III. Overview of the B1700

The B1700 is a small, general-purpose computer (Burroughs, 1972b) that is particularly wellsuited for interpretation and emulation. The features of the B1700 that make it unique and unprecedented are:

1) Dynamically alterable, vertical microprogramming
2) Bit addressable main memory
3) Dynamic control of functional width of processor registers and busses
4) Dynamic control of memory access width
5) Microprogram subroutine capability
6) Stack structure

(For a more detailed discussion of the B1700, see Wilner, 1972a).

Principles first espoused in the Burroughs B5500 (Burroughs, 1969b) and in the Burroughs B3500 (Burroughs, 1969d) have culminated in the B1700. The B5500 is designed to process ALGOL, while the B3500 is a COBOL machine. Both of these machines have their designs hard-wired into them. The B1700, however, is "soft" at the level that the others are "hard". This, combined with a micro-order designed for interpreter writing, combined with the attributes listed above, have produced a machine that is singular in its capacities.

The virtual machines which have been produced for the B1700, including the SDL machine, are an order of magnitude more powerful at what they do than are hard-wired systems. Programs represented in these soft machine languages are from 25% to 75% smaller than on byte-oriented systems.

IV. The SDL Machine

The SDL language was designed to be used for implementation of the MCP and for implementation of the different compilers. In conjunction with the design of the language, was the design of a "machine" that would "execute" the statements of the language.

The SDL machine is a conglomeration of the ideas of many people. Particularly included are the language-directed design ideas of McKeeman (McKeeman, 1967), the stack and display mechanism of Randell and Russell (Randell, 1964), and the design of the Burroughs B6700 (see Hauck, 1968). See also Burroughs, 1969b and Burroughs, 1969c. The original SDL machine was designed by G. Brevier and B. Rappaport of Burroughs Corporation. Later additions and modifications to the basic machine design included ideas of C. Kaekel and the author, as well as other employees of Burroughs Corporation.

This section will describe the resulting S-machine and S-language.

A. Stack Mechanism

A B1700 program consists of code segments scattered in memory, one block of data bounded by a Base Register and a Limit Register, and a contiguous, read-only block (the Run Structure) containing program attributes. Also scattered throughout memory, in addition to code segments, are file attribute blocks and segment dictionaries. The area inside Base-Limit is divided into two parts: a static part and a dynamic part. In the case of an SDL program, the static area contains the S-machine stacks and the dynamic area contains paged array page tables and paged array pages (see Figure 1).

The SDL machine stack structure originally evolved from Randell and Russell (see Randell, 1964) and from the B6700 (see Hauck, 1968). This scheme has proved to be clean and easy to implement, and has resulted in a relatively small amount of code in the interpreter for stack management.

The structure of the S-machine stacks is shown in Figure 2a. The inter-relationships among the stacks are shown in Figure 2b. The Name Stack and the Program Pointer Stack run toward the Base Register (toward low memory addresses); the others run toward the Limit Register (high memory addresses). The stacks are used as follows:

1) Program Pointer Stack: This is a 32-bit wide stack that holds code addresses. Entries are pushed onto this stack upon procedure or DO group entrance, and are popped off upon procedure or DO group exit.
2) Control Stack: This is a 48-bit wide stack which maintains

the dynamic history of the allocation of data items. Entries are pushed onto this stack upon entrance to procedures with parameters and/or local data, and are popped off upon exit from these procedures.

3) Name Stack: This is a 48-bit wide stack that holds data descriptors. The data descriptors may contain values (self-relative) or the address of the values (in the Value Stack). Each lexic level's data descriptors occupy a contiguous block of entries in the Name Stack.

4) Value Stack: The Value Stack is a variable width stack which contains values of currently allocated (non self-relative) data items, as well as the values of temporary data items (i.e., intermediate values of expressions).

5) Evaluation Stack: The Evaluation Stack is a 48-bit wide stack which contains data descriptors for intermediate results and for temporary storage of procedure actual parameters.

6) Display: Display is a 32-bit wide array, the entries of which contain the addresses of the blocks of data allocated by the currently active lexic levels. The addresses in Display point into the Name Stack. A lexic level number is used to subscript into Display. In other words, Display points to all the groups of descriptors that can be currently addressed.

B. Opcode Structure

Because of SDL's stack structure and segmentation, code and data addresses are short, making the number of bits devoted to opcodes quite significant. In fact, more bits are used for opcode representation than for any other purpose, amounting to over one-third of a program's code space. Consequently, it was essential that not only should opcodes be represented in as compact manner as possible, but also that decode time for opcodes should be minimal.

The SDL S-operators use an encoding based on static frequence of occurrence. Operators are 4,6, or 10 bits in length with the most frequently occurring operators requiring the smaller number of bits.

The first 10 of the 4-bit codes (0_{16} through 9_{16}) represent operators. The next 5 are escape codes which indicate that the next 2 bits are to be examined in order to determine which operator is to be used. The last 4-bit code (F_{16}) is an escape code which indicates that the next 6 bits are to be used in order to determine which operator is to be used (see Figure 3).

Originally, the SDL S-operators were encoded using a 3-bit, 9-bit code. After a fairly large amount of working SDL code had been generated (in the MCP and the compilers) an analysis was done (on a static basis) of the operators used in that code in an attempt to verify that the proper encoding had been chosen, or, alternatively, to empirically arrive at one that would be optimal.

If Huffman's algorithm for minimum redundancy codes (see Huffman, 1952) had been used for SDL opcodes, the space requirements would have been minimal, but the time for decoding would have been large. A fixed field size would have minimized decoding time but would have required a large amount of storage. Using the opcode frequence obtained from the analysis mentioned above, an encoding was obtained that was very near the Huffman encoding in space required, but still small in decoding time (see Figure 4a,b).

Appendix I contains the SDL S-operators, along with their arguments and sizes. It is, perhaps, interesting to note that:

1) The operator associated with IF-THEN (IFTH) is a 4-bit operator while the operator associated with IF-THEN-ELSE (IFEL) is a 6-bit operator .
2) All types of literals are used frequently enough to warrant 4-bit operators (ZOT, ONE, LITN, LIT)
3) Load Address (LA) is a 4-bit operator while Load Value (L) is a 6-bit operator. This result indicates (because of the way that the SDL expression code generator generates code) that there are more "simple" expressions than "complex" ones.
4) The operator (UNDO) for DO group and simple procedure exits is a 4-bit operator
5) Comparison for equal (EQL) and unequal (NEQ) are more frequently used than the other comparison operators (LSS, LEQ, GTR, GEQ)

For further description of B1700 memory utilization, see Wilner, 1972b.

C. Descriptor Formats

Each SDL data item is represented by a descriptor which specifies the attributes of that data item. The data attributes are thus contained in the data area, rather than being imbedded in the code. The implications of this are that there tend to be fewer instructions (for example, there is one add instruction for all possible types—including mixed types—rather than a bit add, a character add, a fixed add, etc.) and that the instructions tend to be more compact since they reference descriptors for attributes, rather than contain the attributes themselves.

Descriptors in SDL are of two types: simple variables and arrays (variables to be subscripted). Simple descriptors are 48 bits in length while array descriptors are 96 bits in length. (See Figure 5.)

