Technical Report 1020

Understanding Problem Solving Strategies

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November 1994

United States Army Research Institute for the Behavioral and Social Sciences

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
1994, November

3. REPORT TYPE AND DATES COVERED
Final May 93 - Aug 94

4. TITLE AND SUBTITLE
Understanding Problem Solving Strategies

5. FUNDING NUMBERS
62785A
790
1111
H01

6. AUTHOR(S)
Pounds, Julia (Consortium); and Fallesen, Jon J. (ARI)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Consortium Research Fellows Program
U.S. Army Research Institute for the Behavioral and Social Sciences
Fort Leavenworth Research Unit
Fort Leavenworth, KS 66027-0348

8. PERFORMING ORGANIZATION REPORT NUMBER
--

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Institute for the Behavioral and Social Sciences
ATTN: PERI-RK
5001 Eisenhower Avenue
Alexandria, VA 22333-5600

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARI Technical Report 1020

11. SUPPLEMENTARY NOTES
Contracting Officer's Representative, Michael Drillings.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution is unlimited.

12b. DISTRIBUTION CODE
--

13. ABSTRACT *(Maximum 200 words)*
The way in which problems are solved can have a dramatic impact on success. This report discusses the role strategies have in thinking processes, metacognition, planning, expertise, and decisions. The report also provides a description of each of 66 strategies identified in psychological studies. The strategies have been grouped into three classes with three subordinate categories each. The classes of strategies are managing information, controlling progress, and making choices. The categories include considering hypotheses, combining information, managing the amount of information, ordering processes by hierarchical structures, sequencing processes, ordering processes by merit, managing the number of options, using compensatory choice, and using noncompensatory choice.

The report discusses the adaptive nature of strategies and how this information can be used to improve military problem solving. Noteably, strategies have a specific contribution to make in the study of expertise, in defining decision aid requirements, and in developing training programs. The principal conclusion was that existing definitions of strategies underrepresent everyday problem situations and that actual
(Continued)

14. SUBJECT TERMS
Command and control
Human performance
Cognitive skills
Battle command
Problem solving
Decision making

15. NUMBER OF PAGES
100

16. PRICE CODE
--

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102

ARI Technical Report 1020

13. ABSTRACT (Continued)

strategies need to be observed, defined, and assessed for improvement. A general plan of research is outlined for improving military problem solving.

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

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Office, Deputy Chief of Staff for Personnel
Department of the Army

November 1994

Army Project Number
2Q162785A790

Human Performance
Effectiveness and Simulation

FOREWORD

The Fort Leavenworth Research Unit of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) conducts research to enhance battle command and staff capabilities of the Army. There is growing interest in how people actually make decisions and, more specifically, in how officers actually solve military problems. This is in contrast to years of research that focused on why people do not follow a rational, ideal model for decision making. This latter perspective viewed decision makers as flawed or biased when they did not act like perfect processors of information, even when important information was not available or was in conflict with other information. Decision-making training was based on ideal models of decision making that considered people to be completely analytical and rational in their judgments. Although the rational perspective continues to influence the doctrine and training related to decision making, more recently researchers have dropped "ideal" models and have tried to understand how it is that people actually make decisions in complex, dynamic situations. Within ARI we have adopted a broader view of the important, operative tasks. The task of interest is no longer simply the decision but how problems are identified and represented, how solutions are explored, and how plans are determined, enacted, and controlled.

This report deals with research related to the broader view of problem solving, focusing on the identification of strategies that people use to solve problems. Strategies are repeated patterns or clusters of cognitive activities used by the problem solver to guide reasoning processes to reach some goal. Descriptions of more than 60 strategies in this report provide a common foundation on which to base research into the use and effectiveness of strategies used in solving military problems. This research was conducted as an exploratory development program entitled "Leader skill assessment and development technologies."

EDGAR M. JOHNSON
Director

UNDERSTANDING PROBLEM SOLVING STRATEGIES

EXECUTIVE SUMMARY

Requirement:

The Army needs to have a better understanding of real problem solving strategies. To date, military services have largely relied on economic decision theories that call for avoiding biases through objective, exhaustive, and systematic comparison of options. Recent findings, however, show the shortcomings of rigid procedures and point to naturalistic strategies as a preferred standard. Tactical decision making has many sources of contextual variation. Simplistic "6 step models" or exhaustive comparisons of options are not sufficient for the complexities of actual situations. This report provides details on problem solving strategies that have been identified in various research studies. It gives an overview of formally documented strategies that may apply to everyday and military decision making. By understanding these strategies better, a base of knowledge can be developed to determine the frequency, efficacy, and improvement of strategies.

Procedure:

Military and general studies and theories on decision making and problem solving were reviewed to identify various problem solving strategies. The strategies were compared to determine which strategies to include in a catalog by using commonalities between processes and operations to identify similar strategies that have appeared among domains and researchers. Each entry in the catalog describes a particular strategy. Descriptive information on the strategies provides definitions, conditions that might trigger their use, example situations in which the strategies might be used, strengths and weaknesses of each strategy, and predisposing conditions of application.

Findings:

The compilation of the strategies from the literature led to three general observations:

1. Although a variety of research domains have examined problem solving strategies, the approaches have not previously produced a cohesive body of knowledge to describe how a problem solver uses strategies or how he or she should use them. In several instances, similar strategies are named differently in different domains. While the processes and operations are not

unique to a particular domain, the label often is, thus restricting knowledge sharing among different fields of research. This report identifies 66 different problem solving strategies.

2. Most problem solving strategies have been examined in impoverished environments, using restricted laboratory tasks, often not accounting for the role of the problem solver's prior knowledge and experience. Thus, previous findings have emphasized strategies that lead to optimal problem solving in a static environment. These optimizing strategies are often brittle in that small changes in conditions can lead to large decreases in a strategy's usefulness. Strategies that problem solvers use in dynamic environments need to be examined.

3. Different strategies may be adopted based on the problem solver's knowledge and experience, resulting in differences in the strategies of experts and novices, with different points where errors may be made. However, methods exist that enable researchers to identify and inspect the component processes of strategies and plans. These methods can be used to examine how the problem solver's use of strategies might vary as a function of training, expertise, or individual style.

Utilization of Findings:

Findings are intended to be used by researchers, curriculum specialists, and decision aid developers. All three communities must have an understanding of how decision makers think. This catalog of strategies helps to identify ways in which decision makers naturally solve problems or how they could do so through education, self-development, or aiding. Researchers need to assemble better information about the frequency with which these strategies are used and their effectiveness. Also other strategies--yet unidentified--need to be recorded upon observation and added to the inventory. Many of the strategies mused in everyday and on-the-job reasoning are pieced together from fragments of the strategies identified here. This catalog can serve as a checklist for future data collection. Short of having frequency and effectiveness data, curriculum specialists and decision aid developers can use the catalog, combined with subject matter expertise, to speculate about which strategies should be of greatest interest for battle command.

UNDERSTANDING PROBLEM SOLVING STRATEGIES

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UNDERSTANDING PROBLEM SOLVING STRATEGIES

INTRODUCTION

Competent battle commanders are problem solvers who demonstrate effective problem solving in complex situations. This skilled problem solving combines high levels of domain knowledge with the use of plans, strategies, processes, and evaluations. Strategies are particularly important for problem with high stakes. They increase the efficient use of mental resources, leading to higher quality decisions and decreasing the likelihood of errors (Alty, 1989; Bruner, Goodnow, and Austin, 1956). By understanding situations where successful strategies are applied, problem solvers can develop strategies to aid their decision making in demanding, complex, stressful, and rapidly changing situations. The purpose of this report is to review the important attributes of problem solving strategies and to establish a foundation of information about strategies to improve military problem solving.

Problem solving is a cognitive activity that occurs in the mind of the problem solver and depends on manipulating internal representations (Mayer, 1991). However, problem solving strategies are also dependent on (or qualified by) other, related cognitive activities (Entwistle, 1991). *Cognitive operations* use well-defined and stable cognitive units that do much the same thing in every context, such as test whether X is a subset of M (Huber, 1989; Neisser, 1983). Elementary units can be combined to form complex units. *Rules* relate concepts and contain information about how changes in one concept influences other concepts, usually in the form of if-then conditions (Andre, 1986; Holyoak & Nisbett, 1988). *Cognitive processes* are the basic cognitive activities that take place in memory, such as encoding or retrieval (Entwistle, 1991). *Cognitive skills* describe the relative ability of an individual to consistently carry out the cognitive processes for a particular type of task, a particular problem, or in a certain situation (Entwistle, 1991). A skill has a set of critical features that identify situations where it applies and which can initiate its operation (Andre, 1986). Skills improve the quality of performance in a particular domain and can become automatic (Baron, 1988). *Cognitive strategies* are regularities in reasoning that can be crafted to guide decision making in a particular set of circumstances for doing an action in the most effective manner (Bruner, Goodnow, & Austin, 1956; van Dijk & Kintsch, 1983; Zsambok, Breach, & Klein, 1992). When organized for problem solving, strategies may also reflect a person's attitude and motives (Entwistle, 1991). *Cognitive style* links cognition to attitudes and motives. Styles are not domain specific, but are a relatively strong and consistent preference for adopting a particular type of strategy (Messick, 1976). Whereas cognitive skills have performance value, cognitive style has adaptive value. The person's cognitive style integrates cognitive processes and strategies that have been successful in the past (Entwistle, 1991).

Problem solving strategies have been studied in a variety of domains, but often as a peripheral issue of interest. As a result, many orthogonal viewpoints exist that contribute to a largely unorganized body of information. However, strategies are inherently part of our thinking. If we are to explore ways in which battle command can be improved, a review of research findings is a necessary starting point. Therefore, we set out to compile, define, and characterize problem solving strategies that have been identified in the scientific literature. The compiled information will provide a basis for concentrated research to apply knowledge about problem solving strategies to battle command. The results will be useful for (1) tracing judgment and decision-making processes of battle commanders, (2) identifying and understanding successful processes of thought, (3) comparing battle command problem solving to that in other domains, (4) developing decision aids and instructional materials to improve battle command, and (5) aiding in commander and staff selection, development, and placement.

The largest part of this report consists of a catalog of strategies. Sixty-six strategies are defined and described with information about their applications. The categories into which the strategies were organized for this report are identified in Table 1. These categories were determined after the individual strategies had been identified from literature searches. This catalog of strategies is preceded by a discussion of strategies in relation to problem solving, processes, metacognition, plans, expertise, and decisions. Figure 1 illustrates the relationship of these concepts as covered in the discussion. The overview concludes with a discussion about when strategies are used, why they are important in thinking, and how this review information can be used.

Table 1

Classes and Categories of Problem Solving Strategies

Class	Category
Managing information	Considering hypotheses, belief, uncertainty Combining information Managing amount of information
Controlling progress	Ordering by hierarchical structure Sequencing Ordering by merit or payoff
Making choices	Managing the number of options Using compensatory choice Using non-compensatory choice

Strategies and Problem Solving

Understanding strategies is necessary to understand problem solving because the use of strategies is conditional upon the presence of a significant problem. A problem is perceived to exist only if a person's present state is different from the desired goal state (Dellarosa, 1988; Smith & Browne, 1993). The nature of the problem is how to change the initial situation into a more desirable situation by reducing the differences between them (Dellarosa, 1988; Walton, 1990).

Moving from the current state to a goal often means that the problem solver uses a sequence of various decision-making and planning activities (see Anderson, 1990; Sinnott, 1989). However, as Svenson (1979) pointed out, different sequences of activities may be applied to what appears to be the same situation. Sometimes, the activities may be a seemingly automatic series of operations, while at other times reaching the goal requires guiding principles that call for explicit testing and feedback on processes that are used (Miller, Galanter, & Pribram, 1960; Weber, Goldstein, & Busmeyer, 1991). Which particular sequence of activities is applied in a situation is contingent upon a variety of task, individual, and context factors (Payne, Bettman, & Johnson, 1993).

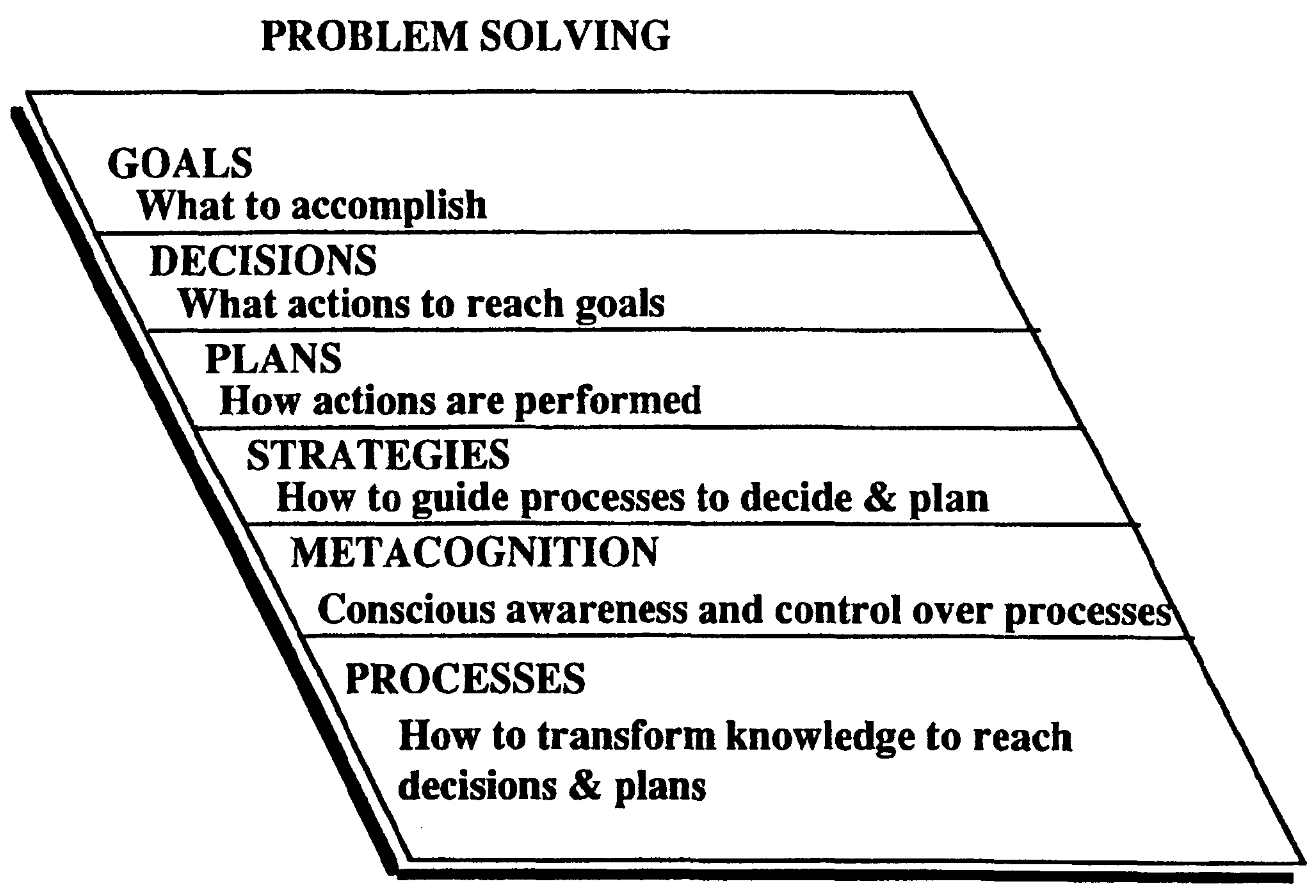

Figure 1. Cognitive concepts related to problem solving strategies.

In either case, problem solving strategies are adaptive patterns of information acquisition and integration which are used to make choices or judgments (Ford, Schmitt, Schechtman, Hults, & Doherty, 1989). Problem solvers employ strategies to make judgments when faced with novel problems or situations for which they have not been specifically trained, often meeting the demands by adapting previously used strategies (Lesgold et al., 1988). Continual adaptation and repositioning to match one's advantages and competencies to environmental opportunitiesdistinguishes successful strategic problem solving from the unsuccessful (Kleindorfer, Kunreuther, & Schoemaker, 1993).

Problem solving strategies have been characterized in a variety of other ways, as well. For example, Bruner, Goodnow, and Austin (1956, p. 54) described them as regularities in reasoning which represent "a pattern of (making) decisions in the acquisition, retention, and utilization of information." Strategies increase the efficient use of mental resources, leading to higher quality decisions, and decreasing the likelihood of errors when solving a problem. This is similar to the definition later proposed by Ford et al. (1989). In short, problem solvers use strategies to achieve their goals.

Strategies and Processes

Processes are instrumental components of strategies. In particular, cognitive processes are basic operations that transform knowledge in a generally consistent manner from one application to another. One or more operators (i.e. what to do) are applied to the initial state to transform it into the goal state (Huber, 1989). Different results and different behaviors occur when inputs and conditions differ. An information processing perspective is useful for better understanding the nature of processes. Under this approach, a person is considered an active processor of information and is capable of thinking by dynamically organizing complex patterns of information (Dellarosa, 1988; Kyllonen & Shute, 1989). Broadly conceived, thinking is based on the coordinated operation of active mental processes within a multicomponent memory system (Solso, 1988; see also Stubbart & Ramaprasad, 1990).

The information-processing model does not attempt to describe how goal-directed activity is achieved by physical brain structures. Rather, it describes thinking as computations and "the manipulation of an internal representation of an external domain" (Hunt, 1989, pg. 604). Further, the information-processing model characterizes reasoning as representational thought and provides methods to examine how thoughts are employed to work through problems and to explain what will happen or why something happened.

Lord and Hall (1992) further distinguish between rational and expert information processing. On one hand, rational information processing models assume that an exhaustive collection of information is combined through logical and conscious processing, that a thorough information search is conducted, that possible options are carefully evaluated, and that the optimal alternative is selected. On the other hand, expert information processing substitutes one's pre-existing knowledge for effortful, analytic processing and relies instead on recognition-based processes.

The relationship between processes and cognitive strategies makes it difficult to define precisely what strategies are. A simple way to think about interconnected processes was proposed by Miller et al. (1960) based on the simple test-operate-test-exit (TOTE) unit. They described a way to organize and coordinate both the transfer of information and the transfer of control, as well as feedback (see Miller et al., 1960). By proposing that the operational component could itself be a combination of TOTE units, a hierarchy of embedded units can be described. Strategies identify prospective processes and guide the sequencing of the processes as thought progresses towards the goal. This conceptualization of TOTE units has led to proposals that both learning and performance can be characterized by this arrangement (see Anderson, 1987).

Strategies and Plans

To achieve goals, problems solvers also use plans. A plan is the problem solver's global mental representation of an action or strategy and its final result, including possible actions and strategies contained in the global action (Rebok, 1989; van Dijk & Kintsch, 1983). Strategies can be loosely linked to form purposive sequences of actions or plans (Galambos, 1986). A strategy can be described as a global mental representation of a way of doing the action in the most effective manner--a general instruction to guide choices. While planning can be thought of as a set of overt actions necessary to achieve a goal, a strategy is the sequencing of the mental processes (Miller et al., 1960). When a strategy is adopted which is appropriate given the problem constraints, plans to reach goals are formulated faster (Hayes-Roth, 1980).

Reaching a goal can involve expending resources or resolving conflicting goals (Slade, 1994). Accordingly, an accurate characterization of the problem solving process requires a description in terms of resources and conflicts, which includes how people solve problems by generating solutions, by forming plans to reach goals, and by exploiting acquired knowledge in developing strategies to reach those goals (Dellarosa, 1988; Smith & Browne, 1993).

Strategies and Metacognition

Instrumental to reaching goals by using strategies are two concepts (Alty, 1989; Hammond, McClelland, & Mumpower, 1980). The first is the concept of cognitive control, or the purposeful use of the knowledge which one possesses to exert control over processing. The second is the level at which a strategy is employed, a relationship between global and local processing. Global use of a strategy implies that the strategy may be viewed as changing over time, whereas local use of the strategy is more determined by any given moment. How cognitive control is exercised over global and local dimensions can affect consistency in problem solving performance and goal attainment, and can be influenced by the situation or the individual.

To facilitate efficiency, quality, and accuracy, people can also have strategies to develop a strategy for a current situation. These strategies are referred to as *executive* or *metacognitive* strategies. Metacognition is the knowledge or set of beliefs that one has about his or her own cognitive processes (Morris, 1992). Development of these higher level strategies may be adopted to overcome processing or capacity limitations. For example, as one acquires knowledge of a domain, increasing the accessibility of knowledge also increases its usefulness. A problem solver "cannot exploit ignorance" (Hinrichs, 1992, p. 7). Rather, people often employ prior knowledge to find possible solutions for the current problem using strategic retrieval of information from memory. However, how one uses his or her cognitive processes to perform these activities is not clear.

