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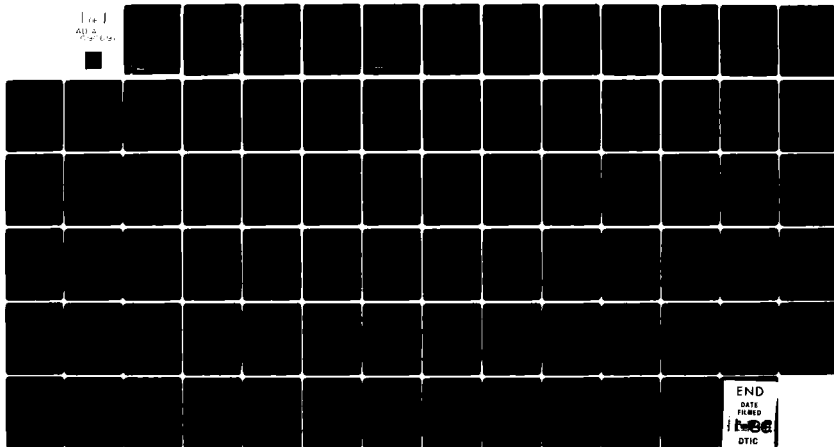
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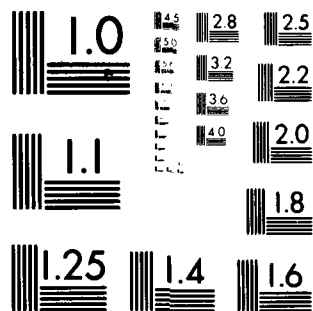
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FLEXIBILITY IN EXECUTIVE STRATEGIES

Barbara Hayes-Roth

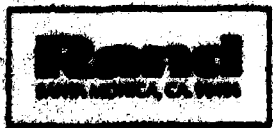
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Executive strategies determine the allocation of cognitive resources during problem-solving. Earlier research has suggested that people can adopt alternative strategies for solving particular problems. This note examines an "opportunistic" model of executive strategies and evaluates some of its predictions for performance of an errand-planning task. Five experiments confirmed that (a) people can adopt different strategies for this task; (b) people can learn new strategies from explicit instruction or from experience; (c) problem characteristics can influence which strategy people adopt; and (d) adopted strategy interacts with problem characteristics to determine planning time and number and importance of planned errands. The results also suggest that some people have a proclivity toward adopting a particular strategy and resist adopting a new one. Implications of the results and desirable properties of the model are discussed.

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A RAND NOTE

FLEXIBILITY IN EXECUTIVE STRATEGIES

Barbara Hayes-Roth

September 1980

N-1170-ONR

Prepared For

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PREFACE

This Note documents a series of Rand experiments on the strategies that people use to control their own planning activity. The results illustrate the inherent flexibility of cognitive strategies as well as an apparent human predisposition to prefer particular strategies. The results are related to a cognitive model of the planning process described in Rand Report R-2366-ONR, Cognitive Processes in Planning.

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SUMMARY

Executive strategies determine the allocation of cognitive resources during problem-solving. Earlier research has suggested that people can adopt alternative strategies for solving particular problems. This Note examines an "opportunistic" model of executive strategies and evaluates some of its predictions for performance of an errand-planning task. Five experiments confirmed that (a) people can adopt different strategies for this task; (b) people can learn new strategies from explicit instruction or from experience; (c) problem characteristics can influence which strategy people adopt; and (d) adopted strategy interacts with problem characteristics to determine planning time and number and importance of planned errands. The results also suggest that some people have a proclivity toward adopting a particular strategy and resist adopting a new one. Implications of the results and desirable properties of the model are discussed.

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I. INTRODUCTION

An executive strategy is a set of decisions regarding the allocation of cognitive resources during problem-solving. Thus, it determines which of several cognitive operations a problem-solver performs at each point in the problem-solving process. For example, in choosing a chess move, a player can consider a variety of data and, as a consequence, choose one of several moves. Presumably, an executive strategy determines which data the player considers and which move she or he chooses to make. The problem-solver may or may not consciously adopt a particular strategy. However, some strategy is presumably implicit in all problem-solving behavior (Bruner, Goodnow, & Austin, 1956).

For many problem-solving tasks, several alternative executive strategies can produce satisfactory solutions (Amarel, 1968; Anzai & Simon, 1979; Bruner, et al., 1956; Greeno & Simon, 1974; Newell & Simon, 1972; Simon, 1975). Bruner et al. (1956) documented individuals' adoption of a range of strategies for concept-attainment tasks. Other researchers have induced people to adopt different strategies for other kinds of problem-solving tasks (e.g., Reed, Ernst, & Banerji, 1974; Simon & Reed, 1976). Thus, people exhibit considerable flexibility in their adoption of executive strategies.

How can we model this flexibility in executive strategies? One method might be to simply postulate multiple problem-solving "programs." Each program would organize all of the operations necessary to solve the problem using a particular executive strategy. This would permit different people to exhibit different strategies. Similarly, if one person had several programs, she or he could exhibit different strategies. A

person could also change strategies in the course of solving a problem by interrupting execution of one program and instead executing another.

The multiple-program approach to modeling executive strategies has two major inefficiencies. First, different executive strategies frequently apply to identical or overlapping sets of basic operations. Modeling them as separate problem-solving programs entails considerable redundancy in the representations of their constituent operations. Permitting programs to share subroutines might eliminate some of this redundancy. However, because different strategies often do not share long sequences of operations, the reduction in redundancy from shared subroutines would probably be minimal. Second, this approach leads to arbitrarily large numbers of stored programs for dealing with a single task. As indicated above, researchers have enumerated a variety of executive strategies for particular tasks, and there are undoubtedly others. Further, we can expect people to combine known strategies in idiosyncratic ways. It seems unreasonable to postulate a separate program for each strategy and combination of strategies possible for a given task.

The multiple-program approach also resists postulation of simple acquisition mechanisms. How do people acquire new strategies? Obviously, one could acquire a new program in a straightforward way from explicit instruction. But how would one acquire it from experience? It is unlikely that one would carry out a complete strategic program by chance. It is still less likely that one would do so enough times to detect its utility and commit it to memory. Considering the large number of hybrid strategies a person might, in principle, apply to a given task, the assumption that each one could have been learned intact

becomes untenable.

Alternatively, we might view problem-solving as the activity of a production system (Newell, 1972; Newell & Simon, 1972; Waterman & Hayes-Roth, 1978). A person might possess many independent rules, each of which could perform a single operation. Presumably, the person could organize the application of these rules according to different executive strategies. This approach would provide the flexibility of the multiple-program approach while avoiding some of its inefficiencies.

However, we still need a model of executive strategies per se. How should we represent different strategies? How do different strategies get invoked? What variables influence the invocation and switching of strategies?

Recently, Hayes-Roth and Hayes-Roth (1978, 1979) proposed an "opportunistic" model of executive strategies. The model assumes that an executive strategy comprises a set of decisions regarding allocation of cognitive resources. These include decisions about the overall organization of problem-solving activity as well as decisions about which specific operations to perform at particular points in the solution process. People presumably make explicit executive decisions in the course of solving a problem. Further, in making these decisions, they use the same kind of rules they use in problem-solving and they "record" the resulting decisions in the same data base in which they record decisions about problem solution.

This Note will examine the opportunistic model and test some of its predictions. The next section reviews the model as it applies to an

errand-planning task.[1] The third section shows how the model would implement two different executive strategies for performing the task. The fourth section derives predictions for performance under each strategy. The next sections report five experiments which test the model's predictions. The final section discusses implications of the experiments and some additional properties of the model.

