Decision Problem Structuring: Generating Options

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Abstract —**An integrative framework of methods for generating options for subsequent evaluation in a formal decision analysis is proposed. First, the overall process of decision problem structuring is briefly discussed. An associative network model of the way knowledge is represented cognitively is presented. Next, five categories of option-generating procedures are identified, including attribute-based, state-based, composite, option-based, and creativity techniques. The different option-generating procedures are seen as different strategies for traversing the cognitive network to search for and/or create new options. The approaches differ by the type of cognitive unit (decision problem attribute, state, or option) to be brought into short-term memory to stimulate further search. Criteria for evaluating the sufficiency of the set of generated options are also presented. A discussion of future research directions is included.**

I. Introduction

When FACED with a decision problem, a person must create a structure for the problem prior to subsequent evaluation of the different action options. The dynamic process of structuring a decision problem involves the specification of options, attributes for evaluating options, and states of nature that may occur, with repeated cycling back in the process to revise or augment the structure. When finished, the structured problem can be represented in a decision tree, as shown in Fig. 1. The experimental literature has demonstrated that the use of decision analytic techniques may lead to better decisions (e.g., Nisbett *et al.* [60]). A variety of tools have been developed to aid decisionmakers in choosing among alternative action options when faced with multiple conflicting attributes and/or unknown probabilistic states of nature. So far, much of the tool development work has focused on techniques, such as multiattribute utility theory (Keeney and Raiffa [40]), to be used *after* the structure of the problem has been determined. However, many real decision tasks are ill defined, i.e., the options, attributes, outcomes, and states of nature are not yet specified (Einhorn [17]). Decision aids are required, in most cases, to better structure the task and the subsequent analysis process. von Winterfeldt and Edwards [80, p. 569] point out, "Every working analyst we know agrees that good problem structuring is the key to successful analysis." Discussions of the problem structuring process in general are given by Berkeley and Humphreys [7], [31], Kirkwood [44], [45], Gasparski [23], Phillips [63], and Von Winterfeldt [78].

There has been relatively little previous research on option generation. To improve decisionmaking, decision analysts, psychologists, management scientists, and expert systems developers should pay more attention to the predecision phase in which the options (also called actions or alternatives) are developed. The following personal experience involved the placing of insufficient attention on this predecision phase. One of the authors recently attended a party at a colleague's home. Upon arriving at the front door, she noticed a sign above the doorbell stating "Please knock, the bell isn't working." She obediently knocked on the door and windows, but it took some minutes before she could get the attention of any of the loud early-arriving revelers. Later in the evening, she noticed that a late arriver had rung the doorbell, and the bell worked. She had failed once again to consider a good alternative option: trying the doorbell just in case it worked. Just as people fail to consider good options in day-to-day living, organizational and societal decisionmakers sometimes fail to consider worthwhile options, even when substantial formal analysis is carried out.

The structuring of decision problems has often been called an "art rather than a science." The purpose of this paper is to provide an integrative framework of methods for generating options for subsequent evaluation in a formal decision analysis. Thus we provide a step toward making the art more scientific.

We do not cover methods for generating attributes for evaluating options or for generating states of nature. Experimental laboratory research investigating how people generate states of nature, or "hypotheses," has been conducted by Gettys and his colleagues [21], [24], [26]. Von Winterfeldt and Edwards [80] describe means for modeling uncertainties about states via inference trees, fault trees, and event trees. Some modeling procedures which also may prove useful in representing the relationships among probabilistic events include cognitive maps [68], influence diagrams [28], interpretive structural modeling, and diagnostic questioning [42]. An integrative framework for