Simple descriptors have a type field (discussed below), a length field, and a field which contains the data (if the data is not more than 24 bits in length and is not in a structure), or the address of the data (if the data is more than 24 bits in length or is in a structure).

Array descriptors have a type field, a field giving the length of each element, a field giving the address of the first element, a field giving the number of bits to truncate from the right of a subscript to obtain the page subscript (paged arrays only), a field giving the length between elements (this is equal to the length of the element on the lowest level only of a structured array), and a field giving the number of elements in the array.

The bits in the type field (see Figure 5) are used as follows:

Bit	Use
0	1 if the value has been loaded to the top of the Value Stack (used when the descriptor is on the Evaluation Stack only); 0 otherwise
1	1 if descriptor is non self-relative; 0 otherwise (data item is in address field)
2	1 if array descriptor; 0 if simple descriptor
3	1 if length of element equals length between elements; 0 otherwise (arrays only)
4,5	Data type; BIT (00), FIXED (01), CHARACTER (10), VARYING (11) (formal descriptors only)
6	1 if paged array; 0 otherwise (arrays only)
7	1 if length varying (formal descriptors only)

It should be pointed out that the use of descriptors along with the bit-addressability of the B1700 allows a greater variety of data representations, so that the extra bits are more than made up for by not having to use "unnatural" representations (a byte for a one-bit flag, for example).

D. Code Addressing

All code on the B1700 is not only re-entrant, but also automatically relocatable, since code addressing is done through code pointers (segment Dictionary entries), rather than with memory addresses (this is necessary for re-entrancy when the code is overlayable, but not sufficient: see IV-E, Data Addressing). The MCP and compilers tend to be large programs and, hence, have a large number of segments since the segments themselves must be small (due to the memory restrictions of the B1700). In addition, in procedure-oriented languages such as SDL, and in compilers in particular, programs are written in"passes" (this is also true for the MCP, to some extent: the collection of procedures to process control cards, for example, or the procedures to process I/O error conditions). In other words, code which is executed together in time is gathered into segments, and segments which are executed together in time are gathered together into pages. Thus, SDL code addresses specify (either explicitly or implicitly) a triple that is used to generate an actual memory address if the segment is present, or a disk address if the segment is missing from memory.

Code addresses in the SDL machine actually appear as pairs, triplets, or quadruplets (Figure 6).

The Type field indicates the presence or absence of the Segment Number field and of the Page Number field, as well as the size of the Displacement field. The Page Number is the entry in the master Segment Dictionary used to find the minor Segment Dictionary to be used (if the minor Segment

Dictionary is not present, then an interrupt is generated). The Segment Number is used to locate the entry in the minor Segment Dictionary which gives the location of the desired segment (if the segment is not present, then an interrupt is generated). The Displacement gives the relative offset into the segment of the instruction being referenced.

This encoding allows the SDL machine to directly address 2^{30} bits of code. This yields a 38.4% savings in space for the SDL machine when compared to a byte-oriented machine with equal addressing capability (see Wilner, 1972b).

E. Data Addressing

SDL data addresses are two-part addresses, the first part specifying the lexic level of declaration of the data item, and the second part specifying the occurrence number of the data item within that lexic level. The data addresses do not contain memory addresses: this is the second condition that is necessary for re-entrancy. It also allows SDL procedures to be automatically recursive, and is part of the up-level addressing scheme.

SDL data addresses are three-part addresses (see Figure 7). The Type field specifies the size (and type of contents) of the two following fields. The lexic level field indicates which entry of Display to use to subscript into the Name Stack. The occurrence number field is the number of 48-bit descriptors to offset to find the indicated descriptor. If Display and the Name Stack are considered as arrays, and V(LL,ON) is the address represented by a Type, Lexic Level, Occurrence Number triple, then

V(LL,ON)=NAME.STACK(DISPLAY(LL)+ON)

represents the formula used to calculate an address in the Name Stack.

F. Descriptor Construction Operators

As a procedure (lexic level) is entered, the local data for that lexic level is created by entering onto the Name Stack the descriptors for the local data. The descriptors are constructed with operators.

Rather than carry the descriptors intact in the code or somewhere else in memory, they are carried, in an encoded form, in-line behind the operators which describe how the address field of the descriptor is to be derived. The in-line descriptor format and the Construct Descriptor Operators and their arguments are shown in Figure 8a. The formulae for descriptor address calculations are shown in Figure 8b.

The action of each of the operators is as follows:

Construct Descriptor Base Zero (CDBZ): A descriptor is put on the Name Stack with an address of zero.

Construct Descriptor Local Data (CDLD): The number of descriptors specified are constructed using the current value of the Value Stack Pointer as the address. The Value Stack Pointer is kept current as each descriptor is put on the Name Stack by adding to the Value Stack Pointer the length of the data item described.

Construct Descriptor From Previous (CDPR), Construct Descriptor From Previous and Add (CDAD), Construct Descriptor From Previous and Multiply (CDMP): The number of descriptors specified are constructed using the following formulae to calculate the addresses:

CDPR: A'=A+F

CDAD: A'=A+F+L

CDMP: A'=A+F+L+(E-1)xLB

where

A' is the new address part

A is the address part of the previous entry in the Name

F is the in-line filler value if present

L is the length part of the previous entry on the Name Stack

E is the number-of-entries part of the previous entry on the Name Stack

LB is the length-between part of the previous entry on the Name Stack

Note that CDMP assumes that the previous entry on the Name Stack is an array descriptor.

Construct Descriptor Lexic Level (CDLL): A descriptor is constructed on the Name Stack which has as its address part the address of the value described by the descriptor specified by the LL, ON part.

These 6 operators are sufficient to construct all the descriptors required by all possible combinations of arrays, structures, and filler as described in II-C.

G. Handling of Control Statements

SDL's sophisticated segmentation allows segment changes to appear virtually anywhere within SDL programs. This non-sequential program flow combined with the lack of a GO TO in the S-machine created some interesting complexities. In an attempt to handle all of these complexities in a uniform manner, very heavy use was made of the Program Pointer Stack. All of the control statement operators (except Cycle) cause insertion or removal of entries from this stack. All of these operators can or do affect the next instruction address. The format of the control statement operators is given in Figure 9. A description of the operators follows.

Call (CALL): The Call operator is used to enter DO and DO FOREVER groups when these do not follow THEN and ELSE, and are not part of a CASE. The argument of the Call is the code address of the DO or DO FOREVER. Execution of the Call causes the current program address to be pushed onto the Program Pointer Stack, and the next instruction to be executed from the address indicated by the argument.

If-Then (IFTH): The If-Then operator is (as might be expected) used to handle the IF-THEN statement. The operator examines the low-order bit of the value described by the descriptor on the top of the Evaluation Stack. If this bit is 1 then the current program address is pushed onto the Program Pointer Stack, and the next instruction to be executed is taken from the address indicated by the (code address) argument.

If-Then-Else (IFEL): The If-Then-Else operator is used to handle the IF-THEN-ELSE statement. The current program address is pushed onto the Program Pointer Stack. If the low-order bit of the value described by the descriptor on the top of the Evaluation Stack is 1, then the next instruction address is indicated by the first code address following the operator; otherwise, the next instruction address is indicated by the second code address following the operator.