[1] For a more detailed account of the model and the justification of its assumptions, see Hayes-Roth & Hayes-Roth (1979), Hayes-Roth, Hayes-Roth, Rosenschein, & Cammarata (1979), and Hayes-Roth & Thorndyke (1980).

II. REVIEW OF THE OPPORTUNISTIC MODEL

To facilitate this discussion, consider an errand-planning task. For this task, the problem-solver receives (a) a list of desired errands; (b) contextual information bearing on but not explicitly specifying the importance and amount of time required for each errand; (c) a map of the town in which to perform the errands; and (d) starting and ending times and locations. Thus, the problem-solver must decide (a) which errands to include in the plan; (b) when to perform each errand; (c) how much time to allocate for each errand; and (d) what route to traverse between successive errands.

The opportunistic model assumes that the problem-solving process comprises the activities of many independent cognitive "specialists." [1] Each specialist is a rule or heuristic that suggests a specific decision for incorporation into the plan. The model assumes that different specialists suggest decisions at different levels of abstraction. Thus, some specialists suggest high-level decisions that have far-reaching implications for future additions to the plan, while others affect only very specific details of the plan.

[1] Hayes-Roth and Hayes-Roth (1978) introduced the term "specialists" to distinguish the more complex, pattern-directed activity of the rules they postulated from the simpler, symbol-manipulating activity originally associated with production rules (Newell & Simon, 1972). In this respect, specialists are similar to the "knowledge sources" of Hearsay-II (CMU Computer Science Research Group, 1977), the cooperative "beings" discussed by Lenat (1975), and the pattern-directed modules of many other artificial intelligence systems (Hayes-Roth, Waterman, & Lenat, 1978).

Figure 1 illustrates several levels of abstraction at which specialists might suggest decisions.[1] Beginning at the top level, some specialists suggest particular outcomes, indicating what the plan should accomplish when the planner carries it out (e.g., which errands to accomplish). Other specialists suggest designs characterizing the general organization of the plan (e.g., which spatial cluster of errands to perform first, next, and so on). Other specialists suggest procedures specifying sequences of actions (e.g., which sequence of individual errands to perform). Finally, some specialists suggest operations specifying details of the actions (e.g., which route to traverse from each errand to the next or how to perform an individual errand).

Each specialist has a condition component and an action component. The condition component characterizes the situation to which the specialist's heuristic applies. Ordinarily, a condition will require a particular prior decision. The action component defines the specialist's behavior. Ordinarily, the action will suggest a new decision for incorporation into the plan.

Whenever a situation satisfies a specialist's condition, the specialist is invoked and enters a queue of specialists waiting to execute their respective actions. As each specialist executes its action, it records its suggested decision in a global data base, the "blackboard." (Figure 1 represents part of the complete blackboard postulated in

[1] Hayes-Roth and Hayes-Roth (1978) assume that a variety of other kinds of decisions occur during the planning process. For the present purposes, however, we need only consider the kinds of decisions indicated in Figure 1 and the executive decisions indicated in Figure 2.

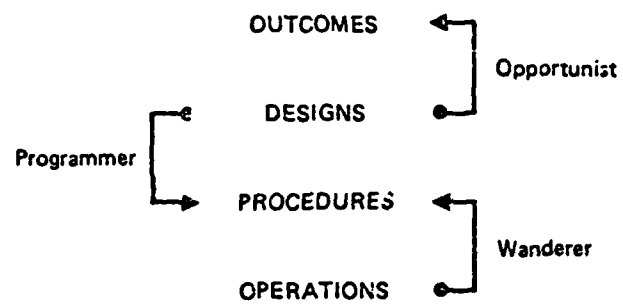


Figure 1. Levels of abstraction and illustrative specialists

Hayes-Roth and Hayes-Roth (1978).) This enables the specialists to influence one another indirectly. For example, the condition of one specialist might require that a particular prior decision, generated by some other specialist, appear on the blackboard. Thus, the former specialist would be invoked only if the latter had already been invoked and had executed its action.

A few examples of specialists and their behavior will clarify the concepts introduced above. Figure 1 illustrates the behavior of three specialists, referred to as the programmer, the wanderer, and the opportunist. The circle and arrow ends of the arc associated with each specialist indicate the levels of abstraction at which its condition and action appear. For example, the programmer gets invoked when a new design appears on the blackboard. When executed, it suggests a procedure that would implement the design. The opportunist also gets invoked when a new design appears on the blackboard. When executed, it suggests outcomes that would be easily achieved if the design were adopted. The wanderer gets invoked when a new operation appears on the blackboard. When executed, it suggests a procedure that incorporates the operation.

Note that some specialists operate top-down, suggesting new decisions at levels lower than those at which their condition decisions occur. Other specialists operate bottom-up, suggesting new decisions at levels higher than those at which their condition decisions occur. This multidirectionality of processing characterizes the opportunistic model and distinguishes it from other models of planning (e.g., Sacerdoti, 1974, 1975).

The model assumes that many specialists simultaneously monitor the blackboard for the occurrence of decisions specified in their conditions. As their conditions are satisfied, invoked knowledge sources queue up for execution. Thus, at any point in the planning process, a potentially large number of invoked specialists await execution. Presumably, executive decisions determine which of the currently invoked specialists should execute its action next. These decisions, of course, determine which specialists are invoked subsequently. As a consequence, different sequences of executive decisions can produce top-down, bottom-up, or more complex strategies.

The model assumes that people make executive decisions by the same type of process they use to make decisions about the plan itself. Thus, it assumes that a variety of independent specialists suggest executive decisions at different levels of abstraction. Thus, some specialists suggest high-level executive decisions which have far-reaching implications for allocation of cognitive resources throughout the planning process. Other specialists suggest decisions which affect only short-term allocation of cognitive resources.

Figure 2 illustrates the levels of abstraction at which specialists make executive decisions. Beginning at the top level, some specialists suggest priorities, indicating a preference for allocating processing activity to certain areas of the blackboard before others. For example, the planner might decide to determine what errand sequences one could do conveniently, rather than deciding what errands one ought to do. These priorities would permit specialists that made the former kinds of decisions to execute their actions before specialists that made the latter kinds of decisions. Other specialists suggest a particular focus,

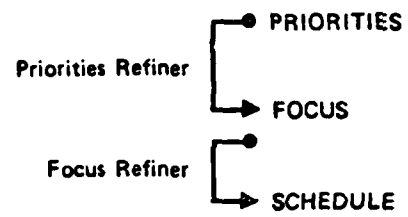


Figure 2. Levels of abstraction for executive decisions

indicating a preference for allocating processing activity to certain areas of the blackboard at the current point in the planning process. For example, the planner might decide to focus attention on generating an operation-level refinement of a previously generated procedure. This focus would permit specialists that made that kind of decision to execute before specialists that made other kinds of decisions. Finally, other specialists suggest particular scheduling decisions, indicating which of the currently invoked specialists should execute its action. If, for example, both the programmer and the wanderer had been invoked and both were consistent with current priorities and focus, the planner might decide to schedule the programmer.

