load	13 bits	
QAVNDA	Address of start of Notional Data Area	13 bits	
P	input output parameter	a small integer	
BA	Base Address of programs		

6.2 Names of codes

Alphabetically listed names for 5 bit pord functions.

<u>Mnemonic name</u>	<u>Explanation</u>	<u>Notes</u>
CF	Call Function	
CFF	Call Formal Function	
GT	Go To	Refers to labels area
GTF	Go To Formal	
GTFS	Go To Formal Switch	
GTS	Go To Switch	
IFJ	If False Jump	Conditionals
IFUN	Integer Function	
INDA	Index Address	Subscript references
INDR	Index Result	
INDS	Index Switch	
INOUT	Input/Output	
MAMPS	Make Array Maps	At array declaration

<u>Mnemonic name</u>	<u>Explanation</u>	<u>Notes</u>
PE	Procedure Entry	
PEM	Procedure Entry machine code	
PRIM	Primitive Entry	
RFUN	Real Function	
TA	Take Address	In program
TF	Take Formal	Parameter references
TIA	Take Integer Address	
TIC	Take Integer Constant	
TICA	Take Integer Constant Address	
TIR	Take Integer Result	
TLA	Take Label Address	
TRA	Take Real Address	
TRC	Take Real Constant	
TRCA	Take Real Constant Address	
TRCN	Take Result Call by name	
TRR	Take Real Result	
UJ	Unconditional Jump	
(TRAP	Take Real Address in Program)	Hand pording only

6.3 Address parts

<u>Mnemonic</u>	<u>Loader code</u>	<u>Function code</u>	<u>Punched Address</u>	<u>Referenced Address</u>
CF	2 or 4	21	N or NAME	N+BA or library NAME entry
CFE	1	22	BN,n	3n+FP
GT	1	10	N	N+QACODL
GTF	1	11	BN,n	3n+FP
GTFS	1	14	BN,n	"
GTS	1	9	N	N+QACODL
IFJ	1 or 2	7	8191 or N	N+BA
IFUN	1	28	BN,n	3n+FP
INDA	1	12	3n	SP-3n etc see below
INDR	1	13	"	"
INDS	1	27	N	N+QACODL
INOUT	1	15	P	see below
MAMPS	1	6	d,a	see below
PE	1	23	BN,n	
PEM	1	30	n	
PRIM	1	31	N	N+PBA
RFUN	1	29	BN,n	3n+FP

<u>Mnemonic</u>	<u>Loader code</u>	<u>Function code</u>	<u>Punched Address</u>	<u>Referenced Address</u>
TA	2	0	N	N+BA
TF	1	24	BN,n	3n+FP
TIA	1	1	N	N+QAVNDA
TIC	1	18	N	N+QACODL
TICA	1	17	N	N+QACODL see also TLA
TIR	1	2	N	N+QAVNDA
TLA	1	17	N	N+QACODL see also TICA
TRA	1	3	N	N+QAVNDA
TRC	1	20	N	N+QACODL
TRCA	1	19	N	"
TRCN	1	26	BN,n	3n+FP
TRR	1	4	N	N+QAVNDA
UJ	1 or 2	8	8191 or N	N+BA
(TRAP	2	16	N	N+BA cf TA)

6.4 Actions specified

- CF The intention of this is to make a partial stack entry before jumping to a procedure body.
- ```
"address:= N+BA;
LI: store EP at SP; store SP in Entry Pointer
 register; add 1 to SP; store PP at SP;
 add 1 to SP;
 PP:= address;"
```
- CFF This is for a call of a formal function.
- ```
"Find FP using BN; address:= contents of
  3n+FP; go to L1 in CF above;"
```
- GT An ordinary GO TO is executed by reference to two words in QACODL, of which the first contains the label address and the second the Block Number. The Block Number is needed in case a jump to an outer block is involved.
- ```
"address:= N+QACODL;
L2: if BN equals contents of (address + 1)
 then go to contents of address;

L3: if contents of (EP+3) equals contents
 of (address + 1) then to L4;
 EP:= contents of EP; go to L3;

L4: if contents of (EP+2) <0 then go to L5;
 SP:= contents of (EP+2);
 FP:= SP-3; go to L6;

L5: SP:= EP;

L6: EP:= contents of EP;
 BN:= contents of (EP+3);
 go to contents of address;"
```

- GTF "Find FP using BN; address: = contents of (3n+FP); go to L2 in GT above;"
- GTFs "Find FP using BN; address: = contents of (3n+FP); go to L7 in GTS below;"
- GTS "address: = N+QACODL;  
L7: subtract 3 from SP; get integer from stack; if integer is zero or greater than contents of address then FAIL;  
address: = 2 x integer -1 + address; go to L2 in GT above;"
- IFJ "subtract 3 from SP; get boolean (integer) from stack; if zero then go to address N+BA;"
- IFUN This stacks the address of a function name if n = 0 or of a parameter if n ≠ 0.  
  