Case (CASE): The Case operator is used for CASE statements. The value described by the descriptor on the top of the Evaluation Stack is compared to the number, N, of code addresses following the operator: if the value is greater than X or equal to N, then an error occurrs; otherwise, the value is used to subscript into the code addresses. If the code address selected is null, then the operator is terminated and the next instruction is executed; otherwise, the current program address is pushed onto the Program Pointer Stack and the selected code address is used to obtain the next instruction address.

Undo (UNDO): UNDO statements are handled by the Undo operator. Since more than one level of nesting may be undone by any given UNDO statement, the number of levels to undo is contained in the instruction. The number of levels specified is popped from the Program Pointer Stack and the last one popped is used as the address of the next instruction.

Undo Conditionally (UNDC): The statement

IF ⟨condition⟩ THEN UNDO;

is one that causes needless manipulation of the Program Pointer

Stack if handled with the If-Then and Undo operators. Consequently, a special operator was devised which is no more than the amalgamation of these operators: if the low-order bit of the value described by the descriptor on the top of the Evaluation Stack is 1, then an Undo operation is performed; otherwise, the next instruction is executed.

Cycle (CYCL): DO FOREVER loops are handled by the Cycle operator. Since DO (and DO FOREVER) groups are required to terminate in the segment in which they began, it is sufficient to subtract some amount from the current program address. The amount to be subtracted is contained in the field following the Cycle operator.

It might be noted that, because some of these operators contain code addresses, it is possible to obtain some nice optimizations. In particular, if UTP is the name of an untyped procedure which has no parameters, then the following cases may be optimized by merely using the address of the procedure as part of the instruction;

```
IF ⟨condition⟩ THEN UTP;
IF ⟨condition⟩ THEN ...;  ELSE UTP;
CASE ⟨expression⟩;
     .
     .
     .
     UTP;
     .
     .
     .
END CASE;
```

H. Procedure Entrance and Exit

Procedure entrance and exit are a form of control statement execution, but are more complex than those statements described in IV-G, since the Control Stack and the Display may also be affected.

Procedure entrance and exit always affects the Program Pointer Stack and affect the Control Stack and Display when there is local data and/or parameters.

A call to a procedure with no local data and no parameters requires only the Call operator (see IV-G). A call to a procedure with local data but no parameters requires a Call operator followed by a Mark Stack and Update operator executed inside the procedure. A procedure with parameters and with or without local data requires a Mark Stack operator, followed by the operators to put the actual parameters on the Evaluation Stack, followed by a Call operator. Inside the procedure, a Construct Descriptor Formal operator is executed. (See Figure 10).

The Call, Mark Stack, and Mark Stack and Update operators will be described here; the Construct Descriptor Formal operator will be described in section IV-I.

Call (CALL): The argument of the Call is the code address of the procedure to be entered. Execution of the Call causes the current program address to be pushed onto the Program Pointer Stack, and the next instruction to be executed from the address indicated by the argument.

Mark Stack (MKS): The Mark Stack operator causes construction of an entry on the top of the Control Stack. This entry contains the current values of the Name and Value Stack Pointers. The Exited Lexic Level field of the entry is set to the value of the current lexic level, and the Entered Lexic Level field is set to zero.

Mark Stack and Update (MKU): The Mark Stack and Update operator has as an argument the lexic level of the procedure being entered. This operator causes construction of an entry on the top of the Control Stack. The entry contains the current values of the Name and Value Stack Pointers. The Exited Lexic Level field of the entry is set to the value of the current lexic level, and the Entered Lexic Level field is set to the value specified as the operator argument. The Display Stack entry for the specified lexic level is set to the current value of the Name Stack Pointer. The current lexic level is changed to the specified lexic level.

All procedure exits are done with the RETURN statement; however, the operator generated depends upon whether or not the procedure contains local data or parameters, and upon whether or not the procedure is typed.

If the procedure contains no local data and has no parameters (and therefore did not change the Control Stack upon entrance), then an Undo operator is used to effect the return. If there is either local data or parameters and the procedure is not typed, then an Exit operator is used. If there is either local data or parameters and the procedure is typed, then a Return operator is used. (See Figure 10.)

The Undo operator was described in IV-G. The Exit operator will be described here, and the Return operator will be described in section IV-I.

Exit (EXIT): The Name and Value Stack Pointers are set to the values obtained from the top entry of the Control Stack. The Display entry pointed to by the current lexic level is restored to the Name Stack value obtained from the first (proceeding from top to bottom) Control Stack entry, if any, having an Entered Lexic Level field equal to the current lexic level (unless a prior or the present entry has a zero Exited Lexic Level field). The Exited Lexic Level field is used to set the current lexic level, and the top entry is popped from the Control Stack. The number of levels specified is popped from the Program Pointer Stack and the last one popped is used as the address of the next instruction.

I. Parameter Passing—Returning of Values

The formal parameter statement assigns a type (and length) to each of the formal parameters. The SDL programmer has the option of having the SDL machine (interpreter) verify that the actual parameter matches the formal parameter. Since this check is time-comsuming, it is typically not performed once a program has been debugged. The consistency check is performed by the Construct Descriptor Formal operator (see Figure 11). When the check is to be done, this operator has, as its arguments, "descriptor templates" for each of the formal parameters. The description of this operator follows:

> Construct Descriptor Formal (CDFM): The Construct Descriptor Formal operator assumes that a Mark Stack operator was executed before the actual parameters were placed on the Evaluation Stack. The current lexic level is changed to the lexic level specified by the operator. The specified lexic level is also put into the Entered Lexic Level field of the top entry in the Control Stack. The Display Stack entry for the specified lexic level is set to the current value of the Name Stack Pointer. The current lexic level is set to the specified lexic level. The number of descriptors specified is constructed on the Name Stack using the in-line descriptor information plus the corresponding descriptor information on the Evaluation Stack. The type and length fields are compared for consistency between corresponding descriptors on the Evaluation and Name Stacks. The Evaluation Stack is cut back after construction of the descriptors; the Value Stack is not.

The values returned by typed procedures in SDL should agree in type and length with the formal type of the procedure itself. The SDL programmer again has the option of specifying whether or not this consistency check is performed by the interpreter. If this check is to be performed then the Return operator contains a descriptor template in-line following the operator.

Return (RTRN): The Return is the same as the Exit operator prior to popping entries off the Program Pointer Stack. At this point, the data descriptor on the Evaluation Stack is compared to the in-line descriptor for consistency. If the data is on the Value Stack, then after cutting back the Value Stack, the data is moved to the new top of the Value Stack. The number of levels specified is popped from the Program Pointer Stack and the last one popped is used as the address of the next instruction.

J. Special Operators

In order to illustrate further the complexity and flexibility possible with a machine such as the B1700, several of the special operators will also be described.

