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Title: 4-50 ALGOL COMPILER:-
THE INTERMEDIATE CODE

SUMMARY A definition of the Intermediate Code generated by the first pass of the 4-50 ALGOL Compiler

Distribution: see end of report

Introduction

The purpose of this document is to define the form of the Intermediate Code generated by the first pass of the System 4-50 ALGOL Compiler. Since the design of the Intermediate Code is based on that of the Object Program generated by the Whetstone KDF9 ALGOL Translator, use is made of the fact that the Whetstone Object Code is fully defined in the book 'ALGOL 60 Implementation', by B. Randell and L.J. Russell, Academic Press, 1964. The differences between the Intermediate Code and the Whetstone Object Code arise from (i) the three-pass structure of the System 4-50 ALGOL Compiler, which is designed to generate machine code as the end product, and (ii) the altered method of handling the run-time stack, now based on the ideas of the ALCOR-ILLINOIS 7090 ALGOL Compiler.

This document has a scope restricted to a definition of those parts of the System 4-50 ALGOL Intermediate Code which differ from the corresponding parts of the Whetstone KDF9 ALGOL Object Code. A working knowledge of the Whetstone Object Code is therefore assumed, although for those without access to the reference quoted above, a brief introductory section to the System 4 form is included. No attempt will be made in this document to describe the generation of Intermediate Code from the source Algol or the translation of the Intermediate Code into machine code, nor will the detailed modus operandi of the generated machine code programs be mentioned. A brief description of the overall structure of the compiler is included.

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A. GENERAL DESCRIPTION OF THE COMPILER

The System 4-50 ALGOL compiler is a three pass compiler, which translates source ALGOL into machine code modules. The three passes of the compiler are known as Phase 10, Phase 20, Phase 30. The System 4-50 ALGOL language and the compiler's relationship with the 5J Program Trials System are fully described in the System 4-50 ALGOL Reference Manual, Parts I and II.

The compiler translates a module at a time. A source ALGOL program, or a procedure for independent compilation, is presented to Phase 10. The action of Phase 10 is to

10.a) convert the source ALGOL into an internal code called Intermediate Code, generating as it does so

10.b) a set of two support tables. One is the Position Identifier Table, and is a reference table of labels and procedures, the other is the Level Parameters (b), containing information about the types and characteristics of procedures and their parameters. The Intermediate Code and the Position Identifier Table may be listed on request, as may

10.c) the Storage Map, a listing of the stack locations of the ALGOL variables. This item is not preserved after listing. A further function of Phase 10 is

10.d) to perform rigorous checks on the syntactic legality of the source ALGOL. The failure mechanism employed is, briefly, to detect and notify as many syntactic errors as possible without aborting either the translation or the generation of Intermediate Code and support tables. Upon detecting a syntactic error, the error is notified and a FAIL operation is planted in the generated Intermediate Code; then error recovery procedures are used to find the earliest point in the succeeding text at which translation can be resumed. This generally implies the loss of a statement or of a cluster of declarations. Naturally, this mechanism is not applied to catastrophic failures. The result is a sprinkling of FAIL operations in the generated Intermediate Code for the various syntactic errors detected. At object execute time each of these is an entry into the run-time failure routine, so that the first one to be dynamically encountered will terminate the run.

Phase 10 writes the Intermediate Code (10.a) and the support tables (10.b) to a work file, and finally initiates the call of Phase 20 as an overlay to itself. The action of Phase 20 is to

20.a) process the Intermediate Code and the support tables produced by Phase 10, to generate machine code with forward references missing.

20.b) The information required to supply these missing references is built up into a table which is an updated machine address form of the Position Identifier Table.

Phase 20 writes the machine code in this form (20.a) and the reference table (20.b) to a work file, and finally initiates the call of Phase 30 as an overlay to itself.

The action of Phase 30 is to

30.a) update the machine code using the information left in the work file by Phase 20. Phase 30 also

30.b) ensures that the resulting machine code module is in a form recognisable to the operating regime in which it will eventually run. This involves the generation of ESD, RLD, and END information. Then

30.c) the generated machine code module may optionally be listed in pseudo-usercode form.

The organisation of the transfer of information between one pass and the next via the work file (on the 5J Trials Library disc) is performed by a set of three special purpose disc handling routines (D,H,R.s) one for each pass. These D.H.R.s are written so as to use the disc as efficiently as possible.

The overlay structure of the compiler is controlled by a small root segment which consists of a single control module. The overlays brought down successively by the root segment are:

(1) Options processor
(2) Phase 10
(3) Phase 20
(4) Phase 30

Each overlay returns control to ROOT which then brings down the next overlay or returns control to the system (Compilation Control).

A(i). Note on the Running of the Object Code.

A relocatable binary module generated by the compiler will contain external references to other modules, namely:-

a) independently compiled modules, written originally in ALGOL or in usercode (later extensions may be made to include other languages), written by the user and called by him in the module concerned. If written in usercode, the rules listed in the Part II Reference Manual must be observed.

b) a standard module without which no object program can be run, containing a set of support routines for processes initiated in the object module or bound object modules being run. These routines are the Slave Routines. Examples are Float, Fix, Call by name, Procedure entry, Make array storage function, etc.. The full list appears in the Part II Reference Manual. This module is written initially in usercode, and is a standard package, supplied with the compiler.

c) a set of input-output modules, in sufficient number to satisfy the peripheral requirements of the program being run. The input-output procedures required to use the full range of System 4-50 standard peripheral devices are arranged in self-contained groups. The arrangement into modules is fully described in the Part II Manual. The input-output modules are written initially in usercode, and are supplied with the compiler as standard packages.

d) if required, any of the standard function modules required to perform the functions SIN, COS, etc.. For a full list see the Reference Manual Part II. These modules are written initially in usercode, and are supplied with the compiler as standard packages.

e) a dummy module destined to hold the run-time stack. This must always appear in store after all the other modules, that is its start address must be higher than the final address of any other module, to allow for its expansion when the object program is running. This module must always be present.

Having bound the generated object module with such object modules of types (a), (b), (c), (d) and (e) as are necessary, the resulting program may be run in the normal way. Note that modules of types (b), (c) and (d) will be bound automatically into the root segment unless otherwise specified. It is hoped to arrange for the stack (e) to be automatically included in the correct position for programs which do not use overlays.

1. INTRODUCTION TO THE INTERMEDIATE CODE:

NOTATION

The Intermediate Code generated by Phase 10 is a string of variable length pseudo-instructions, each pseudo-instruction comprising an operation field of 1 byte, and an operand field of length zero bytes or greater.

The operation field for convenience is assigned a mnemonic name for use in discussion. Such mnemonics are CF ("Call Function"), TFI ("Take Formal Integer"), PST ("Parameter String"). For the full list, see the Dictionary of Intermediate Code Operations, section 14. For the hexadecimal internal representations of these operations, see section 14B.

The operand field may consist of counts, labels, pointers, stack addresses, constants, or may be absent. The symbols used in this Report to denote quantities in the operand field are:-

k The hierarchy number. This is the nested procedure depth of the current procedure, starting at zero for the outermost program level. The maximum permitted value is k = 14.

s The stack address, in words, within the hierarchy, starting at s = Ø.

Both k and s are needed to specify a stack address completely. Stack addresses are denoted by (k,s), indicating that k and s are packed into two bytes, with 4 bits for k and 12 bits for s.

n The block level within the current (or destination) hierarchy, starting at n = 1. n requires 1 byte.

π The π'th entry in a support table called Level Parameters (b) (see below section 1B). Each entry in this table is 1 byte in length. π requires two bytes.

m Number of words of stack space in the current hierarchy required to hold the link data and parameters for this hierarchy. m requires 1 byte.

