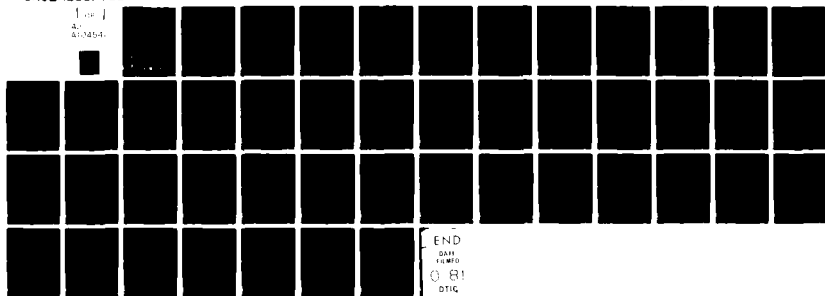


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THE EFFECTS OF THE SYMBOLOGY AND SPATIAL ARRANGEMENT
OF SOFTWARE SPECIFICATIONS IN A DEBUGGING TASK

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THE EFFECTS OF THE SYMBOLOGY AND SPATIAL ARRANGEMENT
OF SOFTWARE SPECIFICATIONS IN A DEBUGGING TASK

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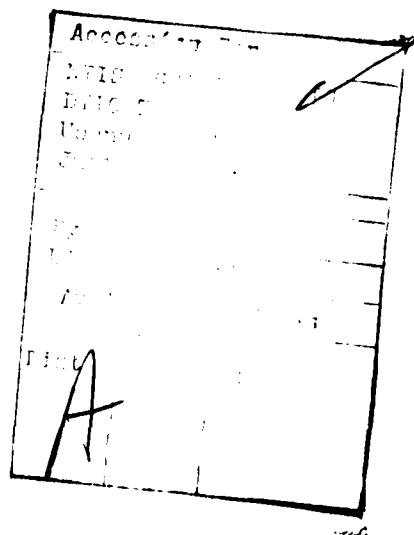
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes the third in a series of experiments to evaluate the effects of the format of software specifications on programmer performance. The current experiment examined performance on a debugging task. Thirty-six professional programmers were presented with specifications for each of three modular-sized programs. Nine different specification formats were prepared for each program. These formats varied along two dimensions: type of symbology and spatial arrangement. The type of symbology included natural		

language, constrained language (PDL), and ideograms (flowchart symbols). The spatial arrangement included sequential (vertical flow), branching (flowchart), and hierarchical (tree-like).

The participants compared correct specifications to error-seeded program listings. Their task was to locate the several errors per program and to correct the errors using a text editor. The program output was checked automatically and a message informed the participants whether the output was correct or incorrect. The participants were asked to continue debugging until all errors had been located and corrected. The difficulty of the debugging task was measured by the time required to detect and correct the errors and by the number of submissions required for a correct run.

Substantial differences in the time to debug were associated with the type of symbology. Debugging from natural language specifications took longer than debugging from either constrained language or ideograms. This result is consistent with the results from the previous experiments in which natural language specifications were associated with longer response times in a comprehension task and in a coding task.

The overall effect of spatial arrangement was not pronounced in this experiment. However, individual combinations of symbology and spatial arrangement appeared to be differentially useful in the debugging task. Four formats resulted in a high level of performance. These were the sequential and branching constrained language versions and the branching and hierarchical ideograms.



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INTRODUCTION

Large-scale software projects necessarily involve communications among individuals with diverse skills and experience. Software design, coding, and maintenance are commonly performed by a variety of individuals at different points in time. The efficiency with which software-related tasks are performed depends critically on the documentation supplied from the previous phases of the software life cycle. The purpose of this research is to empirically evaluate a number of different documentation formats. Previous experiments in this series have examined the effects of these formats on comprehension and coding performance. The current experiment investigated performance in a debugging task.

Empirical Evaluation of Software Documentation Formats

There has been a continued interest in the relative value of flowcharts, program design language (PDL), and English prose as software development and documentation tools. An early empirical assessment of the value of flowcharts in programming was reported by Shneiderman, Mayer, McKay and Heller (1977). They performed a series of experiments on the composition, comprehension, debugging and modification of programs. For the

composition task, the participants were asked to write a program; some were also asked to produce a flowchart in addition to the program. For the comprehension, debugging, and modification tasks, all participants were given a program listing while some were given a flowchart as an additional aid. Shneiderman et al. found no significant differences in any of their experiments between groups that did and did not use flowcharts.