Search Linked List

The Search Linked List operator is used principally by the MCP to allocate memory space. This operator compares a value with a list of linked structures, searching for the indicated relationship or the end of the list. The argument specifies the compare type: less, less or equal, equal, not equal, greater or equal, greater. There are four descriptors on the Evaluation Stack. The descriptors represent:

1) Link Index: the relative offset in the structure, and the size, of the field which contains the address of the next structure to be examined
2) Compare Variable: the variable to be compared to the linked structure
3) Argument Index: the relative offset in the structure, and the size, of the field to which Compare Variable is to be compared
4) Record Address: the address of the first structure to examine

The operator returns the address of the structure whose compare field was in the desired relationship to the Compare Variable, or it returns an indicator that there were no structures in the desired relationship.

Reinstate

The Reinstate operator is the operator used by the MCP to reinstate a

user program. The descriptor on the top of the Evaluation Stack is assumed to describe a field in the Run Structure of the program to be reinstated. The reinstating program's M-machine state is stored in its own Run Structure (each program currently executing has a Run Structure which contains the program's execution attributes). The address of the reinstating program's Run Structure is stored in the reinstated program's Run Structure. The descriptor at the top of the Evaluation Stack is removed. The address field of this descriptor addresses the Run Structure of the program which is then reinstated.

Next Token

The Next Token operator is used by compilers to scan source images. The first argument is the data address of a descriptor which describes the first character to be examined. It is assumed that this character is non-blank. The second argument is a "separator" character (such as "-" in COBOL). The third argument is the "numeric-to-alpha indicator".

If the character described by the first argument is a special character, then the operator is exited with a descriptor on the top of the Evaluation Stack which describes this character, and with the descriptor described by the first argument advanced to point to the next character in the source image.

If numeric-to-alpha indicator is 1 then the stopper is set to "A"; otherwise, if the first character is numeric then the stopper is set to "0"; otherwise, the stopper is set to "A". Characters are sequentially compared to the stopper until one is found which is less than the stopper

and not equal to the separator. The operator then exits with a descriptor on the top of the Evaluation Stack which describes the token just found, and with the descriptor described by the first argument advanced to point to the next character in the source image. (The EBCDIC collating sequence is assumed).

V. Conclusion

In this brief description of the B1700 Software Development Language (SDL), and its underlying S-machine, I have attempted to give some indication of the flavor of SDL but, more importantly, to illustrate the extrème flexibility and suitability of the B1700 for the tasks for which it was designed: the writing of (language) interpreters and emulators. We who have used SDL feel that it is well-suited for the type of programming for which it was designed. We could not agree more with Saltzer et al (MIT, 1970) that one of our best decisions was to program the operating system in a higher-level language. However, the degree of success of the software depends very heavily upon the suitability of the hardware to the software and to the language in which the software is written. The Burroughs B1700, by its very nature, has proven to be quite suitable to the tasks to which it has been assigned. It should be pointed out, that because all of the software for the B1700 has been written in a higher-level language, all of it (including the MCP) is theoretically transportable to any other system which has soft interpretation (of the flexibility of the B1700).

VI. Acknowledgements

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VII. APPENDIX I: SDL S-OPERATORS

RELATIONAL OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
EQUAL TO	EQL	6	
LESS THAN	LSS	10	
LESS THAN OR EQUAL TO	LEQ	10	
GREATER THAN	GTR	10	
GREATER THAN OR EQUAL TO	GEQ	10	
NOT EQUAL TO	NEQ	6	

ARITHMETIC OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
ADD	ADD	6	
SUBTRACT	SUB	6	
MULTIPLY	MUL	10	
DIVIDE	DIV	10	
MODULO	MOD	10	
REVERSE SUBTRACT	RSUB	10	
REVERSE DIVIDE	RDIV	10	
REVERSE MODULO	RMOD	10	
NEGATE	NEG	10	
CONVERT TO DECIMAL	DEC	10	
CONVERT TO BINARY	BIN	10	

LOGICAL OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
AND	AND	10	
OR	OR	10	
EXCLUSIVE-OR	XOR	10	
NOT	NOT	10	

STRING OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
CONCATENATE	CAT	6	
SUBSTRING TWO	SS2	10	
SUBSTRING THREE	SS3	6	

SDL S-OPERATORS (CONTINUED)

LOAD OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
MAKE DESCRIPTOR	MDSC	10	
VALUE DESCRIPTOR	VDSC	10	
DESCRIPTOR	DESC	6	DA
NEXT OR PREVIOUS ITEM	NPIT	10	V,DA
LOAD VALUE	L	6	DA
LOAD ADDRESS	LA	4	DA
ARRAY LOAD VALUE	AL	10	DA
ARRAY LOAD ADDRESS	ALA	6	DA
INDEXED LOAD VALUE	IL	10	DA
INDEXED LOAD ADDRESS	ILA	4	DA
LOAD LITERAL	LIT	4	D,LITERAL
LOAD 10-BIT LITERAL	LITN	4	LITERAL
LOAD LITERAL ZERO	ZOT	4	
LOAD LITERAL ONE	ONE	4	

STACK OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
BUMP VALUE STACK POINTER	BVSP	10	
DUPLICATE	DUP	6	
DELETE	DEL	10	
EXCHANGE	XCH	6	
FORCE VALUE STACK	FVS	6	

STORE OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
STORE DESTRUCTIVE	STOD	4	
STORE NON-DESTRUCTIVE LEFT	SNDL	6	
STORE NON-DESTRUCTIVE RIGHT	SNDR	10	

CONSTRUCT DESCRIPTOR OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
CONSTRUCT DES. BASE ZERO	CDBZ	10	D
CONSTRUCT DES. LOCAL DATA	CDLD	6	N,D1,...,DN
CONSTRUCT DES. FORMAL	CDFM	10	LL,E
CONSTRUCT DES. FORMAL-V2	CDFM	10	LL,E,D1,...,DN

SDL S-OPERATORS (CONTINUED)

CONSTRUCT DESCRIPTOR OPERATORS (CONTINUED)

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
CONSTRUCT DES. FROM PREV.	CDPR	6	N,D1,...,DN
CONSTRUCT DES. FROM PREV. & ADD	CDAD	6	N,D1,...,DN
CONSTRUCT DES. FROM PREV. & MULTIPLY	CDMP	10	N,D1,...,DN
CONSTRUCT DES. LEXIC LEVEL	CDLL	10	DA,D

PROCEDURE OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
CALL	CALL	4	CA
IF THEN	IFTH	4	CA
IF THEN ELSE	ITEL	6	TYPE,CA,CA
CASE	CASE	10	N,TYPE,CA1,...,CAN
UNDO	UNDO	4	L
UNDO CONDITIONALLY	UNDC	10	L
RETURN-V1	RTRN	10	L
RETURN-V2	RTRN	10	L,D
EXIT	EXIT	6	L
CYCLE	CYCL	6	DISPLACEMENT
MARK STACK	MKS	6	
MARK AND UPDATE	MKU	10	LL

MISCELLANEOUS OPERATORS

NAME	MNEMONIC	OP CODE SIZE	ARGUMENTS
SWAP	SWAP	10	
INTERRUPT STATUS	IIS	10	
FETCH	FECH	10	
DISPATCH	DISP	10	
HALT	HALT	10	
READ CASSETTE	RDCS	10	
LENGTH	LENG	10	
LOAD SPECIAL	LSP	10	V
CLEAR	CLR	10	
COMMUNICATE	COMM	10	
REINSTATE	REIN	10	
FETCH CMP	FCMP	10	
ADDRESS	ADDR	10	
SAVE STATE	SVST	10	
HARDWARE MONITOR	HMON	10	
OVERLAY	OVLY	10	
PROFILE	PRFL	10	N
SEARCH LINKED LIST	SLL	10	V

