COGNITIVE PROCESSES AND ILL-DEFINED PROBLEMS: A CASE STUDY FROM DESIGN*

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Summary

In this paper the information processing theory of problem solving is extended to include ill-defined problems. A protocol of problem solving in architectural design and its analysis is presented. The significant difference between well- and ill-defined problem solving is shown to be a specification process similar to information retrieval processes now studied in artificial intelligence. A variety of issues in this retrieval process are examined. The search process involved in the space planning aspect of design is shown to correspond well with existing formulations of search. The interactive effects of retrieval and search processes are examined.

Introduction

All problems can be said to consist of translating some entity (A), into some other entity (B), which is specified in terms of goals to be achieved (A -► B). The major efforts of problem solving theory to date deal with problems where A, the initial problem state, →, the operators available to alter the problem state, and B, the goals to be achieved, are specified, either explicitly or by some agreed upon formal convention'. Thus detailed analyses have been made of how people determine chess moves, how they solve geometry, word algebra, and crypt-arithmetic problems, and how they solve logic proofs[2]. While some are less well-specified than others (in chess, the goals for evaluating a specific move are open to individual interpretation), all of the tasks thus far analyzed have an operational formulation. Such problems are considered to be <u>well-defined</u>.

This paper describes efforts to extend the information processing model of problem solving to those problems where part of the problem specification is lacking. Of interest are those tasks where a formal language for describing the problem space, operators for moving through the problem space, or the precise expression of an acceptable goal state is not given. In such tasks, the problem solver must specify the missing information before search of the problem space is possible. Such problems can be called <u>ill-defined</u>.

An example of ill-defined problems are the space planning tasks found in engineering, architecture, and urban design. Space planning can be defined as the selection and arrangement of elements in a two- or three-dimensional space, subject to a variety of constraints and/or evaluation functions. Space planning problems lack a well-specified language for their representation. The generative transformations available to the problem solver for manipulating a design are not known. Most such problems also lack a precise formulation of an acceptable goal state.

This paper presents a detailed analysis of one example of ill-defined problem solving. The problem is a space planning task commonly found in architecture, the selection and arrangement of elements in a room. Evidence from this analysis is presented which advances two hypotheses: (1) the major distinction between well- and ill-defined problems is the assumed availability of a specification process for defining the problem space and goals of a problem. Ill-defined problems are subjectively specified; (2) if the specification process is the major distinction between well- and ill-defined problems, then a complementary hypothesis would be that the search processes used by humans to solve both types of problems would be similar. The motives behind these efforts include gaining a better knowledge of those processes which society has traditionally called "creative." Such studies may also provide the foundations of a method for automatically solving ill-defined problems.

Psychological Foundations

The psychological premises of these studies are similar to those involved in the work of Newell and Simon, E. B. Hunt, and many others who use information processing concepts to study concept formation and problem solving[3]. The best descriptions of these premises are found in Miller, Galenter and Pibram's <u>Plans and the Structure of Behavior</u> or in Walter Reitman*s <u>Cognition and Thought</u>4.

The model proposed is as follows. Thinking is information processing. The sources of information may be the environment, the physiological state of the individual, or his memory. Memory is interpreted as allowing independent recall of past environmental or physiological states and recall of past Intermediate processing. Cognition--or thinking—is the resultant of specific information being brought together in a unique combinatorial sequence. In this light, a problem situation is unique because a specific response to a set of inputs is not directly available. At issue is the selection of appropriate inputs from memory or from the environment and the search for their possibly unique combinatorial sequence. The processing that cognition and problem solving Involves can be modeled as a series of transformations generating a

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sequence of Information states. The total number of states generated by applying all permutations of applicable information to all information states defines the total problem space. The means used to sequentially generate information states so that one is created that satisfies the problem goals is called the search strategy.

Information processing, whether it be in man or machine, can only be achieved when the relevant information is in an appropriate processing language. Processing languages provide the operators necessary for combining information. Well specified processing languages include computer programming languages, algebra, symbolic logic, and other calculi. The processing language used in human cognitive processes has not been identified. Human problem solving theory has proceeded on the assumption that the well-specified processing languages listed above, since they are used by man, are partial subsets of the formal language internally available to him. Problem solving tasks have been analyzed in terms of the problem spaces and operations available in these languages. In the past, problem solving analysts have limited themselves to those tasks where some well-specified formal representation was available.

Problem solving analysis usually takes the form of studying how a problem solver treats a special task assigned him. Generally unreported in the literature, yet a common occurence in most actual experiments is the problem solver's difficulty in understanding the task exactly as it is conceived by the analyst. The problem solver's initial assumptions are different and require correction before the experiment can proceed. This problem points out the fact that problem solving analysis Involves the comparison of two parallel processes. From the explicit problem statement both problem solver and analyst identify the goals to be achieved and elaborate them as needed. Both either assume or select a processing language to work in and within it devise various strategies for exploring the problem space thus created. The analyst can understand the problem solver's processes to the degree that he can find correspondence between the processes he has experienced and thus understands and those of the s. Fruitful analysis requires the analyst to ha"ve processed significant portions of the problem space so as to maximize these correspondences. To further maximize such correspondences, only problems that allow the analyst to make strong assumptions about the goals and problem space used by the problem solver have normally been used. Yet the difficulties of the s in understanding the analyst's conception of the task emphasizes the variability in the processes by which tasks can be specified.

If the assumptions of parallel processes and the search for correspondences is applied to the specification of problem goals and a processing language, this aspect of processing also should be amenable to analysis. It need not be predetermined.

Like most studies of human problem solving, the method used in the studies reported here consisted of giving a Subject *(S)* a complex task and recording his expressive behavior while solving the problem. Detailed records of sketches and verbal behavior were carefully collected. Other potentially significant behavior, such as facial expressions and looking at objects as a source of auxiliary input, were also recorded. Together, this information made up a protocol from which the internal processing of the S, could be analyzed 5,

The Task

A typical small scale space planning problem is shown in Figure I. It asks a Subject to redesign an existing room so as to make it "more luxurious[11] and "spacious" and sets boundaries for the solution in terms of cost.*

This particular task is ill-defined in at least two ways. No existing formal language can adequately represent space planning problems. While the informal representation for such problems is orthographic projection, the elements of this language, its syntax, and rules for generation or manipulation are unknown. These aspects of the representation are left to the problem solver to intuitively identify. Another ill-defined aspect of space planning problems in design is the identification of problem goals. The problem in Figure I is typical in that no specific information is provided as to what a satisfactory design should consist of. Generally, design tasks have as their explicit goal the specification of some physical entity in a form allowing construction. Left implicit are many criteria the specification must satisfy. It is assumed that the engineer, architect, or city planner solving the problem is familiar enough with it to know what specific elements are to be included in the design and their function. From his background, he is expected to be able to identify the goals which apply to various selection and arrangement possibilities.