In another study, Ramsey, Atwood, and Van Doren (1978) compared the effectiveness of flowcharts to that of a program design language. In one experiment, programmers expressed a design in either a flowchart or PDL. In a second experiment, programmers produced code from designs expressed in either a flowchart or PDL. Ramsey et al. found no difference in performance on the tasks in either experiment. However, the designs expressed in a PDL were judged to be of superior quality in that they included greater algorithmic detail, more modularization, and less abbreviation of variable names than those expressed as flowcharts.

Brooke and Duncan (1980) compared flowcharts and sequential instructions as debugging tools. They concluded that flowcharts were useful for tracing execution sequences in a program but were not helpful in conceptualizing relationships among non-contiguous segments of the program.

Although studies performed on software-related tasks have not been especially favorable to flowcharts, experiments performed in other areas of information presentation have demonstrated an advantage for flowcharts over alternative presentation formats including prose descriptions, short sentences, and decision tables (Wright and Reid, 1973; Blaiwes, 1974; Kammann, 1975). Kammann, for example, presented participants with a set of telephone dialing problems. The dialing instructions were presented in the form of a prose description or a flowchart. Fewer errors were made with the flowchart. [For a review of the non-software research, see Sheppard, Kruesi, and Curtis (1981)].

An experiment recently reported by Miller (1981) raises some doubts about the advisability of natural language as either a development or documentation tool. Miller asked non-programmers to write procedures for solving problems that were representative of common computer applications. Careful analysis of the protocols led Miller to conclude that even minor increases in the complexity of problems led to marked decreases in the quality of the solutions. Further, the high degree of contextual referencing found in the solutions provided doubts about the feasibility of adequate natural language specifications. Miller suggests that we would improve the quality of programs "...with tools that structure the problem and the implementation processes" (p.212).

Characteristics of Software Documentation

The studies described above have involved an analysis of documentation formats currently in use. A comparison of any two or more formats, such as PDL and flowcharts, may yield useful information about the relative value of these formats. This comparison does not, however, allow us to isolate the source of any observed differences since documentation formats vary along more than one dimension.

In general, there are two primary dimensions for categorizing how available documentation aids configure the information they present to programmers (Jones, 1979). The first dimension is the type of symbology in which information is presented. The second dimension is the spatial arrangement of this information. PDL, for example, uses constrained language as the symbology presented in a sequential spatial arrangement. Flowcharts use ideogram symbols presented in a branching spatial arrangement. Thus, any differences observed in the effectiveness of PDL and flowcharts may be due to the differences in the symbols, in the spatial arrangement or to an interaction of these two dimensions.

Our approach to evaluating various forms of documentation is to investigate the separate and combined effects of these two dimensions. Specifically, we have factorially combined three types of symbols with three spatial arrangements to produce nine different formats.

Type of Symbology. The symbology dimension includes natural language, constrained language, and ideograms. Documentation in the form of natural language is frequently found embedded in the source code as either global or in-line comments. Constrained language, which is embodied in a Program Design Language (PDL), is more succinct than natural language, using strictly defined keywords to describe arguments or predicates. Ideograms are frequently found in flowcharts and HIPO charts (Bohl, 1971; Katzen, 1976). A standard set of ideograms has come to represent processes or entities within a program.

Spatial Arrangement. The spatial arrangement of information in documentation is a second dimension along which documentation techniques can be categorized. In the current experiment, this dimension is represented by a sequential, a branching, and a hierarchical arrangement. A sequential arrangement is typical of narrative description, program listings and PDL while a branching arrangement is typical of flowcharts. A hierarchical arrangement is not generally used for individual module specifications but, rather, at the system level to present a visual display of the relationship among modules.

This report describes the third in a series of experiments to investigate the effects of the type of symbology and the spatial arrangement. For all experiments, the three types of

symbology (natural language, constrained language, and ideograms) are factorially combined with the three spatial arrangements to produce nine different documentation formats. The first experiment, which is described in Sheppard, Kruesi, and Curtis (1981), investigated comprehension performance. The second experiment examined the influence of these dimensions on the ability of programmers to translate the specifications into code (Sheppard & Kruesi, 1981). This experiment examined the effects of these dimensions on performance in a debugging task. The results of the first two experiments are described briefly in the following sections.