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SDL MEMORY STRUCTURE

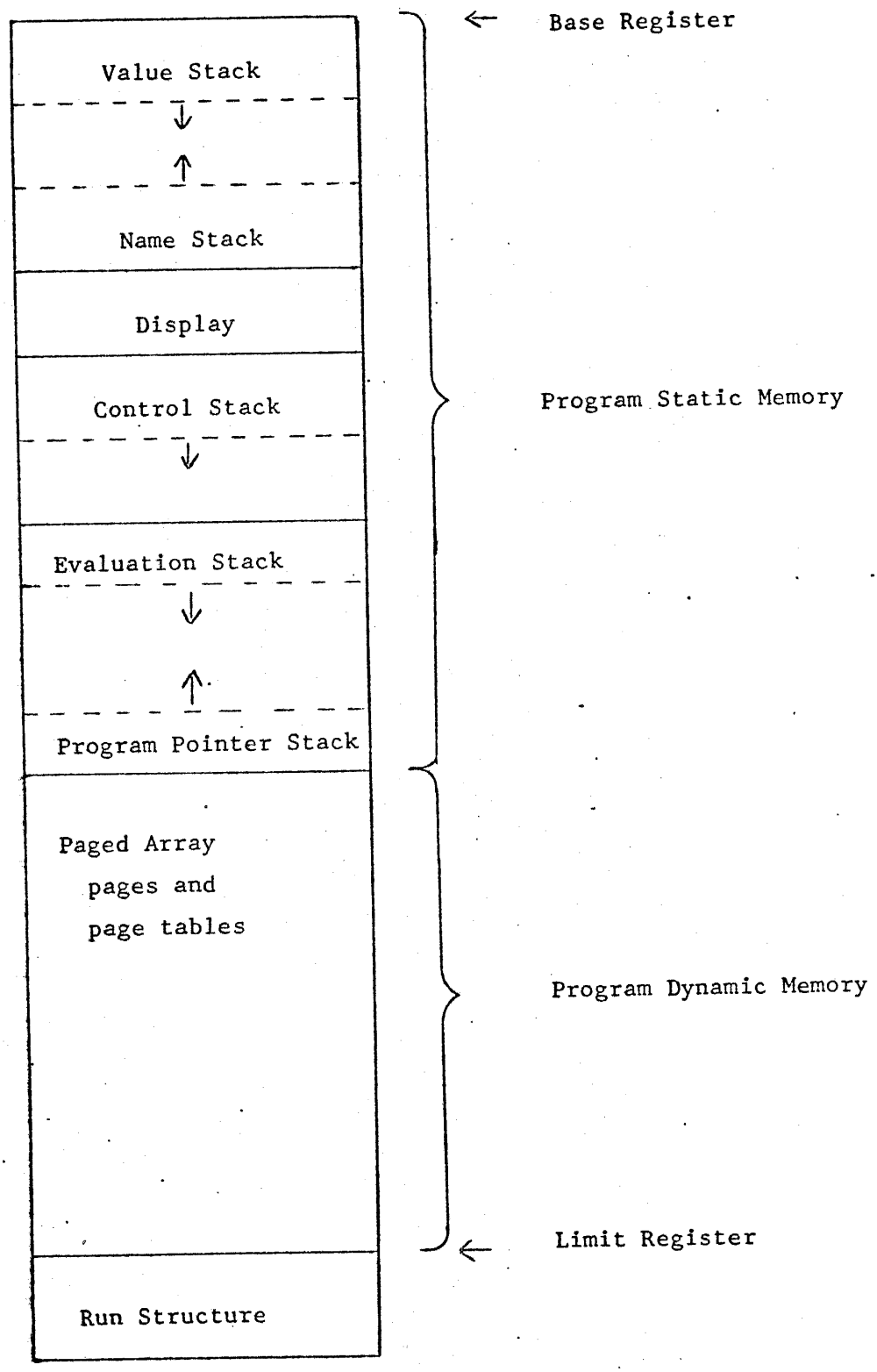


FIGURE 1.