Hayes-Roth (1980) proposed that a person's problem solving activities are the result of many independent cognitive processes, or cognitive "specialists." These rules and heuristics each suggest decisions at different levels of abstraction, from immediate specific details to potential future additions to the plan. When the context triggers the conditions of a specialist, the specialist's associated heuristic applies, the specialist is invoked and enters a queue of other specialists. Each specialist's outcome influences the actions of the follow-on specialists, producing many potentially different sequences of strategies. A "planner" makes independent focus and schedule decisions based on current and long-term priorities. The notion of recombining "specialists" in this model permits considerable flexibility in the strategy the planner adopts for a problem.

Further, Nelson and Narens (1990) proposed that cognitive control processes can be split into at least two interrelated levels, the meta-level and the object-level. Processes at the object-level initiate, continue, or terminate an action, while processes at the meta-level support a dynamic representation of the object-level. Control and monitoring functions at the meta-level interact with the state of the object-level. Meta-level control modifies or changes the object-level process, while meta-level monitoring updates the representation of the situation based on information from the object-level.

Meta-level and object-level processes have both been included in definitions of metacognition, which is believed to have a central role in strategy development, selection, and use. The awareness of one's own cognition can be used to manage one's thinking. Metacognition plays an executive role in problem solving and thinking such as setting goals, selecting strategies, organizing thoughts, controlling search, allocating attention, self-reflection (for assessment of performance), assessing likelihood of knowing (Nelson & Narens, 1990), and making predictions about learning (Nelson & Narens, 1994).

Brown (1978) defined metacognitive skill as an executive skill used to control one's information processing and cognitive skills as nonexecutive skills used to implement the task strategies. He proposed five types of metacognitive processes. These processes determine which cognitive processes are appropriate for completing a task.

1. Planning one's next move in executing a strategy.
2. Monitoring the effectiveness of individual steps in a strategy.
3. Testing one's strategy as one performs it.
4. Revising one's strategy as the need arises.
5. Evaluating one's strategy in order to determine its effectiveness.

In comparison, Sternberg (1980, 1985) proposed that cognition consists of three types of components: metacomponents, performance components, and knowledge-acquisition components. Metacomponents are higher order control processes used for executive planning, monitoring, and evaluation of one's own performance in a task, and can be applied in a variety of tasks (see also Davidson, Deuser, & Sternberg, 1994). Performance components are lower order processes used to execute various strategies employed to perform the task. Knowledge-acquisition components are processes involved in learning new information and storing it in memory.

Other related concepts have been linked to metacognitive processing. For example, Greeno and Simon (1988) refer to strategic knowledge as the process "for setting goals and adopting general plans or methods in working on a problem" (p. 590). In addition, Cavanaugh (1988) described three kinds of memory awareness.

1. Systemic awareness consists of knowing how memory works, what kinds of things are easy or difficult to remember, or what kinds of encoding and retrieval strategies produce the best results.

2. Epistemic awareness (metaknowledge) consists of knowing what we know, knowing what knowledge is in store, and being able to make judgments about its accuracy.

3. On-line awareness consists of knowing about ongoing memory processes and being able to monitor the current functioning of memory, as in prospective memory tasks. A failure of on-line awareness results in cases of absent-mindedness.

Although this implies that processes are available for efficient memory processes, as Morris (1992) points out, we are often not aware of our thoughts and are not very efficient at regulating them and retrieving memories. Rather, most of our cognitive processing takes place without our involvement in what is being done or how. This can be a severe limitation on an individual's ability to develop knowledge about metacognitive processes. It also suggests that sometimes we may be aware of our strategies and at others time not fully aware of them (Weber et al. 1991).

People probably use many metacognitive strategies that have not yet been identified with a label and description. However, all known metacognitive processes share the quality of being able to facilitate or inhibit accurate performance. One important metacognitive factor is one's subjective feeling of knowing (FOK) and its converse, feeling of not knowing (Nelson, Gerler, & Narens, 1984). Having a sense of the likelihood that a piece of information can be retrieved is an important factor in allocating attention and selecting particular strategies (e.g. 'should I try to remember my earlier conclusion by retracing my thoughts or should I go look at what I wrote down earlier?'). Studies of the relationship between cognition and memory have found that people are not always accurate judges of what they will or will not be able to retrieve from memory (Read & Bruce, 1982; Gruneberg & Sykes, 1978; Lachman, Lachman, & Thronesberry, 1981).

It is likely that an individual will develop, select, or adapt strategies based on metacognitive assessments of one's own capabilities, limitations, knowledge, goals, and processes. Metacognitive processes complicate the identification of strategies in that strategies can be and are modified by metacognition. In addition, some researchers have proposed that metacognition is the same as strategy. To further complicate identification of strategies, metacognition leads to concepts of recursion and embedded, hierarchical structures in the regulation of cognitive operations: strategies to develop strategies (e.g. a person who may approach problems with a preference for noncompensatory decision strategies), strategies to select strategies (e.g. a strategy may be adopted in which the general rule is to maximize gain while minimizing effort), and strategies to guide processing (e.g., "proceed" strategies to monitor and control the use of strategies).

Strategies and Expertise

Metacognitive processes seem to play an important role in expertise. One characteristic of expertise is the ability to circumvent one's information processing limitations (Salthouse, 1991). These limitations include not knowing (1) what to expect, (2) what to do and when to do it, (3) how variables are related, (4) what information is relevant, (5) how to combine information, (6) how to discriminate between information, and (7) how to perform a behavior.

VanLehn (1991) suggested that it is not that experts have more powerful overall strategies; rather, they have better knowledge for making decisions at the points where the overall strategy calls for a specific choice. He indicated that experts are better at self-monitoring and control, or in other words, they have better metacognitive strategies.

Strategies and Decisions

The problem solver may be faced with deciding among several options when constructing a plan and, therefore, may need to decide among strategies to generate and choose options. Decisions can be viewed as the building blocks of plans and strategies (Slade, 1994).

Researchers generally agree to classify decision making strategies according to whether they involve compensatory or noncompensatory processes. Compensatory choice means that attributes of the options are valued in a commensurable manner. For example, if one were selecting one person for a job, in a compensatory strategy the job candidate's attributes would have to be scaled so levels of one attribute (such as experience) can be equated with another (such as productivity). In this manner a high value on one attribute can *compensate* for a low value on another.

Non-compensatory choice strategies do not require that the option's attributes be identified by equitable scales. When these strategies are employed, the decision maker is assumed to not make explicit trade-offs among attributes. These strategies are more likely to be categorized as non-analytic because the decision maker is more likely to rely on prior knowledge about the options.

However, decision strategies can also be distinguished in a variety of other ways as well. The following differences among choice strategies identify other dimensions which could also lead to differences in decision processes and decision outcomes.

1. Values of attributes can be based on nominal, ordinal, interval, or ratio scales. Some techniques require a common scale, others accomodate mixed scale types and various scaling ranges.

2. Choice strategies can guide whether judgments are comprehensive and simultaneous (as in compensatory strategies) or partial and sequential (as in noncompensatory ones). Some techniques try to use the fewest number of attributes as possible, others are more expansive and inclusive in their consideration of features.

3. They can be defined by whether they are employed to *select* or *eliminate* options based on the values of attributes.

4. Attributes can be weighted or unweighted in the process. Other ways to differentiate in the importance of attributes uses sequential passes through the decision rule based on importance.

5. Strategies can differ depending on the selection rule. Selection can be made based on the determination of the largest or smallest values within attributes, or sums across attributes or across options.

6. In some strategies the trade-offs are implicit, in others explicit.

7. Some strategies identify one final option, others serve as a screening function to reduce the set of possible options, others can be used for both purposes.

8. In some choice strategies, options are screened or selected by comparing to standard values or minimum acceptable levels.

9. The strategy can be characterized by whether the values, options, or attributes are fixed or changeable during the process.

The first five of these characteristics are used in two tables comparing choice strategies (see Table 3 and Table 4 in the catalog).

Strategies as Adaptive Responses

So why consider strategies as part of problem solving? Increasingly, high-stakes decisions have to be made in demanding, complex, stressful, and rapidly changing situations, and strategy selection is partially contingent upon the attributes of the problem (Payne et al. 1993). Strategies represent intelligent, adaptive responses by decision makers who are faced with making trade-offs between accuracy and effort in order to integrate information and make judgments. The decision maker brings his or her own goals, values, and prior knowledge to the task.

Based on this line of thinking, the general definition of strategies offered by Bruner et al., (1956) in the introduction can be restated. More specifically, a strategy is a purposeful sequence of mental operations and decisions which are used by the problem solver to maximize task performance by the transformation of an initial knowledge state into a state believed to represent a solution to the problem (Massaro & Cowan, 1993). The problem solver may already have a set of processes which have been acquired (implicitly) or have been developed purposively (explicitly). However, if no predetermined strategy is available the problem may require that the decision maker develop a strategy concurrently. A strategy's adaptiveness derives from its sequential nature that allows opportunistic use of feedback and inference processes which, in turn, allow the decision maker to learn and to modify the strategy based on problem demands.

Thus, to also restate the purpose of this report, it is to identify and characterize a set of strategies likely to be used by problem solvers to respond adaptively to dynamic situational demands. Strategies are treated as flexibly applied sets of component processes. This follows Simon (1990, p. 4), who described each kind of problem solving task addressed by the human mind as a different type of thought which can be described in "greater or lesser detail." Successful problem solvers seem able to coordinate these processes at levels of detail required by the situation.

With respect to level of detail, strategies have been described in terms of skills and/or rules (see Newell & Simon, 1972; Shank & Abelson, 1977; Smith, Langston, & Nisbett, 1992; Stevens & Gentner, 1983). As noted in the Introduction, cognitive skills are groups of processes that focus on transforming knowledge to reach specific performance results (Baron, 1988; Squire, Knowton, & Musen, 1993). Skill generally results from long and intensive training and allows rapid operations, such as stimulus-response actions (Anderson, 1992; Andre, 1986). Anderson (1992) proposed that skills are generally not subject to conscious control, interfere less with a concurrent task as it becomes more practiced, and are less interfered with by a concurrent task.

How skill translates into performance depends on how well-practiced the productions are and the problem solver's working memory capacity (Anderson, 1987). Rules are mandatory condition-action pairs which relate concepts when critical features satisfy the condition; they tell how changes in one concept influences other concepts (Andre, 1986; Karlsson, 1989).

Impact of Strategies on Problem Solving

The ability to coordinate strategies provides certain benefits for the problem solver (cf. Bruner et al, 1956). Strategies can be flexibly applied in a variety of situations (Hayes-Roth, 1980; Schwartz, 1971). They increase the likelihood that relevant information will be selected for use. They make information processing less effortful. They allow the problem solver to regulate the risk involved in finding an answer by controlling the strategy used to identify a set of options. They allow the problem solver to adjust to requirements of the situation, such as time limitations or too much new information. The following, from Payne et al. (1993), describes ways problem solvers used strategies in various situations and under different types of constraints.

> Strategy selection often attempts to maximize accuracy while minimizing demands on cognitive effort. Problem solvers can decide to invest effort into rearranging, transforming, or eliminating information for the purpose of making later choice processes more efficient. This suggests that adaptive problem solvers would have strategies to modify the way information is received and processed or to change the way alternatives are identified and assigned importance. Similarly, adaptive problem solvers would have strategies to adapt to situations where there is too much information to process or where there are too many alternatives in the choice set.
>
> To successfully use strategies one must have appropriate domain knowledge but one must also know when, how, and why to apply that specific knowledge (see also Cohen, 1993b). Related to this, the decision maker must be able to recognize when the current problem requires a new strategy rather than a generalized, routinely used, and possibly more familiar, strategy. This ability affects the likelihood of success in complex situations because assessment of and adaptation to context characteristics (such as the interrelatedness of information cues) is generally more difficult than is adaptation to task factors (such as the display of information and time constraints). The value of contextual information is often subjective, based on the individual's perceptions, while task factors depend on the structure of the problem.
>
> On the other hand, strategies can also hinder problem solving. When the problem has not been correctly identified or when important information is not salient, a particular strategy may be adopted which is not appropriate for the task. For example, heuristics can be used to narrow the range of possibilities, but an inappropriate heuristic may omit important information (Alty, 1989; Lenat, 1983). Adaptive strategies will also fail when the decision maker lacks knowledge about appropriate strategies or is unable to retrieve or construct one suitable for the situation. Less than optimal strategies may also be adopted if the decision maker does not know how to trade off accuracy and effort. Because feedback about the effort one puts forth is often more available than feedback about the accuracy of one's judgment, decision makers may choose strategies based more on the effort required by the process and less on the accuracy of the outcome.

However, choice of strategy also depends on the nature of the task and the context of the problem. Even when a good strategy is selected, factors such as environmental stressors, problem representation, computational requirements, and working memory demands can make the strategy difficult to use. For example, analytic strategies require more cognitive effort and are often used when the decision is perceived as irreversible and time to deliberate is available. Although differences in effort vary among individuals, use of strategies is viewed as an intelligent response to situational demands such as complexity and uncertainty.

Which strategy or combination of strategies is employed in the effort-accuracy trade-off process can depend on variables such as the familiarity of the task, the time available to generate a solution, and the stakes involved. For example, problems which have been previously encountered and successfully solved would have a predetermined solution which only needs to be recalled and implemented. On the other hand, more effort might be invested when making high stakes or unfamiliar decisions.

How Problem Solving Strategies Can Improve Military Problem Solving

As noted earlier, competent battle commanders are required to make judgments in demanding, complex, stressful, and rapidly changing situations. Their solutions often have high stakes consequences. This report characterizes strategies evoked by problem solving tasks or situations and describes strategies used by successful decision makers in ill-defined or complex situations. The contents can also useful for developing decision aiding techniques to support vulnerable points in processing.

Operational definitions. By characterizing strategic and component processes of problem solving, a common operational vocabulary for those who study problem solving and decision making processes will be available.

Process tracing. A common lexicon will increase inter-rater reliability for tracing the process of problem solving, as proposed by Ford et al. (1989). Process tracing examines the influence of task, environment, and individual difference factors on the use of strategies by focusing on the steps in the problem solving process (Payne, 1980; Sundström, 1991; Svenson, 1979, 1989). Process tracing can reveal regularities and structure in the problem solving process, as well as processes not previously thought to be important (Lockhead, 1980). Further, it can reveal the assumptions that problem solvers make and what information they use to come to a solution. Fraser, Smith, and Smith (1992) suggest that behaviors which have been labeled as errors and biases in thinking may be revisited to search for deeper understanding of the cognitive processes which lead to the observed behavior.

Process tracing focuses on the nature of the process rather than merely the stimulus input and resulting decision. It is useful for a detailed level of analysis when only a few qualified individuals are available to study. As Keren (1990) noted, in order to understand why processes are not adaptive, it is important to understand the corresponding cognitive processes. Similarly, Lopes (1987) argued that before procedural engineering in any domain can take place one must have knowledge of the processes to be engineered.

Expert processes. Expert knowledge can be elicited from experienced battlefield leaders who have demonstrated superior problem solving skills. This knowledge can then be analyzed to determine the characteristics which make up superior strategies. Once identified, these characteristics can be incorporated into decisions aids or programs of instruction and training.

For example, several questions which are relevant to identifying and developing expert battlefield problem solvers are still unanswered. One, it is not clear whether expert problem solvers have general guiding principles which they use across tasks. Two, it is not clear whether the individuals who eventually become expert bring individual predispositions (such as a particular cognitive style) to their learning environments and training tasks. If such individual predispositions affect the selection and use of strategies then these could also be identified to aid in selection and training.

Decision aids. Various approaches are emerging to show how to understand decision making and to link decision aiding to the problem and cognitive requirements (e.g., Essens, Fallesen, McCann, Cannon-Bowers, & Doerfel, 1994). As suggested by Pitz and Sachs (1984), development of decision aids should come after understanding the process involved in performing the task. By identifying the links in problem solving strategies, any weak links which contribute to suboptimal decision making performance can be identified and targeted for aiding, allowing a more specific intervention.

By targeting areas where decision making is weak, decision aids can be designed to meet specific needs and to support adaptive problem solving. Problem solvers can be better accommodated when decision aids take into account existing knowledge and skills rather than trying to force humans to use mechanical, algorithmic methods (Keren, 1990).

Training. Often, the high-stakes problems are those with increasing complexity, abstractness, uncertainty, ambiguity, variability, and with multiple information sources. A good problem solver requires flexibility in thinking to stay abreast of rapidly changing situations under stressful conditions and flexibility implies responsiveness.

Maier (1970) proposed that if reasoning and problem solving success depends on one's ability to combine past experiences, then this implies that past experiences can be reorganized, a process requiring flexibility. From this, it followed that characteristics of the situation (e.g. time stress) can alter these reorganization processes. "From this point of view success in reasoning will not be limited by the way we have learned things, but will depend upon the readiness with which the past learning is subject to modification and reorganization (Maier, 1970, p. 144)." Therefore, training techniques to enhance flexibility can result in greater responsiveness to situational changes.

Similarly, Hinrichs (1992) identified flexibility as the source of power for the human intellect. He suggested that flexibility relies on the content and quantity of domain knowledge as well as its accessibility and use. In turn, this relies on cognitive processes for encoding knowledge, accessing it, and determining its importance. Adams, Kasserman, Yearwood, Perfetto, Bransford, and Franks (1988) pointed out that the knowledge which leads to competent performance is represented as condition-action productions. These productions contain information about critical attributes of the situation which make a particular action relevant to the problem. Training, therefore, should help students acquire conditional knowledge rather than knowledge represented as isolated facts.

To this end, instruction in problem solving should occur while the student is solving the problem (Anderson, Boyle, Farrell, & Reiser, 1987; Bransford, Franks, Vye, & Sherwood, 1989).

By providing instruction in context and by providing new information as needed, features of the context become associated, understanding of the problem and solution is enhanced, and information will more likely be applied correctly (Anderson et al. 1987). Further, learning of strategic knowledge is promoted by examining situations where current knowledge is inadequate and where one's expectations fail to be met (Birnbaum & Collins, 1988). Kyllonen and Shute (1989) note that people trained to be more reflective in problem solving exhibited better performance. Finally, Langley and Simon (1980) point out that knowledge follows performance. Therefore, more efficient learning is promoted by examination and evaluation of past performance by making causal attributions about the results.

It follows then that training leaders to be proficient problem solvers would be facilitated by (1) increasing domain knowledge, (2) aiding them in its access and use, and (3) distinguishing among situational differences in the problem environment. Practice solving complex organizational and battlefield problems would encourage individuals' development of executive control processes to organize, integrate, and access their expanding knowledge base.

While providing external aids could increase processing capacity and decrease amount of effort, training problem solvers to use a variety of strategies would give them more flexibility, and thereby greater adaptiveness and effectiveness. Training which incorporates frequent feedback about the accuracy of the outcome would also enable decision makers to understand where error might enter the process, making them more vigilant and sensitive to feedback.

METHOD

Identified Strategies

The purpose of the report was to identify a set of strategies which could be employed as flexible components in problem solving and decision making. Research literatures from various disciplines (e.g. psychology, judgment and decision making, artificial intelligence, operations research, economics, and education) were examined to find cognitive processes which researchers in these fields had identified as problem solving strategies. In addition to the list of strategies, the definitions and everyday examples were also collected.

A cognitive activity was retained as a strategy if it could be purposefully and flexibly employed in a problem solving situation. Strategies which managed the flow of the problem solving process or the information selected for use by the process were included (what to do, which way to do it, and how much of it to do). Because of the many decision points possible in any problem solving strategy, choice processes were grouped separately in the traditional compensatory and noncompensatory classification. In several cases different instances of strategy were included under a more common or general name of strategy. So even though there are 66 strategies described, there were 26 more that were identified from the literature but were not sufficiently distinct to warrant a separate listing. Approximately 31 other possible strategies were considered for inclusion but were rejected because they did not fit the definition of a strategy. Each strategy included in this report is identified in the following ways.

Strategy labels. The strategy was identified by the label which was either (1) used by the initial researchers or (2) used most frequently in discussion of the strategy.

Sources. All of the sources consulted prior to integrating the information are listed following the strategy label.

Definitions. Strategies were defined in the terminology of the discipline from which they were identified. However, some of the same underlying processes had been addressed in more than one domain. In all cases, multiple definitions were integrated using more standardized vocabulary terms.

Trigger. Where available, the trigger for the strategy was noted. According to Shallice and Burgess (1993), control elements of relevant mental representations are activated, or "triggered" by salient aspects of the situation. In the absence of strong task-relevant information, inappropriate representations might be activated.

Strengths and weaknesses. Situations in which the strategy would likely increase or decrease performance were noted, including when it leads successful outcomes versus leading to errors in performance or biases in thinking.

