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THE HEURISTIC COMPILER

Herbert A. Simon

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The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

PREFACE

The research reported in this Memorandum, rather than being aimed at the construction of a specific compiler (a computer program for translating instructions from a language convenient to the programmer to the machine language), is directed towards deepening our understanding of the kinds of problem-solving activity that are involved in computer programming, and the kinds of language and representational means that are needed to produce more sophisticated compilers. The Memorandum takes the form, therefore, of a series of illustrative problems of compiler design, with proposals, worked out in some detail, for their solution.

There has been, in the past decade, enormous progress in the development of higher-level programming languages for instructing computers. Through the invention of algebraic compilers, like FORTRAN, IT, and ALGOL, data processing languages like COBOL, and list-processing languages like IPL, LISP, and COMIT, the labor of programming has been reduced several orders of magnitude. Yet, when we are faced with the complexities of modern command and control systems, and the programming problems they present, we recognize that the progress made to date is not nearly enough. Programming a computer to perform a complex task is still very much more intricate and tedious than instructing an intelligent and trained human being for that task.

Most visibly, the human--if, to repeat, he is intelligent and knowledgeable--does not have the literalness of mind that is so characteristic of the computer, and so exasperating in our interaction with it. From his own store of knowledge, he supplies facts that we neglect to give him; given statements of objectives in broad functional terms, he applies his problem-solving powers to filling in the detail of method; confronted with the vagueness and informality of natural language, he interprets meaning and intent.

The experiments reported in this Memorandum aim at further bridging the gap between the explicitness of existing computer programming languages and the freedom and flexibility of human communication. The work was motivated by the belief that until we bridge that gap, we shall not be able to harness effectively the powers made available to us by modern digital computers and apply them to the vast systems (e.g., command and control) that are becoming such a central feature of our military and civilian technology.

This work is part of The RAND Corporation's continuing program of research in the area of complex information processing, under U.S. Air Force Project RAND. The author, a RAND consultant, is a member of the faculty at Carnegie Institute of Technology. The Memorandum is directed primarily to systems programmers who are faced with problems of compiler design, with the hope that its proposals will suggest means for increasing the power, generality, and flexibility of compiling systems.

SUMMARY

Two major themes run through the topics discussed in this Memorandum. The first thesis is that more of the programming burden can be shifted from programmer to computer if the computer is given some problem-solving powers. In previous works it has been shown how a computer program, the General Problem-Solver, can simulate the kinds of means-end analysis that humans use to solve problems.* Part I of the present Memorandum shows how a compiler can be designed that makes use of heuristic problem-solving techniques like those incorporated in the General Problem-Solver (GPS). Such a scheme permits a desired program to be specified in general terms, with the compiler using means-end analysis and selective trial-and-error search to work out the exact "how" of it.

The second main theme is that if we are to have flexibility in a compiler language commensurate with the flexibility of natural language, we must first gain an

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*The General Problem-Solver has been described, and its behavior analyzed, in several RAND publications by A. Newell, J. C. Shaw, and H. A. Simon: Report on a General Problem-Solving Program, P-1584, February 9, 1959; The Simulation of Human Thought, P-1734, June 22, 1959; A Variety of Intelligent Learning in a General Problem Solver, P-1742, July 6, 1959; GPS: A Program that Simulates Human Thought, P-2257, April 10, 1961; Computer Simulation of Human Thinking, P-2276, April 20, 1961; Computer Simulation of Human Thinking and Problem Solving, P-2312, May 29, 1961.

Also see, A Guide to the General Problem-Solver Program GPS-2-2, Allen Newell, RM-3337-PR, February 1963.

understanding of the ways in which meanings are represented in natural language, and then devise representations of corresponding power (and ambiguity) for compiling languages. Parts II and III are devoted primarily to questions of language and representation. They provide a number of suggestions for increasing the generality and flexibility of compiler languages.

The boundaries between the three parts are largely chronological. Part I represents work completed during the winter of 1960-61; Part II, work done during the spring of 1961; and Part III, work done since the summer of 1961, particularly during the summer and autumn of 1962. A program listing for the main portion of the compiling scheme, described in Sections I-V of Part I, is given in Appendix A. A program listing for the annexing scheme, described in Sec. IX of Part III, is given in Appendix B.

ACKNOWLEDGMENT

I am greatly indebted to H. S. Kelly, of The RAND Corporation, for numerous discussions of the work described in this paper, and for help in solving many of the problems that arose.

CONTENTS

PART I

A PROBLEM-SOLVING COMPILER

In this first part, we describe a compiler that makes use of heuristic problem-solving techniques like those incorporated in the General Problem-Solver (GPS).* Section I provides a brief introduction to the theory of problem solving and the structure of GPS. Section II shows how programming can be interpreted as a problem-solving activity, within this framework. Section III describes the main components of the compiler, and Sec. IV indicates how the compiler could be incorporated as a set of subroutines to GPS. Section V describes an extension of the compiler to handle flow diagrams. A complete program listing for the compiler is given in Appendix A.

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*_Op. cit._, p. vii.

I. THEORY OF PROBLEM SOLVING

The motivation for the Heuristic Compiler is supplied by a theory of problem solving that also provides the basic framework for the General Problem-Solver. By a problem, we mean a situation of the following kind:

1. We are given a (partial) description of a present situation and a desired situation. These situations are described in a language that we may call the state language. The state language is sufficiently rich to permit us to describe situations (we shall call such descriptions objects), and to describe differences between pairs of situations.
2. We are given a list of operators that can be applied to situations to transform them into new situations. Operators are named in a language that we may call the process language. Any sequence of operators named in the process language, also names an operator--the compound operator that consists in applying, successively, the elementary operators belonging to the sequence.
3. A problem solution is a (compound) operator in the process language that will transform the object describing the present situation into the object describing the desired situation.

EXAMPLE: We take as the objects in the state language the integers, 1, 2, $\cdots$. We take as the elementary operator the successor operation, which we shall designate as ' in the process language. Then ''' and ''''' are examples of compound operators. Consider the problem of transforming the present object 5 into the goal object 8. The solution is the operator ''', for $5''' = 8$. More generally, ''' is the operator that removes the difference +3 between any two objects, x and y; for if $y - x = +3$, then $x''' = y$. Here +3 is a difference in the state language; ''' is the operator <u>relevant to that difference</u> in the process language. We may construct a <u>table of connections</u> to associate with each difference the operator or operators relevant to it.

With this formulation of the concept of "problem," many techniques of problem solving can be subsumed under the following general paradigm:

> MEANS-END ANALYSIS. Given the present and desired objects, find a difference between them. Next find an operator relevant to the difference; determine if the operator can be applied to the present object. If so, apply it. (If not, describe the objects to which it would apply and transform the present object into an object of that kind--a new "desired object.") Take the new object thus obtained as the present object and repeat the process.

The General Problem-Solver is a program that uses this scheme of means-end analysis for attempting the solution of any problem that can be cast into the form described.*

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*This is a bare-bone description of GPS, but it will suffice for our purposes.

II. PROGRAM WRITING AS PROBLEM SOLVING

The task of proving a theorem can be formulated as a problem for GPS. The desired object is the theorem to be proved. The present object is the set of axioms and already-proved theorems. The operators are the legitimate processes for transforming a subset of axioms and/or theorems into a new theorem. We have a proof when we have a sequence of operators that transforms the present object into the desired object. (What we call a proof here is usually regarded as the justification for the proof steps; the proof, as usually written out, consists of the sequence of successive transformations of the axioms and given theorems.)

The sequence of operators that constitutes a proof can also be interpreted as a <u>program</u> that generates the desired object from the given object; for if we apply the operators of the proof, in sequence, to the present object (the axioms and previous theorems), we obtain precisely the desired object--the theorem to be proved. Thus, a theorem-proving system can be regarded, at least formally, as a program-writing system. Conversely, if we can formulate a programming goal as a difference between a present and a desired object, we can presumably use the same processes, which in the other context will generate the proof of a theorem, to generate a program.

III. OUTLINE OF A HEURISTIC CODER FOR IPL-V

In the remainder of Part I, I shall describe a number of routines for compiling programs in Information Processing Language V (IPL-V), an interpretive list-processing language.* What is common to all of these compiling procedures is that they embody the problem-solving notions discussed in the preceding paragraphs. That is, each of the compiling routines accepts the task of writing programs in IPL-V on the basis of certain information provided to it. The task is accomplished by the application of the means-end analysis that has been described. The several compiling routines differ with respect to their methods of formulating or representing the problem--that is, each operates with a different state language. At present, there are three compiling routines:

1. SDSC Compiler (State Description Compiler) [U140].** This routine takes as its input a description (SDSC) of the contents of the relevant computer cells before and after the routine to be compiled has been executed. It produces an IPL-V routine that will transform the input state description into the output state description.

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*See Newell, Allen (Ed.), Information Processing Language V Manual, Prentice-Hall, Englewood Cliffs, N.J., 1961.

**Expressions in square brackets are names of the corresponding routines, data list structures, and symbols in the compiler program.

2. DSCN Compiler (Descriptive Name Compiler) [U134]. This routine takes as its input a verbal definition (in the form of an imperative sentence) of the routine to be compiled. It produces an IPL-V routine that is the translation, in the interpretive language, of that definition.

3. General Compiler [U135]. This is an executive routine that can use the SDSC Compiler, the DSCN Compiler, and others as subroutines. It takes as its input information about the routine to be compiled; the information can be stated in any one of several representations (e.g., those appropriate to SDSC or DSCN). The routine then selects subroutines that can use this information to produce the desired IPL-V code.

From a logical standpoint, we could describe the Heuristic Coder as a single program whose executive routine is the General Compiler, and which contains the SDSC Compiler and the DSCN Compiler as subroutines. For clarity of exposition, it will be better to describe the two parts first as independent programs, and then show how they are imbedded in the General Compiler.

THE SDSC COMPILER

A computer routine can be defined by specifying the changes it produces in the contents of the storage location it affects, or, what amounts to almost the same thing, by specifying the before and after conditions of these storage registers. A definition of this kind is not, of course, univocal, for programming is a synthetic, not an analytic task; there will generally be many programs (not all equally efficient or elegant) that will do the same work. As presently constituted, the SDSC Compiler attempts to find some one routine to accomplish a given task.

EXAMPLE: In IPL-V there is a process, PUT SYMBOL J3 IN MEMORY LOCATION H5, which affects a single memory location, H5. This process [X105] happens to have the name J3; its state description (SDSC) is the following:

BEFORE J3 is executed, cell H5 contains a symbol, call it S1, followed by an indeterminate list of symbols, R0 (call this the <u>pushdown list</u> associated with H5).

AFTER J3 has been executed, cell H5 contains the symbol J3, followed by the same list of symbols, R0, as before. The token of symbol S1 that was previously in H5 has been destroyed.

Notice that it is implicit in this SDSC definition of J3 that the content of no cell other than H5 has been altered by the routine. We can represent the SDSC [the value of attribute X24 of the routine] diagrammatically as follows:

SDSC of J3

	Affected Cells
	H5
Input	S1,R0
Output	J3,R0.

Generalizing, the SDSC of a routine consists of a list of affected cells [attribute X71 of X24]. For each affected cell on the list, the SDSC specifies its input state [attribute X75 of X71] and its output state [attribute X76 of X71].

To compile the IPL-V code (JDEF) for J3, the SDSC Compiler [U140] proceeds as follows:

1. It matches [X7] the input states with the output states of the affected cells until it finds a difference. In the example cited, the difference between the input and output states of H5 may be called a replacement in H5.

2. It searches [U150] a table of connections [X90] that associates with each difference a list of operators (compiled IPL-V routines) that are relevant to that difference. In the example, the table of connections would contain, associated with the replacement difference [X83], the IPL-V routine P2(C) [X106]. P2(C) replaces the symbol in cell C, a variable, with the symbol in cell H0. Thus, P2(C) has the following SDSC [see local 95 of X106]:

SDSC of P2(C)

	Affected Cells	
	HO	C
Input	S2,RO	S1,RO
Output	RO	S2,RO.

3. It tentatively applies [U141] the relevant operator it has found to the input state of the SDSC to be compiled, and determines the resulting output state. In applying the operator, it makes appropriate substitutions for the variables in the operator [U153, U154]. Thus, applying P2(C) to the input of J3, we find, by matching, that we should set C = H5 and S2 = J3, giving:

SDSC of P2(H5)

	HO	H5
Input	J3,RO	S1,RO
Output	RO	J3,RO.

4. The application of the operator creates two new subproblems: Let I_a be the input state of the routine to be compiled, 0_a its output state, I_b the input state of the operator, and 0_b its output state. The original problem was to transform I_a into 0_a. The new problems are: (1) to transform I_a into I_b (i.e., to establish the input conditions for application of the operator), and (2) to transform 0_b into 0_a (i.e., to transform the output state of the operator into the desired output state of the routine to be compiled). Either of these new

problems may reduce to the identity transformation, in which case that part of the problem is solved. If this reduction does not occur, then the same steps, 1, 2, 3, are applied [recursion of U140] to the new subproblem.

In the example at hand, 0_b is identical with 0_a; hence, the remaining subproblem is to transform I_a into I_b, that is, to compile a routine with SDSC:

<u>H0</u>

S2,R0
J3,S2,R0.

The repetition of step 1 for this subproblem discovers a new difference, an <u>addition</u> [X82] to H0. Step 2 finds the relevant operator, process P1(S) [X107], which adds the symbol S to the symbol list in H0. Applying, in step 3, the operator P1(J3), the input state of H0: S2,R0, is transformed into the output state, J3,S2,R0. Hence, the solution to the original problem of compiling J3 is obtained by the sequence, P1(J3), P2(H5), or, in the usual IPL-V format [X22 of the routine]:

```
J3      10 J3
        20 H5  0.
```

We see that for the SDSC compiler to operate, it must be provided with a set of differences and matching tests for noticing differences, a set of already-compiled operators, and a table of connections between differences and operators. Further, when it has compiled a new routine, the compiler can annex this routine to its set of available operators and use it in compiling subsequent routines.

THE DSCN COMPILER

Let us now consider an alternative compiling scheme for the same routine, J3. Instead of specifying the before and after condition of the computer cells, we define the routine [X20 of the routine] in terms of the function it performs: REPLACE THE SYMBOL IN H5 BY J3. (This definition (DSCN) resembles more closely than the previous one the manner in which routines are defined for "conventional" compilers like FORTRAN or LISP. What distinguishes the present scheme from these is the use of heuristic means-end analysis for working from the definition to the compiled routine.)

The first step in the DSCN Compiler [U134] is to search a list of available (compiled) routines to find one whose DSCN is as similar as possible to the DSCN of the routine to be compiled. In the case at hand, we would find the routine P2(C): REPLACE THE SYMBOL IN C BY (H0).

At the second step [U130], means-end analysis is performed to transform the compiled routine that has been found into the new routine. The transformations are performed on the DSCN's. Thus, in the present example, there are two differences between P2(C) and J3. The former refers to the cell C, the latter to H5; the former refers to the symbol that is contained in cell H0, the latter to the symbol J3.

The compiler notices these differences (in a sequence), and searches for an operator relevant to removing the differences. In this case, C can be transformed to H5 by a substitution operator. (H0) can be changed to J3 by an addition operator (MAKE (H0)=J3 BY ADDITION). The application of these operators to the DSCN of P2(C) would compile the desired routine in the following stages:

P2(C)	REPLACE THE SYMBOL IN C BY (H0).
Apply substitution	
	REPLACE THE SYMBOL IN H5 BY (H0).
Apply addition	
	REPLACE THE SYMBOL IN H5 BY J3.

The resulting program in this case is identical with that obtained by the SDSC Compiler.

A somewhat more complex routine compiled by the DSCN Compiler is:

J13: INSERT (1) AT THE END OF (THE VALUE OF ATTRIBUTE (0) OF (2)).

The list of available IPL routines includes:

J65: INSERT (0) AT THE END OF (1).

The differences between J65 and J13 are in their arguments. J65 has the argument (0), where J13 has the argument (1); J65 has the argument (1), where J13 has the argument (THE VALUE OF ATTRIBUTE (0) OF (2)). Since it is not easy in IPL-V to rearrange arguments that are located in the pushdown list of the communication cell, H0, the compiler facilitates matters by incorporating in the compiled routine an algorithm that moves the inputs of the routine to be compiled into known working storage locations, then puts these inputs back into H0 in the order in which they are needed for the subprocesses. That is, the compiler first transforms J13 into another routine, call it K13, which it then compiles. The DSCN of K13 is:

K13: INSERT 1W1 AT THE END OF THE VALUE OF ATTRIBUTE 1W0 OF 1W2.

The code for J13 may be written as:

```
J13     J52
        K13
        J32     0 .
```

Now K13 is to be compiled with the aid of J65. Comparing the corresponding arguments of the two routines, we see that this involves finding the value of attribute 1W0 of 1W2, placing this value in H0, bringing 1W1 into H0, and then performing J65. That is to say, K13 will have the general form:

```
K13     FIND V(1W0,1W2)
        11W0
          J65.
```

In the list of available routines, the compiler finds:

J10: FIND THE VALUE OF ATTRIBUTE (0) OF (1),

which may be abbreviated, FIND V((0),(1)). Comparing the arguments of J10 with V(1W0,1W2), we see that (1) must be set equal to 1W2 and (0) to 1W0. Hence, V(1W0,1W2) is equivalent to

```
11W2
11W0
  J10.
```

Hence, the complete code for K13 is:

```
11W2
11W0
  J10
11W1
  J65,
```

and the complete code for J13 is simply:

```
J13       J52
        11W2
        11W0
          J10
        11W1
          J65
          J32    0 .
```

<u>THE GENERAL COMPILER</u>

The General Compiler [U135] is an executive routine whose task is to compile a routine from information in any of the forms already discussed (SDSC and DSCN) or in other forms that may be described. It takes as its input the name of the routine to be compiled. Associated with this name (on its description list) is the information to be used in the compilation. More formally:

A <u>routine</u> is a description list containing values of some subset of the following attributes:

1. IPLN--<u>IPL name</u> [X25]. The value of this attribute is a description list that names a region

[X33] and a location [X34] in the region; e.g., J60, R149, J3.

2. JDEF--<u>IPL-V definition</u> [X22]. The value of this attribute is a list of IPL-V instructions, each in the form of a description list describing [attributes X40-X46] the corresponding IPL-V word, that defines an IPL-V routine with the specified name. For example, the routine with IPLN J3 might have the following JDEF:

```
J3    10J3
      20H5    0 .
```

3. DSCN--<u>Descriptive name</u> [X20]. The value of this attribute is an imperative sentence (encoded as a list structure) that describes [with attribute X30,X31] the process defined by the JDEF. For example, the routine with IPLN J3 has, as already explained, the DSCN:

   REPLACE THE SYMBOL IN H5 BY J3.

4. SDSC--<u>State description</u> [X240]. The value of this attribute is a list structure that describes the state of the IPL computer before and after the routine in question has been executed. Only changes are mentioned explicitly. Thus the SDSC of J3 is:

   H5: S1,R0. J3,R0.

5. FLWD--Flow diagram [X267]. The value of this attribute is a list structure that gives the flow diagram corresponding to the JDEF. This list structure will be described in more detail later.

6. ASOJ--Associated J definition [X23]. The value of this attribute is the IPL name of a routine associated, in a manner to be described later, with a given routine.

A compiled routine is a routine that has a JDEF. Now we can state the problem of compiling a routine as follows: Given a routine without a JDEF (the present object), find the corresponding routine with a JDEF (the goal object). "Corresponding" means that the compiled routine has the same SDSC or DSCN as the given routine. Figure 1 presents the flow diagram of a compiler [U135] that uses means-end analysis to accomplish this compilation.

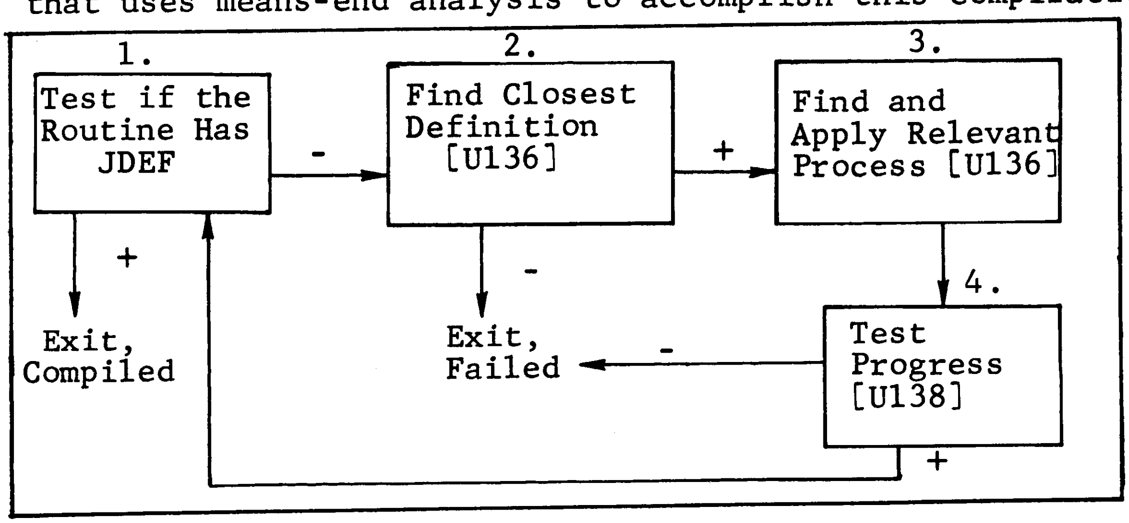

Fig. 1--Flow Diagram for: COMPILE ROUTINE R1

Let us translate this flow diagram into the language of means-end analysis.

1. Test if the routine has JDEF. This test determines whether the present object has the characteristics of the desired object. If so, the compilation is complete.

2. Find the closest definition [U136]. This process corresponds to finding a difference between the present and desired objects. However, we generalize this notion to mean look for a characteristic of the present object that will suggest a relevant operator. If the object possesses a DSCN, then an attempt could be made to compile the JDEF from the DSCN; if it possesses a SDSC, an attempt could be made to compile the JDEF from the SDSC. The attributes that the routine could possess are listed in an order that reflects the relative ease of compiling a JDEF from them. The process then finds the first attribute on this list that the routine to be compiled possesses. In the present form of the compiler, it is assumed that it is easier to compile from a DSCN than from a SDSC; hence, the attributes are listed in this order. If the routine possesses no attribute that can be used as a basis for compilation, the compiler reports a failure.

3. Find and apply the relevant process [U137]. The input to this process is the "closest definition" that has just been found. A table of connections is searched to find a process that is relevant to compiling the JDEF from the closest definition. If one is found, it is applied (in a manner to be described later).

4. Test progress [U138]. If the operator has been applied successfully, the routine will now possess at least one attribute (a JDEF or another) it didn't previously possess. If the progress test detects that it now has a definition closer to the JDEF than any it had previously, it initiates a new compilation cycle; if not, it reports a failure and quits.

The present list of "closest definitions" is very short, consisting only of DSCN and SDSC. The present table of connections [X198] is also brief:

1. If the routine possesses a DSCN, apply the operator, COMPILE JDEF FROM DSCN.
2. If the routine possesses only a SDSC, apply the operator, COMPILE JDEF FROM SDSC.

IV. RELATION OF THE HEURISTIC COMPILER TO GPS

Since each of the major components of the Heuristic Compiler is a system of means-end analysis, each of these components can be viewed as a rudimentary GPS. It should therefore be feasible, by modifying the top-level programs, to bring the Heuristic Compiler into a form that would allow its problem-solving processes to be governed by GPS. The programs for detecting differences, the tables of connections, and the operators would provide definitions of task environments for GPS. To accomplish this, GPS would have to be arranged so that a subproblem could be attached by applying GPS to a new task environment. That is, GPS would first be applied to the task environment of the General Compiler; applying an operator in this environment would consist in applying GPS to the task environment of the DSCN's or the SDSC's, as the case may be.

V. FLOW DIAGRAMS

Up to this point, we have considered only very simple programs, requiring no branches or loops. Each program is a list of instructions; each instruction is an IPL word represented as a description list with the attributes type [X40], name [X41], sign [X42], P [X43], Q [X44], symbol [X45], and link [X46].

To represent a program with branches and loops, we divide the program into segments. Each entry point to a loop (an instruction with a local name) begins a new segment; each branch instruction (P = 7) ends a segment. Each segment has the same attributes as an IPL word--specifically: name, P, symbol, link, and an additional attribute [X22], whose value is the list of IPL instructions for the segment. The name of the first instruction of the segment is assigned as the name of the segment; if the segment ends in a branch instruction, it is assigned P=7, and its symbol and link are set equal to the symbol and link of the branch instruction. If the segment does not end in a branch, it is assigned P = 0 and SYMB = 0, and its LINK is set equal to the link of its last instruction. Under these conventions, the list of segments is a flow diagram of the routine with the detail of the routine segments appended.