"Find FP using BN; store(3n+FP) at SP; add 1 to SP; store the constant +1 at SP; add 2 to SP;"
- The constant +1 indicates that the address is that of an integer or boolean variable; this is checked at a procedure entry against the parameter checking word (see 8 below).
- INDA The purpose of this is to place the absolute address of an array element in the stack having been given the address of the map entry and n index values. If the array has real elements then the most significant digit of the result is a one, picked up from the array map. Next to this is placed +1 for an integer or +2 for a real array element. See 8 below.
- INDR As for INDA except that the value of the array element is brought to the stack and unpacked into 3 locations if real.
- INDS "address: = N+QACODL; subtract 3 from SP; get integer from stack;  
if integer is zero or greater than contents of address then FAIL;  
store 2 x integer -1 +address at SP; add 3 to SP;"
- INOUT See section 9; the address part of the pord, p, determines the action in an identical way to that of the address part of a PRIM pord.
- MAMPS This operation is executed immediately after entry to a block in which local arrays are declared. The number of dimensions, d, and arrays, a, are

packed with 6 bits each at the right hand end of the word containing MAMPS.

begin real array A,B,C,D [P:Q, R:S, T:U];

is translated to

|    |       |     |                           |
|----|-------|-----|---------------------------|
|    | TIR   | P   |                           |
|    | TIR   | Q   |                           |
|    | TIR   | R   |                           |
|    | TIR   | S   |                           |
|    | TIR   | T   |                           |
|    | TIR   | U   |                           |
|    | MAMPS | 3,4 |                           |
| A: | /0    | 0   | / indicates real          |
|    | 3     | 7   | 3 dimensions; 7 locations |
|    |       |     | onwards to map address    |
| B: | /0    | 0   |                           |
|    | 3     | 5   |                           |
| C: | /0    | 0   |                           |
|    | 3     | 3   |                           |
| D: | /0    | 0   |                           |
|    | 3     | 1   |                           |
|    | +0    |     |                           |

Map address filled in here by action of MAMPS (equal to SP).

The indications "A:" etc do not mean that a global label is punched, merely that reference to array A is by specifying the address of the "array pair" marked "A:".

Using the top six entries in the stack an array map is calculated and placed in the stack, advancing SP appropriately. The array map for a d, \* dimensional array contains  $2d + 1$  words in all. \* These are arrayed as follows (for  $d = 3$ ):-

|             |            |
|-------------|------------|
| array map : | TOTAL SIZE |
|             | OFFSET     |
|             | l1         |
|             | c1         |
|             | l2         |
|             | c2         |
|             | l3         |

→ d  
→ c  
OFFSET  
m/c size

Note that there is one more lowbound value, l, than map coefficient, c, TOTAL SIZE is the number of locations occupied by the array itself. OFFSET is the number of locations between the leading element of the array and the element all of whose index values are zero; it is positive if the element with zero indices lies at a higher address than the leading element.

\* now  $2d + 2$  words because the number of dimensions is stored in front of TOTAL SIZE. Action different. A "pointer pair" is created in QAVNDA - first pointer points to array, second to map.

The coefficients c1, c2 etc are calculated as follows:-

c1 is the range of the first subscript multiplied by two if the array is real.

c2 is the range of the second subscript multiplied by c1.

The lowbound values l1, l2 etc are not necessary for the evaluation of the address of an element of the array, but are necessary for the standard procedure lowbound.

The address of the leading element of each array is filled in at A:, B: etc., the first being equal to SP, the next to SP + TOTAL SIZE etc. OFFSET is then calculated

$$\text{OFFSET} = - 2 \times P - R \times c1 - T \times c2$$

Finally there is a jump to execute the next pord beyond the map address.

The address of element B [i,j,k] is -  
the contents of location B: with its "/" to  
indicate real plus

$$\begin{aligned} & \text{OFFSET} \\ & \text{plus} \\ & 2i + j \times c1 + k \times c2 \end{aligned}$$

PE This operation is at the head of a block bearing the number BN' and expecting m parameters. The action is to complete the stack entry set up by CF or by CFF, and do parameter checking (see 8 below).

BN occupies 9 bits, m 4 bits.

"store EP-3m at SP; add 1 to SP; store (old) BN at SP; add 1 to SP; store BN' in Block Number register; store EP-3m-3 in Formal Pointer register;"

PEM This is placed at the head of a piece of machine code to make it look like pords when called from within the User's Algol program.

Example.

```
[ARCTAN]
ARCTAN PEM 1
 +0 for return address
 ...
 ...
 ...
 0 ARCTAN+1 normal exit in machine
 /8 1 code
```

The stack entry is completed as for a PE operation but using the current value of BN in place of BN'. There is then a call of the machine code from within the interpreter. On returning to the interpreter in the normal way for a machine code subroutine the action for RETURN (see 7.2 below) are executed.

PRIM Enter a subroutine at address N+PBA.

RFUN This stacks the address of a real type procedure or a real parameter so that an assignment can be made to it.

```
"find FP using BN;
store FP+3n + /0 0 at SP; add 1 to SP;
store /0 2 at SP; add 2 to SP;
```

The sign bit on the address word indicates a real address, and the sign bit on the +2 indicates an unpacked quantity. The +2 indicates a real quantity for parameter checking (see 8 below).