Application. Often the effective use of a strategy depends on the experience, past learning opportunities, or expertise of the problem solver. The positive and negative impacts of familiarity and learning on the use of the strategy were listed when available.

Choice strategies have additional information categories, including a table depicting a strict structural view of the strategy in mathematical terms and an explicit discussion of the decision rule. Also examples are given, providing a description of a situation in which a problem solver might use a particular strategy. Some examples were adapted from literature, some from everyday life, and some from military situations.

Categories of Strategies

The strategies that were identified from the literature search were organized according to three general classes which emerged from the similarity comparisons. These classes are: to guide managing information, to guide controlling progress in a problem, and to guide how choices are made. Three levels within each class were identified. Within managing information, strategies were clustered into how the information itself is considered, how information is combined, and how to manage the amount of information to prevent from becoming overwhelmed or to focus on the most important aspects of a problem. Progress control strategies clustered into whether the strategies dealt with a hierarchical structure for the problem solving, whether it guided the sequencing of how the problem is solved, or whether the components of problem solving are ordered by merit. Making choices was subdivided into categories dealing with managing the number of options and using compensatory or noncompensatory choice techniques. The complete list of strategies that are described appears in Table 2.

Table 2

Classes, Categories, and Types of Problem Solving Strategies

Class	Category	Strategy
Managing information	Considering hypotheses, belief, uncertainty	Analogical reasoning
		Conflict resolution
		Contingency planning
		Focus-conservative
		Focus-gambling
		Positive test strategy
		Seek disconfirming evidence
	Combining information	Functional relations seeking
		Story building
	Managing amount of information	Conversion
		Decomposition
		Fractionation
Controlling progress	Ordering by hierarchical structure	Back-up strategy
		Balanced development
		Breadth-first search
		Decoupling
		Deep reasoning strategy
		Depth-first search
		Depth-first subgoaling
		Operator subgoaling
		Progressive deepening
	Sequencing	Backward chaining
		Forward chaining
		Hedge clipping
		Heuristic search
		Means-ends analysis
		Proceed strategy
		Similarity matching
		Tree felling
		Trial-and-error search
	Ordering by merit or payoff	Best-first search
		Win-stay/lose-shift

Class	Category	Strategy
Making choices	Managing the number of options	Compatibility test
		Profitability test
		Pruning
		Scanning-simultaneous
		Scanning-successive
		Scoping
		Screening
	Using compensatory choice	Addition of utilities
		Additive difference strategy
		Choice by greatest attractiveness difference rule
		Choice by most attractive aspect rule
		Cost-benefit analysis
		Dimensional reduction
		Elimination by least attractive aspect
		Expected value strategy
		Majority of confirming dimensions
		Marginal rate of substitution
		Maximax
		Maximin
	Using non-compensatory choice	Choice by least potentially profitable dimensions
		Choice by most potentially profitable dimensions
		Conjunction
		Disjunction
		Dominance
		Dominance structuring
		Elimination by aspects
		Frequency gambling
		Lexicographic strategy
		Minimum difference lexicographic rule
		Satisficing
		Satisficing-plus
		Single feature difference, inferiority, superiority

MANAGING INFORMATION

Managing information is one of five classes used in this catalog to combine similar strategies. Managing information consists of three categories for dealing with information that people acquire from their environment. They are (1) considering hypotheses, belief, or uncertainty, (2) combining information, and (3) managing amount of information.

Considering Hypotheses, Belief, or Uncertainty

The first group of strategies is clustered around the theme of manipulating knowledge. This group is concerned with establishing, updating, or questioning hypotheses, beliefs, and uncertainties. This set of strategies could possibly be expanded further by including additional characterizations of reasoning, such as plausible thinking, logical inferences, and critical thinking. Although these instances of thinking are similar to strategies included here (like analogical reasoning) they have not been included in this catalog because they generally depict what the thought processes are instead of how processes are guided.

<u>ANALOGICAL REASONING</u> Anderson, 1989; Antonietti, 1991; Bejar, Chaffin, & Embretson, 1991; Brown & VanLehn, 1980; Chi, Feltovich, & Glaser, 1981; Galotti, 1989; Gick & Holyoak, 1983; Keane, 1988; Kotovsky & Fallside, 1989; Medin & Smith, 1984; Novick, 1988; Omerod, Manketlow, Steward, & Robson, 1990

Definition: This problem solving strategy uses a familiar knowledge structure (schema content and process) to organize a new domain or problem. Quality of the analogy can be based on the number of relations that map from the base domain to the target domain, similarity, or number of overlapping attributes between the domains. Similarity between the known and the new can be based on superficial and/or conceptual levels. Transfer generally occurs in the exploratory phase rather than in the search for a final solution. A good analogy is one in which the relationship between base and target domains is high.

Trigger: This method is often triggered by encountering difficulty in solving a problem (e.g., failing to recognize previous similar situations or to recall previous solutions), or by the way a problem is structured. It is more likely to be used when both domains share structural concepts and surface cues. Representations are abstracted from context-specific solutions and are evoked by the presence of similar context in a new problem.

Example: A design engineer needs to develop a vapor-proof closure for space suits. He imagines a spider that spins a thread as it passes through rings attached to each side of the material (i.e., a modified zipper). It is as if the spider is sewing the suit together. The analogy is then reversed to find a mechanical substitute for the spider. The eventual solution involves a wire that is inserted up through two lines of interlocking rings attached to rubber sides. As the wire brings the rings from the two sides together, the rubber sides are tightly joined. (Adapted from Adams' 1986 account of Gordon's Synectic approach.)

Strengths and weaknesses: The usefulness of reasoning by analogy depends on how knowledge is organized in memory. When the base knowledge is not highly organized and the target domain is not very familiar, initial similarities between both are taken into account before the base procedures are constructed and applied to the target.

Successful analogical transfer depends on schema induction between two isomorphic problems. Negative transfer can occur if the procedures specified in the analogy do not correspond to the steps of the solution. Errors can occur if critical information is lost from working memory, or if misconceptions or faulty inferences are transferred to the new domain. Errors also occur when the match between representations is overestimated: conjunction fallacy.

Application: Analogical reasoning can be an intentional learned strategy used to overcome mind sets. Increased overlap between representations increases the amount of transfer. Good analogical reasoners spend more time on encoding. Experts concentrate on more conceptual or qualitative similarities while novices use specific strategies encouraged by the surface features of the task. For example, experts spontaneously generate bridging analogies when solving novel problems (physics). Novice problem solvers notice that an analogy would be useful in solving the problem only when the objects in the problem are similar in surface features.

<u>CONFLICT RESOLUTION</u> Johnson, 1988; Kramer, 1989; Lenat & Harris, 1978; Waterman & Hayes-Roth, 1978; Zeleny, 1982

Definition: This is a process which resolves a state where incompatible goals are perceived to exist. Resolution is the negotiation of a solution that satisfies both goals. In rule-based systems this is defined as a process for selecting which rule is activated in a set, given data which simultaneously satisfy several productions. The data set is first searched for matches to the antecedents (or consequents, in consequent-driven processes) for stored rules. All rules that have conditions which are satisfied by the data make up the choice set of rules. The mechanism which determines which rule will ultimately be chosen to fire can be either implicit in the system (tacit, concentrated, analogical information) or a set of explicit metarules or procedures describing how to choose which rule to fire. In sum, the highest priority rule fires first.

Trigger: Conditions are present which satisfy conditions for more than one rule.

Example: A young man is considering whether to invest in the stock market. He has never bought stocks and has limited knowledge about this type of investment. He does know that stocks on the average provide a good return over the long term and that it is good to buy low and sell high. He has also heard to be wary of "bear" markets. The value of a particular stock of interest has been down for about a week. He has read that some financial experts are considering the recent drop in values as the start of a bear market, but also he has heard other specialists judge that current trends indicate only a one-time adjustment in values. He sees conflicts in goals: lower prices suggest that it is a good time to buy, but the information about a bear market suggests that other investments might be better. He is not quite clear about what the risks are in a bear market, but does clearly understand the rule of buying at a discount. Using a conflict resolution strategy, he reasons that it is worth the chance of taking a risk to optimize gain.

Strengths and weaknesses: The process for matching the data to the antecedents can be time consuming. Because of this, screening processes which select a subset of knowledge to use can make the process more efficient.

In situations where conflict is resolved cooperatively, this is called conflict resolution. In situations where the conflict is resolved by coercion, this is called conflict regulation. Resolution generally results in a stronger relationship (constructive), while regulation does not result in true resolution, so that the conflict may arise again later (destructive). Resolution leads to better future problem solving while regulation does not.

Application: Experts tend to focus on conflicts in situations and goals, while less expert decision makers avoid conflicts and tend to deal with more certain information--even though it may not be as critical to the solution.

<u>CONTINGENCY PLANNING</u> Robertshaw, Mecca, & Rerick, 1978; Tenney, Adams, Pew, Huggins, & Rogers, 1992; Woods & Davies, 1973

Definition: This type of planning involves predictions for parts of a plan that might be flawed or that might have multiple future outcomes. This prediction is used to generate alternative courses of action for each point in the main action which might be flawed and which would preclude reaching the goal. Instead of letting the overall strategy fail, initiation of a contingency plan would make reaching the goal more likely.

Trigger: Recognition of potential failure to accomplish the goal. Some decision makers may routinely do contingency planning either from a conservative, hedging standpoint or because they prefer shorter planning horizons to assess nearer-term goals before committing to long term actions.

Example: An Army commander has reports that the enemy has two possible main avenues of approach. The commander sees that there are plausible reasons for each. A northern attack would correspond to a diversionary tactic to draw the commander's forces away from his higher command's stronghold. A southern attack suggests a rapid, forceful maneuver by the enemy against the stronghold. The commander realizes that he must commit to a plan before knowing exactly what the enemy will do. The commander decides to defend strongly in the south and to develop contingency plans for handling a northern attack. His contingency plan recognizes the possibility of enemy action other than for the immediate decision. After directing his planning staff to prepare for the southern attack he considers what to do as a departure from the basic plan in case the enemy attack actually occurs in the north.

Strengths and weaknesses: Contingency planning builds flexibility into the plan.

Application: For successful problem solving, prior knowledge and flexible thinking would probably be important here, as would be the information learned from prior experience with failure or from difficult planning situations. Successful cockpit crews use normal times to anticipate and rehearse for possible later difficulties, such as emergencies. In this way, necessary information can be processed before it is needed. Experts use more contingency planning than novices. More contingency planning results in fewer errors.

<u>FOCUS--CONSERVATIVE (OR SIMPLE)</u> Bruner, Goodnow, & Austin, 1956; Morrison & Duncan, 1988

Definition: To solve any problem, an immediate goal is to determine the order in which to ask questions to get the most information to find a solution to the larger problem--or how to direct the inquiry by reducing the set of all possible hypotheses to a smaller set. In this selection strategy, a positive instance is found and used as an example to guide the strategy, i.e. what to focus on. For each other possible alternative one attribute at a time is removed and the changed item is tested to see if it yields a positive or negative example of the concept. Attributes receiving positive feedback as being characteristic of the concept are not considered further. This is a positive test strategy using one attribute at a time.

Trigger: This is initiated by a "What is this?" concept question, a well-ordered alternative set, and a desire for less cognitive effort than one would use to test multiple attributes at one time (e.g. gambling focus).

Example: An electronics technician tries to find out why a circuit board is not working. He tests a critical component in the middle of the circuit. If the component works up to that point he knows that the failure occurred later in the circuit. If failure is indicated, he knows that there must be a failure in the first part of the circuit. Once locating a fault in one half or the other, the technician repeats splitting the circuit into successive "halves" to isolate the fault.

Strengths and weaknesses: Using this strategy, redundancy is completely avoided but an alternative which is tested almost never contains the maximum amount of information possible. The number of possible hypotheses is reduced by testing the relevance of attributes one at a time and by using one positive instance it is easier to keep track of information which has already been considered. However, unless all possible options to be considered can be arranged in some orderly fashion, the cognitive demand can become severe. When the problem is not perceptually available, this strategy makes fewer cognitive demands than does successive scanning.

Application: Learning was more effective when only one aspect was varied (conservative focus) rather than holding one constant and varying several (focus gambling) or haphazardly changing all aspects.

<u>FOCUS--GAMBLING</u> Bruner, Goodnow, & Austin, 1956; Morrison & Duncan, 1988

Definition: This selection strategy has the same objective as conservative focus: to determine the set of attributes which identifies the member according to its category membership. However, instead of changing one attribute at a time, the person using a gambling focus changes more than one attribute at a time before the option is compared to the focal example.

Trigger: This strategy can be used when trials are costly and a quick solution is needed.

Example: A mechanic uses a gambling focus to get a stalled car started. Instead of checking each individual component of the car, he focuses on engine subsystems. He knows that failed starts are usually due to a relatively small set of problems in a subsystem. Which subsystem is at fault can be determined by high level checks, like listening to the sound when the ignition is turned on or smelling for gas fumes. If the engine does not "turn over," the mechanic using a gambling focus might replace the battery. In doing so he unknowingly fixes a loose connection that was at fault all along.

Strengths and weaknesses: Use of this strategy can be efficient as long as information is gained from comparing the new instance to the focus example. However, the risk is higher for this strategy because when negative (uninformative) feedback is encountered the decision maker may change to less efficient strategies. Risk is also a factor in another way--that the quick solution (and its pay off) will not be found. In this case, using a gambling focus may result in many more trials. The decision maker is taking the risk in that the solution may be very fast, very slow, or somewhere in between. A lot of search may be required to find instances to test against the focal example.

Application: The implications for use are indicated above in strengths and weaknesses.

<u>POSITIVE TEST STRATEGY</u> Fraser, Smith, & Smith, 1992; Klayman & Ha, 1987; Wason & Johnson-Laird, 1972

Definition: This is a hypothesis-testing heuristic which problem solvers employ to evaluate the current hypothesis. Instances are chosen to test if they are thought to confirm the hypothesis, i.e. the target property is thought to be present. Similar to focus gambling and conservative focus.

Trigger: This strategy is task specific; it depends on rules or attributes specific to a domain, the hypothesis, event, or object.

Example: An unknown aircraft is detected on a military ship's radar. The ship needs to know whether the aircraft is potentially hostile in order to take defensive measures in time. The radar operator knows the various indications for whether an aircraft is hostile, friendly, or unknown. The operator knows that if the plane prepares to take hostile actions, that it should be engaged. He knows to monitor for positive indications of hostile acts (like an aircraft in unauthorized airspace or approaching the ship or refusing to reply to attempts at communication). The operator looks for positive instances of the criteria for classification.

Strengths and weaknesses: This strategy is useful when the target is rare, so the test is for a positive instance. This test is also less costly and less risky than testing for negative instances. When used to discover rules, this strategy can provide misleading feedback by too few tests of sufficient conditions but needless tests of necessary conditions for membership in the concept. Subjects in the Wason four-card task typically use a positive test strategy. Subjects in this task are asked to turn over cards to obtain conclusive evidence about a rule (Wason & Johnson-Laird, 1972). In judgment tasks, this positive test strategy can lead to overweighting and underweighting of data which results in inefficient or inaccurate results. The consequence of using the strategy depends on the characteristics of the task.

Application: This heuristic is a general default that is used when there is an absence of specific information about which test would be most appropriate to use or when the task demands high cognitive effort.

<u>SEEK DISCONFIRMING EVIDENCE</u> Galotti, 1989; Kirschenbaum, 1992; Klayman & Ha, 1987; Payne, Bettman, & Johnson, 1993; Scardamalia & Bereiter, 1991; Shanteau, 1988

Definition: This testing strategy can appear in two forms: as a positive-test or negative-test strategy. In one, the problem solver checks for information not included in the current model which might falsify the hypothesis. This form is generally considered to be the stronger test. In the other, a negative test is conducted for instances which are predicted to not support the hypothesis (and a positive test of instances predicted to support the hypothesis). A check may uncover previously ignored information or lead to realization that the belief is unwarranted. The value of which form to apply often depends on task characteristics. When concrete and task-specific information is lacking, or cognitive demands are high, the positive-test form is used as the default heuristic.

Trigger: Seeking disconfirming evidence may be a style characteristic of individuals.

Example: An intelligence officer feels that the position of the enemy's artillery is an indication that the main attack will be against his unit's center. He knows that the assessment of the location of the enemy's attack is critical to the success of his unit. He continues to seek information which would falsify his assessment. He looks to find out where the enemy's reserve force is located, the positioning of their most lethal weapon systems, and other potential target areas they can reach from their artillery location.

Strengths and weaknesses: This strategy can be knowledge-transforming if the existing schemata are altered or abandoned. However, a decision maker's attention to information which potentially alters the situation can lead to working memory overload and incoherence in the decision process. Consideration of the possibilities can depend on available processing capacity. In complex decisions, a method for identifying more important new evidence from less important information decreases the likelihood that the decision maker will be distracted. If the form preferred most often works well, the problem solver may not be aware of which form of the strategy he or she uses, although falsification is considered to be optimal in most conditions.

Application: These strategies are task-independent and may be involved in developing expertise. Inexpert decision makers tend to overlook the testing of information that is inconsistent with their prior knowledge or current understanding of the situation. Expertise shows a cyclical testing and updating process going on between prior knowledge and current understanding to resolve inconsistencies. However, experts are more likely to disregard irrelevant information. Use of a systematic and explicit technique reduces the problem of distractibility. The positive-test form is probably most commonly used because people are probably not aware of task variables that determine the 'best' test strategies.

Combining Information

Two very different strategies that deal with ways information is combined are clustered in this section. One, functional relations seeking, occurs when the problem solver tries to identify a formal relationship, usually quantitative, between elements in a problem. The other, story building, occurs when the problem solver tries to develop a cohesive story to describe elements in a problem and ways they are related in time. Other strategies also exist which distinguish the ways that information is combined, but they are included in other categories. For example, the compensatory choice strategies clearly differ on whether they attempt to aggregate or isolate the information on which a choice is made.

FUNCTIONAL RELATIONS SEEKING Hammond, 1993; Knez, 1991; Knez, 1992a; Knez, 1992b; Reed & Evans, 1987

Definition: The goal of the problem solver using this strategy is to determine the relationships between cues and outcome. Functional relations are used to integrate the information. Four functional rules have been identified. They are: positive linear relation (PL), negative linear relation (NL), U-formed relation (U), and inverted U-formed relation (IU).

Trigger: The type of task will play a part in whether this strategy is used. If task information is not organized in a coherent fashion, and the person needs to make a prediction or description, then he or she might seek to specify a functional relation.

Example: A platoon leader needs to arrive at a checkpoint by dusk. He thinks about using the already familiar positive linear relationship of time equals distance divided by speed. A functional relations seeking strategy may be employed when he thinks about how to modify and apply the equation for real-world constraints like variable route speeds and traffic volume, incorrect estimates of distances, and making wrong turns and getting lost. Other examples (from Knez (1992a) include positive linear relation: land area and maximum population; negative linear relations: 'too many cooks spoil the broth;' U-formed relation: blood pressure and likelihood of being sick; inverted U-formed relation: age and physical performance.

Strengths & weaknesses: (not identified)

Application: Using principles in a familiar model led to successful performance levels when transferred to an unfamiliar domain.

STORY BUILDING Pennington & Hastie, 1988, 1993

Definition: Explanation-based decision making combines the problem solver's real world knowledge with expectations about what an adequate explanation should be like. This strategy proposes that information is organized in the form of narrative stories and that the form of the story influences the decision outcome. A story narrative is an interrelated series of episodes, each containing initiating events, goals, actions, consequences, and states. The representation of the story is constructed and held in memory as a semantic structure. The importance of information is determined by its role in the causal structure of the story. The structure helps the decision maker make inferences about missing information, organize information according to importance. If more than one story can be constructed, the story which is most complete, most consistent, and most plausible is used.

Trigger: This strategy is appropriate when a coherent explanation is needed.

Example: An officer on a court martial panel listens to evidence presented by the trial counsel and defense officers. The officer uses the prosecuting information to develop a story about how the offense might have taken place using a story-building strategy by filling in a story schema. The officer might consider the plausibility of a guilty verdict based on the strength of the evidence for and against the alleged actions. Structural components of the story, like intentions, actions, and consequences, are filled in as they are presented to the panel. The attributes of the constructed story are then matched against the criteria (attributes) which define each possible verdict category.

Strengths and weaknesses: Confidence in the decision depends on the coherence of the story model which is constructed. Decisions can be influenced by the order in which information is presented. Also, if one unique story cannot be constructed (i.e. more than one coherent story can be constructed) then uncertainty is introduced into the decision. If the person has to generate the choice set of decision alternatives, the person's decision processes may influence the ultimate outcome. On the other hand, if the choice set is given to the person, one's prior knowledge may have the greater impact on the category decision.