To illustrate the format of a flow diagram, we show below the code for IPL routine J77, followed by its flow diagram. The DSCN of J77 is: TEST IF THERE IS A SYMBOL EQUAL TO (0) ON LIST (1).

IPL-V CODE FOR J77

```
------------------
J77      J50     90      Segment I: Put (0) in W0.
------------------
90        J60            Segment II: Find next
        7091     92      location on list (1).
------------------
92      12H0             Segment III: Test if
        11W0             symbol at location is
          J2             equal to (0).
        7090     91
------------------
91      30H0             Segment IV: Clean up
          J30    0       and exit.
------------------
```

FLOW DIAGRAM FOR J77

```
J77     0        90
90      7 91     92
92      7 90     91
91      0        0
```

From the description of the flow diagram, it is easy to provide a program [U139] that will construct a flow diagram from an IPL routine, and a program [U133] that will compile an IPL routine from the flow diagram and appended code segments. In this way the task of compiling an IPL routine is reduced to the problem of compiling its flow diagram, and compiling the code for each of the segments of the flow diagram.

The program for compiling such a routine from its DSCN has not yet been written, but examination of the structure of the routine itself shows what is involved. The test involves a quantifier--whether there exists a symbol with a certain property on a particular list of symbols. In IPL-V, such existence tests are performed by means of a loop or a generator; the members of the set in question are produced one by one and tested for their possession of the property. If a test result is positive, the process stops, and the signal, H5, is set plus. If the set is exhausted, the signal, H5, is set minus. Thus, a standard flow diagram can be used for all routines of this kind:

A Perform required setup.
B Locate another member of set
  (if none, exit, via D).
C Perform test on member
  (if it succeeds, exit, via E;
  if it fails, return to B).
D Exit with signal minus.
E Exit with signal plus.

Except for the provision of two distinct exits, this is identical with the flow diagram previously shown for J77 (Set A = J77, B = 90, C = 92, D = E = 91). Now, we can compile for each segment of the flow diagram a routine that corresponds to the DSCN of that segment. For example, FIND ANOTHER MEMBER OF (1) becomes J60 (after appropriate recognition of the changed location of (1)); PERFORM TEST ON MEMBER becomes:

```
12H0
11W0
  J2 .
```

The only complications lie in moving the inputs for the various processes (J60 and J2) in appropriate ways. The compiler can do this in a straightforward, if inefficient, way by using the working storages. Thus, an unedited compiled version of J77 might look like this:

```
J77        J51      90
90       11W1
           J60
         20W1
         7091       92
92       12W1
         11W0
           J2
         7090       93
91         J31      0
93         J31      0  .
```

The same flow diagram would be used in the compilation of J62: LOCATE ON (1) AN X SUCH THAT C(X)=(0). In fact, this routine is identical with the one just discussed, except that it requires 11W1 before the exit. It should be observed that the indefinite article "an" plays the same role in the DSCN of J62 as the quantifier "there is a" in J77. The compiler, therefore, would be provided with the knowledge that the above flow diagram, using J60 in the second segment, is the appropriate means for translating this quantifier.

Declarative and interrogative sentences in a DSCN correspond to tests in the compiled routine. Thus, the phrase, "such that C(X)=(0)," leads to the question, "Does C(X) equal (0)?" and thence to the test J2(C(X),(0)).

PART II

GENERAL IMPLICATIONS FOR REPRESENTATIONS

Our examination of flow diagrams has already led us to consider how some syntactical devices of English (e.g., the definite and indefinite articles) are to be rendered in the compiler. In this part, we raise at a more general level the question of the syntactical flexibility and range of the compiler languages. In Sec. VI, we ask what forms of English expressions are handled naturally and simply by the DSCN and SDSC languages, respectively. In Sec. VII, we ask how we would go about formalizing the notion of representation so that a problem-solving compiler could be given the task of designing its own representations.

VI. LANGUAGE AND REPRESENTATIONS IN THE COMPILER

We can ask appropriately about any compiler, "What range of source statements can it accept?" In Part I, we have discussed two kinds of source statements, DSCN's and SDSC's. Let us now consider in a little more detail the range of English-language expressions that these compilers can handle. We take up the language of descriptive names and the language of state descriptions in turn.

DESCRIPTIVE NAMES

The DSCN's are particularly interesting because they take the form of English sentences--imperatives, or, as we have just shown, declaratives and interrogatives. How restricted is the language of DSCN's in relation to the whole class of grammatical English sentences?

Consider the sentence, "What is the color of that apple?" The answer might be, "It's color is red," or even, "It is red." In the original sentence, "that apple" denotes a particular object; "the color," an attribute of that object; and "what," the unknown value of the attribute. In the replies, "it" denotes the same object as "that apple"; "red," the (now known) value of the attribute. Thus, we might represent the question and the first answer, respectively, as:

? = Color (that apple)

Red = Color (it).

The second answer can be interpreted as synonymous with the first if we stipulate that "red" can be a value only of the function "color."

The process in IPL-V that provides the answer to such questions is J10: FIND THE VALUE OF ATTRIBUTE (0) OF (1). In terms of our example, this is: "Find the value of attribute 'color' of that apple." Thus, the process that answers the question takes two inputs--the names of the attribute and the object--and produces the value as its output. It defines a function, in the mathematical sense of the term. In the statement of the process, "attribute" is in apposition with "color," the former term specifying the genus to which the argument belongs. We could equally (though not quite grammatically) have said, "of the object, 'that apple.'" Likewise, the phrase, "Find the value of the color," is synonymous with, "Find the color," "value" being in apposition with the (implicit) "?". That is, in English, we abridge, "The value of the attribute, the color, of the object, that apple, is red," to, "The color of that object is red," or, "That object is red." We can do this because "color" is an attribute, "that apple" is an object, and "red" is a value--nothing is added to meaning by making these classifications explicit.

This example shows how, in general, we can handle a wide class of grammatical forms within the framework of the DSCN's. Interrogatives are unknowns, like the x's of algebra, whose genera may be specified, in part or full, to identify them. The couple "the ... of ..." signals a <u>determiner</u>--a phrase that names something by giving enough of its properties to tag it uniquely. Pronouns (e.g., "it") and pronominal adjectives ("that") identify by reference to terms that have occurred in previous sentences. "Find" is a general process that replaces a determiner by the object determined. Appositive phrases and relative clauses provide additional identificatory information about the object to which they refer. Adjectives, adverbs, prepositional phrases (other than "of" phrases), and adjectival nouns have the same function--identification or description. Quantifiers ("there is," "all," "a," "some," etc.) require special treatment--several of them have already been discussed.

The present DSCN Compiler was constructed specifically to handle verbs (processes), determiners (especially those involving "the ... of ..."), and proper names (in IPL-V these are always locations). Essentially, what the compiler does is replace determiners by the appropriate proper names, using the FIND processes for the compilation. In the previous section, we indicated how loops and flow diagrams could be used to handle quantifiers and conjunctions, including "and," "but," and "if ... then." Pronouns could be handled in a manner similar to that used for determiners. Appositive and modifying words, phrases, and clauses could be used as aids in identifying proper names. It appears that with these extensions, the DSCN format would encompass most of the forms of grammatical English sentences. Only programming, of course, can determine to what extent this claim is correct.

STATE DESCRIPTIONS

Just as the DSCN language admits of considerable flexibility in representing English sentences, so the SDSC language admits of broad flexibility in the representations of information in the computer. This flexibility is achieved by using description lists as the holders of information. Each computer address that is referred to in the SDSC is represented by a cell having a description list. On the description list are the attributes NAME, TYPE, P, Q, SIGN, SYMBOL, LINK--i.e., precisely the attributes that name the fields in an IPL word (and the name of that word) and that appear on the coding sheet. Since the SDSC makes these attributes explicit, the program that uses the SDSC's need not be provided with this information in any format more specialized than the description list format itself. Moreover, additional attributes and their values can be added, ad lib, to the description list.

By introducing attributes that refer to a particular machine representation of IPL, the SDSC language is readily extended to admit statements about the relation between IPL and its particular representations. For example, suppose the fields in the words of a particular computer were designated by the attributes DECREMENT, ADDRESS, etc. We could then <u>define</u> a machine language representation of IPL by setting up appropriate correspondences between IPL attributes and machine language attributes. (For example, we might specify SYMB = DECREMENT, LINK = ADDRESS, etc.) We shall indicate in the next section how this technique can be used to give the Heuristic Compiler the capability of designing appropriate representations--hence, how the compiler itself might choose an appropriate machine language representation of IPL prior to undertaking the task of compiling IPL into a machine language program.

There is also no necessity in SDSC that each description list should give the description of the contents of a single computer address. Alternatively, it may describe a whole list. Suppose, for example, we wish to represent the fact that the symbol in cell H5 is J3, and that H5 is linked to a pushdown list having unknown contents. All of this information can be given in two description lists:

	NAME	SYMB	LINK	KIND OF OBJECT
1.	H5	J3	R0	Pushdown cell

	NAME	KIND OF OBJECT
2.	R0	List

We have already illustrated how this flexibility is used to represent segments of instructions in flow diagrams.

VII. THE DESIGN OF REPRESENTATIONS

One distinction between the restricted, relatively simple tasks we call "coding," and the broader, more difficult tasks we call "programming," is that the latter may encompass the selection or design of an appropriate problem representation, while the former do not. Our discussion of languages now enables us to see what is involved in the design or selection of a representation, and what we would need to do in order to give the Heuristic Compiler the capacity to grapple with such design and selection tasks. To illustrate this point, we shall take an example of a representation problem within the structure of IPL-V itself.

Let us suppose that we had an operating "basic" IPL system, quite like the language defined in the IPL-V Manual, except that the description list processes were omitted. We now give a programmer the task of introducing description lists into the language, using the basic system itself to define them, without writing any new machine code.

What do we mean by "introducing description lists"? We mean that we wish to be able to associate with the name of an object (which in IPL is always an address) a description of that object. The description consists of a set of pairs: one member of each pair is an attribute;

the other member of the pair is the value of that attribute for the object to which the description belongs. Moreover, we wish to be able to store and retrieve descriptive information about objects. That is, we wish to be able to add new pairs to descriptions, and when we are given the name of an object and an attribute, we wish to be able to find the value of that attribute for that object. Stated formally:

With every object A_i, we associate a set of pairs, (B_j, C_{ij}). The number of pairs is to be arbitrary and variable, and we want a process that will answer questions of the form: $? = B_j(A_i)$.

How could a programmer solve this problem? By the basic conventions of IPL-V, "object" already means "address." Thus, he must find some way of associating a set with each address. Again, in IPL, the standard way to represent a set is by a list. The question then becomes, "What list can we associate with an address?" The basic relations that are represented in IPL-V are CONTENT OF and NEXT. The CONTENT OF a cell is the SYMB of that cell, and the NEXT of the cell is its LINK. Moreover, basic processes exist for FIND CONTENTS (P = 1, Q = 1) and FIND NEXT (J60). Thus, the set we associate with an address can be taken to be the list whose name is the SYMB (or, alternatively, the LINK) at that address. Let us call this list (pursuing the first alternative) the <u>description list</u> associated with the address.

We must next define a format for description lists that will represent the pairing of attributes and values. One method would be to associate a pair of words with each element of the description list, again using the relations CONTENT and NEXT. Thus, if S_j is the content of the j^{th} number of the description list, we could define B_j = CONTENT OF S_j, and C_{ij} = CONTENT OF NEXT OF S_j. (This is substantially the representation that was used in an earlier version of IPL. An even simpler representation would make C_{ij} = LINK OF S_j.) Now, to add a pair, B_j, C_{ij}, to the description list of A_i, we add a cell to the description list, assign it a SYMB (S_j), assign B_j as the SYMB of S_j, and assign C_{ij} as the SYMB of the LINK of S_j. Similarly, if we are given A_i and B_j, to find C_{ij}, we first find the description list, CONTENT OF A_i, and we go down this list comparing B_j with the CONTENT of the CONTENT of each location on the list. When we obtain a match, we find the CONTENT of the cell next to the matched cell, and this is the desired value. These processes follow from the representation.

An alternative representation is obtained by dividing the members of the description list into two subsets--its ODDS and its EVENS. We then take the ODDS as the attributes; the value of an attribute is simply the EVEN that follows it. These definitions, again, make use only of the relations CONTENTS and NEXT. Thus, an ODD of a list is the FIRST of the list or the NEXT of the NEXT of an ODD.

This definition allows us to construct a loop that will find, in sequence, all the attributes on the list. Given the location of an attribute, a FIND CONTENTS OF NEXT finds its value. This representation is, of course, the one actually adopted in IPL-V.

It will be instructive to see what the program for J10: FIND THE VALUE OF ATTRIBUTE (0) OF (1), looks like in each of these representations. We write the two programs side by side:

```
J10     J51               J10     J51
      12W1                      12W1            Find description list.
92      J60               92      J60
      7090                      7090
      60W1                      60W1
      52H0                      52H0            Find next attribute.
      12H0                      11W0
      11W0                        J2            Test if it is equal to (0).
        J2                      7091
      7091                      11W1
        J60                       J60           If so, find value.
      52H0    J31               52H0    J31
91    30H0                91    11W1
      11W1    92                  J60   92      Proceed down description list.
90    30H0    J31         90    30H0    J31     Exit, attribute not
                                                 found.
```

We see from this example that designing a suitable representation amounts to finding an isomorphism. A "description" was defined in terms of certain elements (objects, attributes, values), relations between elements (e.g., the attributes of an object), and processes (e.g., FIND THE VALUE OF (0) OF (1)). The programmer had to find a set of elements, relations, and processes defined in IPL-V that were isomorphic with the required elements, relations, and processes. I have not worked out how such a search could be automated, but the main requirements are clear. In particular, to enable the Heuristic Compiler to perform this search, it would have to be provided with lists of the available elements, relations, and processes, or it would have to be able to recognize such things when they were described in the DSCN or SDSC languages. For example, it would have to recognize that every determiner (e.g., "the ... of ...") defines a relation.

As a second example of what is involved in designing a representation, let us consider the representation of IPL-V words in SDSC. Since each word consists of a number of symbols belonging to different fields, we can again use the description list format, in which we equate "field" with "attribute" and "symbol in field" with "value of attribute." But the symbols in the NAME, SYMB, and LINK fields themselves contain encoded information, for they are in the form ANNNN, where A is an alphameric symbol, and NNNN is a number. Hence, we represent each of these symbols by an object with a description list containing the attributes REGION and LOCATION. The value of REGION is the alphameric symbol A; the value of LOCATION, the number NNNN. Therefore, the information that a "local symbol" is one with A = 9 can be represented. Again, the lesson here is that we must create an isomorphism between the elements of the representation, their relations, and the structure to be represented.

Suppose, as a third example, that we set ourselves the task of writing a program to sort a bridge hand. To accomplish this task the meanings of "sort" and "bridge hand" must be known. A bridge hand is a set of (13) elements, each characterized by a primary characteristic, suit (4 possible values), and a secondary characteristic, denomination (13 ordered values). Sorting means ordering a set of elements by one or more characteristics, taking account of the ordering of values where this is defined.

In this case we find a straightforward isomorphism: Each element in the bridge hand is to be represented by an object having a description list with attributes SUIT and DENOMINATION. A sorted bridge hand is to be represented by a list of such elements, with the ordering of the list to correspond with the ordering of the sort. It now becomes a straightforward (if difficult) compiling job to write a SORT routine that will produce a list with these properties. Moreover, if it is done correctly, it should be possible to write the routine in the generalized form: SORT (0) IN FORMAT (1), where (1) enumerates the attributes, their ordering, and the orderings of the values that define the sorted object.

We shall explore this particular scheme in more detail in Sec. VIII of Part III. Perhaps enough has been said here to demonstrate that selecting or designing a representation is a problem-solving task that can be attacked with the same general kinds of heuristic techniques as other problem-solving tasks.

PART III

EXPERIMENTS WITH REPRESENTATIONS

In Part III, we propose some extensions of the Heuristic Compiler, most of which are motivated by linguistic considerations. In particular, we explore some methods for enabling the compiler to handle input statements in forms that are close to natural language.

There are a number of important respects in which natural languages differ from the usual programming languages. We shall be especially concerned with three of these differences:

1. In natural languages, the word is the most important unit of meaning. (For the moment, we do not need to distinguish among "word," "morpheme," and "idiom.") In most computer languages, the sentence (usually an imperative sentence, called an "instruction") is the basic unit of meaning. Thus, if a person understands, separately, the verb "sort," and the noun phrase "bridge hand," he can probably obey the instruction, "Sort the bridge hand." In most computer languages, a compiler would not be able to assemble, "Sort a bridge hand," from "sort" and "bridge hand," but would have to be provided with a number of specialized sort routines.

2. In natural languages, most communication makes use of sentences in the indicative or declarative mode.

In computer languages, most sentences are in the imperative mode. Computer languages are primarily languages of command, and not languages of information, description, or advice.

3. In natural languages, many alternative sentences can be phrased that "mean" about the same thing. The recipient of a natural-language communication is able to decode the communication without too much concern for details of format. In computer languages, there are various harassing constraints on format. Failure to observe these constraints usually causes an error condition.

These differences are, of course, differences of degree and not of kind. Moreover, research on computer languages over the past decade has already made substantial progress toward decreasing or erasing them. Basic processes have become more general and parameterized; various forms of declarative statements have been introduced; compilers have been designed to accept relatively informal input statements. The gap, however, between natural language and computer languages is still large, and annoying to those who are engaged in man-machine communication.

We are here concerned with extensions of the Heuristic Compiler directed towards reducing these differences.* Section VIII indicates how generalized processes (verbs) can be introduced into the DSCN Compiler. Section IX describes subroutines for storing and retrieving descriptive information in declarative sentences. Section X describes an approach toward natural-language flexibility in input statements for the SDSC Compiler, making use of the descriptive information provided by the techniques of Sec. IX.

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*The thinking reported here, particularly in Sections IX and X, was greatly stimulated by the work of Robert K. Lindsay, "The Reading Machine Problem" (Unpublished Ph.D. Thesis, Carnegie Institute of Technology, 1960), which has been revised as Toward the Development of a Machine Which Comprehends, University of Texas, Austin, May 1961. I owe a great deal also to stimulating discussions with Hugh Kelly and Allen Newell of The RAND Corporation and Carnegie Tech, respectively.

VIII. GENERALIZED PROCESSES

We shall consider two classes of processes: one designated by the verb "find," the other by the verb "sort."

"FIND" PROCESSES

The possible interpretations of FIND are numerous to the point of being meaningless. Any routine that takes some symbolic structures as inputs and produces one or more other structures as outputs may be called a process for "finding" the latter. Thus: FIND SINE A, FIND THE STATE DESCRIPTION OF ROUTINE K, FIND THE PROOF OF THEOREM T. From this point of view, a program like the General Problem-Solver is simply a fairly general FIND routine.

Hence, any routine flexible enough to interpret correctly the verb "find" wherever it occurs in normal English prose, would have to make considerable use of context. In the present section we shall aim at a lesser degree of flexibility. Consider the two classes of processes typified by:

FIND THE <u>state description</u> OF <u>routine</u> K, and

FIND A .... ON ....

The first example designates an object associated in a particular way with a specific object, K. In IPL-V there is provided a special format, the description list, for holding such information in memory, and a set of processes, J10 to J16, for entering and retrieving the information. Section IX examines definite descriptions of this special kind at length. In the present section, then, we shall limit ourselves to the verb "find" as it occurs in instructions like, FIND A ... ON ..., and FIND THE ... ON ... . Even this scheme covers a considerable variety of processes:

FIND A symbol, S10, ON list L.

FIND AN object whose type is A4 ON list structure L.

FIND THE third symbol ON list L.

FIND THE largest integer data term ON the lists of list L.

In the first two examples, the indefinite article indicates that the object sought is not necessarily unique; in the last two examples it is. In the first two examples the properties that define the object sought are absolute--their presence or absence can be ascertained without reference to other objects. In the last two examples, the properties are relative; and indeed, in the fourth example, the entire set of objects must be examined before the one sought can be identified. In the first example, the object sought is designated by proper name (and the information is added that it is a "symbol"). This example can be approximated to the others by rephrasing it: FIND A token equal to S10 ON list L.

With these preliminaries out of the way, we shall describe in detail a rather general FIND process. The object sought will be specified by some sublist of the symbols on the pushdown list of the communication cell, H0. The specification of the place to be searched will be given by other symbols on that pushdown list. Hence, we can symbolize the desired process:

$$\text{FIND A } F_1[(0), (1), \ldots, (k)] \text{ IN } F_2[(k+1), (k+2), \ldots, (n)],$$

where (0), (1), etc., designate, as usual, the symbols on the pushdown list of H0.

We suppose that the compiler is provided with a lexicon that contains, among others, the words "FIND," "F_1 [ ]," and "F_2 [ ]." The lexical entry for each of these is a description list containing, for "FIND" and "F_1," the attribute IPL ROUTINE, and for "F_2," the attribute TYPE OF OBJECT.

The IPL ROUTINE associated with FIND in the lexicon will contain certain variables, to be replaced by constants derived from an examination of F_1 and F_2. We will first present the routine, as it would appear in the lexicon, and then explain the meaning of certain of the symbols in it.

```
FIND      J5n
         11W(n-k)
         1090
           GEN (F1,F2)
           J5              J3n
90       40H0
         11Wk
           TEST(F1)
           J5
         7090              J8
```

As previously indicated, k is the number of arguments in F_1, (n-k) the number of arguments in F_2, and n the number of arguments in the two functions taken together. Thus J5n preserves W0 to Wn and moves all the arguments of F_1 and F_2 into the W's; J3n restores W0 to Wn. The instruction 11W(n-k) brings into H0 the arguments of F_2, while 11Wk brings in the arguments of F_1. The numbers k and n-k are to be determined, of course, by examining F_1 and F_2. The variable, GEN(F_1,F_2), is to be replaced with a generator obtained from the lexical entry for F_2, while TEST(F_1) is to be replaced with a test associated with the lexical entry for F_1. All the other symbols have their usual IPL-V meanings.

We can now compile FIND A F_1 IN F_2 as follows:

1. Get IPL ROUTINE of FIND.
2. Supply values for k, n, and n-k where required.
3. Make list of subroutines required (GEN(F_1,F_2), TEST(F_1)).
4. Get the IPL ROUTINE of TEST, supply it with its arguments, and insert it in the IPL-V code for FIND.
5. Get TYPE OF OBJECT of F_2, and get the associated GEN for that type in the dictionary of generators; insert it in the IPL-V code for FIND.

A word may be added to this account to indicate how relative properties are handled in FIND THE THIRD ..., or FIND THE LARGEST. In these cases, the test needs to be based on a recursive process--in the case of FIND THE THIRD ..., a counting process; in the case of FIND THE

LARGEST ..., a process that resets LARGEST SO FAR equal to the larger of LARGEST SO FAR and the current integer. The test--the function F_1--would, in these cases, make provision for storing in the W's the intermediate products of calculation.

<u>"SORT" PROCESSES</u>

As our second essay toward generalized processes, we take the verb "sort." Suppose that the objects we wish to sort are description lists. It is easy to construct a general routine, SORT (0) ON (1), where (0) is the list of objects to be sorted and (1) is a specification of the attributes, their ordering, and the orderings of attribute values on which the sorting is to be based. Thus, if (0) were a list of description lists representing the cards in a bridge hand, (1) would specify that the attributes are suit and denomination (in that order), that the suit values are S,H,D,C, in that order, and the denomination values A,K,Q,J,10,9, etc., in that order. A further step toward generalization would allow the sort routine to be compiled from a <u>definition</u> of the collection of objects to be sorted. Let us see how this can be done when the object to be sorted is a bridge hand. First, we store in memory description lists providing information about the terms LIST, DESCRIPTION LIST, and ATTRIBUTE:

LIST
- TYPE: Class of objects
- ATTRIBUTES: Type of members

DESCRIPTION LIST
- TYPE: Class of objects
- ATTRIBUTES: Attributes

ATTRIBUTE
- TYPE: Class of symbols
- ATTRIBUTES: Values.

That is to say, a list is a class of objects; the description list for any class of objects of type LIST will have the attribute CLASS OF MEMBERS. A description list is also a class of objects; the description list for any class of objects of type DESCRIPTION LIST will have the attribute ATTRIBUTES. An attribute is a class of symbols; the description list for any class of objects of type ATTRIBUTE will have the attributive VALUES.

Next, we store in memory description lists providing information about the terms BRIDGE HAND, CARD, SUIT, and DENOMINATION.

