AN ANALYSIS OF FIRST IMPRESSION IN THE READING OF ELECTRICAL SCHEMATIC DIAGRAMS

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ABSTRACT

The initial impression of electronic troubleshooters of schematic diagrams was studied in a series of two experiments. In one experiment the time available to the subjects to view the information was restricted to 12 seconds and in the second experiment the subjects could look at the material as often and as long as they wished. The characteristics of the first element redrawn were: (1) the same elements were consistently selected, (2) the element was chunked with other elements, (3) the element was in a branch instead of a loop, (4) the element was along the exterior of the element and (5) the element was active more often than would be expected from the number of active elements in the circuit.

Introduction

The overall purpose of this experiment was to study the mental encoding mechanisms used by troubleshooters of varying skill levels. Such mechanisms are viewed as the means by which technicians cognitively combine and summarize information essential to their problem solving, or electronics troubleshooting, responsibilities. Prior to dealing directly with the details of the experiment, a few preliminary comments on the relationship of these encoding mechanisms to problem solving and troubleshooting will be presented.

In problem solving, the individual starts with given conditions and utilizes a solution route to work toward a goal. It is characteristic of the problem solving situation that of these three elements, the least visible and most difficult to study is the solution route. This study; therefore, considered one of the important aspects of the solution process, that of how information relating to the problem is perceptually structured for introduction into that process.

The actual means by which this standardized, or encoded, information is transformed in the problem solving solution route process are not well understood. Earlier, it was suggested that elementary processes are arranged in a series of steps, similar to a computer program (Newell & Simon, 1972, and Fischhoff, 1975). Each grouping of the elementary processes, or program, represents a separate thought structure. Different thought structures can then be combined to form a solution route for a given problem. During the problem solving process, information in standardized form is input into the problem solver's cognitive facilities, where it is operated on by these thought structures.

In electronics troubleshooting, the technician primarily uses visual inputs in gathering information, although inputs from touch, smell and hearing are also employed. Visual inputs come from the observation of control settings, dial readings, signal paths and circuit components. Some of these inputs can be perceptually difficult to interpret, due to the invisible nature of electricity. The perceptual structures seen by the technician represent the information inputs used by him in constructing his psychological model of the troubleshooting problem. Those perceptual structures are made up of information which has been encoded or chunked into various standardized formats. Such structures are then compatible with the cognitive operations used later in the troubleshooting process. For a fuller discussion, see Burroughs (1979).

Scope

Three tasks will make up the body

of the experiment. In the perception task, technicians will reconstruct a circuit diagram while it remains visually accessible. The technician's successive glances at the reference circuit diagram will be used as an index of chunking. The assumption here is that under the conditions of the experiment, the technician will encode only one chunk per glance, while reconstructing the diagram (Chase & Simon, 1973).

In the memory task, the technicians will be asked to reconstruct a circuit diagram from memory after a brief exposure to it. The timing or clustering in recall will be used to segment the output into chunks. This task will be useful in establishing a measure of chunking capacity. Here, the technicians will be obliged to encode as much information from the schematic as they can accommodate in one 12 second visual exposure to it.

The impression task will be a subset of both the perception and memory tasks, in that the technician's initial element, chunked or otherwise, in both of these tasks will be of interest. Impression is defined here to be the most cognitively dominant aspects of the visual display. Thus, it constitutes the subject's initial description of a visual stimulus (Hyman, 1976). Hence, the first element encoded from each of these tasks will be analyzed in an effort to identify cognitively outstanding features for each circuit. The details of the methodology for this experiment are described below.

Methodology

Fifteen technicians, equally divided with regard to the three level (lowest rating), five level and seven level (highest rating) Air Force skill ratings were used as subjects. Ten circuit diagrams from technical manuals and design handbooks were used to generate the stimuli.

Schematic diagrams were used in the experiment rather than the actual circuitry, since schematics are the common mode of presentation for circuit information, and they are routinely used and depended upon by technicians engaged in troubleshooting work. Moreover, the analysis and reasoning processes in troubleshooting are more apt to be done using a schematic than using the actual circuitry.

The subjects reconstructed all circuit schematics using only a sheet of paper and a felt tip pen. Timing to one second for each circuit schematic reconstruction was maintained, and all reconstruction performances were videotaped.

In each trial for the perception task, two sheets of paper, 8 1/2" x 11", were used, along with a felt tip pen and a brown manila folder. The schematic to be used for a given trial was drawn on one of the sheets of paper and taped to the inside of the manila folder. The other sheet of paper, which was blank, was taped to the front of the folder. The technician was instructed that when the signal was given, he was to open the folder, look at the schematic, close the folder and redraw as much of the schematic as could be remembered onto the blank sheet of paper, as quickly and as accurately as possible. He was advised that he could glance at the reference schematic as often as was required to complete the task. The folder remained flat on the work surface at all times, and the technician simply flipped back and forth between the two sheets of paper. In this way, only one sheet of paper was visible at any given time, thereby requiring the subject to mentally encode the relevant circuit information.