TA "store N+BA at SP; add 3 to SP;"

TF "find FP using BN;  
store contents of (3n+FP) at SP;  
store contents of (3n+FP+1) at SP+1;  
store contents of (3n+FP+2) at SP+2;  
add 3 to SP;

TIA "store N+QAVNDA at SP; add 1 to SP; store +1  
at SP; add 2 to SP;"

TIC "store contents of (N+QACODL) at SP; add 3 to SP;"

TICA ) "store N+QACODL + the constant 8 0 at SP;  
TLA ) add 1 to SP; store +1 at SP; add 2 to SP;"

The +1 written by TLA gets overwritten by +9 if a label is an actual parameter.

TIR "store contents of (N+QAVNDA) at SP; add 3 to SP;"

TRA "store N+QAVNDA + the constant /0 0 at SP; add  
1 to SP; store +2 at SP; add 2 to SP;

TRC "store contents of (N+QACODL) at SP; unpack the  
contents of (N+1+QACODL) and store at SP+1, SP+2;  
add 3 to SP;"

TRCA "store /8 0 plus N+QACODL at SP; store +2 at  
SP+1; add 3 to SP;

```

TRCN "Find FP using BN; address: = contents of
 3n+FP; store contents of address at SP;
 if address has sign bit =1 then
 begin if contents of 3n+FP+1 has
 sign bit =1 then transfer contents
 of (address +1) to SP+1 and (address +2)
 to SP+2 else unpack contents of (address
 +1) and transfer to SP+1, SP+2 end;
 add 3 to SP;

TRR "store contents of (N+QAVNDA) at SP; unpack
 the contents of (N+1+QAVNDA) and store at
 SP+1, SP+2;
 add 3 to SP;

UJ "PP: = N+BA;"

TRAP "store /8 0 plus N+BA at SP;
 store +2 at SP+1; add 3 to SP;"

```

This is only for referring to real constants in hand porded programs. This function is not produced by the translator.

## 7.

### PRIMITIVES

#### 7.1 Listed in numerical order

Each primitive is a subroutine and is numbered from 1 to 70; those which are numbered 1-29 and 63-70 are organisational and the remainder are arithmetic, relational, logical or standard procedure routines such as log and exp.

The numerical value of the primitive is used to enter the routine via a table of addresses, and each pord has the function part 31 or /15.

| <u>Primitive number</u> | <u>Mnemonic</u> | <u>Explanation</u>     |
|-------------------------|-----------------|------------------------|
| 1                       | CBL             | Call Block             |
| 2                       | CHECKB          | Check boolean          |
| 3                       | CHECKI          | Check integer          |
| 4                       | CHECKR          | Check real             |
| 5                       | CHECKS          | Check string           |
| 6                       | DO              |                        |
| 7                       | STW             | Store While            |
| 8                       | FINISH          | End of program         |
| 9                       | FOR             | Start of FOR statement |
| 10                      | FR              | For Return             |
| 11                      | FSE             | For statement end      |
| 12                      | DIV             | Integer divide         |
| 13                      | ITOR1           | Integer to Real 1      |



| <u>Primitive number</u> | <u>Mnemonic</u>              | <u>Explanation</u>      |
|-------------------------|------------------------------|-------------------------|
| 14                      | ITOR2                        | Integer to Real 2       |
| 15                      | NEGI                         | Negate integer          |
| 16                      | NEGR                         | Negate real             |
| 17                      | RETURN                       | At end of block         |
| 18                      | RTOI1                        | Real to integer 1       |
| 19                      |                              |                         |
| 20                      | ST                           | Store                   |
| 21                      | STA                          | Store Also              |
| 22                      | STEP                         |                         |
| 23                      |                              |                         |
| 24                      | WAIT                         | Wait                    |
| 25                      |                              |                         |
| 26                      | UNTIL                        |                         |
| 27                      | UP                           |                         |
| 28                      | $R \uparrow I \rightarrow R$ | Arithmetic              |
| 29                      | WHILE                        |                         |
| 30                      | $I + I \rightarrow I$        | <i>Arithmetic</i> — 305 |
| 31                      | $R + R \rightarrow R$        |                         |
| 32                      | $I - I \rightarrow I$        |                         |
| 33                      | $R - R \rightarrow R$        |                         |
| 34                      | $I * I \rightarrow I$        |                         |
| 35                      | $R * R \rightarrow R$        | Arithmetic              |
| 36                      | $I / I \rightarrow R$        |                         |
| 37                      | $R / R \rightarrow R$        |                         |
| 38                      | $I \uparrow I \rightarrow I$ |                         |
| 39                      | $I \uparrow I \rightarrow R$ |                         |
| 40                      | $R \uparrow R \rightarrow R$ |                         |
| 41                      | $I < I \rightarrow B$        |                         |
| 42                      | $R < R \rightarrow B$        |                         |
| 43                      | $I \leq I \rightarrow B$     | Relational              |
| 44                      | $R \leq R \rightarrow B$     |                         |
| 45                      | $I = I \rightarrow B$        |                         |
| 46                      | $R = R \rightarrow B$        |                         |
| 47                      | $I \neq I \rightarrow B$     |                         |
| 48                      | $R \neq R \rightarrow B$     |                         |
| 49                      | $I > I \rightarrow B$        | Relational              |
| 50                      | $R > R \rightarrow B$        |                         |
| 51                      | $I \gg I \rightarrow B$      |                         |
| 52                      | $R \gg R \rightarrow B$      |                         |
| 53                      | $B \wedge B \rightarrow B$   |                         |
| 54                      | $B \vee B \rightarrow B$     |                         |
| 55                      | $B \equiv B \rightarrow B$   | Logical                 |
| 56                      | $B \supset B \rightarrow B$  |                         |
| 57                      | $\neg B \rightarrow B$       |                         |
| 58                      | ABS                          |                         |
| 59                      | ENTIER                       |                         |
| 60                      | EXP                          | Standard procedures     |