BRIDGE HAND
- TYPE: List
- MEMBERS: Cards

CARD
- TYPE: Description List
- ATTRIBUTES: Suit, denomination

SUIT
- TYPE: Attribute
- VALUES: Spade, hearts, diamonds, clubs

DENOMINATION
- TYPE: Attribute
- VALUES: A,K,Q,J,10,9,8,7,6,5,4,3,2

Now we can compile SORT THE BRIDGE HAND (0), as follows: From the information just stored, we find that BRIDGE HAND has the type LIST. From LIST, we find that BRIDGE HAND will have the attribute TYPE OF MEMBERS. Finding the value of this attribute, we determine that the members of bridge hands are cards. CARD is a description list, which has the attribute ATTRIBUTES. The attributes of cards are suit and denomination. We would therefore compile the sort routine to sort on suit and denomination, in that order of priority. Examining the values of these two terms, in turn, we find the order in which these values are to be arranged in sorting.

If it were known to the program that a bridge hand is a list of description lists, then the sorting routine could obtain the information about attributes and values by direct examination of one or more examples of a sorted bridge hand, and without being given the information about CARD, SUIT, or DENOMINATION explicitly. If the examples were not too special (e.g., a hand of thirteen spades), the program could determine what attributes a card possessed, which of these was relevant to the sorting, the hierarchy of attributes, and the ordering, if any, of the values of each. This information could then be used to compile the specific sorting routine required.

Thus, we see that the key to providing a generalized routine for a verb like SORT lies in providing syntactically or semantically the information needed to supply the routine with the parameter values it requires. This can be accomplished (syntactically) through a scheme of declarative sentences that describe the objects under consideration; or (semantically) by providing examples that can be analyzed. Moreover, the description itself can be generated inductively from examples.

The description that would allow compilation of the "sort" routine could also be used to compile TEST IF X IS A BRIDGE HAND. Thus, storing descriptions of classes of objects is an important means for factoring sentence meanings of nouns and verbs, respectively. It provides a powerful basis for introducing general processes.

RECURSIVE FUNCTIONAL LANGUAGES

Consider an instruction language consisting of a set of functions each admitting as arguments the values of functions of the set. Each of the functions can be regarded as a FIND instruction--i.e., FIND THE VALUE OF F FOR THE GIVEN ARGUMENT VALUES. It may be executed recursively by finding, first, the values of each of its arguments, then using these to compute the value of the function. Hence, the interpreter of such a language may itself be regarded as a generalized FIND instruction.

Next, consider an instruction like SORT OBJECT A, in a recursive functional language. The definition of SORT, if it is a generalized routine like those described in the previous section, may read something like ARRANGE ACCORDING TO THE ATTRIBUTE VALUES OF. The definition has different arguments from SORT itself--it refers to the attribute values of A instead of the object A. The interpreter would need to be general enough to replace SORT A by ARRANGE A BY THE ATTRIBUTE VALUES OF A; then execute FIND THE ATTRIBUTE VALUES OF A, and insert the value of this function as the second argument of the ARRANGE function. We have already indicated how the FIND might be accomplished.

With a little further generalization, the scheme could handle apposition--e.g., SORT THE BRIDGE HAND, A. The phrase in apposition would provide information about the type of the object designated, and as we have seen, this information could be used to find the other argument of the ARRANGE routine. Further light will be cast on apposition in the next section, where we shall discuss modifiers that <u>identify</u> an argument, and their relation to modifiers that <u>describe</u> the object.

IX. DEFINITE DESCRIPTIONS

The meaning of much descriptive and expository prose can be captured in a fairly simple language--a sub-language of English--that uses only the verb "is" and noun phrases with definite or indefinite articles in subjects and predicates. Consider the following example, which, while it does not fit this restricted form exactly, is not far from it:

> The state description of a routine consists of a list of affected cells. For each affected cell on the list, the state description specifies its input state and its output state.

SYNTACTIC CHARACTERIZATION

We might proceed to formalize this description in either of several ways. I shall call the first of these <u>syntactical</u>, since it makes statements about the terms "state description," "affected cells," "input state," and "output state." These statements can then be stored in association with the relevant terms in a lexicon.

> The type of "state description" is "description list";
> The attribute of "state description" is "list of affected cells";
> The type of "list of affected cells" is "list";
> The type of "affected cell" is "description list";
> The attributes of "affected cell" are "input state" and "output state."

We have already seen this kind of description in our discussion of generalized SORT routines in the previous section. Readers who are familiar with the notation known as Backus normal form will observe that a syntactical description of this kind could without much difficulty be translated into that form--or a slight extension thereof. Our interest, however, is in staying close to natural English.

SEMANTIC CHARACTERIZATION

An alternative, semantic, formalization characterizes a given type of object (STATE DESCRIPTION in this instance) by describing an example:

```
X1 is a state description of a routine if
            there are an X0, X2, X3, X4,
            and X5, such that:
X0 is a routine;
X1 is the state description of X0;
X2 is the list of affected cells of X1;
X3 is a member of X2;
X4 is the input state of X3;
X5 is the output state of X3.
```

Properly interpreted, the example implies the syntactic description we gave previously. Consider, for instance, "X3 is a member of X2." With the convention that only lists have members, this statement implies that X2 is a list. From the previous statement, "X2 is the list of affected cells of X1," we observe that this list is the value of the attribute, LIST OF AFFECTED CELLS, of X1.

We can store the example in memory by storing a description list, X0, with attribute STATE DESCRIPTION having value X1. X1, in turn, is a description list, with attribute LIST OF AFFECTED CELLS having the value X2. X2 is a list whose sole member is X3. X3 is a description list with attribute INPUT STATE having value X4, and attribute OUTPUT STATE having value X5.

ANNEXING DESCRIPTIVE INFORMATION TO AN INFORMATION STORE

Let us use symbols from the X region--e.g., X114, X33--to designate nouns. These nouns will be either proper names (of objects to be represented by lists or list structures) or attributes. Consider now the sentence:

"X114 is the X33 of the X25 of X105."

In this sentence, which is grammatical if inelegant English, "X114" and "X105" are proper names, while "X33" and "X25" name attributes. The objects referred to in this sentence are X114 (or synonymously, the X33 of the X25 of X105), the X25 or X105, and X105. The problem of annexing the information provided by this sentence to an existing memory store depends on what is already in the store.

Suppose, as a first possibility, that no information has been stored previously about the objects mentioned in this sentence. We store the new information by creating a name, call it X200, and assigning it as the value of attribute X25 of X105. Then we assign X114 as the value of attribute X33 of the newly named object, X200.

Suppose, however, that we had previously stored in memory the information that an object named X130 was the value of attribute X25 of X105. Then, to store the new information, we would first have to find X130, and then assign X114 as the value of attribute X33 of X130.

In the first case, we annexed the new information by two ASSIGN processes--in IPL-V, two applications of J11. In the second case, we annexed the new information by a FIND process (J10 in IPL-V) followed by an ASSIGN. We can write a general routine to accomplish this. In processing a sentence like the one we are using as example, we start at the extreme right and search in memory for the object named. If we find it, we proceed to the left, find the first attribute, and find the value of this attribute of the object. If the value exists, it becomes a new object on which we can repeat the process, moving to the next attribute to the left.

When we fail to find an object meeting the description (when J10 fails), we enter a second phase. We now proceed from the left-hand side of the sentence, creating names for new objects as these are needed, and annexing their descriptions to them (by J11), until we reach an object that is already mentioned in memory.

Thus, depending on what is already stored in memory, the same piece of information in the input sentence can serve either as a descriptive phrase, providing new information to be annexed to the memory structure, or as an identifying phrase, to be used in locating the place in memory where the new information is to be annexed.

In this scheme ambiguity is entirely possible. It can enter because the scheme allows indefinite, as well as definite description. Again, an example will make the point clear. We consider the following sequence of four input sentences:

> X114 is the X33 of the X25 of X105.
> X115 and X116 are the X99 of the X34 of the X25 of X105.
> X125 is the X41 of a member of the X71 of the X24 of X105.
> X117 is the X75 of the member whose X41 is X125 of the X71 of the X24 of X105.

Suppose we begin with no information about X105 in memory. Then, as we have seen, the first sentence is stored by two executions of J11. The first creates a new object, say X200, and assigns X114 as its X33; the second assigns X200 as the X25 of X105.

The second sentence is stored by two executions of J11 and one of J10. Working from the right, by J10, X200 is found to be already in memory as the X25 of X105. But there is no value for attribute X34 of X200. Hence, a list, say X201, is created whose members are X115 and X116, and X201 is assigned as the value of X99 of another new object, say X202. Finally, X202 is assigned as the X34 of X200.

Storing the third sentence brings about the creation of X203, whose X41 is X125; of a list X204, of which X203 is member; and of an object, X205, whose X71 is X204, and which is, in turn, the X24 of X105.

The fourth sentence introduces a new complication. It refers to "the member of the X71 of the X24 of X105 whose X41 is X125." A series of J10's will find the X71 of the X24 of X105--that is, X204. The sentence now calls for locating that member of X204 whose X41 is X125. From the previous paragraph, we see that the object in question is none other than X203. Thus X117 would be assigned as the X75 of X203.

Now let us return to the question of ambiguity. Suppose that the fourth sentence read:

> X117 is the X75 of the member whose X76 is X130 of the X71 of the X24 of X105.

Now, when we examine X204, we find, as before, that it has a member, X203. But we have no information to tell us whether or not X203 is "the member of X204 whose X76 is X130." Hence, we do not know whether to assign X117 as the X75 of X203 or to create a new member of the list X204--say X205, and assign X117 as the X75 of X205.

The ambiguity is not a consequence of the particular annexing scheme we have used, but resides more deeply in the nature of things. Let r and s be relations; A, B, C, and X, objects. Suppose we know that ArB and that there exists a Y such that CsY and YrB. Then we can neither affirm nor deny that Y is identical with A. (The same difficulty arises in R. Lindsay's program for annexing genealogical information to a family tree.* If we know only that Isaac is a son of Abraham, and Jacob is a son of a son of Abraham, then we do not know whether or not Jacob is a son of Isaac.) Our only recourse is to arrange the annexing routine so that, when it detects such an ambiguity, it outputs an appropriate question.

A program for an annexing routine is given in detail in Appendix B. It will not deal with the ambiguity problem just discussed, but is in all other respects capable of annexing to memory the contents of sets of sentences of the kinds we have been considering.

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*Op. cit., p. 43.

X. COMPILATION OF ROUTINES FROM PARTIAL DESCRIPTIONS

One part of the flexibility of natural language depends on the problem-solving capacity of the listener. Information already in his memory allows him to supply details that are omitted from, or only implicit in, the communication. Suppose we wish to give a (human) programmer the task of coding a routine in IPL-V for J3. We might tell him:

> "Write a routine, J3, that changes the contents of cell H5 from [S1,R0] to [J3,R0]."

The programmer, familiar with IPL-V, knows that H5 is a so-called "pushdown cell," and that what is wanted is to replace the contents of the SYMB field of that cell, whatever they may be, by the symbol "J3."

What instruction would we have to give to the SDSC Compiler to induce it to perform the same task? The instructions would read:

> "Compile the IPL-V definition of the following routine: The NAME of the routine is J3. The LIST OF AFFECTED CELLS of its STATE DESCRIPTION has a member, whose NAME is H5, whose INPUT STATE is the list, S1, R0, and whose OUTPUT STATE is the list, J3, R0."

Given some such statement, the annexing routine described in the previous section could construct an appropriate description list as input to the SDSC Compiler. In Part I, we showed how the SDSC Compiler could then write the desired routine from its state description.

Now the instructions to the compiler have required about three times as many words as the instructions to the human programmer. The reason is easy to see. The essential information to be provided is that the cell to be changed is H5, and that the change is to replace an unknown symbol by the symbol J3. The compiler cannot receive this information without explicit mention that J3 is the first symbol in the list of the output state of affected cell H5 of the list of affected cells of the state description of the routine named J3. The human programmer is capable of supplying this additional information, because he knows what the structure of a state description is like.

The last observation suggests that we might give the compiler the same capability by providing it prior information about the structure of a state description, and allowing it to fill in the implicit detail. Let us employ the language of Sec. IX to see how this might be done.

The complete description list, necessary to the Heuristic Compiler, is equivalent to the following set of sentences:

Let X100 be a routine whose NAME is J3.
Let X101 be the STATE DESCRIPTION OF X100.
Let X102 be a member, whose NAME is H5, of
    the LIST OF AFFECTED CELLS OF X101.
Let S1, R0 be the INPUT STATE OF X102.
Let J3, R0 be the OUTPUT STATE OF X102.

In parallel fashion, we can store in memory a "template" for the description of a routine. We will use symbols from region "Y" to denote variables.

Y1 is the NAME of Y2.
Y3 is the STATE OF DESCRIPTION of Y2.
Y4 is the LIST OF AFFECTED CELLS OF Y3.
Y5 is a typical member of Y4.
Y6 is the NAME of Y5.
Y7 is the INPUT STATE OF Y5.
Y8 is the OUTPUT STATE OF Y5.
X7 and Y8 are lists.

Now to fit the specific example to the template, we identify J3 with Y1, X100 with Y2, X101 with Y3, X102 with Y5, and so on. Suppose, however, the example were incomplete, as follows:

X100 is a routine whose NAME is J3.
N101 is a cell whose NAME is H5.
S1, R0 is the M1 of X101.
J3, R0 is the M2 of X101.

Here "M1" and "M2" designate attributes whose meanings are not given in the lexicon. It should not be too difficult to devise a process for matching this description with the template. The matching process would discover that X101 has to be identified with Y5, and X100 with Y1. New objects could then be created to correspond with Y3 and Y4, and the appropriate description list stored in memory. The SDSC Compiler, taking this description list as its input, could now compile the code for J3.

Our basic proposal, then, for compiling routines from partial descriptions rests on two devices: (1) the use of an annexing routine like that described in Sec. IX as a means for constructing description lists from expository sentences; (2) the use of templates to provide information that is not given explicitly in the input sentences. The routine for accomplishing the second task has not yet been written.

Appendix A

PROGRAM LISTING OF THE HEURISTIC COMPILER

This listing includes a rather simple form of the General Compiler [U135], DSCN and SDSC Compilers [U134 and U140, respectively], routines for assembling flow diagrams [U133], and routines for printing JDEF [U125], DSCN [U126], SDSC [U127], and all three of the above [U128]. These routines are called in by a general executive [T1].

List structures in regions E, T, and U, and X5 and X7 are routines. The remaining list structures in region X are data. The version of T1 that is listed will print X102, then compile and print X105 and X100, compile X182 from its flow chart, printing the result, and reconstruct the flow chart of X102 from its code.