The procedure used in the memory task was similar to that used in the perception task. Here, however, the technician was able to view the reference schematic for only twelve seconds. The technician then redrew as much of the reference circuit as could be remembered on the blank sheet of paper in front of him, taking as much time as necessary.

For the impression task, the initial element encoded in each of the above two tasks was recorded and compared across all of the trials. These comparisons were made in order to highlight the most prominent encoding features of the schematic diagrams. The initial element aspects which were considered were the element itself, whether or not it was chunked, if the element was part of a branch or part of a loop, if it was an internal or an external element, if it was active or passive and its spatial location. Each of these characteristics are analyzed separately below.

Analysis of First Element Preference

First element preferences for each of the ten schematics were determined by tabulating the frequencies with which different circuit elements appeared first in the redrawn circuits. First

Table 1 First Element Preferences by Schematic Number

Schematic Number	MEMORY TASK First Elements (Number in parenthesis indicates the number of times a particular element was picked first)	PERCEPTION TASK First Elements (Number in parenthesis indicates the number of times a particular element was picked first)	Total Number of Circuit Elements
1	6 (8), 1 (6), 17 (1)	6 (7), 1 (6), 2 (2)	18
2	5 (8), 1 (5), 20 (1), 19 (1)	5 (8), 1 (5), 20 (1), 3 (1)	20
3	1 (7), 5 (7), 10 (1)	1 (8), 5 (7)	11
4	1 (7), 16 (4), 12 (2), 7 (1), 24 (1)	1 (7), 16 (5), 12 (1), 7 (1), 14 (1)	24
5	1 (10), 2 (5)	1 (9), 2 (5), 4 (1)	31
6	1 (10), 15 (2), 3 (1), 10 (1), 20 (1)	1 (6), 15 (4), 7 (4), 3 (1)	21
7	7 (8), 2 (5), 3 (1), 8 (1)	1 (6), 1 (4), 3 (3), 8 (1), 17 (1)	17
8	1 (9), 11 (3), 4 (2), 2 (1)	1 (9), 11 (2), 4 (1), 2 (1), 3 (1)	21
9	1 (15)	1 (13), 7 (1), 14 (1)	16
10	1 (11), 5 (2), 7 (1), 15 (1)	1 (11), 5 (3), 6 (1)	16

element preferences are summarized in Table 1. The numbers used to identify different circuit components were assigned after the experiment was completed, and they were not available to the technicians during any phase of the memory or perception tasks.

The first point to be noted from Table 1 is that there was perfect agreement between the memory and perception tasks with regard to the element most often redrawn first. Indeed, on the second most preferred initial element, there was agreement on eight of the ten schematics, with the only differences being on schematic seven and schematic nine. The remaining choices are, for the most part, one time selections. Using a simple binomial distribution calculation, it can be rejected with 0.9999 confidence in favor of the alternative hypothesis of a patterned selection.

Analysis of First Element Chunking

The information on first element chunking is summarized below for the memory and perception tasks. The data reflect a clear disposition on the part of the technicians to initially absorb information in chunks, rather than element by element separately. Hypothesizing a 4 to 1 chunking ratio for first elements, one can perform a goodness of fit test. The 4 to 1 chunking ratio implies that 4 out of every 5 first elements are chunked. Under the null hypothesis, the chi square value for the perception task is 7.04 and for the memory task, the chi square value is 0.81. Hence, for the perception task, there is no question whether the hypothesized chunking ratio applies, while for the memory task, the null hypothesis cannot be rejected with any significant degree of confidence.

Table 2 First element chunking, indicating the extent to which the initial elements were chunked by technicians during the memory and perception tasks.

	Memory Task	Perception Task
Number of First Elements Chunked......	127	107
Number of First Elements Not Chunked..	23	43
Total Number of First Elements........	150	150

Of the two tasks, there is more inclination on the part of the technician to chunk information in the memory task than in the perception task, as discussed earlier. With perception, he had free access to the schematic, and therefore he could encode as little as one element per glance. This difference between the two tasks very likely accounts for the discrepancy between the observed and the hypothesized chunking ratio in the perception task.

Analysis of Branch Versus Loop First Elements

In courses on circuit theory, there are two principal methods of circuit analysis which are taught. One method applies to closed loops and is called loop analysis, while the other method applies primarily to branches and is called node analysis. Therefore, the circuit geometry applicable to a particular element determines how that element would be viewed from a circuit analysis standpoint.

The ten schematics used in the study contained a total of 195 elements. Of these, 91 were branch elements and 104 were loop elements. Since there were only a total of 150 first elements in each of the tasks, the actual numbers of both types of elements will be changed from a base of 195 to a base of 150 for purposes of analysis. These new expected values, along with the observed values, are shown in Table 3 below.