Many protocols have been collected from this particular task. Some were presented in an earlier report6. A new protocol gained from this task is shown on the left side of Figure II (which continues for several pages). The s of the protocol was a twenty-six year old industrial designer, who was attending graduate school. He had two years of professional design experience. Approximations of the figures drawn by this s while solving the problem are included in the protocol. It is broken into sections, each of which corresponds to a protocol minute (PM).

* The particular task presented here, the design of a bathroom, was chosen because of its general familiarity to a wide diversity of people both within and outside of the design professions. Its use here was not to gain detailed information concerning the solution to this specific type of problem but to learn more about the method by which a human deals with common yet problems.

Essentially, the S presented here created an alternative design for the bathroom by identifying and satisfying goals from his own experience as to what a good bathroom design should be. Privacy, a neatly ordered appearance, adequate circulation and access, short plumbing lines, and low cost were the most evident concerns. While generally there was more emphasis on identifying design goals early in the protocol and on search for an arrangement at the end, both processes were highly intermixed. In all, five alternative bathroom designs were created and evaluated. Only two were completely developed. Figure III presents the general sequence of processing described in the protocol. All external processing took place in a plan drawing representation, except for a short sequence which utilized a vertical section. The total processing time was forty-eight minutes.

Task Analysis

Ill-defined problems are without a predetermined language or explicit goals. The initial requirement for analyzing ill-defined problems is Identification of these aspects of the problem solver's processes. The general identification of goals and processing languages turned out to be straightforward for the example protocol and was achieved by scanning it for the following types of information:

1. All physical elements that were considered or manipulated during problem solving (what we call Design Units (DUs));
2. All information that was used to test or determine a design arrangement or selection of a DU, or any information used to derive such information. This information was assumed to identify the problem goals;*
3. All operations that produced new solution states. A solution state was considered to consist of the current arrangement of DUs and current information about the problem. A change in either the arrangment or the information available was considered a new solution state.

The information that was identified is listed in Figures IV and V. These listings give an interpretation, in verbal form, of all information which evidence suggests was processed during the problem solving described in the protocol. Much of it was never verbalized, but was only silently applied in some manipulation within the problem. Other information was mentioned but its use never verified. This information has not been listed.

In our terminology, a constraint is a function applied to a solution state and returns a boolean evaluation. An evaluation function is a function whose value continuously varies with its state, A goal is the general name for both evaluation functions and constraints. A consideration is information used to derive a goal.

Corresponding to each section of the protocol and to its right is a detailed description of the processing that transpired, coded in terms of the information listed in Figures IV and V.

Our knowledge of design methods allows us to correctly anticipate orthographic drawings as the processing language used in searching for a satisfactory arrangement. This intuitively defined language seemed to be automatically assumed by the S. Alternative formal descriptions of the operations, element, and syntax of orthographic projection have been developed and presented elsewhere 7. They will not be elaborated here. The operations and language used in the selection of DUs and identification of goals was not orthographic projection, but took quite a different form.

Even though the protocol did not present search and problem specification processes as disjoint processes, the following discussion initially considers each separately. This approach allows existing knowledge about each of these processes to be brought to bear on the protocol. Following individual consideration, their interactive and confounding effects are considered.

Goal and Design Unit Specification

Given the partial specification of a problem, a problem solver has available at least two means to complete it. He may: (1) disambiguate the given specification and attempt to identify subtle or implicit information within it, or (2) re-identify the problem using his own perceptions of the initial situation. Both approaches are used in design. The first approach predominated in a previously presented protocol, gained from the same task used here[8]. The S. in the included protocol, in contrast, chose to re-identify the problem.

In order to understand the processes by which the S specified DUs and goals for the problem, an attempt has been made to intuitively reconstruct two portions of his specification process. The sequence in which information is expressed has been identified so as to suggest what kinds of processes may be generating it. In recording the sequences of processing, simple diagrams are used. They should not be considered literal models of the internal data structures being accessed, but may be serve to suggest some properties of those structures.

In an early part of the protocol, the S is told that the design he is to generate should respond to the needs of children (see PM2). Soon afterwards, he recognizes a need to store bathtowels and children's dirty clothes. He also relates dirty clothes to the location where they are cleaned - the washroom - and wonders about the distance between it and the bathroom. He suggests that temporary storage for dirty clothes might be needed. Much later (PM21), this line of thought is picked up again and the recognition made that a clothes hamper would be a positive component of the design. This information is generated when the utilization of storage space is being considered. The sequence of associations made is presented in Figure VIa.

What seems to transpire here is a sequence of thinking ending with the identification of a particular Design Unit relevant to the problem.

Another example of an association process is seen at the very end of the protocol (PM47). Earlier, the s was told that the window was of the operable variety and that it contained frosted glass. The S in the current sequence is considering the detail design of the storage cabinet located in front of the window. While working on the cabinet, he identifies that it may be difficult to close the drapes in the window. This seems to have been achieved by recognizing the distance between the clear floor area and the window. See Figure VIb.

In both these sequences, information from the environment (e.g., from the Experimenter, the original design, or from the problem statement) is related to original information generated by the j>. No other source for this new information is possible. In both examples, several pieces of information are generated and related with those that are given before information of specific relevance to the problem is generated. The first sequence identifies a new DU; the second identifies a constraint. The two examples are the longest sequences of related information that produce design information. Thus they are the most explicit. Sequences of unitary length are common (see PM5, PM11, PM15, PM33).

The processes which produce such information might best be considered and examined for potential modelling as information retrieval processes operating on a large base associatively stored memory. The given problem information is the initial queries into the system. Sometimes a desired access is not initially made; only further inputs allow isolation of relevant design information. Most further inputs are gained from cues identified while processing other parts of the problem. By mixing information retrieval with arrangement processes, new access queries can be identified and used to reinformce those made with the originally available information. These additional cues seem to allow accesses that no single inference making capability could match.

Only a few insights are offered as to the detail structure of this system. Some evidence suggests that the major elements of the retrieval system are physical elements (e.g., DUs, people - most generally, nouns). These are the aspects of the information that are expressed most often and which seem to gain elaboration from further processing. The structure between these nodes cannot be identified from the protocol data. Most reasonably, they would be verb and prepositional phrases. Such a structure is supported by recent work reported in the psychological literature.9

The DUs identified by the took one type of organization during one phase of processing, only to take another later on. These different definitions were not disjoint, but rather overlapping in a set-theoretic manner. For example, during major portions of the protocol the toilet-tub was manipulated as a single element. Later, though, it was treated as two separate elements. At one point the bathtub was further decomposed into its components. Each element thus had the possibility of being broken into the elements of which it was a set. The hierarchical decomposition thus produced is shown in Figure V.