The program is in IPL-V (Information Processing Language-V) and is machine independent.

```
                                             2 A0               0200
                                             2 E0               0200
                                             2 L0               0200
                                             2 N0               0200
                                             2 T0               0200
                                             2 U0               0200
                                             2 X0               0200
                                             5
E4. PRINT LIST (0) OF DATA TERMS               E4    40H0                          E4   000
WITHOUT NAMES. ENTER LIST NAME                         J156                        E4   010
                                                       E54    91                   E4   020
                                               91      J60                         E4   030
                                                     7092                          E4   040
                                                     12H0                          E4   050
                                                       J157   91                   E4   060
                                               92      E53    J8                   E4   070
                                               E8    1090                          E8   000
                                                       J101   E50                  E8   010
                                               90    70       91                   E8   020
                                                     12H0                          E8   030
                                                       J156                        E8   040
                                                     7092                          E8   050
                                                     30H0                          E8   060
                                                       E54                         E8   070
                                                     7093     0                    E8   080
                                               91      E50                         E8   090
                                                       J156   E53                  E8   100
                                               92      E50                         E8   110
                                                     10N10                         E8   120
                                                       J161                        E8   130
                                                     52H0                          E8   140
                                                       J156   E54                  E8   150
                                               93      E50                         E8   160
                                                     10N10                         E8   170
                                                       J161   J4                   E8   180
E40. MARK ROUTINES ON (0) TO TRACE             E40   1090                          E40  000
                                                       J100   0                    E40  010
                                               90      J147   J4                   E40  020
E41. MARK ROUTINES ON (0)                      E41   1090                          E41  000
NOT TO TRACE                                           J100   0                    E41  010
                                               90      J149   J4                   E41  020
PRINT, CLEAR                                   E50     J155   J154                 E50  000
SPACE BAR ONCE                                 E51   10N1     J161                 E51  000
SPACE BAR TWICE                                E52   10N2     J161                 E52  000
PERIOD, SPACE TWICE                            E53   1091                          E53  000
                                                       J157   E52                  E53  010
                                               91    +21.                          E53  020
COMMA, SPACE ONCE                              E54   1091                          E54  000
                                                       J157   E51                  E54  010
                                               91    +21,                          E54  020
E55. PRINT LIST STRUCTURE,                     E55     E50                         E55  000
SAVING FOR NEXT PROCESS                              40H0     E8                   E55  010
                                               T1     3J0                          T1   000
                                                     10A99                         T1   010
                                                       J154                        T1   020
```

```
                                                13A0
                                                10930
                                                  J100
                                                10X102                   T1
                                                  U128                   T1
                                                10X105                   T1    030
                                                40H0                     T1    040
                                                  U135                   T1    050
                                                30H0                     T1    060
                                                  U128                   T1    070
                                                10X100                   T1    080
                                                40H0                     T1    090
                                                  U135                   T1    100
                                                30H0                     T1    110
                                                  U128                   T1    120
                                                10X182                   T1    130
                                                10X41                    T1    140
                                                  J10                    T1    150
                                                10X180                   T1    160
                                                10X181                   T1    170
                                                  U133                   T1    180
                                                  J50                    T1    190
                                                  J90                    T1    200
                                                40H0                     T1    210
                                                11W0                     T1    220
                                                10X22                    T1    230
                                                  J11                    T1    240
                                                40H0                     T1    250
                                                  U128                   T1    260
                                                40H0                     T1    270
                                                  U139                   T1    280
                                                40H0                     T1    290
                                                10X26                    T1    300
                                                  J10                    T1    310
                                                40H0                     T1    320
                                                  U125   0               T1    330
                                        930       J147   0
                                        T99       J166   J165            T99   000
CONSTRUCT IPLV WORD (3), WITH           U100      J52                    U100  000
                                                  J90                    U100  005
                                                  J136                   U100  006
P=(0),Q=(1),SYMB=(2). NO OUTPUT                 40H0                     U100  010
                                                11W0                     U100  020
ASSIGN P                                        10X43                    U100  030
                                                  J11                    U100  040
                                                40H0                     U100  050
                                                11W1                     U100  060
ASSIGN Q                                        10X44                    U100  070
                                                  J11                    U100  080
                                                40H0                     U100  085
                                                11W2                     U100  090
ASSIGN SYMB                                     10X45                    U100  100
                                                  J11    J32             U100  110
CONSTRUCT IPLV SYMBOL, WITH             U101      J51                    U101  000
```

```
                                                 J90                 U101 005
REGION=(0),LOCATION=(1). OUTPUT                  J136                U101 010
(0) IS LOCAL NAME OF SYMBOL                    40H0                  U101 020
                                               11W0                  U101 030
ASSIGN REGION                                  10X33                 U101 040
                                                 J11                 U101 050
SAVE LOCAL NAME                                40H0                  U101 055
ASSIGN LOCATION                                11W1                  U101 060
                                               10X34                 U101 070
                                                 J11      J31        U101 080
CONSTRUCT DESIGNATED SYMBOL,            U102     J51                 U102 000
(0)=Q, (1)=SYMB. OUTPUT (0) IS                   J90                 U102 010
LOCAL NAME OF D.SYMB                             J136                U102 020
                                               40H0                  U102 030
                                               11W0                  U102 040
ASSIGN Q VALUE                                 10X44                 U102 050
                                                 J11                 U102 060
                                               40H0                  U102 070
                                               11W1                  U102 080
ASSIGN SYMB VALUE                              10X45                 U102 090
                                                 J11      J31        U102 100
CONSTRUCT - INPUT D.S.,(0) IS D.S.      U103   10N1                  U103 000
NO OUTPUT                                      10X43      J11        U103 010
CONSTRUCT - PROCESS,P=(0),              U104     J50                 U104 000
DES.SYMB.=(1). OUTPUT (0) IS LOCAL             40H0                  U104 010
NAME OF PROCESS                                11W0                  U104 020
                                               10X43                 U104 030
                                                 J11      J30        U104 040
CONSTR. J-DEF.,NAME (0),OF (1).         U105   10X41      J11        U105 000
CONSTRUCT PROCESS, P=0, Q=0,            U106     J50                 U106 000
(0)=SYMB. OUTPUT (0) IS LOCAL                    J90                 U106 010
NAME OF PROCESS                                  J136                U106 020
CREATE WORD                                    40H0                  U106 030
AND MAKE (0) ITS SYMB                          11W0                  U106 040
                                               10X45                 U106 050
                                                 J11      J30        U106 060
COMPARE IPL SYMBOLS (0) AND (1)         U107     J51                 U107 000
FOR IDENTITY. SET H5                           11W1                  U107 010
                                               10X33                 U107 020
                                                 J10                 U107 030
                                               11W0                  U107 040
                                               10X33                 U107 050
                                                 J10                 U107 060
TEST IF REGIONS EQUAL.                           J114                U107 070
                                               70J31                 U107 080
IF SO,                                         11W1                  U107 090
                                               10X34                 U107 100
                                                 J10                 U107 110
                                               11W0                  U107 120
                                               10X34                 U107 130
                                                 J10                 U107 140
TEST IF LOCATIONS EQUAL.                         J114     J31        U107 150
REPLACE ARGS. IN ROUTINE (0)            U108     J40                 U108 000
WITH COPIES.                                     U114                U108 010
```

```
FIND NEXT ARG.                      90      J60                           U108 020
IF NONE, EXIT                              7091                           U108 030
                                           60W0                           U108 040
COPY ARGUMENT, AND                         52H0                           U108 050
                                            J74                           U108 060
INSERT COPY IH LIST                        61W0                           U108 070
                                           40H0                           U108 080
                                           10X32                          U108 090
                                            J10                           U108 100
TEST IF ARG. IS DETERMINER                 10X37                          U108 110
                                            J2                            U108 120
                                           70          92                 U108 130
IF NOT, CONTINUE                           30H0                           U108 140
WITH NEXT ARGUMENT.                 93     11W0        90                 U108 150
IF A DETERMINER( RECURSE.           92      U108       93                 U108 160
NO MORE ARGS., EXIT                 91     30H0        J30                U108 170
FIND ON LIST (0) ROUTINE WITH       U110    J42                           U110 000
SAME PROCESS(DSCN) AS (1). SET H5          20W0                           U110 010
                                            U111                          U110 020
PUT PROC(DSCN) IN W1                       20W1                           U110 030
COMPARE WITH LIST ITEMS                    11W0                           U110 040
                                           1090                           U110 050
                                            J100                          U110 060
SET H5 + IF FOUND( - IF NOT                 J5         J32                U110 070
STORE ITEM IN W2                    90     60W2                           U110 080
AND FIND PROC(DSCN)                         U111                          U110 090
COMPARE IT WITH 1W1                        11W1                           U110 100
SET H5 - IF FOUND                           J2         J5                 U110 110
FIND PROCESS OF DSCN                U111   10X20                          U111 000
OF ROUTINE (0).                             J10                           U111 010
(ASSUME IT EXISTS)                         10X30       J10                U111 020
TRANSFER H0-LIST ARGUMENT OF        U112    J42                           U112 000
ROUTINE (0) TO WS.                         60W0                           U112 010
BRING IN N-LIST                            10X199                         U112 020
COPY IT                                     J73                           U112 030
AND STORE IN W1                            20W1                           U112 040
FIND LIST OF ARGUMENTS                     10X20                          U112 050
OF DSCN OF (0)                              J10                           U112 060
                                           10X31                          U112 070
                                            J10                           U112 080
                                            90                            U112 090
                                           30H0        J32                U112 100
                                    92     04J0                           U112 110
BRING IN TALLY                             12W1                           U112 112
                                           10L23                          U112 114
                                            U101                          U112 116
                                           10N1                           U112 120
                                           10N1                           U112 121
CONSTRUCT TRANSFER PROCESS                  U100                          U112 122
INSERT IN J-DEF OF (0)                     11W0                           U112 130
                                            J6                            U112 140
                                           10X22       J12                U112 150
LOCATE NEXT ARGUMENT                90     04J60                          U112 170
IF NONE, GO TO 92                          700                            U112 180
```

```
                                                60W2                U112 190
                                                52H0                U112 200
                                                10X32               U112 210
FIND TYPE OF ARGUMENT                             J10               U112 220
                                                10X35               U112 230
TEST IF IN H-REGION                               J2                U112 240
IF NOT, LOCATE NEXT ARGUMENT                    7091                U112 250
IF SO,                                          12W2                U112 260
COPY OLD ARGUMENT                                 J74               U112 270
AND MAKE IT LOCAL                                 J136              U112 275
                                                11W2                U112 280
                                                40H0                U112 290
DELETE OLD ARGUMENT                               J68               U112 300
                                                  J6                U112 310
INSERT COPY AS NEW ARGUMENT                       J63               U112 320
BRING IN ARGUMENT                               12W2                U112 330
                                                40H0                U112 340
ASSIGN X36 AS NEW TYPE                          10X36               U112 350
                                                10X32               U112 360
                                                  J11               U112 370
CHANGE ARG TO WN                                  U119              U112 380
                                                11W1                U112 410
                                                  J60               U112 420
                                                70J7                U112 430
                                                20W1                U112 440
                                                  92        91      U112 445
                                          91    11W2        90      U112 450
LOC. ARGS. IN ROUTINES (2), (1)           U113    J42               U113 000
CORRESPONDING TO HN, N=(0)                      20W0                U113 010
IN ROUTINE (1)                                    U114              U113 020
PUT ARG. LIST OF (1) IN W1                      20W1                U113 030
                                                40H0
                                                  U125
                                                  U114              U113 040
PUT ARG. LIST OF (2) IN W2                      20W2                U113 050
                                          90    11W1                U113 060
LOCATE NEXT ARG. OF (1)                           J60               U113 070
IF NONE , TERMINATE                             7091                U113 075
AND SAVE IT                                     60W1                U113 080
                                                11W2                U113 090
LOCATE NEXT ARG. OF (2)                           J60               U113 100
                                                20W2                U113 110
                                                52H0                U113 120
                                                10X32               U113 130
                                                  J10               U113 140
TEST IF ARG (1) IN H0                           10X35               U113 150
                                                  J2                U113 160
IF NOT, TRY NEXT ARG.                           7090                U113 170
TEST IF  LOC (ARG)= (0)                         12W1                U113 182
                                                10X37               U113 184
FIND ITS DETERMINER                               J10               U113 186
                                                70J7                U113 188
SET UP TALLY IN W3                                J90               U113 190
                                                  J124              U113 192
```

```
                                            40W3                        U113 194
                                            20W3                        U113 196
COUNT NUMBER OF X150S                 93      J60                       U113 202
                                            7092                        U113 204
                                            12H0                        U113 206
                                            10X150                      U113 208
                                              J2                        U113 210
                                            7093                        U113 212
                                            11W3                        U113 214
                                              J125                      U113 216
                                            30H0     93                 U113 218
COMPARE NUMBER WITH (0)               92    30H0                        U113 220
                                            11W3                        U113 222
                                            11W0                        U113 224
                                              J114                      U113 226
                                            30W3                        U113 228
IF NOT, TRY NEXT ARG.                       7090                        U113 230
IF SO, INPUT LOCATION (2)                   11W2                        U113 240
AND (1), AND EXIT.                          11W1     J32                U113 250
TERMINATE                             91    30H0     J32                U113 260
FIND ARG. LIST OF DSCN                U114  10X20                       U114 000
OF ROUTINE (0)                                J10                       U114 010
(ASSUMES IT EXISTS)                         10X31    J10                U114 020
COMPILE ROUTINE (1) FROM              U115    J43                       U115 000
ROUTINE (0). DSCN PROCESSES SAME              J74            W2=R(1)    U115 010
COPY R(0) AND BRING IN TALLY                  J136                      U115 015
(1) HAS NAMED ARGS.,                        10X199           W1=R(0)    U115 020
(0) HAS H-REGION ARGS.                        J60            W0=TALLY   U115 030
                                              J22                       U115 040
                                      91    11W2                        U115 050
                                            11W1                        U115 060
                                            12W0                        U115 070
LOCATE ARGS. FOR  HN                          U113                      U115 080
IF NONE, TERMINATE                          7090                        U115 090
DISCARD ARG. LIST OF R(0)                   30H0                        U115 100
                                            52H0                        U115 130
COPY SUBSTITUTE ARGUMENT                      J74                       U115 150
AND MAKE COPY LOCAL                           J136                      U115 160
                                            10N1                        U115 210
                                            10N1                        U115 220
MAKE IPL WORD = UUWN                          U100                      U115 230
                                            11W1                        U115 240
                                              J6                        U115 250
INSERT WORD IN JDEF OF R(0)                 10X22                       U115 260
                                              J12                       U115 270
                                            11W0                        U115 280
ADVANCE TALLY AND EXIT                        J60                       U115 290
                                            20W0     91                 U115 295
TERMINATE                             90    11W2                        U115 300
                                            11W1                        U115 310
TRANSFER JDEF OF R(0) TO R(1).              10X22                       U115 320
                                              J10                       U115 330
COPY JDEF                                     J74                       U115 335
AND MARK COPY LOCAL                           J136                      U115 336
```

```
                                                     10X22                         U115 340
                                                       J11                         U115 350
                                                     11W1                          U115 360
ERASE COPY OF R(0) AND EXIT                            J72     J33                 U115 370
COMPILE JDEF OF (0)FROM ROUTINE(1).          U116    40H0                          U116 000
BOTH HAVE SAME PROCESS IN DSCN                       10X20                         U116 010
(0) HAS H-REGION ARGS.                                 J10                         U116 020
(1) HAS W-REGION ARGS.                               10X31                         U116 030
FIND ARGS. OF DSCN OF (0)                              J10                         U116 040
                                                     10N0                          U116 050
                                                       J120                        U116 060
CREATE TALLY IN W0                                     J50                         U116 070
TALLY NO. OF H-ARGS.                                 1090                          U116 080
                                                       J100                        U116 090
                                                       J6                          U116 100
                                                     10X22                         U116 110
                                                       J10                         U116 120
COPY J-DEF OF (1)                                      J74                         U116 130
                                                     40H0                          U116 140
                                                       J61                         U116 150
FIND LAST SYMBOL OF J-DEF                            52H0                          U116 160
                                                     10X46                         U116 170
ERASE ITS LINK                                         J14                         U116 180
SAVE J-DEF                                           40H0                          U116 190
MAKE INSTR. J5N                                      10N49                         U116 200
                                                       91                          U116 210
INSERT AT FRONT OF JDEF                                J64                         U116 220
                                                     40H0                          U116 230
                                                     10N29                         U116 240
MAKE INSTR. J3N                                        91                          U116 250
                                                     40H0                          U116 260
ASSIGN NO AS LINK OF INSTRUCTION                       92                          U116 280
INSERT INSTR. AT END OF JDEF                           J65                         U116 300
                                                     10X22                         U116 310
INSERT JDEF IN ROUT. (0).                              J11     J30                 U116 320
                                             90      14X32                         U116 330
TEST IF ARGUMENT IS                                    J10                         U116 340
IN H-REGION                                          10X35                         U116 350
                                                       J2                          U116 360
IF NOT, CONTINUE                                     70J4                          U116 370
IF SO, TALLY AND CONTINUE                            11W0                          U116 380
                                                       J125    J8                  U116 390
                                             91       4J0                          U116 400
                                                     11W0                          U116 410
CONSTRUCT NEW INSTRUCTION                              J120                        U116 420
                                                     40H0                          U116 430
                                                       J110                        U116 440
                                                     10L10                         U116 450
                                                       U101    U106                U116 460
ASSIGN NO AS LINK OF INSTR.                  92       4J90                         U116 470
CREATE LOCAL SYMBOL                                    J136                        U116 480
                                                     40H0                          U116 490
SAVE IT                                                J50                         U116 500
BRING IN NO                                          10N0                          U116 510
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                                                    10X33                         U116 520
MAKE IT REGION OF SYMBOL                              J11                         U116 530
                                                    11W0                          U116 540
MAKE 1W0 LINK OF INSTR.                             10X46                         U116 550
                                                      J11    J30                  U116 560
REPLACE HS BY WS IN DSCN                 U117         J90                         U117 000
OF (0).  OUTPUT (0)=N, NUMBER                         J124                        U117 010
OF REPLACEMENTS.                                      J50           1W0=TALLY     U117 020
                                                    10X20                         U117 030
                                                      J10                         U117 040
FIND LIST OF ARGS OF DSCN OF (0)                    10X31                         U117 050
                                                      J10                         U117 060
DO 90 TO ARGS ON LIST                               1090                          U117 070
                                                      J100                        U117 080
BRING IN TALLY AND EXIT                             11W0     J30                  U117 090
SAVE ARG.                                90         44H0                          U117 100
                                                    10X32                         U117 110
FIND ITS TYPE                                         J10                         U117 120
                                                    10X37                         U117 130
TEST IF DETERMINER                                    J2                          U117 140
                                                    70       91                   U117 150
                                                    40H0                          U117 155
DESIG. SYMB. FIND REGION                            10X45                         U117 160
                                                      J10                         U117 170
                                                    10X33                         U117 190
                                                      J10                         U117 200
TEST IF H-REGION                                    10L8                          U117 210
                                                      J2                          U117 220
IF NOT, EXIT                                        7092                          U117 230
CHANGE ARG TO WN                                      U119                        U117 240
AND ADD ONE TO TALLY                                11W0                          U117 270
                                                      J125                        U117 280
                                         92         30H0     J4                   U117 290
DETERMINER.                              91         10X20                         U117 300
FIND ITS LIST OF ARGUMENTS                            J10                         U117 310
                                                    10X31                         U117 320
                                                      J10                         U117 330
                                                    1090                          U117 340
                                                      J100   0                    U117 350
MODIFY JDEF OF (0) TO TAKE N=(1)         U118         J51                         U118 000
INPUTS FROM WS. NO OUTPUT.                          11W0                          U118 010
                                                    10X22                         U118 020
                                                      J10                         U118 030
FIND AND SAVE JDEF OF (0)                           40H0                          U118 040
FIND ITS LAST SYMBOL                                  J61                         U118 050
                                                    52H0                          U118 060
                                                    10X46                         U118 070
ERASE ITS LINK                                        J14                         U118 080
SAVE JDEF                                           40H0                          U118 090
MAKE INSTR. J5N                                     10N49                         U118 100
                                                      91                          U118 110
INSERT AT FRONT OF JDEF                               J64                         U118 120
MAKE INSTR. J3N                                     10N29                         U118 140
                                                      91                          U118 150
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                                               40H0                         U118 160
ASSIGN N0 AS LINK OF INSTR.                      92                         U118 170
INSERT INSTR. AT END OF JDEF                     J65    J31                 U118 180
CONSTRUCT NEW INSTRUCTION              91       4J0                         U118 190
BRING IN N                                     11W1                         U118 200
COMPUTE XN                                       J120                       U118 210
                                               40H0                         U118 220
                                                 J110                       U118 230
MAKE JXN                                       10L10                        U118 240
                                                 U101   U106                U118 250
ASSIGN N0 AS LINK OF INSTR.            92       4J90                        U118 260
CREATE LOCAL SYMBOL                              J136                       U118 270
                                               40H0                         U118 280
SAVE IT                                          J50                        U118 290
BRING IN N0                                    10N0                         U118 300
                                               10X33                        U118 310
MAKE IT REGION OF SYMBOL                         J11                        U118 320
MAKE SYMBOL LINK OF INSTR.                     11W0                         U118 330
                                               10X46                        U118 340
                                                 J11    J30                 U118 350
CHANGE ARG (0)=HN TO WN,               U119    40H0                         U119 000
NO OUTPUT                                      10X37                        U119 010
FIND ITS DETERMINER                              J10                        U119 020
SET UP TALLY IN W0                               J90                        U119 040
                                                 J124                       U119 050
                                                 J50                        U119 060
TALLY AND ERASE X150S                  93      40H0                         U119 070
FROM DETERMINER                                10X150                       U119 080
                                                 J62                        U119 090
                                               7094                         U119 100
                                               11W0                         U119 110
                                                 J125                       U119 120
                                               30H0                         U119 130
                                                 J68    93                  U119 140
                                       94      30H0                         U119 150
CONSTRUCT SYMBOL WN                            30H0                         U119 160
                                               11W0                         U119 170
                                               30W0                         U119 180
                                               10L23                        U119 190
                                                 U101                       U119 200
ASSIGN IT AS X45 OF ARGUMENT                   10X45                        U119 210
                                                 J11    0                   U119 220
MODIFY JDEF TO DO PROCESS (2)          U120    10N9                         U120 005
AFTER (3) WITH FIELD (1)=(0). SET                U101                       U120 010
H5+ IF (2) WAS NAMELESS, H5- IF                  J53                        U120 015
(2) HAS NAME. NO OUTPUT.                       11W2                         U120 020
                                                 J81                        U120 025
FIND FIRST INSTR. OF (1)                       40H0                         U120 030
                                               10X41                        U120 040
IF IT HAS NAME, REPLACE (0)                      J10                        U120 050
WITH NAME, IF NOT, SKIP TO 90.                 7090                         U120 060
                                               20W0                         U120 070
                                               30H0     91                  U120 080
PUT (0) AS NAME OF FIRST OF (1).       90      11W0                         U120 090
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                                                     10X41                 U120 100
                                                       J11                 U120 110
FIND LAST INSTR. OF (3)                      91      11W3                  U120 120
                                                       J61                 U120 130
                                                     52H0                  U120 140
MAKE 1W0 ITS LINK.                                   11W0                  U120 150
OR SYMB                                              11W1                  U120 160
                                                       J11                 U120 170
SET H5 AND EXIT                                        J5       J33        U120 180
MODIFY JDEF TO EXIT AFTER                    U122      J61                 U122 000
PROCESS (0). NO OUTPUT                               52H0                  U122 010
                                                     40H0                  U122 012
                                                     10X46                 U122 014
                                                       J10                 U122 016
                                                     70         90         U122 018
MAKE SYMB. 0.                                        10N0                  U122 020
                                                     40H0                  U122 030
                                                       U101                U122 040
ASSIGN IT AS LINK OF LAST OF (0).                    10X46      J11        U122 050
                                             90      30H0       J8         U122 060
PRINT THE JDEF OF (0)                        U125    10X22                 U125 000
FIND JDEF                                              J10                 U125 010
CLEAR PRINT LINE                                       J154                U125 020
PRINT LIST OF INSTRUCTIONS                           1090                  U125 030
                                                       J100     E50        U125 040
PROCESS INSTRUCTION                          90      04J0                  U125 050
                                                     10X40                 U125 055
                                                     10N28                 U125 060
ENTER TYPE IN COL. 28                                  920                 U125 070
                                                     10X41                 U125 080
                                                     10N30                 U125 090
ENTER NAME IN COLS. 30-34                              910                 U125 100
                                                     10X42                 U125 110
                                                     10N35                 U125 120
ENTER SIGN IN COL. 35                                  920                 U125 130
                                                     10X43                 U125 140
                                                     10N36                 U125 150
ENTER P IN COL. 36                                     920                 U125 160
                                                     10X44                 U125 170
                                                     10N37                 U125 180
ENTER Q IN COL. 37                                     920                 U125 190
                                                     10X45                 U125 200
                                                     10N38                 U125 210
ENTER SYMB IN COLS. 38-42                              910                 U125 220
                                                     10X46                 U125 230
                                                     10N44                 U125 240
ENTER LINK IN COLS. 44-48.                             910                 U125 245
PRINT.                                                 E50                 U125 250
                                                     30H0       J4         U125 255
FIND VALUE OF ATTRIBUTE (1)                  910     04930                 U125 260
AND ENTER ITS REGION AND                             70J31                 U125 270
LOCATION IN COLS. BEGINNING                            J160                U125 280
                                                     40H0                  U125 285
AT (0).                                              10X33                 U125 290
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ENTER REGION                               J10                U125 300
                                         70912                U125 310
                                           J157               U125 320
                                   911   10X34                U125 330
ENTER LOCATION                             J10                U125 340
                                         70J31                U125 350
                                           J157   J31         U125 360
                                   912   10N1                 U125 365
                                           J161   911         U125 367
FIND VALUE OF ATTRIBUTE (1)        920   04930                U125 370
AND ENTER IN COL. (0)                    70J31                U125 380
                                           J160               U125 390
                                           J157   J31         U125 400
PROCESS FOR 910 AND 920            930   04J51                U125 410
                                         40H0                 U125 420
                                         11W1                 U125 430
                                           J10                U125 440
                                         700                  U125 450
                                         11W0     0           U125 460
ENTER IN PRINT LINE THE NAME OF    U126    J41                U126 000
                                         40H0                 U126 001
TEST IF ROUTINE                          10X32                U126 002
IS A DETERMINER                            J10                U126 003
                                         7096                 U126 004
                                         10X37                U126 005
                                           J2                 U126 006
IF NOT, GO TO 96                         7096                 U126 007
IF SO, PRINT ITS VERB                    40H0                 U126 008
                                         10X20                U126 009
                                           J10                U126 010
ENTER DATA TERMS OF VERB           98      J60                U126 011
                                         7097                 U126 012
                                         12H0                 U126 013
                                           910    98          U126 014
                                   97      E51                U126 015
AND CONTINUE AT 96                       30H0     96          U126 016
                                   96    10X20                U126 019
FIND ITS DSCN                              J10                U126 020
                                         40H0                 U126 030
                                         10X30                U126 040
                                           J10                U126 050
PUT PROCESS IN W0                        20W0                 U126 060
                                         10X31                U126 070
                                           J10                U126 080
PUT ARGS IN W1                           20W1                 U126 090
                                   91    11W0                 U126 100
FIND NEXT WORD IN NAME                     J60                U126 110
EXIT IF NONE                             7092                 U126 120
                                         60W0                 U126 130
                                         52H0                 U126 140
                                         40H0                 U126 150
TEST IF 1H0 NAMES DATA TERM                J131               U126 160
                                         7090                 U126 170
                                           910    91          U126 180
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DOES NOT NAME DATA TERM              90     30H0                     U126 190
                                            11W1                     U126 191
SPACE ONCE                                    E51                    U126 195
FIND NEXT ARGUMENT                            J60                    U126 200
ERROR STOP                                  70J7                     U126 210
                                            60W1                     U126 220
                                            52H0                     U126 230
                                            40H0                     U126 240
                                            10X32                    U126 250
                                              J10                    U126 260
                                            10X37                    U126 270
TEST IF ARG IS A DETERMINER                   J2                     U126 280
                                            70       94              U126 290
IF NOT, SAVE IT                             40H0                     U126 300
TEST IF MEMBER OF H0 LIST                   10X32                    U126 301
                                              J10                    U126 302
                                            10X35                    U126 303
                                              J2                     U126 304
IF SO, BRANCH TO 95                         70       95              U126 305
IF NOT, SAVE IT                             40H0                     U126 306
FIND ITS DETERMINER                         10X37                    U126 310
                                              J10                    U126 315
                                            1093                     U126 320
AND ENTER IT                                  J100                   U126 330
SPACE ONCE                                    E51                    U126 335
FIND ITS SYMBOL                             10X45                    U126 340
                                              J10                    U126 350
                                            40H0                     U126 360
                                            10X33                    U126 370
                                              J10                    U126 380
                                              910                    U126 390
                                            10X34                    U126 400
                                              J10                    U126 410
                                              910                    U126 420
                                              E51    91              U126 425
                                     92     30H0     J31             U126 430
                                     93     10910                    U126 440
                                              J100   0               U126 450
                                     94       U126   91              U126 460
ENTER IN PRINT LINE                  910    40H0                     U126 470
                                              J157                   U126 475
LINE SPACE IF NO ROOM                       70       J8              U126 480
                                              E50                    U126 490
                                            10N10                    U126 500
                                              J160   910             U126 510
ENTER NAME OF MEMBER                 95       J60                    U126 530
OF H0 LIST                                  70J7                     U126 540
                                            52H0                     U126 550
                                              910                    U126 560
                                              E51    91              U126 570
PRINT THE SDSC OF ROUTINE (0)        U127     J40                    U127 000
CLEAR PRINT LINE                              J154                   U127 010
                                            10X24                    U127 020
FIND SDSC                                     J10                    U127 030
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                                                70J30                U127 040
FIND LIST OF AFFECTED CELLS                     10X71                U127 050
                                                  J10                U127 060
                                                70J30                U127 070
DO 90 TO AFFECTED CELLS                         1090                 U127 080
AND EXIT                                          J100   J30         U127 090
                                        90      60W0                 U127 100
FIND NAME OF CELL                               10X41                U127 110
                                                  J10                U127 120
ENTER IT IN PRINT LINE                            91                 U127 130
                                                  E53                U127 140
                                                11W0                 U127 150
FIND INPUT LIST                                 10X75                U127 160
                                                  J10                U127 170
AND ENTER ITS SYMBOLS                           1092                 U127 180
                                                  J100               U127 190
ENTER PERIOD                                      E53                U127 200
                                                11W0                 U127 210
FIND OUTPUT LIST                                10X76                U127 220
                                                  J10                U127 230
ENTER ITS SYMBOLS                               1092                 U127 240
                                                  J100               U127 250
ENTER PERIOD AND PRINT LINE                       E53    E50         U127 260
ENTER A SYMBOL IN THE PRINT LINE        91      40H0                 U127 270
                                                10X33                U127 280
                                                  J10                U127 290
                                                  J157               U127 300
                                                10X34                U127 310
                                                  J10    J157        U127 320
ENTER THE SYMBOLS, THEN COMMAS          92        91     E54         U127 330
PRINT NAME, DSCN, JDEF, AND             U128      J50                U128 000
SDSC OF ROUTINE (0)                               90                 U128 010
                                                  E50                U128 020
                                                11W0                 U128 040
                                                40H0                 U128 050
                                                10X20                U128 060
TEST OF IT HAS A DSCN                             J10                U128 070
IF NOT, SKIP TO 92                              7092                 U128 080
                                                30H0                 U128 090
ENTER DSCN IN PRINT LINE                          U126               U128 100
PRINT                                             E50                U128 110
AND SPACE                                         E50                U128 120
                                                11W0                 U128 130
                                        92      40H0                 U128 140
                                                10X22                U128 150
TEST IF IT HAS A JDEF                             J10                U128 160
IF NOT, SKIP TO 92                              7093                 U128 170
                                                30H0                 U128 180
PRINT JDEF                                        U125               U128 190
AND SPACE                                         E50                U128 200
                                                11W0                 U128 210
                                        93      40H0                 U128 220
                                                10X24                U128 230
TEST IF IT HAS A SDSC                             J10                U128 240
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IF NOT, EXIT BY 95                          7095              U128 250
                                            30H0              U128 290
PRINT SDSC AND EXIT                           U127   J30      U128 300
                                      95    30H0     J30      U128 310
                                      90    04J0              U128 320
                                            11W0              U128 330
TEST IF IT HAS AN IPLN                      10X25             U128 340
                                              J10             U128 350
IF NOT, EXIT                                700               U128 360
                                            40H0              U128 370
IF SO, ENTER IN PRINT LINE                  10X33             U128 380
                                              J10             U128 390
                                              J157            U128 400
                                            10X34             U128 410
                                              J10    J157     U128 420
COMPILE JDEF OF ROUT.(0) FROM         U130    J43             U130 000
JDEF OF ROUT.(1). ROUT(1) IS A J.             J21             U130 010
                                            11W0              U130 020
COPY R1W0 AND                                 J74             U130 030
COPY ARGS OF DSCN                           40H0              U130 031
                                              U108            U130 040
                                            60W2              U130 043
REPLACE HS BY WS IN DSCN OF COPY.             U117            U130 050
SAVE(0)=NUMBER OF REPLACEMENTS.             20W3              U130 060
                                            11W1              U130 070
COMPILE JDEF OF 1W2                         11W2              U130 080
FROM JDEF OF 1W1.                             U131            U130 090
MODIFY JDEF OF 1W2 TO TAKE                  11W3              U130 100
N=1W3 INPUTS FROM WS.                       11W2              U130 110
                                              U118            U130 120
BRING IN 1W0.                               11W0              U130 130
                                            11W2              U130 140
FIND JDEF OF 1W2                            10X22             U130 150
AND ASSIGN IT AS JDEF OF 1W0                  J10             U130 160
                                              J74             U130 161
                                              J136            U130 162
                                            10X22             U130 165
                                              J11             U130 170
ASSIGN NAME TO JDEF.                          910             U130 175
                                            11W2              U130 180.
ERASE 1W2,                                    J72             U130 190
AND TALLY CELL,                             11W3              U130 200
AND EXIT                                      J9     J33      U130 210
                                      910   11W0              U130 220
FIND JDEF                                   10X22             U130 230
                                              J10             U130 240
FIND FIRST INSTRUCTION.                       J81             U130 250
                                            40H0              U130 260
                                            10X41             U130 265
                                              J10             U130 266
IF IT HAS NO NAME,                          70       911      U130 270
                                            11W0              U130 280
                                            10X25             U130 290
ASSIGN IT V(X25) OF ROUTINE.                  J10             U130 300
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                                              10X41   J11                  U130 310
IF IT HAS NAME, EXIT.                   911   30H0    J8                   U130 320
COMPILE JDEF OF ROUT.(0)                U131    J45            1W0=(0)     U131 000
FROM JDEF OF ROUT.(1), (0) IS                   J21            1W1=(1)     U131 010
A J, (1) HAS W-REGION INPUTS                    J90                        U131 020
                                                J124                       U131 030
SET UP TALLY IN W2                            20W2             1W2=TALLY   U131 040
                                              11W0                         U131 050
                                              11W1                         U131 060
COPY JDEF OF (1) AND                          10X22                        U131 070
ASSIGN COPY AS JDEF OF (0).                     J10                        U131 080
                                                J74                        U131 090
                                                J136                       U131 100
                                              10X22                        U131 110
                                                J11                        U131 120
LOCATE ARGS IN 1W0 AND 1w1              90    11W0                         U131 130
FOR HN, N=TALLY, IN 1W1,                      11W1                         U131 140
                                              11W2                         U131 150
                                                U113                       U131 160
IF NONE, EXIT.                                7091                         U131 170
SAVE ARG. OF 1W1 IN W3.                       52H0                         U131 180
                                                J74                        U131 190
                                              20W3                         U131 200
                                              11W2                         U131 210
ADD 1 TO TALLY                                  J125                       U131 220
                                              30H0                         U131 230
SAVE LOC. OF ARG OF 1W0 IN W4                 60W4                         U131 240
FIND ARG. OF 1W0                              52H0                         U131 250
COMPILE (FIND ARG.)                             U132                       U131 260
                                              11W0                         U131 270
INSERT (FIND ARG.) AT FRONT                   10X22                        U131 280
OF JDEF OF 1W0                                  J10                        U131 290
                                                92                         U131 300
REPLACE ARG OF 1W0 WITH                       11W3                         U131 310
ARG OF 1W1                                    21W4    90                   U131 320
                                        91    11W2                         U131 330
ERASE TALLY AND EXIT                            J9    J35                  U131 340
INSERT COMPILED (FIND ARG.)             92    44H0                         U131 350
DIVIDE JDEF                                     J75                        U131 360
SAVE REMAINDER                                20W5                         U131 370
                                                J6                         U131 380
ADD (FIND ARG.) TO HEAD                         J76                        U131 390
ADD REMAINDER                                 11W5                         U131 400
                                                J76   J8                   U131 410
COMPILE (FIND ARG) (0).  FINAL          U132  40H0                         U132 000
ARGS. ARE DESIG. SYMBS.  OUTPUT (0)             J90                        U132 010
IS LIST OF INSTRS. WITHOUT TERM.                J136                       U132 020
                                              40W1                         U132 030
CREATE OUTPUT LIST IN W1.                     20W1                         U132 040
                                              10X32                        U132 050
TEST IF ARGUMENT                                J10                        U132 060
IS DETERMINER.                                10X37                        U132 070
                                                J2                         U132 080
ARGUMENT NOT A DETERMINER,                    70      90                   U132 090
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		J90		U132 100
SET UP Q-TALLY IN WO.		J124		U132 110
		J50		U132 120
SAVE ARGUMENT	92	40H0		U132 130
FIND ITS DETERMINER		10X37		U132 135
		J10		U132 140
	94	J60		U132 145
		7093		U132 150
TALLY X151S=Q		12H0		U132 155
OF DETERMINER IN WO		10X151		U132 160
		J2		U132 170
		7094		U132 180
		11W0		U132 190
		J125		U132 200
		30H0	94	U132 210
COPY SYMBOL OF ARGUMENT	93	30H0		U132 220
		10X45		U132 225
		J10		U132 230
		J74		U132 240
MAKE INSTRUCTION 1QS.		11W0		U132 250
		10N1		U132 260
		U100		U132 270
INSERT INSTR. AT FRONT		11W1		U132 300
OF LIST 1W1.		J6		U132 310
EXIT, LEAVING 1W1.		J64		U132 320
		11W1	J31	U132 330
SET UP INSTR. SUBLIST,	90	J90		U132 340
AND MARK IT LOCAL,		J136		U132 350
AND SAVE IT IN WO.		J50		U132 360
SAVE DETERMINER		40H0		U132 363
FIND ITS DSCN		10X20		U132 365
		J10		U132 366
FIND LIST OF ARGUMENTS		10X31		U132 380
AND PROCESS THEM.		J10		U132 390
		10910		U132 400
		J100		U132 410
FIND JDEF		10X22		U132 420
		J10		U132 430
COPY IT		J74		U132 432
		J136		U132 433
		40H0		U132 434
FIND LAST INSTRUCTION		J61		U132 435
		52H0		U132 436
ERASE ITS LINK		10X46		U132 437
		J14		U132 438
		11W0		U132 440
FIND END OF LIST		J61		U132 445
INSERT LIST ON MAIN LIST		95		U132 460
INSERT SUBLIST IN LIST		11W0		U132 470
		11W1		U132 480
INSERT LIST ON MAIN LIST		95		U132 490
BRING IN LIST AND EXIT.		11W1	J31	U132 500
COMPILE (FIND ARG.)	910	U132		U132 510
AND INSERT IN SUBLIST.		11W0		U132 520

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INSERT LIST ON MAIN LIST                    95     J4                U132 530
INSERT LIST AT FRONT OF MAIN LIST     95   44H0                      U132 540
                                             J75                     U132 550
                                           40W2                      U132 560
                                           20W2                      U132 570
                                             J6                      U132 580
                                             J76                     U132 590
                                           11W2                      U132 600
                                             J76                     U132 610
                                           30W2     J8               U132 620
                                      U133   J45                     U133 000
COMPILE JDEF WITH NAME (2)                 10X199         1W4=NAME   U133 005
LIST OF SEGMENTS (1) AND FLOW                J73          1W3=SEG L  U133 010
CHART (0). OUTPUT (0) IS JDEF                J136         1W2=FLOW   U133 020
NAME NEW JDEF                                J90          1W1=TALLY  U133 030
                                             J136         1W0=JDEF   U133 040
                                             J24                     U133 050
ASSIGN NAME TO FIRST INSTRUCTION           11W3                      U133 053
                                             J81                     U133 054
                                             J81                     U133 055
                                           11W4                      U133 056
                                           10X41                     U133 057
                                             J11                     U133 058
                                           11W2                      U133 060
                                           40W3                      U133 070
ATTACH SEGMENTS TO FLOW CHART         91     J60                     U133 080
                                           7090                      U133 090
                                           12H0                      U133 100
                                           11W3                      U133 110
                                             J60                     U133 120
                                           70J7                      U133 130
                                           60W3                      U133 140
                                           52H0                      U133 145
                                           10X22                     U133 150
                                             J11    91               U133 160
ASSIGN ADDRESSES TO SEGMENTS          90   30H0                      U133 170
                                           30W3                      U133 180
                                           11W2                      U133 190
                                           1092                      U133 200
                                             J100                    U133 210
                                           11W0                      U133 215
ASSEMBLE SEGMENTS IN NEW JDEF              11W3                      U133 220
                                           10910                     U133 230
                                             J100                    U133 235
                                           40H0                      U133 240
                                             U122   J35              U133 245
                                      910  11W0                      U133 251
                                             J6                      U133 260
                                             J76                     U133 262
                                           20W0     J4               U133 264
ASSIGN ADDRESSES TO SEGMENT           92   64W5           1W5=SEGM   U133 270
FIND JDEF OF SEGMENT                       10X22                     U133 280
                                             J10                     U133 290
                                           11W5                      U133 310
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ND P OF SEGMENT               10X43                U133 320
                                J10                U133 330
TEST IF P=7                   10N7                 U133 340
                                J2                 U133 350
IF NOT, GO TO 93              7093                 U133 360
IF P=7                        11W5                 U133 370
                              40H0                 U133 375
                                925                U133 376
FIND SYMB OF SEGM             10X45                U133 380
                                J10                U133 390
                              40H0                 U133 400
TEST IF SYMB IS 0             10N0                 U133 410
                                J2                 U133 420
IF NOT, GO TO 94              7094                 U133 430
IF SO, GO TO 93               30H0     93          U133 440
                        94    11W2                 U133 450
                                J6                 U133 460
FIND SYMB ON FLOW               920                U133 470
                              10X22                U133 480
FIND ITS JDEF                   J10                U133 490
                              70J7                 U133 500
BRING IN (FIELD)=(SYMB)       10X45                U133 510
                              11W1                 U133 520
                                J60                U133 530
                              60W1                 U133 540
                              52H0                 U133 545
LINK SEGM TO SYMB               U120               U133 550
                              11W5                 U133 560
                              10X22                U133 570
BRING IN JDEF OF SEGM           J10                U133 580
FIND LINK OF SEGM       93    11W5                 U133 590
                              10X46                U133 600
                                J10                U133 610
                              40H0                 U133 620
TEST IF LINK IS 0             10N0                 U133 630
                                J2                 U133 640
                              7095                 U133 650
IF IT IS, EXIT                30H0     J8          U133 660
IF LINK IS NOT 0        95    11W2                 U133 670
                                J6                 U133 680
FIND SYMB ON FLOW               920                U133 690
                              10X22                U133 700
FIND ITS JDEF                   J10                U133 710
                              70J7                 U133 720
BRING IN (FIELD)=(LINK)       10X46                U133 730
                              11W1                 U133 740
                                J60                U133 750
                              60W1                 U133 755
                              52H0                 U133 756
LINK SEGM TO SYMB               U120   J4          U133 760
FIND SYMB ON FLOW      920    04J50                U133 765
                              10921                U133 770
                                J100   J30         U133 775
FIND NAME OF SYMB      921    40H0                 U133 780
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COMPARE WITH 1W0                              10X41                  U133 785
                                                J10                  U133 790
                                              11W0                   U133 795
                                                J2                   U133 800
EXIT, STOP GENERATOR                          70        J3           U133 805
EXIT, CONTINUE GENERATOR                      30H0      J4           U133 810
                                        925   14X22                  U133 815
                                                J10                  U133 820
                                                J90                  U133 825
                                                J136                 U133 830
                                              40H0                   U133 835
                                              10N7                   U133 840
                                              10X43                  U133 845
                                                J11     J65          U133 850
COMPILE (0) FROM ITS DSCN               U134    J50                  U134 000
FIND LIST OF COMPILED ROUTINES                10X196                 U134 010
AND SEEK SOURCE ROUTINE                       1090                   U134 020
                                                J100                 U134 030
                                              70        J30          U134 040
IF FOUND, COMPILE (0)                         11W0                   U134 050
FROM DSCN OF XOURCE                             U130    J30          U134 060
FIND SOURCE ROUTINE FOR (0)             90    40H0                   U134 070
                                              10X20                  U134 080
FIND PROCESS OF DSCN                            J10                  U134 090
                                              7091                   U134 095
OF SOURCE                                     10X30                  U134 100
                                                J10                  U134 110
                                              7091                   U134 115
                                              11W0                   U134 120
                                              10X20                  U134 130
                                                J10                  U134 140
                                              10X30                  U134 150
                                                J10                  U134 160
COMPARE WITH PROCESS OF (0)                     J2                   U134 170
EXIT WITH SIGNAL                              70        J3           U134 180
TO GENERATOR                            91    30H0      J4           U134 190
COMPILE JDEF OF ROUTINE (0).            U135    J41                  U135 000
OUT.(0) IS JDEF, IF EXISTS. SET H5.           60W0                   U135 010
TEST IF IT EXISTS                       90    10X22                  U135 020
                                                J10                  U135 030
IF SO, EXIT WITH H5+                          70        J31          U135 040
                                              11W0                   U135 050
FIND CLOSEST DEFCINITION                        U136                 U135 060
IF NONE, EXIT WITH H5-                        70J31                  U135 070
                                              40H0                   U135 080
FIND AND APPLY                                11W0                   U135 090
RELEVANT PROCESS                                U137                 U135 100
                                              11W0                   U135 110
FIND CLOSEST DEFINITION                         U136                 U135 120
TEST PROGRESS                                   U138                 U135 140
EXIT OR REPEAT.                               70J31                  U135 150
                                              11W0      90           U135 160
FIND CLOSEST DEF. OF ROUTINE (0)        U136    J50                  U136 000
                                              11W0                   U136 010
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                                                      10X20                           U136 020
                                                        J10                           U136 030
                                                      70        90                    U136 040
                                                      11W0                            U136 050
                                                      10X24                           U136 060
                                                        J10                           U136 070
                                                      70J30     91                    U136 080
                                               90     30H0                            U136 090
                                                      10X20     J30                   U136 100
                                               91     30H0                            U136 110
                                                      10X24     J30                   U136 120
FIND AND APPLY RELEVANT PROCESS                U137     J6                            U137 000
TO ROUTINE (0) WITH DEF. (1)                          10X198                          U137 010
NO OUTPUT                                               J6                            U137 020
                                                        J10                           U137 030
                                                        J1      0                     U137 040
TEST IF DEF (0) IS CLOSER TO                   U138   10X197                          U138 000
JDEF THAN DEF (1)                                       J6                            U138 010
                                                        J62                           U138 020
                                                        J6                            U138 030
                                                        J62     0                     U138 040
COMPOSE FLOW CHART OF ROUTINE (0)              U139     J42                           U139 000
FROM ITS JDEF                                         60W0                            U139 010
                                                        J90                           U139 020
                                                        J136                          U139 030
STORE NAME OF CHART IN W1                             60W1                            U139 040
                                                      10X26                           U139 050
ASSIGN IT TO ROUTINE 1W0                                J11                           U139 060
                                                      11W0                            U139 070
                                                      10X22                           U139 080
FIND JDEF OF ROUTINE                                    J10                           U139 090
COPY JDEF, MARK IT LOCAL                                J74                           U139 100
                                                        J136                          U139 110
STORE IT IN W2                                 91     60W2                            U139 120
                                                        J90                           U139 130
CREATE SEGMENT                                          J136                          U139 140
AND STORE IT                                          40H0                            U139 150
                                                      11W1                            U139 160
INSERT SEGMENT                                          J6                            U139 170
AT END OF FLOW CHART                                    J65                           U139 180
                                                        J6                            U139 190
MAKE JDEF THE                                         10X22                           U139 200
X22 OF SEGM.                                            J11                           U139 210
                                                      11W2                            U139 220
FIND NEXT INSTRUCTION                          92       J60                           U139 230
                                                      7094                            U139 240
                                                      12H0                            U139 260
FIND ITS P                                            10X43                           U139 270
                                                        J10                           U139 280
                                                      7090                            U139 285
TEST IF P=7                                           10N7                            U139 290
                                                        J2                            U139 300
IF SO, DIVIDE SEGMENT                                 7090      93                    U139 310
AND REPEAT.                                    93       J75     91                    U139 320
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IF NOT,	90	12H0		U139 330
		10X46		U139 340
		J10		U139 350
TEST IF LINK IS LOCAL		7092		U139 360
IF SO,		10X33		U139 370
DIVIDE SEGMENT AND REPEAT.		J10		U139 380
		10N9		U139 390
		J2		U139 400
IF NOT, FIND NEXT INSTRUCTION		7092	93	U139 410
	94	30H0		U139 420
		11W1		U139 430
LOCATE NEXT SEGMENT	98	J60		U139 440
IF NONE, EXIT		7099		U139 450
		12H0		U139 460
PUT ITS NAME IN W0		60W0		U139 470
		10X22		U139 480
FIND ITS JDEF		J10		U139 490
AND PUT IT IN W2		60W2		U139 500
FIND FIRST INSTRUCTION		J81		U139 510
		10X41		U139 520
FIND ITS NAME		J10		U139 530
IF NONE, SKIP TO 95		7095		U139 540
		11W0		U139 550
		J6		U139 560
ASSIGN IT AS SEGMENT NAME		10X41		U139 570
		J11		U139 580
	95	11W2		U139 590
FIND LAST INSTRUCTION		J61		U139 600
		52H0		U139 610
STORE IT IN W2		60W2		U139 620
		10X43		U139 630
TEST IF ITS P=7		J10		U139 640
		7096		U139 645
		10N7		U139 650
		J2		U139 660
IF NOT, SKIP TO 96		7096		U139 670
IF SO, SET P=7 IN SEGMENT		11W0		U139 680
		10N7		U139 690
		10X43		U139 700
		J11		U139 710
ASSIGN SYMB. OF INSTRUCTION		11W0		U139 720
TO SEGMENT		11W2		U139 730
		10X45		U139 740
		J10		U139 750
		10X45		U139 760
		J11	97	U139 770
SET P=0 IN SEGMENT	96	11W0		U139 780
		10N0		U139 790
		10X43		U139 800
		J11	97	U139 810
ASSIGN LINK OF INSTRUCTION	97	11W0		U139 820
TO SEGMENT		11W2		U139 830
		10X46		U139 840
		J10		U139 850

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                                                10X46                         U139 860
                                                  J11    98                   U139 870
EXIT                                     99     30H0     J32                  U139 880
COMPILE JDEF OF ROUTINE (0)              U140     J50                         U140 000
FROM ITS SDSC. NO OUTPUT                        11W0                          U140 001
COMPILE IT                                        930                         U140 003
ASSIGN A NAME TO IT                               910                         U140 005
ASSIGN A TERMINATION TO IT                        920    J30                  U140 007
                                         930      J42                         U140 009
FROM ITS SDSC. NO OUTPUT.                       60W0              1W0=(0)     U140 010
                                                10X24                         U140 020
FIND SDSC.                                        J10                         U140 030
FIND INPUT-OUTPUT DIFFERENCE.                     X7                          U140 040
                                                40H0                          U140 050
                                                10X50                         U140 055
                                                  J10                         U140 056
TEST FOR NO DIFFERENCE.                         10X80                         U140 060
                                                  J2                          U140 070
                                                7090                          U140 080
IF NO DIFFERENCE                                  J32                         U140 090
EXIT WITH H5=-                                    J8     J3                   U140 095
IF DIFFERENCE EXISTS,                    90     11W0                          U140 100
PRODUCE NEW ROUTINE WITHOUT DIFF.,                U141                        U140 110
STORE IT IN W1.                                 60W1                          U140 120
CONSTRUCT SDSC FOR A NEW ROUTINE,               11W0                          U140 130
  I(1W0) I(1W1).                                  U144                        U140 140
SAVE NEW ROUTINE                                60W2                          U140 150
COMPILE ITS JDEF                                  930                         U140 160
IF NULL, SKIP TO 91                             7091                          U140 165
BRING IN NEW ROUTINE                            11W2                          U140 170
PREFIX JDEF OF NEW ROUTINE TO JDEF              11W1                          U140 180
OF 1W1, AND MODIFY SDSC OF 1W1.                   U145                        U140 190
                                         91     11W2                          U140 195
ERASE PREFIXED ROUTINE                            J72                         U140 200
                                                11W0                          U140 210
CONSTRUCT SDSC FOR A NEW ROUTINE,               11W1                          U140 220
  O(1W1) O(1W0).                                  U146                        U140 230
SAVE NEW ROUTINE                                60W2                          U140 240
COMPILE ITS JDEF.                                 930                         U140 250
IF NULL, SKIP TO 92                             7092                          U140 255
BRING IN NEW ROUTINE                            11W2                          U140 260
SUFFIX JDEF OF NEW ROUTINE TO JDEF              11W1                          U140 270
OF 1W1, AND MODIFY SDSC OF 1W1.                   U147                        U140 280
ERASE SUFFIXED ROUTINE                   92     11W2                          U140 285
                                                  J72                         U140 290
BRING IN 1W0.                                   11W0                          U140 300
FIND JDEF OF 1W1,                               11W1                          U140 310
                                                10X22                         U140 320
                                                  J10                         U140 330
COPY IT.                                          J74                         U140 340
                                                  J136                        U140 350
ASSIGN COPY AS JDEF OF 1W0.                     10X22                         U140 360
                                                  J11                         U140 370
                                                11W1                          U140 380
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ERASE 1W1                                      J72                          U140 390
AND EXIT WITH H5=+                             J32     J4                   U140 400
                                         910  11W0                          U140 410
FIND JDEF.                                    10X22                         U140 420
                                               J10                          U140 430
FIND FIRST INSTRUCTION.                        J81                          U140 440
                                              40H0                          U140 450
                                              10X41                         U140 455
                                               J10                          U140 456
IF IT HAS NO NAME,                            70       911                  U140 460
                                              11W0                          U140 470
ASSIGN IT V(X25) OF ROUTINE.                  10X25                         U140 480
                                               J10                          U140 490
                                              10X41    J11                  U140 500
IF IT HAS NAME, EXIT.                    911  30H0     J8                   U140 510
                                         920  11W0                          U140 520
                                              10X22                         U140 530
                                               J10                          U140 540
                                              40H0                          U140 550
TEST IF LAST INSTRUCTION                       J61                          U140 560
HAS A LINK.                                   52H0                          U140 570
                                              10X46                         U140 580
                                               J10                          U140 590
IF NOT, ASSIGN LINK 0                         70U122                        U140 600
IF SO, EXIT.                                  30H0     J8                   U140 610
PRODUCE ROUTINE FROM (0)                 U141  J44              (0)=1W0     U141 000
WITHOUT DIFFERENCE (1).                        J21              (1)=1W1     U141 010
OUTPUT (0) IS NEW ROUTINE.                    11W1                          U141 020
FIND ROUTINE RELEVANT TO DIFF.                 U150                         U141 030
                                               J74                          U141 040
COPY IT AND MARK COPY LOCAL.                   J136                         U141 050
PUT RELEVANT ROUT. IN W2                      60W2                          U141 060
                                              10X24                         U141 070
                                               J10                          U141 080
PUT ITS SDSC IN W3                            60W3                          U141 090
SAVE IT                                       40H0                          U141 100
LOCATE ITS VARIABLE CELL.                      U152                         U141 110
IF NONE, GO TO 90, AFTER J8                   7093                          U141 120
FIND ITS NAME                                 52H0                          U141 130
FIND ITS VARIABLES                            10X41                         U141 135
                                               J10                          U141 136
                                              11W1                          U141 140
                                              10X41                         U141 150
FIND VARIABLE OF DIFFERENCE,                   J10                          U141 160
SUBSTITUTE IT FOR VAR. CELL NAME.              U153                         U141 170
BRING IN SDSC OF REL. ROUT.              90   11W3                          U141 180
FIND VARIABLE OF DIFF.                        11W1                          U141 190
                                              10X41                         U141 200
                                               J10                          U141 210
LOCATE CELL OF SDSC WITH THIS NAME             U151                         U141 220
IF NONE, GO TO 91.                            7091                          U141 230
                                              52H0                          U141 232
                                              10X41                         U141 234
                                               J10                          U141 235
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BRING IN SDSC OF REL. ROUT.		11W3		U141 240
		11W0		U141 250
FIND SDSC OF 1W0		10X24		U141 260
		J10		U141 270
SUB. NAMES OF (0) FOR VAR. OF W3		U154		U141 280
	91	11W0		U141 290
		10X24		U141 300
		J10		U141 310
FIND LIST OF AFFECTED CELLS OF 1W0		10X71		U141 320
		J10		U141 330
LOCATE NEXT CELL	92	J60		U141 340
		7094		U141 350
FIND CELL		12H0		U141 360
FIND ITS NAME		10X41		U141 370
		J10		U141 380
STORE IT IN W4		60W4		U141 390
FIND W3		11W3		U141 400
		J6		U141 410
LOCATE CELL OF W3 WITH SAME NAME		U151		U141 420
IF NONE, FIND NEXT.		7092		U141 430
		30H0		U141 440
		11W4		U141 450
		11W3		U141 460
SUBSTITUTE NAMES OF SDSC (W0) FOR		11W0		U141 470
VARIABLES OF (W3) IN CELL (W4)		10X24		U141 480
		J10		U141 490
		U154	92	U141 500
	95	11W1		U141 510
FIND ROUTINE RELEVANT TO W1,		U150		U141 520
FIND MODIFIED COPY.		11W2		U141 530
MAKE JDEF OF (0) FROM (1).		U155		U141 540
LEAVE NEW ROUTINE		11W2	J34	U141 550
	93	30H0		U141 560
		30H0	90	U141 565
	94	30H0	95	U141 570
CONSTRUCT SDSC FOR A NEW ROUTINE	U142	J53		U142 000
(0) OF (1) TO (2) OF (3). (0)=NAME		11W1		U142 010
		10X24		U142 015
		J10		U142 016
OF NEW ROUTINE.		10X71		U142 020
		J10		U142 030
COPY X71 OF 1W1		J74		U142 035
		J136		U142 036
REPLACE 1W1 WITH ITS X71		20W1		U142 040
		11W3		U142 050
		10X24		U142 055
		J10		U142 056
		10X71		U142 060
		J10		U142 070
		J74		U142 075
		J136		U142 076
REPLACE 1W3 WITH ITS X71		60W3		U142 080
		11W2		U142 090
ERASE HALF OF 1W2		U143		U142 100

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                                            11W1              U142 110
                                            11W0              U142 120
ERASE HALF OF 1W0                             U143            U142 130
                                            11W0              U142 140
                                            10X75             U142 150
TEST IF 1W1 NEEDS REVERSAL                    J2              U142 160
                                            70        90      U142 170
                                            11W1              U142 180
IF SO, REVERSE                              11W0              U142 190
                                              U148    90      U142 200
                                     90     11W2              U142 210
                                            10X76             U142 220
TEST IF 1W3 NEEDS REVERSAL                    J2              U142 230
                                            70        91      U142 240
                                            11W3              U142 250
IF SO, REVERSE                              11W2              U142 260
                                              U148    91      U142 270
COMBINE LISTS OF AFFECTED CELLS      91     11W3              U142 280
INTO NEW LIST.                              11W1              U142 290
                                              U149            U142 300
ASSIGN COMBINED LIST                          J90             U142 310
AS X71 OF NEW ROUTINE.                      60W0              U142 320
                                              J6              U142 330
                                              J90             U142 332
                                              J136            U142 334
                                            60W2              U142 336
                                              J6              U142 338
                                            10X71             U142 340
                                              J11             U142 350
                                            11W2              U142 352
                                            10X24             U142 354
                                              J11             U142 356
                                            11W0      J33     U142 360
ERASE ATTRIBUTE NOT-(0) OF           U143   10X75             U143 000
ITEMS OF (1).  NO OUTPUT                      J2              U143 010
                                            7090              U143 020
FIND ATTRIBUTE NOT-(0).                     10X76     91      U143 030
                                     90     10X75     91      U143 040
                                     91       J50             U143 050
ERASE IT.                                   1092              U143 060
                                              J100    J30     U143 070
                                     92     11W0              U143 080
                                              J14     J4      U143 090
CONSTRUCT SDSC FOR A NEW ROUTINE     U144     J50             U144 000
  X75(0) TO X75(1)=OUTPUT ROUTINE           10X75             U144 010
                                            11W0              U144 020
                                            10X75             U144 030
                                              U142    J30     U144 040
PREFIX JDEF OF (1) TO JDEF OF (0)    U145     J51             U145 000
IN (0), AND MODIFY SDSC.                    11W0              U145 010
                                            10X22             U145 020
FIND JDEF OF (1),                             J10             U145 030
SAVE IT.                                    40H0              U145 040
DIVIDE IT AFTER HEAD,                         J75             U145 050
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                                                40W2              U145 060
SAVE TAIL IN W2.                                20W2              U145 070
                                                11W1              U145 080
FIND JDEF OF (0),                               10X22             U145 090
                                                  J10             U145 100
                                                  J74             U145 105
                                                  J136            U145 106
INSERT IT AFTER HEAD OF JDEF (1).                 J76             U145 110
                                                11W2              U145 120
ADD TAIL.                                         J76             U145 130
                                                30H0      J32     U145 135
CONSTRUCT SDSC FOR A NEW ROUTINE        U146      J50             U146 000
  X76(0) TO X76(1)=OUTPUT ROUTINE               10X76             U146 010
                                                11W0              U146 020
                                                10X76             U146 030
                                                  U142    J30     U146 040
SUFFIX JDEF OF (1) TO JDEF OF           U147      J51             U147 000
(0) IN (0), AND MODIFY SDSC                     11W0              U147 010
                                                10X22             U147 020
FIND JDEF OF (0)                                  J10             U147 030
LOCATE ITS LAST SYMBOL                            J61             U147 040
                                                11W1              U147 050
                                                10X22             U147 060
FIND JDEF OF (1)                                  J10             U147 070
                                                  J74             U147 075
                                                  J136            U147 076
INSERT AFTER JDEF OF (0).                         J76             U147 080
                                                30H0      J31     U147 085
REVERSE ATTRIBUTES (0) OF ITEMS         U148    40H0              U148 000
ON (1).                                         10X75             U148 010
                                                  J2              U148 020
                                                70        90      U148 030
FIND ATTRIBUTE OPPOSITE TO (0).                 10X75     91      U148 040
                                        90      10X76     91      U148 050
STORE (0) IN W1, OPPOSITE IN W0.        91        J51             U148 060
GENERATE ITEMS AND REVERSE.                     1092              U148 070
                                                  J100    J31     U148 080
                                        92      40H0              U148 090
                                                40H0              U148 100
                                                11W1              U148 110
FIND VALUE OF ATTRIBUTE,                          J10             U148 120
COPY IT,                                          J74             U148 130
AND ASSIGN AS VALUE OF OPPOSITE                   J136            U148 140
                                                11W0              U148 145
                                                  J11             U148 150
ERASE ATTRIBUTE.                                11W1      J14     U148 160
COMBINE LISTS OF AFFECTED CELLS,        U149      J90             U149 000
(0)=LX75,(1)=LX76,OUTPUT=NEW LIST.                J136            U149 010
1W0=NEW LIST, 1W1=LX75,                           J46             U149 020
1W2=LX76.                                         J22             U149 030
                                                11W1              U149 040
COMBINE PAIRS                                   1090              U149 050
                                                  J100            U149 060
                                                11W1              U149 070
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ADD REMAINDER OF LX75                      1091                U149 080
                                             J100              U149 090
                                           11W2                U149 100
ADD REMAINDER OF LX76                      1092                U149 110
                                             J100              U149 120
                                           11W0      J36       U149 130
COMBINE PAIRS                         90   24W3                U149 140
                                           11W2                U149 150
GENERATE MEMBERS OF LX76                   1093                U149 160
                                             J100    J4        U149 170
                                      93   24W4                U149 180
                                           11W3                U149 190
                                           10X41               U149 200
FIND SYMBOL OF LX75                          J10               U149 210
                                           11W4                U149 220
                                           10X41               U149 230
FIND SYMBOL OF LX76                          J10               U149 240
COMPARE FOR EQUALITY.                        U107              U149 250
IF UNEQUAL TRY NEXT OF LX76.               70J4                U149 260
IF EQUAL,                                  11W1                U149 270
DELETE FROM LX75,                          11W3                U149 280
                                             U169              U149 290
                                           11W2                U149 300
DELETE FROM LX76.                          11W4                U149 310
                                             U169              U149 320
                                           11W4                U149 330
                                           40H0                U149 340
ADD LX75 TO LX76,                          11W3                U149 350
                                           10X75               U149 360
                                             J10               U149 370
                                           10X75               U149 380
                                             J11               U149 390
IF PAIR IDENTICAL, DELETE                    910               U149 395
                                           70        915       U149 396
AND INSERT PAIR IN NEW LIST.               11W0                U149 400
                                             J6                U149 410
STOP LX76 GENERATOR.                         J64     J3        U149 420
ADD REMAINDER OF LX75                 91   11W1                U149 430
                                           14X76               U149 435
                                           10X75               U149 440
                                             94      0         U149 450
ADD REMAINDER OF LX76                 92   11W2                U149 460
                                           14X75               U149 465
                                           10X76               U149 470
                                             94      0         U149 480
ADD REMAINDER OF 1W3 TO 1W2           94   24W4                U149 490
                                           20W5                U149 500
                                           20W6                U149 505
                                           60W3                U149 510
                                           11W4                U149 520
                                             J10               U149 530
TEST FOR NORMAL FORM                         96                U149 540
                                           7095                U149 550
IF NORMAL, DELETE                     99   11W6                U149 560
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                                                   11W3                        U149 570
                                                     U169   0                  U149 580
IF NOT NORMAL,                             95      11W3                        U149 590
CONSTRUCT PAIR ATTRIBUTE,                            J90                       U149 600
                                                     J136                      U149 610
                                                   40H0                        U149 620
                                                   10X1                        U149 630
INSERT IT,                                           J64                       U149 640
                                                   11W5                        U149 650
                                                     J11                       U149 660
ADD TO 1W0                                         11W0                        U149 670
AND DELETE FROM 1W3.                               11W3                        U149 680
                                                     J64    98                 U149 690
TEST IF NORMAL                             96      44H0                        U149 700
                                                     J81                       U149 710
                                                   40H0                        U149 720
TEST IF FIRST SYMBOL IS X1                         10X1                        U149 730
                                                     J2                        U149 740
IF SO, EXIT WITH H5+.                              70       97                 U149 750
TEST IF FIRST SYMBOL IS X2.                        10X2                        U149 760
                                                     J2                        U149 770
IF NOT, EXIT WITH H5-.                             70J8                        U149 780
IF SO, TEST IF SECOND IS X1                          J82                       U149 790
                                                   10X1                        U149 800
EXIT WITH H5 SET                                     J2     0                  U149 810
                                           97      30H0     J8                 U149 830
                                           98        J4     99                 U149 840
                                           910     44H0                        U149 845
                                                   10X75                       U149 850
                                                     J10                       U149 855
                                                   40W0                        U149 860
                                                   20W0                        U149 865
                                                   40H0                        U149 870
                                                   10X76                       U149 875
                                                     J10                       U149 880
                                           914       J60                       U149 890
                                                   70911                       U149 895
                                                   12H0                        U149 900
                                                   11W0                        U149 905
                                                     J60                       U149 910
                                                   70912                       U149 915
                                                   60W0                        U149 920
                                                   52W0                        U149 925
                                                     U107                      U149 930
                                                   70913    914                U149 935
                                           913     30H0     J30                U149 940
                                           912     30H0                        U149 945
                                                   30H0     913                U149 950
                                           911     30H0                        U149 955
                                                   11W0                        U149 960
                                                     J60                       U149 965
                                                     J5     913                U149 970
                                           915     30H0     J3                 U149 975
FIND ROUTINE RELEVANT                      U150    40H0                        U150 000
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TO DIFFERENCE (0)                          10X50                      U150 010
FIND TYPE OF DIFFERENCE                     J10                       U150 020
                                           10X90                      U150 030
                                            J6                        U150 040
FIND LIST OF RELEVANT ROUTINES              J10                       U150 050
                                            J50                       U150 060
                                           10X41                      U150 065
                                            J10                       U150 066
                                           10X32                      U150 070
FIND TYPE OF AFFECTED CELL                  J10                       U150 080
                                           11W0                       U150 090
                                            J6                        U150 100
FIND RELEVANT ROUTINE                       J10    J30                U150 110
LOCATE AFFECTED CELL (0) OF         U151    J50                       U151 000
SDSC (1).                                  10X71                      U151 010
FIND LIST OF AFFECTED CELLS                 J10                       U151 020
LOCATE NEXT CELL                    90      J60                       U151 030
IF NONE, EXIT WITH H5-                     70J30                      U151 040
                                           12H0                       U151 050
FIND ITS NAME                              10X41                      U151 060
                                            J10                       U151 070
                                           11W0                       U151 080
COMPARE WITH (0).                           U107                      U151 090
EXIT OR CONTINUE                           7090    J30                U151 100
LOCATE VARIABLE AFFECTED CELL       U152   10X71                      U152 000
IN SDSC (0)                                 J10                       U152 010
LOCATE NEXT CELL                    90      J60                       U152 020
IF NONE, EXIT WITH H5-                     700                        U152 030
                                           12H0                       U152 040
FIND ITS NAME                              10X41                      U152 050
                                            J10                       U152 060
FIND ITS TYPE                              10X32                      U152 070
                                            J10                       U152 080
TEST IF VARIABLE                           10X39                      U152 090
                                            J2                        U152 100
IF YES, EXIT WITH H5+                      7090    J4                 U152 110
SUBSTITUTE (0) FOR VARIABLE (1)     U153    J51          6W1=VAR.     U153 000
THROUGHOUT SDSC(2).                        10X71         1W0=SUB.     U153 010
FIND LIST OF AFFECTED CLESS,                J10                       U153 020
AND PROCESS IT.                            1090                       U153 030
                                            J100   J31                U153 040
SAVE CELL                           90     40H0                       U153 050
                                           10X41                      U153 060
FIND ITS NAME                               J10                       U153 070
                                           11W1                       U153 080
COMPARE IT WITH VARIABLE (1).               U107                      U153 090
IF UNEQUAL, SKIP TO 91                     7091                       U153 100
IF EQUAL, SAVE CELL,                       40H0                       U153 110
ERASE ITS NAME,                            10X41                      U153 120
                                            J14                       U153 130
AND SUBSTITUTE (0).                        40H0                       U153 140
                                           11W0                       U153 150
                                           10X41                      U153 160
                                            J11    91                 U153 170
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FIND INPUT OF CELL,                    91      40H0                                U153 180
                                               10X75                               U153 190
                                                 J10                               U153 200
AND MAKE SUBSTITUTIONS.                          92                                U153 210
                                               10X76                               U153 220
FIND OUTPUT OF CELL,                             J10                               U153 230
AND MAKE SUBSTITUTIONS.                          92       J4                       U153 240
SUBSTITUTE FOR CONTENTS OF LIST        92       4J60                               U153 250
IF NO MORE CELLS, EXIT                         70J8                                U153 260
FIND FIRST SYMBOL                              12H0                                U153 270
AND COMPARE WITH 1W1                           11W1                                U153 300
                                                 U107                              U153 310
IF UNEQUAL, FIND NEXT                          7092                                U153 320
IF EQUAL                                       40W2                                U153 330
                                               60W2                                U153 340
MAKE SUBSTITUTION                              11W0                                U153 350
                                                 J74                               U153 355
                                                 J136                              U153 356
                                               21W2                                U153 360
                                               30W2       92                       U153 370
SUBSTITUTE NAMES OF SDSC (0) FOR       U154      J46                 1W0=SDSC0     U154 000
VARIABLES OF SDSC (1) IN CELL                    J22                 1W1=SDSC1     U154 010
NAMED (2) OF (1).                              11W0                  1W2=CELL      U154 020
LOCATE CELL 1W2 IN SDSC 1W0                    11W2                  1W3=CELL0     U154 030
                                                 U151                1W4=CELL1     U154 040
IF NONE, EXIT.                                 70J36                 1W5=OUT.1     U154 050
PUT LOC. OF CELL OF W0 IN W3                   20W3                                U154 060
                                               11W1                                U154 070
LOCATE CELL W2 IN SDSC W1                      11W2                                U154 080
                                                 U151                              U154 090
ERROR STOP                                     70J7                                U154 100
PUT LOC OF CELL OF W1 IN W4                    20W4                                U154 110
                                               12W3                                U154 120
                                               10X76                               U154 130
FIND OUTPUT LIST OF W0 CELL                      J10                               U154 140
                                               12W4                                U154 150
                                               10X76                               U154 160
FIND OUTPUT LIST OF W1 CELL.,                    J10                               U154 170
AND STORE IN W5                                20W5                                U154 180
                                                 90                                U154 190
                                               12W3                                U154 200
                                               10X75                               U154 210
                                                 J10                               U154 215
                                               12W4                                U154 220
                                               10X75                               U154 230
                                                 J10                               U154 240
                                               20W5                                U154 250
                                                 90       J36                      U154 260
LOCATE NEXT SYMBOL OF CELL 0           90       4J60                               U154 270
IF NONE, EXIT                                  70J8                                U154 280
                                               60W6                                U154 285
                                               11W5                                U154 290
LOCATE NEXT SYMBOL OF CELL 1                     J60                               U154 300
IF NONE, EXIT VIA 91                           7091                                U154 310
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STORE LOCATION IN W5                          60W5                      U154 320
                                              12H0                      U154 330
FIND TYPE OF SYMBOL OF 1                      10X32                     U154 340
                                                J10                     U154 350
TEST IF A VARIABLE                            10X39                     U154 360
                                                J2                      U154 370
IF NOT, GO TO 90 VIA 93                       7092                      U154 380
                                              52H0                      U154 390
BRING IN SDSC 1                               11W1                      U154 420
                                                J6                      U154 430
                                              12W6                      U154 440
SUBSTITUTE THROUGH SDSC 1                       U153    90              U154 470
                                        91    30H0      J8              U154 480
                                        92    30H0      90              U154 490
MAKE JDEF OF (0). (0) IS ROUTINE        U155    J47                     U155 000
                                                J21                     U155 005
WITH SDSC MODIFIED FROM (1).                  11W0                      U155 010
                                              11W1                      U155 020
FIND JDEF OF (1)                              10X22                     U155 030
                                                J10                     U155 040
                                                J74                     U155 045
                                                J136                    U155 046
ASSIGN IT AS JDEF OF (0)                      10X22                     U155 050
                                                J11                     U155 060
BRING IN LISTS OF AFFECTED CELLS                93      91              U155 065
                                        93    04J0                      U155 066
                                              11W0                      U155 070
                                              10X24                     U155 080
FIND SDSC OF (0)                                J10                     U155 090
                                              10X71                     U155 100
FIND LIST OF AFFECTED CELLS                     J10                     U155 110
AND PUT IN W2                                 20W2                      U155 120
                                              11W1                      U155 130
                                              10X24                     U155 140
FIND SDSC OF (1)                                J10                     U155 150
                                              10X71                     U155 160
FIND LIST OF AFFECTED CELLS                     J10                     U155 170
AND PUT IN W3                                 60W3                      U155 180
                                              11W2      0               U155 190
FIND NEXT CELL OF (0)                   91      J60                     U155 200
                                              7090                      U155 210
                                              11W3                      U155 220
FIND NEXT CELL OF (1)                           J60                     U155 230
                                              60W3                      U155 240
                                              70J7                      U155 250
                                              52H0                      U155 260
                                              40H0                      U155 220
FIND ITS NAME                                 10X41                     U155 280
                                                J10                     U155 290
TEST IF IT IS A VARIABLE                      10X32                     U155 300
                                                J10                     U155 310
                                              10X39                     U155 320
                                                J2                      U155 330
                                              7092                      U155 340
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   SO, STORE IN W4                          20W4               U155 350
STORE NAME OF SYMBOL OF (0) IN W5           12H0               U155 360
                                            20W5               U155 370
                                              99     91        U155 375
SUBSTITUTE W5 FOR W4                   99   04J0               U155 380
                                            11W0               U155 385
                                            10X22              U155 385
                                              J10              U155 386
THROUGHOUT (0)                              11W4               U155 390
                                            10X41              U155 395
                                              J10              U155 396
                                            11W5               U155 400
                                            10X41              U155 405
                                              J10              U155 406
                                              U156   0         U155 410
                                       92   30H0     91        U155 420
                                       90   30H0               U155 430
                                            30H0               U155 440
                                              93               U155 450
SUBSTITUTE FOR VARIABLES IN CELLS      94     J60              U155 460
                                            7095               U155 470
                                            60W2               U155 480
                                            52H0               U155 490
                                            10X75              U155 500
                                              J10              U155 510
PUT X75 OF W2 IN W6                         20W6               U155 520
                                              J60              U155 530
                                            70J7               U155 540
                                            60W3               U155 550
                                            52H0               U155 560
                                            10X75              U155 570
                                              J10              U155 580
PUT X75 OF W3 IN W7                         20W7               U155 590
SUBS. FOR VARIABLE IN X75                     96               U155 600
                                            12W2               U155 610
                                            10X76              U155 620
                                              J10              U155 630
PUT X76 OF W2 IN W6                         20W6               U155 640
                                            12W3               U155 650
                                            10X76              U155 660
                                              J10              U155 670
PUT X76 OF W3 IN W7                         20W7               U155 680
SUBS. FOR VARIABLE IN X76                     96               U155 690
                                            11W3               U155 700
                                            11W2     94        U155 710
EXIT                                   95   30H0               U155 720
                                            30H0     J37       U155 730
FIND VARIABLES AND SUBSTITUTE          96   04J0               U155 740
                                            11W6               U155 745
FIND NEXT IN W6                               J60              U155 750
IF NONE, EXIT                               70J8               U155 760
                                            60W6               U155 770
                                            11W7               U155 780
                                              J60              U155 790
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                                                  70J7                 U155 800
                                                  60W7                 U155 810
TEST IF NEXT IN W7 IS VARIABLE                    12H0                 U155 820
                                                  10X32                U155 830
                                                    J10                U155 840
                                                  10X39                U155 850
                                                    J2                 U155 860
IF NOT, FIND NEXT                                 7098                 U155 870
IF SO,                                            52H0                 U155 880
SUBSTITUTE W5 FOR W4                              20W4                 U155 890
THROUGHOUT W0                                     52H0                 U155 900
                                                  20W5                 U155 910
                                                  11W0                 U155 920
                                                  10X22                U155 921
                                                    J10                U155 922
                                                  11W4                 U155 924
                                                  11W5                 U155 926
                                                    U156      96       U155 928
                                          98      30H0                 U155 930
                                                  30H0        96       U155 940
SUBSTITUTE SYMBOL (0) FOR                 U156      J52                U156 000
VARIABLE (1) IN JDEF OF (2)                       11W2                 U156 010
FIND NEXT LINE OF JDEF                    90        J60                U156 020
IF NONE, EXIT                                     7091                 U156 030
                                                  12H0                 U156 040
FIND ITS SYMB.                                    10X45                U156 050
                                                    J10                U156 060
COMPARE SYMB WITH 1W1                             11W1                 U156 070
                                                    U107               U156 080
IF UNEQUAL, FIND NEXT                             7090                 U156 090
IF EQUAL,                                         12H0                 U156 100
COPY 1W0 AS NEW SYMB                              11W0                 U156 110
FOR LINE OF JDEF                                    J74                U156 120
                                                    J136               U156 130
                                                  10X45                U156 140
                                                    J11       90       U156 210
                                          91      30H0        J32      U156 220
DELETE CAREFULLY SYMBOL (0)               U169      J41                U169 000
FROM LIST (1)                                     20W0                 U169 010
                                                  40H0                 U169 020
                                                  11W0                 U169 030
LOCATE (0) ON (1)                                   J62                U169 040
                                                  70J30                U169 050
DIVIDE LIST AFTER LOC(0)                            J75                U169 060
PUT REMAINDER IN W1                               20W1                 U169 070
DELETE LAST SYMBOL FROM (1)                       40H0                 U169 080
                                                    J70                U169 090
LOCATE LAST SYMBOL OF (1)                           J61                U169 100
                                                  11W1                 U169 110
REATTACH REMAINDER                                  J76                U169 120
                                                  30H0        J31      U169 130
FIND BIGGEST DIFFERENCE                   X5        J43                X5   000
BETWEEN DSNS (0) AND (1)                          20W0                 X5   010
                                                  60W1                 X5   020
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		10X30		X5 030
FIND PROCESS OF (1)		J10		X5 040
		11W0		X5 050
		10X30		X5 060
FIND PROCESS OF (0)		J10		X5 070
COMPARE PROCESSES		J2		X5 080
IF EQUAL, COMPARE ARGUMENTS		70	90	X5 090
IF UNEQUAL, SIGNAL X62		10X62	J33	X5 100
FIND ARG. LISTS OF (0) AND (1)	90	910		X5 110
FIND NEXT ARGS. OF (0) AND (1)	92	911		X5 120
NONE, GO TO 91		7091		X5 130
TEST ARGUMENT TYPES		X6		X5 140
IF UNEQUAL, EXIT WITH SIGNAL		70J33	92	X5 150
ALL TYPES EQUAL, TEST ARGS.	91	910		X5 160
FIND NEXT ARGS, OF (0) AND (1)	93	911		X5 170
NONE, GO TO 94		7094		X5 180
		40H0		X5 190
		10X32		X5 200
FIND ARGUMENT TYPE		J10		X5 210
		70J7		X5 220
		10X37		X5 230
TEST IF DETERMINER		J2		X5 240
IF NOT, FIND NEXT ARG.		7093		X5 250
IF SO, FIND BIGGEST DIFFERENCE		X5		X5 260
SAVE DIFFERENCE SIGNAL		40H0		X5 270
TEST IF NO DIFFERENCE		10X55		X5 280
		J2		X5 290
IF DIFFERENCE, EXIT WITH SIGNAL		7097		X5 300
NO DIFFERENCE, FIND NEXT ARG.		30H0	93	X5 310
NO DETERMINER DIFFERENCES	94	910		X5 320
FIND NEXT ARGS. OF (0) AND (1)		911		X5 330
NONE, EXIT WITH X55		7095		X5 340
		40H0		X5 350
TEST IF NAMES		10X36		X5 360
		J2		X5 370
		7096		X5 380
SIGNAL DIFFERENT NAMES		10X66	J33	X5 390
SIGNAL DIFFERENT LOCATIONS	96	10X67	J33	X5 400
EXIT, NO DIFFERENCE	95	10X55	J33	X5 410
FIND ARGUMENT LISTS	910	11W0		X5 420
		10X31		X5 430
FIND LIST OF (0)		J10		X5 440
AND PUT IN W2.		20W2		X5 450
		11W1		X5 460
		10X31		X5 470
FIND LIST OF (1),		J10		X5 480
AND PUT IN W3.		20W3	0	X5 490
FIND NEXT ARGS. OF (0) AND (1)	911	11W2		X5 500
FIND NEXT OF (0)		J60		X5 510
IF NONE, SET H5 -		700		X5 520
		60W2		X5 530
		52H0		X5 540
		11W3		X5 550
FIND NEXT OF (1)		J60		X5 560

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                                               .       70J7                  X5   570
                                                       60W3                  X5   580
                                                       52H0      0           X5   590
TEST TYPES OF ARGUMENTS (0), (1)               X6        J43                 X6   000
OUTPUT (0) IS DIFFERENCE, SET H5.                      20W0                  X6   010
                                                       60W1                  X6   020
                                                       10X32                 X6   030
FIND ARGUMENT TYPE OF (1)                                J10                 X6   040
STORE IN W3                                            60W3                  X6   045
                                                       11W0                  X6   050
                                                       10X32                 X6   060
FIND ARGUMENT TYPE OF (0)                                J10                 X6   070
STORE IN W2                                            60W2                  X6   075
COMPARE ARGUMENT TYPES                                   J2                  X6   080
                                                       70        J33         X6   090
UNEQUAL, TEST IF (0) DETERMINER                        11W2                  X6   100
                                                       10X37                 X6   110
                                                         J2                  X6   120
                                                       7091                  X6   130
SIGNAL (0) IS DETERMINER                               10X65     90          X6   140
TEST IF (0) IS A NAME                          91      11W2                  X6   150
                                                       10X36                 X6   160
                                                         J2                  X6   170
                                                       7092                  X6   180
SIGNAL (0) A NAME                                      10X68     90          X6   190
IF (0) A LOCATION, SIGNAL X69                  92      10X69     J33         X6   200
                                               90        J5      J33         X6   210
FIND LARGEST DIFFERENCE                        X7        J44                 X7   000
BETWEEN INPUT AND OUTPUT                               10X71                 X7   010
OF SDSC (0).  PUT DIFF. IN (0).                          J10                 X7   020
PUT LIST OF AFFECTED CELLS IN W0.                      60W0                  X7   030
FIND DIFFERENCE, NOT IN H0.                            1090                  X7   040
                                                         J100                X7   050
EXIT IF FOUND                                          70J34                 X7   060
                                                       11W0                  X7   070
FIND DIFFERENCE IN H0                                  1091                  X7   080
                                                         J100                X7   090
EXIT IF FOUND                                          70J34                 X7   100
                                                         J90                 X7   110
IF NOT FOUND,                                            J136                X7   120
                                                       40H0                  X7   125
LEAVE NULL DIFFERENCE,                                 10X80                 X7   130
V(X50)=X80, IN H0                                      10X50                 X7   140
                                                         J11     J34         X7   150
PUT AFFECTED CELL IN W1                        90      64W1                  X7   160
                                                       10X41                 X7   170
FIND TYPE OF AFFECTED CELL                               J10                 X7   180
COPY AND SAVE ITS NAME                                   J74                 X7   182
                                                         J136                X7   183
                                                       40H0                  X7   184
                                                       10X32                 X7   190
                                                         J10                 X7   200
TEST IF H0                                             10X35                 X7   220
                                                         J2                  X7   230
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IF SO, EXIT.		7092	J8	X7	240
IF NOT, CREATE DIFFERENCE,	92	J90		X7	250
		J136		X7	260
SAVE ITS NAME IN W2,		60W2		X7	270
		J6		X7	280
ASSIGN TYPE OF CELL		10X41		X7	290
		J11		X7	300
		11W1		X7	310
FIND TYPE OF DIFFERENCE		93		X7	320
		11W2		X7	330
		J6		X7	340
		10X50		X7	350
ASSIGN TYPE TO 1W2		J11		X7	360
BRING DIFFERENCE IN, AND QUIT		11W2	J3	X7	370
FIND TYPE OF AFFECTED CELL	91	64W1		X7	380
		10X41		X7	390
		J10		X7	400
COPY ITS NAME		J74		X7	410
		J136		X7	420
		J3	92	X7	430
SAVE AFFECTED CELL	93	44H0		X7	440
		10X75		X7	450
		J10		X7	460
FIND ITS FIRST INPUT SYMBOL,		J81		X7	470
AND SAVE IN W3.		20W3		X7	480
SAVE AFFECTED CELL		40H0		X7	490
		10X76		X7	500
		J10		X7	510
FIND ITS FIRST OUTPUT SYMBOL		J81		X7	520
		11W3		X7	530
COMPARE SYMBOLS		U107		X7	540
		7094		X7	550
IF IDENTICAL,		30H0		X7	560
CALL DIFFERENCE (COPY)		10X84	0	X7	570
NOT IDENTICAL,	94	40H0		X7	580
COUNT LIST X75		10X75		X7	590
		J10		X7	600
		J126		X7	610
		20W3		X7	620
COUNT LIST X76		10X76		X7	630
		J10		X7	640
		J126		X7	650
		60W4		X7	660
		11W3		X7	670
		J114		X7	680
IF LISTS EQUAL		7095		X7	690
CALL DIFFERENCE (REPLACE)		10X83	0	X7	700
	95	11W3		X7	710
		11W4		X7	720
		J115		X7	730
IF 1W4 LARGER,		7096		X7	740
CALL DIFFERENCE (ADD)		10X82	0	X7	750
IF SMALLER, (DELETE)	96	10X81	0	X7	760
DATA 5		1			

	A0	0	0	A0	000
A	L1	21A		L1	000
B	L2	21B		L2	000
C	L3	21C		L3	000
D	L4	21D		L4	000
E	L5	21E		L5	000
F	L6	21F		L6	000
G	L7	21G		L7	000
H	L8	21H		L8	000
I	L9	21I		L9	000
J	L10	21J		L10	000
K	L11	21K		L11	000
L	L12	21L		L12	000
M	L13	21M		L13	000
N	L14	21N		L14	000
O	L15	21O		L15	000
P	L16	21P		L16	000
Q	L17	21Q		L17	000
R	L18	21R		L18	000
S	L19	21S		L19	000
T	L20	21T		L20	000
U	L21	21U		L21	000
V	L22	21V		L22	000
W	L23	21W		L23	000
X	L24	21X		L24	000
Y	L25	21Y		L25	000
Z	L26	21Z		L26	000
0	L30	210		L30	000
1	L31	211		L31	000
2	L32	212		L32	000
3	L33	213		L33	000
4	L34	214		L34	000
5	L35	215		L35	000
6	L36	216		L36	000
7	L37	217		L37	000
8	L38	218		L38	000
9	L39	219		L39	000
(0)	L40	21(0)		L40	000
(1)	L41	21(1)		L41	000
(2)	L42	21(2)		L42	000
(3)	L43	21(3)		L43	000
(4)	L44	21(4)		L44	000
	N0	1	0000	N0	000
	N1	1	0001	N1	000
	N2	1	0002	N2	000
	N3	1	0003	N3	000
	N4	1	0004	N4	000
	N5	1	0005	N5	000
	N6	1	0006	N6	000
	N7	1	0007	N7	000
	N8	1	0008	N8	000
	N9	1	0009	N9	000
	N10	1	0010	N10	000
	N13	1	0013	N13	000

	N28	1	0028	N28	000
	N29	1	0029	N29	000
	N30	1	0030	N30	000
	N35	1	0035	N35	000
	N36	1	0036	N36	000
	N37	1	0037	N37	000
	N38	1	0038	N38	000
	N44	1	0044	N43	000
	N49	1	0049	N49	000
	N50	1	0050	N50	000
	N60	1	0060	N60	000
	N65	1	0065	N65	000
	N77	1	0077	N77	000
	N116	1	0116	N116	000
DIFFERENCE	X0	0	0	X0	000
REMAINDER OF PUSHDOWN LIST	X1	90	0	X1	000
	90	0		X1	010
		X32		X1	020
		X1		X1	030
		X33		X1	040
		L18		X1	050
		X34		X1	060
		N0	0	X1	070
VARIABLE S1	X2	90	0	X2	000
	90	0		X2	010
		X32		X2	020
		X38		X2	030
		X33		X2	040
		L19		X2	050
		X34		X2	060
		N1	0	X2	070
VARIABLE S0	X3	90	0	X3	000
	90	0		X3	010
		X32		X3	020
		X39		X3	030
		X33		X3	040
		L19		X3	050
		X34		X3	060
		N0	0	X3	070
VARIABLE S2	X4	90	0	X4	000
	90	0		X4	010
		X32		X4	020
		X39		X4	030
		X33		X4	040
		L19		X4	050
		X34		X4	060
		N2	0	X4	070
DSCN (DESCRIPTIVE NAME)	X20	0	0	X20	000
LDEF (L-DEFINITION)	X21	0	0	X21	000
JDEF (J-DEFINITION)	X22	0	0	X22	000
ASOJ (ASSOCIATED J)	X23	0	0	X23	000
SDSC OF ROUTINE	X24	0	0	X24	000
IPLN OF ROUTINE	X25	0	0	X25	000
PROCESS	X30	0	0	X30	000

LIST OF ARGUMENTS	X31	0	0	X31	000
TYPE (OF ARGUMENT)	X32	0	0	X32	000
REGION	X33	0	0	X33	000
LOCATION	X34	0	0	X34	000
MEMBER OF H0 LIST	X35	0	0	X35	000
NAMED SYMBOL	X36	0	0	X36	000
DETERMINER	X37	0	0	X37	000
UNKNOWN CONSTANT	X38	0	0	X38	000
VARIABLE	X39	0	0	X39	000
TYPE (OF IPL WORD)	X40	0	0	X40	000
NAME	X41	0	0	X41	000
SIGN	X42	0	0	X42	000
P-PREFIX	X43	0	0	X43	000
Q-PREFIX	X44	0	0	X44	000
SYMB	X45	0	0	X45	000
LINK	X46	0	0	X46	000
TYPE OF DIFFERENCE	X50	0	0	X50	000
TEST FOR DIFFERENCE	X51	0	0	X51	000
NO DIFFERENCE	X55	0	0	X55	000
JDEF ABSENT	X60	0	0	X60	000
LDEF ABSENT	X61	0	0	X61	000
DSCN-WRONG FUNCTION NAME	X62	0	0	X62	000
DSCN-WRONG ARGUMENT TYPE	X63	0	0	X63	000
LDEF HAS CONNECTIVE	X64	0	0	X64	000
DSCN-DETERM. FOR OTHER	X65	0	0	X65	000
DSCN-ONE NAME FOR OTHER	X66	0	0	X66	000
DSCN-ONE LOC FOR OTHER	X67	0	0	X67	000
DSCN-NAME FOR LOCATION	X68	0	0	X68	000
DSCN-LOCATION FOR NAME	X69	0	0	X69	000
OPERATOR ROUTINE	X70	0	0	X70	000
LIST OF AFFECTED CELLS OF SDSC	X71	0	0	X71	000
INPUT STATE OF CELL	X75	0	0	X75	000
OUTPUT STATE OF CELL	X76	0	0	X76	000
SDSC - NO DIFFERENCE	X80	0	0	X80	000
SDSC - DELETION	X81	0	0	X81	000
SDSC - ADDITION	X82	0	0	X82	000
SDSC - REPLACEMENT	X83	0	0	X83	000
SDSC - COPY	X84	0	0	X84	000
INDEX TO RELEVANT ROUTINES	X90	90	0	X90	000
	90	0		X90	050
LIST OF ADD ROUTINES		X82		X90	100
		91		X90	110
LIST OF REPLACE ROUTINES		X83		X90	200
		92	0	X90	210
	91	93	0	X90	300
ADD.	93	0		X90	350
H0 IS AFFECTED CELL		X35		X90	400
		X107	0	X90	410
	92	94	0	X90	500
REPLACE.	94	0		X90	550
NAMED CELL IS AFFECTED CELL		X36		X90	600
		X106	0	X90	610
ROUT. INSERT (1) AT END OF	X100	90	0	X100	000
VALUE LIST OF ATTRIBUTE	90	0		X100	010