Effects of Symbology and Spatial Arrangement on Comprehension

In the first experiment, seventy-two professional programmers were presented with specifications for each of three modular-sized computer programs. The participants answered a series of comprehension questions for each program using only the specifications. The questions were presented interactively on a CRT and consisted of three different types. For forward-tracing questions, the participants were given the values for a set of conditions in the program. Their task was to trace through the specifications and find the first statement executed under those conditions. For backward-tracing questions, they were required to locate a

input-output questions, they were given input data and were asked to determine the value of particular variables at a later point in the program.

Both forward and backward-tracing questions were answered more quickly from specifications presented in constrained language or ideograms than in natural language. On the average, forward-tracing questions were answered most quickly from a branching arrangement and backward-tracing questions were answered more quickly from the branching and hierarchical arrangements. An examination of the individual formats revealed that the sequential constrained language (normal PDL), the branching constrained language and the branching ideogram (normal flowchart) versions were associated with very quick responses for both types of questions. For the input-output questions, no significant differences were found as a function of the type of symbology or the spatial arrangement. At the conclusion of the experimental session, participants were asked to list the type of symbology and the spatial arrangement they most preferred. Constrained language was the most preferred symbology and the branching spatial arrangement was the most preferred arrangement.

Effects of Symbology and Spatial Arrangement in a Coding Task

In the second experiment (Sheppard & Kruesi, 1981), thirty-six professional programmers were presented with

specifications and partially completed code for the same three programs. The participants constructed a section of code at the middle of each program. These sections contained about fifteen lines and included the most complex decision structures present in the programs. The code was completed using a text editor, and the participants were asked to submit the program for compilation and execution. If the program did not run correctly, they were asked to correct the errors and submit it again.

Substantial differences in coding time were associated with the type of symbology. The natural language was considerably more difficult to code from than the constrained language or ideograms. An examination of the error data showed that these differences were due both to errors in coding the control flow and errors related to assignment statements and variables. The effect of the spatial arrangement was not as great as the effect of symbology. Although not statistically significant, the branching arrangement appeared to be superior to the sequential and hierarchical arrangements in minimizing control-flow errors. A comparison of the individual formats revealed that the constrained language presented in a sequential or in a branching arrangement resulted in the highest level of performance.

Again, constrained language was preferred by more participants than ideograms or natural language, and branching was the preferred spatial arrangement.

Debugging

The current experiment compared the same nine formats in a debugging task. The participants were given specifications for each of three modular-sized programs (about 50 lines of code). They compared these specifications to error-seeded program listings. Their task was to locate and correct the errors using a text editor. Performance was measured by the time required to detect and correct the errors and by the number of submissions required for a correct run.

METHOD

Participants

Thirty-six professional programmers from two different locations participated in this experiment. All were General Electric employees. The participants averaged 6.2 years of professional programming experience (S.D. = 4.9) and had used an average of 5 programming languages (S.D. = 2.3).

Independent Variables

The experiment was designed to study the effects of three independent variables: the type of symbology, the spatial arrangement of the information, and the type of program.

Program type. In our previous research (Sheppard, Curtis, Milliman & Love, 1979) significant differences in programmer performance were often associated with differences among programs. Three programs of varying types were chosen for use in this experiment. (These three programs were used in the first two experiments as well.) A program which calculated the trajectory of a rocket was chosen as representative of an engineering algorithm. An inventory system for a grocery

distribution center represented the class of programs that manipulate data bases. A third program combined these two types of applications. This program interrogated a data base for information concerning the traffic pattern at an airport and simulated future needs using a queuing algorithm.

These three programs were based on algorithms contained in Barrodale, Roberts, and Ehle (1971). The algorithms were modified to incorporate only the constructs of sequence, structured iteration, and structured selection. They were then coded in Fortran and verified for correctness. Each of the resulting programs contained approximately 50 lines of executable code. In addition a short algorithm (18 lines) to find the largest of three integers was used as a practice program.

The practice program was modified to contain one error. The experimental programs each contained three errors. The errors were selected from among errors made in the coding experiment, which had used the same experimental materials. The errors included both transfer of control and assignment/variable errors but did not include syntax errors. Listings of the incorrect programs are shown in Appendix A. Handwritten corrections are included for the reader's benefit.

Type of Symbology. The statements from each program were translated into detailed specifications. Three types of symbology were used: natural language, constrained language, and ideograms. A consistent set of rules was used to map assignment, selection, and iteration statements across the three types of symbology.