The purpose of composition or decomposition of DUs is essentially one of search efficiency. Decomposition widens the solution space by allowing a greater number of primitive DUs to generate a greater number of design alternatives. This is useful when the current solution space is too restrictive to easily find a solution. Alternatively, composition narrows the search space. Composition is especially applicable to sets of DUs which are relatively non-Interactive with others and can be arranged so as to satisfy the interactive goals or constraints within the set][0] The bathtub-watercloset combination in the protocol is an excellent example of the use of composition. An information retrieval system useful for design problem solving would need the capability of composing and decomposing DUs.

The issue possibly raised here and elsewhere as to whether information is stored discretely in the agglomerated concepts used in the given description and protocol analysis is easily resolved. In all memories known, a trade-off exists between the alternatives of explicitly storing large amounts of data and possessing a process that dynamically generates the information when it is needed. If this trade-off exists in a memory, then the modelling of that memory can reflect this trade-off also. It may be most expedient at any level of model building to assume that information is explicitly stored. But a single node in a model at one level of organization may represent a whole pattern of processing at another level. The only requirement that is logically imposed is that information processing, at some point, pass through the state defined as a discrete element in any model. The value of the particular points chosen is determined by the parsimony of the description allowed.

The implications gained from the analysis of this and other protocols is that human performance in retrieving information from memory for application to ill-defined problems is quite limited. In space planning, a retrieval rate of one piece of applicable information per minute was exceptional. The size of memory required to intelligently solve a class of ill-defined problems is only now becoming known. That size seems to be smaller than expected. The eventual development of automated problem solvers may actually benefit from a memory even more limited than the size implied as necessary from human protocols. The controlled input of new information could delimit the data base to verified information, eliminating much questionable data. An initial exploration of an automated design retrieval system has been made by Moran.[11] More extensive models of memories capable of the kinds of retrievals required here have been developed by Green et al and Quilllan.[12] No model of memory developed thus far can perform, both in speed and diversity, in a manner similar to that described in the protocol. No model has yet been proposed that takes advantage of auxiliary inputs gained from intervening processing. The interaction of search and retrieval processes may offer major benefits to large base associative memories.

Search Processes in Design

When faced with the problem of arranging elements in a predefined space according to some partially specified goals, all designers thus far tested have used a modus operandi for generating solutions that included as its main activity the sequential selection of both a location and a physical element to be located. If the DU could be located in the proposed location and an evaluation of the current total configuration was successful, then a new element was added to the design. If the evaluation failed, the current element or another was manipulated. Such operations can be viewed as transformations in a problem state space according to the traditional search paradigm. Examples of this sequence are evident in Figure III as sequences of intermixed tests and operations.

Space planning aspects of design' problems seem to fall within the transformational paradigm of heuristic search according to the following formulation. A apace planning problem can thus be defined as a

$\{a\} \equiv$ a space,

$\{b_1, b_2, b_m\} \equiv$ a set of elements to locate in that space. (Some elements may be defined as any member of a set.),

$\{c_1, c_2, c_n\} \equiv$ a set of constraints delimiting acceptable solutions and possibly evaluation functions to be achieved,

$\{d_1, d_2, d_p\} \equiv$ a set of operators for manipulating elements within the space, and

$\{e_r\} \equiv$ the current design state.

Each transformation consists of a triplet consisting of the current design state, an element to be operated upon, and an operator. Each transformation is made in an environment defined by all or a set of the goals to be achieved. Thus

$$\{c_1, c_2, c_n\}(e_r, b_m, d_p) \rightarrow e_{r+1}$$

The problem is to locate the elements within the space in an arrangement that satisfies the constraints and optimizes the evaluation functions.

Obviously needed is a process or method that selects an appropriate operation and an appropriate DU on which to operate. Highly diverse methods are possible. Algorithmic methods include lists or stacks of Design Units or operators. More complex operations usually include feedback from the current or past states of the problem. Processes that include such feedback are called heuristics [13]

The protocol included here, like others analyzed, show few examples where all combinatorial possibilities are exhaustively searched. Instead, all protocols showed reliance on a wide variety of heuristics. By a heuristic is meant a relation between some part of the current problem state and some part of the desirable next state. Most models of heuristics have framed them as productions in a Markov system.14 The production takes the pattern of

condition ——→ response

If the left hand side of the condition is met, then the right hand side is applied to determine or partially determine the next transformation to be made. In the heuristics found in design problems, the left hand side is commonly a single DU or a constraint, or possibly a doublet made up of both a constraint and a Design Unit. The right hand side is commonly an operator, a Design Unit, or both. Examples of heuristics used in the accompanying protocol are CI9, which looks for uses of empty space, and C24, which identifies space for locating towel racks. CI9 has as its left hand component a test which checks for the existence of a space bounded on three sides and adjacent to the major space in the room. When a situation exists that meets these conditions, the right hand side of the production searches for any DU that may make use of the identified space. The left hand condition for C24 is the existence of a bathtub or sink. The right hand side searches for empty vertical wall space. Upon finding it, a towel rack is located. It may be repeatedly applied. The value of heuristics is that they orient the range of possible future solution states in directions that have been found empirically to be fruitful.

A schematic flow chart of the process outlined in the above formulation and described in the protocol is shown in Figure IX. This process corresponds closely with other formulations of heuristic search.'[15] Heuristic search is not the only search process used in space planning. Occasionally, generate and test and hill-climbing have been observed in protocols. But the main process relied on in the intuitive solving of space planning problems seems to be the one outlined here. Great individual variations within this general paradigm exist, in terms of the heuristics used and in the definition of the search space, as specified by the composition and decomposition of DUs.

The Confounding of Specification and Search

Throughout the protocol, search and specification operations were highly intermixed. No clear cycling or other separation of activities was identified. The value of such intermixing for retrieval processes has already been proposed. But intermixing is not without its costs. Confounding of retrieval processes also result.

An exceptional example of confounding is shown in PM7. At this point in processing the *S* is at a particular solution state that will be achieved again. At this state he asks for Information about the minimum distance between a wall and the front of a sink. Looking in Graphic

Standards (an architectural reference), he finds a wide variety of other Information. This Information distracts him from his original search and his processing takes off In another direction. Much later (PM37), the S has the same solution state represented and asks the same question as he did earlier. This time he gains the information he desires and generates a particular new state.

In this example, new information destroyed a search sequence originally developed by the s. It was only fortuitous that he was able to pick up the same solution state later. It seems that the control system monitoring search and retrieval processes is fallible - at least in some problem solvers - and that this intermixing of processes places demands on processing that can lead to errors. Other examples of confounding have been observed, though they are rare. Designers seem familiar with such aimless processing, having such names for it as "playing with the problem", "daydreaming", etc. The implication is that significant overhead costs accrue from effectively mixing search with specification.