```
                                           X25                          X100 015
                                           97                           X100 016
(0) OF (2).                                X20                          X100 020
DSCN IS 91.                                91       0                   X100 030
                                  91       92       0                   X100 040
                                  92       0                            X100 050
PROCESS IS X110                            X30                          X100 060
                                           X110                         X100 070
                                           X31                          X100 080
                                           93       0                   X100 090
ARGS. ARE                         93       0                            X100 100
X120                                       X120                         X100 110
X121                                       X121     0                   X100 120
                                  97       99       0                   X100 210
                                  99       0                            X100 220
SYMB. = J13                                X33                          X100 230
                                           L10                          X100 240
                                           X34                          X100 250
                                           N13      0                   X100 260
ROUT. INSERT (0) AT END OF (1)    X101     90       0                   X101 000
                                  90       0                            X101 010
                                           X20                          X101 020
                                           91                           X101 030
JDEF IS 94                                 X22                          X101 035
                                           94       0                   X101 036
                                  91       92       0                   X101 040
                                  92       0                            X101 050
PROCESS IS X110                            X30                          X101 060
                                           X110                         X101 070
                                           X31                          X101 080
                                           93       0                   X101 090
                                  93       0                            X101 100
                                           X122                         X101 110
                                           X120     0                   X101 120
                                  94       0                            X101 130
                                           95       0                   X101 140
                                  95       96       0                   X101 150
                                  96       0                            X101 160
J65                                        X45                          X101 170
                                           97                           X101 180
                                           X46                          X101 190
                                           98       0                   X101 200
                                  97       99       0                   X101 210
PROCESS J65                       99       0                            X101 220
                                           X33                          X101 230
                                           L10                          X101 240
                                           X34                          X101 250
                                           N65      0                   X101 260
                                  98       910      0                   X101 270
LINK 0                            910      0                            X101 280
                                           X33                          X101 290
                                           N0       0                   X101 300
ROUT. FIND V((0),(1))             X102     90       0                   X102 000
                                  90       0                            X102 010
```

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                                              X32              X102 020
TYPE--DETERMINER                              X37              X102 030
                                              X20              X102 040
                                              91               X102 050
JDEF IS 94                                    X22              X102 060
                                              94        0      X102 070
                                    91        92               X102 080
VERB                                          920       0      X102 085
                                    92        0                X102 090
                                              X30              X102 100
PROCESS IS X111. FIND VALUE                   X111             X102 110
                                              X31              X102 120
                                              93        0      X102 130
ARGS. ARE                           93        0                X102 140
 X122.   (0)                                  X122             X102 150
 X120.   (1)                                  X120      0      X102 160
                                    94        0                X102 170
                                              95        0      X102 180
                                    95        96        0      X102 190
                                    96        0                X102 200
                                              X45              X102 210
                                              97               X102 220
                                              X46              X102 230
                                              98        0      X102 240
                                    97        99        0      X102 250
PROCESS J10                         99        0                X102 260
                                              X33              X102 270
                                              L10              X102 280
                                              X34              X102 290
                                              N10       0      X102 300
                                    98        910       0      X102 310
LINK 0                              910       0                X102 320
                                              X33              X102 330
                                              N0        0      X102 340
VERB (FIND)                         920     21FIND             X102 350
ROUT. TESTN IF (0) LESS THAN N0     X103      90        0      X103 000
                                    90        0                X103 010
                                              X20              X103 020
                                              91               X103 030
                                              X22              X103 040
                                              94        0      X103 050
                                    91        92        0      X103 060
                                    92        0                X103 070
                                              X30              X103 080
PROCESS IS X112 TESTN, LESS                   X112             X103 090
                                              X31              X103 100
                                              93        0      X103 110
ARGUMENTS                           93        0                X103 120
(0)                                           X122             X103 130
N0                                            X124      0      X103 140
                                    94        0         0      X103 150
ROUT. TESTN IF (0) LESS THAN (1)    X104      90        0      X104 000
                                    90        0                X104 010
                                              X20              X104 020
```