| <u>Primitive number</u> | <u>Mnemonic</u> | <u>Explanation</u>                                                                                                                                           |
|-------------------------|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 61                      | LN              | Standard procedures<br><br>These place integer $x$ in stack at SP-2 where $x$ runs from 3 to 10 for primitives 63-70. The purpose is for parameter checking. |
| 62                      | SIGN            |                                                                                                                                                              |
| 63                      |                 |                                                                                                                                                              |
| 64                      |                 |                                                                                                                                                              |
| 65                      |                 |                                                                                                                                                              |
| 66                      |                 |                                                                                                                                                              |
| 67                      |                 |                                                                                                                                                              |
| 68                      |                 |                                                                                                                                                              |
| 69                      |                 |                                                                                                                                                              |
| 70                      |                 |                                                                                                                                                              |

## 7.2 Actions specified

|     |        |                                                                                                                                                                                                                                                                                                                                                                |
|-----|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | CBL    | This has the same effect as a function CF to a point two pords on and therefore makes a partial stack entry.                                                                                                                                                                                                                                                   |
| 2-5 | CHECK  | These punch "newline, asterisk" followed by a boolean, integer or real whose value is at the top of the stack or a string whose address is at the top of the stack. SP is unchanged except for CHECKS which reduces it by 3.                                                                                                                                   |
| 6   | DO     | This makes use of the common procedure ASSIGN (see below).<br><br>"ASSIGN; store PP at EP+1;<br>store contents of (EP+2) in Pord Pointer register;"                                                                                                                                                                                                            |
| 7   | STW    | "ASSIGN;"                                                                                                                                                                                                                                                                                                                                                      |
| 8   | FINISH | Punch 100 rows of blank tape, the word FINISH and a halt code. Then stop.                                                                                                                                                                                                                                                                                      |
| 9   | FOR    | A stack entry is made. In the object program FOR is followed by three pords.<br><br>PRIM FOR<br>a address of controlled statement<br>BN' address of next statement<br><br>"store EP at SP;<br>store (PP+4) at SP+1;*<br>store a + /O 0 at SP+2;<br>store old BN at SP+3;<br>store b at SP+4;<br>EP: = SP; add 5 to SP;<br>store BN' in Block Number register;" |
| 10  | FR     | This ends a controlled statement.<br>"PP: = contents of (EP+1);"                                                                                                                                                                                                                                                                                               |

\* PP+4 points to 5 locations after PRIM FOR

|    |        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 11 | FSE    | <p>This undoes the effect of FOR and is the last for list element.</p> <p>"BN: = contents of (EP+3);<br/> PP: = contents of (EP +4);<br/> SP: = EP; EP: = contents of EP;"</p>                                                                                                                                                                                                                                                                                                                                                                                       |
| 12 | DIV    | See arithmetic primitives.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 13 | ITOR1  | { Convert contents of SP-3 and SP-6 from integer to unpacked real respectively.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 14 | ITOR2  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 15 | NEGI   | { Replace the contents of SP-3 by minus the contents.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 16 | NEGR   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 17 | RETURN | <p>Used at the end of a block or procedure.</p> <p>"BN: = contents of (EP+3);<br/> SP: = contents of (EP+2);<br/> PP: = contents of (EP+1);<br/> EP: = contents of EP;<br/> FP: = contents of (EP+2) minus 3;"</p>                                                                                                                                                                                                                                                                                                                                                   |
| 18 | RTOI1  | Convert contents of SP-3 from unpacked real to integer with FAIL if overflow.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 20 | ST     | <p>This makes use of the common procedure ASSIGN (see below)</p> <p>"ASSIGN; subtract 3 from SP;</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 21 | STA    | <p>"ASSIGN; copy the contents of SP to SP-3<br/> (SP+1) to SP-2<br/> (SP+2) to SP-1;"</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 22 | STEP   | <p>"ASSIGN; store PP at EP+1;<br/> clear location EP+7;"</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 24 | WAIT   | Halt but prepare to resume after a start at 9.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 26 | UNTIL  | <p>"If the contents of (EP+7) are zero then make them non zero else add the contents of (EP+8) to the variable whose address is at EP+5;</p> <p>If the sign of ( the increment held at EP+8 times ( the controlled variable whose address is at EP+5 minus the final value given in (EP+11)) is greater than zero then store PP at EP+1; this corresponds to element exhausted;</p> <p>subtract 6 from SP;</p> <p>If the above sign is <math>\leq 0</math> then store the contents of (EP+2) in the pointer register; this causes the statement to be executed;"</p> |

The type of arithmetic is determined\* by the address of the controlled variable held at EP+5.