Conclusion

In this study, ill-defined problems such as those found in architectural space planning were shown to be tractable in analysis if they were separated into their information retrieval and search aspects. The task of operationally specifying a problem was proposed as the major distinction between ill- and well-defined problem solving. Some suggestions as to the structure and capabilities of an automated problem specification system have been made. Also presented is a formulation of the search aspect of space planning problems. It is suggested that the search and specification processes together can completely depict a large number, if not all, of those problems now classed as ill-defined. By further delineating the specification and search processes of problem solving, greater intelligence and creativity may be allowed to be built into future computer programs.

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EXPERIMENT NUMBER TOW

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)

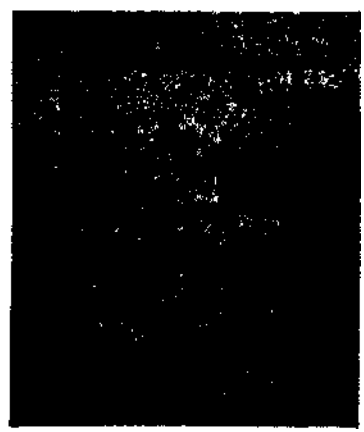
The house is the cheapest model of a group of models selling between 23,000 and 35,000. It is two stories with a ranch style exterior. The bath is at the end of a hall serving two bedrooms and guests.

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

FIGURE I

A round vanity makes the most off a square-shaped bathroom

It permits two lavatories in a minimum-size countertop. And it also lets two people use the sinks at the same time without getting in each others' way. Extra shelves are set between the lower cabinets



Experiment Two
Subject Number Four

February, 1967

PROTOCOL: Experimenter's remarks in parentheses.	ANALYSIS:
PM1 (This sheet here represents the design project. It is self-explanatory. For all questions, I'll act as the client. Here's scratch paper, some blank, some with plans on it. You have about forty minutes to work.') . . . . I would first of all like to know if you had brought in other comments than the fact that the sink would waste space and the bathroom was not luxurious. ('There wasn't enough storage space. The two sinks were appreciated. These were comments.') Yet they also made a comment that the sink wastes space.	Reads CI. ("Sink wastes space" is never utilized.) Given C4. Given C3.
PM2 ('Also from sales most buyers of these homes have young children. There is another bath--off the master bedroom.') Is the other one a two sink arrangement too? ('The other is small and has one sink.') Was there any remarks about privacy? Where does this door lead to— the hall or? ('Hall. You can see in the plan.')	Given C5. ("Other bath" never utilized.) Retrieves C13 from memory. <C13 - C14>
PM3 The developer's willing to spend more for the existing design, up to fifty dollars. (Writes down "50.00".) I think that this statement about hoping to find a more luxurious bath.. This is a partition that can be removed, I take it. (Refers to the one at the end of the tub.) ('Yes'.) Can we move the fixture around? ('Yes'.)	Reads C2. [CI] Identifies DU12. Removes DU12. Given C6.
PM4 We can change the cabinet? ('Yes.') Looking at this and things that can be done, I think storage is important. I don't see where they can store too many bathtowels. Being that it is used by children, a large storage space for dirty clothes is also necessary.	Identifies DU4. C4 ~ DU6 C5 ~C15
PM5 I don't know how it connects on to the washroom. Perhaps for at least temporary storage until the time the clothes are washed. In the picture here, the cabinet does include some storage. This is a shower-bath arrangement. From what I CAN see, I'll leave this "luxurious bath" until the last. I'll try and work with these cwo elements as they are placed (e.g., tub and watercloset). What I can see is trying to slim down this area (e.g., in front of watercloset) and add some storage. I'm limited by the window. How high is the window? ('3' x 4' window, 6'-8" head, so it's 3'-8" off the ground.')	C15 ~ C16 C15 ~ C4 <C4 ~ DU6c> DU6 ε DU4 Identifies DU3. [C1] Mentions processing strategy. C19 x (?) Locates DU4. Identifies DU12. Location of DU6 ~ C17. C17x. **STARTS ALTERNATIVE ONE**
PM6 (Sketches figure A, lightly.) This partition here can come out. Location...Is this thing called a "john" by the trade or...('water-closet') right "W.C." and the tubs. We will	Removes DU4 and DU12, locates DU4. Identifies DU2.

Figure Ha

maintain the two sinks. It seems that they are accepted. They just don't like the arrangement.

[C3]

PM7 It looks like we're going to have one more element to our already somewhat cramped space--a storage area. Do I have to talk while I'm drawing? ('If it seems natural, do so'.) You don't have a human factors book here? ('No. You are free to use Graphic Standards'.) I'm interested in spaces between, say, sink and a wall. ('Those are in Graphic Standards.)

[C4]
[DU6]
(Same question that is asked in PM36.)

PM8 Oh, okay. Let's see. (Looks in Graphic Standards.) Well, there's the answer. I'll just use Number Three here. Laugh. So, a double sink and I don't have the...I would like to have how wide these sinks are. They're completely round? (*The sinks are 19" in diameter to the stainless steel trim/) Nineteen inches, placed side by side with space in between makes..(Locates first sink as in Figure B.) My first thoughts about the sink

Given C7.
Locates DU5. Identifies CI8, [C18*location of DU5.]

PM9 are that instead of being placed back to back with a double mirror, they will be placed side by side with a full length mirror running in front, with the addition of work space between the two, with the full length mirror running across them. Or perhaps you could use these two mirrors with the detail between them removed to keep the cost down.

Explains operation.
[C18]
<C18 ~ DU8>

PM10 ('The fifty dollars additional cost allowed is fifty dollars above all costs for the current design. It's not necessary to be concerned with remodeling this one. We're concerned with those still to be built'.) Oh, good. Well, initially, I think I prefer having the storage go beneath the window, A low storage cabinet. Just by looking at the space--it would be a low storage cabinet that goes just beneath the window and flush with it.

[C2]
<C11 x (Removes DU2).>
CI9 x DU4 "I prefer storage beneath window".
Identifies C20. [C20*location of DU4.]

PM11 The window looks awfully high in the photograph. It would be, according to standards, probably about 18" deep....(Alters sketch as in Figure C.) This is primarily a space

Identifies C33. C33 x (design fails.)
Locates DU4. No room for DU5.

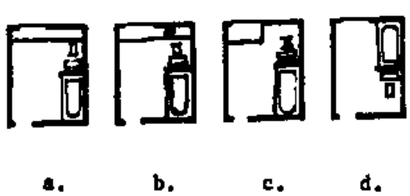


Figure IIb

problem, as I see it. (Alters sketch as in Figure D.) It's a matter of moving these elements aroung to get the best location. I do like the idea of this type of arrangement where the tub and the watercloset are back to back, because then the shower.