		91		X104 030
		X22		X104 040
		94	0	X104 050
	91	92	0	X104 060
	92	0		X104 070
		X30		X104 080
PROCESS IS X112 TESTN, LESS		X112		X104 090
		X31		X104 100
		93	0	X104 110
	93	0		X104 120
		X122		X104 130
		X120	0	X104 140
	94	0		X104 150
		95	0	X104 160
	95	96	0	X104 170
	96	0		X104 180
		X45		X104 190
		97		X104 200
		X46		X104 210
		98	0	X104 220
	97	99	0	X104 230
	99	0		X104 240
		X33		X104 250
		L10		X104 260
		X34		X104 270
		N116	0	X104 280
	98	910	0	X104 290
	910	0		X104 300
		X33		X104 310
		N0	0	X104 320
J3. REPLACE TOP OF H5 WITH J3.	X105	90	0	X105 000
	90	0		X105 010
		X20		X105 015
		920		X105 016
		X25		X105 020
		91		X105 030
		X24		X105 040
		92	0	X105 050
IPLN OF J3	91	93	0	X105 060
	93	0		X105 070
		X33		X105 080
		L10		X105 090
		X34		X105 100
		N3	0	X105 110
SDSC OF J3	92	94	0	X105 120
	94	0		X105 130
		X71		X105 140
		95	0	X105 150
	95	0		X105 160
AFFECTED CELL IS 97		97	0	X105 170
	97	98	0	X105 180
	98	0		X105 190
		X41		X105 200
		X175		X105 210