- 27 UP This makes space in the stack for the result of a type procedure.  
"Add 3 to SP;"
- 29 WHILE If the topmost value is false then the next word is taken, but if true then a word jump occurs to the address given in EP+2.

"subtract 3 from SP;  
if false store PP in EP+1;  
if true store contents of (EP+2) in Word Pointer register;"

procedure ASSIGN; "subtract 3 from SP;  
address: = contents of (SP-3);  
type: = contents of (SP-2);

if address has an "8 0" bit then  
FAIL because assignment to a  
constant is being attempted;

store contents of SP at address;

if address < 0 then begin,if type  
< 0 then

transfer contents of (SP+1) to  
address+1 and contents of (SP+2)  
to address +2

else

pack together the contents of (SP+1)  
and (SP+2) with round off and store  
at address +1

end;"

The primitives numbered 30-56 have two inputs and one output. The left hand input is at SP-6, the right hand input is at SP-3. The output occupies SP-3 or, if real, the three words starting at SP-3. The net effect of each primitive is to reduce SP by 3. Failure actions are not indicated.

|            |       |                        |
|------------|-------|------------------------|
| Arithmetic | 30-40 | (and <u>div</u> no.12) |
| Relational | 41-52 |                        |
| Logical    | 53-57 | (note 57 is like NEGI) |

\* Packing is determined by the contents of (EP+6).

The primitive\_ numbered 58-62 are the ones which execute the Algol procedures which are always in the store. A call of one of these procedures does not produce a PRIM UP as an ordinary procedure call would. The actions of all these primitives are:-

"replace contents of (SP-3) by the function of the contents".

The primitives numbered 63-70 serve the purpose of filling the stack with type information alongside the address of any call-by name actual parameter. This is for parameter checking.

## 8. PARAMETER CHECKING

At each procedure entry having  $m$  parameters there are  $m$  parameter checking words following the "PE BN, $m$ " pord. During the execution of the PE pord, a check is made between the relevant word which describes the formal parameter, and the corresponding actual parameter given in the stack; the check includes number of dimensions or parameters.

No check is made for a formal parameter called by value.

If an array parameter is called by value then the copying of the array is done within the PE pord.

|   |   |    |
|---|---|----|
| 1 | 4 | 13 |
|---|---|----|

a checking word

$v$       $\alpha$              dim

$v=1$  if called by value

$\alpha$  has values as given below.

dim contains the number of dimensions plus the base address of the pord program; this latter is a nuisance but is an inevitable consequence of the way the checking word is updated by the loader program.

| value of $\alpha$ | parameter type               | value of dim |
|-------------------|------------------------------|--------------|
| 1                 | integer or boolean           | 0            |
| 2                 | real                         | 0            |
| 3                 | integer or boolean array     | $n+BA$       |
| 4                 | real array                   | $n+BA$       |
| 5                 | integer or boolean procedure | $n+BA$       |
| 6                 | real procedure               | $n+BA$       |
| 7                 | procedure                    | $n+BA$       |
| 8                 | switch                       | 0            |
| 9                 | label                        | 0            |
| 10                | string                       | 0            |

It will be noticed that all pords which stack a real or integer address also fill the adjacent location with +2 or +1 as in the table above. Pords corresponding to actual parameters of types 3-10 are each followed by the appropriate primitives.

9. INPUT OUTPUT

These operations all have a function part of 15 , INOUT and an address part p.

|   | value of p | action                                             |   |   |   |
|---|------------|----------------------------------------------------|---|---|---|
| * | 1          | read an integer                                    |   |   |   |
| * | 2          | read a real                                        |   |   |   |
|   | 3          | print an integer                                   |   |   |   |
|   | 4          | print a real                                       |   |   |   |
|   | 5          | aligned                                            | } |   |   |
|   | 6          | punch                                              |   | } |   |
|   | 7          | digits                                             |   |   | } |
|   | 8          | freepoint                                          |   |   |   |
|   | 9          |                                                    |   |   |   |
|   | 10         |                                                    |   |   |   |
| * | 11         | prefix                                             | } |   |   |
|   | 12         | sameline                                           |   | } |   |
|   | 13         | scaled                                             |   |   | } |
|   | 14         | reader                                             |   |   |   |
| * | 15         | print a string within a print list                 |   |   |   |
|   | 16         | aligned                                            | } |   |   |
|   | 17         | punch                                              |   | } |   |
|   | 18         | digits                                             |   |   | } |
|   | 19         | freepoint                                          |   |   |   |
|   | 20         | reset the local settings from the global settings. |   |   |   |
|   | 21         |                                                    |   |   |   |
| * | 22         | prefix                                             | } |   |   |
|   | 23         | sameline                                           |   | } |   |
|   | 24         | scaled                                             |   |   | } |
|   | 25         | reader                                             |   |   |   |

The parameters to all the above lie in the stack - if there is one at SP-3 and if there are two at SP-6 and SP-3. The operations with an asterisk \* have addresses in the stack and all the others, with the exception of sameline, have values.