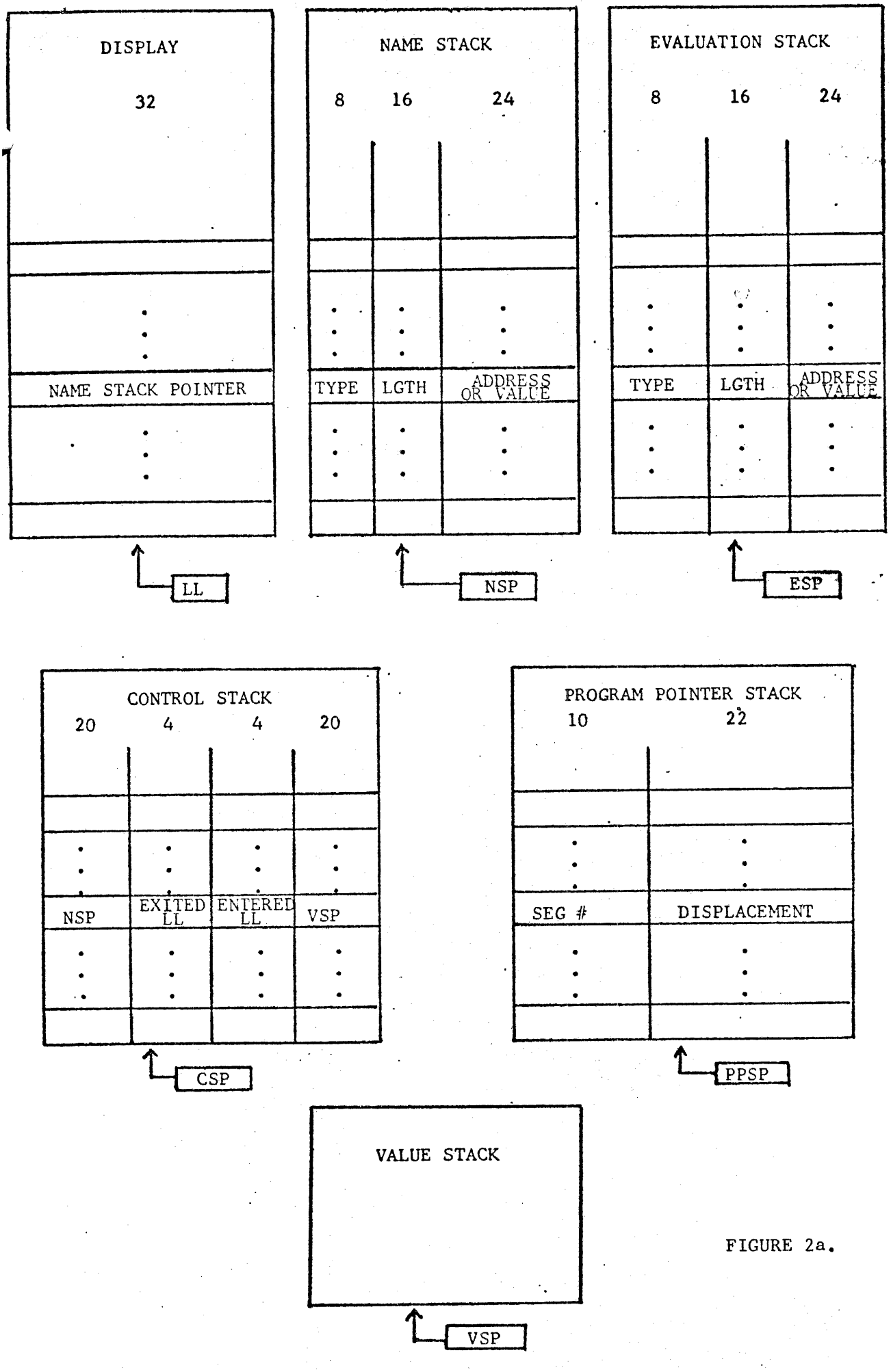
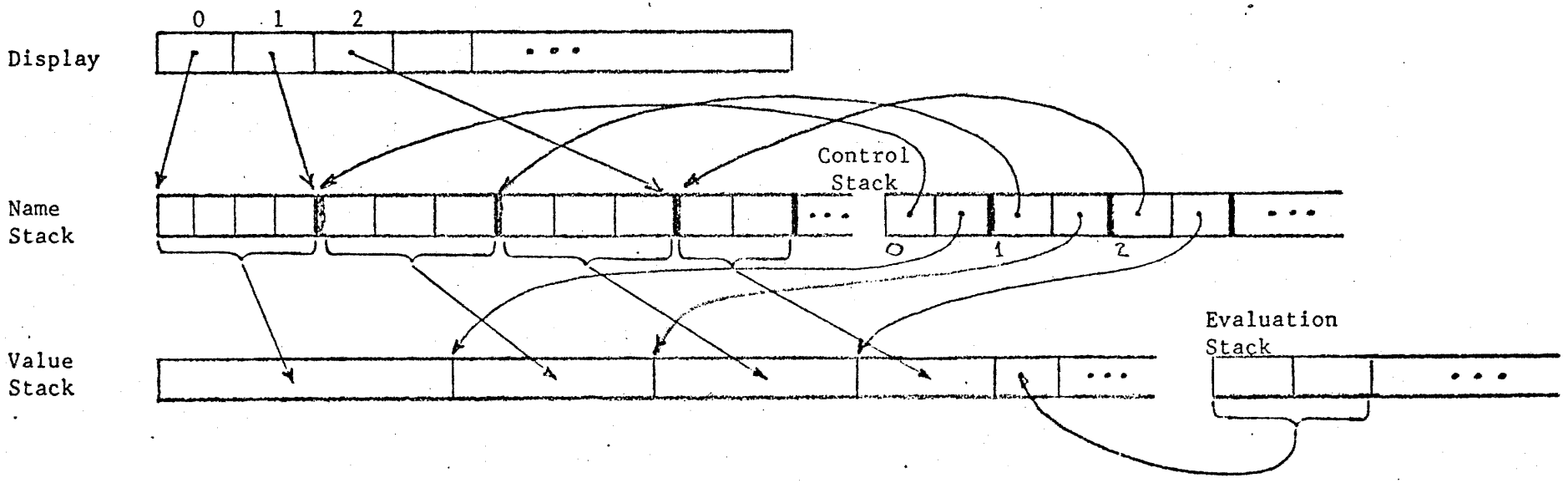

DISPLAY
32
NAME STACK POINTER
LL
NAME STACK
8
16
24
TYPE
LGTH
ADDRESS OR VALUE
NSP
EVALUATION STACK
8
16
24
TYPE
LGTH
ADDRESS OR VALUE
ESP
CONTROL STACK
20
4
4
20
NSP
EXITED LL
ENTERED LL
VSP
CSP
PROGRAM POINTER STACK
10
22
SEG #
DISPLACEMENT
PPSP
VALUE STACK
VSP

FIGURE 2a.

SDL STACK INTER-RELATIONSHIP



Control Stack Entry 1 describes a currently inactive lexic level.

FIGURE 2b.

SDL OPCODE STRUCTURE

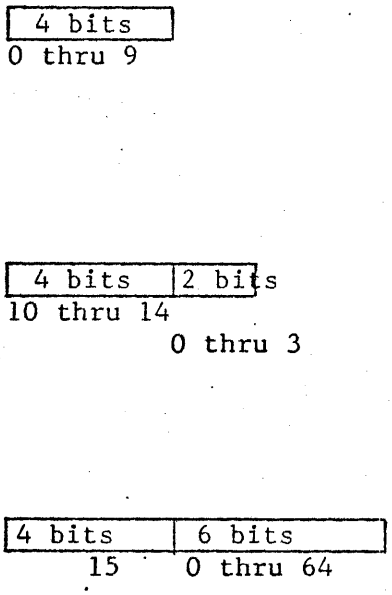


FIGURE 3.

MCP OPERATOR ENCODING

ENCODING METHOD	TOTAL BITS FOR MCP'S OPCODES	UTILIZATION IMPROVEMENT	DECODING PENALTY
HUFFMAN	172,346	43%	17.2%
SDL 4,6,10	184,966	39%	2.6%
8-BIT FIELD	301,248	0%	0.0%

FIGURE 4a.