<PU1>
STARTS ALTERNATIVE TWO
<C2 ~ C21>
C21 x DU1. "I Like this. .arrangement.

FM12 I think it's a good way of putting the shower pipes. The two sinks will...Let's see, what is the distance from...you said the window was 3'-4" square ('No. 3' by 4'.') Oh, four feet wide. That leaves five feet.

Identifies C22, not CI2 for use in front of bathtub.
Measures tub to far wall.

PM13 That's three foot six across...Would the window have to stay where it is? ('No. It could be moved.')...(Moves window, draws cabinet as in Figure E.) I'm trying to think what you'd do with a window in a bathroom. You generally have it closed off most of the time.

Measures window to wall.
C22*location of DU4.
C20*location of DU9.

PM14 Does this window open? ('Yes. Code requires it--or a fan.') You could have a non-opening window and a fan...but it'd be pretty stupid to put in a window that didn't open. (Adds to sketch as in Figure F.) There's enough room. The door opens in or out?

Given C8 identifies DU9.
<C19*location of DU4.>
Locates DU2.

PM15 ('In.') To the left or right? ('Left'.) Adds to sketch as in Figure G. Do they ever have doors that are hinged on the right? ('Sure'.) In homes? ('Yes'.) On either side, then...(Then as in Figure H.)

identifies C23. C13 ~ C14.>
C14 and C23*location of DU10.(?)
C33*location of DU4 and DU5.

PM16 ....I'm now trying to visually locate these elements. Do they have towel racks within the shower? (No.') Okey. Well, they do now. How about the towels for this sink? Are they hanging on this wall? (Ves. On that blank wall. There are two towel racks on that wall.[1])

Identifies DU13. identifies C24.>
Identifies C25.> [C24 and C25* location of DU13.]
<C24*location of DU13.>

PM17 Here's what my initial design is. I may have it a little out of scale....Here's what I have—my initial concept. I moved the tub—switched the tub and the watercloset around.

EXPLAINS ALTERNATIVE TWO
[DU1]

PM18 I wanted the window moved over, just about—if I gave 12 inches on that side there probably about 2 inches from the wall. My reason for moving the window is that I'm putting this storage area that would start underneath the window and this would then be able to flush off with the window. It would create a more unified look to it and also provide the space necessary between the tub and storage area.

[Locates DU9]
[C22 x]
[C20 x]
[C22 x]

PM19 The fact that the faucets and stuff are up here will mean the tub will be used in this area

Retrieves C25 from memory.
[C25 x]

Figure lie

primarily. It will very seldom be used down here, The towel rack for the shower—there would be a towel rack on the end of this storage for this	C24* location of DU13.
sink. There could be a towel rack on the storage or on this wall for it would provide plenty of clearance for this door opening. This initial problem is that you've got this much wasted space as far as storage (referring to corner storage area). This box down here could be additional storage.	Identifies C26. C26 x "This much wasted space.[11]
PM20 We're running—if we're limited to fifty dollars additional, we might find that the additional material here and here will take up that fifty dollars....	C2 x
Okey, I would use here a full mirror that would run from this area in front of the two sinks.	[DU5]
(Adds to sketch as in Figure I.) I would not use a medicine cabinet.	No DU8.
The storage underneath the sinks could be used for this, or the top of this storage area. (Draws arrows as in Figure I.)	[CI8 x]
This would all be the same height, of course.	
FM21 The whole thing could be constructed as a single L-unit. This storage area would be useful (e.g., on the south wall).	C2 x DU6.
I don't know how neeessary it is. For kids, they could generally use	**Identifies C34**. C34 ~ DU6c.
a lot of storage area, used for perhaps a swing-out hamper, or something like this (adds hamper	[Locates DU6c.]
as in Figure I).	Locates DU6c.
Right now I have a "set" on this combination of the tub and the watercloset.	[DU1]
In this particular design there would be a "quote--unquote pleasing vista when you look into the...outdoor naturally lit aspect.	CI4 x "pleasing vista"
FM22 If it's at night it still has the connotation of being oriented towards nature. (Draws arrow as in Figure J.) This could be a rather pleasing unit, esthetically. It could be fairly clean.	C14 x "fairly clean".
This is why I feel the tub and the watercloset have to be located on this side of the wall, or in this area. It will...the tub will fit going this way.	
PM23 It's a five foot tub. That would give me	STARTS ALTERNATIVE THREE

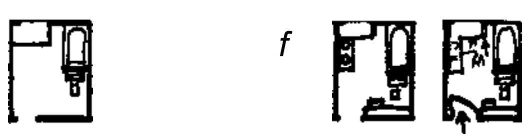


Figure IId e. f. h.

enough for a four inch wall? ("Walls are 5.5 inches'). That wouldn't give me an adequate wall. How about moving the door? ('Within the confines of the possibilities—fine[1].) I was thinking of going to another possibility of putting the tub

DU3. Wall ≡ tub = 4 inches.

Locates DU10.

C14 x.

PM24 .,1 think this is an efficient way of putting the plumbing into it. I think that..don't both outlets go to the same place? ('Yes'.) This could be an efficiency here. Would they still take down tow lines or would they connect it? ('In this case they would connect it. There's plumbing downstairs below here. Variations along this one wall adds no cost.')

GOES BACK TO ALTERNATIVE TWO

DU3.

C2 **C21 x "Alt. Two efficient"**

PM25 If I put my sink over here, then I have to put an additional amount of plumbing. But of course it's fairly impossible to put the sink and watercloset and everything on one wall—unless you have small people. Let me look at this other one and see if I could move the door. (Draws Figure K.) I really feel just by looking at this, the way they have the sink and the watercloset together is really fairly efficient—a good way of doing it

57. C21 x "additional amount of plumbing",

GOES ON TO ALTERNATIVE THREE

Locates DU3.

GOES TO ORIGINAL SOLUTION

C21 xoriginal sol. "fairly efficient".

GOES TO ALTERNATIVE TWO

PM26 ....Now I'm trying to eliminate that corner of the shelving. (In Figure J.) It can't be used for storage very readily. I wonder if I'm making these shelves wide enough. 19 inches. That includes the faucets? (Usually a countertop for a bathroom is 22" deep.[1])

Given C9.

PM27 I haven't been making them wide enough... Let's see, twenty-two, oh, I imagine that would have to be a twenty-two inch area for the sinks, or very close to it...(Draws Figure L.) Ah, yes, now I'm trying to find a way to put all this plumbing along one side.

C9xall solutions, "not wide enough".

GOES TO ALTERNATIVE THREE

C21*location of DU2.

[Locates DU9.]