		X75		X105 220
		99		X105 230
		X76		X105 240
		910	0	X105 250
INPUT STATE OF H5	99	0		X105 260
		X2		X105 270
		X1	0	X105 280
OUTPUT STATE OF H5.	910	0		X105 290
		911		X105 300
		X1	0	X105 310
	911	912	0	X105 320
	912	0		X105 330
		X32		X105 335
		X36		X105 336
		X33		X105 340
		L10		X105 350
		X34		X105 360
		N3	0	X105 370
	920	921	0	X105 380
DSCN	921	0		X105 390
		X30		X105 400
PROCESS IS X113		X113	0	X105 410
P2(C). REPLACE TOP OF C WITH	X106	90	0	X106 000
TOP OF H0.	90	0		X106 010
DSCN		X20		X106 012
		930		X106 013
		X22		X106 015
		920		X106 016
		X25		X106 020
		91		X106 030
		X24		X106 040
		92	0	X106 050
IPLN OF P2(C)	91	93	0	X106 060
	93	0		X106 070
		X33		X106 080
		L16		X106 090
		X34		X106 100
		N2	0	X106 110
SDSC OF P2(C)	92	94	0	X106 120
	94	0		X106 130
		X71		X106 140
		95	0	X106 150
	95	0		X106 160
AFFECTED CELLS ARE		96		X106 170
96 AND 97		97	0	X106 180
	96	98	0	X106 190
	98	0		X106 200
		X41		X106 210
		X170		X106 220
		X75		X106 240
		99		X106 250
		X76		X106 260
		910	0	X106 270
INPUT STATE OF H0	99	0		X106 280

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                                          X3                   X106 290
                                          X1      0            X106 300
OUTPUT STATE OF H0                910     0                    X106 310
                                          X1      0            X106 320
                                  97      914     0            X106 330
                                  914     0                    X106 340
                                          X41                  X106 341
NAME IS VARIABLE, X4                      X4                   X106 342
                                          X75                  X106 350
                                          915                  X106 360
                                          X76                  X106 370
                                          916     0            X106 380
INPUT STATE OF C                  915     0                    X106 390
                                          X2                   X106 400
                                          X1      0            X106 410
OUTPUT STATE OF C                 916     0                    X106 420
                                          X3                   X106 430
                                          X1      0            X106 440
                                  920     0                    X106 450
                                          921     0            X106 460
                                  921     922     0            X106 470
                                  922     0                    X106 480
                                          X43                  X106 490
                                          N2                   X106 500
                                          X45                  X106 510
                                          X4      0            X106 520
                                  930     0                    X106 530
                                          X30                  X106 540
PROCESS IS X114.                          X114                 X106 550
                                          X31                  X106 560
                                          931     0            X106 570
                                  931     0                    X106 580
ARG. IS X125.                             X125    0            X106 590
P1(S). ADD S TO TOP OF H0.        X107    90      0            X107 000
                                  90      0                    X107 010
                                          X20                  X107 012
                                          930                  X107 013
                                          X22                  X107 015
                                          920                  X107 016
                                          X25                  X107 020
                                          91                   X107 030
                                          X24                  X107 040
                                          92      0            X107 050
IPLN OF P1(S)                     91      93      0            X107 060
                                  93      0                    X107 070
                                          X33                  X107 080
                                          L16                  X107 090
                                          X34                  X107 100
                                          N1      0            X107 110
SDSC OF P1(S)                     92      94      0            X107 120
                                  94      0                    X107 130
                                          X71                  X107 140
                                          95      0            X107 150
                                  95      0                    X107 160
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                                97     0        X107 170
AFFECTED CELL IS H0     97      98     0        X107 180
                        98      0               X107 190
                                X41             X107 200
                                X170            X107 210
                                X75             X107 220
                                99              X107 230
                                X76             X107 240
                                910    0        X107 250
INPUT STATE OF H0       99      0               X107 260
                                X1     0        X107 270
OUTPUT STATE OF H0      910     0               X107 280
                                X3              X107 290
                                X1     0        X107 300
                        920     0               X107 310
                                921    0        X107 320
                        921     922    0        X107 330
                        922     0               X107 340
                                X43             X107 350
                                N1              X107 360
                                X45             X107 370
                                X3     0        X107 380
DSCN                    930     0               X107 390
                                X30             X107 400
PROCESS IS X115.                X115            X107 410
                                X31             X107 420
                                931    0        X107 430
                        931     0               X107 440
ARG. IS X126                    X126   0        X107 450
                        X110    0               X110 000
                                911             X110 010
                                912             X110 020
                                X31             X110 030
                                914             X110 040
                                915             X110 050
                                X31    0        X110 060
                        911   21INSER           X110 001
                        912   21T               X110 002
                        914   21AT EN           X110 004
                        915   21D OF            X110 005
                        X111    0               X111 000
                                911             X111 010
                                912             X111 020
                                913             X111 030
                                914             X111 040
                                915             X111 050
                                916             X111 060
                                X31             X111 070
                                918             X111 080
                                X31    0        X111 090
                        911   21THE V           X111 001
                        912   21ALUE            X111 002
                        913   21-OF T           X111 003
                        914   21HE AT           X111 004
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                                      915   21TRIBU                 X111 005
                                      916   21TE                    X111 006
                                      918   21OF                    X111 008
PROCESS  TESTN ( ) LESS ( )           X112    0                     X112 000
                                              911                   X112 010
                                              912                   X112 020
                                              X31                   X112 030
                                              914                   X112 040
                                              915                   X112 050
                                              916                   X112 060
                                              X31    0              X112 070
                                      911   21TEST-                 X112 080
                                      912   21N IF                  X112 090
                                      914   21IS LE                 X112 100
                                      915   21SS TH                 X112 110
                                      916   21AN                    X112 120
PROCESS. SET H5 -                     X113    0                     X113 000
                                              911                   X113 010
                                              912                   X113 020
                                              913    0              X113 030
                                      911   21SET H                 X113 040
                                      912   215 MIN                 X113 050
                                      913   21US                    X113 060
PROCESS. OUTPUT (0) TO ( ).           X114    0                     X114 000
                                              911                   X114 010
                                              912                   X114 020
                                              913                   X114 030
                                              X31    0              X114 040
                                      911   21OUTPU                 X114 050
                                      912   21T (0)                 X114 060
                                      913   21 TO                   X114 070
PROCESS. INPUT ( ).                   X115    0                     X115 000
                                              911                   X115 010
                                              X31    0              X115 020
                                      911   21INPUT                 X115 030
ARG. X120 (1)                         X120    90                    X120 000
                                              92     0              X120 005
                                      90      0                     X120 010
TYPE- H0 LIST LOCATION                        X32                   X120 020
                                              X35                   X120 030
                                              X37                   X120 040
                                              91                    X120 050
                                              X45                   X120 060
                                              X170   0              X120 070
                                      91      0                     X120 080
                                              X151                  X120 090
                                              X150   0              X120 100
                                      92    21(1)                   X120 110
ARG. X121                             X121    90     0              X121 000
                                      90      0                     X121 010
TYPE- DETERMINER                              X32                   X121 020
                                              X37                   X121 030
                                              X22                   X121 035
JDEF IS 94                                    94                    X121 036
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DSCN IS 91.                                X20                     X121 040
                                           91      0               X121 050
                                    91     92      0               X121 060
                                    92     0                       X121 070
PROCESS IS X111.                           X30                     X121 080
                                           X111                    X121 090
                                           X31                     X121 100
                                           93      0               X121 110
ARGS. ARE                           93     0                       X121 120
X122                                       X122                    X121 130
X123                                       X123    0               X121 140
                                    94     0                       X121 150
                                           95      0               X121 160
                                    95     96      0               X121 170
                                    96     0                       X121 180
                                           X45                     X121 190
                                           97                      X121 200
                                           X46                     X121 210
                                           98      0               X121 220
                                    97     99      0               X121 230
                                    99     0                       X121 240
                                           X33                     X121 250
                                           L10                     X121 260
                                           X34                     X121 270
                                           N10     0               X121 280
                                    98     910     0               X121 290
                                    910    0                       X121 300
                                           X33                     X121 310
                                           N0      0               X121 320
ARG. X122 (0)                       X122   90                      X122 000
                                           92      0               X122 005
                                    90     0                       X122 010
TYPE- HO LIST LOCATION                     X32                     X122 020
                                           X35                     X122 030
                                           X37                     X122 040
                                           91                      X122 050
                                           X45                     X122 060
                                           X170    0               X122 070
                                    91     0                       X122 080
                                           X151    0               X122 090
                                    92   21(0)                     X122 100
ARG. X123 (2)                       X123   90                      X123 000
                                           92      0               X123 005
                                    90     0                       X123 010
TYPE- HO LIST LOCATION                     X32                     X123 020
                                           X35                     X123 030
                                           X37                     X123 040
                                           91                      X123 050
                                           X45                     X123 060
                                           X170    0               X123 070
                                    91     0                       X123 080
                                           X151                    X123 090
                                           X150                    X123 100
                                           X150    0               X123 110
```

