3 On the Analysis of Intuitive Design Processes

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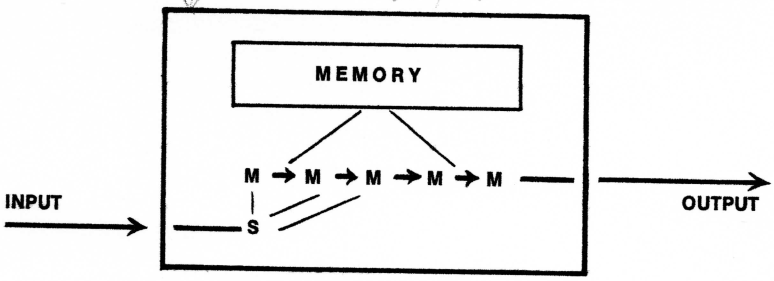
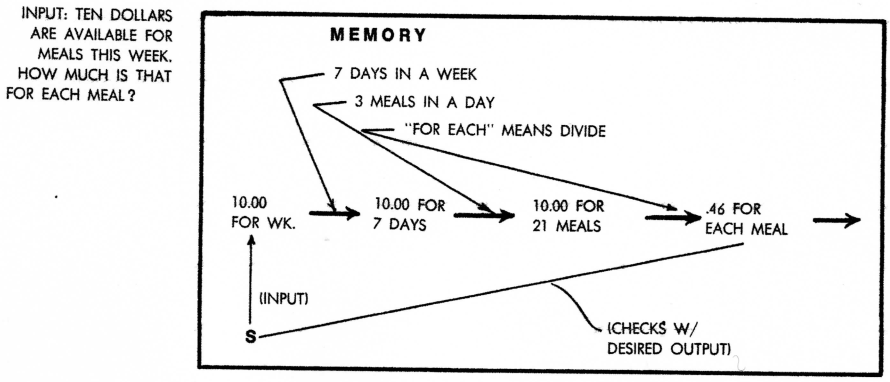
Intuitive design as carried out by industrial designers, architects, and engineers concerned with the physical environment can be analyzed as a problem-solving task within the framework of an information-processing model of cognition. The theory of such studies and technique for making them are presented, along with an example of the typical data collected. Two major findings about design processes were uncovered by these studies. First, there is a clear correspondence between the kinds of constraints considered by the designer and the types of design representations used—words, numbers, flow diagrams, plans, sections, and perspectives. And second, in terms of problem identification it has been found that designers relying on direct retrieval from past experience or memory are far superior to those who rely on external cues for generating problem constraints. Finally, certain weaknesses and limitations of the efforts made thus far are discussed.

The information-processing model of human problem-solving developed in psychology has been used to gain insight into how people carry out such mental activities as playing games, particularly chess, how they solve geometry and word-algebra problems, and develop proofs in logic. This paper describes some of the results from ongoing studies that apply the information-processing model of cognition to the realm of environmental design.

This paper concerns intuitive design processes. By this is meant the procedures that designers have implicitly derived from their own design experience through case studies in school or from professional experience. If a design methodology can be defined as a formal and explicit procedure taught to a designer, intuitive design can be considered the antithesis of a design methodology.

It is important to understand intuitive design processes for several reasons. As methodologies are proposed, some means for evaluating them against current procedures is required. Just because a methodology is explicit does not mean it is superior to intuition. Little is known about what makes a superior designer or a superior design process. By comparing processes and what they produce we may learn the unique capabilities of the superior





1. Model of a problem solver

2. An information-processing model of problem solving

designer. It may be possible to teach these processes to future designers. Also, the development of computer-aided design systems requires a clear understanding of the operations and processes that a designer uses.

This paper has four parts: First, a technique for analyzing design using psychological problem-solving theory is offered, followed by an example of typical results gained thus far, some of the findings about design uncovered by these studies, and finally, some of the shortcomings and weaknesses of the present efforts.

Background

The psychological premises under which these studies were made have evolved mainly from European psychology, especially Selz.[1] In the United States the approach evolved independently out of information theory as applied to human behavior by Fitts and Miller.[2] My approach builds upon the work of Newell, Shaw, Simon, Hunt, and many others using information-processing concepts to study concept formation and problem-solving.[3] The best descriptions of the psychological model may be found in Miller, Galenter, and Pribram, and in Reitman.[4]

The model that is proposed is shown in Figure 1 and may be described as follows. It is asserted that thinking is information-processing. Man's nervous system seems to process complex information sequentially. Memory is interpreted as allowing independent recall of past inputs and recall of past intermediate processing states. Cognition, or thinking, is a resultant of information from the environment and from memory being brought together in unique sequence.

In this light, a problem situation is unique because a specific response is not directly available. At issue is the selection of appropriate inputs from memory and from the environment and the search for their possibly unique combinatorial sequence. The determinant of a processing sequence has been called a strategy. Little is known concerning the basis of strategies, though it seems that previous experience, the limits of short-term memory, and the organizational structure of memory are strong influences.[5] Processing can be modeled as a series of transformations generating a sequence of information states.

A simple example is shown in Figure 2. As can be seen, information is sequentially combined in a particular order. Notice also that at least two processing sequences could be used to gain the same answer; division could have been carried out after each new input. Out of all combinations of this information, only a very few lead to solutions, and those leading to a solution vary in their efficiency. This example shows that initial inputs give some information concerning the makeup of a response. Some information designating what a solution should be is part of most problems.[6] This type of information is normally called a goal. By studying such a process to determine what information is used to organize a processing sequence and by comparing one person's process with other person's, much can be learned about the different ways in which people solve problems.