PM28 I've moved both the door and the window in this one. Ha! Diabolically I'm going to put a large full-length mirror here and the watercloset directly across from it. I imagine you wouldn't be able to sell this place that way. Okey, dressing area, this could be almost flushed off. We're still maintaining the same type of tub, is that right?

[Locates DU10.]

Locates mirror. (Joke).

C22 x.

PM29 Five foot-two inch tub? Let's see. The plumbing could be run up through the walls if necessary? This is just a shower curtain. So we have to provide a wall for the plumbing and shower curtain.

Identifies DU3a.

Retrieves C27 from memory.

C27*location of DU12.

PM30 It's becoming inefficient. Moving it this

C21 x"becoming inefficient'

Figure He

way, it's beginning to look like my own bathroom, which is inefficient...The tub is against the wall, then the John is next, then the sink. This is what this is turning out to be. You can get a lot in a close space but it isn't very attractive. I want to maintain a fairly pleasant view that still says bathroom

PM31 but eliminates the more unpleasant parts of it, such as looking at the watercloset, or perhaps bathtub. Shower is here, the main area of the entrance...(Looks in Graphic Standards.)... I need two feet four inches minimum. And from the sink. I'm looking for the minimum area of a work counter space.

Cl4 x"eliminates the more unpleasant parts".

Retrieves CIO.

PM32 I guess there isn't such information. That leaves only two feet six inches, so that eliminates putting the watercloset in there at all. We could put it over here (on the opposite wall) which I don't go along with. So arrangement two which is trying to put the tub along this wall, masking it off to give a sort of hall effect, is not efficient. It provides a lot of space, but if you put the watercloset in there, it will cramp the work space.....

Measures distance from drying area to counter. = 2'4".
Size of watercloset = Cl Ox.

Locates DU2. C14 x "don't go along with".

ABANDONS ALTERNATIVE THREE

PM33 Could I ask a question about this "hoping to find a more luxurious bath." Could you fill me in on that a little bit better? What was meant by "a more luxurious bath?" What were their objectives. ('They have seen all kind of fancy things. Evidently this just didn't meet their expectations.')..I would imagine that a glass enclosure would increase the cost well over the fifty dollars. I was thinking of, instead of using a shower curtain, of incorporating a glass enclosure into the wall and extending beyond just a little bit.

[Cl]

REVIEWS FIRST ALTERNATIVE
<C1 ~ DU3b>
Identifies DU3b.C2 x.
Locates DU3b.

C14 ~ DU12
C14*location of DU12.

PM34 ('It would cost about thirty dollars.') There's something about a plastic shower curtain as opposed to a glass enclosure. I think you get more than your thirty dollars in Just the looks of a more costlier solution. We're

C2 x (DU3a ≡ DU3b)
"more than your thirty dollars".

Figure IIf j. k. l. m. n.

talking about a twenty-three to thirty-five thousand dollar home. What's that old saying that your first alternative is generally your best one. Is that a true dictum? Well, we're going to attack this thing once more.	Reviews all solutions.
<u>PM35</u> As far as the additional fifty dollars, it would not include moving the door and window? Right? ('Yes'.) So the fifty dollars is primarily in the addition of accessories, cabinetry and so forth. ('Yes'.) Well, let's see. I'm going to try it with the existing John and tub, as they are (Draws Figure M,)....I like the idea of being able to have natural light on at least part of you....	Determine boundary of application of C2. '"Would not apply to door or window." <u>STARTS ALTERNATIVE FOUR</u> (Same as alternative one) [C2.] [Orig. solution] DU1. Identifies C28.
<u>PM36</u> (Adds to figure as in Figure N, then 0.) ...Can we assume that, say, between the wall and the sink tvo feet would be enough of an area to stand in? I don't see anything here. (Looking in <u>Graphic Standards</u>.) Here it says toilet is one foot six inches and two feet four inches between sink and tub.	C28*location of DU4. C7*location of DU5. C20 and C4*location of DU6. <u>BEGINS ALTERNATIVE FIVE</u> identifies C29.> C28 and C29*location of DU4. Reads CII.
<u>PM3 7</u> Then two feet four inches between tub and wall. But I don't see anything off the sink. Like here is down to one foot six inches. There's two-four. I don't see anything that has it close-up against the wall. Well, I'll operate under the assumption that of two feet to see what it'd look like. That is, to build sort of an island. (Draws Figure P then Q.) That's cramping up already.	Identifies C12. Locates DU4 & DU5. C33*location of DU6. Locates DU1. C22 x "cramping up already".
<u>PM38</u> Getting back to the same problem we had before....There's not enough room. What I've done,,what started me along these lines was if the sinks are by the window you could utilize some of the light. Then I thought, what would happen if the mirrors were actually facing the window? So that even if you had a head shadow there with diffused light	Explains alternative five. [C28] [C29]
<u>PM39</u> it would be an additional source besides your incandescent light or flourescents which would be mounted over the sink. But, we're getting back to the same problem. Evidently,to have a floating unit or one standing out in the middle like this, you need more space to be able to work around it. Because by the time I put the thing out there, I haven't got the width. I was going to back this up with storage. I think the first design will be the best one. I seem to have a set for certain parts of the design.	Identifies DU11, REJECTS ALTERNATIVE FIVE RETURNS TO ALTERNATIVE FOUR

Figure IIg

PM40 I like the bathtub and watereloset in this position. They're efficiently related so as to take up little space and have efficient plumbing which can be in this one wall. Though there may be another arrangement which is better, like this one. (Draws Figure R, then S.) For storage, it would be required to have built-ins in the cabinets. They should be all we will need....I like the window and door being close to the wall. It looks less arbitrary.

[C21]
Locates DU1 and DU4.
C4 x.
C20*location of DU9 and DU10.

PM41 I think they could both be the minimum normal size. Again, I would like to utilize the view. (Makes site lines from door into bathroom.) (Adds to sketch as in Figure S.)... I'm worried about that wasted space here (in corner of cabinets). We need as much useful cabinet space as possible. (Draws Figure T.)

[C14]
C26 x"wasted space here".
C7 and C33*location of DU5.
Measures wall.

FM42 We have four feet of cabinet along this wall, which is satisfactory for two counters... I think this is about the solution I would offer, It has two sinks with more counter space than before. I'll keep the watercloset and tub like they were in the original design—but put a glass panel in above the tub. I want this tub here because it is out of the view from the doorway.

[C7 x] "satisfactory for two counters".
[C3]
[C8]
[Locates DU3b]
C14*location of DU3.

PM43 I might extend this wall around the watercloset to be flush with the "W.C." box (Adds to sketch as in Figure T.)...I've added this "L" cabinet with a full length mirror five feet long. About a foot between sinks seems satisfactory with storage beneath. There's no medicine cabinet. All that sort of thing can go in the one foot area. Wait a minute!