```
                            92      21(2)           X123 120
ARG. X124 ONO               X124     90      0      X124 000
                            90       0              X124 010
                                     X32            X124 020
                                     X36            X124 030
                                     X37            X124 040
                                     91             X124 050
                                     X45            X124 060
                                     92      0      X124 070
                            91       0       0      X124 080
                            92       93      0      X124 090
                            93       0              X124 100
                                     X33            X124 110
                                     L14            X124 120
                                     X34            X124 130
                                     NO      0      X124 140
ARG. X125. VARIABLE S2.     X125     90      0      X125 000
                            90       0              X125 010
                                     X32            X125 020
                                     X36            X125 030
                                     X37            X125 040
                                     91             X125 050
                                     X45            X125 060
                                     X4      0      X125 070
                            91       0       0      X125 080
ARG. X126. VARIABLE SO.     X126     90      0      X126 000
                            90       0              X126 010
                                     X32            X126 020
                                     X36            X126 030
                                     X37            X126 040
                                     91             X126 050
                                     X45            X126 060
                                     X3      0      X126 070
                            91       0       0      X126 080
                            X150     0              X150 000
                                     911            X150 010
                                     912            X150 020
                                     913     0      X150 030
                            911     21THE N         X150 001
                            912     21EXT O         X150 002
                            913     21F             X150
                            X151     0              X151 000
                                     911            X151 010
                                     912            X151 020
                                     913     0      X151 030
                            911     21THE C         X151 001
                            912     21ONTEN         X151 002
                            913     21TS OF         X151 003
SYMB HO                     X170     90      0      X170 000
                            90       0              X170 010
                                     X32            X170 015
                                     X35            X170 016
                                     X33            X170 020
                                     L8             X170 030
```

		X34		X170 040
		N0	0	X170 050
SYMB H1	X171	90	0	X171 000
	90	0		X171 010
		X32		X171 015
		X36		X171 016
		X33		X171 020
		L8		X171 030
		X34		X171 040
		N1	0	X171 050
SYMB H2	X172	90	0	X172 000
	90	0		X172 010
		X32		X172 015
		X36		X172 016
		X33		X172 020
		L8		X172 030
		X34		X172 040
		N2	0	X172 050
SYMB. H5	X175	90	0	X175 000
	90	0		X175 010
		X32		X175 015
		X36		X175 016
		X33		X175 020
		L8		X175 030
		X34		X175 040
		N5	0	X175 050
LIST OF SEGMENTS FOR	X180	0		X180 000
COMPOSING J77		90		X180 005
		91		X180 010
		92		X180 015
		93	0	X180 020
	90	0		X180 025
		94	0	X180 030
	94	940	0	X180 035
	940	0		X180 040
		X45		X180 045
		941	0	X180 050
	941	942	0	X180 055
	942	0		X180 060
		X33		X180 065
		L10		X180 070
		X34		X180 075
		N50	0	X180 080
	91	0		X180 085
		95	0	X180 090
	95	950	0	X180 095
	950	0		X180 100
		X45		X180 105
		951	0	X180 110
	951	952	0	X180 115
	952	0		X180 120
		X33		X180 125
		L10		X180 130
		X34		X180 135

	N60	0	X180	140
92	0		X180	145
	96		X180	150
	97		X180	155
	98	0	X180	160
96	960	0	X180	165
960	0		X180	170
	X43		X180	175
	N1		X180	180
	X44		X180	185
	N2		X180	190
	X45		X180	195
	961	0	X180	200
961	962	0	X180	205
962	0		X180	210
	X33		X180	215
	L8		X180	220
	X34		X180	225
	N0	0	X180	230
97	970	0	X180	235
970	0		X180	240
	X43		X180	245
	N1		X180	250
	X44		X180	255
	N1		X180	260
	X45		X180	265
	971	0	X180	270
971	972	0	X180	275
972	0		X180	280
	X33		X180	285
	L23		X180	290
	X34		X180	295
	N0	0	X180	300
98	980	0	X180	305
980	0		X180	310
	X45		X180	315
	981	0	X180	320
981	982	0	X180	325
982	0		X180	330
	X33		X180	335
	L10		X180	340
	X34		X180	345
	N2	0	X180	350
93	0		X180	355
	99		X180	360
	910	0	X180	365
99	990	0	X180	370
990	0		X180	375
	X43		X180	380
	N3		X180	385
	X44		X180	390
	N0		X180	395
	X45		X180	400
	991	0	X180	405

	991	992	0	X180 410
	992	0		X180 415
		X33		X180 420
		L8		X180 425
		X34		X180 430
		N0	0	X180 435
	910	995	0	X180 440
	995	0		X180 445
		X45		X180 450
		996	0	X180 455
	996	997	0	X180 460
	997	0		X180 465
		X33		X180 470
		L10		X180 475
		X34		X180 480
		N30	0	X180 485
FLOW DIAGRAM FOR J77	X181	0		X181 000
		90		X181 010
		91		X181 020
		92		X181 030
		93	0	X181 040
	90	905	0	X181 050
	905	0		X181 060
		X41		X181 070
		N1		X181 080
		X43		X181 090
		N0		X181 100
		X46		X181 110
		N2	0	X181 120
	91	915	0	X181 130
	915	0		X181 140
		X41		X181 150
		N2		X181 160
		X43		X181 170
		N7		X181 180
		X45		X181 190
		N4		X181 200
		X46		X181 210
		N3	0	X181 220
	92	925	0	X181 230
	925	0		X181 240
		X41		X181 250
		N3		X181 260
		X43		X181 270
		N7		X181 280
		X45		X181 290
		N2		X181 300
		X46		X181 310
		N4	0	X181 320
	93	935	0	X181 330
	935	0		X181 340
		X41		X181 350
		N4		X181 360
		X43		X181 370

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                                          N0                       X181 380
                                          X46                      X181 390
                                          N0     0                 X181 400
ROUTINE J77                       X182    90     0                 X182 000
                                  90      0                        X182 010
                                          X41                      X182 020
                                          91     0                 X182 030
                                  91      92     0                 X182 040
                                  92      0                        X182 050
                                          X33                      X182 055
                                          L10                      X182 060
                                          X34                      X182 070
                                          N77    0                 X182 080
LIST OF COMPILED ROUTINES         X196    0                        X196 000
WITH DSCNS.                               X101                     X196 010
                                          X102                     X196 020
                                          X104   0                 X196 030
                                  X197    0                        X197 000
                                          X20                      X197 010
                                          X24    0                 X197 020
                                  X198    90     0                 X198 000
                                  90      0                        X198 010
                                          X20                      X198 020
                                          U134                     X198 030
                                          X24                      X198 040
                                          U140   0                 X198 050
DESCRIBABLE N-LIST                X199    0                        X199 000
                                          N0                       X199 010
                                          N1                       X199 020
                                          N2                       X199 030
                                          N3                       X199 040
                                          N4                       X199 050
                                          N5                       X199 060
                                          N6                       X199 070
                                          N7                       X199 080
                                          N8                       X199 090
                                          N9     0                 X199 100
KICKOFF                         5         T1                       T1   000
                                                                     002793



                                                                     002793
```

Appendix B

PROGRAM LISTING OF AN INFORMATION-ANNEXING SCHEME

The listing in this Appendix is for an annexing routine, capable of annexing to memory the contents of sets of sentences of the kinds considered in Part III.

```
                                          2 A                      10
                                          2 M                     100
                                          2 N                     100
                                          2 X                     200
                                          2 Y                     200
                                          5
5306M0. PREPARE LIST (0) FOR                M0    40H0               M000010
3073  M1. OUTPUT (0) IS VALUE                     10X99              M000020
3075  (1) IS FUNCTION                               J62              M000030
3076     X99= ... IS THE                            J75              M000040
3077     VALUE OF ...                               J50              M000050
3078PUT FUNCTION IN W0                            40H0               M000060
3080                                                J70              M000070
3081                                              40H0               M000080
3083IF VALUE IS SYMBOL                              J60              M000090
3084FIND IT, AND DO 90                            70J7               M000095
3086                                                J60              M000100
3087                                              30H0               M000110
3091                                              70          90     M000120
3093                                                J60              M000130
3094                                              52H0        90     M000140
3089BRING IN FUNCTION                       90    11W0               M000150
3097  AND EXIT                                      J6        J30    M000160
5307ASSIGN (0) AS VALUE OF THE (1)          M1      J42              M001010
3090                                                J21              M001020
3098                                              11W1               M001025
3100                                              40H0
3102                                                M20              M001026
3103SIMPLIFY (0)                                    M21              M001027
3104                                              40H0
3106                                                M20              M001028
3107                                              20W1               M001029
3109                                                J71
3110                                                J71
3111                                        91    11W1               M001030
3114                                                J83              M001040
3118                                              7090               M001050
3120                                              30H0               M001060
3122                                                J90              M001070
3123                                                J136             M001080
3124                                              60W2               M001090
3129                                                910              M001110
3130                                              11W1               M001140
3132                                                J60              M001150
3133                                                J68              M001160
3134                                              11W2               M001170
3136                                              20W0        91     M001180
3116                                        90    11W1               M001190
3139                                                J82              M001195
3140                                                910              M001210
3141                                              11W1               M001230
3143                                                J71       J32    M001240
3127ASSIGN 1W0                              910   11W0               M001250
3145  AS VALUE OF J81(1W1) OF (0).                11W1               M001260
3147                                                J81              M001270
3148                                              40H0               M001280
3150IF J81(1W1)=X98                               10X98              M001290
3152  PUT 1W0 AT END OF (0)                         J2               M001300
3153                                              70J11              M001310
```

```
3155                                                   30H0     J65     M001320
5308                                            M2      M10             M002010
3128                                                   40H0
3117                                                    J150
3115                                                    J4              M002015
3158                                                   1090             M002020
3160                                                    J100            M002025
3161                                                    J154
3162                                                    J155
3163                                                   10X105           M002026
3165                                                    M4      M7      M002027
3112                                            90      M0              M002030
3166                                                    M1              M002040
3167                                                    J154            M002045
3168                                                    J155            M002046
3169                                                   10X105           M002050
3171                                                    J150    J4      M002060
5309DELETE X98 TO X97 OF (0)                    M3     10X97            M003010
3172                                                   10X98    M26     M003020
5310M4. CREATE DESCRIPTION                      M4      J90             M004010
3174   OF EXPRESSION (0)                                J90             M04 020
3175OUTPUT (0) IS DESCRIPTION                           J52             M04 030
3176                                                   11W1             M004032
3178                                                   10X100           M004034
3180                                                    J65             M004036
31811W0 IS OUTPUT LIST                                 11W1             M04 040
31831W1 IS GENERATOR LIST                              11W2             M04 050
31851W2 IS EXPRESSION                                   J64             M04 060
3186                                                   11W1             M04 070
3190                                                   1090             M04 080
3192                                                    J100            M04 090
3193                                                   11W0     J32     M004100
31881W2 IS CURRENT EXPRESSION                   90     40H0             M004 0110
3196                                                    J152
3197                                                   60W2
3199FIND ITS TYPE                                       M5              M04 120
3200ADD IT TO END OF VALUE LIST                        40H0             M04 130
3202   FOR TYPE                                        11W0             M04 140
3204                                                    J6              M04 150
3205                                                   11W2             M04 160
3207                                                    J6              M04 170
3208                                                    J13             M04 180
3209                                                   11W2             M04 190
3211PUT COMPONENTS ON GEN. LIST                        11W1             M004200
3213                                                    M6      J4      M004210
5311M5. FIND TYPE OF EXPRESSION (0)             M5      J0              M005010
3189                                                   12H0             M05 015
3215OUTPUT (0) IS TYPE                                  J60             M05 020
3216                                                   30H0             M05 030
3220                                                   70       90      M005050
3222                                                    J60             M05 050
3223                                                   30H0             M05 060
3228                                                   7091             M05 070
3230                                                   10X85    0       M05 080
3218                                            90     30H0             M005090
3233                                                   10X86    0       M005095
3226                                            91     10X45    0       M05 100
3237                                            92     30H0     91      M005110
5312M6. PUT COMPONENTS OF (1)                   M6      J52             M006010
3238   OF TYPE (2)                                     11W2             M06 020
```

```
3227ON GENERATOR LIST (0)                  10X45               M06 030
3219NO OUTPUT                                J2                M06 040
3240                                       70          J32     M06 050
3242                                       11W0                M006052
3244                                       10X100              M006054
3246                                         J62               M006056
3247                                       20W0                M006058
3249                                       11W2                M06 060
3251                                       10X85               M06 070
3253                                         J2                M06 080
3256                                       7090                M06 090
3258                                       11W1                M006141
3261                                 96      J60               M006142
3266                                       7092                M006143
3268                                       12H0                M006144
3270                                       11W0                M006145
3272                                         J6                M006146
3273                                         J63       96      M006147
3254                                 90    12W1                M06 150
3276                                 91      J60               M06 160
3278                                       7092                M06 170
3280                                         J60               M006175
3281                                       12H0                M06 180
3283                                       11W0                M06 190
3285                                         J6                M06 200
3286                                         J63       91      M006210
3264                                 92    30H0        J32     M06 230
5313M7. PRINT DESCRIPTION (0)        M7      J40               M007010
3277  SAVE IT IN W0                        60W0                M007020
3265  PRINTS ITS LIST OF DLS               10X86               M002030
3255                                         910               M007040
3288                                       11W0                M007050
3290  PRINT ITS LIST OF LIST               10X85               M007060
3292                                         910               M007070
3293                                       11W0                M007080
3295  PRINT ITS LIST OF SYMBOLS            10X45               M007090
3297                                         910       J30     M007100
3262                                 910   40H0                M007110
3299  PRINT ATTRIBUTE                        J152              M007120
3300                                         J10               M007130
3304                                       7090                M007140
3306  PRINT LIST                             J151              M007150
3302  SPACE                          90      J154      J155    M007160
5316M10. READ LIST OF STATEMENT      M10     J0                M10005
3303                                         J154
3301                                       10W25               M10010
3307  AND STORE AS LIST OF                   M11               M10020
3308  LISTS (0).                           10W30               M10030
3310                                         M11               M10040
3311SET UP OUTPUT LIST                       J90               M10050
3312                                         J50               M10060
3313READ NEXT LINE                   90      J180              M10070
3318                                       7091                M10080
3320SET UP STATEMENT LIST                    J90               M10090
3321                                         J136              M10100
3322SET POINTER TO PSJ 0                   11W25               M10110
3324                                         J124              M10120
3325SET POINTER TO FIRST SUMB                J184              M10130
3326                                       7091                M10135
3328                                       30H0                M10140
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3331                                        92     11W30              M10150
3334                                                J124              M10160
3335MEASURE SYMB                                    J183              M10170
3336                                               30H0               M10180
3338  AND SAVE IT                                  40H0               M10100
3340AND INPUT IT TO H0                              J181              M10190
3341PUT IT AT END OF STATEMENT LIST                 J65               M10200
3342                                               11W25              M10210
3344FIND NEXT SYMB                                  J184              M10220
3345                                               30H0               M10230
3350                                               7093       92      M10240
3316                                        91     30W25              M10250
3353                                               30W30              M10260
3355                                               11W0       J30     M10270
3348                                        93     11W0               M10280
3358                                                J6                M10290
3359                                                J65       90      M10300
5317M11. SET UP D.T. IN (0)                 M11     J50               M11010
3349                                                J90               M11020
3347                                                J124              M11030
3332                                               41W0               M11040
3317                                               21W0       J30     M11050
5326M20. CREATE FIND LIST                   M20     J50               M020010
3314  FROM DESCRIPTION LIST (0)                     J90               M020020
3360  OUTPUT (0) IS FIND LIST.                     40H0               M020030
3362                                               11W0               M020040
3366                                               1090               M020050
3368                                                J100              M020060
3369                                               30H0       J30     M020065
3364                                        90      J64               M020070
3371                                               40H0       0       M020080
5327M21. REDUCE FIND LIST (0)               M21     J41               M021010
3365  OUTPUT (0) IS REDUCED LIST                   40H0               M021020
3374                                                J60               M021030
3375                                               60W0               M021040
3377  FIND NEXT ARGUMENT                           52H0               M021050
3379                                        92     11W0               M021060
3382LOCATE NEXT DETERMINER                          J60               M021070
3386  IF NONE, GO TO 90                            7090               M021080
3388FIND DETERMINER                                52H0               M021090
3390  SAVE IT                                      60W1               M021100
3392DETERMINE FUNCTION                              J10               M021110
3396IF NO VALUE, GO TO 91                          7091               M021120
3398DELETE ARGUMENT FROM LIST                      11W0               M021130
3400                                                J68               M021140
3401REPLACE DETERMINER WITH VALUE                  61W0       92      M021150
3384END OF LIST                             90     30H0               M021160
3404                                               30H0       J31     M021170
3394PROCESS X97 OR QUIT                     91     11W1               M021180
3407                                               10X97              M021190
3409                                                J2                M021200
3410                                               70J31              M021210
3412POINT TO PREDECESSOR OF X97                    11W0               M021220
3414AND PROCESS IT                                  M22               M021230
3418                                               7093               M021240
3420                                               61W0               M021250
3425                                                94        92      M021254
3423                                        94      J0                M021255
3426                                               11W0               M021256
3428                                                M24               M021260
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3429DELETE X98                                 11W0              M021270
3431                                             J60     J68     M021280
3416CREATE OBJECT FOR                   93     40W2              M021300
3433SUBDESCRIPTION                             11W0              M021310
3435COPY PART DESCRIPTION                        M23             M021320
3436                                           20W2              M021330
3438CREATE NEW OBJECT                            J90             M021340
3439                                             J136            M021345
3440                                           40H0              M021350
3442                                           40H0              M021360
3444                                           11W2              M021370
3446                                             J6              M021380
3447PUT IT AT HEAD OF PART DESCRIPT              J64             M021390
3448                                           12W0              M021400
3450                                             J6              M021410
3451PUT IT AT END OF ARG LIST                    J65             M021420
3452                                           11W2              M021430
3454DESCRIBE IT                                  M20             M021440
3455                                             M0              M021450
3456                                             M1              M021460
3457SUBSTITUTE IT FOR ARG                      21W0              M021470
3459                                             94      J32     M021480
5328M22. IDENTIFY LIST MEMBER           M22      J0              M022010
3424                                           12H0              M022015
3417  WITH ARG. LOCATION (0)                     J50             M022020
3415  X97 AT N(0)                                M23             M022030
3395IF IDENTIFIED, OUTPUT                      40H0              M022040
3385(0) IS NAME OF MEMBER,                     11W0              M022050
3461IF NOT IDENTIFIED, NO                      1090              M022060
3463OUTPUT, FIND LIST NOT                        J100            M022070
3464                                             J5              M022072
3465                                           70        J30     M022074
3467                                           30H0              M022076
3469                                           30H0      J30     M022078
3380MUTILATED                           90     60W0              M022080
3472                                             M25             M022090
3476                                           70        91      M022100
3478                                           40H0      J4      M022110
3474                                    91     51W0      J3      M022120
5329M23. COPY DESCRIPTION FROM          M23      J0              M023010
3475  X97 TO X98 OF (0)                 91       J60             M023020
3460  OUTPUT (0) IS COPY                       70J7              M023030
3482                                           12H0              M023040
3484                                           10X97             M023050
3486  TEST IF = X97                              J2              M023060
3487                                           7091              M023070
3489  PUT LOC OF X97 OUT                         J50             M023080
3490  CREATE NAME OF COPY                        J90             M023090
3491                                           40H0              M023100
3493                                           11W0              M023110
3498DO 90 ON CELLS OF (0)                      1090              M023120
3500                                             J100    J30     M023130
3496                                    90     40H0              M023140
3502IF SYMB IS X98, QUIT                       10X98             M023150
3504                                             J2              M023160
3505                                             J5              M023170
3509                                           70        92      M023180
3511                                             J8      J8      M023190
3507IF NOT, ADD TO LIST                 92       J65             M023200
3512                                           40H0      0       M023210
```

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5330DELETE X97 TO X98 OF (0)            M24    10X98              M024010
3506                                           10X97     M26      M024020
5331M25. TEST IF (0) FITS               M25      J51              M025010
3495  DESCRIPTION (1)                   91     11W0               M025020
3515                                           11W1               M025030
3517LOCATE NEXT DETERMINER                       J60              M025040
3518SAVRE LOCATION                             60W1               M025050
3520FIND IT                                    52H0               M025060
3522                                           40H0               M025070
3524                                           10X99              M025080
3526IS IT X99                                    J2               M025090
3530IF SO, TERMINATE TEST                      70        90       M025100
3532FIND VALUE OF (0)                            J10              M025110
3533IF NONE, EXIT WITH -                       70J31              M025120
3535IF SO, SUBSTITUTE IT FOR (0)               20W0      91       M025130
3528COMPARE VALUE WITH VALUE            90     30H0               M025140
3538OF DESCRIPTION                             11W1               M025150
3540                                             J60              M025160
3541                                           70J7               M025170
3543                                           52H0               M025180
3545AND EXIT WITH SIGNAL                         J2      J31      M025190
5332M26 DELETE SECT FROM (0) TO (1)     M26      J52              M026010
3529OF LIT (0), NO OUTPUT.                     11W2               M026020
3473TESTS THAT CN(2)=(0), IF (1)               11W1               M026030
3547NOT ON LIST, DOES NOTHING                    J77              M026040
3548                                           70J32              M026050
3550                                           11W2               M026060
3552                                             J60              M026070
3553                                           12H0               M026080
3555                                           11W0               M026090
3557                                             J2               M026100
3558                                           70J7               M026110
3560                                    90       J68              M026120
3562                                           11W2               M026130
3564                                             J60              M026140
3565                                           70J7               M026150
3567                                           12H0               M026160
3569                                           11W1               M026170
3571                                             J2               M026180
3572                                           7090               M026190
3574                                           30H0      J32      M026200
                                       5         1
5619                                    X113                      X113010
5296                                    A0       0                A000010
3561                                             X113             A000013
3576                                             X99              A000015
3577                                             X31              A000020
3578                                             X20              A000030
3579                                             X105    0        A000040
5297                                    A1       0                A001010
3580                                             X114             A001013
3581                                             X99              A001015
3582                                             X33              A001020
3583                                             X25              A001030
3584                                             X105    0        A001040
5298                                    A2       0                A002010
3585                                             X115             A002013
3586                                             X116             A002015
3587                                             X99              A002017
3588                                             X34              A002020
```

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3589                                                X25               A002030
3590                                                X105    0         A002040
5407                                        N1      1              1  N001010
5530SDSC OF ROUTINE                         X24     90      0         X24 010
3591                                        90      0                 X24 020
3593                                                X32               X24 030
3594                                                X86               X24 040
3595                                                X87               X24 050
3599                                                91      0         X24 060
3597                                        91      0                 X24 070
3600                                                X71     0         X24 080
5547NAME                                    X41     90      0         X41 010
3598                                        90      0                 X41 020
3592                                                X32               X41 030
3601                                                X45     0         X41 040
5577LIST OF AFFECTED CELLS                  X71     90      0         X71 010
3596                                        90      0                 X71 020
3603                                                X32               X71 030
3604                                                X85               X71 040
3605                                                X91               X71 050
3606                                                X72     0         X71 060
5578AFFECTED CELL                           X72     90      0         X72 010
3602                                        90      0                 X72 020
3608                                                X32               X72 030
3609                                                X86               X72 045
3610                                                X87               X72 050
3614                                                91      0         X72 060
3612                                        91      0                 X72 070
3615                                                X41               X72 080
3616                                                X75               X72 090
3617                                                X76     0         X72 100
5581INPUT STATE OF CELL                     X75     90      0         X75 010
3613                                        90      0                 X75 020
3607                                                X32               X75 030
3618                                                X85               X75 040
3619                                                X91               X75 050
3620                                                X45     0         X75 060
5582OUTPUT STATE OF CELL                    X76     90      0         X76 010
3611                                        90      0                 X76 020
3622                                                X32               X76 030
3623                                                X85               X76 040
3624                                                X91               X76 050
3625                                                X45     0         X76 060
5591LIST                                    X85                       X85
5592DESCRIPTION LIST                        X86                       X86
5593ATTRIBUTE                               X87                       X87
5594OBJECT                                  X88                       X88
5595VALUE                                   X89                       X89
5597MEMBER TYPE                             X91                       X91 010
 112                                      5         M2
       3630  3  0
             2  3627
             2  3637
             2  3644

       3627  3  0
             0 X113
             0 X99
             0 X31
             0 X20
```