A planner presumably makes many executive decisions in the course of formulating a plan.[1] Frequently, the planner decides on a single set of priorities early in the planning process, and they apply throughout the process. Sometimes, however, the planner makes several priorities decisions, modifying or replacing earlier decisions. The planner typically makes several focus decisions during the planning process. As the plan develops, the planner tries to identify promising areas for subsequent development and to focus cognitive resources in those areas. Focus decisions frequently implement earlier priorities

[1] In general, subjects may or may not make executive decisions consciously. Intuitively, it seems likely that one would make global priorities decisions consciously, while making low-level scheduling decisions more automatically. Several of the experiments reported below confirm that subjects can at least articulate intended executive strategies. However, there are undoubtedly a number of variables which influence a person's consciousness of these decisions.

decisions. However, they need not do so and they might contradict earlier priorities decisions. Finally, the planner will make numerous scheduling decisions. After each decision in the planning process, the planner must decide which of the currently invoked specialists to schedule next. Again, scheduling decisions frequently implement earlier priorities and focus decisions. However, they need not do so and they might contradict earlier decisions.

This conception of executive strategies permits considerable flexibility in the strategy a planner adopts for a problem. For example, different priorities decisions permit the planner to adopt a strictly top-down strategy, a strictly bottom-up strategy, or even a "middle-out" strategy. Other priorities decisions might produce various combinations of these or other strategies. In addition, the planner can change previous priorities decisions at any point in the planning process. The planner's capacity to make independent focus and schedule decisions permits decisions to depart temporarily from the current priorities. For example, the planner might decide initially to work top-down but constrain subsequent decisionmaking to include particular low-level decisions. Independent focus and scheduling decisions might even lead the planner to complete the planning process without ever following the prescription of an early priorities decision.

III. IMPLEMENTATION OF ALTERNATIVE EXECUTIVE STRATEGIES

This section explains how the proposed model implements two alternatives: the traveling salesman strategy and the scheduling strategy. As discussed above, the model permits a planner to adopt a variety of alternative strategies. These two were selected for study because they have already been studied extensively by computer scientists and graph theorists (Aho, Hopcroft, & Ullman, 1974; Christophides, 1975) and because they are easy to distinguish experimentally.

The traveling salesman strategy emphasizes finding an efficient route among the errands. The planner reasons forward from the starting location, planning successive errands to minimize route distances. Under this strategy, most decisions would occur at the operation and procedure levels of the blackboard (Figure 1). These decisions would implicitly determine design- and outcome-level decisions. Thus, the traveling salesman strategy is basically a bottom-up strategy.

The scheduling strategy responds to a perception of insufficient time to perform all of the errands by emphasizing the completion of important tasks. The planner first decides which errands to perform and then decides how to organize the plan, sequence errands, and travel between successive errands. Under this strategy, the planner would make outcome decisions first, then design decisions, then procedure decisions, and finally, operation decisions. Thus, the scheduling strategy is basically a top-down strategy.

The following discussion shows how the opportunistic model would implement each strategy as a series of executive decisions. In some ways, the discussion greatly simplifies the model's assumptions. These

simplifications preserve the main features of the model but avoid unnecessary detail. Some of the simplifications are noted in the discussion, but see Hayes-Roth and Hayes-Roth (1978) and Hayes-Roth, Hayes-Roth, Rosenschein, and Cammarata (1979) for more detailed descriptions of the model and its implementation.

Table 1 lists ten specialists. The first six (ES1-ES6) are executive specialists. They generate decisions on the executive blackboard (Figure 2). The remaining four specialists (PS1-PS4) are plan specialists. They generate decisions on the plan blackboard (Figure 1). Note that Table 1 contains English-language descriptions of the specialists. Of course, the LISP code necessary to implement these specialists in a computer simulation is considerably more complex. In addition, the specialists in Table 1 are more powerful than those currently implemented in the model. In particular, each plan specialist in Table 1 aggregates the behavior of three to five more molecular specialists distinguished in the current model.

Table 2 schematizes the series of executive decisions that would implement the traveling salesman strategy. Presumably, the problem description presented to the planner provides sufficient time to perform the errands. Since that information satisfies ES1's condition, it establishes initial priorities to find an efficient route among the errands. These priorities satisfy ES2's condition, so it suggests a decision to focus on the operation level. Given this focus, ES5 schedules PS4, the route planner. PS4 produces alternative routes at the operation level of the plan blackboard (not shown). At this point, an errand must be planned before the route can be extended, so ES2 changes the focus to the procedure level. Given this focus, ES5

Table 1

EXAMPLES OF EXECUTIVE AND PLAN SPECIALISTS

Executive Specialists

- ES1: If there is adequate time to perform all errands
Then set priorities to find an efficient route among the errands
- ES2: If priorities are to find an efficient route among the errands
Then focus on the lowest level at which a decision can be made
- ES3: If there is insufficient time to perform all errands
Then set priorities to establish intended outcome before
deciding on details of plan
- ES4: If priorities are to establish intended outcome before
deciding on details of plan
Then focus on the highest level at which a decision can
refine the most recent higher-level decision
- ES5: If a focus has been established
Then schedule a specialist that operates at the level in focus
- ES6: If at least one specialist can be scheduled
Then schedule the most recently invoked specialist

Plan Specialists

- PS1: If errands differ in importance
Then establish the most important errands as intended outcomes
- PS2: If intended errands form convenient spatial clusters
Then formulate a design that moves from starting location
through clusters to ending location in order of proximity
- PS3: If an intended errand is near the current location
Then insert it as the next errand in the procedure
- PS4: If the current location is an errand site
Then establish routes leading away from that site as
alternative new current locations

Table 2
IMPLEMENTATION OF TRAVELING SALESMAN STRATEGY

Executive Decisions	Level of Abstraction		
	Priorities	Focus	Schedule
First set	ES1 -> Find an efficient route among the errands	ES2 -> Operation	ES5 -> PS4: Route planner
Second set		ES2 -> Procedure	ES5 -> PS3: Errand planner
Third set		ES2 -> Operation	ES5 -> PS4: Route planner
Fourth set		ES2 -> Procedure	ES5 -> PS4: Errand planner

schedules PS3, the errand planner. PS3 changes the current location to an errand site. It is now possible to extend the route, so ES2 changes the focus to the operation level, and ES5 schedules PS4, the route planner. The problem-solver continues alternating route planning and errand planning in this fashion until a complete plan emerges.

Table 3 schematizes the series of executive decisions that would implement the scheduling strategy. Presumably, the problem description presented to the planner provides insufficient time to perform the errands. Since that information satisfies ES3's condition, it establishes initial priorities to establish the intended outcome before deciding on the details of the plan. These priorities satisfy ES4's condition, so it suggests a decision to focus on the outcome level. Given this focus, ES5 schedules PS1, the errand evaluator. PS1 produces a list of intended errands at the outcome level of the plan blackboard (not shown). Given this outcome decision, ES4 changes the focus to the design level, and ES5 schedules PS2, the cluster detector. PS2 generates a design organized around spatial clusters of intended errands. Given this design, ES4 changes the focus to the procedure level, and ES5 schedules PS3, the errand planner. PS3 plans the "first errand" in accord with the established design. Because this changes the current location to an errand site, ES4 changes the focus to the operation level, and ES5 schedules PS4, the route planner. PS4 plans the route connecting the starting location to the planned first errand. Given that refinement, ES4 changes the focus back to the procedure level, and ES5 schedules PS3, the errand planner. The planner continues planning errands in accord with the design and routes to connect the errands until a complete plan emerges.