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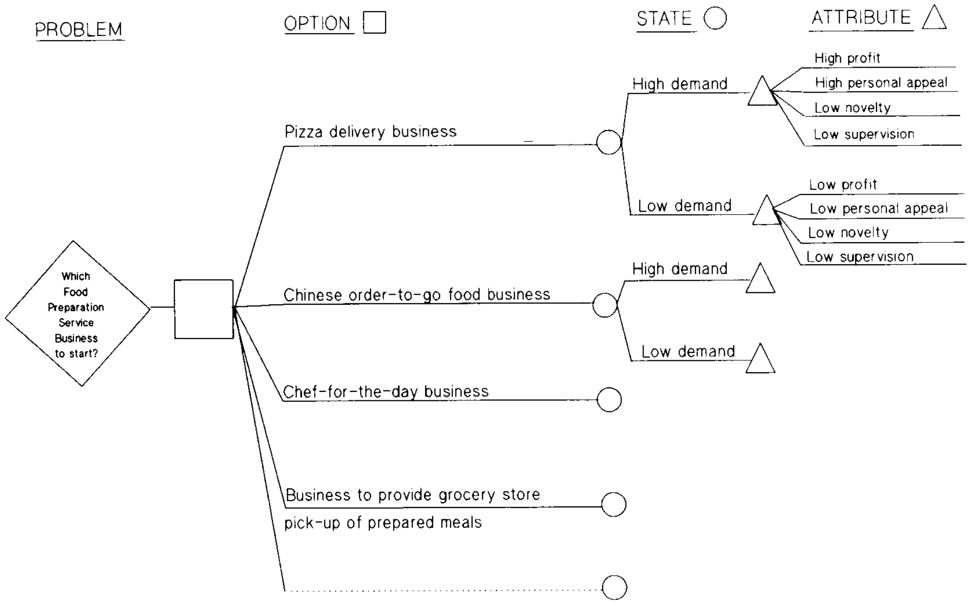
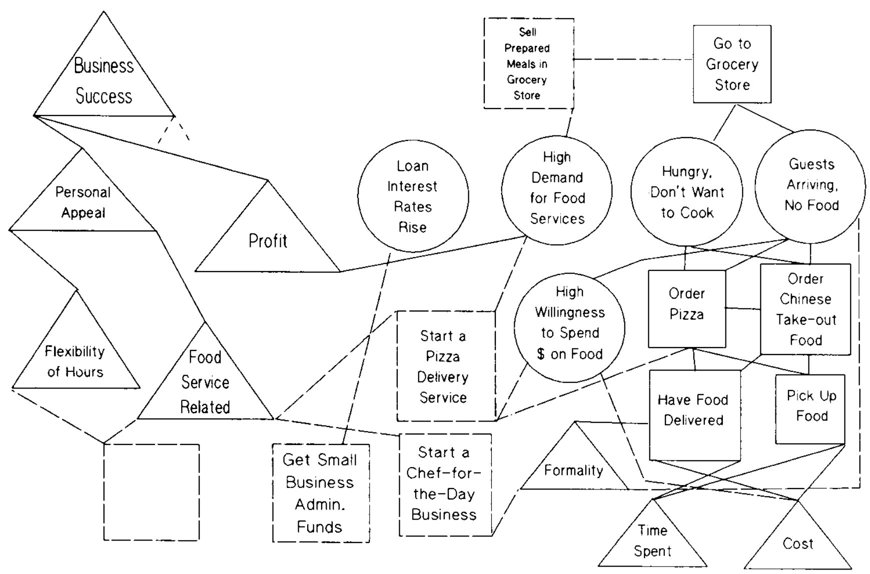


Fig. 1. Decision problem structured into a decision tree.



Dotted lines: arcs and nodes that do not exist (or are weakly represented) in the associative network

Fig. 2. Partial cognitive representation containing some decision problem elements.

choosing among methods for state generation is in Keller [41]. Attributes (or goals or objectives) to use in evaluating options will usually be represented in a hierarchical value tree in which lower level attributes are chunked together under broader attribute categories. Criteria for evaluating the sufficiency of a value tree are in Keeney and Raiffa [40] and von Winterfeldt and Edwards [80].

The remaining sections of this paper are organized as follows. A description of the way knowledge is represented cognitively is presented in Section II, and general strategies for searching through a person's cognitive network are briefly discussed. Section III contains five categories of option-generating procedures (attribute-based, state-based, composite, option-based, and creativity techniques) and criteria for evaluating the sufficiency of the set of generated options. Finally, a summary and discussion of future research directions is in Section IV.

II. A Description of Knowledge Representation

A valid description of the way a decisionmaker organizes and accesses relevant knowledge in long-term memory is a prerequisite for the development of effective methods for aiding option generation. Many elements of a decision problem will already be components of a person's knowledge representation (Jungermann *et al.* [38]), although they may not be organized yet in a coherent structure useful for the current problem. Other elements will be added to the cognitive representation by creatively combining existing knowledge pieces and by adding additional information from the environment. Since the cognitive representation of the task, in turn, determines the way in which the problems are solved, a number of researchers have reported that the cognitive representation of the problem is of major importance in judgment and choice (see Einhorn and Hogarth [18]).

Associative Network Structure

The way a person's knowledge is stored in memory can be modeled with an associative network structure in which the network nodes are cognitive units and the arcs are connections among units. There are many types of cognitive units, including prototypes of sets of objects, plausible causal patterns, propositions, temporal strings, and spatial images. Some cognitive units will be relevant to the current decision problem. When diagramming a portion of a person's knowledge, we represent nodes that can be options for the current problem as squares; states of nature nodes are circular, and attribute nodes are triangular. Fig. 2 contains an example diagram of a partial cognitive network for a person facing the problem of starting a business providing food preparation services. As can be seen, this knowledge structure consists of tangled hierarchies formed from many cognitive units. The purpose of this prescriptive problem structuring research is to develop ways to aid a person to untangle and augment such a cognitive representation to form a coherent structure for the current problem, like in Fig. 1.

When a person thinks about a problem, attention alternates among the different elements of the problem. The current level of activation of a node in the cognitive network can be thought of as the degree of attention currently being paid to it. Activation will be spread from a source node to other nodes throughout the network along arcs leading to the stronger nodes (those having more direct links). Nodes can become transient source nodes by being encoded from the environment (such as prompting by a decision analyst to consider a specific example) or by being deposited in short-term memory. A less transient source node is a goal element which is a source node with a constant level of activation until the goal is met or transformed. Activation spreading from this current goal maintains all closely linked goals in short-term memory.