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1. For a history, see Adriaan D. de Groot, *Thought and Choice in Chess*, or George Humphrey, *Thinking, An Introduction to its Experimental Literature.* De Groot was Selz's student.
2. George Miller, *Language and Communication.*
3. Allen Newell and Herbert A. Simon, "GPS: A Program that Simulates Human Thought," in Edward A. Feigenbaum and Julian Feldman, eds., *Computers and Thought,* pp. 279–296. Earl B. Hunt, *Concept Learning: An Information-Processing Problem.* See also Carl I. Hovland, "Computer Simulation of Thinking."
4. George A. Miller, Eugene Galenter, and Karl Pribram, *Plans and the Structure of Behavior.* Walter R. Reitman, *Cognition and Thought.*
5. Jerome S. Bruner, Jacqueline J. Goodnow, and George A. Austin, *A Study of Thinking.*
6. For an elaboration, see Walter R. Reitman, "Heuristic Design Procedures, Open Constraints, and the Structure of Ill-defined Problems," in Maynard W. Shelly and Glenn L. Bryan, eds., *Human Judgments and Optimality,* pp. 282–315.

Most studies of problem-solving involve giving a subject *S* a complex task and recording his information-expressing behavior in the form of a protocol. The traditional means to encourage *S* to express information hɛ been to instruct him to "think out loud." But what is the correspondence this situation between internal processing and external expressions? Thɛ instruction to "think out loud" is sometimes mistakenly interpreted. It do not mean that the analysis of a protocol simply requires an experimenter to determine what *S* thinks he is doing when he solves a problem. Rather, the analysis of a problem-solving protocol assumes that verbalization anc our case sketches are simply behavior, to be studied like any other behavi The expressed behavior requires certain capabilities and specific informa which must have been available to *S*. The capabilities and necessary prec dents are studied to determine the sequential organization of processing.

For example, if a room is laid out by a designer who then says, "the lightin is poor," we can assume that certain relationships between the elements the drawing were considered and from these was made an inference abou lighting. If this person later accepts another design that is the same as the earlier one in all respects except that the window is moved, then it may be assumed that his evaluation of lighting included, among other things; the location of the window. By examining other situations in which he consid lighting it may be possible to find out in detail how this particular designe deals with lighting considerations. By analyzing in a similar manner all co siderations made by *S*, significant insight into his problem-solving proces possible.

One task of *E* in making such a study is to maximize *S*'s external expressic of information. The studies of design at Carnegie-Mellon University utilize *S*'s sketches, his talking while solving the problem, and his looking at obje in the room or at his drawings. Eye movements, better recording of the generation of sketches and facial expression will hopefully be included in future studies by utilizing a video tape recorder.

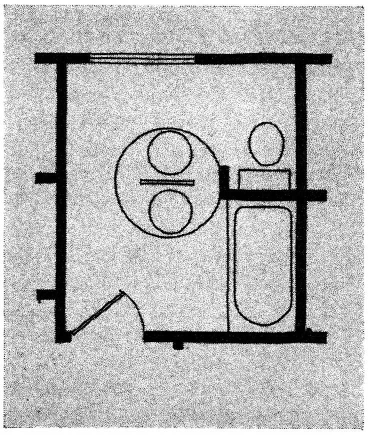
To summarize, the approach elaborated here for analyzing intuitive desigr follows five steps:
1. The collection of an accurate and detailed protocol.
2. The analysis of the protocol to determine the information expressed by the sequence of its expression, and the processes that must have been use to generate each piece of information.
3. The organization of the resulting information to allow an overall descrip- tion of the transformations from state to state.
4. The determination of consistencies within the problem-solving process.
5. The incorporation of the consistencies into general hypotheses concern ing the basic organization of design problem-solving.[7]

An Example Protocol and Analysis

The first studies of design were made by using simple and relatively well-controlled tasks, for example, the design of tableware. As experience in analyzing protocols was gained, more complex tasks were given. In relatio to significant design problems, the tasks are still quite simple. The protoco collected vary greatly in complexity. Complexity does not imply sophistica-tion. A protocol may be complex because it does not express the informati used in processing. On the other hand, some of the most original informa-tion-processing thus far recorded has been very clearly expressed. The ex-ample task presented is the most complex yet attempted, but the example protocol is one of the simpler ones collected from this task.

The task is shown in Figure 3. *S* was asked to redesign a bathroom in a mass-marketed house. The problem was open-ended in that much more information was required to solve the problem than was given. *S* had to use his own experience and could also ask *E* for specific facts. *S* was also given a print of the plan view of the existing design.

7. The procedures of protocol analysis presented here are based on the techniques developed by Allen Newell, *On the Analysis of Human Problem-Solving Protocols.*



analyze problem (A, B, ⇒)