Spatial Arrangements. Three spatial arrangements were used to represent the program structure: sequential, branching, and hierarchical. These three arrangements differed in the representation of control flow and nesting levels. In the sequential arrangement, both the control flow and the levels of nesting were represented vertically. In the branching arrangement, the flow of control was represented vertically while nesting levels were represented horizontally. Finally, in the hierarchical arrangement, the flow of control was represented horizontally while nesting levels were represented vertically.

Each of the three types of symbology was presented in the three spatial arrangements, resulting in nine specification formats for each program. Examples of the nine forms for the rocket trajectory program may be found in the first technical report of this series (Sheppard, Kruesi, and Curtis, 1980).

Procedure

Prior to the experiment, the participants were given a 20-minute training session in which they were shown each spatial arrangement and each type of symbology. The experimenter described the control flow for each arrangement using a sorting program as an example; this program was not seen in the actual experiment. The procedure for using the text editor to correct the programs was also explained in detail during the training session.

Experimental sessions were conducted at CRT terminals on a VAX 11/780. All coding was done in Fortran. The participants were first given a practice program containing a single error. Identical listings of the code appeared on the CRT screen and on a paper printout. The participants were told there was one error and were asked to correct the code, using the text editor. When satisfied that the program would perform correctly, a participant exited from the editor and activated a command file to compile and run the program. If the compilation was unsuccessful, a compiler message appeared on the screen directly below the line or lines containing the error. If the program compiled without errors, it was automatically executed with test data, and the output from the program appeared on the screen with one of the following messages: "OUTPUT IS CORRECT" or "OUTPUT IS INCORRECT." In the latter case, the participant was asked to keep trying until the program was correct.

Following the practice program, the three experimental programs were presented. For each program, the participants received a correct version of the specifications; these were contained on a single piece of paper. In addition, they received identical listings of the error-seeded code on the CRT screen and on a paper printout. They also received a data dictionary listing each variable, a natural language description of it, and its data type.

The participants were told that there were several errors in each experimental program and that all of them were located in the center section of the code, labeled the "COMPUTATION" section (See Appendix A). They were instructed to compare the specifications to the code, locate the errors and correct them. If a participant tried running the program without making any changes, the program compiled successfully but produced the message that the output was incorrect.

An interactive data collection system prompted the participant throughout the experimental procedure. The system recorded each change made to a program. An interval timer, accurate to the nearest second, recorded the time for each action. When a participant required more than one editing session to locate and correct the errors, the experimental system recorded exits from the editor, any compilation errors,

and the incorrect outputs generated. From these data, the time to debug the programs was calculated by summing the times from the individual editing sessions; time for compiling and running the programs was not included.

On the average, the participants spent approximately 16 minutes on each experimental program. They were required to continue working on a program until all errors had been located and corrected. They were allowed to take breaks between programs.

Following the experiment, the participants completed a questionnaire about their previous programming experience. The information requested included number of years of professional experience, number of programming languages known, and whether they had previously worked with algorithms of the types used in the experiment. The participants were also asked about their preferences for type of symbology and spatial arrangement.

Design

The three types of symbology (natural language, constrained language, and ideograms) were factorially combined with the three spatial arrangements (sequential, branching, and hierarchical) to produce nine specification formats. These nine formats were constructed for each of the three programs, resulting in a total of 27 conditions.

Participants received a set of specifications for each program. Across the three programs, they saw each type of symbology and each spatial arrangement. The first participant, for example, saw the rocket trajectory program presented in sequential natural language, the inventory control program in hierarchical constrained language, and the airport traffic program in branching ideograms. The participants were assigned to conditions according to the procedures outlined in Winer (1971). [See also Kirk (1968)]. Each of the 27 conditions was used once within a set of nine participants. For this 3^3 randomized block design, a minimum of 36 participants is required to assess all interactions and main effects. Across the 36 participants, each program, symbology, and arrangement was presented first, second, and third an equal number of times.

RESULTS

Debugging Task

The participants required an average of 16 minutes to debug a program. This represents the amount of time spent studying the program and using the text editor (i.e., the total time spent at the terminal less the time for compiling, linking and running).

There were no differences among the times to debug the three programs. The rocket program required an average of 15.7 minutes, the airport program 15.8 minutes and the inventory program 16.0 minutes.

There was a significant difference among the types of symbology. The natural language versions required 18.7 minutes as compared to 14.5 minutes for the constrained language and 14.2 minutes for the ideograms (Table 1). This difference was verified by an analysis of variance ($p < .05$) (See Table 2). For this analysis, a logarithmic transformation was carried out on the times to attenuate the influence of extreme scores and to produce a more normal distribution (Kirk, 1968).