C14*location of DU12.
<DU5 ≡ DU6 ≡ DU5.>
No DU8.

PM44 Why no medicine cabinet?.[1]! To have a cabinet in this design it would have to be five feet long and much too expensive. I could have a mirror and a floating element below it. It would extend out, say, about six inches...... (Draws Figure U.) We can't have six inches and only four inches clearance to the faucets.

Identifies DU7. Identifies DU7a.
C2 x DU7a "too expensive".
Identifies DU7b <C2x(DU7a=DU7b).
<u>USES ANOTHER REPRESENTATION</u>
Locates DU7b.
Retrieves C30 from memory.
C30 x DU8b. "can't have..."

o. p. q. r. s. t.

Figure IIh

The medicine cabinet must be about three inches—which is about their normal depth anyway. I've lived in places without a medicine cabinet . . . .

PM45 I'll consider putting a rotary tray in the center of this one foot area. Children won't have need for getting into the cabinets every-day. This storage area would stop at the window edge. That gives us plenty. (writes 2'x2x 2'6" =10). It totals about ten cubic feet total, not including the area under the sink.

GOES BACK TO FIGURE "T.
Identifies DU7c.
Locates DU7c.
C5 x.(?)
C20* location of DU6.
Measurements ≡.

PM46 It would be for towels and linen, etc. There's also semi-usable space for children's winter clothing in the corner space...Let's see. I guess sliding doors are more expensive than the regular kind. But if possible, I'd like to see sliding doors that go right into the space. At least one shelf would be circular, lazy susan type...(Adds sliding door and tray to Figure U, as shown.) Going back to the cabinet, I would put towel racks at the end of both cabinets. That would make them accessible.

Identifies DU6a and DU6b.
C2 x (DU6a ≡ DU6b).
? x
[Locates DU7c.]
Locates (DU7c and DU6a).
C24* location of DU13.

PM47 There might be a problem in closing the drapes. Usually in bathrooms, they are pulled closed without pull cords. But if the window's frosted glass, drapes seem a more decorative element. I'll leave it the same as it now is. The plan seems spacious enough, and offers clear passage to all the different fixtures.

Retrieves C31 from memory.
C31 x.
[C8]
[C22]

PM48 The towels might go on the back of the bath or maybe outside on this wall. That would be nice for guests, because you could show off your best towels in a highly visible place. . . . . I guess that's it.
48:50

[C24*location of DU13.] Identifies C32.
[C24 and C34*location of DU15.]

u.

v.

Figure Ili

SUBJECT'S BEHAVIOR GRAPH

Legend: I ≡ identify; A ≡ associate ; O ≡ operate ; T ≡ evaluate .

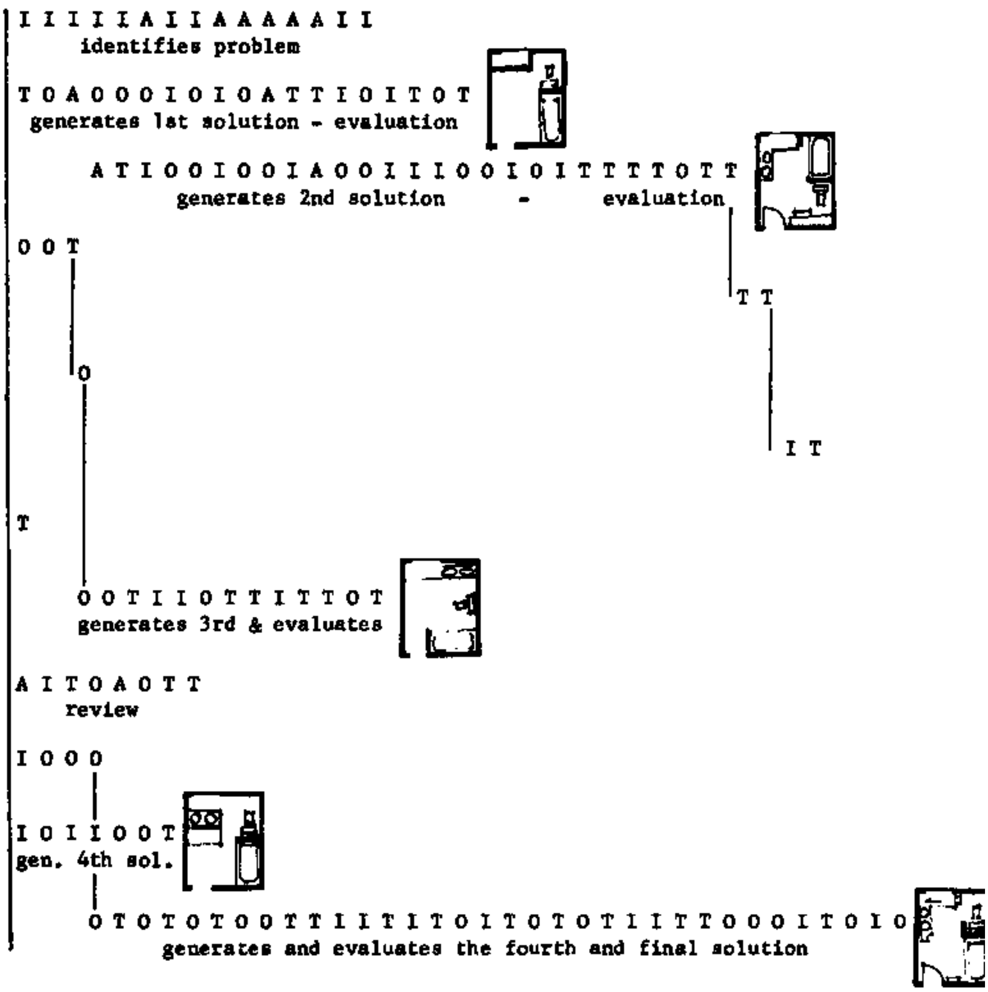


Figure III. Schematic behavior graph of processing carried out by the S. Time is in the direction of across the graph then down. Processing which begins with a partial solution or cycles between two solutions can be identified. Each symbol represents a transformation.

DESIGN CONSIDERATIONS, CONSTRAINTS AND GOALS

The following are written interpretations of the information utilized in specifying and resolving the problem.

Information Given in the Problem Statement;

C1. A more luxurious bath was desired.
C2. The redesign should not cost more than fifty dollars greater than the existing design.

Information Given by the Experimenter (Client):

C3. Two sinks are desired.
C4. More storage is desired.
C5. Most potential buyers have young children.
C6. Boundaries of the room should not be altered.
C7. Sinks take up about twenty inches of counter space apiece.
C8. The existing window opens and is frosted.
C9. Bathroom counters are normally twenty-two inches deep.