All parameters are cleared from the stack by decreasing SP appropriately.

The global and local presumed settings are affected by the operations as indicated.

A string is stored with its opening and closing string quotes packed three characters to a word left justified and space filled; inner strings in the 503 Algol sense are permitted. The inner string is interpreted on output.

## 10. LIBRARY AND MACHINE CODE PROCEDURES

The library is a set of machine code procedures each introduced by a PEM pord but there is no reason why hand porded procedures should not be added. A hand porded procedure must start with a PE pord containing a Block Number less than 50 and be followed by the correct parameter checking words.

### Example

10.1 As declared near the front of the Algol text.

code

```
integer procedure SUM (a, b);
value a; integer a, b;
```

algol;

This is not needed for library procedures such as arctan which behave exactly as if such a declaration had already been made before the User's program is read.

10.2 As called from further on in the text

"x := SUM (y+y , z);" is translated to

```
TIA "x"
PRIM UP make room for result
TIR "y"
TIR "y"
PRIM I+I → I
TIA "z" call by name
CF SUM using loader global name
PRIM ST
```

10.3 As offered for assembly by SIR for "SUM: = a+b"

```
[SUM]
SUM /14 2
 +0
 0 38
 /0 6
```

|    |       |
|----|-------|
| /4 | 0     |
| 0  | 38    |
| /1 | 3     |
| /5 | 0     |
| 0  | SUM+1 |
| /8 | 1     |

%

10.4 As hand porded

[SUM]

|     |     |     |                 |
|-----|-----|-----|-----------------|
| SUM | /7  | 642 | Block Number 40 |
|     | /1  | 0   | Checking words  |
|     | 1   | 0   |                 |
|     | /12 | 640 |                 |
|     | /8  | 641 |                 |
|     | /10 | 642 |                 |
|     | /15 | 30  |                 |
|     | /15 | 20  |                 |
|     | /15 | 17  |                 |

%

11.

EXAMPLE TRANSLATIONS

In what follows the pords have been written symbolically as far as possible and in a notation which is close to SIR in the belief that this helps the explanation.

11.1 Notation

The function parts of pords are given mnemonically e.g. TIA, TRR etc.

A variable name in small case replaces its address in QAVNDA e.g. TIA x replaces TIA 5 if the address of x is 5.

A parameter name replaces BN,n.

A primitive name replaces its number e.g. PRIM ST for PRIM 20.

The address part of a pord referring to a constant is given correctly in its absolute form and the value of the constant mentioned in a comment.

The names of switches, labels, arrays and procedures are freely used as local SIR labels for explanatory purposes only.

Implicit forward jumps use a series of local SIR labels beginning R1, R2 for historical reasons.



Global labels are declared for QACODL, QAVNDA, the name of the program itself, any library calls and any calls of machine coded procedures.

The semicolon convention e.g. ;+2 and 84; is used

11.2 Program without a run time block

```

TEST1;
 begin integer a, b, c;
 b: = 6;
 a: = c: = b+5
 end;
*+0

```

```

[TEST1 QACODL QAVNDA]
TEST1 INPUT 20
 TIC 2 (+3)
 INOUT 17
 UJ 9;
 £''L
 £3`
 £TES
 £T1
 £`
 TA 4;
 INOUT 15 (PUNCHES PROG NAME)

 TIA b
 TIC 3 (+6)
 PRIM ST

 TIA a
 TIA c
 TIR b
 TIC 4 (+5)
 PRIM I+I→I
 PRIM STA
 PRIM ST

 PRIM FINISH

QACODL +0
 +1
 +3
 +6
 +5

QAVNDA
>+4
%
```

11.3 Program with run time block.

```

TEST2;
 begin switch s: = loop, ret;
 integer a, b;
 ret .: b: = 4;
 loop: a: = b; go to ret
 end;

```

As for TEST1 for the first 10 words then

|        |       |        |           |
|--------|-------|--------|-----------|
|        | PRIM  | CBL    |           |
|        | UJ    | R1     |           |
|        | PE    | 816    | (BN = 51) |
| RET    | TIA   | b      |           |
|        | TIC   | 3      | ( +4)     |
|        | PRIM  | ST     |           |
| LOOP   | TIA   | a      |           |
|        | TIR . | b      |           |
|        | PRIM  | ST     |           |
|        | GT    | 6      | (RET)     |
|        | PRIM  | RETURN |           |
| R1     | PRIM  | FINISH |           |
| QACODL | +0    |        |           |
|        | +1    |        |           |
|        | +3    |        |           |
| S      | +2    |        |           |
|        | 0     | LOOP   |           |
|        | +816  |        |           |
|        | 0     | RET    |           |
|        | +816  |        |           |
|        | +4    |        |           |
| QAVNDA |       |        |           |
| >+3    |       |        |           |
| %      |       |        |           |

The only difference between a program translated from Algol and the example of 11.2 or 11.3 as assembled by SIR in relocatable binary form, is that the Algol tape has a checksum inserted just before QAVNDA; if this is not done then the first library tape which gets copied after QACODL will cause a checksum failure at load time.