Employing a chi square goodness of fit test under the null hypothesis that chance factors alone dictate whether a loop element or a branch element will be chosen first, the memory chi square value is computed as 18.35. These correspond to P values which are both less than 0.005 (chi square: 7.88, 1).

Table 3 Branch versus loop first elements, indicating the extent to which branch or loop initial elements were selected by technicians during the memory and perception tasks.

	MEMORY TASK	PERCEPTION TASK
Observed/Expected Loop Elements	53/85	59/85
Observed/Expected Branch Elements	97/65	91/65

The observed frequencies suggest that for the circuits employed in this study, branch elements are preferred or selected first on a 2 to 1 ratio over loop elements. Employing a goodness of fit test under this hypothesis results in a memory chi square value of 0.27 and a perception chi square value of 2.43. Hence the null hypothesis cannot be rejected with any significant degree of confidence.

Analysis of Interior Versus Exterior First Elements

The impression analysis along this dimension is similar to that just undertaken with regard to branch and loop elements. Exterior elements are those which are located on the perimeter of a circuit, while interior elements are those which are not exterior elements. The observed and expected frequencies are shown in Table 4. As in the previous section, the expected frequencies have been based on a total of 150 elements.

Under the null hypothesis that chance factors alone determine whether an interior or an exterior element is selected first, the memory chi value is 14.62, as is the perception chi square value. For one degree of freedom, the null hypothesis may be rejected with greater than 0.995 confidence.

Table 4 Interior versus exterior first elements, indicating the extent to which exterior or interior initial elements were selected by technicians during the memory and perception tasks.

	MEMORY TASK	PERCEPTION TASK
Observed/Expected Interior Elements...	16/36	16/36
Observed/Expected Exterior Elements..	134/114	134/114

Analysis of Active Versus Passive First Elements

Active elements contribute energy to a circuit, while passive elements either store or dissipate circuit energy. The observed and expected frequencies for these two categories are shown in Table 5. As in the previous two sections, the expected frequencies have been based on a total of 150 elements.

Table 5 Active versus passive first elements, indicating the extent to which active or passive initial elements were selected by technicians during the memory and perception tasks.

	MEMORY TASK	PERCEPTION TASK
Observed/Expected Active Elements....	47/8	46/8
Observed/Expected Passive Elements...	103/142	104/142

Under the null hypothesis that chance factors alone determine whether an active or a passive element is selected first, the memory chi square value is 200.84 and the perception chi square value is 190.67. For one degree of freedom, the null hypothesis may be rejected with greater than 0.995 confidence.

The observed frequencies suggest that for the circuits employed in this study, passive elements are selected first over active elements at about a 2 to 1 ratio. Employing a goodness of fit test under this hypothesis results in a memory chi square value of 0.27 and a perception chi square value of 0.48. Hence the null hypothesis cannot be rejected with any significant degree of confidence.

Analysis of First Element Spatial Locations

For the purpose of identifying an element's spatial location, the pages on which the schematics were presented to the technicians were divided up into four quadrants. The identification of the quadrants was accomplished using the upper left hand quadrant as 1 and reading down the columns. These quadrant designations were not available to technicians during the experiment. The summarized data with regard to spatial preference is shown in Table 6.

Table 6 Spatial locations of first elements, indicating the quadrant in which initial elements selected by technicians were located.

	1	2	3	4
Memory Task	118	13	14	5
Perception Task	116	13	15	6
Actual Number Per Quadrant Adjusted to Base 150	31	38	55	26

Under the null hypothesis that chance alone determines the likelihood of a first element coming from a given quadrant, the memory chi square value is 315.91 and the perception chi square value is 301.66. For three degrees of freedom, the null hypothesis may be rejected with greater than 0.995 confidence.

The observed frequencies suggest that for the circuits employed in this study, first elements are selected from the first quadrant over the other three quadrants at about a 4 to 1 ratio. Employing a goodness of fit test under this hypothesis results in a memory chi square value of 0.16 and a perception chi square value of 0.66. Hence, the null hypothesis cannot be rejected with any significant degree of confidence.

Impression Task Summary

The previous sections suggest that it is possible to categorize a technician's initial impression of an electrical schematic diagram. For a given schematic, there is general agreement as to which element will receive his attention first. Occasionally, either of two elements will serve as the consensus initial focal point for a given circuit. Technicians have a tendency to group or chunk other circuit information with the initial element rather than isolating on it alone. The initial element will typically be a branch element along the exterior of the circuit. Also, the first element picked will generally be in the top left quadrant of the drawing. While the first element is almost always a passive element, technicians choose active elements more often than their numbers would predict. Technicians apparently find it relevant to focus initially on active elements if they are also exterior branch elements in the upper left part of the schematic.

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