Application: Confidence and certainty about a decision are derived from the completeness, consistency, plausibility, and uniqueness of the story constructed from the evidence. Weights may be derived (e.g. for integration models) from the importance of the information to the story. Probabilities (e.g. for Bayesian models) can be derived from the relationships between elements of information in the story.

Managing Amount of Information

One of the great strengths of humans is their capacity for filtering information that they receive from their environment. Strategies in this category depict some of the formal ways in which people control their information. These strategies are useful when too much information or too much data can be overwhelming to use simultaneously or to link together over time in some logical fashion. Three strategies in this category describe how information can be changed or selectively chosen for use.

CONVERSION Newell & Simon, 1972; Voss & Post, 1988

Definition: This strategy is a general problem solving method which is used to change an unsolvable problem into one which can be solved. The original problem is reformulated (restated) in more concrete terms or as problems which already have been solved--in other domains, for example.

Trigger: The trigger for conversion strategies may be previous solutions that were unsatisfactory, that is, solving the wrong problem.

Example: A management firm for a high-rise apartment building was faced with threats of tenants moving out because of slow elevators. The firm explored various measures to speed up the elevators. They hired consultants to develop new ways for cycling the elevators among floors. More complaints were received and some tennants started to move out. Other consultants determined it would be too costly to add more elevators. The problem was redefined to find other approaches. Using a conversion strategy one person noted that the problem was not necessarily the slow speed of the elevators, but the objections to the delays. Once the problem was converted to this viewpoint, there were several new ways to address the problem. For example, rents could be reduced to counteract the negative impressions of the slow elevators. (The eventual solution occurred unintentionally when the common areas were redecorated and mirrors were added to the elevator waiting areas.) (Adapted from an anecdote told by Thomas, 1989).

Strengths and weaknesses: Often, a variety of different types of information must be combined in this process. Therefore, a symmetry must be established between structures which may be discrepant.

Application: The extent of the knowledge base influences whether information is available about the major contributing factors in the problem, e.g. what is the history of the problem, what solutions have been attempted in the past, and why they have failed.

DECOMPOSITION Jeffries, Turner, Polson, & Atwood, 1980; Peng & Reggia, 1990; Reimann & Chi, 1989; Reitman, 1965; Voss & Post, 1988

Definition: This is a problem solving strategy which is directed at restructuring the problem into subproblems which have specific identifiable goals and particular constraints. Breaking down the problem into no more than three primary elements has been suggested. Once the subproblems have been solved, they are recombined to identify the solution for the larger problem.

Trigger: Decomposition occurs when difficulties in solving the problem are encountered or for problems that are complex.

Example: The operations section (S3) of a battalion staff was participating in a simulated battle for training. The enemy needed to be kept from reaching a key phase line. Eight subgoals were: (1) determine where and (2) when the enemy was coming, (3) slow enemy's advance, (4) canalize the enemy, (5) allow the withdrawal of friendly troops, (6) move friendly troops to new positions, (7) establish the friendly defensive plan, and (8) satisfy the commander's intent. Decomposition was used further to determine subgoals and sub-subgoals. (Adapted from Thordsen, Galushka, Klein, Young, & Brezovic, 1990)

Strengths and weaknesses: This method can be successfully used to impose structure on an ill-defined problem. Decomposing the problem into subproblems becomes problematic when there is disagreement about how to constrain a problem or about what constraints to apply; then there can be no universally acceptable solution. This situation often occurs when many of the problem constraints are unspecified, when there is not agreement on relevant attributes, permissible operations, or their consequences. However, the effort to solve a problem in the form of its subproblems is less than the amount of effort required to solve the problem in its overall form. Comparatively, most of the effort in the problem solving process goes to restructuring, leaving only a fraction for the actual solution process.

Application: Experts use prior knowledge to break down the problem into meaningful subproblems. Further, as the problem solver understands and controls the decomposition process, ability to generate and test different solutions increases. Experts have more solutions and methods to use in decomposition.

<u>FRACTIONATION</u> Bransford & Stein, 1984; de Bono, 1970

Definition: This is a problem solving strategy to increase the generation of new alternatives by focussing on parts of the problem, or attributes of the object by looking at the concept from a different perspective. The problem is broken into subproblems in order to free thinking from the assumptions associated with the larger problem, such as thinking about only an object's major attributes or function (functional fixedness). This strategy refocuses the problem solver's attention on the parts rather than the whole.

Trigger: Fractionation is useful when problems persist across time or if one perspective on the problem is relatively fixed in the minds of the solvers.

Example: Civil engineers are faced with complaints from a housing area about the noise of a new adjoining expressway. When thinking about the problem only at this level there are not many avenues for resolution. A fractionation strategy led to considering ways to reduce the sound in terms of the elements involved: the people who are bothered by noise, people's auditory mechanisms, people live in houses which suppress sound, sound that travels through the atmosphere, sound is abated by vegetation and man-made structures, cars and trucks are the source of noise, vehicles are equipped with mufflers, etc. By thinking about the properties and functions of these elements individually, more solutions to a problem can be considered. (Adapted from Bransford & Stein, 1984).

Strengths and weaknesses: This strategy helps the problem solver focus on atypical properties or functions associated with the problem or object. By making assumptions explicit, it is often easier to break away from them or consider the problem based on new or different assumptions.

Application: Many people find that by using this technique, generation of new alternatives increases.

CONTROLLING PROGRESS

Compatible with the notion of strategies are the ways people proceed through a problem solving process. When people proceed with the intention of achieving some certain effect, like increasing efficiency or following an explicit set of procedures, the problem solver is using a strategy to control the progress in the understanding and solution of the problem. There are three categories of strategies in this class. These categories relate to hierarchical structures and the ordering they convey, progressing through some processes to solve the problem, and basing order on what is most beneficial to do.

Ordering by Hierarchical Structure

A problem can be viewed as having different types of components, like the level of specificity of goals or situation states, level of potential actions, or level of mental processes. These types of components can be placed in a hierarchical structure. Sometimes the hierarchy may be well-established in the problem domain, while others may be developed as part of the problem solving process. The nine strategies in this category all have in common the notion of ordering problem solving processes from a hierarchy.

<u>BACK-UP STRATEGY</u> Newell & Simon, 1972; VanLehn, 1991

Definition: This strategy is used when an unprofitable state (node) is reached during the search through the problem space. The current search path is abandoned as the problem solver returns to a previously visited element and begins consideration of untried elements stemming from that point. When a contradiction is discovered, this strategy provides for backtracking on a series of implications. This may occur when the features of the new state are compared with the present state. If the new state is rejected, the search returns to a profitable point encountered earlier in the search. Alternatively, when insufficient information exists or more than one choice is available, the problem solver may use a subgoaling procedure to resolve the conflict (e.g. operator subgoaling, decomposition).

Trigger: This strategy is used when current search fails and prior states of knowledge are available (remembered).

Example: The operations section of a battalion staff was working to find a way to deny the enemy access to a phase line. The staff was determining how to canalize the enemy and slow them down. First they considered that they could blow up or crater a major road intersection, but they realized that they did not have the personnel to do that. So they backed up in their chain of thinking to consider another approach. They considered mining the road, but they realized that the enemy could just go around the mines. So they backed up and considered using air-emplaced mines in the trees, but realized that the mines do not work good in the trees. So they backed up to an earlier point in their thinking and looked for effective locations to emplace the mines. (Adapted from Thordsen et al., 1990.)

Strengths and weaknesses: Effective use of this strategy for search of the problem space depends upon whether the previously visited states (and their outcomes) can be held in memory.

Application: This strategy is efficient because when an error or irrelevant information is discovered, all processing which led to the erroroneous information may need to be eliminated.

BALANCED DEVELOPMENT Adelson & Soloway, 1988

Definition: This strategy keeps all aspects of the problem at the same level of detail as the problem progresses, making it possible to run a mental simulation at any point in the process. All of the issues at one level are dealt with before moving to greater detail. Consideration of constraints, partial solutions, and inconsistencies are maintained as the design progresses. If an element is too highly specified, then when the simulation is run it either will not function or extra computation will be required to move the element to a useable level of abstraction. If the element is insufficiently specified, then information needed to run the simulation will not be present. Successful simulation moves the model to the next level of detail (cf. breadth-first search, progressive deepening).

Trigger: This strategy results from the need to push the overall plan or design ahead while resolving subproblems.

Example: A commander and his staff need to develop a plan for an operation. The commander recognizes that an attack against the enemy is needed to secure key terrain to protect a refugee camp. The commander and staff break the problem down first into the phases of the operation and goals to be reached during each phase. The phases identified were preparation, attack, exploitation, and consolidation. Using a balanced development strategy, the staff generates general concepts for each phase before going through detailed planning for any one phase.

Strengths and weaknesses: This strategy allows one to check a plan in progress through simulation, but its success depends on the domain knowledge available.

Application: Experts appear to be able to manage successfully the tension between processes that push the plan ahead and processes that insist on attending to the immediate goal.

BREADTH-FIRST SEARCH du Boulay, 1989; Galotti, 1989; Newell & Simon, 1972; Volkema, 1988; Winston, 1977

Definition: In a search of the problem space, the goal is sought first among all nodes at a given level before descending to the next level.

Trigger: (not identified)

Example: The tactical planner considers multiple general concepts for defending against the enemy, before considering individual difficulties and how to address them.

Strengths and weaknesses: This strategy is conservative but inefficient. All points to be considered must be stored until they are considered and this requires more memory, effort, and organization which can strain working memory capacity.

Application: When working outside one's area of expertise, idea generation can be enhanced by reformulating the problem in successively broader terms, that is, including operators and states which were not included in the original problem space.

DECOUPLING Lesgold, Rubinson, Feltovich, Glaser, Klopfer, & Wang, 1988

Definition: This pattern recognition strategy occurs before a choice is made to increase the likelihood that the correct schema which represents the data will be found. The perceived features of the problem are examined without determining the final mental representation of it. The emphasis is on the bottom-up processing of information. Any mental representations generated to correspond to perceptual information are held as tentative until "rigorously" tested by the data. Given a set of likely candidate schemata, the one with the highest probability given the data is selected. Decoupling is different from fractionation. Fractionation is an attempt to increase the number of possible solutions in the option set by separating attributes. Decoupling separates perceptual processes.

Trigger: This strategy is used in diagnostic tasks and implies a higher level of cognitive control.

Example: X-ray experts interpret x-rays by comparing features present in an image against prior knowledge about characteristics of the disease and artifacts from the x-ray process. The assessment decouples the source of features on the image. Some features are indicative of the disease, while others are visual noise coming from the X-ray process. A spot on the image is tested against what the interpreter knows about the disease and about how errors create spots when the film is developed. Based on the various schemata brought to mind, a conclusion could be made to classify the spot as either disease or error related (Lesgold et al, 1988).

Strengths and weaknesses: The hazard in using this strategy is that a developing cognitive process of schema comparison and testing has to contend with an already developed perceptual process. Therefore, rather than schema being chosen to fit to perceptions, perceptions may be revised to fit schema.

Application: Novice schemata are tightly bound to the perceptual information, often due to the lack of domain knowledge. The decoupling strategy shifts control of schema manipulation from the purely perceptual to the cognitively controlled processes.

DEEP REASONING STRATEGY Soloway, Adelson, & Ehrlich, 1988

Definition: This strategy is used when a prestored plan or next step is not available or is not reliable. Using available features, prior knowledge about relationships between parts of the problem, and likely goals, hypotheses can be generated and tested to determine whether expectations related to the likely goals are met. This is in contrast to shallow reasoning where the plan is obvious, as well as its purpose and expectations, and the data are tested to confirm expectations.

Trigger: This strategy is used when prestored plans or stereotypes meet a violation of their conventions which then requires an inductive step be made before the plan can continue toward the goal.

Example: When computer programmers write code, subroutines which have been used in other software can be re-used to meet the needs of the new program. However, when the programmer reaches a point where existing subroutines and standard knowledge about programming are insufficient to continue toward the goal of the program (e.g., routing messages to multiple workstation addresses), other likely subroutines are tested. The current state of the program is compared with the goal to determine how to bridge the gap in the program (Soloway et al, 1988).

Strengths and weaknesses: Errors can occur using this method if typical responses are used to meet violations of conventions, rather than using inductive reasoning based on causal relationships between the current state and the goal state. Reasoning accurately takes longer when prestored plans are not available.

Application: This strategy argues for mental simulation of prestored plans using a bottom-up technique. This should be facilitated by balanced development in levels of detail, and inference should be enhanced by a developed knowledge base. However, with reference to the example, advanced and novice programmers were found to have similar performance when presented with an unconventional plan-like program.

<u>DEPTH-FIRST SEARCH</u> du Boulay, 1989; Galotti, 1989; Newell & Simon, 1972; Winston, 1977

Definition: This method of search repeatedly selects the "first child" of every node. The first child is the first option available for the next step. Other alternatives are ignored as long as there is hope of reaching the destination (as long as the option selected is profitable). When a dead end (i.e., an unprofitable option) is reached, the search returns to the last most-recent position and continues. In this way, all lower levels in the tree are searched before that part of the tree is abandoned.

Trigger: Depth-first is appropriate when elements of the solution are readily available and the problem is to search through the elements or choices and test which satisfy solution constraints.

Example: The operations officers who were planning to keep the enemy from reaching a phase line used depth-first search and not breadth-first search (see back-up strategy example). They considered a notion in sufficient depth to determine whether it was likely to work or until they lost confidence in the approach.

Strengths and weaknesses: This method is effective and easily implemented to eliminate unprofitable avenues early because once a failure is encountered an entire sub-tree can be eliminated. However, in a large search space fruitless paths are explored if the search space is not bounded or if relevant models are not constructed. This interferes with making inferences from the model. In complex search spaces, this strategy increases the likelihood that the search will slip past the parent node of the solution and waste time and energy in exploring the tree lower down.

Application: In planning, this method requires only the highest level plan be completed before planning activity can proceed. However, it presupposes that the plan will eventually be complete and fully integrated at all levels of abstraction.

<u>DEPTH-FIRST SUBGOALING</u> Newell & Simon, 1972; Winston, 1977

Definition: If the preconditions for the choice of the next operator are not met or a unique best-choice is not suggested by the process, processing activity is interrupted to engage a subgoal. The subproblem is initiated so that the solution of the main problem can continue.

This is a variation of operator subgoaling but the subgoal which is selected follows the pattern of depth-first search. In this case, the preferred method also selects as the subgoal the "first child" (most likely) of the node at which processing is interrupted. This preference continues as long as subgoaling is profitable, moving the preconditions of the original problem state closer to the choice of a next operator in the main problem. Once a next operator is selected, the strategy returns to the activity directed toward the original goal, using the information supplied by the subgoal.

Trigger: Subgoaling begins when the current state is not fully supported or a single next-move is not completely specified. In this case depth-first is preferred over breadth-first.

Example: The goal of a writer is a complete and coherent sentence. However, an obstacle is encountered if a desired word cannot be retrieved from memory to complete the thought. At this point, the writer believes that the desired word begins with the letter 'T' so several variations of words beginning with that letter are identified. Unsure of the exact letter, the writer tries words beginning with the letter 'P'. All re-callable words beginning with the letter 'P' are evaluated. This process continues until the appropriate word is found. Following the "first child" strategy, words are tried which have higher frequency letter combinations with 'T', e.g. 'TH'. Then the highest frequency associated letter combination with 'TH' is tried, and so on. If at some point, the writer decides that 'TH + E' combination is not profitable, he or she may elect to adopt a back-up strategy, return to 'T' and begin again.

Strengths and weaknesses: Similar to other subgoaling processes: when the subgoaling continues to a depth of several goals before returning search control to the main path, the evidence is particularly conclusive in support of the next move. However, this is a step-wise process which can be time consuming and an effortful working memory load if the problem space is large and no stop rules are attached to the depth searches (e.g. the subroutine provides no more useful information).

Application: Solving early subgoals facilitates the process if they reappear as children of other nodes.

<u>OPERATOR SUBGOALING</u> Akyurek, 1992; Newell & Simon 1972; VanLehn, 1991

Definition: This is a general strategy which is employed through variations such as depth-first subgoaling. If the preconditions for the choice of the next operator are not met or a unique best-choice is not suggested by the process, processing activity is interrupted to engage a subgoal, which is used to find a way to change the current state until the precondition is true. Then the strategy returns to the activity directed toward the original goal, using the information supplied by the subgoal.

Trigger: This strategy might be triggered when the current state is not fully supported (not enough information) or when a single next-move is not identified (an obstacle is encountered) that moves the process toward the goal.

Example: Consider the example from depth-first subgoaling which specified a particular direction of moves. The goal of a writer is a complete and coherent sentence. This is the same as depth-first subgoaling except that the manner in which subgoaling is accomplished and how operators are selected are not specified. When not qualified by a depth-first criteria, rather than choosing to combine 'T'+ 'H' + 'E' etc. based on prior knowledge of letter and word frequency in the language, the letters might be tried in alphabetical or random order.

Strengths and weaknesses: This process leaves no memory for the history of operators used. This can lead to repetition of search behavior.

Application: When the subgoaling continues to a depth of several goals before returning search control to the main path, the evidence is particularly conclusive in changing the original state.

PROGRESSIVE DEEPENING Galotti, 1989; Klein, 1989; Newell, 1989; Newell & Simon, 1972; Winston, 1977

Definition: This is a guiding search strategy in which one repeats the same task, acquiring new information at each pass during information gathering or design tasks. Repetition is the mark of progressive deepening. This strategy provides control processes for what to refine (in successive refinements) by repeatedly going over what has been done, finding the next item of relevant information, or finding the next place in the problem that should be extended or refined. Side branches are explored and potential options are evaluated.

Trigger: (not identified)

Example: The operations officer (S3) for the battalion goes through progressive deepening as he considers various options in progressive levels of detail. He considers the terrain and tries to determine how to deny the enemy use of a certain road. He figures that they could blow or mine a particular bridge. But then he sees that cratering the road would keep the enemy off of it. But no, the enemy could just pull off the road and go around the craters. So then the S3 thinks about how to keep them on the road. He thinks that indirect artillery fires on either side of the road would keep them pinned down. But then he realizes that it is wooded on either side of the road. The S3 remembers that indirect fires are not very effective in wooded areas. Since he cannot think of any other ways to stop them on that part of the road, he looks for other places to stop them on the road. When all readily-thought of possibilities are exhausted, he revisits his original goal and thinks about what else could be done. He asks why he wanted to deny the road; it was to delay the enemy. He then begins again to consider other ways to delay. (Adapted from Thordsen et al., 1990).

Strengths and weaknesses: Information processing capacity limitations (e.g. working memory limits) can limit construction and interpretation of relevant mental models. Bias can result from a failure to search for or construct relevant models. Also, error can result if search is not systematic and exhaustive, or if all of the implications of the information are not assessed.

Application: Deepening of the mental model depends on domain knowledge.

Sequencing

Perhaps what best fits the definition of strategy is the order or sequence of tasks or processes to solve a problem. Strategies in this category deal with how processes are ordered in time and on what basis the sequencing is done.

<u>BACKWARD CHAINING</u> Anzai, 1991; Carlson, Khoo, Yaure, & Schneider, 1990; Harris, Hill, Lysaught, & Christ, 1992; Hegarty, 1991; Hunt, 1989; Lesgold, Rubinson, Feltovich, Glaser, Klopfer, & Wang, 1988; Morrison & Duncan, 1988; Newell & Simon, 1972; Norman & Rumelhart, 1975; Patel & Groen, 1991; Polya, 1945; VanLehn, 1991; Waterman & Hayes-Roth, 1978; Winston, 1977

Definition: This consequent-driven search process begins when the goal, solution, or hypothesis is specified and the problem solver works from the conclusion to the facts on which it depends in a sequential, reverse direction by breaking the problem into smaller ones. This procedure can be used to verify or deny a conclusion by running backward productions to a given set of facts (e.g. by hypothesizing a conclusion and identifying the facts that support it). In rule-based systems, the consequents of the rules are searched to find one which has antecedents that might confirm the truth of the conclusion. When one is found, it is fired, or activated. The goal is to find a causal chain from consequent to antecedent which proves the conclusion by matching the data.

Trigger: Schema or domain knowledge for the problem is inadequate or the problem is novel. This strategy is also used when an impasse is reached in forward reasoning methods.

Example: A mechanic trainee was trying to diagnose a stalled car. His approach is to reason from the possible cause to find evidence to support his theory. He considers how he knows the car will not start. He was told by the customer who suspects a dead battery. He adopts this theory and looks for data to support it. He confirms that the car will not start by turning the ignition key. He considers whether there is any sound indicating that the electrical system is not working. He then considers other causes in the reverse order of what is necessary for the car to start.