3. Statement of experiment 2

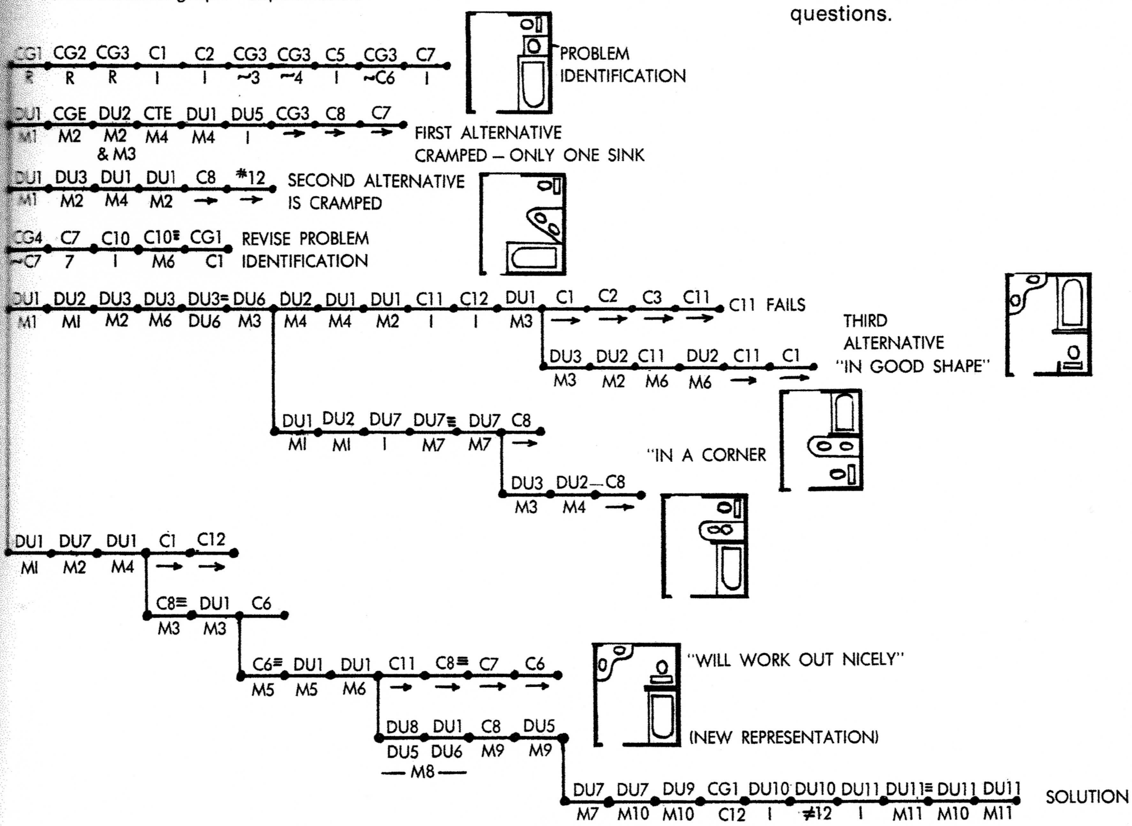
Experiment Number Two

The accompanying plan and photograph represent an existing bathroom plan for one model of a home sold by Pearson Developers in California. This model of house has not sold well. The sales personnel have heard prospective buyers remark on the poor design of the bath. Several comments are remembered: "that sink wastes space"; "I was hoping to find a more luxurious bath." You are hired to remodel the existing baths and propose changes for all future ones. (these should be the same)

The house is the cheapest model of a group of models selling between 23,000 and 35,000. It is two stories with a ranch style exterior. The bath is at the end of a hall serving two bedrooms and guests.

You are to come up with a total design concept. The developer is willing to spend more for the new design—up to fifty dollars. For all other questions, Mr. Eastman will serve as client. He will answer other questions.

4. Problem behavior graph—experiment 2



A protocol collected from this task is contained in Appendix A. The *S* it was collected from is a thirty-year-old industrial designer with approximately seven years' professional experience, who returned to school for advanced study and was considered creative by his colleagues. The protocol gave his verbal and graphic behavior. The series of sketches are reproductions of those made by *S*, exclusively with a plan view until the very end of the protocol. He made tracings of each of the original fixtures to use as templates for sketching. The graphics presented show the sequential development of the sketches and the movements of the templates. Some of his trials represented considerations of only a second or so. Each sketch or alteration made in relation to his verbal expressions was noted in the protocol text.

The first step in protocol analysis is determination of the information used, its sequence of use, and the operations applied at each state to produce a new state. Ascertaining the information used requires going through all the data collected in the protocol, identifying each piece of information expressed about the problem, and also determining the probable source of that information.

In making such an analysis it has been found useful to look initially for four kinds of information: (1) physical elements which are manipulated (design units), (2) desired relationships between elements and the desired attributes of elements (we call these constraints), and (3) the manipulations made on a design to fulfill the relationships or attributes. Clues to the source of each piece of information are also looked for. They may be *S*'s memory, his perception of the current design, information from the client, or deductions from other information. The notation describing the results of this analysis is shown in the right column of the protocol in the Appendix, opposite the verbal protocol on the left.

Upon completion of this part of the analysis, the sequential organization of the whole protocol should begin to emerge. Where or how was each piece of information gained, how was it used, and what did it produce in the way of new information? These questions should indicate a sequence of processing.[8] The analysis should also allow a complete tabulation of the information used to generate the solution in terms of elements and their desired relations or attributes, and the manipulations carried out on them. For the protocol described, this tabulation is shown in Table 1.

Changes in this *S*'s design can be explained by this information and an appropriate process. Some people have been surprised that a designer's efforts of forty minutes can be tied to so little information. But this is not always the case. It seems to be a matter of the distribution of effort. Another *S* who was given this problem dealt with over three times as much information but generated fewer schemes and considered fewer combinatorial relations.

The relatively small amount of information considered by this designer defined a small solution space. By counting the number of alternatives considered for each dimension of the design, this *S*'s protocol suggested a search space of 2×10^4 discrete alternatives. As a comparison, de Groot estimates 10^{12} move alternatives considered by the master chess player in a twenty-move game.[9] Other design protocols have had search spaces of up to 10^9 combinations considered in a fifty-minute period. Thus it seems evident that the protocol presented here deals with a rather small search space that was fairly thoroughly explored.

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8. The derivation of processing determinants can only regress to levels of processing where cognitive processes can be behaviorally expressed. Beyond this point inputs must be considered as independent variables. Even above this point, inputs with few clues as to their precedents are considered independent variables. Information-retrieval processes are treated in this way in the presented study. For example, see operations 25, 43, and 80 in the protocol analysis presented in the Appendix.
9. Adriaan D. de Groot, "Perception and Memory versus Thought," in Benjamin Kleinmuntz, ed., *Problem Solving: Research, Method, and Theory*, pp. 19–50.

It has been generally found in protocol analyses that the processing at any particular moment is influenced by prior processing, by what information is brought to bear at the moment being considered, and by what operations are available for operating on the current information. It has been found useful to show these influences graphically in what is called a Problem Behavior Graph (PBG). The PBG shown in Figure 4 is simply the concise expression of the previously described analysis and taxonomy. Each node represents an information state. Each line represents a transformation involving specific information and the operations used (both of which are noted). The PBG is coded according to the taxonomy given in Table 1. The PBG is read from left to right, then down. Reiterations of part of the design process show up as branches in the processing sequence. Abandoned lines of thought clearly show through.