Some parts of the cognitive network may be organized around problem categories, such as the problem of a person who has some guests arriving but has no food to serve, as in the hierarchy on the right side of Fig. 2. Other parts of the network may consist of value tree hierarchies with alternative options attached to lower-level goals, as in the set of attributes for evaluating business success on the left side of the figure. When faced with the problem of generating alternative solutions to a problem, a person will structure the problem by encoding environmental factors (which may include prompts from a decision analyst or a decision-aiding compouter package) as nodes in the network and examining existing goal or problem category nodes which will simulate the spreading activation of nodes in portions of the cognitive network. This stimulation should lead to activation of weakly linked pre-existing nodes or creative generation of new nodes or arcs relevant to the problem which were not contained originally in the cognitive network. For example, prompting a person to think of the formality of a meal service may lead to the creative construction of a new option node, starting a "hire a formally dressed chef-for-the-day" business.

We have adopted a general framework to describe knowledge representation. Such an associative network framework underlies several theoretical approaches for describing how people organize and access knowledge in long-term memory. For example, Anderson [2] has developed an associative network-based descriptive theory of cognitive architecture ACT (adaptive control of thought) using production systems, and McClelland and Rumelhart [55] have proposed a distributed model of memory. Johnson–Laird [36] employs mental models to elaborate on the forms of mental representations and mental processes.

Judgmental Heuristics in Option Generation

In familiar well-defined problems, option generation may be relatively routine. In these cases, problem prototypes and their associated cues play the major role in option generation. When people are faced with a problem, they first measure its similarity to a set of common or previous problems stored in their long-term memories. If the similarity is high, a prototypical or causal cue pattern associated with the most representative problem will be retrieved from the long-term memory and brought into the short-term memory. Hence either a menu of options is readily recalled from memory (i.e., order pizza or Chinese food), or options can be quickly retrieved by searching memory for similar previous problems (Gettys *et al.*, [25]). This type of option generation is consistent with use of the *representativeness* heuristic. Even in well-defined problems, due to limited information processing ability (e.g., the strain on short-term memory), decisionmakers may employ another simple rule or heuristic, i.e., *availability*. In such cases the option is generated by retrieving what is readily available in the memory using the availability heuristic. For example, if a person ate take-out fried chicken last week, that option will be most available in memory. The use of judgmental heuristics is often an effective strategy for generating options; however, suboptimal or biased performance may sometimes occur due to irretrievability of instances and a lack of imaginability. One potential bias resulting from use of the representativeness heuristic involves the failure to create new nodes and the inability to move from a highly representative option node to less representative nodes. For example, if ordering pizza and Chinese food are the two most representative actions when take-out food is ordered, a person may anchor thinking on these options and be unable to recall the option of take-out sushi. One potential bias resulting from use of the availability heuristic involves the failure to consider a sufficient number of options due to an inability to retrieve enough instances of similar problem situations. This was demonstrated by Gettys *et al.* [25] who manipulated monetary incentives by paying one group of subjects for quality options and another group for the quantity of reasonable options generated for a parking problem. No significant differences were found in the number or quality of options generated in these groups or in a no-incentive control group. The authors were inclined to "attribute most of the [observed] difficulty in act retrieval to failure in accessing information available in memory or appreciating its significance." The other potential bias involves the failure to retrieve the correct options because of an inability to creatively imagine high-quality solutions to a problem.

It is not easy to define the boundary between well-structured and ill-structured problems. According to Simon [69], when problems are ill-structured a great deal of effort and the ability to access a very large amount of potentially relevant information in the long-term memory is needed to structure the problem. Therefore, when people are faced with unfamiliar ill-structured problems (e.g., starting a new business or planning for nuclear reactor safety management), the similarity of these problems to the problems stored in the long-term memory is judged very low. Since no prototypical or causal patterns are stored in long-term memory, a menu of options is not readily accessible in memory and actions can not be quickly retrieved by searching memory. Therefore, people have to generate options in imaginative or creative ways. In these cases, the option-generating procedures in this paper should be most useful since they should aid a person to 1) recognize options which were not thought of in unaided recall and 2) think of new options.

Searching Through the Cognitive Network for Options

Since the structure of memory and the characteristics of the environment combine to determine the way in which different types of problems are represented and solved (Newell and Simon [59]), we can alter inputs from the environment to aid a decisionmaker's option generation if routine memory search does not elicit satisfactory options. More specifically, Smith *et al.* [70, p. 342] point out, "One's ability to retrieve (or recognize) an item is heavily influenced by the relation between that item's storage and retrieval contexts." Thus we should be able to help a person recognize a prestored item by varying the context of the search through memory. Varying levels of activation at different source nodes (representing different contextual aspects of the problem) will stimulate the spread of activation in different directions and along lesser used pathways in different locations of the cognitive network. Therefore, different option-generation procedures can be seen as different strategies for traversing the cognitive network to search for and/or create new options.

For example, prompting the person whose knowledge matches the network shown in Fig. 2 by suggesting that the attribute of the formality of the food service be considered may lead to creatively generating the new option of hiring a formally dressed chef-for-the-day. However, suppose we prompt this decisionmaker to think of options similar to delivery of pizza. This different option-generation procedure will lead to a different search pattern. Using the "delivery of pizza" retrieval cue will likely activate the node on the pathway leading from "ordering a pizza" to "having ordered food delivered." Now, activation will likely spread upwards and to the right and raise the activation level of the next preexisting cognitive unit, "ordering Chinese take-out food."