Strengths and weaknesses: In diagnostic problem solving, working back from the goal progressively constrains the search. In diagnosis, this is more effective than a forward search because the search is confined to smaller sections of the problem. This method is slower to use than forward chaining and makes higher demand on working memory because concept-driven processes are generally conscious and serial processes.

Application: This reasoning strategy is the primary sequence used by novices; however, it is used by both experts and novices for unfamiliar problems. Backward processes can be guided by prior experience but are often adopted when constraints are absent. A sign of acquisition of expertise is that search strategies shift from backward to forward search, but problems outside of the area of expertise will evoke backward search in experts. This strategy may be the technique by which problem solving schemata are built. The difference between novice and expert may be in the number of problem solving schemata which have been created as a result of using backward chaining as a reasoning strategy. Working forward is used to compile input-output relations, which are then stored and used in working backward strategies.

FORWARD CHAINING Anzai, 1991; du Boulay, 1989; Groner, Groner, & Bischof, 1983; Harris, Hill, & Lysaught, 1992; Hunt, 1989; Lesgold, Rubinson, Feltovich, Glaser, Klopfer, & Wang, 1988; Newell & Simon, 1972; Patel & Groen, 1991; Rumelhart, 1977; Simon & Simon, 1978; VanLehn, 1991; Winston, 1977

Definition: This is a simple step-wise strategy to proceed toward a goal by making inferences based on the current state without regard for the goal. The process is finding a theory to support the data. Input cues or data are used to select operators from among those applicable to the current state using IF-THEN rules. More than one operator may be applicable. Inputs are matched to the IF-part of the rule which generates the THEN-part in order to use these rules to move through the knowledge base. More than one likely path may be generated. The terminal point is chosen which satisfies the conditions of the original expression. This is the basis of deduction.

Trigger: Searching forward requires a specific routine problem state with useful cues, a specific goal, variables that are well understood, and a high degree of relevant knowledge.

Example: An experienced mechanic looks for clues to explain why a car won't start. He turns the key. He uses his vast knowledge about cars to guide his selection of information in the current situation. The key is turned and there is no sound, the lights do not work, and the gauges do not move. He assumes that the battery needs a jump or there is a break in the connections. If jumping does not start the car, then he checks battery connections. Turning the key still does not "turn over" the engine. Therefore, based on these indicators the mechanic adopts the theory that the battery may need to be replaced.

Strengths and weaknesses: Working forward when solving a problem can sometimes be used to generate a branching "discovery" tree with several potential solution paths. However, working forward makes automatizing inference processes more difficult. The terminal points of each path can then compared with the goal. Generally, this type of data-driven process is characterized as parallel, automatic, unconscious, and relatively unaffected by capacity limitations. Forward reasoning ability correlates with accurate diagnosis, but the process may become disordered if interrupted. However, as domain knowledge increases, error rate most likely decreases because domain knowledge constrains and qualifies the inferences being made and reduces the impact of irrelevant information that is present. Superior pattern recognition is associated with the ability to successfully use forward reasoning.

Application: This is the simplest proceed search strategy which uses substitution and replacement as elementary operators. Forward reasoning, a mark of accurate performance by experts in their knowledge domain, appears to be a superficial process. Experts seem to use a macrostructure/schema of highly specialized domain knowledge to filter irrelevant information which might otherwise influence chunking and search strategies. A few cues can be used to generate early hypothesis which can then be refined and evaluated. This also enables identification of "loose ends" and their associated uncertainty. On the other hand, subexperts have a generic but inadequate specialization of domain knowledge which makes use of this strategy less successful. Whether forward or backward reasoning is used depends on how easily the problem solver can access the antecedent part of the production (backward reasoning) or the consequent (forward reasoning).

HEDGE CLIPPING Connolly, 1988

Definition: Decisions are broken down into a series of actions so that more feedback is provided than would be available from just one overall decision--a more sweeping move. Information provided by each step can then be evaluated prior to the next action. As conditions warrant, the next step can be modified based on the most current information.

Trigger: This strategy is useful when goals are ambiguous or conflicting and the future is uncertain. It might also be used when feedback is desired. Outcomes at each step are relatively less significant and so consequences at each step are smaller.

Example: A manager of a small independent grocery is considering whether to add mangos to his produce offering. First he considers that if he wants to sell them, he must contract with the fruit supplier for at least three months. Knowing that this will be a risk if customers do not buy them, the manager considers possible actions to get more information. First he surveys three nearby stores to see if they offer mangos. He finds that the largest store does and the others do not. He concludes that there must be some demand for them and that the supply will not be exceeded if he also offers them. Next he surveys stores in another part of the city to see whether any or all offer mangos. He confirms his finding that some stores offer them and some do not. He feels more confident about the idea, but also realizes that unless he is careful he may make no profit since all stores do not sell mangos. He concludes that he really needs to know the willingness of his clientele to purchase mangos. He talks to some of his customers, who seem interested but are not quite sure how to prepare mangos. Next he purchases a lug of mangos from another grocer to resell at cost as a test of the market. He offers a display with free produce recipes, each recipe card featuring a different fruit or vegetable. He watches to see how quickly the mangos are sold and how many customers are interested in the mango recipes. The feedback provided through a hedge clipping strategy lets him know through successive actions whether to commit to mango sales.

Strengths and weaknesses: More time and effort is involved at each step rather than investing these resources in thinking far ahead.

Application: This is useful as an exploratory activity.

HEURISTIC SEARCH Basu & Dutta, 1989; du Boulay, 1989; Groner, Groner, & Bischof, 1983; Hunt, 1989; Newell & Simon, 1972; Sinnott, 1989; VanLehn, 1991; Voss & Post, 1988

Definition: This is a search method for "guided discovery" which depends on knowledge of the domain to decide what line of search to follow by delimiting the problem space. It produces a selection of possible solution actions and paths based on criteria for admissibility (constraints) and existing information. The search is guided by the relative merits of the nodes and operators, and guesswork is reduced so that the path taken appears to stay on a promising line to the goal.

Trigger: This is the underlying problem solving method for most unstructured problems when the problem space is too large to conduct an effective search. This can happen when the problem solver has too much information to be held in working memory.

Example: A national leader of a strategically-located country is described as bold, outgoing, strong-willed, and cooperative. A State Department analyst must consider these traits and decide whether it is likely that the leader can be persuaded to allow landings for refueling of U.S. planes. The analyst uses the adjectives to delimit the possible set of potential reactions for this type of personality. The leader's reaction is then categorized by the degree to which he is likely to respond.

Strengths and weaknesses: This method depends on domain knowledge to define the search. Error can occur if the decision maker fails to use domain knowledge or if relevant information is excluded. The computational effort required to search the knowledge base is reduced by using this search strategy but is increased if imprecise knowledge is included in the search. Poor performance on well-structured problems is due to "not having the concept," even though performance may be rapid.

Application: When errors are present, training for flexibility can improve performance. The heuristic stage of reasoning is thought by some to be an earlier stage of problem solving in which relevant aspects of problem information are identified and selected for further processing. It would then be followed by an analytic phase.

<u>MEANS-ENDS ANALYSIS</u> Anderson, 1990; du Boulay, 1989; Newell & Simon, 1972; Reimann & Chi, 1989; Sinnott, 1989; VanLehn, 1991; Winston, 1977

Definition: This is a generalized proceed strategy which is recursive and which employs several other strategies, such as subgoaling. This strategy also provides the decision maker some criteria with which to evaluate a problem solving step. The current state is compared to the desired goal state and operators are selected to reduce the difference between them. If an operator is not applicable, inputs can be modified to make it apply. If the difference (main problem) is too difficult to affect, new and less difficult differences (subproblems) can be introduced and solved so long as progress is made toward the goal (i.e. subgoals are introduced and reached). The likelihood of achieving the main goal is dependent upon the probability of meeting the subgoals.

Trigger: This method is often used when the goal is highly specified, domain knowledge is low, a learned heuristic is not available.

Example: The goal is to get the car started but the driver has little mechanical knowledge and because of this has to rely on using reasonable subgoals. The key will turn but nothing happens (a subgoal is solved and one potential cause for the problem is eliminated). The alternator is thought to be a potential problem and is replaced, but the car still does not start (a subgoal is solved). The battery cables look worn and are replaced (a subgoal is solved) but the car does not start, and so on, until the solution is found and the goal of starting the car is reached.

Strengths and weaknesses: Means-ends strategy increases the probability of reaching the goal. However, this strategy is limiting in that the problem solver only needs to remember the current goal. The information about problem structure, previous moves, and the conditions which led to one specific path is easily lost. Means-ends analysis also requires greater effort when subgoaling is used. Further, if subgoals are retained in working memory, a memory load is imposed. If the problem solver needs to reconstruct the reason for the main goal a failure can occur and a different path might be chosen which leads to a different outcome. This is particularly likely in unusual paths or solution in novel domains. However, this strategy can illuminate out-of-sequence, disorganized reasoning.

Application: Novices resort to MEA for unfamiliar problems. Use of this strategy by novices when the goal is highly specified may prevent induction of problem-specific rules. By decreasing goal specificity, novices can be induced to adopt a forward-working strategy. Using MEA directs attention to the goal and away from the relationship between problem state, an associated move, and its consequence, thus inhibiting learning the structure of the problem. Problem solving efficiency depends on the problem solver identifying the operator which will reduce more difference than it creates.

PROCEED STRATEGY Beach, 1990; VanLehn, 1991; Vlek, 1987

Definition: This is a control strategy which determines whether the search will continue. An operator is chosen, applied to the current state, and the results are evaluated. If the current state is closer toward the goal then the process is repeated. If the current state is the desired state then search is terminated. If the current state is not profitable, search continues by giving control to the backup strategy to return to the last-visited state to continue the search. This strategy has also been called a progress decision in Image theory.

Trigger: This is used when the previous operation has produced favorable results and the goal is not yet reached.

Example: A medical corpsman has found himself in the midst of refugees who are fleeing a push forward by the enemy. One of the refugees is in need of medical assistance to help deliver a baby. The corpsman does not immediately remember the exact procedures for delivery. He starts with taking vital signs. The check on vital signs shows that blood pressure is not as good as it should be. The corpsman follows a proceed strategy to assess the level of risk that the expectant woman is in and how immediate the birth might occur. The corpsman uses this information to decide whether the woman should continue with the evacuation or whether he should help deliver the baby.

Strengths and weaknesses: There are often a number of choice points at which an operator is chosen, making decision strategies important in the selection of the next operator.

Application: The search for the next operator can be simplified/made more efficient by using heuristics to narrow the set of choices. When the rules are overlearned, any conflict would be resolved because gaps would be filled by inference rather than stopping the process and backing up.

SIMILARITY MATCHING Akyurek, 1992; Chi, Feltovich, & Glaser, 1981; Medin & Smith, 1984; Metcalfe, 1991; Pitz & Sachs, 1984; VanLehn, 1991

Definition: This is a goal-directed selection strategy used to reduce differences between the current state and the goal state. Selection of an operator (what to do) for the current state is determined based on whether the new state (result) would be more similar to the goal than if other operators had been selected. This strategy is related to means-ends analysis and subgoaling.

Trigger: This strategy is used when categorization is desirable.

Example: A company of Rangers is ordered to drive any enemy forces that they encounter off a hill, set up overwatch positions, and supporting fires on a key cross roads below. The company commander assesses his current situation. He must decide how to approach the hill. He first recognizes a direct route that would be quickest. Getting to the hill quickly is desirable. He stops to consider whether anything is sacrificed using this route. He sees that the open sloping terrain would open his troops to direct observation and fire. The considered action of taking the direct route is not similar to the goal states of the subsequent phases of his mission. He considers what he must think of to find a better route. He thinks that he should look for a way to conceal their approach to the hill, that would establish the conditions to match all goals.

Strengths and weaknesses: The number of pathways that must be searched are reduced by this strategy and the search is more efficient than random or systematically exhaustive strategies. However, familiarity or imaginability of items can be confused with actual frequency, so that stereotypes might be relied on rather than objective frequencies.

Application: This strategy is often used when the rule is not known and when category exemplars or general stereotypes are known. Expertise allows one to substitute recognition for search. Experts perceive similarities in terms of fundamental concepts in a domain rather than superficial features.

<u>TREE-FELLING</u> Connolly, 1988

Definition: This is a decision strategy in which a consequential decision is made in one step after a period of planning or deliberation. This method differs from hedge-clipping in that it does not provide for feedback adjustments.

Trigger: The goals are well defined and there is a clear way of achieving them.

Example: A new meat cutter in a grocery store wants to capture the attention of the clientele. He thinks that what is needed is something visual to catch everyone's attention. He reasons that if customers take more notice of the meat counter they will spend more time there, take more interest, and make more purchases. Without seeking any input from others or any partial test of his idea, he paints a wall mural on behind the meat counter.

Strengths and weaknesses: This strategy does not provide for incremental steps to provide feedback and correction.

Application: The decision maker must be highly confident of the outcome or the state of their accessible knowledge about the problem.

<u>TRIAL-AND-ERROR SEARCH</u> Anzai, 1991; Newell & Simon, 1972; Sinnott, 1989

Definition: This is the strategy when there is no other strategy. No criteria or constraints exist to aid in selecting the next operator. The problem is considered to be solved when a goal is reached which produces a result (or error) that is acceptable to the problem solver's belief system.

Trigger: This strategy is used in a very large problem space where no heuristics are available and when the goal is not clearly specified.

Example: A G3 (operations) planner is asked to think of a way to lure the enemy into an engagement area. First he thinks about having one of the reconnaissance elements slowly return through that area to draw the enemy into it. He quickly gives up on that idea, realizing that the enemy would not have to commit any sizable force to engage the recon element. Next he considers portraying a larger force by using simulated radio traffic and dummy units. He then sees that this would not work unless he could somehow conceal the size and location of the rest of his unit. His planning continues through mental trial-and-error until he meets all of his goals or no more ideas are found.

Strengths and weaknesses: This is an inefficient problem solving strategy which operates independently of domain knowledge. The set to be searched is too large and so testing of operators is very costly. No criteria are used to select operators and minimal criteria define an acceptable solution. Problem solvers using this strategy make errors on well-structured problems because they see more options than necessarily required by the task. Performance declines because the process takes too long.

Application: This search strategy is independent of domain-specific knowledge. It differs from hypothesis testing in that hypothesis testing provides feedback about the rule or goal. Trial-and-error is a search for feedback about the nature of the problem. [In this sense, trial-and-error might be the first step in developing/defining constraints for the problem in the absence of prior knowledge.]

Ordering by Merit or Payoff

Two strategies were identified from the literature that describe how progress is controlled based on the potential merit or payoff of a selected process.

<u>BEST-FIRST SEARCH</u> Galotti, 1989; Reimann & Chi, 1989; Winston, 1977

Definition: Domain knowledge helps select the most profitable path to search. Forward motion in the search starts from the best node found so far, regardless of where it is in the problem space. This is related to hill-climbing in that it seeks to continue forward motion, always in the most economical direction. Generally, this path to a solution is shorter than those using breadth-first or depth-first methods without regard for the particular problem characteristics and prior knowledge.

Trigger: (not identified)

Example: When buying a new car, a consumer may have information that the new car dealership which is further away than some others also has the lowest prices. Because of this, the buyer begins deliberating about buying a new car at this dealership despite the fact that it is farther away. A different pattern of search, such as depth-first, might have begun deliberating about the dealership closest to the buyer's home.

Strengths and weaknesses: A shortage of working memory capacity hinders the construction and use of mental models, which may result in a failure to search systematically and exhaustively (i.e. for counter examples) or in a failure to understand the implications of the models which are searched. Success depends on the ability to distinguish relevant and irrelevant problem features.

Application: Failure to use or lack of domain knowledge can result in failure to construct correct models. Experience in a domain develops search control knowledge which guides the search by selecting regions of the existing problem spaces or by helping to create new problem spaces.

<u>WIN-STAY/LOSE-SHIFT</u> Anderson, 1989; Gettys & Fisher, 1979; Holding, 1989; Klayman & Ha, 1987; Levine, 1966

Definition: This strategy guides search for alternative hypotheses by evaluating the outcome of each step in the plan. If the outcome of the move is favorable, the hypothesis is retained and the plan continues. If the outcome is unfavorable, a new hypothesis is generated and a different move is chosen. This is a positive-test strategy.

Trigger: (not identified)

Example: The president of Acme fan belts is pursuing a plan to target a specific local market. As long as that market is profitable she will continue with it. However, she knows if the local market drops off and does not provide enough profit for natural growth of the company, then she will need to change the target market.

Strengths and weaknesses: This method is not the most effective strategy, especially when there are finite sets of hypotheses. A more effortful "gambling focus or scanning focus" strategy would be more efficient. It can also result in "Einstellung errors" which occur when a once-successful rule is applied when it is no longer appropriate. Players often show a failure to shift to a new hypothesis after a negative outcome, preferring to stay on an unfavorable course and shifting only after exhausting all likely continuations of that path (sunk-cost effects).

Application: Experts increased search size after a negative outcome and decreased search size after a positive outcome, but did not change when the outcome was neutral (homing heuristic).

MAKING CHOICES

How choices are made appears to be a very important aspect of thinking when one considers the number of possible strategies available for decision making. It is probably not the case that choice is necessarily more important than other stages of problem solving (understanding situations, identifying problems, generating options, enacting solutions, and getting feedback), but analytical choice strategies have been more prone to precise definition. Many of the analytic choice strategies come from formal models that prescribe quantitative techniques for selection. On the other hand, there are not so many choice strategies that characterize natural or untaught approaches. The decision strategies have been broken down into three categories: managing the number of options, using compensatory techniques, and using noncompensatory techniques.

Managing the Number of Options

A problem solver must somehow manage the possibilities that are considered. Humans have a powerful capacity to create (or induce) relationships among knowledge and to create new knowledge. In order to limit the possibilities and to achieve solutions to problems, people need strategies to focus their efforts on the best options. One way to do this is to control the number of options considered. Eight strategies for managing the number of options were identified from the literature.

<u>COMPATIBILITY TEST</u> Beach, 1990, 1993; Vlek, 1987

Definition: This strategy tests the "fit" of each candidate option and screens ("weeds out") options sequentially based upon whether they meet criteria compatible with the goal. If the option does not conform to the decision maker's relevant principles, or adversely affects attainment of the goals and plans, then it violates the criteria. The number of violations that an option may have before it is rejected depends on the decision makers threshold. A candidate is presumed to be acceptable unless violations exceed a threshold of acceptability. If several candidates pass this rejection threshold test, then the profitability test (see below) is applied to choose the best option from the set.

Trigger: Multiple options exist in the possible set of solutions.

Example: A certain company commander does not volunteer or lobby for assignments unless he expects that he can succeed.

Strengths and weaknesses: This strategy can be used to reduce a choice set.

Application: Rejection threshold depends on the individual's principles, goals, and plans.

<u>PROFITABILITY TEST</u> Beach, 1990; Kerstholt, 1992; Lipshitz, 1993; Newell & Simon, 1972; Vlek, 1987

Definition: The options which survive the screening test of compatibility are then subjected to a profitability test--a strategy based on task, environment, and decision maker characteristics. The profitability test is a meta-decision about which strategy to apply to the decision task. The test follows a cost-benefit, subjective expected utility logic in that the cost of using a particular strategy is balanced against the benefit of making a correct decision--not making a decision correctly.

Trigger: More than one option survives a screening strategy which weeds out undesirable alternatives.

Example: A new S4 for an armor battalion has a problem in one of the motor pools. There are too many missing tool kits. He needs to decide what action to take to discover the source of the problem and what can be done about it. He considers how he should think about the problem using a profitability strategy. Is it best just to forget about it for now and see what turns up? He could just get more kits. Should he try to develop some kind of informal investigative technique so he can get more information? He doesn't have time for that. Should he make regular site visits to the motor pool to better understand what happens there? This would enable him to build rapport with the soldiers. Should he take the problem to the master sergeant or the executive officer and get their advice? He assesses the pros and cons of all the options he can think of and compares each to his own beliefs about how he should perform his duties as an S4.

Strengths and weaknesses: As complexity of a decision increases, the greater the decision makers' tendency to use intuitive, noncompensatory tests for profitability.

Application: Decision makers use different tests of profitability to make reasonable good decisions at a minimal level of effort.

PRUNING Harris, Hill, & Lysaught, 1992

Definition: This strategy can be used to constrain search of the problem space. Based on available resources, portions of the solution space are eliminated from consideration to reduce the set of alternatives.

Trigger: (not identified)

Example: A Bradley squad leader must get his units across a river. No bridging equipment is available and their on-board fording kits have been lost or are irreparable. The squad leader eliminates or prunes the possibility of finding another crossing site or waiting for engineers to locate and construct bridging. He revisits the problem of fording kits and decides to locate a near-by unit to borrow from them.