Table 3
IMPLEMENTATION OF SCHEDULING STRATEGY

Executive Decisions	Level of Abstraction		
	Priorities	Focus	Schedule
First set	ES3 -> Establish intended outcome before details	ES4 -> Outcome	ES5 -> PS1: Errand evaluator
Second set		ES4 -> Design	ES5 -> PS2: Cluster detector
Third set		ES4 -> Procedure	ES5 -> PS3: Errand planner
Fourth set		ES4 -> Operation	ES5 -> PS4: Route planner

Comparison of Tables 2 and 3 shows that for a given number of planned errands, the scheduling strategy requires more decisions than the traveling salesman strategy. Both strategies require a pair of related decisions at the procedure and operation levels, along with the associated executive decisions, for each planned errand. In addition, the scheduling strategy requires preliminary higher-level decisions at the outcome level and perhaps at the design level, along with their associated executive decisions. This difference in number of required decisions underlies predictions about planning time discussed below.

Before continuing, a few simplifications in the preceding discussion should be noted. First, the discussion ignores the scheduling of executive specialists. The model schedules executive specialists exactly as it schedules plan specialists, using rules such as ES6. These decisions were omitted for brevity. Second, the discussion suggests that implementation of either of these strategies would produce a straightforward sequencing of a few specialists. In fact, our simulation of the model (Hayes-Roth et al., 1979) includes many more specialists. Frequently, several specialists have true conditions simultaneously and, as a consequence, they compete for scheduling. Competitors may operate at the same or different levels of abstraction. Further, alternative executive specialists resolve these conflicts differently. In some cases, scheduled specialists might even contradict the chosen strategy. Thus, the actual performance of the model is considerably more complex than the activity represented in Tables 2 and 3. For the present purposes, however, these simplifications do not alter the model's predictions.

IV. PREDICTIONS FOR PERFORMANCE OF THE ERRAND-PLANNING TASK

The experiments reported below investigated the consequences of adopting the traveling salesman strategy versus the scheduling strategy for the errand-planning task. The experiments shared the following basic methodology. Immediately upon presentation of a problem, subjects recorded the time. Subjects then read the problem. An example follows:

You need to plan some errands before going home to give your son a birthday party. Here are the errands you want to do:

- > pick up a package at post office (26)
- > buy hooks for hanging plants at hardware store (77)
- > buy ice cream for your son's birthday party (58)
- > buy a birthday cake (6)
- > buy party decorations at the card and gift shop (37)
- > buy your son a baseball bat at sports equipment store (27)
- > buy a few items at Pine Street pharmacy (54)
- > exchange your new tea kettle at Truc (61)
- > sign some papers at lawyer's office (53)

You are starting from the Maple Street parking structure (56). It's 10:30 now and you have to pick up your car at 2:00 in order to get home in time for the party. It takes about fifteen minutes to cross town in either direction.

As this problem illustrates, problems provided only implicit information regarding errand importance and time requirements. Presumably, the birthday party context would lead most people to assign greater importance to those errands associated with the party than to others. Time estimates relied on world knowledge.

After reading the problem description, subjects responded to the instruction: "In two or three sentences, describe how you plan to solve this problem." Then they formulated plans for performing the errands in the fictional town shown in Figure 3. Each picture on the map in Figure 3 symbolizes a particular store or other destination. Instructions for

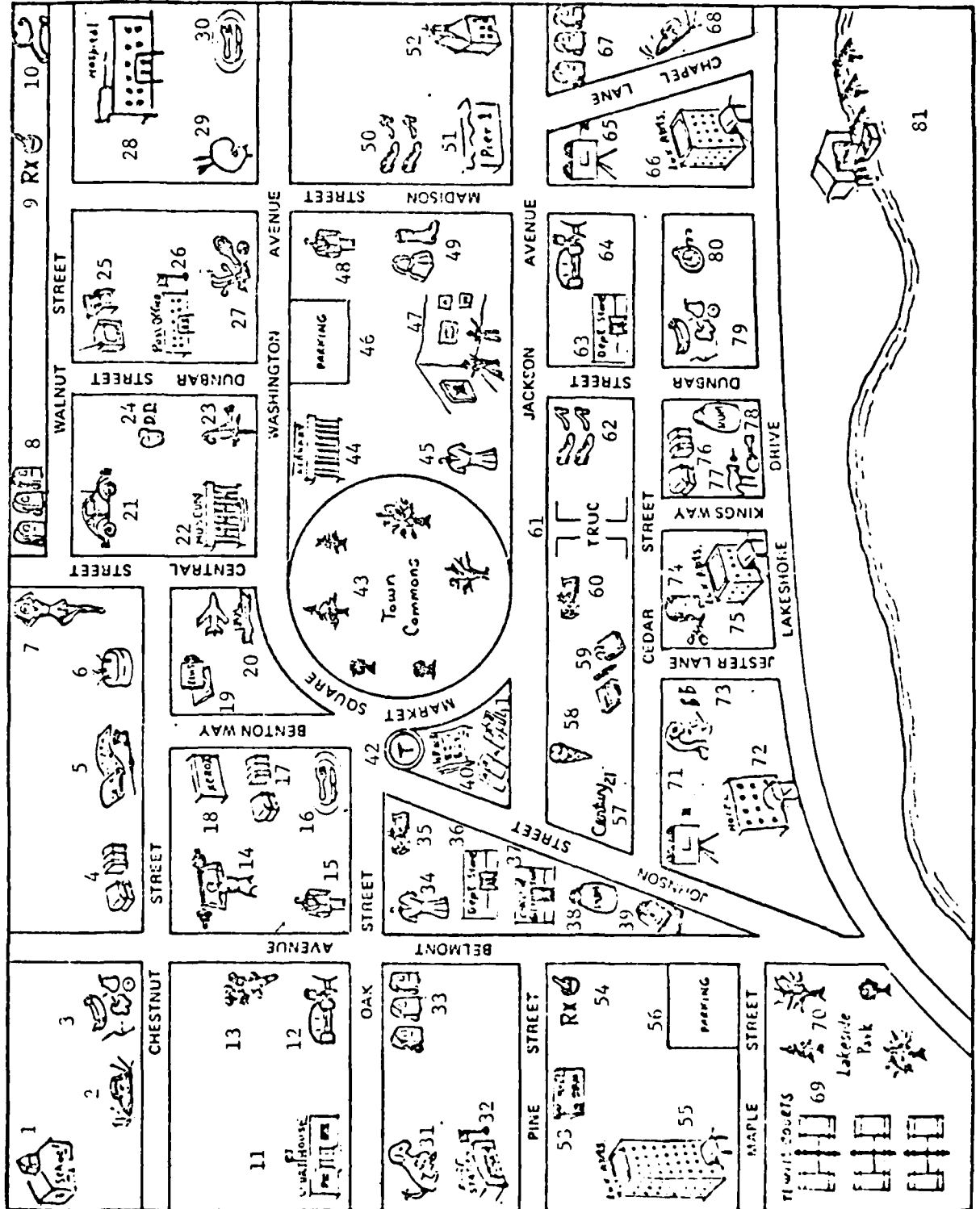


Figure 3. Town map.

each problem referred to errands by the numbers associated with each symbol on the map, as illustrated in the example above. Immediately upon completing their plans, subjects again recorded the time.

In Experiment 1, subjects spontaneously adopted the strategy of their choice. In Experiments 2 and 4, the experimenter instructed subjects to adopt one of the strategies in particular. In Experiments 3 and 5, the experimenter instructed subjects to adopt one of the strategies on several "primer" problems to induce strategy transfer on subsequent problems.

Subjects' self-reports should reflect the strategy they adopt. Subjects who adopt the traveling salesman strategy should emphasize designing an efficient route. Subjects who adopt the scheduling strategy should emphasize planning the most important errands before working out the details of the plan. In addition, the model predicts that adoption of a particular strategy should influence planning time, number of planned errands, and average importance of planned errands. Each of these predictions is discussed below.