Some Results of the Protocol Analysis

The last step of protocol analysis is the determination of the general processing rules implicit within the PBG. In other words, what operations always follow others? What consistencies are expressed that suggest specific processing strategies? To give an indication of the types of answers thus far gained, the major consistencies found in the presented protocol follow.

This *S*, and all others, began design by developing a clearer definition of the problem. He generated operational rules for testing design alternatives that would later be developed, for example, the constraint that the toilet should not be seen by a person using the counter. The field of vision was defined by a 180° field parallel to, but two feet in front of, the bathroom sink. He only commented on a need for privacy, but when designing, this was the operational rule that was applied. Another example was the definition of "no wasted space." The operational definition consisted of a rule "minor areas of clear rectangular floor space must have more than about 45 percent of their perimeter adjacent to the major space." Such constraints were primarily expressed before any form solutions were generated, though new ones were generated throughout design, as was shown in Table 1.

This *S* gained operational constraints by comparing the complaints expressed in the original problem statement—that the bath was "not luxurious," and "wasted space"—to situations in the existing design that could have evoked these comments. He implicitly viewed the problem as one of error correction. This is in contrast to other *S*'s who ignored the complaints and retrieved directly from memory the qualities thought to produce "a good bathroom." Always, the initial task was to retrieve from memory operational tests that would give direction to how the present design should be changed.

Little is known about the organization of memory and the retrieval mechanisms that operate on it. But one approach to the problem was consistently expressed in all protocols. Instead of generating abstract relationships and attributes, then deriving the appropriate object to be considered, the *S*'s always generated a design element and then determined its qualities. This sequence suggests that we may easily think of a kitchen and then define the relationships and attributes of it, but it may be structurally more difficult to think of the relationships and attributes without utilizing the conventional concept. Memory organization would be the delimiting factor. The evidence suggested here is supported by psychological evidence generated both by Kusysgyn and Paivio and by Deese.[10]

used in interacting w/ CAD & other comp. programs.

The pieces of information that are received, perceived, or retrieved are related during processing to produce a new information state. Each such transformation requires an operation. Four types of operations found were categorized:

1. Logical, including all arithmetic and verbal logic.

10. I. Kusysgyn and A. Paivio, "Transition Probability, Word Order, and Noun Abstractions in the Learning of Adjective-noun Paired Associates," and James Deese, *The Structure of Associations in Language and Thought.*

2. Corroboration and possibly expansion of information from one source by gaining similar information from another source.
3, Application of a manipulation or constraint to the current information state, producing a new form alternative or a test result.
4. Inductive association of a manipulation or sequence of manipulations with a constraint.

An example of the fourth operation was the constraint for visual privacy, directly evoking the creation of a partition. In contrast, the position of the mirror was automatically evoked, or at least there was no evidence of intervening processing. This type of operation well fits the concept of a search heuristic. It also corresponds to Newell, Shaw, and Simon's "table of connections," and to what Minsky calls "heuristic connections."[11] These four operations are those used for analyzing the earlier protocol.

More specific understanding has been gained in studying the manipulative aspect of design. One significant set of rules becomes evident when the sequence in which elements were manipulated and the sequence of manipulations that were made were looked at. Table 2 shows all sequences of design units treated and the corresponding manipulations. These were taken directly from the PBG.

First, it was clear that two different design strategies were involved. In the first strategy the design units were treated in an order called in computer jargon a "stack." Like a deck of cards, a sequence was taken from the top, then replaced in the reverse sequence. In the protocol the order was to work first with counter, then toilet, then tub; then the reverse of these, tub, toilet, and counter. These elements were manipulated in a trial-and-error process, which closely approximated a breadth-first search. By breadth-first is meant a search where all trials of one element are made until all tests relevant to the locating of the element are passed. Then the next element is located. After each trial a test was applied to see if it was satisfactory.

The strategy for dealing with all other elements of the design was quite different. No trial and error was involved. They were directly placed in accordance with search heuristics. Heuristics were used to locate the mirror, medicine cabinet, and towel racks.

Of the operations used, the third type where an *S* manipulated or applied a constraint to Design Units could be systematized. As can be seen in Table 2, the sequence approximated M1, M2, M3, M4, or "remove the first designated unit," "rotate previous unit 90°," if still unsatisfactory "move it along the same wall to another corner," then repeat these operations on other walls. If all manipulations failed, the next unit was tried. If the design passed all constraint tests while the unit was in a given location, the prior unit was manipulated.

After a general solution was found, Phase Two involved aesthetic touches such as aligning edges, considering symmetry, and locating towel racks. While all earlier work had been done in plan, these operations were done in perspective.

The sum of these manipulation rules, along with those determining the other three types of operations, constitutes a design strategy. They were *S*'s total means for dealing with this problem. Whether such rules represent how this *S* generally treats this type of problem is not known. It would be valuable to apply a series of similar problems at widely spaced intervals to a single designer to gain some clue to an answer.

The Phase One activities may be combined into a flow chart as shown in Figure 5. Using the same information-retrieval sequence as the *S* and the

11. Newell and Simon, "GPS"; Marvin Minsky, "Steps towards Artificial Intelligence," in Feigenbaum and Feldman, *Computers and Thought*.

strong heuristic weak methods

breadth-first

depth-first

Table 1.
A taxonomy of information for a bathroom

1. Constraints

Identified Before Trial Sketches Were Made

Given Information (Constraints Given)
CG1 More luxurious bath
CG2 Total design concept
CG3 Wasting space
CG4 Cost = existing + $50
Retrieved Information
C1 "Looks small"
C2 "Functions okay"
C3 Wasted space between toilet and washbowl
C4 Wasted space between tub and washbowl
C5 Round objects are expected to rotate
C6 Blocks of space should have 45% of perimeter common with larger space
C7 Plumbing on one wall

Identified While Making Trial Sketches

C8 Adequate use space for fixture
C10 No exposed bathtub corners
C11 No sightline to toilet from door
C12 Toilet should not fall within 180° radius centered toward sink and one to two feet in front of it
C13 Should have large mirror
C14 Locate towel racks where towels are used