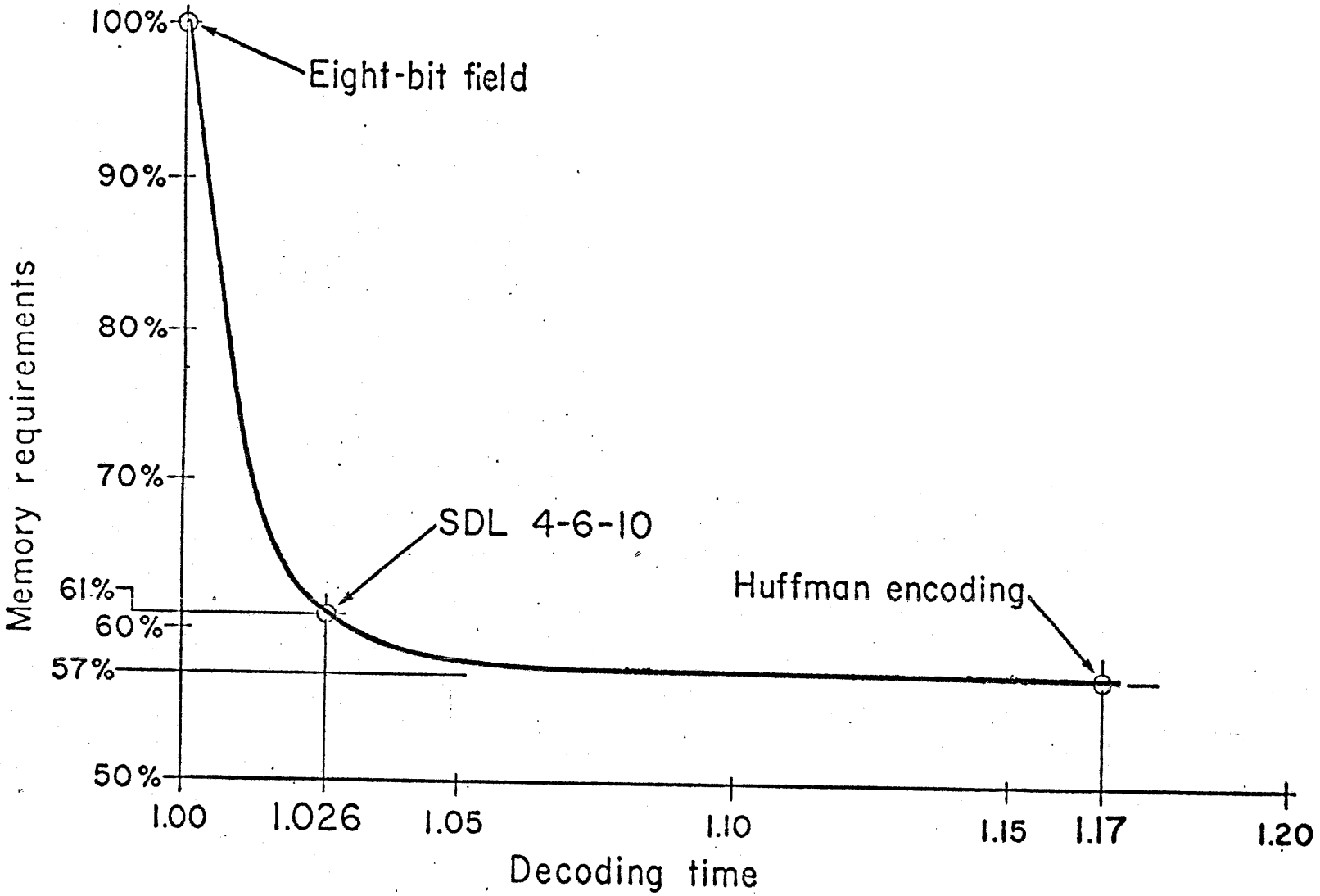
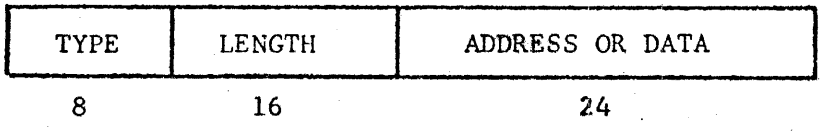

100%
90%
80%
70%
61%
60%
57%
50%
Memory requirements
Eight-bit field
SDL 4-6-10
Huffman encoding
1.00
1.026
1.05
1.10
1.15
1.17
1.20
Decoding time

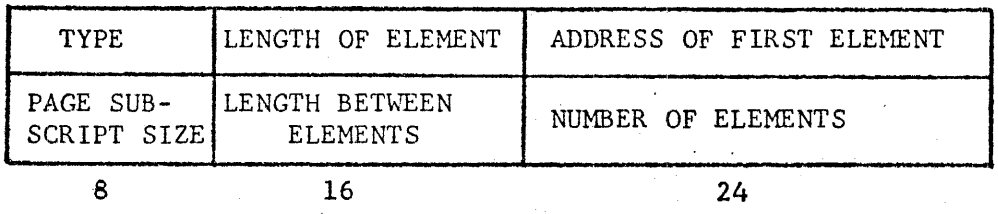
FIGURE 4b.

SDL DESCRIPTOR FORMATS

SIMPLE DESCRIPTOR:



ARRAY DESCRIPTOR:



TYPE FIELD:

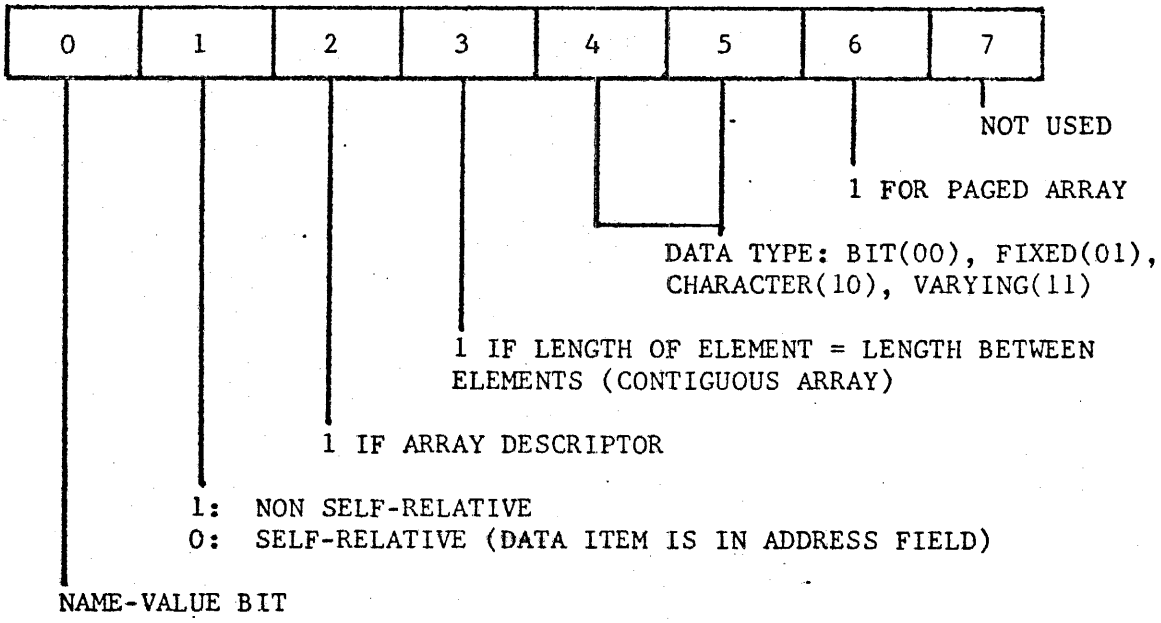


FIGURE 5.

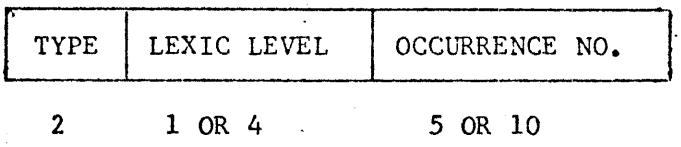
SDL CODE ADDRESS

TYPE	SEGMENT NO.	PAGE NO.	DISPLACEMENT
3	0 OR 6	0 OR 4	12,16,OR20

TYPE	SEGMENT NO.	PAGE NO.	DISPLACEMENT	TOTAL BITS
000	CURRENT	CURRENT	12 BITS	15
001	CURRENT	CURRENT	16 BITS	19
010	6 BITS	CURRENT	12 BITS	21
011	6 BITS	CURRENT	16 BITS	25
100	6 BITS	4 BITS	12 BITS	25
101	6 BITS	4 BITS	16 BITS	29
110	6 BITS	4 BITS	20 BITS	33
111	-	-	-	3

FIGURE 6.