Strengths and weaknesses: This strategy reduces the problem space to be searched.

Application: Extent of prior knowledge and current mental workload would determine how effective the pruning would be.

SCANNING--simultaneous Bruner, Goodnow, & Austin, 1956; Morrison & Duncan, 1988

Definition: This strategy for categorization (concept attainment) uses the information of the instance to eliminate more than one hypothesis at a time. By gathering global information early in the process, each alternative can be described by the hypotheses that it logically eliminates (what it is not).

Trigger: This can be triggered by either the nature of the task (need for categorization) or individual processing preferences.

Example: A student in ornithology is on a field trip. The student sees a large bird and tries to identify what it is. The student sees that the bird has light-colored feathers on its breast with brown feathers interspersed and the reverse coloring on its back and wings. It has a heavy body, short bill, and short wings. She recognizes from the combination of markings that it as one of the gallinaceous family, probably of the grouse (tetraonidae) genera.

Strengths and weaknesses: This method is higher in cognitive strain than is successive scanning because global information is gathered and compared to details. Therefore, it requires that more hypotheses are held in memory. Also, this strategy does not guarantee that the next test will maximize informativeness and minimize redundancy. However, this method is a less redundant method than successive scan.

Application: This strategy is used/preferred by the more efficient subjects.

<u>**SCANNING--successive**</u> Bruner, Goodnow, & Austin, 1956; Morrison & Duncan, 1988

Definition: This is a categorization (concept attainment) strategy which tests one hypothesis at a time to determine if the instance is a member of the category. Options to test are selected because they permit a direct test of the hypothesis (what it is).

Trigger: This strategy is used when the task requires categorization. It is used when past experience has shown this method to be effective.

Example: Another student on the field trip (see the simultaneous scanning example) wishes to identify the species of the grouse. He first looks to the shape of the tail, knowing that if it is pointed it would likely be a sharp-tailed grouse or maybe a sage grouse. The student sees that the tail is narrow but does not end in a point. Thinking further the student knows that the ruffed grouse has raised head feathers and a broad tail with a black terminal band. Not seeing these distinct markings, he tries to determine whether the bird is a blue or a spruce grouse. He must recognize what the different markings are not just between the two species of grouse, but also between male and female. The successive nature of scanning relates to the classifications that are recalled sequentially instead of simultaneously. The bird has no particular different coloring around the eye, so it is recognized as a female. The tail feathers end in a brown band. Since it is a brown instead of a gray band, the student identifies it as a spruce grouse (Canachites canadénsis).

Strengths and weaknesses: This strategy reduces cognitive strain by reducing required inferences and memory load. It is a direct test of the hypothesis. Little knowledge transformation is needed to test a hypothesis. Memory is required to keep track of the hypotheses already tested and rejected. However, this method does not eliminate the risk of redundant choices and subjects may resort to guessing, especially in large sets.

Application: This strategy of direct test is necessary when more than two alternatives may be right. It is used by less efficient subjects.

<u>SCOPING</u> Lussier, in preparation

aka: estimation, rough "ballpark" estimation, gross estimation

Definition: This is a problem solving strategy to simplify complex problems. Using this strategy the problem solver looks for the key/most important factors and concentrates on these while collapsing factors of lesser importance into one treatment group. Any factors which are identified as irrelevant or insignificant are initially disregarded. However, once the "best case" and "worst case" solutions have been estimated, the less important factors are included in consideration of the final solution.

Trigger: This strategy is appropriate when a complex problem is encountered.

Example: A member of a Congresswoman's staff is considering how much additional revenue an increase in the gas tax would bring in during a one year period. To estimate this, he first estimates how many gallons are used by one car for one year and calculates the tax for one car. This number is then multiplied by the total number of cars in the US. The staffer does not remember ever knowing the total number of cars in the U.S. but makes an estimate based on the population and the ratio or distribution of cars to people. Other miscellaneous uses of gas are not considered at this point. An estimate of the number of cars which is slightly high will compensate for the miscellaneous uses which were not originally included. In this way an idea about how much revenue can be produced from an additional tax is quickly derived (adapted from Lussier, in preparation).

Strengths and weaknesses: This method mobilizes the problem solver to look at the entire problem while using only the most salient information to generate an early solution. When time is constrained, this method can screen out unfeasible COAs. Scoping is a heuristic procedure which does not guarantee one correct solution. It depends on the ability of the problem solver to identify important aspects of the problem and to disregard what is unimportant. Comparison of the calculated answer to the estimation is a necessary step to catch errors. However, it seems as if the need for calculation and comparison defeats the purpose of scoping to simplify the problem and to save time except as a learning exercise.

Application: This process depends on the domain knowledge available to the problem solver so that reasonable estimations can be made.

<u>SCREENING</u> Beach, 1990, 1993; Potter, 1991; Vlek, 1987

Definition: This is a problem solving strategy to reduce a set of options based on a compatibility test. The decision maker sets a minimal standard of acceptability depending upon the current situation and options are admitted to the choice set if they are compatible with the standard. If no options pass the test, the decision maker lowers the standards and becomes more tolerant of violations. External standards, such as those imposed by one's job, seem to be lowered less than one's private standards. Screening is similar to other strategies which reduce the set of options, such as pruning.

Trigger: Initially, too many options to choose from are available.

Example: An apartment seeker wants to get a dwelling within four blocks of her job. Available apartments are first identified by calling a rental company and checking the newspaper. No apartments were available that were within four blocks. So the apartment seeker relaxes the screening standard and identifies five possible apartments that are currently available. These were then further screened by determining whether they meet basic levels of cleanliness and convenience. Most of them seem to meet the quality check. so the next screening factor she uses is the amount of rent.

Strengths and weaknesses: Screening reduces the workload by reducing the set of options. It also reduces the potential for bad choices. However, if screening information is not carried forward a good choice may also be eliminated if it does not meet the standard on that attribute.

Application: The quality of the options allowed to enter the choice set depends on the decision maker's knowledge about setting the criteria.

Using Compensatory Choice Strategies

Twelve strategies are classified as compensatory choice and are shown below. Compensatory means that a low score on one attribute can be compensated for by a higher score on another attribute. Attributes are the dimensions, characteristics, features, or criteria which indicate desired goal or option states. Each attribute might have several aspects. Aspects are the values of an attribute. For example, the noise level in a command post might be the attribute, the quality of being too loud to talk on the radio might be the aspect, while attractiveness is when an aspect is mapped onto a scale of attractiveness. An aspect might also be stated more objectively, e.g., in terms of 85 decibels as measured by a sound level meter. A clearly measurable aspect could be stated as a standard. Table 3 presents a comparison of the compensatory choice strategies.

Table 3

Characteristics of Compensatory Choice Strategies

Compensatory Strategies	Common scale for attributes	Considers minimal or expansive numbers of attributes	Eliminate or select options	Considers attribute importance	Decision rule
Addition of utilities	Y	Expansive	Select	N	Select option with largest sum.
Additive difference	Y	Expansive	Select	Y	Select option corresponding to + or - difference.
Choice by greatest attractiveness difference rule	N	Minimal	Select	Y	Select option with largest value on attribute with largest range.
Choice by most attractive aspect	N	Minimal	Select	N	Select option with greatest attractiveness on aspect or attribute.
Cost-benefit analysis	Y	Expansive	Select	Y	Select option with most favorable ratio, difference.
Dimensional reduction	Y	Minimal	Eliminate	N	Eliminate attribute with smallest range for all options.
Elimination by least attractive aspect	N	Minimal	Eliminate	Y	Eliminate option with worst aspect over all attributes.
Expected value	Y	Expansive	Select	Y	Select option with largest expected value.
Majority of confirming dimensions	N	Expansive	Select	N	Select option with greatest number of attractiveness values over all attributes.
Marginal rate of substitution	N	Expansive	Modify option	Y	Trade off value of one attribute to gain added value on another attribute.
Maximax	N	Minimal	Select	N	Select option with largest attribute value.
Maximin	Y	Minimal	Select	N	Select option with largest attribute value from set of lowest values across options.

Four characteristics are used to describe the compensatory strategies in Table 3 (and the noncompensatory ones in Table 4). Common scale for the attributes refers to whether the technique requires that attributes use the same ratio, interval, or ordinal scale. A common scale allows for arithmetic operations to be performed across attributes and options. The second characteristic tries to illustrate whether a strategy seeks to use minimal attribute information for the purposes of reducing workload or whether a strategy seeks to be more complete and expansive in its consideration of attributes. Expansive techniques typically aggregate across attributes, while minimal techniques tries to find the most important or discriminating feature. Some of the strategies focus on the selection of an option, while others focus on eliminating options (i.e., a "weeding out" process or selection by a process of elimination). Another characteristic is whether the strategies consider a difference in the importance of attributes or whether it treats one attribute as telling as another. Finally the decision rule is a simple statement of the procedure by which the strategy selects or eliminates options.

To help describe the strategies, matrices are given to depict the various structures of the compensatory choice strategies. The tables are conceptual in that they do not mean that when a strategy is used that it will be represented in a matrix or that the particular values or calculations will be performed. Many of the techniques address how to focus on critical, distinguishing parts of the problem without completing the whole matrix. In this sense the matrices allow an image of likenesses and differences in underlying structure, not necessarily how the strategy is used. A common set of terms is used throughout, though the literature in this area is not so consistent. Attributes are consistently displayed in the rows of the tables. They are denoted by letters (a, b, c, ...) in the tables. Columns are used to depict options, which are the same as courses of action--those things being chosen from. Options are labeled as numbers (1, 2, 3, 4) in the tables. Values represent the intersection between attributes and options. Values are also known as dimensions, criteria, attractiveness, aspects, etc. Values are denoted by the letter v in the tables. Subscripts are used to identify unique values, where the first subscript relates to rows and the second to columns. A dot is used to denote the summation over that row or column. Weights are denoted by the letter w in the tables.

<u>ADDITION OF UTILITIES</u> Hwang & Yoon, 1981; Kerstholt, 1992; Paquette & Kidda, 1988; Svenson, 1979

aka: additive compensatory strategy; additive weighting method

Definition: A decision strategy used for making a choice between options. Every attribute of each option is assigned a utility value. Utility is defined as an interval rating of usefulness, satisfaction, or attractiveness. These values are then summed. The sum for each option is computed before options are compared. The option with the highest overall score is selected. This is a compensatory choice strategy because a low score on one attribute can be offset by a high score on another attribute of that option.

Trigger: The trigger for addition of utilities strategies is similar to all compensatory strategies. One of this class of strategies is more likely to be used when the task is simple, expertise is low, time is unrestricted, the decision has greater consequences, and the decision needs to be justified.

Example: An office manager needs to select a new copier. To standardize repair and maintenance, the purchasing department limits consideration to seven models. The office manager identifies five attributes on which to rate the seven copiers. The attributes or criteria are price, reliability, ease of operation, clarity of copies, and size of the copier. She thinks about each attribute for each of the copiers and assigns an utility rating or a value. She then adds the values for copier one, then copier two, and so on. She recommends that the copier with the highest overall sum be purchased.

Strengths and weaknesses: Attributes must be comparable and the weights must reflect the importance of each attribute, the assignment of numerical values requires decision maker judgment.

Application: These utility models rely on a sophisticated and cognitively demanding way of representing decision alternatives.

Compensatory decision rule: Select option with largest sum ($\sum v$) across attributes.

Addition of Utilities		Options			
		1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}
	Sum across attributes	$\sum v_{.1}$	$\sum v_{.2}$	$\sum v_{.3}$	$\sum v_{.4}$

<u>ADDITIVE DIFFERENCE STRATEGY</u> Beach, 1990; Kerstholt, 1992; Paquette & Kidda, 1988; Payne, 1982; Svenson, 1979; Tversky, 1969

aka: addition of utility differences

Definition: This decision strategy is used to choose an option by comparing options on all attributes relevant to the decision. Each option is evaluated by assigning to each attribute a weight based on importance (i.e. a ranking) and utility (measure of usefulness, attractiveness or satisfaction). The difference in utility of one option from the other within each attribute is calculated. The weighted differences on all attributes are then summed and the option with the highest overall (relative) utility is chosen. This strategy is typically used with a choice between two alternatives but can be extended to sequential pairs by retaining the best alternative as the new standard.

Trigger: The additive difference strategy can be useful when few options with several attributes are evaluated.

Example: The office manager now needs to select a new fax machine. Purchasing offers two different models. She decides to select a fax based on speed, ease of operation, and cost. The importance of these attributes is that cost is equal in importance to speed and operability combined and operability is twice as important as speed. She determines the attractiveness of each attribute for the first fax and then she repeats these judgments for the second fax. As she has listed the scores down two columns it is easy to subtract the second set of values from the corresponding set in the first column. The differences are multiplied by the importance weights and these weighted differences are summed. If the difference is positive then the first fax is preferred; if negative, then the second is preferred.

Strengths and weaknesses: This is a compensatory strategy with which one option which is low on one attribute can still be selected by being superior on another attribute. These utility models rely on a sophisticated and cognitively demanding way of representing decision alternatives. This type of strategy is considered high in processing requirements because all cues considered relevant to the decision are examined for all alternatives.

Application: Selection of important attributes and assigning judgments of relative importance to them is easier when the decision maker has knowledge upon which to base the judgments.

Compensatory decision rule: If the sum of attribute differences is positive then choose option 1, if negative then option 2, if equal then either. If there are more than two options to be compared then the best option of a pair is taken and compared to the next new option.

Additive Difference Strategy		Weights	Options		
			1	2	Weight * Difference
Attributes	a	w_a	v_{a1}	v_{a2}	$w_a*(v_{a1} - v_{a2})$
	b	w_b	v_{b1}	v_{b2}	$w_b*(v_{b1} - v_{b2})$
	c	w_c	v_{c1}	v_{c2}	$w_c*(v_{c1} - v_{c2})$
	d	w_d	v_{d1}	v_{d2}	$w_d*(v_{d1} - v_{d2})$
	e	w_e	v_{e1}	v_{e2}	$w_e*(v_{e1} - v_{e2})$
	f	w_f	v_{f1}	v_{f2}	$w_f*(v_{f1} - v_{f2})$
	Sum of difference				$\sum w_.*(v_{.1} - v_{.2})$

<u>CHOICE BY GREATEST ATTRACTIVENESS DIFFERENCE RULE</u> Svenson, 1979

Definition: The decision maker first examines all options to determine the attribute on which they differ the most. Then the option which is more attractive on this attribute is chosen, regardless of the other attributes. This is a within-attribute strategy. The process is similar to single feature superiority strategy.

Trigger: (not identified)

Example: A coach is having try-outs for his basketball team. He has one opening for a new player. He considers six players who are trying out and notices that they are most similar in terms of speed, less so in terms of agility, even less so in jumping ability, and differ the most in aggressiveness. Although some recruits have more agility or jumping height, he picks the recruit that is most aggressive.

Strengths and weaknesses: This is a simplifying strategy. However, this strategy would overlook a superior choice if the attribute was not included in the decision.

Application: (not identified)

Compensatory decision rule: Determine which attribute has the largest difference (Max of $v_{.1} - v_2$). If this difference is positive then choose option 1, if negative option 2, if equal then either, or another method is used to break ties. (The process is basically the same as the noncompensatory single feature difference, however the difference shows in the scale used for valuation. Attractiveness is more like single feature difference, but if the value can be quantified, then it becomes the compensatory greatest attractiveness difference rule.)

Choice by Greatest Attractiveness Difference Rule		Options		
		1	2	Difference
Attributes	a	v_{a1}	v_{a2}	$v_{a1} - v_{a2}$
	b	v_{b1}	v_{b2}	$v_{b1} - v_{b2}$
	c	v_{c1}	v_{c2}	$v_{c1} - v_{c2}$
	d	v_{d1}	v_{d2}	$v_{d1} - v_{d2}$
	e	v_{e1}	v_{e2}	$v_{e1} - v_{e2}$
	f	v_{f1}	v_{f2}	$v_{f1} - v_{f2}$

<u>CHOICE BY MOST ATTRACTIVE ASPECT RULE</u> Svenson, 1979

Definition: The option is chosen which has the overall most attractive aspect or value on any attribute. This can be a between-attribute decision. The process is similar to the noncompensatory strategy of "choice by most potentially profitable dimensions." In the "choice by most attractive aspect" strategy, the attributes' aspects are ranked, whereas in the 'choice by most potentially profitable dimensions' strategy, the alternative is chosen by its goal-reaching potential on some attribute.

Trigger: (not identified)

Example: A new business school graduate is looking for a job and has several offers. She considers various attributes on which the jobs differ (salary, benefits, opportunity for advancement, co-workers, and location). She ranks each of the jobs on the attributes. The one aspect that is most attractive to her is the large salary of one of the jobs. This is the job offer that is accepted.

Strengths and weaknesses: This assumes that all attributes have attractiveness values which are comparable.

Application: This strategy requires only ordinal rankings of attractiveness.

Compensatory decision rule: Choose the option with the largest aspect or value (Maximum of v_{ij},) on any attribute.

Choice by Most Attractive Aspect Rule		Options			
		1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

<u>COST-BENEFIT ANALYSIS</u> Anderson, 1990; Bunn, 1984; Payne, Bettman, & Johnson, 1988; Robertshaw, Mecca, & Rerick, 1978; Walton, 1990

aka: maximization model

Definition: Each option is defined according to all costs and benefits associated with all of its attributes (usually stated in monetary amounts). Attractiveness scaling can be incorporated to ensure that all attributes have a common base. A total cost score (C) and total benefits score (B) can be computed for each alternative. An overall score of expected value for each option is then determined by using an overall total such as the differences or ratio of C and B. All options can then be compared using these scores to make the choice between alternatives. Walton (1990) defined this procedure as just a utilities model of decision making which uses a set of mutually exclusive outcomes, each assigned a value and a probability.

Trigger: This strategy is used when all attributes are stated or can be restated in monetary amounts.

Example: A garrison commander has been tasked with considering how to use funds for improving the quality of life on post. He has decided to use a cost-benefit analysis where monetary costs and benefits and intangible (qualitative) costs and benefits are determined. Monetary costs are identified as direct planning, implementation, and sustainment. Monetary benefits will be direct savings resulting in other programs (e.g., replacement of air conditioning for quarters will result in a near-term reduction in maintenance costs). Intangible costs and benefits will be determined from strengths and weaknesses identified for each proposal. The proposal with the best cost-benefit ratio will be the one recommended. The intangible and monetary values will have to be done on a common scale so they can be combined.

Strengths and weaknesses: For this strategy, each option that is considered should be mutually exclusive. Probabilities are explicitly considered. However, this strategy requires that the decision maker be able to fix a numeric probability to each outcome. All relevant attributes are assumed to have been included in the equation. Opportunity costs may be overlooked when only two options are considered. Another option with a better overall cost-benefit score may have not been considered. This strategy also assumes a static environment for decision making. Cost-benefit computations do not include uncertainty and risk, assuming that the decision maker is risk-neutral.

Application: This strategy often takes the form of a two-alternative choice and has not been useful for valuing public goods, but has been used for options which lend themselves to valuation in monetary terms. However, some (e.g. Anderson, 1990; Payne, Bettman, & Johnson, 1988) use this term in a broader sense, thinking that a decision maker selects from a variety of decision strategies by considering the costs and benefits of each strategy.

Compensatory decision rule: Compute ratio (or difference) of benefits to costs for each option. Choose option with largest ratio or difference.

Cost Benefit Analysis		Options			
		1	2	3	4
Costs	a	cv_{a1}	c_{a2}	c_{a3}	c_{a4}
	b	c_{b1}	c_{b2}	c_{b3}	c_{b4}
	Sum	$\sum c_{.1}$	$\sum c_{.2}$	$\sum c_{.3}$	$\sum c_{.4}$
Benefits	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}
	Sum	$\sum v_{.1}$	$\sum v_{.2}$	$\sum v_{.3}$	$\sum v_{.4}$
Ratio of benefits to costs		$\sum v_{.1}/\sum c_{.1}$	$\sum v_{.2}/\sum c_{.2}$	$\sum v_{.3}/\sum c_{.3}$	$\sum v_{.4}/\sum c_{.4}$

<u>DIMENSIONAL REDUCTION</u> Svenson, 1979

Definition: This is a choice heuristic where one attribute (dimension) is eliminated from consideration in a choice between two multiattribute alternatives. Generally, the attribute with the smaller difference between aspects of the alternative are ignored and the attribute with the greatest difference is used for the choice. The process is similar to the noncompensatory 'single feature inferiority' strategy.

Trigger: This heuristic process is used as a simplifying strategy when people are required to make slow, repetitive decisions.