2. Manipulations

Plan
M1 Remove current unit
M2 Rotate designated unit 90°
M3 Move unit to another corner first on same wall then on other walls
M4 Add new unit next to previously manipulated unit
M5 Extend unit around corner
M6 Locate wall next to fixture
M7 Locate over sink
M8 Align spatial metrics
M9 Move unit to align with others

Perspective

M10 Align horizontal edges
M11 Locate along wall

3. Design units

DU1 Counter
DU2 Toilet
DU3 Bathtub
DU4 Mirror
DU5 Sinks (two)
DU6 Tub and wall
DU7 Mirror
DU8 Sink, tub, and mirror
DU9 Window
DU10 Medicine cabinet
DU11 Towel racks

Table 2
Sequence of Design Units and Manipulations*

Design Units	Manipulations
Phase One	
DU1, DU2, DU2, DU1	M1, M2, M3, M4
DU1, DU3, DU1, DU1,	M1, M2, M4, M2,
DU1, DU2, DU3, DU6, DU2, DU1, DU1, DU1,	M1, M1, M2, M6, M3, M4, M4, M2, M3
DU2, DU2, DU2	M3, M2, M6
DU1, DU2, DU1, DU1, DU7, DU8, DU2	M1, M1, M2, M4, M7, M3, M4
DU1, DU1, DU1	M1, M4, M3,
DU1, DU1	M4, M6
Phase Two	
DU8, DU5, DU1, DU6, DU5, DU7, DU7, DU8 DU10, DU10	M8, M8, M8, M8, M9, M7, M10, M10 M10, M11

* Each row represents a sequence of transformations performed without a major review of constraints. Underlined manipulations are those directly responding to a search heuristic.

flow-charted process, the manipulations of this one problem-designer situation can be partially replicated. The state transformations produced by the information-retrieval sequence, the heuristics, and the flow chart in Figure 5 are shown in the PBG of Figure 6. The correspondence between this PBG and the one in Figure 4 indicates the degree to which the *S*'s behavior has been modeled or simulated.[12] The major sequences of alternatives were duplicated.

This protocol and others can be well described in terms of a problem-definition process mixed with a generate-and-test sequence. The tests applied were overwhelmingly of a binary or threshold nature, corresponding to Simon's notion of "satisficing."[13] Only one instance of an attempt to optimize a solution has been found in thirteen protocols concerning three different design tasks.

Findings and Conclusions

The most important general finding from these studies thus far has been the significance of representational languages to problem-solving ability. The processing of information often depends upon some means for representing it. Thus one designer poor in math is not able to deal with cost or other numerical constraints. Less obvious is the difference in the constraints considered by those designers who worked in section versus those who did not. The accessibility to children of sink fixture controls becomes an issue only with the generation of a section representation. Generally, a clear correspondence was found between the kinds of constraints that could be considered and the representations used. One of the strengths of the human problem-solver is his ability to use several representations—words, numbers, flow diagrams, plans, sections, perspectives—to represent, compare, and manipulate information. It would seem that any man-machine system to aid the designer must recognize his reliance on multiple representations. Any methodology must also be able to include within it all information relevant to design or it must allow a designer to work back and forth between representations. It can be argued that most methodologies are in fact new representations that allow explicit comparison of information not previously relatable. Like other representational languages, they augment intuitive design rather than replace it. In this sense engineering is possibly different from architecture, primarily because it is dominated by a particular representation, numerical, versus an iconic one.

expert — has structured info about a domain

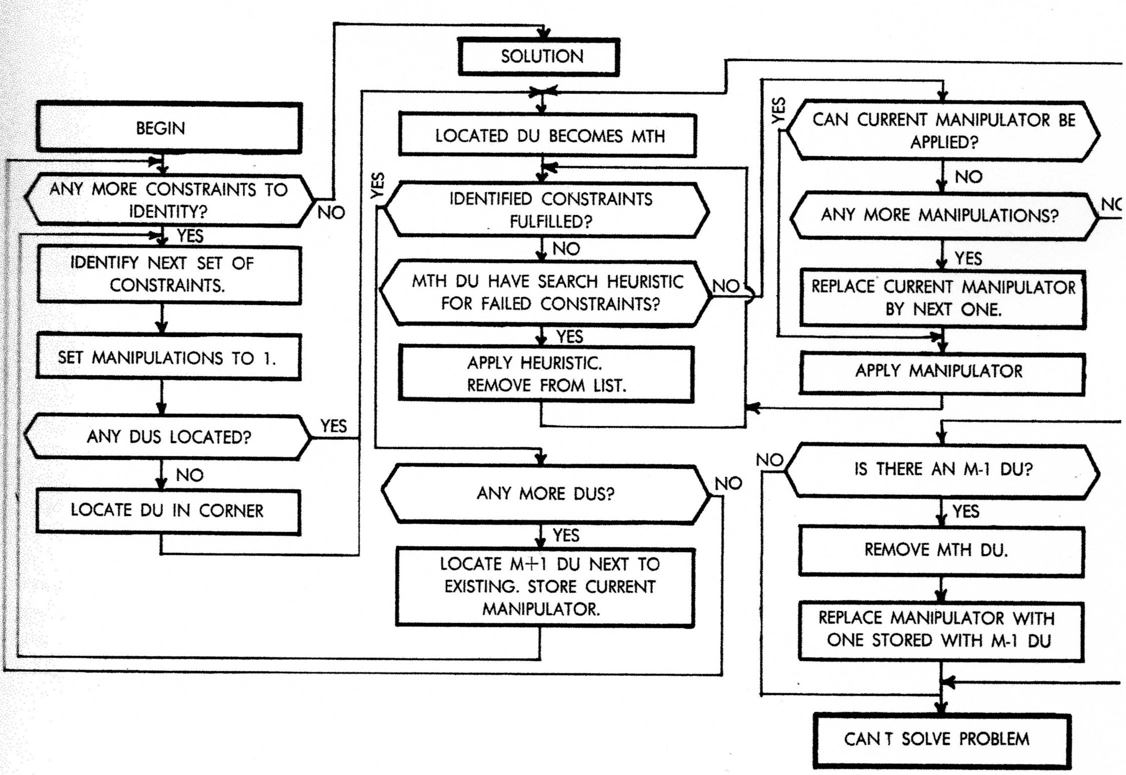
Another finding had to do with the problem identification process, which began to yield some understanding. Relying on the limited sample of six subjects doing two problems each, it has been found that those relying on direct retrieval from memory are far superior to those who rely on external cues for generating problem constraints. Also, while most seemed to retrieve constraints from memory randomly, certain *S*'s seemed to have "automatically" organized considerations in memory so that they could be retrieved in a highly structured form. One generated five constraints for the bathtub, then eighteen for the counter and sink, all in order. Other strategies for retrieving constraints such as "imagining yourself functioning in the space" have not been elicited from *S*'s thus far. At some later date, these studies may allow much more to be known about why certain designers are superior in bringing to bear much information to a design problem. We tend to assume that designers utilize all the information mentally available. It can be shown, though, that designers are quite at the mercy of a fallible memory.