SDL DATA ADDRESSES



TYPE	LEXIC LEVEL	OCCURRENCE NO.	TOTAL BITS
00	4 BITS	10 BITS	16
01	4 BITS	5 BITS	11
10	1 BIT *	10 BITS	13
11	1 BIT *	5 BITS	8

* 0: LEXIC LEVEL 0
  1: CURRENT LEXIC LEVEL

FIGURE 7.

SDL CONSTRUCT DESCRIPTOR OPERATORS

IN-LINE DESCRIPTOR FORMAT:

TYPE	LENGTH	FILLER	LENGTH BETWEEN ELEMENTS	PAGE SUBSCRIPT SIZE	NUMBER OF ELEMENTS
8	6 OR 17	0,6,OR 17	0,6, OR 17	0 OR 8	0, 6, 17

6- OR 17-BIT FIELDS:

0	5 BITS

1	16 BITS

CONSTRUCT DESCRIPTOR OPERATORS:

OPERATOR	MNEMONIC	OPCODE	ARGUMENTS
BASE ZERO	CDBZ	1111 10 0100	D
LOCAL DATA	CDLD	1110 00	N,D1,...,DN
FROM PREVIOUS	CDPR	1110 10	N,D1,...,DN
FROM PREVIOUS AND ADD	CDAD	1110 01	N,D1,...,DN
FROM PREVIOUS AND MULTIPLY	CDMP	1111 10 0101	N,D1,...,DN
LEXIC LEVEL	CDLL	1111 10 0011	DA,D

WHERE D AND DI ARE IN-LINE DESCRIPTORS, AND DA IS A DATA ADDRESS (TYPE, LEXIC LEVEL, OCCURRENCE NUMBER)

FIGURE 8a.

SDL CONSTRUCT DESCRIPTOR ADDRESS CALCULATIONS

OPERATOR	ADDRESS
CDBZ	A' = 0
CDLD	A' = V
CDPR	A' = A + F
CDAD	A' = A + F + L
CDMP	A' = A + F + L + (E-1) × LB
CDLL	A' = ADDRESS(DA) + F

WHERE

A' IS THE NEW ADDRESS PART

V IS THE VALUE STACK POINTER

A IS THE ADDRESS PART OF THE PREVIOUS ENTRY IN THE NAME STACK

F IS THE IN-LINE FILLER VALUE, IF PRESENT

L IS THE LENGTH OF THE PREVIOUS ENTRY ON THE NAME STACK

E IS THE NUMBER-OF-ENTRIES PART OF THE PREVIOUS ENTRY ON THE NAME STACK

LB IS THE LENGTH-BETWEEN-ENTRIES PART OF THE PREVIOUS ENTRY ON THE NAME STACK

DA IS THE IN-LINE DATA ADDRESS

FIGURE 8b.

SDL CONTROL STATEMENT OPERATORS

OPERATOR	MNEMONIC	OPCODE	ARGUMENTS
CALL	CALL	0111	CA
IF-THEN	IFTH	1001	CA
IF-THEN-ELSE	IFEL	1101 10	AT,CA,CA
CASE	CASE	1111 01 0100	N,AT,CA1,...,CAN
UNDO	UNDO	1000	L
UNDO CONDITIONALLY	UNDC	1111 01 0011	L
CYCLE	CYCL	1110 11	D

WHERE

CA IS A CODE ADDRESS (TYPE, SEGMENT NUMBER, PAGE NUMBER, DISPLACEMENT)

AT IS THE CODE ADDRESS TYPE

N IS THE NUMBER OF CODE ADDRESSES

L IS THE NUMBER OF LEVELS TO UNDO

D IS THE NUMBER OF BITS OF DISPLACEMENT

FIGURE 9.

SDL PROCEDURE ENTRANCE AND EXIT OPERATORS

OPERATOR	MNEMONIC	OPCODE	ARGUMENTS
MARK STACK	MKS	1011 11	
MARK STACK AND UPDATE	MKU	1111 01 1111	LL
CALL	CALL	0111	CA
EXIT	EXIT	1101 11	L
UNDO	UNDO	1000	L
RETURN	RTRN	1111 01 0101	L,D

WHERE

LL IS THE ENTERED LEXIC LEVEL

CA IS A CODE ADDRESS

L IS THE NUMBER OF LEVELS TO REMOVE FROM THE PROGRAM POINTER STACK

D IS A TYPE, LENGTH PAIR

FIGURE 10.

SDL CONSTRUCT DESCRIPTOR FORMAL

OPERATOR	MNEMONIC	OPCODE	ARGUMENTS
CONSTRUCT DESCRIPTOR FORMAL	CDFM	1111 01 0001	L,E,D1,...,DN

WHERE

L IS THE ENTERED LEXIC LEVEL

E IS THE NUMBER OF 48-BIT ENTRIES ON THE EVALUATION STACK

DI ARE IN-LINE DESCRIPTOR TEMPLATES OF THE FORM:

TYPE	LENGTH	NUMBER OF ENTRIES
8	0,16	0,16

TYPE:

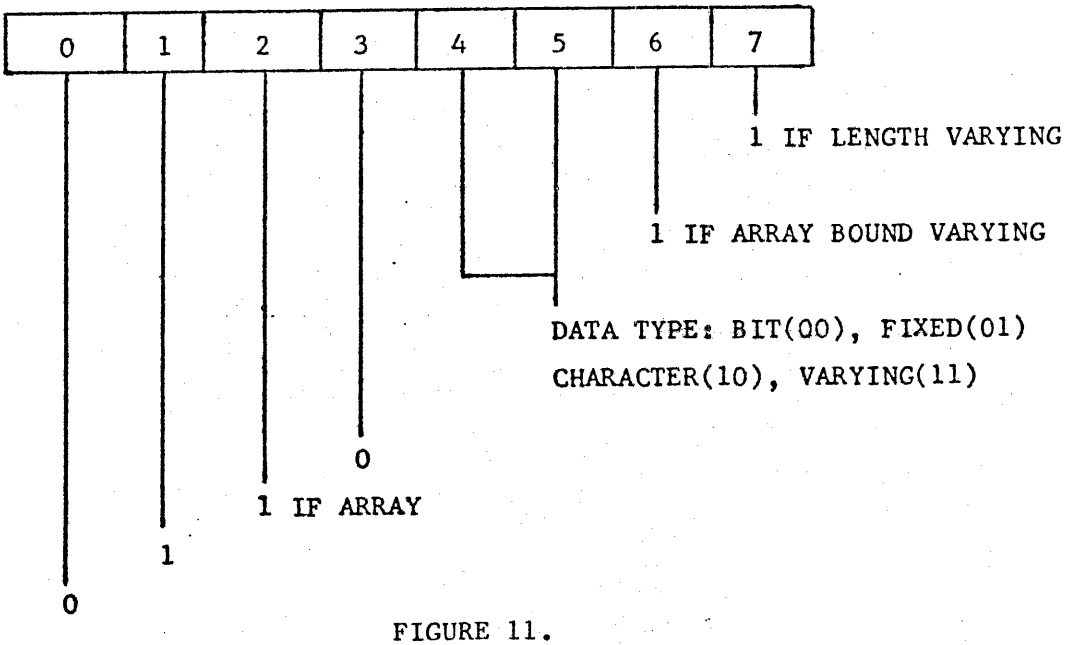


FIGURE 11.