Example: A college student needs to locate an apartment. Two possibilities are identified in the newspaper's classifieds. They vary little in rent per month. But the student notices that one is quite a distance from campus, while the other is not. The choice would be made on the distance from campus.

Strengths and weaknesses: Simplifying strategies can be disadvantageous if the heuristic was useful once but is still used even though it becomes less applicable in a rapidly changing world. This strategy can be useful when alternatives can be ranked on an ordinal scale for attractiveness.

Application: This has been defined by Svenson (1979) as a simplifying choice heuristic which is used when people have to make many repeated choices between two multiattribute alternatives where time is not a factor.

Compensatory decision rule: This strategy has the same decision rule as greatest attractiveness difference rule except that this dimensional reduction eliminates alternatives, while greatest attractiveness difference selects alternatives. They are both compensatory but the processes are related to single feature inferiority and single feature superiority, respectively.

<u>ELIMINATION BY LEAST ATTRACTIVE ASPECT</u> Svenson, 1979

Definition: Using this choice strategy the decision maker eliminates the alternative with the overall worst aspect among all of the attributes.

Trigger: (not identified)

Example: The apartment seeker still has not found an apartment. Two potential apartments are considered: one with an undesirable location and one with a very high rent. The apartment with the very high rent is eliminated because the cost aspect is less attractive than the bad location.

Strengths and weaknesses: (not identified)

Application: This strategy can be used when the attributes can be rank ordered on attractiveness and when attractiveness values can be compared across attributes.

Compensatory decision rule: Eliminate option with smallest value (Min of v_{ij}) on any attribute. Eliminate option with next smallest value until one option is left.

Eliminate by Least Attractive Aspect		Options			
		1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

<u>EXPECTED VALUE STRATEGY</u> Anderson, Deane, Hammond, & McClelland, 1981; Beach, 1990; Doherty, 1993; Edwards, 1954; Kerstholt, 1992; Sinnott, 1989; Tversky, 1969; Walton, 1990; Zsambok, Beach, & Klein, 1992

Definition: The expected value of an alternative with uncertain consequences is the sum of the values of its possible outcomes each weighted by its probability of occurrence. Value can be measures of satisfaction (e.g. value judgments) or monetary worth (e.g. bids) on levels of a dimension. Each option is weighted for each attribute by the potential probabilities for values which the decision maker would collect if that option were chosen. The score for each option is the sum of these weights. The option which has the highest total is chosen. This type of strategy can be used when two or more options are in the choice set and the alternatives involve risk. This strategy can also be used in the long run when the gamble is repeated. This strategy, when combined to consider more than one option on more than one attribute, becomes Multiattribute Utility Analysis or maximizing.

Methods such as maximization depend on the memory of the decision maker for all of the alternatives so that all relevant attributes will be included. Unintended and intended side effects of the action should be weighted and entered into the decision, particularly where original intention conflicts with side effects of the action. This is a micro decision of maximization in the larger decision.

Expected value strategy belongs to the family of utility theories, i.e. addition of utilities; additive difference strategy, where *v* is the objective value in the improvement of the situation, *u* is the subjective value of the profit to the decision maker, *w* is the objective probability of the actual potential that the choice will accrue the profits, and *s* is the decision maker's judgment of likelihood that the choice will accrue the profit. Expected value is the same as addition of utilities when values are multiplied by weights (importance or probability of payoff).

expected value: $\sum$ (value x objective probability)
expected utility: $\sum$ (utility x objective probability)
subjective expected value: $\sum$ (value x subjective probability)
subjective expected utility: $\sum$ (utility x subjective probability)

Trigger: These strategies are used when analytic precision is desired and are used when a well-structured problem is perceived as having a single solution.

Example: A doctor offers the patient two alternatives to treat a cancer. The probability of successful treatment is .9 for Treatment 1 and the value of treatment length is 50 because it has relatively short duration. For Treatment 2, the probability of success is .6 but treatment length is valued higher at 80 because it is longer than Treatment 1. The probability of side effects for Treatment 1 is .25 and .15 for Treatment 1. The value of side effects is -20 for Treatment 1 and -15 for Treatment 2. Therefore, Treatment 1's expected value is 40 and Treatment 2's is 45.75. Treatment 2 is the preferred choice using the expected value method.

Strengths and weaknesses: The method may not be applicable for unique situations. Use of subjective values often results in a 'flat maximum' where the options with the highest expected values do not differ significantly from each other. Also, the assumption of independence between probabilities and utilities seldom applies for subjective measurements and real life decisions. Other strategies have produced almost the same results in similar conditions. These methods help decision makers impose order on their thinking. This type of strategy is generally applied once and requires complete information about the attributes for each option.

Application: It has been demonstrated that people can use these methods when probability is diagnostic information. However, how often this is the case has been questioned. Normative theoretical interpretations of how people should make decisions do not agree with real people's preferences. When decision makers perceive control over events, the gambling analogy does not apply. People trained in these strategies seldom use them and distrust the results if they are counter to the decision makers' intuitions.

Expected Value		Weights	Options							
			1		2		3		4	
Attributes	a	w_a	v_{a1}	w_a*v_{a1}	v_{a2}	w_a*v_{a2}	v_{a3}	w_a*v_{a3}	v_{a4}	w_a*v_{a4}
	b	w_b	v_{b1}	w_b*v_{b1}	v_{b2}	w_b*v_{b2}	v_{b3}	w_b*v_{b3}	v_{b4}	w_b*v_{b4}
	c	w_c	v_{c1}	w_c*v_{c1}	v_{c2}	w_c*v_{c2}	v_{c3}	$w_c \cdot v_{c3}$	v_{c4}	w_c*v_{c4}
	d	w_d	v_{d1}	w_d*v_{d1}	v_{d2}	w_d*v_{d2}	v_{d3}	w_d*v_{d3}	v_{d4}	w_dv_{d4}
	e	w_e	v_{e1}	w_e*v_{e1}	v_{e2}	w_e*v_{e2}	v_{e3}	$w_e \cdot v_{e3}$	v_{e4}	w_e*v_{e4}
	f	w_f	v_{f1}	w_f*v_{f1}	v_{f2}	w_f*v_{f2}	v_{f3}	w_f*v_{f3}	v_{f4}	w_f*v_{f4}
	Sum of weighted values		$\Sigma(w_.*v_{.1})$		$\Sigma(w_.*v_{.2})$		$\Sigma(w_.*v_{.3})$		$\Sigma(w_.*v_{.4})$	

<u>MAJORITY OF CONFIRMING DIMENSIONS</u> Svenson, 1979

Definition: The alternative is chosen which has the greater attractiveness over the attributes. If attractiveness on each attribute can be ranked then each attribute is compared across options.

The option with the most attractiveness across all attributes compared to the others is chosen. However, more than one aspect of each attribute can be ranked. In this case, the "maximizing the number of attributes with greater attractiveness" strategy applies. The more general "majority of confirming dimensions" form ranks attractiveness of attributes, while the "maximizing the number of attributes with greater attractiveness" form allows the ranking of several aspects of one attribute. Both forms are related to 'number of superior features', a noncompensatory form of the strategy.

Trigger: This simplifying process appears as a decision making strategy when slow, more detailed processes are repeated many times.

Example: Given that two apartments are available to rent, the decision maker compares each apartment on its ranking for each attribute. The decision maker chooses to rent the apartment which has the best location and the lowest price although it has a mediocre floor plan.

Strengths and weaknesses: Use of this strategy can be detrimental in the choice process if it was once useful but is now outdated due to a rapidly changing decision environment. However, the strategy requires only ordinal ranking of attractiveness.

Application: This is a simplifying strategy which can develop over repeated, slow choices.

Compensatory decision rule: Count the number of times that an option has the largest value on each attribute. Choose the option with the largest number.

Majority of Confirming Dimensions		Options			
		1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}
	Number of times option had largest attribute value	n_1	n_2	n_3	n_4

<u>MARGINAL RATE OF SUBSTITUTION</u> Hwang & Yoon, 1981

Definition: This strategy is an explicit trade-off of information about the attributes of an option. The nature of the trade-off is that the decision maker may settle for a lower value on one attribute if the value of another attribute is expected to improve the overall value of the option.

Trigger: (not identified)

Example: A car buyer might give up interior roominess in a new car in favor of higher gas mileage, particularly if the buyer favors saving money more than increasing leg room. This strategy would not be profitable if gas costs were not decreased more than the personal costs of decreased leg room.

Strengths and weaknesses: Trade-offs are not relevant if attributes of the option are independent because the value forsaken on one attribute will not be gained by the other.

Application: (not identified)

Compensatory decision rule: Determine the value that you are willing to give up in attribute a to get an increase in the value of attribute b. The value will depend on the starting levels of the values. In effect the option is being changed to have different attributes and values of those attributes. (Usually hold all but two attributes constant.) The value lost on attribute a may not equal the value gained on b.

Marginal Rate of Substitution	Option 1	Substitution/ tradeoff		Option 1'
Attributes				
a	v_{a1}	$v_{a1} - v_{-}$	-->	$v_{a1'}$
b	v_{b1}	$v_{b1} + v_{+}$	-->	$v_{b1'}$
	$\sum v_{.1}$		=	$\sum v_{.1'}$

Marginal Rate of Substitution Example	Option 1	Substitution/ tradeoff		Option 1'
Attributes of Automobile				
Roominess	$v_{a1} = 16$	16 - 4	-->	$v_{a1'} = 12$
Gas mileage	$v_{b1} = 10$	10 + 1	-->	$v_{b1'} = 11$
	$\sum v_{.1} = 26$		=	$\sum v_{.1'} = 23$

<u>MAXIMAX</u> Hwang & Yoon, 1981

Definition: Among all of the attributes for an option, the attribute with the highest value is identified. Then the highest of these across all options and all attributes is selected.

Trigger: This strategy is used to find the best option on the best attribute.

Example: Car 1 will save the most in gas of all cars examined. Car 2 will have the best insurance premiums. Car 3 will have the lowest repair bills. Since Car 1 will accrue the most profit to the buyer by saving the most money per year, it is chosen.

Strengths and weaknesses: The attributes need to be valued on a common scale.

Application: (not identified)

Compensatory decision rule: Determine which option has the highest value on each attribute. Choose the option with largest value regardless of the attribute.

Maximax		Options				
		1	2	3	4	Sum values across options
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}	$\sum v_{a.}$
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}	$\sum v_{b.}$
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}	$\sum v_{c.}$
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}	$\sum v_{d.}$
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}	$\sum v_{e.}$
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}	$\sum v_{f.}$

<u>MAXIMIN</u> Hwang & Yoon, 1981

Definition: The strategy here is to choose the option which is the best on the worst attribute over all candidates. This considers the worst case and selects the least of the worst. Attribute values for each option are examined, noting the lowest attribute value for each one. The option with the highest value in this set is then selected. The choice does not have to be made on the same attribute across options, merely on level of value.

Minimax is the reverse of maximin and is used minimize the maximum value of an attribute. The attribute having the highest value is identified for all options and then the lowest of this set is selected. Example: Tom, Bob, and Ron are trying out for the rowing team. The coach wants a new member who will fit in with the current team on rowing strength. Tom and Bob pull at a faster rhythm than Ron and all three stroke faster than the current team members. Ron is selected because he is the slowest of the three candidates and so would fit best with the team's style. This strategy seems to trim outliers from the upper distribution.

Trigger: This strategy is used when no option has an overall worth more than the others or all provide the same function.

Example: A rowing team needs to select a new member. Three candidates have applied to fill the vacancy. Team selection is based on scores from three tests of rowing skill. Given a battery of tests (A, B, and C), person 1's lowest score was on the A test; person 2's lowest score was on the B test; person 3's lowest score was on the C test. The person is selected to be on the team who has the highest score from these three lowest scores, therefore the maximum of the minimum scores. The allows balancing, so the new member will be consistent with the existing team members and not greatly exceed their capabilities.

Strengths and weaknesses: This can be used only when interattribute values can be measured on a common scale. However, this strategy uses only one attribute per option so an average option may be chosen over a superior one. This strategy is useful when the consideration is to optimize the weakest link in a chain or to screen outliers from the lower end of the distribution.

Application: This has also been generalized and defined as a search strategy to determine a set of possible moves from the current state based on comparing the consequences of the best and worst options. In addition, this method has been hypothesized to be a way in which the value of the current state can be estimated by looking at possible outcomes.

Compensatory decision rule: Determine which option has the lowest value on each attribute. Choose the option with highest value regardless of the attribute.

Maximin		Options				
		1	2	3	4	Sum values across options
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}	$\sum v_{a.}$
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}	$\sum v_{b.}$
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}	$\sum v_{c.}$
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}	$\sum v_{d.}$
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}	$\sum v_{e.}$
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}	$\sum v_{f.}$

Using Noncompensatory Choice Strategies

The 15 noncompensatory strategies included in this catalog are compared in Table 4. The difference between compensatory and noncompensatory strategies is not straightforward. When values of interval or ratio scales are used in the techniques in a balanced fashion, then it is likely that the strategy can be appropriately called compensatory. If attributes or aspects are not considered equivalent, then the strategy is considered noncompensatory.

Table 4

Characteristics of Noncompensatory Choice Strategies

Noncompensatory Strategies	Common scale for attributes	Considers minimal or expansive numbers of attributes	Eliminate or select options	Considers attribute importance	Decision rule
Choice by least potentially profitable dimension	No	Minimal	Eliminate	Yes	Eliminate option when it has lowest potential value for an attribute.
Choice by most potentially profitable dimension	No	Minimal	Select	Yes	Select option when it has largest potential value for an attribute.
Conjunction	No	Expansive	Select	No	Select option if standards are met on all attributes.
Disjunction	No	Expansive	Select	No	Select option if all standards met and at least as good as any other option.
Dominance	No	Expansive	Select	Yes	Select option if it is at least as good as all others.
Dominance structuring	No	Expansive	Select (by restructure)	Yes	Considers whether option can be viewed as best, hypothesis test.
Elimination by aspects	No	Minimal	Eliminate	Yes	Eliminate option less than standard on most important attribute, next most, so on.
Frequency gambling	No	Expansive	Select	No	Select most common when options are same or information incomplete.
Lexicographic strategy	Yes	Minimal	Select	Yes	Select option with largest value on most important attribute.
Minimum difference lexicographic rule	No	Minimal	Select	Yes	Same as lexicographic, but range of attributes must exceed standard.
Satisficing	No	Expansive	Select	No	Select first option that meets criteria.
Satisficing-plus	No	Expansive	Eliminate	No	Eliminate options that don't meet criteria, reset the cut-offs and repeat.
Single feature difference	No	Minimal	Select	Yes	Select option that is best on attribute where options differ most.
Single feature inferiority	No	Minimal	Eliminate	Yes	Eliminate worst option on an attribute.
Single feature superiority	No	Minimal	Select	Yes	Select best option on an attribute.

CHOICE BY LEAST POTENTIALLY PROFITABLE DIMENSIONS Kerstholt, 1992; Svenson, 1979

Definition: From the set of options, the problem solver eliminates the options having the least potential on any attribute in terms of reaching the goal, fitting the decision maker's principles, and facilitating the plan. It is related to the compensatory strategy of elimination by the least attractive aspect.

Trigger: (not identified)

Example: A worker needed to get home quickly and could choose to take a taxi, a bus, or ask a friend for a ride. Taking a taxi was eliminated because it had the greatest expense. Going with a friend was eliminated because the person does not like to ask for favors and was not that much faster than taking the bus. Therefore, the bus was chosen.

Strengths and weaknesses: This strategy can reduce the load on working memory during complex tasks.

Application: (not identified)

Noncompensatory decision rule: Eliminate the option if it has a minimum value for any attribute. Same as elimination by least attractive aspect, but this is more determined by subjective personal values while the other assumes a rating procedure. Value of an attribute here is based on its potential for reaching the goal, completing the plan, etc. rather than a monetary or ranking value.

Choice by Least Potentially Profitable Dimensions		Options			
		1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

CHOICE BY MOST POTENTIALLY PROFITABLE DIMENSIONS Kerstholt, 1992; Svenson, 1979

Definition: This strategy is the reverse of the choice by least potentially profitable dimensions strategy because the option is chosen that possesses greatest potential on some attribute which meets the decision maker's principles and facilitates the plan to reach the goal. This strategy is similar in process to the compensatory strategy of 'choice by most attractive aspect.'

Trigger: (not identified)

Example: Another worker needs to get home quickly and considers taking a taxi, using the bus, or renting a car. This worker chooses to take a taxi because this option has the greatest potential for getting home quickest.

Strengths and weaknesses: This also is a non-compensatory strategy which can reduce the strain on working memory during complex tasks.

Application: (not identified)

Noncompensatory decision rule: Select the option with the maximum value. Same as most attractive aspect rule but the value is based on its likelihood of facilitating the plan to reach the goal.

Choice by Most Potentially Profitable Dimensions		Options			
		1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

<u>CONJUNCTION</u> Beach, 1990; Dawes, 1964; Hwang & Yoon, 1981; Kerstholt, 1992; Svenson, 1979; Zsambok, Beach, & Klein, 1992

Definition: The option is chosen if it satisfies a critical level on all attributes of interest. For example, if the candidate reaches some critical level on dimension A and dimension B and dimension C, etc.

Trigger: It is often used to categorize options rather than to select alternatives. It can also be used to identify a reduced set of options; changing the cutoffs in an iterative way can break ties or eventually narrow the set to a single choice.

Example: When hiring an instructor to teach both French and history, poor knowledge of French cannot be compensated for by a good knowledge of history. The candidate must meet the thresholds in both areas (adapted from Hwang & Yoon, 1981).

Strengths and weaknesses: This strategy can be used when attractiveness of the alternatives on an attribute can be rank ordered. However, this strategy does not account for uncertainty and it requires a well-structured problem. Using this method, one risks the tendency to overestimate the degree of match (of schema) between the option and all attributes based on one's expectation of what would be a good explanation (conjunction fallacy).

Application: (not identified)

Noncompensatory decision rule: Like the compatibility test (above), this process eliminates any option that does not meet thresholds on all attributes. Threshold values can be more specific than are the standards for compatibility.

<u>DISJUNCTION</u> Dawes, 1964; Kerstholt, 1992; Leddo, Abelson, & Gross, 1984; Svenson, 1979; Zsambok, Beach, & Klein, 1992

Definition: Like conjunction, the disjunctive decision rule also requires criterion values on the attributes. The alternative is chosen if it is greater than the criterion value for at least one attribute, while all of the other alternatives are either equal to or fall below the criterion values. Choosing based on only one attribute makes the values on others irrelevant. The rule may not always lead to a decision if all of the alternatives just meet or fall below the criterion value. If several alternatives remain in the set after the rule is applied, another choice strategy can be used or the criterion value raised until one option remains.

Trigger: (not identified)

Example: When choosing a model for a picture advertisement of a hand lotion, the agency considers only the hands. If only the hands are important to the ad, it would not matter what the other body parts looked like.

Strengths and weaknesses: By relying on one attribute, the complexity of the task and strain on working memory capacity is reduced. Also, the attractiveness ratings do not need to be comparable across attributes. This strategy can be used if the options can be rank ordered on an attribute.

Application: (not identified)

Noncompensatory decision rule: Select the option that meets all thresholds, is at least as good on attributes as any other option, and exceeds other options on some attributes. (For example, does option 1 exceed all minimum thresholds? No. Then how about option 2? It meets all thresholds, as do options 3 and 4. Option 2 is at least as good as options 3 and 4 because there are no attribute values for 3 and 4 that are greater than 2, plus option 2 exceeds option 3 on three attributes and exceeds option 4 on two attributes.)

Disjunction Example			Options			
		Standard	1	2	3	4
Attributes	a	$v_a=5$	$v_{a1}=6$	$v_{a2}=6$	$v_{a3}=5$	$v_{a4}=6$
	b	$v_b=8$	$v_{b1}=10$	$v_{b2}=12$	$v_{b3}=11$	$v_{b4}=12$
	c	$v_c=3$	$v_{c1}=2$	$v_{c2}=4$	$v_{c3}=3$	$v_{c4}=3$
	d	$v_d=3$	$v_{d1}=3$	$v_{d2}=5$	$v_{d3}=5$	$v_{d4}=4$
	e	$v_e=4$	$v_{e1}=6$	$v_{e2}=6$	$v_{e3}=6$	$v_{e4}=5$
	f	$v_f=5$	$v_{f1}=6$	$v_{f2}=7$	$v_{f3}=6$	$v_{f4}=7$

<u>DOMINANCE</u> Beach, 1990; Hwang & Yoon, 1981; Leddo, Abelson, & Gross, 1984; Lipshitz, 1993; Montgomery, 1989; Ranyard, 1990; Svenson, 1979; Tversky & Kahneman, 1974

Definition: One alternative should be chosen over another if the first is better on at least one attribute of interest (or profitability) and equal on all other attributes. This can also be used as a screening strategy when a large choice set exists.