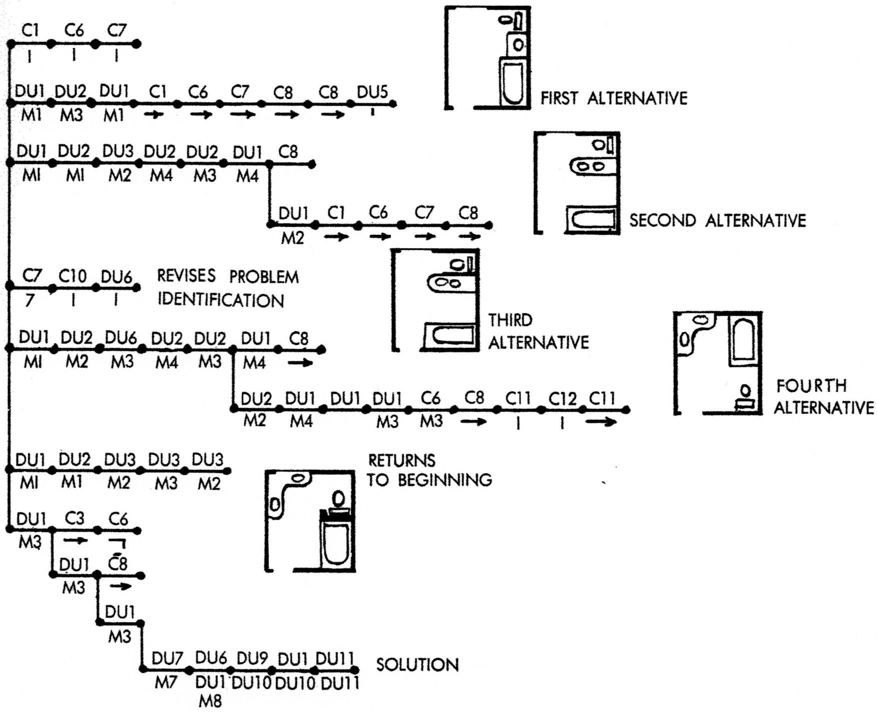
A current weakness of our studies is that protocols dealing with several intermixed representations have not been treated adequately. The theory of problem-solving and protocol analysis requires refinement in this area. Also,

12. An implication of the protocol analysis and model presented here is that the design process may be "driven" or controlled by the particular sequence in which design information is retrieved. The model was implicitly formed this way because information retrieval is currently an independent variable.
13. Herbert A. Simon, *Models of Man*, Chapter 14.

5. Block diagram for an administrative process relying on search heuristics

6. Problem behavior graph—simulation 2





we have only gained a few protocols that clearly show hierarchical processes where one element is designed of smaller elements which in turn become part of a larger design. Surely, this is a central feature of many design problems. Also missing from our studies is an understanding of the many phases that transpire between the receiving of a commission and the production of working drawings. We have looked at only a small portion of the design process.

Larger potential weaknesses may lie in the approach. How deep a penetration these studies will allow into the problem-solving process is an open question. The approach relies on external expression of the information used in design. Currently the density of concept utilization which these studies represent is about one every twelve seconds. Protocol studies in other areas show that processing of familiar information may take place at a rate greater than one concept per second.[14] Studies of design have a long way to go to fill in what's happening in that eleven-seconds gap. Certainly part is spent on the motor activities of drawing or perception. But we still have at least six seconds between each piece of processing that are not accounted for. Whether the approach outlined here will allow understanding of processing at this level of detail may depend on whether external traces of the intervening information can be made available. In eliciting expression of information we are creating some distortion of the design process. This is certainly one issue. Whether the nature of the inputs to design processing are conceptual enough for expression is another issue. At most, one-half the total processing time of short-term memory has been accounted for here. Hopefully the void represented by the other half may slowly be filled in.

This type of a problem-solving analysis, when applied to design, may allow us to understand much more than we know presently about the capabilities of the superior designer. It may give us insights as to what are powerful, and conversely, weak procedural techniques. It may also lead to new methodologies that augment current weaknesses of the human designer. Others are encouraged to explore this approach.

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14. Allen Newell, personal communication.

Appendix
A Protocol and Analysis

Each PA section corresponds to one minute of time.

Legend:
< > implicit activity
[ ] a repeated activity
~ relates information
→ applies constraint
≡ constraint heuristically related to manipulation
GC = general constraint
C = constraint
M = manipulation
DU = design unit

PA1 An objective is "a more luxurious bath," "a total design concept." The list of comments remembered were "wasting space," and some opposite of luxurious. Whoever wants these to be redesigned considers these are the most objectionable.

1. Reads GC1.
2. Reads GC2.
3. Reads GC3. [GC1]

PA2 One reason that it doesn't have a luxurious quality, I think this would look rather small. In this picture it looks very spacious, but it must have been taken from outside the room in the hall. When you get into this thing you're about four feet to the sink, standing in the door. . . .