The model predicts that planning time (measured as the difference between the two times a subject recorded) will be shorter when subjects adopt the "appropriate" executive strategy than when they adopt the "inappropriate" executive strategy for a problem. Consider problems that provide sufficient time for planning all the errands. For these problems, the traveling salesman strategy is appropriate. It should produce an efficient route encompassing all of the errands. The scheduling strategy will also produce a reasonable plan. However, as discussed above, its implementation entails more decisions than does implementation of the traveling salesman strategy. Therefore, planning

time should be longer for these problems when subjects adopt the scheduling strategy than when they adopt the traveling salesman strategy.

Consider problems which provide insufficient time for planning all the errands. For these problems, the scheduling strategy is appropriate. It insures inclusion of the most important errands in the plan, leaving the planner the option of including less important errands if time permits. The traveling salesman strategy is inappropriate for these problems. An efficient route through all the errands would be an unrealistic plan. Presumably, many subjects will recognize this problem at some time during the planning process and will have to revise their plans. This planning and replanning under the traveling salesman strategy should produce longer planning times than planning under the more appropriate scheduling strategy.

The executive strategy adopted should also influence the number and importance of planned errands. As illustrated in Table 2, the traveling salesman strategy leads to indiscriminate inclusion of all or most errands in the plan. As illustrated in Table 3, the scheduling strategy selects only the most important errands for inclusion in the plan. Therefore, subjects should plan fewer but more important errands under the scheduling strategy than under the traveling salesman strategy.

The following experiments tested these predictions.

V. EXPERIMENT 1

Subjects worked on the errand-planning problem given above. For half the subjects, the starting time was 10:30. For the remaining subjects, the starting time was 12:00. These two versions of the problem are referred to as the T problem (traveling salesman strategy appropriate) and the S problem (scheduling strategy appropriate).

The experiment addressed two questions. First, do subjects have both the traveling salesman strategy and the scheduling strategy in their repertoires? If so, some subjects' statements of intended executive strategy should indicate each strategy. Second, assuming subjects know both strategies, do they adopt the appropriate strategy for a given problem? If so, subjects who work on the T problem should indicate the traveling salesman strategy, while subjects who work on the S problem should indicate the scheduling strategy. In addition, subjects in these two groups should produce plans that differ in the number and importance of planned errands, as discussed above.

METHOD

The method was essentially as described above. After reading the problem, subjects reported their intended strategy. They then wrote their plans on forms provided by the experimenter. Subjects tried to write their plans so that a stranger could carry them out exactly as they would. Thus, they indicated which errands to perform, the times at which to begin and finish each errand, and how to travel between successive errands. Forty UCLA undergraduates served as subjects.

RESULTS AND DISCUSSION

Subjects' statements of intended executive strategy were classified as representing the scheduling strategy, the traveling salesman strategy, both strategies, or neither strategy. A statement represented the scheduling strategy if it emphasized planning all of the most important errands before incorporating other errands in the plan. For example, one subject wrote:

I plan on definitely getting the items I need for my son's birthday. Then, if there are any stores very close to the ones I have to go to, I will run into them too.

A statement represented the traveling salesman strategy if it emphasized design of an efficient route. For example, one subject wrote:

I would try and make a circular route. I wouldn't want to do any backtracking.

A statement represented both strategies if it emphasized both errand importance and route efficiency. For example, one subject wrote:

You need certain items for the birthday party so those are the most important. I will not backtrack, but will continue to go in one line.

A statement represented neither strategy if it did not refer either to errand importance or route efficiency. For example, one subject wrote:

Plan to pick up the ice cream and cake last.

A theoretically naive judge classified the statements. Spot-checking by a second judge produced no disagreements.

Table 4 shows the frequencies of statements in each category for each problem. Most subjects adopted the traveling salesman strategy regardless of its appropriateness. Only three of the 33 subjects who indicated an intended executive strategy indicated the scheduling strategy. (One of the three indicated both strategies.) Accordingly, subjects planned comparable numbers of errands for the S and T problems (means = 8.35 and 8.5). They also planned errands of comparable importance for the two problems (median importance = 2.28 and 2.39). [1]

These results suggest that most people have a proclivity toward adopting the traveling salesman strategy, but not the scheduling strategy. This proclivity might reflect either (a) ignorance of the scheduling strategy or (b) disinclination to use it. In either case, we might view the traveling salesman strategy as an instance of the stored general-purpose executive programs discussed by Newell and Simon (1972). Although it is not always the best strategy, the traveling salesman strategy will suffice for many problems requiring scheduling in a spatial environment.

[1] We quantified the importance of an errand as the median rating (1-3) given by an independent sample of ten judges.

Table 4
SELF-REPORTS OF INTENDED EXECUTIVE STRATEGY FOR EXPERIMENT 1

Problem	Intended Strategy			
	Scheduling Strategy	Traveling Salesman Strategy	Both Strategies	Neither Strategy
S	2	13	1	4
T	0	17	0	3

VI. EXPERIMENT 2

Given the results of Experiment 1, we need to determine whether people can adopt either the traveling salesman strategy or the scheduling strategy. That is, do people have the flexibility in executive strategies presumed by the opportunistic model? Newell and Simon (1972) suggested that task instructions might influence executive strategy. The opportunistic model would implement the effects of instruction as the creation of new executive specialists. It would create ES1 and ES2 following instructions in the traveling salesman strategy and ES3 and ES4 following instructions in the scheduling strategy.

Accordingly, in Experiment 2, subjects were instructed to adopt one or the other strategy. Subjects worked with T or S problems, as defined above for Experiment 1. Half the subjects working with each problem received no special instructions, while the other half received instructions to adopt the appropriate strategy.

The predictions are similar to those for Experiment 1. For S problems, adoption of the scheduling strategy should produce shorter planning times and fewer, but more important, planned errands. For T problems, adoption of the traveling salesman strategy should produce shorter planning times and more, less important, planned errands. However, Experiment 1 suggested that most people spontaneously adopt the traveling salesman strategy. Therefore, instruction and problem type should interact. Instructions to adopt the scheduling strategy for S problems should produce greater effects than instructions to adopt the traveling salesman strategy for T problems.

METHOD

The method was similar to the method for Experiment 1, with these exceptions. First, subjects solved three errand-planning problems, rather than one. Second, half of the subjects worked on problems that contained strategy instructions. For example, one T problem contained the following instruction:

You have a blister on your left foot from hiking last weekend, so you want to minimize the amount of walking around you do. Find the shortest route you can that permits you to do your errands.

One S problem contained the following instruction:

Since you only have two hours, you can't possibly do all the errands on your list. So first decide which errands are really important and be sure to include them in your plan. Then, if you have time to do any other errands, include them too.

Thus, the experiment crossed executive strategy instruction (none versus appropriate) with problem (T versus S) in a between-subjects design. Eighty UCLA undergraduates served as subjects.

RESULTS AND DISCUSSION

The first panel in Table 5 shows the mean time to formulate a plan for each of the four conditions. The results show the predicted interaction between instruction and problem ($F(1,76) = 13.04, p < .001$). Instructions to adopt the scheduling strategy substantially reduced planning time for the S problems. However, instructions to adopt the traveling salesman strategy did not reduce planning time for the T problems.