Madni *et al.* [54] discuss several search strategies and also propose a blackboard model which is primarily used in ill-structured problems. The blackboard model is used to sequentially extract well-defined subproblems, thereby enlarging the search space to include the regions surrounding each subproblem. In addition, the efficient memory search strategies employed by Kolodner's [46] CYRUS computer program may also be generally useful for decisionmakers when searching for new options. Her model of the structure and processes of human long-term memory is implemented in CYRUS and linked with a database of Cyrus Vance's U.S. Secretary of State activities. It is assumed that a category to be searched for will be identified in memory by a set of indices or features associated with it. First, the original statement of a problem may not remind a person of an appropriate feature. *Index fitting* is the process of transforming stated features into features that might be indexed (e.g., thinking about *the formality of a meal* can help consumers think of meal options when they *do not want to change clothes*, or thinking about *sightseeing at oil fields in Iran and Saudi Arabia* can help a person answer when was the last time he/she saw an *oil field in the Middle East*). This allows downward traversal in the network to nodes with more specific content, leading to a more in-depth search of the local region of the network. Second, *alternate context search* involves looking for a different type of event than the one desired, since it may provide cues to activate the desired nodes (e.g., thinking about *going to the grocery store* may suggest ideas for a *food service business*, or thinking about a *trip to England* may help remind a person about *museums* visited). This stimulates lateral traversal of the network, leading to a search with greater breadth across the network.

Option Generation in Organizational Groups

Although we do not want to focus on how options are generated in organizations, a descriptive understanding of it is needed for a more complete perspective. Field studies of the decisionmaking process in organizations provide insights on how problems are structured. Mintzberg *et al.*

[57] categorized case studies of decision processes in ill-structured problem situations and observed two general types of option-generating procedures. First, sometimes a search routine was followed where options were searched for by directly seeking new options, by scanning the organization's written or unwritten memory, by initiating a call for proposed alternatives, or by passively waiting for unsolicited alternatives, Also, sometimes a design routine was followed where only one custom-made alternative was designed, or else modifications were made to existing alternatives.

This paper is limited to a discussion of methods for generating more than one alternative for a model of a decision problem which could be subsequently used in a formal decision analysis. We also will not consider cases in which the set of all feasible alternatives can be readily specified; in such cases the predecision phase is spent screening out poor alternatives prior to subsequent evaluation (see Keeney [39]).

III. Option-Generating Procedures and Evaluation Criteria

In this section, we employ the general framework of knowledge representation described in Section II to provide five general approaches to option generation. The approaches differ by the type of cognitive unit (decision problem attributes, states, or options) to be brought into short-term memory to stimulate further search for new options. First, some procedures rely on prior specification of the attributes by which the options will be evaluated. Second, other procedures focus on possible states of nature. Third, a composite procedure uses aspects of both attribute-based and state-based procedures. Fourth, some procedures focus on previously generated options or the characteristics of options. Finally, the use of creativity techniques in option generation is described. The five categories of procedures are summarized in Table I. Our model of the way knowledge is represented cognitively will be used to examine the procedures.

The characteristics of possible options vary from problem to problem. For example, Humphreys [29] describes the selection of different possible *portfolios* of hardware and software packages. Sometimes options can be specified by different *factors* such as identifying a vacation package by choosing elementary actions in eight categories, including location and transport [38]. Options also can consist of a *process or a sequence of steps* [23], such as solving the problem of running out of gas on a freeway [25]. Sometimes options are actually *coordinated alternatives* consisting of two or more components. For example, attending a conference en route to a Tahiti vacation creates a vacation option that is cheaper due to partial tax deductibility [39].

There are only a few studies addressing the issue of decision aids for option generation (e.g., Tong *et al.* [73], Arbel *et al.* [4]). Tong *et al.* [73] study whether decision

TABLE I
Summary of Option Generating Procedures and Evaluation Criteria

Category of Method	Specific Procedure	Evaluation Criterion
Attribute based	present attributes one at a time	maximum number of options in set which are perfect or good on at least one attribute
	design options to do well on the heavily weighted attributes	maximum number of options in set which are close to optimal
	partition the attributes prior to eliciting options	maximum number of reasonable options
	deemphasize the personal nature of the attributes	maximum number of novel options
	enumerate all possible options by combining all possible levels of each attribute	maximum fraction of total possible major variants included in set
	attribute invention or replacement	maximum flexibility of the option set
	examine higher level attributes	maximum flexibility of the option set
State based	present possible states of nature one at a time	maximum probability best option in set
	design options to do well in the more probable states of nature	maximum number of options in set which are close to optimal
Composite (attribute based and state based)	elicit a preliminary set of options on heavily weighted attributes; then conduct a sensitivity analysis before eliciting more options	maximum number of options in set which are close to optimal
Option based	present examples of options and elicit more options	maximum number of options related to examples
	specify the characteristic or generic structure of options, then select options which will meet the required structure	maximum fraction of total possible major variants included in the option set
	visualize the ideal option and design options which are close to it	maximum number of options in set which are close to optimal
	present examples of options framed in a different way	maximum number of reasonable options
General creativity	brainstorming	maximum number of novel options
	synectics	maximum number of novel options