Table 1. Time to Debug (Minutes)

SPATIAL ARRANGEMENT	TYPE OF SYMBOLOGY			TOTAL
	NATURAL LANGUAGE	CONSTRAINED LANGUAGE	IDEOGRAMS	
SEQUENTIAL	19.8	12.1	18.2	16.7
BRANCHING	18.2	14.6	14.6	15.8
HIERARCHICAL	18.1	16.7	9.8	14.9
TOTAL	18.7	14.5	14.2	15.8

Note: Individual cell means represent 12 participants.

Table 2. Summary of ANOVA
Time to Debug

SOURCE	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>	<u>p</u>
TOTAL	107	3.61			
BETWEEN PARTICIPANTS AND REPLICATIONS					
REPLICATIONS	3	.15			
PARTICIPANTS WITHIN REPLICATIONS	32	.02			
WITHIN PARTICIPANTS AND REPLICATIONS					
PROGRAM (P)	2	.01	.01	.20	
SYMBOLOGY (S)	2	.37	.18	3.60	.05
ARRANGEMENT (A)	2	.03	.01	.20	
P × S	4	.17	.04	.80	
P × A	4	.07	.02	.40	
S × A	4	.23	.06	1.20	
P × S × A	8	.24	.03	.60	
RESIDUAL	46	2.32	.05		

The effect of the spatial arrangement was not significant, and there were no significant interactions.

Number of Submissions

All of the errors in the programs were successfully located and corrected by all of the participants. An average of 2.0 submissions were required to run the programs correctly. As with the debugging times, there were no differences in number of submissions across programs.

Table 3 presents the number of submissions broken down by type of symbology and spatial arrangement. Unlike the debugging times, there were no significant differences for type of symbology. An analysis of variance indicated no significant main effects or interactions.

Preferences for Type of Symbology and Spatial Arrangement

Across the three programs, each participant received specifications in each type of symbology and in each spatial arrangement. The questionnaire indicated which three of the nine versions they had experienced during the experiment. They were asked to state which of the three versions they preferred. Table 4 shows these preferences.

**Table 3. Number of Submissions
Required to Complete Task**

SPATIAL ARRANGEMENT	TYPE OF SYMBOLOGY			TOTAL
	NATURAL LANGUAGE	CONSTRAINED LANGUAGE	IDEOGRAMS	
SEQUENTIAL	1.8	1.9	2.5	2.1
BRANCHING	2.2	1.9	1.8	2.0
HIERARCHICAL	1.6	1.8	1.3	1.8
TOTAL	1.9	1.9	2.2	2.0

Note: Individual cell means represent 12 participants.

**Table 4. Percent of Preferences
for Symbology and Spatial Arrangement**

SPATIAL ARRANGEMENT	TYPE OF SYMBOLOGY			TOTAL
	NATURAL LANGUAGE	CONSTRAINED LANGUAGE	IDEOGRAMS	
SEQUENTIAL	9	9	6	24
BRANCHING	15	18	25	58
HIERARCHICAL	9	6	3	18
TOTAL	33	33	34	100

The three types of symbology were preferred equally often. In terms of the spatial arrangement, branching was the most preferred, sequential was intermediate and hierarchical was the least preferred.

Experiential Factors

The questionnaire also asked for the number of years the participants had programmed professionally and the number of programming languages they had used. No correlation was found between years of experience and time to debug. Number of languages and debugging time were correlated $-.26$ ($p < .06$), indicating that programmers who had experience with a greater number of programming languages performed the tasks in this experiment more quickly.

DISCUSSION

The same three programs were used in the current experiment as in the comprehension and coding experiments. In the earlier experiments, significant differences in performance were associated with these three programs. Specifically, the airport-scheduling program was considerably more difficult than the inventory-control or rocket-trajectory programs. In the current experiment, no differences were observed in performance across the three programs. One possible explanation for this equality is that the relative difficulty of the errors exactly compensated for the inherent difficulty of the programs. Thus, the errors seeded in the airport-scheduling program may have been easier errors to detect and correct than those seeded in the remaining two programs. This "balancing" explanation appears unlikely since the types of errors (transfer of control and assignment/variable) and their physical locations were similar across programs.

Another possible explanation is that debugging a program from detailed specifications which are known to be correct does not require as much knowledge of the intricacies of the algorithm as does comprehending the specifications or coding from the specifications. Thus, the inherent difficulty of the algorithm may be less important in this type of a debugging task than in the earlier comprehension and coding tasks.