4. Identifies C1.
5. GC1 ~ C1

PA3 I think I would juggle the drawings here on a piece of paper. It seems that there are no objections with how this thing functions. Left out storage space, but all the necessary utilities, toilet and so forth, have been included. Evidently, they're of a decent size.

6. Identifies C2. (Planning strategy)

PA4 If there are problems of space, and I think there are, in looking at it, it would largely be a case of juggling it around. There is wasted space in this design. In between the toilet and the washbowl and the tub and the washbowl. These are inconvenient little spaces that can hardly be used.

7. GC3 ~ C3
8. GC3 ~ C4

PA5 Something that's sort of superficial, this seems to be a rotating device (the counter). I have an uneasy feeling about it. . . .

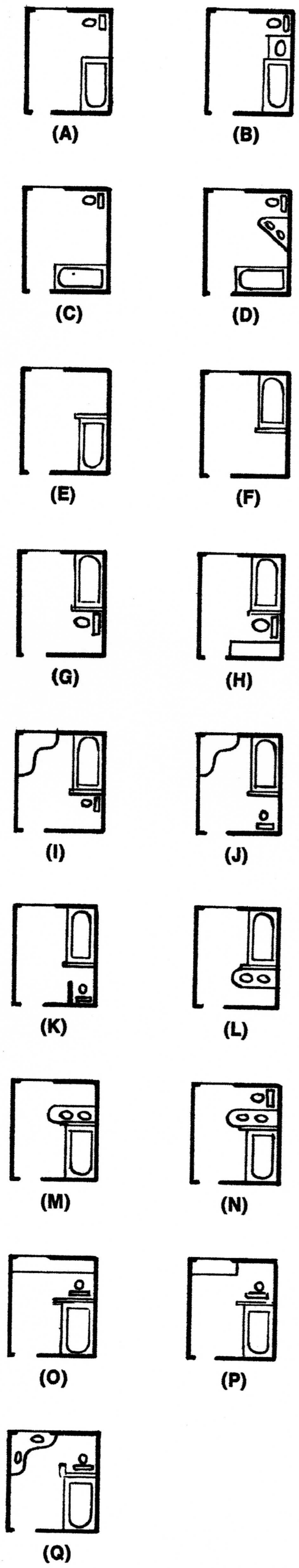
9. <Identifies C5.>

PA6 Another thing that wastes space is the toilet facing the wall, which means that you have a block space in here, which, if the toilet were facing this way (into the room), the space would become part of the larger space out here. . . . I think what I would do in this case is start juggling the fixtures and sketch of the room. When such a situation comes up it means many little drawings.

10. GC3 ~ C6
11. C6 ≡ M2 → DU2

PA7 (Makes tracings of each fixture and of the outline of the room.) I'll assume a washbowl is about that big. . . .

(Generates representation.)



7. Sequence of arrangements in subject's protocol

PA8 First I would try and arrange all three, washbowl, tub, and toilet, along this wall, which might be a little crowded. (He makes sketches that sequentially develop as shown in Figure 7.) You have a lot more space . . . open feeling to it. You have one washbowl and it's crowded. It does retain all the plumbing on one wall. . . . (Makes sketches *A* and *B*.) This is going to boil down into making a lot of sketches and thinking most seriously about what exists and criticize and repair it. . . . This thing next to the tub would be crowded.

12. <Identifies C7.>
13. Applies M1 to DU1.
14. Applies M2 and M3 (?) to DU2.
15. C7 ≡ M4. Applies M4 to DU1.
16. <Identifies C8 and DU5.>
17. GC3 → "A lot more space."
18. C8 → DU1 → "It's crowded."
19. C7 → <OK>

[C8 → "crowded"]

PA9 (He rotates the tub, then completes an arrangement as in *C* and *D*.) I'm trying to make an arrangement of toilet, two sinks, and tub, with plumbing on one wall . . . without coming out into the room. Not only to save plumbing, but also to leave a large open space. So far, I feel these arrangements would be cramped.

20. Applies M1 to DU1.
21. Applies M2 to DU3.
22. <Identifies DU5.>
23. Applies M4 and M2 to DU1.
    [C7]
    [C1]
24. C8 → "Cramped"

PA10 I also feel that this tub position, along the wall . . . I feel very strange about it. I think the idea of orienting the toilet toward the middle of the room instead of the corner is going to be a good one. There's something about hiding the toilet back here that I don't like. . . . There's the privacy angle, but there is also the puritanical thing, about the euphemism. It's something you pretend you don't have. . . . Well, it makes me a little uneasy. The word bathroom is a euphemism. . . .

[C6 ≡ M2 → DU2]

25. Associates operation with deep structure memory.

PA11 How much would it cost to run plumbing to both walls? [Expert: The cost would be a 50¢ a linear foot.] . . . I see why I don't like the tub over here. Having the tub with two corners exposed means you have problems with the shower arrangement. It requires an additional wall, or a curved shower rod. Let's see, is there anything wrong with a curved shower rod? I feel that there is. . . .

26. <GC4 ~ C7> <?>
27. <Removes C7 from problem.>
28. Identifies C10.
29. <C10 ≡ M6 and DU6>
    (Planning strategy)

PA12 This method, seeing what I didn't like about the original arrangement, then eliminate what I didn't like. I've already done that. I have a large amount of space in here. Without cutting down on the functions. There are things I don't like about the arrangement yet. I have got more

[C1]
[C2]

central space, but some functions are cramped. I would like to see if I could iron those out without starting to chop up the space again. I suspect that this lack of space was the basis of the objection that it was not luxurious. I don't like the two sinks I have here. So close together...

[C1 → "OK"]
[C8 → "cramped"]

30. GC1 ~ C1
[C8 → "Sinks too close together"

PA13 (Draws *E*.) Go back to the bath in the corner. Okay, wall at the end of it. Except that's too close to the original? . . .