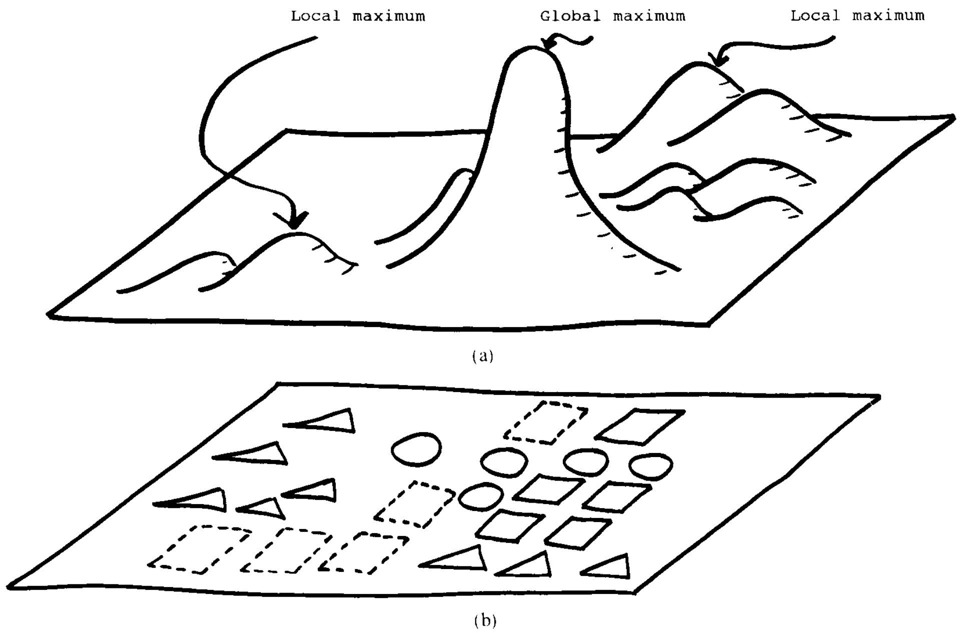


Fig. 3. Locations of locally and globally optimal options within cognitive network. (a) Utility of options. (b) Cognitive network representation.

aids can be developed to help people generate better sets of options in both novel and stressful situations. Noticing deficiencies in the existing decision-aiding technology, especially in the area of option generation, Arbel *et al.* [4] proposed a two-stage iterative option-generation scheme. Since very little research has been done on option-generating procedures, there is little evidence about which procedures will be most effective for options with different characteristics. The procedures to be proposed are designed to use different means for augmenting a person's limited short-term memory, thereby eliciting a greater number of potential options.

Criteria for Evaluating the Option Set

Once a preliminary set of options has been generated, it should be evaluated to determine if additional options need to be included during the predecision phase. (During the analysis phase, additional options may be revealed as a result of the analysis.) Since it may not be possible to determine if good options are included in the set without extensive formal evaluation, Keeney [39] suggests that the "practical aim in creating alternatives is to generate a set of very promising ones." One approach to the problem of evaluating an option set before it is possible to formally evaluate the options it contains (and the ones it does not) is to shift the evaluation backwards onto the option-generation methods used. Methods that can be shown through experiments, previous applications, or through theoretical analyses to produce option sets satisfying desired criteria should then be used.

We assume that the options currently contained in the cognitive network are located in multiple clusters in different locations. For example, different possible kinds of take-out ethnic foods will be closely clustered near the state of nature of being hungry and not wanting to cook, and a number of possible new business ventures will be clustered near the attributes of business success. Thus in each cluster there will be at least one option that has the locally maximal utility. If we constrain our search for options within a few local regions *and* identify all possible options in the region by an *in-depth search*, we can only find the best option in those regions as shown in Fig. 3. If we do an exhaustive search through the entire cognitive representation, we will find the option that is globally optimal within the representation. However, due to limited time, money, and effort available to devote to option generation, as well as limited information processing ability, it will usually be infeasible to search exhaustively. Keeney [39] discusses how to determine when to stop generating additional options by weighting the time, effort, and cost of search with the disadvantages (and advantages) of further delays in solving the problem.

Alternatively, a broad search through many regions of the cognitive network should generate a set of varied options. However, due to search constraints all options in a cluster may not be identified, so locally and globally optimal options may not be found. The framework of option-generating procedures proposed here uses the three types of decision elements (attributes, states, and options) as keys to doors to other pathways in the cognitive network.

A variety of criteria can be used in evaluating the set of options. The procedures presented still must be experimentally evaluated to determine how well choice sets generated with each procedure meet different criteria. Whenever experimental or theoretical evidence suggests that a method will do well on a criterion, we present the evidence after introducing the method. For example, if the best global option must be achieved and all other options are worth nothing, then the criterion might be to maximize the probability that the best option is included in the set. A strategy that might lead to maximizing this objective subject to fixed resources for search would be to select a few source nodes and to activate them highly so depth search leads to discovering the locally optimal option, thus fathoming a few local regions of the network. The notion of probability in criteria such as this can apply in decisions under certainty as well as under risk since it will refer to the frequency with which generated option sets would satisfy a property (such as containing the best option) when a specific elicitation method is used repeatedly on different problems.

In the usual case where the worth of many options can be of varying closeness to that of the best option, other criteria may be appropriate. These include: minimizing the expected difference between the best global option and the best option in the set (Gettys *et al.* [25]), maximizing the number of options in the set which are close to the optimum [25], maximizing the diversity as represented by the fraction of the total possible major option variants included in the set [25], [39], or maximizing the number of options in the choice set which are perfect or good on at least one attribute [71], [81]. Other possible criteria are maximizing the flexibility (responsiveness to unmodeled future changes) of the option set [29], mazimizing the number of reasonable options [38], [66], or maximizing the number of novel options [66].