Differences in the type of symbology followed the pattern established in the first two experiments: the natural language versions resulted in significantly longer response times than the constrained language and ideogram versions. Had the natural language been written casually, one could hypothesize that it was incomplete and misleading. However, the natural language was developed very precisely. Assignment, selection and iteration statements were translated from the original code into the three types of symbology according to a rigid set of rules to insure that the natural language specifications were as complete and precise as the constrained language and ideograms. It is reasonable to conclude, therefore, that the differences were due to real differences among the types of symbology rather than to an experimental artifact. When combined with identical conclusions from the two previous experiments in this series, this result presents strong evidence that detailed program specifications should be presented in a more succinct symbology than natural language.

No pronounced effect for spatial arrangement appeared in this experiment. This result agrees with results from the coding experiment, where time to code and debug showed no significant effect due to spatial arrangement.

The comprehension experiment differed from this experiment and the coding experiment in that there were differences among the spatial arrangements. Forward-tracing questions were

answered most quickly from the branching arrangement, and backward-tracing questions were answered more quickly from the branching and hierarchical arrangements. Response times for input-output questions did not vary significantly as a function of spatial arrangement. One explanation for the differing results among the experiments is that programming activities relating to control flow (such as tracing) benefit from the more pictorial branching and hierarchical arrangements, while other activities are not affected by the spatial arrangement. This explanation is supported by the Brooke and Duncan results presented in the Introduction.

One interesting result found in all three experiments was that the sequential and branching constrained language versions were consistently associated with low response times and a small number of errors. In cases where another version was associated with a lower response time (e.g. the hierarchical ideogram version in this experiment), differences among the two constrained language versions and the other version were not statistically significant. Of the software specifications currently in use (i.e. natural language, PDL, and flowcharts), it appears that PDL results in faster and less error-prone performance than natural language specifications; flowcharts appear in between. Sequential PDL has the additional advantage of being easy to produce at a terminal and easy to read automatically.

The participants in this experiment had no distinct preference for any of the three types of symbology. This result was surprising because in the previous two experiments constrained language was preferred, ideograms were second and natural language was least preferred. As in the previous experiments, the branching arrangement was the most preferred, the sequential arrangement was intermediate and the hierarchical arrangement was preferred least.

Diversity of experience, in terms of the number of languages used, was a better predictor of performance than years of experience. This result replicates results from the comprehension experiment and our previous research (Sheppard, Milliman & Curtis, 1979) and highlights the importance of ensuring that programmers have an opportunity to gain broad applications experience as part of their professional development.

This experiment provides additional evidence that specification format can have a significant effect on the performance of programmers on software-related tasks. A debugging task was carried out more quickly from specifications presented in a succinct symbology. An examination of the individual cell means revealed four formats that led to a high level of performance. These were the constrained language presented in a sequential and in a branching arrangement and the ideograms presented in a branching and in a hierarchical arrangement. Natural language led to consistently poor performance, regardless of the spatial arrangement.

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APPENDIX A

ERROR-SEEDED PROGRAM LISTINGS

PRACTICE PROGRAM

Find the largest of three integers, I, J, & K.

```
5      OPEN(UNIT=1, NAME='PRAC. DAT', TYPE='OLD')
10     READ (1,60) I, J, K
15     IF (I .GT. J) GO TO 20
20     IF (J .GT. K) GO TO 10
25     LARGE = K
30     GO TO 40
35     10 J = LARGE
40     GO TO 40
45     20 IF (I .GT. K) GO TO 30
50     LARGE = K
55     GO TO 40
60     30 LARGE = I
65     40 PRINT 70, LARGE
70     CLOSE(UNIT=1)
75     60 FORMAT (3I3)
80     70 FORMAT (10X, 'LARGEST =   I3)
85     STOP
90     END
```

Handwritten annotations:
A circle around the line `J = LARGE` with an arrow pointing to the text `LARGE = J` written next to it.