N The maximum block nesting depth within the current hierarchy, that is the greatest value of n. N requires 1 byte.

a Number of arrays in an array segment. a requires 1 byte.

b Number of dimensions of an array. b requires 1 byte.

r The r'th failure in this module. r requires 1 byte.

t The type of the operation which eventually gave rise to a syntactic failure. t requires 1 byte.

S4 Special form of the parameter s; thus (k, S4) gives the stack address of the first of the locations in the stack assigned to a for statement.

identifier — An identifier of up to eight EBCDIC characters, left hand justified and padded with spaces (X'40') at the right-hand end if necessary. Requires 8 bytes.

constant — The value of an explicit constant. Requires 4 bytes for integer constants, 8 bytes for real constants.

string — A string of basic symbols representing one-for-one the characters in the string as written in the ALGOL program, including all string quotes. One byte for each basic symbol.

L — Number of words of stack space in the current hierarchy required to hold the first order working storage, given by

$$L = m + \text{number of words of stack space required to hold all variables declared within the hierarchy, including 4 words for every array declaration.}$$

L appears in combined with k, as (k, L), so that 12 bits are required for L.

\- — A one byte space.

The remaining parameters refer to labels, described in the next section (1A).

1A. Labels.

Three kinds of labels are used in the Intermediate Code, as follows:

(i) L labels.

Labels written explicitly in the source ALGOL program are referred to internally as L labels. Thus Ll is the (l+1) th user's label to be declared. The number l is zero for the first label. As a parameter, l always appears in combination with k in the form (k,l), so that l requires 12 bits. Note that switches are assigned L labels, the name used in the Position Identifier Table (see below Section 1B) being the name of the switch.

(ii) P labels.

At a procedure declaration, the procedure is assigned a P label of the form Pp, denoting the (p+1)th procedure to be declared. The number p is zero for the first procedure declared. As a parameter, p always appears in combination with k in the form (k,p), so that 12 bits are required for p. The name used for each P label in the Position Identifier Table (see below) is the name of the procedure.

(iii) G labels.

For transfers of control in the Intermediate Code which are neither explicit (that is using a 'GOTO' statement, which employs L labels) nor procedure calls (which use P labels), G labels are generated of the form Gg, where the number g starts from zero for the first. As a parameter, g always appears on its own, and requires two bytes. For a G label, the name part in the Position Identifier Table (see below) is blank.

Throughout this document these labels, in both their left-hand and right-hand incarnations, have been written explicitly into the Intermediate Code for clarity of exposition. In fact, left-hand labels have no existence in the Intermediate Code; they exist only as entries in the Position Identifier Table (see below, Section 1B). Right-hand labels in the Intermediate Code are in fact the quantities l, p, and q defined above. These act as pointers to the appropriate entries in the Position Identifier Table, wherein are found the Intermediate Code addresses to which the labels refer.

1B. Support Tables.

The support tables required with the Intermediate Code are the Position Identifier Table and Level Parameters (b). There is a table called Level Parameters (a), but this is purely internal to Phase 10 and is not relevant to this discussion of the Intermediate Code.

Position Identifier Table:-

EXTERNAL NAME	INTERNAL NAME	I/C BYTE NO.	CARD NO.
6	3	2	5 BYTES

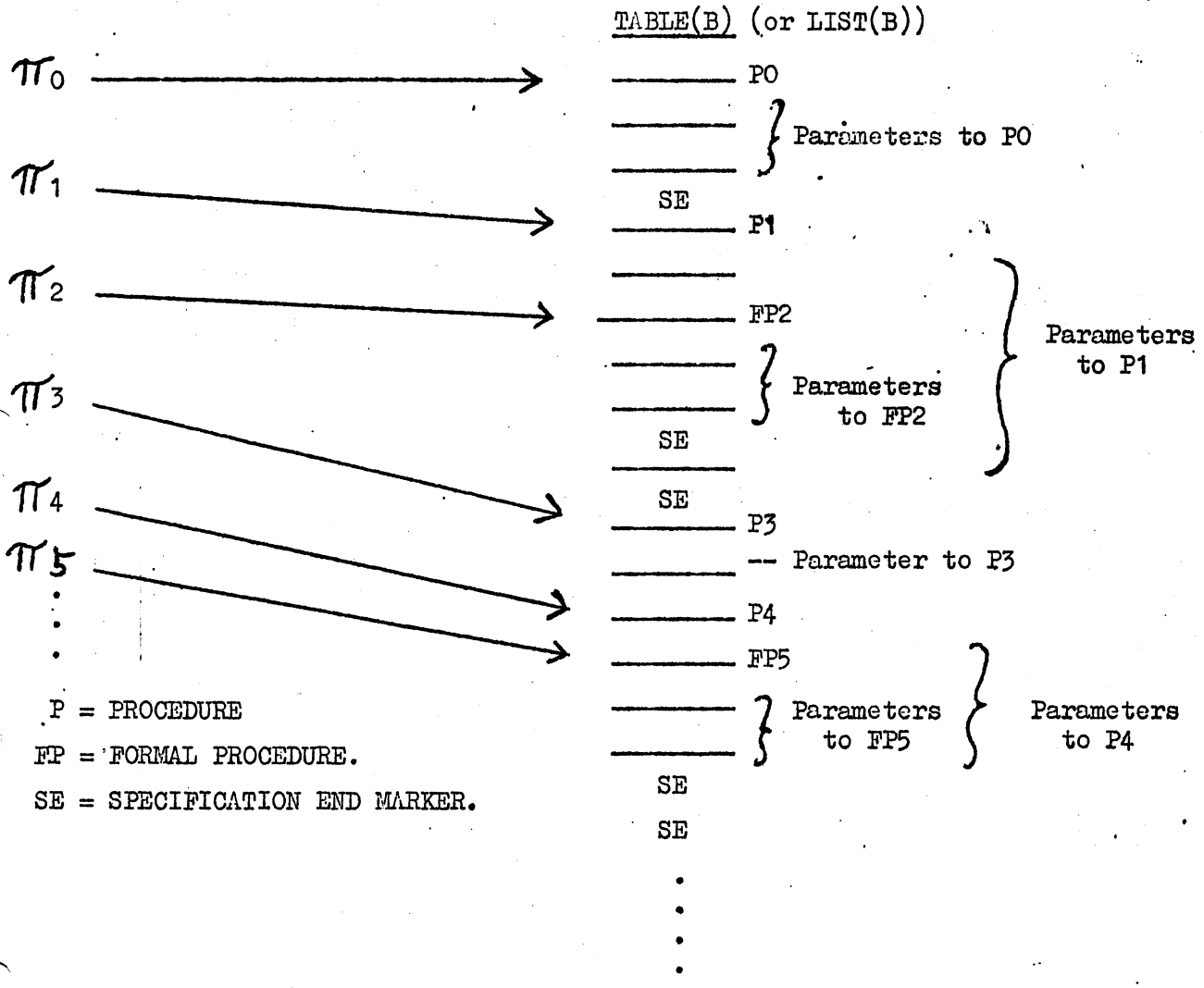
External Name : A string of eight 8-bit basic symbols packed into eight 6-bit characters. All external (source) names are held in this form in Phase 10 for economy of space. This item exists only within Phase 10 for use in failure messages and in diagnostic listings.

Internal Name : The first byte contains the 8-bit basic symbol for G, L, or P. The last two bytes contain the numeric value (as a binary integer) of g, l, or p, starting from Ø.

I/C Byte No. : The byte number of the labelled intermediate code operation, starting from 1.

Card No. : The current card number as read from the card, held as eight packed decimal digits held in 5 bytes. This item exists only within Phase 10 for use in failure messages and in diagnostic listings.