Option-Generating Procedures

1) Attribute-based procedures: A principal strength of a person's information processing system is the complex associative memory in which small cues or attributes can lead to retrieval of complex associations which stimulate the option-generating process. Hence attention to different subsets of attributes could easily lead to different options. Seven versions of attribute-based procedures for generating options are identified. It is important to note that very little research has been done on these procedures, so they should be seen as *suggestions* and not as validated methods. Keeney [39] discusses alternative generation using value-focused thinking and gives examples for societal and personal decision problems. Attribute-based procedures will provide stimulation from the environment by introducing nodes or stimulating existing nodes containing attributes or goals. Since a goal node serves as a relatively constant source of activation in a cognitive network, introducing an attribute should initiate a great deal of activation or search in the local region around that node.

One warning about attribute-based procedures should be given. In stimulating creativity, separation of idea generation from evaluation is recommended to avoid premature censoring of ideas before they are formally stated. In a cognitive network, premature evaluation might occur if a high threshold for activation level must be met before an idea would be added to the option set. Use of goals or attributes to prompt ideas may lead to immediate evaluation of options with respect to those attributes and thus limit the number of options generated.

a) Present attributes one at a time. Elicit options which will help meet each individual attribute: Pitz *et al.* [66] presented experimental subjects with attributes one at a time, two at a time, and all at once. More options for solving personal dilemmas (like a dope-smoking roommate) were generated when the task was first to generate options to satisfy only one attribute, then to consider a different attribute, etc., until all the attributes had been considered. The results of this experiment (and a later one [65]) provide empirical support for the GODDESS computer system developed by Pearl *et al.* [62], [48] which assesses goals and subgoals (attributes) before asking for possible options to lead to improvements in each subgoal. Keeney [39] suggests considering one fundamental objective at a time, then two at a time, and so on, until all objectives are considered together. For instance, in our "starting a food preparation service business" example we can first present to the decisionmaker an attribute "flexibility of hours", then the attributes "flexibility of hours" and "food service related" together, and so on, until all attributes are presented. Altering the presentation order of the attributes may have an effect on the generated choice set since a person might *anchor* on the local regions surrounding the first attribute. Considering one attribute at a time is likely to meet the criterion of maximizing the number of options in the choice set which are either perfect or good on at least one attribute.

b) Design options to do well on the heavily weighted attributes: When the Los Angeles Unified School District was legally ordered to develop and implement a desegregation plan, Edwards helped the school board generate a complete value tree with 144 bottom-level attributes [13], [79], [80]. Interested groups were encouraged to submit possible desegregation plans to the school board for evaluation via the value tree. In addition, the school board developed a new plan after the value tree had been constructed and the attribute weights for an additive multiattribute value function were computed by averaging the weights of five board members. Thus it is possible that the new plan was creatively designed to satisfy the more heavily weighted attributes. This approach is likely to meet the criterion of maximizing the number of options that are close to optimal.

c) Be more detailed in partitioning the attributes prior to eliciting options: Jungermann *et al.* [38] found in an experiment that more vacation package options were elicited when a value tree was specified down to three levels with six attributes (such as mental relaxation) than when it was only identified with two or one level(s). Thus there were more attribute nodes on the cognitive network that could potentially be connected to additional option nodes. This may lead to a number of reasonable options, which are feasible based on the person's values. However, if a value tree is specified in too much detail, viable options may be screened out. For example, when planning a vacation, the attribute "variety" might be partitioned into "number of towns visited" and "number of activities done." This may preclude the potentially attractive option of taking an ocean cruise.

d) Deemphasize the personal nature of the attributes to increase the number of options generated upon consideration of goals; emphasize the personal nature of the attributes to increase the quality of the options generated: Jungermann *et al.* [38] had some subjects rate the importance of vacation goals (attributes) to themselves prior to generating options. These subjects generated fewer options than those who did not rate the goals first. However, the options generated by this "personally involved group" were rated higher on goal achievement scales than the options generated by other subjects. Thus fewer and "better" options seem to have been generated by emphasizing the personal nature of attributes. On the contrary, deemphasizing the personal nature of attributes is likely to lead to maximizing the number of novel options. This suggests that varying the decisionmaker's role perspective may lead to a better option set. Suggestions about varying people's "world view," such as their role in the decision process, will be mentioned again under creativity techniques.

e) Completely enumerate all possible options by combining all possible levels of each attribute: In designing creative options, a useful procedure is *forcing morphological connections* in which the attributes of the "standard" option are listed, then alternative levels of each attribute are generated. Finally candidate options are created by forcing all possible connections across attributes, e.g., see MacCrimmon and Taylor [49]. Starr and Greenwood [71] used this approach in their proposed option-generation procedure. First, they generated a set of options varying on the levels of three hypothetical attributes. Then a second step generated more finely discriminated options within a region surrounding the local optimum found in the first step. Von Winterfeldt and Edwards [80] describe the computer program DESIGN that identifies all nondominated options among the exhaustive set of options generated through forced connections. For example, sports car design options are first scored on a number of benefit attributes and an overall benefit value is computed by an additive value model. Then the Pareto frontier of nondominated options is generated with options that are identified by various combinations of overall value and cost. The commercially available DECISION AIDE II [12] software (based on the approach of Kepner and Tregoe [42]) first has the user list all the features of current options (such as low cost), then the user is prompted to supply a new option matching a forced combination of three features. This approach is likely to meet the criterion of maximizing the fraction of total possible major option variants that are included in the option set.