The remaining examples are usually excerpts from complete programs.

11.4 Subscript variables

```

TEST3;
 begin array a,b,c [1:10, -5, 6];
 real x,y;
 integer i,j;
 i: = j: = 4;
 c [i,j]: = 0;
 x: = a [2, 5];

 end;

```

As for TEST1 and TEST2 then

|   |       |       |            |
|---|-------|-------|------------|
|   | PRIM  | CBL   |            |
|   | UJ    | R1    |            |
|   | PE    | 816   |            |
|   | TIC   | 1     | (+1)       |
|   | TIC   | 3     | (+10)      |
|   | TIC   | 4     | (+5)       |
|   | PRIM  | NEGI  |            |
|   | TIC   | 5     | (+6)       |
|   | MAMPS | 131   | (d=2, a=3) |
| A | /0    | 0     |            |
|   | 2     | 5     |            |
| B | /0    | 0     |            |
|   | 2     | 3     |            |
| C | /0    | 0     |            |
|   | 2     | 1     |            |
|   | +0    |       |            |
|   | TIA   | i     |            |
|   | TIA   | j     |            |
|   | TIC   | 6     | (+4)       |
|   | PRIM  | STA   |            |
|   | PRIM  | ST    |            |
|   | TA    | C     |            |
|   | TIR   | i     |            |
|   | TIR   | j     |            |
|   | INDA  | 6     | (3n)       |
|   | TIC   | 0     | (+0)       |
|   | PRIM  | ITOR1 |            |
|   | PRIM  | ST    |            |
|   | TRA   | x     |            |
|   | TA    | A     |            |
|   | TIC   | 7     | (+2)       |
|   | TIC   | 4     | (+5)       |
|   | INDR  | 6     |            |
|   | PRIM  | ST    |            |

```

 PRIM RETURN
R1 PRIM FINISH
QACODL +0
 +1
 +3
 +10
 +5
 +6
 +4
 +2

QAVNDA
>+7
%
```

### 11.5 Conditional statement

if  $x < y$  then go to CYCLE;

```

 TIR x
 TIR y
 PRIM R<R → B
 IFJ R17
 GT cycle
R17 ...
 ...
```

### 11.6 Conditional expression

This illustrates the IFIP rule that the type of an expression can be taken to be real if this depends on something at run time -

$i :=$  if  $k < 0$  then  $j$  else  $j + 2.0$ ;

```

 TIA i
 TIR k
 TIC 0 (+0)
 PRIM I<I → B
 IFJ R10
 TIR j
 UJ R11

R10 TIR j (+2.0)
 TRC
 PRIM ITOR2
 PRIM R+R → R
 UJ ;+2

R11 PRIM ITOR1
 PRIM RTOI1
 PRIM ST
```

### 11.7 Switch

go to S[k];

TIR k

GTS S

### 11.8 Input output

11.8.1 print x\*y, sameline, digits (3), z;

INOUT 20 (reset settings)

TIR x

TIR y

PRIM |x| → I

INOUT 3 (print integer)

INOUT 23 (sameline local)

TIC 2 (+3)

INOUT 18 (digits local)

TRR z

INOUT 4 (print real)

11.8.2 read a[i,j], k;

INOUT 20 (reset settings)

TA A

TIR i

TIR j

INDA 6

INOUT 2 (read a real)

TIA k

INOUT 1 (read an integer)

11.8.3 digits (4);

TIC (+4)

INOUT 7 (digits global)

11.8.4 print ``L2`TABLE`;

INOUT 20

UJ R23

£'L

£2`T

£ABL

£E`

R23 TA 84; (assumes £'L at location 84)

INOUT 15

11.9 for statement

for  $x := 5, 6, x + 1$  while  $x < 10, 12$  step 1 until 18 do

|      |       |       |             |
|------|-------|-------|-------------|
| PRIM | FOR   |       |             |
| 0    | R14   |       |             |
| +864 |       |       | (BN = 54)   |
| 0    | R15   |       |             |
| TIA  | x     |       |             |
| TIC  |       | (+5)  | ←           |
| PRIM | DO    |       |             |
| TIC  |       | (+6)  | ←           |
| PRIM | DO    |       |             |
| TIR  | x     |       |             |
| TIC  | 1     | (+1)  | ←           |
| PRIM | I+I   |       |             |
| PRIM | STW   |       |             |
| TIR  | x     |       |             |
| TIC  |       | (+10) |             |
| PRIM | I<I→B |       |             |
| PRIM | WHILE |       |             |
| TIC  |       | (+12) |             |
| PRIM | STEP  |       |             |
| TIC  | 1     | (+1)  | ←           |
| TIC  |       | (+18) |             |
| PRIM | UNTIL |       |             |
| PRIM | FSE   |       | ← end dummy |

for list elements

R14 ...  
 controlled statement  
 ...  
 PRIM RR

R15 ...  
 next statement  
 ...