Level Parameters (b):-



Each entry in list (b) is one byte long. The parameter π (see (1)) is a pointer to a procedure entry in list (b), as indicated in the diagram above. The list of values of π is internal to Phase 10, and is indexed by the value of p assigned to each new procedure, including formal procedures. This list is called Level Parameters (a).

The entries in list (b) are, for the various situations:-

1) Procedure entry:-

NØØØtttt

a) N is 1 if the procedure has parameters, Ø otherwise
b) The next 3 bits are always zero.
c) tttt gives the type of the procedure according to the following scheme:-

ØØØ1 procedure	111Ø integer procedure
11Ø1 real procedure	1Ø11 boolean procedure.

2) Formal parameter:-

Ntttttt

a) N is set to 1 for parameters called by value. Thus N may be set to 1 for real, integer, boolean, real array, integer array, boolean array, or label parameters.

b) The next seven bits (t) give the type of the parameter according to the following scheme:-

ØØ111Ø1	real	0111101	real procedure*
0011110	integer	0111110	integer procedure*
0011011	boolean	0111011	boolean procedure*
1011101	real array	0100001	procedure*
1011110	integer array	1010001	switch
1011011	boolean array	0000001	label
		0000000	string

* Included here only for completeness.

3) Procedures which are parameters.

a) The entry for the formal procedure is

Ntttttt

where N is set to 1 if the formal procedure has parameters, and the seven bits (t) represent the type of the formal procedure according to the scheme in (2b) above (marked with an asterisk).

b) Parameters to the formal procedure are entered as in (2) above.

c) A parameter to the formal procedure which is itself a procedure is entered as the single entry

Øttttttt

as in (3a) above, with N=Ø.

4) The marker SE (Specification End) (X'FF') is used to terminate the entries for a normal or a formal procedure (but not in case (3c) above).

5) The information for the entries described in (3a), (3b), (3c) is obtained from the comment specification for the formal procedure.

2. BRIEF ILLUSTRATION OF THE INTERMEDIATE CODE IN USE

The Intermediate Code may be understood as an object language which on execution operates on a simple push-down operand stack. Before proceeding, it is important to note that throughout this section, references to stacking in fact refer to a notional stack imagined to exist for the Intermediate Code to operate on in a straightforward non-optimal way. These references to stacking are not necessarily to be applied to the stack used by the machine code object programs actually generated by this compiler. Whenever possible, the stack visualised for the Intermediate Code to operate on will be referred to as the notional stack.

A simple arithmetic statement will be used as an illustration.

Presuming A,B,C and D to have been declared as 'REAL',

A: = B + C * D

will have the Intermediate Code representation (reverse Polish):-

TRA (k,A)	Place address of A on notional stack
TRR (k,B)	Place value of B on notional stack
TRR (k,C)	Place value of C on notional stack
TRR (k,D)	Place value of D on notional stack
*	Multiply top two items of notional stack, leaving 1 result
+	Add top two items of notional stack, leaving 1 result
ST	Store result into A, leaving the notional stack empty.

TRA stands for Take Real Address, TRR stands for Take Real Result, ST stands for Store. All Take operations place an item on the notional stack. All dyadic operations such as multiply (*) and add (+) operate on the top two items of the notional stack, replacing them by a single result item. The operation store (ST) requires the top two items of the notional stack to be a result and an address, with the result item uppermost; its action is to store the result item into the location specified by the address item, finally deleting both the result item and the address item from the stack.

These manipulations all refer to the working area of the notional stack. The quantities (k,A), (k,B), etc., which define A, B, etc., are themselves addresses in the notional stack, but they are not addresses in the working area. The Intermediate Code operations generated at the declaration or specification of the quantities A, B, etc., define locations on top of the existing notional stack specifically to hold the values associated with A, B, etc., and the corresponding addresses (k,A), (k,B), etc., are thereafter reserved for this use alone. This applies throughout the current block level (but not necessarily throughout the current hierarchy k). Having reserved all such locations on the notional stack for the declared and specified variables, the remainder of the notional stack is used as a working area, as indicated in the example above,

Briefly, every time a new hierarchy is entered, a region of the notional stack is reserved to hold all the parameters to the hierarchy (procedure)

and all the information defining the variables declared in all contained blocks. This is called the first order working storage. The remainder of the notional stack is then used as a working region, and for holding any array elements. On exit from the current hierarchy (procedure), the whole region of the notional stack associated with it is thrown away. Note that the reservation of space on the notional stack for all variables declared in contained blocks is done in an optimal way, such that blocks at the same level in the hierarchy share the same or overlapping areas for their declared variables.

To terminate this brief introductory section, an Algol program will be presented, consisting of the arithmetic statement used above but this time in a procedural environment, together with an annotated listing of the resulting Intermediate Code.

```
'BEGIN' 'REAL' A,B,C,D;
        'PROCEDURE' P(X); 'VALUE' X; 'REAL' X;
                A:= X + C * D;
        A: = B: = C: = D: = 4;
        P(B)
'END'
```

The generated Intermediate Code is

```
    BE (1)          Start block level 1
    UJ (GØ)         Jump to by-pass the procedure declaration
PØ : PE (1,12),12,1 Start hierarchy k=1, reserving 12 words on the notional
                    stack for procedure P's link data and its parameter X.
    CP              . . . . . : This refers to the value of X (which is
                    called by value) in the new hierarchy's notional stack at
                    (1,10).  (See Section 4B)
    TRA (0,10)      A
    TRR (1,10)      X
    TRR (0,14)      C
    TRR (0,16)      D
    *
    +
    ST
    RETURN          End of the procedure.  Uses links in notional stack to
                    return to point of call.
GØ : TRA (0,10)     A
    TRR (0,12)      B
    TRR (0,14)      C
    TRR (0,16)      D
    TIC (4)         Put integer 4 on the notional stack
    STA  }
    STA  }          Store 4 into D,C,B,A successively (the operation STA
    STA  }          leaves 4 on the stack but deletes the destination address).
    ST   }
    CF (1,0),00     Initiates the call of procedure PØ ("Call Function")
    PSR (G1)
    TRR (0,12)      B } Sets up the parameter B
    EIS             }
G1 : APP            Marker for end of parameters
    BEND (1)        End block level 1 (that is main program)
    FINISH
```

2A. Note on the Translation of Designational Expressions

The following conventions are used when translating a designational expression into Intermediate Code:-

(i) Within an actual parameter expression or a switch declaration: The operations TL, TFLN, TFLV, and INDR (when used in a switch call), have the run-time effect of planting the resulting label onto the notional stack. No transfer of control is effected. A stacked label is a two-word item (8 bytes) containing

Topmost word:- address of start of working area in notional stack for the level at which the label is declared

Second word:- a) N (1 byte), the block level within the hierarchy at which the label was declared;

b) address in the compiled program pointed at by the label.

(ii) Elsewhere:

a) The operation TL at run time, having evaluated the label, effects an immediate transfer of control. Nothing is stacked.

b) The operations TFLN, TFLV, and INDR (when used in a switch call), at run time, all operate on the previously stacked label (see (i) above), effecting an immediate transfer of control.

Using these conventions, there is no need for the compiler to generate explicit transfer-of-control instructions, such as the GTA and GTFA of Whetstone KDF9 Algol.

3. BLOCKS

Within a hierarchy, block structure is represented in the Intermediate Code by:-

```
BE (n)                    (BE = Block Entry)
 .
 .
 .
 .
 .
 .
 .
BEND (n)
                          (BEND = Block End)
```

n is the block nesting number in the current hierarchy, starting from one at the start of the procedure body. For a labelled procedure body, n for the label is one, while n for the start of the procedure body becomes two.