ROCKET PROGRAM

```

5      INTEGER MAXT, TIME, FLAG
10     REAL VACCEL, VVELOC, VDIST, HACCEL, HVELOC, HDIST,
15     1  ANGLE, TILT, GRAV, MASS, FUEL, FORCE
20 C
25 C
30 C  INITIALIZATION
35 C
40 C
45     VACCEL = 0.
50     VVELOC = 0.
55     VDIST = 0.
60     HACCEL = 0.
65     HVELOC = 0.
70     HDIST = 0.
75     ANGLE = 0.
80     TILT = 0.3491
85     GRAV = 32.
90     MASS = 10000.
95     FUEL = 50.
100    FORCE = 400000.
105    MAXT = 200
110    FLAG = 0
115    TIME = 1
120 C
125 C
130 C  COMPUTATION:
135 C
140 C
145    10  IF (FLAG .NE. 0) GO TO 60
150        IF (TIME .GE. 100) GO TO 20
155        MASS = MASS - FUEL
160        IF (TIME .NE. 11) GO TO 30
165        ANGLE = TILT
170        GO TO 30
175    20  IF (TIME .NE. 100) GO TO 30
180        FORCE = 0.0
185    30  VACCEL = ((FORCE * COS(ANGLE))/MASS) - GRAV
190        VVELOC = VVELOC + VACCEL
195        VDIST = VDIST + VVELOC
200        HACCEL = (FORCE * SIN(ANGLE))/MASS
205        HVELOC = HVELOC + HACCEL
210        HDIST = HDIST + HVELOC
215        TIME = TIME + 1
220        IF (VDIST .GT. 0) GO TO 40
225        FLAG = 1
230    40  IF (TIME .LE. MAXT) GO TO 10
235        FLAG = 2

```

```

240 C
245 C
250 C   TERMINATION:
255 C
260 C
265   60   TIME = TIME - 1
270       IF (VDIST .GT. 0) GO TO 80
275   70   WRITE(6,3000) TIME, HDIST
280       GO TO 90
285   80   WRITE(6,4000) TIME, MASS, VACCEL, VVELOC, VDIST,
290       1   HACCEL, HVELOC, HDIST
295   90   CONTINUE
300       STOP
305 3000   FORMAT(5X, 'ROCKET HIT GROUND AT TIME=', I5, 'SECONDS'
310       1   5X, 'HORIZONTAL DIST = ', F11.2)
315 4000   FORMAT(5X, 'ROCKET STILL ALOFT AT TIME = ', I5,
320       1   ' SECONDS'/5X, 'MASS = ', F22.2/
325       2   5X, 'VERTICAL ACCEL = ', F12.2/
330       3   5X, 'VERTICAL VELOC = ', F12.2/
335       4   5X, 'VERTICAL DIST = ', F13.2/
340       5   5X, 'HORIZONTAL ACCEL = ', F10.2/
345       6   5X, 'HORIZONTAL VELOC = ', F10.2/
350       7   5X, 'HORIZONTAL DIST = ', F11.2)
355       END

```

INVENTORY PROGRAM

```

5      INTEGER DELIV, FLAG, ITEM, ONHAND, ORDER, RELEV,
10     1 REORD, STORE, UNFILL
15     REAL GTOTAL, PRICE, TOTAL
20 C
25 C
30 C   INITIALIZATION:
35 C
40 C
45     OPEN (UNIT=1, NAME='ORDERS.DAT', TYPE='OLD')
50     OPEN (UNIT=2, NAME='PURCHAS.DAT', TYPE='OLD',
55     1 ACCESS='SEQUENTIAL')
60 C
65 C
70 C   COMPUTATION:
75 C
80 C
85     10 READ (1, 100, END=80) STORE
90     GTOTAL = 0
95     WRITE (6, 110) STORE
100    20 READ (1, 120) ITEM, ORDER
105    IF (ITEM .EQ. 0) GO TO 70
110    CALL FETCH2 (ITEM, PRICE, ONHAND, RELEV, REORD, FLAG)
115    IF (ONHAND .LE. ORDER) GO TO 30
120    DELIV = ORDER
125    ONHAND = ONHAND - ORDER
130    UNFILL = 0
135    30 DELIV = ONHAND
140    ONHAND = ONHAND - ORDER
145    UNFILL = ORDER - DELIV
150    40 IF (ONHAND .GT. RELEV) GO TO 50
155    IF (FLAG .EQ. 0) FLAG = 1
160    50 TOTAL = DELIV * PRICE
165    GTOTAL = GTOTAL + TOTAL
170    IF (FLAG .NE. 1) GO TO 60
175    WRITE (2, 130) ITEM, REORD
180    FLAG = 2
185    60 WRITE (6, 140) ITEM, PRICE, ORDER, DELIV, UNFILL, TOTAL
190    CALL UPDATE (ITEM, ONHAND, FLAG)
195    GO TO 20
200    70 WRITE (6, 150) GTOTAL
205    GO TO 10