11.10 Library Procedure call

11.10.1  $x := \text{abs}(y);$

|      |     |                         |
|------|-----|-------------------------|
| TRA  | x   |                         |
| TRR  | y   |                         |
| PRIM | ABS | (always in interpreter) |
| PRIM | ST  |                         |

11.10.2  $x := \text{sin}(y);$

|      |     |                                     |
|------|-----|-------------------------------------|
| TRA  | x   |                                     |
| PRIM | UP  |                                     |
| TRR  | y   |                                     |
| CF   | SIN | (punched as right hand global name) |
| PRIM | ST  |                                     |

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In this example it is as if SIN had been added to the SIR declarations at the start of the program. The loader does not care whether SIN occurs before or after this point and establishes a chain for a series of calls.

### 11.11 Procedure body and call

```

begin integer procedure SUM (a,b); value a,
 integer a,b;

 SUM: = a+b;

 Integer x,y;

 x: = SUM (4,5);

end;

```

|     |      |         |                    |
|-----|------|---------|--------------------|
|     | PRIM | CBL     |                    |
|     | UJ   | R1      |                    |
|     | PE   | 816     | (BN = 51)          |
|     | UJ   | R2      |                    |
| SUM | PE   | 834     | (BN = 52, m=2)     |
|     | /1   | 0       |                    |
|     | 1    | 0       |                    |
|     | IFUN | 832     |                    |
|     | TF   | a       |                    |
|     | TRCN | b       |                    |
|     | PRIM | I+I → I |                    |
|     | PRIM | ST      |                    |
|     | PRIM | RETURN  | (END OF PROC BODY) |
| R2  | TIA  | x       |                    |
|     | PRIM | UP      |                    |
|     | TIC  |         | {+4}               |
|     | TICA |         | {+5}               |
|     | CF   | SUM     |                    |
|     | PRIM | ST      |                    |
|     | PRIM | RETURN  |                    |
| R1  | PRIM | FINISH  |                    |

### 11.12 Permissible actual/formal correspondence

The general idea is that at the point of call, a value is left in the stack for every formal parameter called by value and an address is left for those which are called by name. Type conversion is explicitly done. The pords at the point of call are shown below:-.

#### 11.12.1 Formal real called by value

|          |         |     |                  |
|----------|---------|-----|------------------|
| Declared | real    | TRR |                  |
| "        | integer | TIR | and PRIM I TO R1 |

|                            |             |                   |             |
|----------------------------|-------------|-------------------|-------------|
| array element              | ...         | INDR and possibly |             |
|                            |             |                   | convert.    |
| type procedure             | PRIM UP ... | CF and            |             |
|                            |             | possibly convert. |             |
| constant                   | TRC or TIC  | and PRIMITORI     |             |
| Formal real on value list  |             |                   | TF          |
| Formal real called by name |             |                   | TRCN        |
| Formal integer             | etc         | as real with      | conversion. |

### 11.12.2 Formal real called by name

|                            |      |
|----------------------------|------|
| Declared real              | TRA  |
| Constant                   | TRCA |
| Formal real on value list  | RFUN |
| Formal real called by name | TF   |

Inside the body the parameter may appear on the left or the right of a: = sign and it may be called by name or value. These four cases produce pords as follows:-

| On the left |      | On the right |
|-------------|------|--------------|
| By name     | TF   | TRCN         |
| By value    | RFUN | TF           |

For arrays, procedures and strings which all have address among the program pords, a TA pord is used at the original point of call; if the parameter is to be handed on to an inside procedure then at the inner point of call a TF pord is produced.

A label may or may not be on the value list; if so then the actual parameter can be either a label TLA, or the element of a switch TIR, INDS ... It is regretted that it cannot be the element of a formal switch.

Array and procedure parameters must always correspond in type and number of dimensions or parameters. At the point of call the pord which refers to the following actual parameters is followed by the indicated primitive which places an integer in the stack for checking purposes.

|                          |      |    |     |
|--------------------------|------|----|-----|
| boolean or integer array | PRIM | 63 | +3  |
| real array               |      | 64 | +4  |
| " integer procedure      |      | 65 | +5  |
| real procedure           |      | 66 | +6  |
| procedure                |      | 67 | +7  |
| switch                   |      | 68 | +8  |
| label                    |      | 69 | +9  |
| string                   |      | 70 | +10 |



Inside the procedure body, at the first reference to an array or procedure parameter the checking word which was punched out at the head of the body is altered to indicate the number of dimensions or parameters. This is done by using loader code 3. If there is no reference to the parameter in question, then the address part of the checking word contains +8191 at run time.

DGNH.