An Intermediate Code block is created only at a 'BEGIN' followed by declarations, terminating at the corresponding 'END'. Space on the notional stack, to hold the necessary information about the declared quantities, is available throughout the period in which the block is active. This information is held in the first order working storage (see Section 2). Variables declared as integer or boolean occupy one word (4 bytes), variables declared as real occupy two words (8 bytes) and must be double-word aligned by the compiler, and quantities declared as arrays occupy four words (16 bytes).

4. PROCEDURES

4A. Procedure Structure in the Intermediate Code

Declarations

The form of the Intermediate Code generated for a procedure declaration is illustrated in the following schematic:-

UJ(Gg)	Present to prevent execution of the procedure before it is called.
Pp : PE(k,L),m,N	Procedure Entry operation.
Parameter list operations	To set up the parameters ready for use in the procedure body, if necessary. See section AB.
Procedure body	Normal Intermediate Code operations.
RETURN	Returns to the point of call of this procedure.
Gg:	If several procedure declarations are presented together, label Gg is not assigned until the last such procedure has been translated into Intermediate Code. That is, more than one procedure declaration may be by-passed by one UJ operation.

Note that at a procedure declaration, the operation PE is always assigned a P label, which is used both in the procedure call mechanism and for diagnostic purposes.

Calls

The form of the Intermediate Code generated at a procedure call is illustrated in the following schematic:-

Call operation	See section AC for details of call operations
Actual operations	Define the actual parameters of this procedure. See section AD.
APP	Marks the end of the list of actual operations.

4B. Parameter List Operations

The full list of these operations is:-

CRFA	Copy real formal array	
CIFA	Copy integer formal array	Arrays by value
ABFA	Copy boolean formal array	
CA	See below	Arrays by name
CP	See below	All other items by name or by value.

These intermediate code operations are all parameterless. The operations CA, CP are used only to locate the array word referred to by a subsequent copy operation (arrays by value).

4C Calls of Function Designators and Procedure Statements

The call operations for the various kinds of procedure (or function) are:-

CF (k,p),π	Call function	CFZ(k,p), π	Call function zero
CTF(k,p),π	Call type function	CTFZ(k,p),π	Call type function zero
CFF(k,s),π	Call formal function	CFFZ(k,s),π	Call formal function zero
CTFF(k,s),π	Call type formal function	CTFFZ(k,s),π	Call type formal function zero

The operations in the righthand column are used to call procedures with no parameters, and are distinguished by the addition of the descriptor 'zero'.
k is the hierarchy number of the called procedure, p is the index number of the called procedure Pp, π is the pointer to level parameters (b). The combination (k,s) for a formal procedure is the stack address of the formal parameter location for that procedure.

A function call which invokes a procedure as a function designator uses one of the operations CTF, CTFZ, CTFF, CTFFZ.

The corresponding call invoking a procedure as a procedure statement uses one of the operations CF, CFZ, CFF, CFFZ.

A location on top of the notional stack is reserved for the result of a type procedure. Use of a procedure statement will result in the deletion of the unused or superfluous result location.

4D. Actual Operations

At a procedure call, any actual parameters are translated into Intermediate Code involving some of the following special-purpose operations:-

PSR(Gg)	Parameter subroutine	EIS	End implicit subroutine
PRA(k,s),- PIA(k,s),- PBA(k,s),-	Par. real array Par. integer array Par. boolean array		
PSW(k,l),-	Par. switch	PFSW(k,s),-	Par. formal switch
PPR(k,p),π	Par. procedure	PFPR(k,s),π	Par. formal procedure
PIF(k,p),π	Par. integer function	PFFI(k,s),π	Par. formal function integer
PRF(k,p),π	Par. real function	PFFR(k,s),π	Par. formal function real
PBF(k,p),π	Par. boolean function	PFFB(k,s),π	Par. formal function boolean
PST ('('STRING')')	Par. string	PFST(k,s),-	Par. formal string
PEST	Par. end string		

Every actual parameter is translated into a sequence of Intermediate Code operations. This sequence of intermediate code operations is called an implicit (parameter) subroutine. The first operation in an implicit subroutine is always PSR, the last operation is always EIS. The label parameter Gg to PSR points to the next PSR or to APP, which ever is appropriate.

When an actual parameter is a (formal) array, a (formal) switch, a (formal) Procedure, or a (formal) string, the body of the implicit subroutine is the appropriate single parameter operation from the above list. Formal array parameters use the operations PRA, PIA or PBA.

When an actual parameter is a constant, the body of the implicit subroutine is one of the operations TIC, TRC, TBC.

When an actual parameter is a string, the body of the implicit subroutine consists of the operation PST, followed by the string in Algol basic symbols (including the opening and closing string quotes), followed by the marker operation PEST.

When an actual parameter is an expression or a designational expression, the body of the implicit subroutine is the sequence of Intermediate Code operations (not parameter operations) necessary to evaluate the appropriate result. This includes label identifiers.

When an actual parameter could be a valid left hand side of an assignment statement then the body of the implicit subroutine is the sequence of Intermediate Code operations (not parameter operations) necessary to evaluate the appropriate address.

4E. Example of a Procedure Call

The following rather unlikely procedure statement will be translated into Intermediate Code as an illustration of the generation of actual parameters.

```
P(A, A, 'TRUE', X + Y, C, 'IF' I = Ø 'THEN' R1 'ELSE' R2,
    S, Q, '('PING')', F, B'<'1, 4'>', T'<'2'>');
```

The following types are assumed for the variables occuring in this procedure statement:-

A	real
X	real
Y	real formal
C	real
C	real array
I	integer
R1	label
R2	label
S	switch
Q	integer procedure
F	procedure formal
B	integer array
T	switch

All parameters will be written symbolically, e.g. no numbers will be supplied for hierarchy numbers, block levels or stack addresses. Label numbers will be assumed to start from zero.

The Intermediate Code translation is:-

```
    CF(k,p),-          procedure call operation
    PSR(GØ)
    TRA(k,A)           A
    EIS
GØ: PSR(G1)
    TIC(4)             4
    EIS
G1: PSR(G2)
    TBCT               'TRUE'
    EIS
G2: PSR(G3)
    TRR(k,X)

    TFR(k,Y)
    +                  X+Y
    EIS
G3: PSR(G4)
    PRA(k,C),-         C
    EIS
```

```
G4: PSR(G5)
    BEX
    TIR(k,I)
    TICØ
    =
    IFJ(G6)
    TL(k,R1),n          R1
    UJ(G7)
G6: TL(k,R2),n          R2
    CEND
G7: EIS
G5: PSR(G8)
    PSW(k,S),-          S
    EIS
G8: PSR(G9)
    PIF(k,Q),π          Q
    EIS
G9: PSR(G1Ø)
    PST ('('PING')')    '('PING')'
    PEST
    EIS
G1Ø:PSR(G11)
    PFPR(k,F),π         F
    EIS
G11:PSR(G12)
    TIAA(k,B),2
    TIC1
    TIC(Λ)
    INDR(2)             B'<'1,Λ'>'
    EIS
G12:PSR(G13)
    SAPP(k,T)
    TIC(2)
    INDR(1)             T'<'2'>'
    EIS
G13:APP
```

AF. Use of Formal Parameters within a Procedure Body

The operations used within a procedure body to refer to a formal parameter fall into the following classes, depending on the specification of the formal parameter:-

a) By value

On entry to a procedure, the parameter locations set up for parameters called by value are initialised with the actual values of these parameters at the point of call of the procedure. By this means they are made local to the procedure body, and are operated on by Intermediate Code operations of the normal (non-formal) kind such as TIR, TRA (i.e. Intermediate Code operations whose mnemonic does not contain F for 'formal'). The stack parameters (k,s) to these Intermediate Code operations are the stack addresses of the parameter locations. This paragraph does not apply to labels by value (see below, (c)).

b) By name

The following Intermediate Code operations are used, in which (k,s) denotes the stack address of the appropriate formal parameter location:-