```

Handwritten annotations: A circle around the '0' in line 130, with an arrow pointing to line 135. A circle around the 'ONHAND - ORDER' in line 140, with an arrow pointing to line 145. A circle around the '+' in line 160, with an arrow pointing to line 165.

```

210 C
215 C
220 C   TERMINATION:
225 C
230 C
235     80  CLOSE (UNIT=1)
240         CLOSE (UNIT=2)
245         STOP
250     100  FORMAT (I2)
255     110  FORMAT (//, 5X, 'INVOICE FOR STORE NUMBER: ', I3)
260     120  FORMAT (I3, I5)
265     130  FORMAT (2I7)
270     140  FORMAT (5X, 'ITEM NUMBER: ', I11 / 5X,
275         1 'PRICE PER ITEM: $', F5.2 / 5X, 'NUMBER ORDERED: ',
280         2 I8 / 5X, 'NUMBER DELIVERED: ', I6 / 5X,
285         3 'UNABLE TO DELIVER: ', I5 / 5X, 'TOTAL PRICE: $', F8.2)
290     150  FORMAT (/, 5X, 'TOTAL PRICE FOR ALL ITEMS: $', F10.2)
295         END

```

AIRPORT PROGRAM

```

5      INTEGER  ARRQUE, BEGINT, CLEAR, DEPGUE, ENDT, MAXWT
10     INTEGER  NUMARR, NUMDEP, TIME, TOLWT
15     REAL     ARPROB, DPPROB, RAND1, RAND2, RSEED
20 C
25 C
30 C      INITIALIZATION:
35 C
40 C
45         RSEED = 0.0
50         NUMARR = 0
55         NUMDEP = 0
60         CALL FETCH1(BEGINT, ARPROB, DPPROB, ARRQUE, DEPGUE,
65 1      CLEAR, TOLWT)
70         TIME = BEGINT
75         ENDT = BEGINT + 20
80 C
85 C
90 C      COMPUTATION:
95 C
100 C
105 10     IF (TIME .GT. ENDT) GO TO 60
110         RAND1 = RND(RSEED)
115         IF (RAND1 .GT. ARPROB) GO TO 20
120         ARRQUE = ARRQUE + 1
125 20     RAND2 = RND(RSEED)
130         IF (RAND2 .GT. DPPROB) GO TO 30
135         DEPGUE = DEPGUE + 1
140 30     CONTINUE
145         IF (CLEAR .GT. TIME) GO TO 50
150         IF (ARRQUE .GT. 0) GO TO 40
155         ARRQUE = ARRQUE - 1
160         NUMARR = NUMARR + 1
165         CLEAR = TIME + 3
170         GO TO 50
175 40     IF (DEPGUE .LE. 0) GO TO 50
180         DEPGUE = DEPGUE + 1
185         NUMDEP = NUMDEP + 1
190         CLEAR = TIME + 2
195 50     TIME = TIME + 1
200         GO TO 10
205 60     MAXWT = ENDT - CLEAR + (ARRQUE*3) + (DEPGUE*2)

```

Handwritten annotations:

- A circle with "LE" is drawn around the "LE" in line 175.
- A circle with "GT" is drawn around the "GT" in line 150.
- A circle with "ENDT" is drawn around the "ENDT" in line 190.
- A circle with "CLEAR - ENDT" is drawn around the expression in line 205.
- A circle with "ENDT - CLEAR" is drawn around the expression in line 205.

```

210 C
215 C
220 C   TERMINATION:
225 C
230 C
235       WRITE (6, 100) ENDT, ARRGUE, NUMARR, DEPGUE,
240       1  NUMDEP, MAXWT
245       IF (MAXWT .GT. TOLWT) GO TO 70
250       WRITE (6, 120)
255       GO TO 80
260       70  WRITE (6, 110)
265       80  CONTINUE
270       STOP
275       100  FORMAT (6X, 'ENDING TIME FOR SIMULATION: ', I5, /,
280       1  12X, 'ARRIVAL QUEUE: ', I5/11X, 'NUMBER ARRIVED: ', I5/
285       1  10X, 'DEPARTURE QUEUE: ', I5/10X, 'NUMBER DEPARTED: ',
290       1  I5/ 13X, 'MAXIMUM WAIT: ', I5, ' MINUTES')
295       110  FORMAT (5X, 'OPEN ANOTHER RUNWAY')
300       120  FORMAT (5X, 'ANOTHER RUNWAY NOT NEEDED')
305       END

```

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