f) Attribute invention or replacement: Inventing a new attribute that has not been considered previously may suggest novel alternatives and may lead to maximizing the flexibility (responsiveness to unmodeled future changes) of the option set [29]. For example, reusability and resealability are two attributes of the small 16-oz plastic Coke bottles which were not factors in pop-top soft drink cans, but introducing them as attributes readily suggests a small sealable bottle.

Second, temporarily replacing an attribute with an isomorphic description may stimulate new ideas (see Keeney [39]). This strategy is an index fitting strategy since an attribute will be transformed to a feature that may be indexed in a different place in the cognitive network. The framing of the description of outcomes has been shown to alter choices, possibly by causing the accessing of different nodes in the cognitive network. Tversky and Kahneman [74] presented outcomes in terms of number of lives saved or number dying and found opposite choices. Representing the outcomes of alternative treatments for coronary heart disease by average numbers of years lived after treatment rather than with probability distributions over health states can lead to different choices. Further, the choice of units and range of the attribute can alter choices. For example, the difference between a 10- and 11-percent return on investment seems smaller than a 10-million and an 11-million-dollar return (on a 100-million-dollar investment.)

Also, the impact of an increment in amount of the attribute may depend on the range of attribute levels considered. For example, Mowen and Mowen [58] replicated a hypothetical problem presented by Tversky and Kahneman [74]. More accounting students chose to drive 20 min to get a $5 discount off a $15 calculator than did those who got a different problem to save $5 off a $125 calculator. They also gave a business problem to the same student subjects and to business people: Save $20 on a $200 order or $20 on a $10 000 order. More subjects took advantage of the $20 discount on the $200 order.

g) Expand the scope of the problem by examining higher level attributes: At the beginning of the modeling process it is important to vary the scope of the problem by asking why the current attributes are important to discover higher level attributes (see Jungermann [37] and Keren [43]). For example, von Winterfeldt [78] describes how considering the problem of North Sea oil pollution from different institutional levels introduces different sorts of options. Fisher and Ury [20] prescribe examination of the scope of bargaining problems as a way of getting more options. One of the authors has been involved in projects sponsored by the U.S. Environmental Protection Agency (EPA) that are designed to evaluate alternative standards for carbon monoxide emissions in the ambient air. Standards are evaluated by examining their effects on coronary heart disease patients and other sensitive health groups. If the EPA's regulatory mission were expanded, it could enlarge the problem domain and consider options for improving the health and well being of those in sensitive groups through other approaches, such as removing sources of carbon monoxide exposure in the home and work environments (e.g., gas stoves and gasoline-powered engines). Volkema [75] found that subjects who expanded the scope of a problem via a "problem-purpose expansion" heuristic generated more ideas than did subjects who were warned that problem formulation and reformulation is important but were not given a specific method. In the problem–purpose expansion method the purpose is first stated in the form of action verb + object phrase + qualifying phrase (e.g., *to make + a profit of* \$20,000 + *within one year*), then it is expanded by repeatedly responding to the means–end question, "What am I trying to accomplish?" (*to attain business success within one year*). Altering the scope of the problem also will help meet the criterion of maximizing the flexibility of the option set by increasing responsiveness to future changes in problem structure that arise due to expansion of the scope.

2) State-Based Procedures: Some procedures depend on prior determination of the states of nature or combinations of probabilistic events that may impact on the outcomes of the decision options. Two procedures are presented here.

a) Present possible states of nature one at a time; elicit options which will be effective in each individual state: First, the possible future scenarios are generated (by combining different probabilistic events to determine alternative states of the world), and then options that would be effective in each scenario are elicited. For example, facing the scenario that both "consumer demand for food preparation service" and "willingness to spend money on food" are high, the decisionmaker might generate the option of starting a pizza delivery business. This approach can also be used in selecting strategic long range plans. In addition, options for gathering more information about the probability of the state (for example, through market research) should be considered. Suppose the best option will be determined after the state is known. Then the best option may be seen as the one that does best in that state, as opposed to the one with the maximum expected utility *a priori*. In this case, this procedure is likely to meet the criterion of maximizing the probability that the best option is included in the set. The order in which states are presented may affect the option set. For example, if the first state is that "business loan interest rates have risen," then this "bad" state may induce a pessimistic mood and alter the pathways of spreading activation through the cognitive network.

b) Design options to do well in the more probable states of nature: Identifying the few states of nature that are most probable, then designing options that will do well on that set of states of nature is another approach. Von Winterfeldt and Edwards [80] mention that a decision tree structure may suggest ideas for the development of hedging options to do satisfactorily under all possible states of nature. For example, a stadium vendor might sell hats as rain hats or sun visors depending on the state of the weather. This procedure will likely lead to creation of options with expected utilities that are close to the expected utility of the best option, meeting the criterion of maximizing the number of options in the set that are close to optimal.