TFRA (k,s) TFIA (k,s) TFBA(k,s)	Addresses of arithmetic or boolean formal variables (scalars)
TFR(k,s) TFI(k,s) TFB(k,s)	Values of arithmetic or boolean formal variables (scalars)

c) Switches

For a formal switch, the operation TFS(k,s) is used instead of the operation SAPP(k,1). See Section 5.

d) Procedures

The operations used are

CFF(k,s),π	Call formal function
CTFF(k,s),π	Call type formal function
CFFZ(k,s),π	Call formal function zero
CTFFZ(k,s),π	Call type formal function zero

See Section(AC).

e) Labels

The operations used are

TFLN(k,s) Take formal label by name.
TFLV(k,s) Take formal label by value.

f) Arrays

The parameter locations on the notional stack for formal array parameters by name or by value contain exactly the same information as is used elsewhere for arrays. Use of such parameters therefore does not involve special operations. To be specific, the only operations involved for any arry accessing whatever are:-

TBAA(k,s),b Take boolean array address
TIAA(k,s),b Take integer array address
TRAA(k,s),b Take real array address

and the operations INDA(b) and INDR(b).

5. SWITCHES

5A. Switch Structure in the Intermediate Code

Declarations

The form of the Intermediate Code generated for a switch declaration is illustrated in the following schematic:-

```
    UJ(GØ)                    Present to prevent execution of the
                              switch before it is called.
L1: DSI(G1)                   Decrement switch index (see below)
    Evaluate 1st switch element
    EIS                       End implicit subroutine (terminator
                                for each element)
G1: DSI(G2)
    Evaluate 2nd switch element
    EIS
     .
     .
     .
     .
     .
     .
G(n-1): DSI(Gn)
    Evaluate nth switch element
    EIS
Gn: ESL                       End switch list (see below)
GØ:  .
     .
     .
     .
     .
     .
```

A switch is called by a switch designator with a subscript expression which is evaluated at the point of call. On transfer of control to the declared switch at the label L1, the function of the operation DSI is to subtract one from the value of the subscript expression and to jump to the next DSI if the result is non-zero. If this process continues until the operation ESL is encountered, a failure condition exists, because the specified subscript is out of the range defined by the switch list. Having found a DSI which reduces the subscript to zero (the mth DSI if the original value of the subscript was m), the appropriate switch element is evaluated, and the associated EIS causes a return to the point of call of the switch.

Note that a switch declaration is not made into a block. Note also that the first DSI in a switch declaration is assigned an L label, which is used both in the switch designator mechanism and for diagnostic purposes.

Designators

The form of the Intermediate Code generated for a switch designator is illustrated in the following schematic:-

SAPP(k,1)	Switch approaching
Evaluate subscript expression	
INDA(1)	Index address

The operation INDA is also used when evaluating subscripted variables, but the context is always sufficient to determine which use is intended.

5B. Switch Designators and Array Elements as Actual Parameters

If an actual parameter in a procedure call is written as e.g.

S'<'2'>'

it may not be known whether S is a switch or an array until later in the translation. It is therefore necessary to allow space for either eventuality in the Intermediate Code.

The alternative final results are:-

Switch designator		Array element
SAPP(k,1) DUMMY	corresponds to	TRAA(kms),1
INDA(1)	corresponds to	INDA(1)
TFS(k,s) DUMMY	corresponds to	TRAA(k,s),1

DUMMY is a one byte Intermediate Code operation whose only function is to fill space.

For the detailed implementation of this technique, refer to the documentation of Phase 1ø.

6. CONDITIONAL STATEMENTS AND EXPRESSIONS

The form of the Intermediate Code generated for a conditional statement or expression will be illustrated schematically for the case 'IF' B 'THEN' C 'ELSE' D, where C and D are either both expressions or both statements:-

```
    BEX                          Boolean expression marker
    Translation of B
    IFJ(GØ)                      If false jump (i.e. if B false)

    Translation of C
    UJ(G1)                       Unconditional jump

GØ: Translation of D
    CEND                         Conditional end marker
G1:  .
     .
     .
     .
     .
```

This implementation permits D itself to be a conditional statement or expression. In the case of a conditional statement 'IF' B 'THEN' C, where C is a statement, the translation into Intermediate Code is:-

```
    BEX
    Translation of B
    IFJ(GØ)
    Translation of C
    CEND
GØ:  .
     .
     .
     .
     .
```

7. ARRAYS

Declarations

The form of the Intermediate Code generated for an array declaration

('OWN') { ('REAL') / 'INTEGER' / 'BOOLEAN' } 'ARRAY' A,B,...,K'<'L1:L2,M1:M2,...,Z1:Z2'>'

where A,B,...,K represent the array identifiers, and L1 and L2, M1 and M2,.... Z1 and Z2 represent expressions defining the lower and upper bounds respectively of the first, second, ..., last dimensions, is illustrated in the following schematic:-

Translation of L1	
STACK	STACK is an array bound
Translation of L2	separator.
STACK	
Translation of M1	
STACK	
.	
.	
.	
.	
Translation of Z1	
STACK	
Translation of Z2	
Make Storage Function	See below for the forms of the
.	operation.
.	
.	
.	

The possible forms of the Make Storage Function operation are:-

MBSF(k,s),a	Make boolean storage function
MISF(k,s),a	Make integer storage function
MRSF(k,s),a	Make real storage function

where (k,s) is the stack address of the last of the stacked array items for A,B,...,K, from which the rest may be found. The stacked array items, each containing all the defining information for each individual array, are normally referred to as the array words, although in fact they each occupy four words on System 4 (16 bytes). All these array words generated from one array segment share the same storage function.

a is the number of arrays in the array segment (i.e. the number of the arrays A,B,...,K). This is also the number of array words generated by the make storage function operation.

Subscripted Variables

The form of the Intermediate Code generated for a subscripted variable A'<'I,J,...,Z'>', where I,J,...,Z are arithmetic expressions each of which may be a further subscripted variable, is illustrated by the following schematic:-

Take array address	See below for possible forms of this operation
Evaluate I	
Evaluate J	
.	
.	
.	
Evaluate Z	
INDR(b) or INDA(b)	Index result or Index address, according to context.

The possible forms of the Take array address operation are:-

TBAA(k,s),b	Take boolean array address
TIAA(k,s),b	Take integer array address
TRAA(k,s),b	Take real array address

where (k,s) is the stack address of the corresponding array word, and b is the number of dimensions of the array.

The operation INDR(b) delivers the value of the subscripted variable, INDA(b) delivers its address (on the notional stack).

8. FOR STATEMENTS

8A. General

A for statement is treated as a block which opens with the Intermediate Code operation.

FBE(n) For block entry,

which performs exactly the same functions as the operation BE(n), and terminates with the Intermediate Code operation

BEND(n) Block end

as used for normal blocks (see Section 3).

Because a for statement requires three parameters to control the running of the various for list elements, these three quantities are 'declared' at this point, that is, space is reserved for them, as if they had been declared explicitly, in the first order working storage (see Sections 2,3). The three parameters are:-

Stack address (words)	Parameter	Function
(k,s)	SA(boolean)	Marker controlling the action of the Intermediate Code operation AST (see Section 8E)
(k,s+1)	FI(integer)	The for index (see below and Section 8E).
(k,s+2)	S3(real)	Holds the initial value of the controlled variable each time round a for list element. Phase 10 treats S3 as real, but Phase 20 later determines its type to be the same as that of the controlled variable.

The stack address (k,s) is double-word aligned.

An extra block is created if the controlled statement is itself a block or a labelled block.

The quantity TI (Test Index) is also used but does not reside on the stack. At the beginning of each for list element it is a copy of FI. TI is the item actually decremented (in a register) by the operation DFI.