31. Applies M1 to DU1 and DU2.
32. Applies M2 to DU3.
33. Applies M6 to DU3.
<DU3 and M6 produce DU6.>

PA14 (Draws *F*.) I've put the tub along the same wall but toward the window. It might allow you to put (draws *G* and *H*). . . . I was thinking the toilet could then go on this wall, leaving room for a large vanity along here. Which would work but cut down on the privacy more than somewhat.

34. Applies M3 to DU6.
35. Applies M4 to DU2.
36. Applies M4 to DU1.>
37. <Applies M2 to DU1.>

38. <Identifies C11 and C12.>

PA15 (Erases and draws/.) This arrangement, with the tub in this corner, is the nicest space so far. It's open. I think it solves all the problems, except for this thing of privacy. It has a large space to stand around in to dry. It gives the appearance of space when you walk in. It's adequate but not cavernous. It gives easy access to all the facilities, to the tub and to the toilet, and washbowls.

39. Applies M3 to DU1.

40. C1 → "It's open."
41. C2 and C8 → "It solves all the problems."

42. C11 → "Except privacy."

[C8 → DU3]
[C1]
[C8 → DU3, DU2, DU5)

PA16 I have an uneasy hesitation about the privacy. . . . This is my personal feeling. And I don't want to appear to try and hide the toilet. I have an idea that the client would like the toilet to be hid. I would like to make a compromise.

43. Associates C11 with deep structure memory.

PA17 (Changes drawing as in *J*.) It would appear as if you could do this. I don't quite know how. (Adds wall in *K*.) There is this wall, by the toilet. It only comes out 2 feet, which does not hide the toilet.

44. Applies M3 to DU2.
45. Applies M2 to DU2.
46. <C11 ≡ MG.> Applies M6 to DU2.

PA18 This would be a good thing. . . . This does form a bit of a nook, but it isn't hidden from the door. This semi-enclosure for the toilet, plus this thing about the open plan. I think we're in good shape. . . .

47. C11→ "A good thing."

48. C6 → (?)
49. C1 → "In good shape."
50. Applies M1 to DU1 and DU2.

PA19 There's another possibility of putting sort of a console coming out from this wall (draws *L*.) . . . mirror in here . . . probably a large sink in here and a smaller one here. This would have nice accessibility. I'm not ter-

51. Applies M4 and M2 to DU1.

52. <Identifies DU7.>
53. <DU7 ≡ M7.> Applies to DU7
54. C8 → "Nice accessibility."

ribly enamored with the design. . . . I feel myself sort of getting into a corner. (Draws *M* and *N*.) This again leaves the toilet . . . in the open.	55. <Current arrangement produces DU8.> 56. Applies M3 to DU8.
PA20 Come to think of it, I wonder if the original design with. . . . (Sketches *O*.) Now this seems to be a nice arrangement here. You get these facilities in a small amount of space. But that leaves the toilet here, which is sort of exposed come to think of it.	57. Applies M4 to DU2. 58. C1 → (?) 59. C12 → "in the open." 60. Returns to beginning. Applies M1 to DU. 61. Applies M4 and M2 to DU1. 62. C1 → (?)
21 I wonder if this original design, replacing that console. . . . (Draws *P*.) I was thinking of bringing the vanity underneath the window, into this area. But that would leave . . . sort of a nook . . . by the toilet.	63. C12 → DU2 "Sort of exposed." 64. Applies M3 to DU1. 65. C6 → "Leaves sort of a nook."
PA22 (Draws *Q*.) This one would do it. This one is getting familiar. . . . It would be nice to have an arrangement like this because it gives some privacy to the toilet, the bathtub still has lots of open space. Unfortunately that means putting. . . . if you're going to have the toilet here means you have the washbowls over here, I think, to get the people's backs to the toilet. . . . This will work out nicely. . . . Yeah. That's just fine.	66. Applies M5 to DU1. 67. Applies M6 to DU1. C11 → "Gives some privacy." 69. C8 → DU3 "Bathtub has open space." 70. <C7 → (?) > 71. C12 → (M5 → DU1.) (?) → "This will work out nicely."
PA23 My objection here was that . . . I dislike rounded corners on these things. It reminds me of artists' pallettes. But it also keeps you from scraping your thighs. I think what I've got right here . . . it's simply a matter of juggling proportions.	72. Associates DU1 with deep structure memory.
PA24 I'd sort of like to have this washbowl right in front of the window. Just have this nice and neat for its length down to here. The length of the counter so it lines up with that wall. Bring the sink down as far as I can so. . . . I think a little space here for shaving cream and stuff like that . . . . make a little more space so you can get two people using washbowls at the same time without being right up against each other. This mirror down to there. There's still some details . . . (draws Figure 8).	73. Applies M8 to DU8 and DU5. 74. Applies M8 to DU1 and DU6. 75. C8 ≡ M9. Applies M9 to DU5 until C8 is O.K. (Generates new representation.) 76. Applies M7 to DU7. 77. Applies M10 to DU7 and DU8.
PA25 Right now the biggest objection I have is that the mirror. . . . I think, visually, and functionally it would be quite nice to have a large mirror here. Of course, not over the window or wrapping around the corner. I think the large mirror seems to	78. <GC1 ~ C13.> (?) 79. <Identifies DU9.>

conflict with having the medicine cabinet. . . . That window doesn't come to the edge either. . . . Well, let's put the medicine cabinet mirror in front of this sink. And then optionally you could extend this mirror or any place along this wall. To carry through visually. If it were easier to get a mirror in standard size that doesn't match the window, well, that's the way it goes. . . . Yes. Here's a place for the towel rack. I'd forgotten about that. Pretty essential to have a place for towels. Near the bathtub, also along here would probably make sense. Towels in this area. They'd be accessible from both the bathtub and the sinks. . . . I think that's it.

80. <Associates DU9 with deep structure memory.>

81. DU10 and C12 conflict.
82. <Abandons C13.>
83. M7 → DU10.

84. Identifies DU11
DU11 ≡ C14 and M11.

85. Applies C14, M10 and M11 to DU11.
(Solution ignores C6.)

8. Subject's final sketch