Table 5
PLAN CHARACTERISTICS FOR EXPERIMENT 2

Problem	Instruction	
	None	Appropriate
Planning Time (minutes)		
S	13.95	8.95
T	9.36	9.40
Number of Errands Planned		
S	5.73	4.30
T	5.87	5.88
Mean Importance of Planned Errands		
S	1.86	2.07
T	1.88	1.87

The second and third panels in Table 5 show the mean number and importance of planned errands for each of the four conditions. Both variables show the predicted interaction ($F(1,76) = 55.97, p < .001$ for number of planned errands; $F(1,76) = 34.47, p < .001$ for importance of planned errands). For S problems, instructions led subjects to plan fewer but more important errands. For T problems, instructions did not affect the number or importance of planned errands.

These results demonstrate that subjects can adopt alternative executive strategies for a single task. In particular, they can adopt either the basically top-down scheduling strategy or the basically bottom-up traveling salesman strategy when planning a day's errands. The observed interactions also confirm the earlier observation that in the absence of instruction, subjects spontaneously adopt the traveling salesman strategy.

VII. EXPERIMENT 3

In a natural setting, people rarely receive explicit instruction regarding executive strategies. Newell and Simon (1972) suggested that previous experience with problems similar to the one at hand might also influence choice of an executive strategy. Previous successful applications of a strategy could reinforce the tendency to make similar executive decisions for subsequent problems. The opportunistic model would implement this effect as an increase in the "goodness" measure (Hayes-Roth & Lesser, 1977) of the corresponding executive specialists. Other things being equal, specialists with higher goodness values are scheduled in favor of those with lower goodness values. Under these assumptions, previous successful applications of the scheduling strategy or the traveling salesman strategy should induce subjects to adopt the same strategy on a subsequent problem. Experiment 3 tested that prediction.

Subjects first worked on three "primer" problems. T primer problems provided sufficient time for performing the errands and instructed subjects to adopt the traveling salesman strategy. S primer problems provided insufficient time for performing the errands and instructed subjects to adopt the scheduling strategy. Solving these problems provided experience with successful application of the prescribed strategy. After solving the three primer problems, subjects worked on a "transfer" problem. Half the subjects in each primer condition worked on an S transfer problem, while the remaining subjects worked on a T transfer problem. Neither version of the transfer problem provided instructions regarding executive strategy.

The predictions for this experiment are similar to those for Experiment 2. Subjects primed to adopt the appropriate strategy for the transfer problem should exhibit shorter planning times than subjects primed to adopt the inappropriate strategy. Subjects primed to adopt the scheduling strategy should plan fewer, but more important, errands than subjects primed to adopt the traveling salesman strategy.

METHOD

The procedure was similar to those for Experiments 1 and 2. First, subjects formulated plans for three T or S primer problems. Then subjects formulated plans for a T or S transfer problem. The experiment crossed primer problem and transfer problem in a between-subjects design. Eighty UCLA undergraduates participated in the experiment.

RESULTS AND DISCUSSION

Subjects' statements of intended executive strategy were scored according to the rules given for Experiment 1. Table 6 shows the frequencies of statements in each category for each of the four conditions. A few subjects in each condition gave neither or both responses. Those subjects were omitted from the analyses, and chi-square statistics were applied to the remaining data.

The first analysis focused on the two-by-two table defined by primer problem (S or T) and intended executive strategy (scheduling strategy or traveling salesman strategy). This analysis collapsed data over transfer problem within each of the primer conditions. As predicted, primer condition had a large effect on subjects' intended executive strategies ($\chi^2 = 40.2$, $p < .001$). Most subjects transferred the primed strategy to the transfer problem. Thus, following S primer problems, 27

Table 6
SELF-REPORTS OF INTENDED EXECUTIVE STRATEGIES FOR EXPERIMENT 3

Transfer Problem	Intended Strategy			
	Scheduling Strategy	Traveling Salesman Strategy	Both Strategies	Neither Strategy
S Primer Problems				
S	15	0	2	3
T	12	5	1	2
T Primer Problems				
S	1	13	0	6
T	1	18	0	1

subjects indicated the scheduling strategy, while only five indicated the traveling salesman strategy. Following T primer problems, 31 subjects indicated the traveling salesman strategy, while only two subjects indicated the scheduling strategy.

We also analyzed the two-by-two tables defined by transfer problem and intended executive strategy separately for each primer condition. Following S primer problems, transfer problem influenced subjects' intended executive strategy ($X^2 = 5.1$, $p < .05$). Subjects primed with the scheduling strategy applied it more often to the S transfer problem than to the T transfer problem. In the latter condition, several subjects spontaneously adopted the more appropriate traveling salesman strategy. Apparently in these conditions, time constraints influenced some subjects to adopt the appropriate strategy. Following T primer problems, on the other hand, subjects apparently chose intended executive strategies independent of transfer problem ($X^2 = .07$). Subjects primed with the traveling salesman strategy adopted that strategy for the transfer problem regardless of its appropriateness.

These results, like the results of Experiments 1 and 2, indicate that many subjects have a natural inclination to adopt the traveling salesman strategy, but not the scheduling strategy. They also suggest that some subjects who have knowledge of both strategies discriminate problems for which each is appropriate (see also Bruner et al., 1956).

The first panel in Table 7 shows the mean time to formulate a plan for each of the four conditions. Planning times varied considerably across subjects, ranging from 3.75 minutes to 40.92 minutes. Times spanned about 25 minutes within each of the four conditions. The between-subjects design made this variability especially problematic.

Table 7
PLAN CHARACTERISTICS FOR EXPERIMENT 3

Transfer Problem	Strategy Induced by the Primer Problems	
	Scheduling Strategy	Traveling Salesman Strategy
Planning Time (minutes)		
S	11.23	14.96
T	13.92	13.31
Number of Errands Planned		
S	5.70	8.45
T	7.95	8.55
Mean Importance of Planned Errands		
S	2.90	2.37
T	2.51	2.39

Therefore, in order to reduce variability and improve the power of the analysis, the highest and lowest two scores were eliminated from each of the four conditions of the design. Note that this technique applies in the same way to all conditions and does not bias the analysis in any way. Thus, the analysis of planning times discussed below represents the performance of 64 subjects, 16 in each condition.

A planned comparison confirmed the predicted interaction ($t(60) = 1.96, p < .05$) between primer condition and transfer problem. S primers improved planning times for S transfer problems, while T primers improved planning times for T transfer problems.

The second and third panels in Table 7 show the mean number and importance of planned errands for each of the four conditions. As predicted, T primers produced more planned errands than S primers ($F(1,76) = 37.07, p < .001$), but S primers produced more important planned errands ($F(1,76) = 44.39, p < .001$). Primer condition and transfer problem also interacted. Primer condition had a greater effect on number ($F(1,76) = 15.27, p < .001$) and importance ($F(1,76) = 17.78, p < .001$) of planned errands for the S transfer problem than for the T transfer problem.

These results confirm that successful application of a strategy on several problems inclines people to adopt that strategy for subsequent similar problems.

VIII. EXPERIMENT 4

Experiments 1-3 illustrated the importance of adopting the appropriate executive strategy for a particular problem. Ideally, people would be capable of distinguishing problems for which each strategy is appropriate. The opportunistic model assumes that people can follow instructions to adopt the strategies appropriately. It implements the effects of such instruction as the creation of new executive specialists and the refinement of existing specialists' conditions. Assuming most people already possess the traveling salesman strategy, instruction will induce creation of specialists necessary to implement the scheduling strategy (ES3 and ES4). In addition, it should refine the conditions of priorities-generating specialists for both strategies (ES1 and ES3) to discriminate problems for which each is appropriate. Experiment 4 evaluated peoples' ability to follow explicit instructions regarding appropriate use of the two strategies.

METHOD

Subjects were instructed in the appropriate use of the traveling salesman strategy and the scheduling strategy as follows:

Here are some helpful suggestions for you to use in formulating your plans.