Several Intermediate Code operations have been introduced specifically for use in the translation of for statements. These operations are:-

DFI(Gg)	Decrement for index
AST(Gg)	Avoid step
STN	Special purpose ST operation with run time effect of ST
STFA	Store from address - special purpose ST operation
FNIT(k,SA)	For initialise
CSM	Controlled statement marker
STUN(Gg)	Step-until macro operation
FI-1	Decrement FI by 1, used in while elements.
STEP	Marker used in step until elements

The use of these operations will be clear from the examples which follow.

8B. For Statement Structure in the Intermediate Code

The form of the Intermediate Code generated for a for statement of the form

'FOR'V:= first element, second element,..., last element 'DO' Controlled statement,
is illustrated in the following schematic:-

```
   FBE(n)                          For block entry
   FNIT(k,S24)                     Initialise by setting SA
                                   to 'TRUE', FI and S3 to zero.
G0:Stack:= address of V
   S3:= value of V
   FI:= FI+1                       The copy . TI of the new FI is
                                   now available (in a register).
   DFI(G1)                         Decrement TI by one, and jump to
                                   G1 if non-zero.
   Translation of first element
   UJ(Gc)                          Jump to controlled statement
                                   (labelled Gc)
G1:DFI(G2)
   Translation of second element
   UJ(Gc)
G2:.
   .
   .
   .
   G(m-1): DFI(Gm)
     Translation of last (mth) element
     CSM
  Gc:Controlled statement
     UJ(G0)                        return for next element
  Gm:BEND(n)                       End of the for statement
```

The formats of the various kinds of for list element will now be described.

8C. Arithmetic Element

An arithmetic for list element is an arithmetic expression, A, say. The Intermediate Code form of A as an arithmetic for list element is illustrated in the following schematic:-

DUMMY	
DUMMY	
DUMMY	
Translation of A	
STN	Stores value of A into the location V whose address has been pre-stacked (see 8B).

This coding fits into the schematic in (8B) where the words "Translation of (nth) element" appear.

The three DUMMY operations are generated in case this element turns out to be a step- until element (see (8E)).

The special operation STN is generated instead of ST as an aid to the subsequent processing of the Intermediate Code by Phase 20. It is effectively a directive to Phase 20 to remember the address of V for use in translating subsequent elements into machine code. The machine code translation of STN is identical to that of the normal operation ST.

8D. While Element

The form of the Intermediate Code for a while element of the form C'WHILE'B, where C is an arithmetic expression and B is a boolean expression, is illustrated in the following schematic:-

DUMMY	
DUMMY	
DUMMY	
Translation of C	
STN	Stores value of C into V, whose address has been pre-stacked.
BEX	
Translation of B	
IFJ(GØ)	Return for next element if current element exhausted.
FI-1	Performs the function FI:=FI-1

This coding fits into the schematic in (8B) where the words "Translation of (nth) element" appear.

The three DUMMYs and the STN operation are present for the reasons listed in (8C).

It may be of interest to note that in this occurrence of IFJ(GØ), GO is a backward reference. With this unique exception, the label parameter to IFJ is always a forward reference.

8E. Step Until Element

The following schematic illustrates the form of the Intermediate Code generated for a step until element of the form
D'STEP'E'UNTIL'F,
where D,E, and F are arithmetic expressions:-

	AST(Gg)	Avoid step
	Translation of D	
	STEP	Marker to terminate D
Gg:	Translation of E	
	Translation of F	
	STUN(GØ)	Step until macro

This coding fits into the schematic in (8B) where the words "Translation of (nth) element" appear.

AST (Gg) takes the place of the three DUMMYs generated for arithmetic and for while elements. The function of this operation is to jump to Gg if SA is false.

The function of STUN (GØ) is to perform the step using S3 and E to evaluate the new value of V, to set SA correctly, and to exit to GØ when the element is exhausted, otherwise to perform FI:=FI-1 and to pass on to the controlled statement. At run time, STUN becomes a call of a Slave Routine (see Section(Δa(b))).

8F. Example of a For Statement

The Intermediate Code translation of the following for statement will be presented:-

'FOR' A:= 1 'STEP'2'UNTIL'1Ø, 15, A+2 'WHILE'A'LT'1Ø .

'DO' I:=A;

A is assumed to be 'REAL', I to be 'INTEGER'. Locations for S4 (boolean), FI (integer) and S3(real) are also created. The translation is:-

```
    FBE(n)
    FNIT(k,S4)
GØ: TRA(k,A)          Address of A on the notional stack
    TRA(k,S3)
    STFA              Performs S3:= value of A, deleting the address
                      of S3 from the notional stack. The value of A
                      is obtained from the location pointed at by the
                      address of A held in the notional stack.

    TIA(k,FI)
    TIR(k,FI)
    TIC1
     +
    STN               Performs FI:=FI+1

    DFI(G1)           Start of first element, 1 'STEP'2'UNTIL'1Ø
    AST(G2)
    TIC1
    STEP
G2: TIC(2)
    TIC(1Ø)
    STUN(GØ)
    UJ(G3)            Transfer control to controlled statement
G1: DFI(G4)           Start of second element, 15.
    DUMMY
    DUMMY
    DUMMY
    TIC(15)
    STN               Performs A:=15
```

```
    UJ(G3)          Transfer control to controlled statement
G4: DFI(G5)         Start of third element, A+2'WHILE'A'LT'1Ø
    DUMMY
    DUMMY
    DUMMY
    TRR(k,A)
    TIC(2)
     +
    STI             Performs A:=A+2
    BEX             Boolean expression marker
    TRR(k,A)
    TIC(1Ø)
     <
    IFJ(GØ)         Return for next element if this element is
                                                    exhausted.
    FI-1            Performs FI:=FI-1
    CSM             Controlled statement marker
G3: TLA(k,I)
    TRR(k,A)
    ST              Performs controlled statement I:=A,
    UJ(GØ)          Return for next element.
G5: BEND(n)         End of for statement
```

9. OWN VARIABLES

Own variables in the Intermediate Code are identified as hierarchy k=-1. That is, for an own variable k is 4 bits of all ones. Because of this convention, there are no Intermediate Code operations referring explicitly to own variables.

Own variables at run time do not reside on the notional stack, but in a special area which also holds the constants required by the generated program. Space for all own variables used in a program is reserved immediately on entry to a running program.

10. NOTE ON INDEPENDENT COMPILATION OF ALGOL PROCEDURES

Algol procedures may be presented to the System A Algol Compiler for independent compilation, provided they are presented to the compiler in the form

```
'BEGIN'
<procedure declaration>;
'END'
```

(The brackets<> are not literals but are used in the Backus normal form sense. See < procedure declaration > in paragraph 5.A.1 of the Revised Report on Algol 60.) The result of such a compilation is a machine code module which may be called from any other Algol module or base program. The Intermediate Code form of an independently compiled procedure, as would be expected from the form of the Algol above and from Section (AA), is:-

```
     ??(1)
     UJ(GØ)
PO:  PE(1,L),n,N
     Parameter list operations
     Procedure body
     RETURN
GØ:  BEND(1)
```

In a module or base program which calls an independently compiled procedure, the source Algol must contain a specification of the called procedure. The syntax of this specification, in the notation of paragraph 5.A.1 of the Revised Report on Algol 60, is

```
   <specification of independently compiled procedure>::=
    'PROCEDURE' <procedure heading> 'ENTER' <module entry name> |
<type>'PROCEDURE' <procedure heading> 'ENTER' <module entry name>
```

Semantically,

```
'ENTER' <module entry name>
```

stands in place of

```
<procedure body>
```

in the definition of a procedure declaration. The module entry name is the entry name assigned to the independently compiled procedure when it was compiled. This specification must be identical with the specification part of the independently compiled procedure. It is the user's responsibility to ensure that this is so, since the compiler makes no check (except that the amount of space reserved for parameters is checked at run time).