Information Retrieved from Other Documents:

C10. Bathtubs should have an adjacent drying space at least twenty-eight inches wide.
C11. Waterclosets require two feet clear space in front for their use.
C12. Sinks require about twenty-four inches in front for their use.

Information Recalled from Memory:

C13. Bathrooms require privacy.
C14. Toilets and bathtubs should not be directly exposed to the door.
C15. Children require space for their dirty clothes.
C16. Dirty clothes are cleaned in a washroom.
C17. Light from the window should be unobstructed.
C18. Free counter space is desirable.
C19. Some use should be found for every partially bounded subspace.
C20. Elements look well arranged If their edges align.
C21. Distances between plumbing fixtures should be minimized.
C22. Circulation areas must be wider than eighteen inches.
C23. Doors should swing open against a partition.
C24. Towels should be located on an empty vertical space near to where they will be used, e.g., sink and bathtub.
C25. Towels should be hung in a dry space.
C26. Storage space should be easily accessible.
C27. Shower rods need walls at their ends for support.
C28. Sink areas should receive some natural lighting.
C29. Light can be bounced off a mirror for added distribution.
C30. Area over faucets must be clear for their use.
C31. Curtains should be easy to reach for their operation.
C32. Some towels should be able to be displayed.
C33. Sinks should be so located that a mirror can be located behind them.
C34. To justify storage space, specific uses should be identified.

Figure IV.

DESIGN UNITS

Below are the physical elements which were selected and arranged during the problem solving sequence. They are hierarchically arranged according to the physical elements of which they are a part.

PUT: toilet - bathtub combination
- DU2: toilet
- DU3: bathtub
  - DU3a: bathtub with curtain enclosure
  - DU3b: bathtub with glass enclosure

DU4: counter
- DU5: sinks (including mirror)
- DU6: general storage
  - DU6a: storage with sliding doors
  - DU6b: storage with hinged doors
  - DU6c: clothes hamper
- DU7: medicine cabinet
  - DU7a: located behind mirror
  - DU7b: located below mirror
  - DU7c: located in the counter cabinet as a rotary tray
- DU8: counter work area
- window
- door
- light fixtures
- partitions
- DU13: towelracks

OPERATORS

The following operations were identified as processes described by the protocol. They are categorized according to what kind of data structure they operated upon.

Space Planning Operations:
- locate a DU
- remove a DU

Arithmetic Operations:
- s ::= numerical comparison or computation

Tests, as Applied in All Representations:
- X ::= evaluation of alternatives
- * ::« guides generation of locations

Semantic Operations:
- a~b ::- a is associated with b
- aeb ::= a is a component of b
- Identification operations are written out.

Context of Operations:
- .... ::= operation externally recorded
- [ ] ::= operation verbally repeated
- < > ::« implicit operation

Figure V.

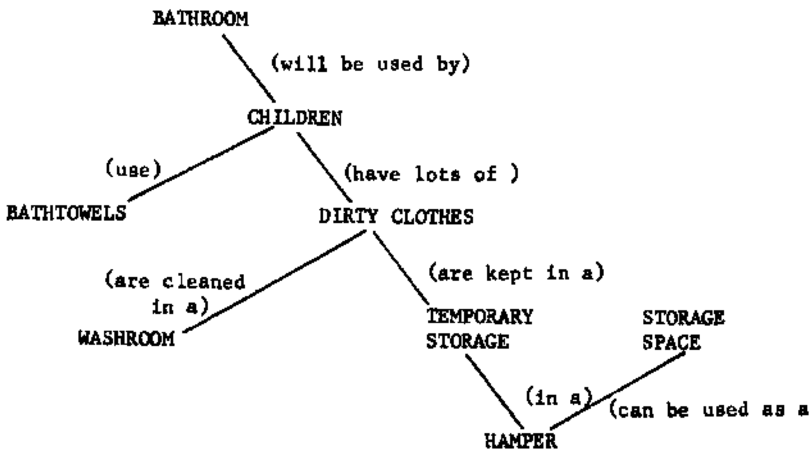


Figure VIa

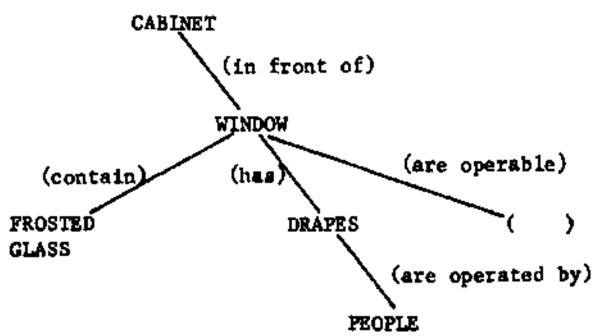


Figure VIb. These two diagrams record the sequential retrieval of information. Time generally is in the direction from top to bottom.

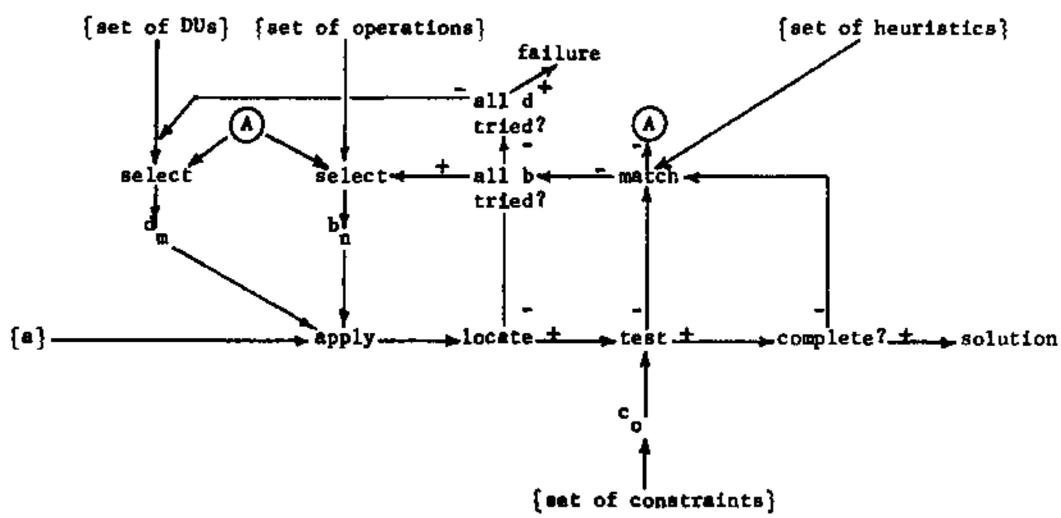


Figure VII. A schematic flowchart of the search aspect of space planning problems.