You will notice that some of the problems do not provide enough time for performing all of the errands. In that kind of situation, you should first decide which errands are really important and be sure to include them in your plan. Then, if you have time to do any other errands, include them too.

Other problems provide plenty of time for doing all of the errands. For these problems, don't worry about which errands are most important. Just concentrate on finding the shortest route you can that permits you to do your errands.

Then subjects worked on four problems, two T problems and two S problems. Subjects worked alternately on T and S problems, with half the subjects working first on a T problem and half working first on an S problem. The order of the problems and the assignment of problems to conditions (T versus S) were counterbalanced across subjects. Forty UCLA undergraduates served as subjects.

RESULTS AND DISCUSSION

Table 8 shows the frequencies of statements in each category for each of the four conditions. The data appear separately for the first, second, third, and fourth problems subjects solved. Again, subjects who indicated both approaches or neither approach were omitted and chi-square statistics were applied to the remaining data for each problem.

As predicted, problem type influenced subjects' choices of executive strategies (first problem: $\chi^2 = 6.6$, $p < .025$; second problem: $\chi^2 = 6.7$, $p < .025$; third problem: $\chi^2 = 4.9$, $p < .05$; fourth problem: $\chi^2 = 11.5$, $p < .0001$). Given instruction in the two executive strategies and when to apply them, most subjects adopted the strategies appropriately.

Although the results confirmed the prediction, the effect was not as large as might have been expected. Some subjects still exhibited a bias toward adopting the more familiar traveling salesman strategy. Thus, given a T problem, virtually all of the subjects adopted the traveling salesman strategy. Given an S problem, on the other hand, some subjects adopted the traveling salesman strategy, rather than the more appropriate scheduling strategy. Averaging across the four problems, subjects adopted the traveling salesman strategy 86 percent of the times

Table 8
SELF-REPORTS OF INTENDED EXECUTIVE STRATEGIES FOR EXPERIMENT 4

Problem	Intended Strategy			
	Scheduling Strategy	Traveling Salesman Strategy	Both Strategies	Neither Strategy
First Problem				
S	7	8	3	2
T	1	15	1	3
Second Problem				
S	11	15	1	3
T	3	11	0	6
Third Problem				
S	7	7	2	4
T	2	10	1	7
Fourth Problem				
S	10	3	2	5
T	2	13	0	5

that it was appropriate. By contrast, subjects adopted the scheduling strategy only 60 percent of the times that it was appropriate.

Subjects who adopt different problem-solving strategies should also exhibit the differences in planning time, number of planned errands, and importance of planned errands observed in Experiments 1-3. For the following analyses, we defined two groups of subjects for each problem type: those who adopted the scheduling strategy and those who adopted the traveling salesman strategy.

The first panel in Table 9 shows the mean time required to formulate a plan for each condition. As predicted, adopted strategy interacted with problem type to produce an effect on planning time ($F(1,111) = 6, p < .025$). For S problems, subjects who adopted the scheduling strategy formulated plans somewhat faster than subjects who adopted the traveling salesman strategy. For T problems, subjects who adopted the traveling salesman strategy formulated plans much faster.

The second and third panels in Table 9 show the mean number and importance of planned errands for each condition. As predicted, subjects who adopted the traveling salesman strategy planned more errands than those who adopted the scheduling strategy ($F(1,111) = 64.57, p < .001$). Subjects who adopted the scheduling strategy planned more important errands than those who adopted the traveling salesman strategy ($F(1,111) = 16.1, p < .001$).

These results confirm that people can learn to adopt alternative strategies as appropriate for the problem at hand.

Table 9
PLAN CHARACTERISTICS FOR EXPERIMENT 4

Problem	Adopted Strategy	
	Scheduling Strategy	Traveling Salesman Strategy
Planning Time (minutes)		
S	10.53	10.80
T	13.94	8.66
Number of Errands Planned		
S	6.94	8.91
T	6.50	8.55
Mean Importance of Planned Errands		
S	2.62	2.32
T	2.58	2.36

IX. EXPERIMENT 5

Again, in a natural setting, people rarely receive explicit instructions regarding how to adopt alternative strategies and when to adopt each strategy. Presumably, subjects acquire this knowledge from previous experience. Previous successful applications of each strategy could reinforce the tendency to make similar executive decisions for subsequent problems. In addition, one would have to learn to discriminate problems for which each strategy is appropriate. Hayes-Roth and Hayes-Roth (1978) refer to this process as adoption of a particular "problem-solving model" (see also Chi & Glaser, 1979; Hinsley, Hayes, & Simon, 1977; Larkin, 1979; Simon & Simon, 1978). As discussed above, the opportunistic model would implement this knowledge as the addition of new executive specialists and the refinement of their conditions.

Experiment 5 investigated people's ability to learn to adopt the traveling salesman strategy and the scheduling strategy on the basis of experience. Subjects worked on four primer problems, two S primers and two T primers. Half of the subjects subsequently worked on an S transfer problem. The remaining subjects worked on a T transfer problem.

The prediction is straightforward. Transfer problem should influence which executive strategy subjects adopt. For the S problem, subjects should adopt the scheduling strategy. For the T problem, subjects should adopt the traveling salesman strategy.

METHOD

The method was identical to the method for Experiment 3 except that subjects worked with two T primer problems and two S primer problems. Eighty UCLA undergraduates served as subjects.

RESULTS AND DISCUSSION

Table 10 shows the frequencies of statements in each category for each condition. Omitting subjects who indicated neither or both executive strategies, a chi-square statistic was computed for the remaining data. As predicted, transfer problem influenced subjects' choices of executive strategy ($X^2(1) = 4.05$, $p < .05$). Thus, many subjects acquired enough knowledge of the two executive strategies from prior experience to apply them appropriately on subsequent problems.

Subjects who adopt different problem-solving models should also exhibit differences in number of planned errands, importance of planned errands, and time required to formulate a plan. Again we defined two groups of subjects for each condition: those who adopted the scheduling strategy and those who adopted the traveling salesman strategy.

The first panel in Table 11 shows the mean time required to formulate a plan for each of the four conditions. For the S problem, subjects who adopted the scheduling strategy formulated plans faster than those who adopted the T strategy. For the T transfer problem, there was a smaller difference in planning time for subjects who adopted the two strategies. Here, however, the interaction was not significant ($F(1,58) < 1.0$). The absence of a statistically significant interaction is not surprising. Only 11 subjects adopted the scheduling strategy for the S problem, and only four adopted it for the T problem. Given the great variability in planning times noted above, we would need many more subjects before we could reasonably expect to observe a statistically significant interaction.

Table 10

SELF-REPORTS OF INTENDED EXECUTIVE STRATEGIES FOR EXPERIMENT 5

Transfer Problem	Intended Strategy			
	Scheduling Strategy	Traveling Salesman Strategy	Both Strategies	Neither Strategy
S	11	23	1	5
T	4	24	3	9

Table 11
PLAN CHARACTERISTICS FOR EXPERIMENT 5

Problem	Adopted Strategy	
	Scheduling Strategy	Traveling Salesman Strategy
Planning Time (minutes)		
S	11.62	12.52
T	12.28	12.79
Number of Errands Planned		
S	5.91	8.65
T	6.50	8.58
Mean Importance of Planned Errands		
S	2.87	2.33
T	2.78	2.35

The second and third panels in Table 11 show the mean number and importance of planned errands for each of the four conditions. As predicted, subjects who adopted the traveling salesman strategy planned more errands than those who adopted the scheduling strategy ($F(1,58) = 67.53, p < .001$). Subjects who adopted the scheduling strategy planned significantly more important errands than those who adopted the traveling salesman strategy ($F(1,58) = 59.37, p < .001$).