In conformity with Section (4A), the Intermediate Code form of the specification of an independently compiled procedure is

```
      UJ(Gg)
Pp:   PE(k,L),m,N
      Parameter list operations
      ENTER (module entry name)
      RETURN
Gg:   .
      .
      .
      .
```

ENTER is here an Intermediate Code operation whose parameter is the entry name of the called module, up to eight characters in length. This method of implementation incidentally means that the procedure identifier used in the calling module need not be the same as the procedure identifier of the called module.

Example:-

Calling module

```
'BEGIN' 'INTEGER' X;
'REAL' 'PROCEDURE' FORGE(A,B,C);
    'INTEGER' A,B,C;
    'ENTER' MODULE1;
X:= FORGE(4,3,2)
'END'
```

Called module

```
'BEGIN' 'REAL' 'PROCEDURE' ANVIL(U,V,W);
        'INTEGER' U,V,W;
        ANVIL:= W↑U↑V;
'END'
```

Compiled with entry name MODULE1.

The call of the procedure FORGE in the calling module is in fact a call of the independently compiled procedure ANVIL, whose entry name is MODULE1.

11. LIBRARY PROCEDURES

All standard input-output procedures, 42 in number, may be used without the specifications described in Section(10), as may all 9 standard functions
ABS, SIGN, SQRT, SIN, COS, ARCTAN, LN, EXP and ENTIER.
The full list of the 42 standard input-output procedures appears in the Algol Reference Manual. If these procedures are used without specification, then the compiler will automatically supply specifications of the standard library versions. If however the user does not desire to use the standard library version of one of these procedures, then he must supply the Algol specification giving the entry name of the module he wishes to use instead, as in Section 10.

The Intermediate Code specifications of the standard procedures supplied by the compiler appear as the final items in the generated Intermediate Code, and they have the format:-

```
PE(1,L),n,N
ENTER (module entry name)
RETURN
```

In the special case of the four procedures FORMAT, ABS, SIGN, and ENTIER, the Intermediate Code specifications generated by the compiler use the parameterless Intermediate Code operations FORMAT, ABS, SIGN, and ENTIER in place of ENTER (module entry name). This is because the four named procedures are implemented without recourse to independently compiled modules. The user, of course, may still pre-empt this system by supplying a specification of a module he prefers to the standard versions that would otherwise be built into his object program.

12. THE INTERMEDIATE CODE OPERATION TRACE

If the option ROUTE is specified on the // COMPILE card for an Algol module (see PS A.13.5 (5J/7400) and Algol Reference Manual Part 2), then the Intermediate Code operation

TRACE (8 character identifier in 6 bytes in packed ABS form)
is generated in the following positions:-

a) Labels

At every use of a label on the left-hand side (a "declaration") the operation TRACE is generated with the identifier of the label itself as parameter.

e.g. L1: FIN2: 'END'

would be translated into

```
    L1:  TRACE (␣␣␣␣␣␣␣ L1)
L(1+1):  TRACE (␣␣␣␣ FIN2)
         BEND (n)
```

in which e.g. the parameter L1 appears in packed Algol basic symbol form as ØØØØØØØØØ 5C1.

b) Procedures

At every procedure declaration the operation TRACE is generated with the identifier of the procedure itself as parameter.

e.g. 'PROCEDURE' STRUM(X);. . .

would be translated into

```
Pp : PE (k,L),n,N
     TRACE ( ␣␣␣ STRUM)
       .
       .
       .
```

This operation TRACE permits an explicit run-time listing of labels passed and procedures entered to be made.

13. THE INTERMEDIATE CODE OPERATIONS FAIL AND LFAIL

When Phase 1Ø detects an error condition at the point of error in an Algol source program, e.g. a mis-spelt basic symbol, then the Intermediate Code operation.

FAIL(r)

is generated, where r is the serial number of the current failure (i.e. the rth failure detected so far). Phase 1Ø then recovers and proceeds with the translation and generation of Intermediate Code. This type of fail operation is called an immediate failure.

When Phase 1Ø detects a failure condition later than the actual point of error (e.g. an identifier not declared), then the Intermediate Code operation

LFAIL (r, skeleton operation)

is generated. LFAIL stands for late failure. r has the same meaning as above. 'Skeleton operation' is a one-byte item whose purpose is to give the successor pass, Phase 2Ø, information about the type of operation that was present before Phase 10 found it necessary to back-track and plant LFAIL. The method of doing this, and the whole problem of skeleton chaining, is dealt with in the documentation of Phase 1Ø. The five possible skeleton operations are:

RO	Result operation	(e.g. TRR)
AO	Address operation	(e.g. TRA)
SO	Statement operation	(e.g. P; - a parameterless procedure call)
FO	Function operation	(e.g. CF)
PO	Parameter operation	(e.g. PRA)

14. DICTIONARY OF INTERMEDIATE CODE OPERATIONS

Operation Mnemonic		Hexadecimal Operation Value	Parameters
ABS	Standard function ABS	C1	None
APP	Actual Parameters terminal marker	19	None
AST	Avoid Step	ØF	g
BE	Block Entry	Ø4	n
BEND	Block End	Ø5	n
BEX	Boolean Expression marker	FC	None
CA		ID	None
CBFA	Copy Boolean Formal Array	6B	None
CEND	Conditional End Marker	FD	None
CF	Call Function	8Ø	(k,p),π
CFF	Call Formal Function	9Ø	(k,s),π
CFFZ	Call Formal Function Zero	98	(k,s),π
CFZ	Call Function Zero	88	(k,p),π
CIFA	Copy Integer Formal Array	6A	None
CP		1C	None
CRFA	Copy Real Formal Array	69	None
CSM	Controlled Statement Marker	FE	None
CTF	Call Type Function	81	(k,p),π
CTFF	Call Type Function Formal	91	(k,s),π
CTFFZ	Call Type Function Formal Zero	99	(k,s),π
CTFZ	Call Type Function Zero	89	(k,p),π
DFI	Decrement For Index	ØE	g
DSI	Decrement Switch Index	Ø8	g
DUMMY	Dummy operation	FF	None
EIS	End Implicit Subroutine marker	14	None
ENTER	Enter independently compiled procedure	Ø7	Entry Name
ENTIER	Standard function Entier	C9	None
ESL	End Switch List marker	Ø9	None
FAIL	Compilation Failure	1F	r

Operation Mnemonic		Hexadecimal Operation Value	Parameters
FBE	For Block entry	Ø6	n
FI-1	For Index minus one	CB	None
FINISH	Finish marker for end of Intermediate Code.	ØØ	None
FNIT	For statement Initialise	CS	(k,S4)
FORMAT	Input-Output Procedure FORMAT	C5	None
IFJ	If False Jump	B2	g
INDA	Index Address	6C	b
INDR	Index Result	7Ø	b
LFAIL	Late compilation failure	1B	r,t
MBSF	Make Boolean Storage Function	63	(k,s),a
MISF	Make Integer Storage Function	62	(k,s),a
MRSF	Make Real Storage Function	61	(k,s),a
NEG	Negate (unary minus)	F1	None
PBA	Parameter Boolean Array	CF	(k,s),-
PBF	Parameter Boolean Function	D3	(k,p),
PE	Procedure Entry	Ø1	(k,L),m,N
PEST	Parameter End String marker	CC	(none),m,N
PFFB	Parameter Formal Function Boolean	DB	(k,s),
PFFI	Parameter Formal Function Integer	DA	(k,s),
PFFR	Parameter Formal Function Real	D9	(k,s),
PFST	Parameter Formal String	DE	(k,s),-
PFSW	Parameter Formal Switch	DF	(k,s),-
PFPR	Parameter Formal Procedure	D8	(k,s),
PIA	Parameter Integer Array	CE	(k,s),-
PIF	Parameter Integer Function	D2	(k,p),
PPR	Parameter Procedure	DØ	(k,p),
PRA	Parameter Real Array	CD	(k,s),-
PRF	Parameter Real Function	D1	(k,p),
PSR	Parameter Subr utine	D1	g
PST	Parameter String	D6	'string'
PSW	Parameter Switch	D7	(k,l),-
RETURN	Return from procedure call	Ø2	None