Trigger: (not identified)

Example: A renter is looking for an apartment. Several apartments have been identified located in a desirable location. They all have about the same utility bills and the same maintenance problems. The one with the lowest rent would be chosen because it is better than the others on that attribute.

Strengths and weaknesses: Dominance strategies are easier on the limited capacities available for problem solving. Dominance does not require preference information from the decision maker. Use of a simple strategy may reduce decisional conflict or anxiety, be easier to explain to others, and therefore be more persuasive.

Application: Dominance is a low level choice mechanism that only requires binary evaluation and little information integration.

Noncompensatory decision rule: Select the option which is better than all other options on at least one dimension and equal in attractiveness on all remaining attributes.

<u>DOMINANCE STRUCTURING</u> Montgomery, 1993

Definition: This strategy is described as a hypothesis-testing process where a tentative option is chosen and tested. If one dominant candidate does not appear based upon the selected relevant criteria, the given information about the task and about the most promising alternative is reinterpreted or restructured so that the preferred alternative becomes dominant by enhancing and deemphasizing, canceling, and integrating information.

Trigger: A promising alternative which is attractive on one important attribute is dominated by another alternative.

Example: A set of apartments available for rent in a particular area all have about the same utility bills, the same rent, and the same maintenance problems. Although one is preferred, it does not clearly dominate the others. Therefore, the importance of maintenance is decreased and the importance of rent is increased so that the preferred candidate is then better than the other candidates.

Strengths and weaknesses: Dominance structuring is seen as facilitative of information processing by keeping compensatory processes to a minimum. However, in restructuring, the decision maker risks distorting reality by the reinterpretation or by quick selection of the most promising candidate. The dominant candidate may be hidden by the way a decision is presented or by erroneous assumptions. Rather than using de-emphasis and bolstering of options, a decision maker can use the more "rational" operations of cancellation of attributes based on trade-offs or collapsing attributes to create a new attribute.

Application: The advantage or disadvantage is determined by comparison to a criterion or to other alternatives. However, this is largely a subjective determination by the decision maker.

Noncompensatory decision rule: If the most likely option is not the dominant option, then determine if the attribute values for that option can be reassessed such that they are greater than the corresponding attributes for the other options. If not then pick another option. (Or reassess attributes or respecify options.) Dominance allows explicit thresholds and reduces the set faster than if disjunction were used and repeated with changing thresholds.

<u>ELIMINATION BY ASPECTS</u> Cohen, 1993a; Paquette & Kida, 1988; Payne, 1980; Payne, Bettman, & Johnson, 1988; Svenson, 1979; Tversky, 1972

Definition: A criterion is adopted for the most important attribute. This method assumes that the decision maker has minimum cutoffs on each dimension. Alternatives are eliminated if they do not meet the preset criteria. If more than one candidate is left, the process is repeated for the second most important dimension: a criteria for that attribute is preset and then the remaining alternatives are eliminated if they do not meet it. The process continues until one candidate remains.

This noncompensatory strategy is similar to the compensatory strategy of elimination by least attractive aspect and to the noncompensatory strategies of least potentially profitable dimensions and both lexicographic strategies. It is similar to the lexicographic method in that one dimension at a time is considered but EbA differs by having a standard cut-off, in being a continuous process until one is left, and that attributes can also be ordered on other dimensions besides importance. It is similar to a conjunctive method. These strategies differ in whether they function to select or eliminate options.

Trigger: (not identified)

Example: When buying a car, the desired features are listed. All models which don't get good gas mileage, predefined as the most important feature, are eliminated from further consideration leaving 10 cars as options. The second most important dimension is maintenance cost and all models requiring high maintenance are eliminated. The process continues until one car is left on the list.

Strengths and weaknesses: This would not work well if an outstanding option just misses making the cut on one dimension. An error may result when trade-offs are ignored. Dimensions can also be ordered on likelihood of discriminatory power. In a Monte Carlo simulation, this strategy (and lexicographic) were more accurate because longer normative strategies had to be abbreviated as time ran out.

Application: This is a reduced processing strategy, since an alternative can be eliminated on the basis of one or a few cues without considering all relevant information.

Noncompensatory decision rule: Eliminate any option which does not meet standard, starting with the most important attribute. If more than one option still exists, continue eliminating subpar options for the next most important attribute, and so on until one is left. [This strategy is similar to the compatability test.] The process is similar to choice by least potentially profitable dimensions and to elimination by least attractive aspect.

Eliminate by Aspects			Options			
		Standard	1	2	3	4
Attributes	a	v_a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

<u>FREQUENCY GAMBLING</u> Reason, 1990

Definition: A decision strategy for resolving conflicts when "candidates" share common elements (or attribute values or aspects), either because the calling conditions (cues) or stored elements are incomplete. Therefore, no option is a unique match, so several candidates may enter working memory. The option which has been most frequently encountered will be chosen because information which is more often triggered will have higher base levels of activation.

Trigger: This strategy is used when two or more options in working memory equally match the calling conditions.

Example: When a word fragment is encountered which is common to a number of different words and a guess is made, the decision maker will choose the word which occurs more frequently than the other in the language of the decision maker.

Strengths and weaknesses: This strategy may be prone to errors of availability.

Application: Similarity and frequency information are proposed to be the cognitive system's computational primitives.

Noncompensatory decision rule: Identify options having elements (attribute values, aspects) in common. Choose the option that has more of the elements than any of the other options. The most common or frequent elements are decided based on strength of recall/level of activation for that option in working memory.

Frequency Gambling		Options			
		1	2	3	4
Attributes	a	Yes	Yes	No	Yes
	b	Yes	No	Yes	No
	c	No	No	Yes	Yes
	d	No	Yes	Yes	No
	...	...	...	...	...
	n	Yes	No	Yes	Yes
Number of common elements		Σ_1 (yes)	Σ_2 (yes)	Σ_3 (yes)	Σ_4 (yes)

<u>LEXICOGRAPHIC STRATEGY</u> Beach, 1990; Dahlstrand & Montgomery, 1989; Hwang & Yoon, 1981; Kerstholt, 1992; Payne, Bettman, & Johnson, 1988; Payne, Bettman, & Johnson, 1993; Svenson, 1979

Definition: To choose an alternative from a set, the candidates are rank ordered on the most important attribute and the most attractive candidate on an aspect of this attribute is chosen. If two or more candidates are equally attractive, then the next most important dimension is used. This process is continued until one option is left.

Trigger: (not identified)

Example: When the renter was choosing an apartment, the most important attribute was identified as noise level in adjacent apartments and in the neighborhood. Because a low noise level was the most attractive aspect of this attribute, all apartments which have a high level of noise are eliminated from further consideration. The apartment will be rented which is the most quiet.

Strengths and weaknesses: This strategy allows for nonsignificant differences on an attribute, and ordinal attractiveness ratings on an attribute can be used. However, it only uses a small part of available information. In a Monte Carlo simulation, this strategy (and EbA) were more accurate than a normative procedure because the longer normative procedure was abbreviated as time ran out.

Application: The "most important attribute" can be identified in a variety of ways, for example, the one which was first attended to by the subject.

Noncompensatory decision rule: First, determine which attribute is the most important (e.g. attribute b). Choose the option that has the greatest value on that attribute (e.g., $v_{b2} > v_{b3} > v_{b1} > v_{b4}$). If there is a tie, then repeat for the next most important attribute (e.g., attribute a).

Lexicographic		Importance Rank	Options			
			1	2	3	4
Attributes	a	2	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	1	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	4	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	3	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	5	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	6	v_{f1}	v_{f2}	v_{f3}	v_{f4}

<u>MINIMUM DIFFERENCE LEXICOGRAPHIC RULE</u> Svenson, 1979

Definition: This choice rule works like the lexicographic rule, but adds the assumption that for each attribute, the attractiveness values can determine the decision only if their difference is greater than a specific minimum value. It their difference is less than this value, then the next attribute in the lexicographic order is considered. If two options are judged on three attributes in the same lexicographic orders of {5, 5, 10} and {5, 7, 6} and the critical difference is 2.5, then the differences on the first and second attributes are too small to make a choice. The alternatives are different enough on the third attribute so that a choice can be made. A special case of this rule is the lexicographic semiorder rule, where the critical difference is defined only for the most important attribute and all others are set to zero. The semiorder rule also allows for nonsignificant differences on an attribute.

Trigger: (not identified)

Example: Assuming the critical difference of 2.5, for example, two apartments are rated equally on noise level, a 5 versus 7 on attractiveness of floor plans, and 10 versus 6 on location. Since the first two do not differ significantly in the mind of the decision maker, the choice would be made based on the attribute of location.

Strengths and weaknesses: (not identified)

Application: When attribute information is missing because of imperfect discrimination or when unreliable information is present, minimum difference rules may be depended upon.

Noncompensatory decision rule: Determine which attribute is the most important as in the lexocographic strategy. Determine whether the magnitude of differences (see second table below) among the options on that attribute are larger than some specified minimum. If not, then repeat for the next most important attribute. Choose the option that has the greatest value on that attribute.

Minimum Difference Lexicographic		Importance Rank	Options			
			1	2	3	4
Attributes	a	3	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	2	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	4	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	1	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	5	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	6	v_{f1}	v_{f2}	v_{f3}	v_{f4}

For attribute (d) which was ranked #1: if the minimum acceptable difference = x and if all d le $|x|$, then move to the next most important attribute (b) and calculate the difference matrix to determine if a choice can be made.

Options	Options		
	3	4	1
2	d_{2-3}	d_{2-4}	d_{2-1}
3		d_{3-4}	d_{3-1}
4			d_{4-1}

<u>SATISFICING</u> Kerstholt, 1992; Ranyard, 1990; Simon, 1955; Svenson, 1979

Definition: This is a choice process which is used to find the first acceptable option on features which have been identified as important. A minimum acceptable criterion for each attribute is determined. The first option which meets or exceeds the threshold on each of the selected attributes is chosen. This is a specific form of conjunction strategy; however, satisficing selects the first option which meets all criteria.

Trigger: The problem is perceived by the decision maker as having multiple solutions. A solution is acceptable which is adequate, rather than investing time or effort in searching for a "perfect" solution.

Example: An armored cavalry platoon leader has been given a mission to move generally west to a crest of a slope. From that terrain he can overlook a large lowland area. Upon arrival he sees that a mobile rocket launching site is being established by the enemy. The terrain is rather featureless making it impossible to get an accurate map location. The platoon leader knows that he needs to call for artillery fire, but if a marking round is called for the unit will move out immediately. His compass is inoperative, so he must quickly determine a way to find the first satisfactory solution for calling for artillery and locating the coordinates of the site. He thinks of using the method of intersection. He picks out two distant terrain features. He moves so that the site is in a direct line with the first distant terrain feature. He carefully locates his position on the crest and draws a line on his map to the far terrain feature. Next he moves along the crest until he has the launcher site in a direct line with the second terrain feature. He plots a second line on his map. The site is at the intersection of the two lines. (Adapted from "How Would You Do It?" 1972).

Strengths and weaknesses: This strategy does not consider whether uncertainty is present in the problem and does not require complete information. Absolute evaluation of the option set is applied only once and does not require a well-structured problem. However, biases may result if the decision maker's total position is ignored. It may be an error to neglect trade-offs in a particular situation or the criteria may be set incorrectly (too high, too low) or an important feature may be ignored. Use of this strategy can lead to biases based on a misperception by the decision maker that two schemata overlap more than they actually do, e.g., conjunction fallacy, belief bias, base rate misuse, and overconfidence bias (in believing that effort reflects accuracy). Use of this strategy can be a way to reduce anxiety when the decision maker is faced with conflicting alternatives that have both good and bad outcomes.

Application: This is a low level (primitive) choice mechanism that requires only binary (yes-no) evaluation and minimal information integration. It is an uncomplicated strategy because it is only necessary to keep track of the important aspects and to evaluate options based on those aspects. Only one negative aspect must be found for an alternative to be eliminated. When the goal is not well specified, this strategy increases the likelihood of hypothesis-testing using previously learned rules and bottom-up processing. Making choices based on satisficing criteria may be an adaptation to capacity constraints when too many variables are present. Being simpler, this method is easy to explain and can be persuasive when the method is explained to others.

Noncompensatory decision rule: The first option that meets the standard values for the attributes is selected.

Satisficing			Options		
		Standard	1	...	n
Attributes	a	v_a	v_{a1}		
	b	v_b	v_{b1}		
	c	v_c	v_{c1}		
	d	v_d	v_{d1}		
	e	v_e	v_{e1}		
	f	v_f	v_{f1}		

SATISFICING-PLUS Kerstholt, 1992; Metcalfe, 1991

Definition: This is a repetitive screening process to reduce the set of options and is not the same as satisficing. With this strategy, all options are evaluated on multiple critical features. All are eliminated which don't meet the criteria. Then the cut-offs for the features are altered and evaluation of options is repeated. This process repeats until only one option is left.

Trigger: (not identified)

Example: The manager of an accounting firm needs to hire a new receptionist. Job applicants are screened using an ordered list of job requirements. First cut of the applicants is based on those not meeting the minimum levels of experience and education. The second cut is made based on the salary each applicant would accept and whether the applicant is willing to work the scheduled hours.

Strengths and weaknesses: This method can lead to error in problems because an ideal solution may be screened out prematurely, as only desired features are considered. Uncertainty is not considered. This method does require time to apply, but is useful as a noncompensatory strategy for complex tasks.

Application: (not identified)

Noncompensatory decision rule: Eliminate all options which do not meet the standard values. Make the standards more severe and eliminate all options not meeting the new standards. Repeat the process until only one option remains.

Satisficing-Plus			Options			
		First Standard	1	2	3	4
Attributes	a	v_a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

(cont.)

Satisficing-Plus			Options			
		Next Standard	1	2	3	4
Attributes	a	v_a'		v_{a2}	v_{a3}	
	b	v_b'		v_{b2}	v_{b3}	
	c	v_c'		v_{c2}	v_{c3}	
	d	v_d'		v_{d2}	v_{d3}	
	e	v_e'		v_{e2}	v_{e3}	
	f	v_f'		v_{f2}	v_{f3}	

<u>SINGLE FEATURE DIFFERENCE</u> Montgomery, 1993

Definition: Single feature strategies are variations on tests of dominance to select an alternative which is either best or worst, dominating all competitors on at least one attribute. In single feature difference, the decision maker finds the one attribute on which the options differ the most and uses that one to make the choice.

Trigger: (not identified)

Example: A buyer using this strategy purchases a car based on its price, if two cars being considered differed most on this feature.

Strengths and weaknesses: (not identified)

Application: (not identified)

Noncompensatory decision rule: Determine on which attribute the options differ the most (largest of $range_{i}$), make choice based on this attribute.

Single Feature Difference		Options			Difference
		1	2	3	
Attributes	a	v_{a1}	v_{a2}	v_{a3}	$range_a$
	b	v_{b1}	v_{b2}	v_{b3}	$range_b$
	c	v_{c1}	v_{c2}	v_{c3}	$range_c$
	d	v_{d1}	v_{d2}	v_{d3}	$range_d$
	e	v_{e1}	v_{e2}	v_{e3}	$range_e$
	f	v_{f1}	v_{f2}	v_{f3}	$range_f$

SINGLE FEATURE INFERIORITY Montgomery, 1993

Definition: In single feature inferiority, the option which is the worst on any one attribute of interest is eliminated. The process is similar to the compensatory strategy of dimensional reduction.

Trigger: (not identified)

Example: The buyer eliminates one car from consideration because it had the highest price and buys the other.

Strengths and weaknesses: (not identified)

Application: (not identified)

Noncompensatory decision rule: Eliminate the option which is worst on any one attribute. If no single option is identified this strategy continues until one option remains.

Single Feature Inferiority		Options			
		1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

SINGLE FEATURE SUPERIORITY Montgomery, 1993

Definition: In single feature superiority, the option which is best on any one selected attribute is chosen. This strategy is similar to the compensatory strategy of 'greatest attractive difference.'

Trigger: (not identified)

Example: The buyer selects one car to buy because it has the lowest price.

Strengths and weaknesses: (not identified)

Application: (not identified)

Noncompensatory decision rule: Select option which is best on any single attribute.

Single Feature Superiority		Options 1	2	3	4
Attributes	a	v_{a1}	v_{a2}	v_{a3}	v_{a4}
	b	v_{b1}	v_{b2}	v_{b3}	v_{b4}
	c	v_{c1}	v_{c2}	v_{c3}	v_{c4}
	d	v_{d1}	v_{d2}	v_{d3}	v_{d4}
	e	v_{e1}	v_{e2}	v_{e3}	v_{e4}
	f	v_{f1}	v_{f2}	v_{f3}	v_{f4}

CONCLUSIONS

When a problem solver is faced with the task of making a high quality decision in a complex, variable, ill-defined and novel real world problem, the optimal strategy and a distinct goal are seldom obvious. There is little scientific or anecdotal knowledge about what methods to use to solve these types of problems. In some situations short-term planning is all that is needed, while others require long-term planning. Some problems can be solved in one operation, while others require a complex combination of contingent subproblems. In some situations a decision strategy is used to identify one option, while in other situations the same strategy may be used to identify a subset of reasonable options from a larger set of possible alternatives. In some situations time is short and the stakes are high.

How people manage to solve everyday or time-critical problems is not usually clear. Since strategies are largely implicit, there is little information based on a naturalistic approach about what strategies are acceptable. In contrast, there is a considerable number of techniques to "improve" decision making using prescriptive utility models derived from decision theory. These models are promoted as problem solving tools by those who believe that people will arrive at more "rational" solutions if the appropriate computations are performed. Only recently has new effort gone into developing an understanding of naturalistic decision making, using realistic problems, with problem solvers who bring their experience and knowledge to the task of finding a workable--if not optimal--solution. The advantage of the latter approach is that the "real world" is dynamic, rather than static. Therefore, robust methods of problem solving and decision making are needed by those who must perform in a complex, changing environment. Often, the strategies which claim to provide an optimal solution are too rigid and time consuming to be appropriate to the situations in which they are attempted.

The proposed classification and categories of strategies can serve as a model of what functions strategies serve for problem solvers. The classes have to do with managing information, progress, and choices. These "strategic" functions may stand as the core guiding principles people use deliberately and implicitly in the control of their thinking. The categories below these three classes represent the types of sub-functions which the identified strategies perform. The categories include sub-functions such as initiating or considering questions or beliefs, managing or combining information, controlling order of operations, managing workload (amount of information or number of attributes or options), and making choices. These sub-functions are valuable constructs that may be useful for identifying common cognitive operations. This scheme of strategy classification and categories may be useful for modeling cognition and developing a better understanding of what cognition is.

By having a variety of candidate strategies available and by learning how to use experience, knowledge, and environment to produce or tailor a problem solving strategy, decision makers become more adaptive, more flexible, and hopefully, more effective. These abilities become particularly important in high stakes, time-stress situations.

From the literatures reviewed for the report, it seems that strategies are developed or modified during problem solving to create a tailored strategy. Strategies can be pieced together from other strategies and applied to the specific problem at hand. Similar processes also appear to be used differently depending upon contextual factors (e.g., satisficing and conjunction). These impressions were supported as we attempted to generate pure examples of the strategies. It was difficult to develop an example that uniquely represented a strategy, thus the reader undoubtedly found overlap and ambiguity in understanding some of the examples as instances of one particular strategy. It seems reasonable that the rather precise definitions of strategies used in this catalog are not so perfectly identifiable in everyday use. Bettman (1979) made a similar observation about choice processes noting that "heuristics" are probably not stored as an entirety in memory, but are constructed when a decision is needed. It is rare that an isolated strategy enables one to adapt to the goals and constraints in a dynamic situation.

Unfortunately, many of the strategies identified in the literature have been elicited in well-structured, laboratory problems or from formal prescriptive definitions--not naturalistic or everyday problem solving. This catalog can serve as a departure point for the further examination of strategies as they occur in naturalistic tasks.

This listing of strategies will be useful for future investigations of problem solving to answer several questions.

1. What is the frequency with which particular strategies are used?

2. What are the conditions that signify when a particular strategy will or should be used? Are the conditions dependent on characteristics of the problem, the problem solver, or both? How do the characteristics of the task influence how strategies are used?

3. Do experts solve problems differently than those who are less experienced or do they use the same patterns of strategies, but just use them better?

4. How efficient are various strategies? Do different patterns of strategies result in more or less effective solutions?

5. Are there points in the process of constructing and executing the strategy where error is more prone to enter the process?

When these questions are answered, basic manipulations can be explored to find out how best to train more effective strategies and how to match computer decision aiding capabilities with various problem solving styles of decision makers.

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