These results confirm that people can learn to adopt alternative strategies appropriately on the basis of previous problem-solving experience. However, many subjects continued to exhibit a bias toward adopting the traveling salesman strategy. Here the bias was stronger than the similar bias exhibited in Experiment 4. Again, subjects chose the traveling salesman strategy 86 percent of the times that it was appropriate. They chose the scheduling model only 46 percent of the times that it was appropriate. (In Experiment 4, subjects chose the scheduling model 60 percent of the times that it was appropriate.) Thus, fewer subjects acquired the necessary knowledge from four primer problems than acquired it from explicit instruction. One possible reason for this may lie in the fact that subjects had only "positive" experiences, that is, successful applications of the two strategies. Some people may require "negative" experiences (relatively unsuccessful applications of the strategies) as well in order to learn to discriminate problems for which each strategy is appropriate.

X. GENERAL DISCUSSION

These experiments illustrate the inherent flexibility in people's executive strategies. Although most people approach the familiar errand-planning task with one general strategy, several factors can cause them to adopt another. These include explicit instructions, set induced by prior problem-solving experiences, problem characteristics, and the apparent appropriateness of alternative strategies to a problem.

Adoption of a particular strategy had important consequences for performance of the task. It influenced the time required to formulate a plan. Subjects formulated plans faster when they had adopted a strategy appropriate to problem constraints than when they had adopted an inappropriate strategy. Adoption of a particular strategy also influenced the selection of errands for incorporation into the plan. Subjects planned fewer but more important errands when they had adopted the scheduling strategy than when they had adopted the traveling salesman strategy. These observations suggest that knowledge of alternative executive strategies and the ability to apply them appropriately may be an important component of planning expertise (see also Anzai & Simon, 1979; Bruner, Goodnow, & Austin, 1956).

The results also provide evidence regarding the acquisition of executive strategies. Subjects learned to adopt particular strategies in four different ways. First, they followed explicit instructions to adopt a strategy. Second, they transferred a strategy they had learned on previous problems to a new problem. Third, they followed explicit instructions to adopt alternative strategies for particular kinds of problems. Fourth, having learned alternative strategies on previous

problems, they transferred appropriate usage of the strategies to a new problem. These are all ways in which people might naturally acquire new executive strategies. In addition, they represent potentially useful strategy training methods.

Despite the considerable flexibility in their executive strategies, subjects exhibited a strong proclivity toward adopting the traveling salesman strategy. Without instruction or training in the scheduling strategy, subjects almost invariably adopted the traveling salesman strategy. Further, many subjects failed to respond to instruction or training in the scheduling strategy. They persisted in adopting the traveling salesman strategy even when it was inappropriate. Only strong, unambiguous training methods (explicit instruction in a single strategy or previous experience with a single strategy) reliably induced adoption of the scheduling strategy. Only about half of the subjects learned to adopt the two strategies as appropriate. Of course, this had unfortunate consequences for their performance on the task.

These results were surprising for several reasons. First, the two strategies were commonplace. Subjects ought to have had prior knowledge of both of them. Second, both strategies were easy to understand and easy to execute. In addition, the subjects were bright, educated people who probably performed better than the average person would on this task. Finally, previous research has shown that for certain other tasks, people readily learn to apply alternative strategies appropriately (Anzai & Simon, 1979; Bruner et al., 1956; Resnick, 1976).

There are several possible explanations for subjects' failure to adopt the scheduling strategy reliably. Subjects may simply have forgotten how to use the scheduling strategy or may have forgotten to evaluate

its appropriateness. These hypotheses seem unlikely because of the simplicity of the task and the relative sophistication of the subjects. Alternatively, subjects may have considered using the scheduling strategy for time-constrained problems, but decided that it was unnecessary. That is, they may have judged that the available time was sufficient for performing all of the errands. A recent study provides some support for this hypothesis. Hayes-Roth (1979) observed that in performing the errand-planning task, subjects systematically overestimated the number of errands they could accomplish in a given period of time. Perhaps subjects in the present experiments also overestimated what they could accomplish. If this hypothesis is correct, the results would reflect an error in judgment, rather than an inability to adopt the strategies appropriately. Additional research should resolve these issues.

Whatever the reason for subjects' behavior, the results suggest that training in when and how to apply executive strategies may be an important aid to the problem-solving process. Although the training methods used in the present experiments produced mixed results, it must be remembered that they were designed to test certain hypotheses rather than to produce expert planners. It is straightforward to elaborate these procedures with additional instruction or practice. It is reasonable to expect such modifications to produce more substantial effects on a larger proportion of subjects.

STATUS OF THE OPPORTUNISTIC MODEL

The results confirm some basic assumptions of the opportunistic model: (a) that people can adopt alternative executive strategies for performance of a task; (b) that people can change strategies or act out

of accord with a previously adopted strategy during the problem-solving process; and (c) that the strategy a person adopts influences problem-solving difficulty and important characteristics of the solution.

The opportunistic model provides a useful framework within which to model flexibility in executive strategies. Its ability to execute a fixed set of problem-solving specialists in different orders permits the model to exhibit arbitrary executive strategies. At the same time, it avoids the redundant specification of subroutines entailed in the multiple-program approach discussed in the Introduction to this Note. Similarly, the model's ability to execute executive specialists in different orders permits it to construct different executive strategies with minimal redundancy in stored "program code."

The different levels of abstraction at which executive specialists operate (priorities, focus, and schedule) increase both the power and flexibility of the model. For example, early adoption of a particular problem-solving model (identification of a problem as one for which a particular strategy is appropriate) might lead a subject to make the corresponding priorities decision and to implement those priorities with subsequent focus and scheduling decisions, as illustrated in Tables 2 and 3. Such a configuration of decisions would provide an algorithmic approach to the problem. By permitting independent decisions at each level of abstraction, however, the model permits a variety of deviations from purely algorithmic problem-solving behavior. For example, the subject might switch to a different algorithm, with or without beginning the problem over again. The subject might begin with a particular algorithm and then abandon it in the course of solving the problem. (This is probably what many of our subjects did when they found they had

inappropriately adopted the traveling salesman strategy.) The subject might make isolated decisions that are inconsistent with otherwise algorithmic behavior. And, of course, the subject might not exhibit any obvious algorithm at all.

The opportunistic model also suggests plausible learning mechanisms. Because executive strategies comprise the actions of a particular configuration of independent specialists, subjects might well acquire them in bits and pieces. Unlike the multiple-program approach, the model does not require that a subject learn from repeated execution of complete strategies. Instead, the subject can acquire and refine various executive specialists independently. For example, the subject might infer that a certain set of priorities works well when the problem has certain time constraints. She or he might infer that a certain focus decision works well after problem solution reaches a certain stage. She or he might infer that when a particular configuration of problem-solving specialists is applicable, scheduling a particular one of them is usually more effective. The model's uniform representation of independent problem-solving specialists and executive specialists makes it amenable to several well-defined learning mechanisms in the literature (Buchanan, Mitchell, Smith, & Johnson, 1979; Hayes-Roth & McDermott, 1978; Neves, 1978; Waterman, 1975; Vere, 1978)

Finally, the model permits people to generate strategies that go beyond their explicit experience. Because the executive specialists operate independently, a subject can execute a configuration of specialists that she or he has never executed before. This permits at least a minimal form of the kind of novelty that characterizes much of human problem-solving behavior.

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