Operation Mnemonic		Hexadecimal Operation Value	Parameters
SAPP	Switch Approaching	18	(k,l)
SIGN	Standard function SIGN	C2	None
ST	Store	F8	None
STA	Store Also	F9	None
STEP	STEP marker in step-until element	ØB	None
STFA	Store From Address, (for statements).	FB	None
STN	Special purpose Store used in for statements	FA	None
STUN	Step Until	ØA	g
TBA	Take Boolean Address	A3	(k,s)
TBAA	Take Boolean Array Address	53	(k,s),b
TBCF	Take Boolean Constant False	3B	None
TBCT	Take Boolean Constant True	37	None
TBR	Take Boolean Result	23	(k,s)
TFB	Take Formal Boolean	2B	(k,s)
TFBA	Take Formal Boolean Address	AB	(k,s)
TFI	Take Formal Integer	2A	(k,s)
TFIA	Take Formal Integer Address	AA	(k,s)
TFLN	Take Formal Label (by Name)	A9	(k,s)
TFLV	Take Formal Label (by Value)	A8	(k,s)
TFR	Take Formal Real	29	(k,s)
TFRA	Take Formal Real Address	A9	(k,s)
TFS	Take Formal Switch	78	(k,s)
TIA	Take Integer Address	A2	(k,s)
TIAA	Take Integer Array Address	52	(k,s),b
TIC	Take Integer Constant	32	constant
TICØ	Take Integer Constant Zero	36	None
TIC1	Take Integer Constant One	3A	None
TIR	Take Integer Result	22	(k,s)

Operation Mnemonic		Hexadecimal Operation Value	Parameters
TL	Take Label	AØ	(k,l),n
TRA	Take Real Address	A1	(k,s)
TRAA	Take Real Array Address	51	(k,s),b
TRACE	Trace	9A	identifier
TRC	Take Real Constant	31	constant
TRR	Take Real Result	21	(k,s)
UJ	Unconditional Jump	B1	g
PLUS	+	EØ	None
MINUS	-	E1	None
MULT	x	E2	None
DVDE	/	E3	None
IDIV	÷	E4	None
EXP	↑	E5	None
GT	>	E8	None
GE	≥	EC	None
=	=	EF	None
NE	≠	EE	None
LE	≤	ED	None
LT	<	E9	None
NOT	¬	FØ	None
AND	∧	F4	None
OR	∨	F5	None
IMPL	⊃	F6	None
EQUIV	≡	F7	None

14A. Parameter Notation

l	l'th User's label (p≤l). Numbered in order of declaration.
g	g'th generated label (Ø≤g). (2 bytes) (2 bytes)
p	p'th procedure label (Ø≤p). Numbered in order of declaration.
k	hierarchy number (Ø≤k). (1 byte) (4 bits)
(k/l)	k and l packed into two bytes with 4 bits for k and 12 bits for l.
(k/s)	Stack address. k and s packed into two bytes with 4 bits for k and 12 bits for s, where s is the number of words along the notional stack from the start (s=Ø) of the stack for the current hierarchy k.
(k,L)	k and L packed into two bytes with 4 bits for k and 12 bits for L, where L is the number of words of first order working storage (including parameter space and link data) for the hierarchy k and its constituent blocks,
(k/p)	k and p packed into two bytes with 4 bits for k and 12 bits for p.
n	n'th block level in current (or destination) hierarchy (1≤n). (1 byte).
π	π'th entry in Level Parameters (b) (0≤π) (2 bytes)
n	Number of words along notional stack for some hierarchy k from s=0 to s= end of parameter space (1 byte).
N	Total block nesting depth within current hierarchy. (1≤N) (1 byte)
Constant	1 word for integer or boolean constants, containing the explicit constant. 2 words for real constants, containing the explicit constant.
'string'	Basic symbol respresentation (unpacked - i.e. 1 byte per symbol) of the string, including the opening and closing string quote symbols.
-	4 one byte space
a	Number of arrays in an array segment (1 byte)
b	Number of dimensions of an array (1 byte)
r	r'th failure for this module
S4	Special location used in for statements. See Section 8A.
t	Type of operation now replaced by the current LFAIL operation, according to the following code:-

RO	X'2Ø'	Result operation	(1 byte)
AO	X'4Ø'	Address operation	
SO	X'6Ø'	Statement operation	
FO	X'8Ø'	Function operation	
PO	X'CØ'	Parameter operation	

Entryname	Up to 8 EBCDIC characters, left-hand justified and padded out with spaces (X'40') as necessary.
Identifier	Up to 8 Algol Basic Symbols packed into 6 bytes, each Basic Symbol occupying 6 bits. The significant 6 bit items are right-hand justified in the 6 byte field, padded out with zeros if necessary.

1st Dig. \ 2nd Dig.	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	FINISH	PE	RETURN		BE	BEND	FBE	ENTER	DSI	ESL	STUN	STEP			DFI	AST
1					EIS				SAPP	APP		LFAIL	CP	CA	STACK	TAIL
2	RO	TRR	TIR	TBR						TFR	TFI	TFB				
3		TRC	TIC				TICØ	TBCT			TIC1	TBCF				
4	AO	TRA	TIA	TBA						TFRA	TFIA	TFBA				
5		TRAA	TIAA	TBAA												
6	SO	MRSF	MISF	MBSF						CRFA	CIFA	CBFA	INDA			
7	INDR								TFS							
8	CF or FO	CTF							CFZ	CTFZ						
9	CFF	CTFF			TRACE				CFFZ	CTFFZ						
A	TL								TFLV	TFLN						
B		UJ	IFJ													
C	PO	ABS	SIGN			FORMAT				ENTIER	FNIT	FIS1	TEST	PRA	PIA	PBA
D	PPR	PRF	PIF	PBF	PSR		PST	PSW	PFPR	PFFR	PFFI	PFFB			PFST	PFSW
E	+	-	X	/	÷	↑			>	<			≥	≤	≠	=
F	NOT	NEG			AND	OR	IMPL	EQUIV	ST	STA	STN	STFA	BEX	CFND	COM	DUMMY

ALGOL BASIC SYMBOL	REPRESENTATION ECMA	REPRESENTATION ALTERNATIVE	
A-Z	A-Z		
a-z	A-Z		
ø-9	ø-9		
$_{10}$ (subscript ten)	'1ø'	@	
.	.		
real etc	'REAL' etc		
↑	'**'	^ or **	
<	'LT'	<	
¬	'NOT'	¬	
(	(		
[	'<'	(/	
' (open string)	'('		
┼ (string space)	'_'	—	N.B — is the 'break' or 'underline' character
+	'/'	//	
≤	'LE'	<=	
^	'AND'	&	
)	)		
;	;		
]	'>'	/)	
' (close string)	')'		
/	/		
=	'EQ'	=	
V	'OR'	| or !	
,	,		
x	*		
≥	'GE'	>=	
⊃	'IMPL'		
:=	:=		
:	:		
(string tab)		?	
+	+		
>	'GT'	>	
≡	'EQUIV'		
(string new line)		o/o	
—	—		
≠	'NE'	# or ¬=	
(string page change)		ø	
(segment)		'ENTER'	