3) Composite Procedure: Attribute Based and State Based: A procedure that relies on specification of both the attributes and the states of nature may be especially useful for generating an enlarged set of options once a preliminary model of the problem has been built.

a) Elicit a preliminary set of options that addresses the heavily weighted attributes; then conduct a sensitivity analysis using a preliminary decision tree before eliciting more options: In decisionmaking under uncertainty, a preliminary decision tree with states of nature and probabilities can be built to aid further option generation. Arbel and Tong [3] created an option-generation procedure that uses a preliminary decision tree with the initial options to conduct a sensitivity analysis. The sensitivity analysis highlights sensitive states so that new options can be generated that reduce or circumvent this sensitivity. Sensitive states are defined as those which have greater differences in the payoffs for the different outcomes. For example, suppose the preliminary option that maximizes expected utility results in utility u_1 if state 1 occurs (with probability p) and a lower utility of u_2 if it does not. Thus the expected utility of the option is $pu_1+(1-p)u_2$. This best option will result in utility u_3 if state 2 (with probability q) occurs and a lower u_4 if it does not. Suppose u_1-u_2 is greater than u_3-u_4. Then state 1 is called more sensitive than state 2 because an "error" in assessing state 1's probability p (e.g., the actual p is found to be 0.1 more) will lead to a greater change in expected utility ($0.1[u_1-u_2]$) than if the same error were made with state 2. Arbel and Tong illustrated their procedure by generating alternative corporate strategic plans. The procedure is likely to lead to maximization of the number of options that are close to optimal.

4) Option-Based Procedures:

a) Present examples of options and elicit more options: Fisher and Ury [20] suggest a circular four-step procedure which can be used to generate new options, especially after one option has been identified. Although their context is the generation of options in negotiations between disputants, the procedure is generalizable to other contexts. This method is intended to increase options by alternating between specific and general thinking:

- Step I *problem*: think about the specific problem (or the previously generated option);
- Step II *analysis*: diagnose the existing situation in general descriptive terms;
- Step III *approaches*: based on the general description, invent prescriptions that your general description suggests;
- Step IV *action ideas*: be specific and identify specific and feasible options.

Although presenting examples seems appropriate, experimental research results give mixed evidence about its effectiveness. Pitz *et al.* [66] presented examples of possible vacation options to experimental subjects. This did not increase the number of options generated, but *it did lead to more options that related to the examples*. Thus providing examples seems to have caused subjects to anchor on those examples in the cognitive network and to generate new options which were representative of the examples using the representativeness heuristic. Gettys *et al.* [25] presented examples to encourage thinking prior to eliciting added options. Though the effectiveness of supplying examples was not directly tested, subjects only generated about 20–30 percent of the possible good options, so giving examples may have limited the quantity of generated options. In contrast, Isenberg [35] found that "concretizing and instantiating from general information (general to specific) was significantly correlated with effectiveness" of action plans generated by 12 managers in a verbal protocol experiment. Also, seven of the 12 managers generated a specific idea or "action seed" prior to generating a complete course of action for an experimental business case. Thus perhaps the decisionmaker should be prompted to supply "just one example" to start off the process rather than being prompted with an externally generated example option. This approach is likely to meet the criterion of maximizing the number of options related to examples.

b) Specify the characteristic or generic structure of options; then select options which will meet the required structure: In an application of decision analysis methods to a real problem, Humphreys [29] reports on a project to generate options and portfolios of options for a psychology department's computer systems. First, they decompose objectives into a tree. Then three requirements spaces (hardware, software, and user) were mapped out. Finally options for subsequent evaluation were designed that would span the requirements spaces. First options suitable in three small worlds (business, laboratory, and statistics/simulation system) were identified, then they were combined as complete options.

Alternatively, the generic structure of example options can be used to identify goals or attributes which may be of interest. Pitz *et al.* [65] found in an experiment that when subjects were told to supply the goals which might be attained by example choices *and* and the choices that could meet example goals, they generated more new options (and new goals). This method presumably aids a person in accessing problem prototypes or scripts in memory consisting of options linked with outcomes described in terms of attributes or goals. This should lead to maximizing the fraction of the total possible major option variations included in the option set.

c) Visualize the ideal option and design options which are close to it: An ideal option that reaches the best level on each attribute can be imagined as an example option. Anchoring option generation on this option may activate search in the cognitive network locally about the node representing the ideal option and lead to maximizing the number of alternatives that are close to ideal. However, if a person is unable to imagine the ideal option, then it may also be hard to imagine options close to it. Keeney [39] stresses the importance of creating a positive mood that reaching the ideal is possible. Zeleny [81] suggests modifying current options to move toward the ideal option that reaches the boundary of technological feasibility on each attribute. He defines a set of options as technologically closed on a given attribute if at least one sequence of options converges to an option that attains the best currently technologically feasible level on that attribute.

The ideal option may be imagined with visual imagery and be represented as a spatial image in the cognitive network. Such visualization may lead to new options. In evaluating consumer purchase options, people have been found to sometimes follow a process of comparing multiple brands on one attribute at a time and sometimes they evaluate one brand at a time holistically. Visual imagery leads to a brand-based processing strategy. MacInnis and Price [52] hypothesize that "when imagery processing is used consumers will be more likely to rely on within-branch processing strategies as opposed to attribute-based strategies," and that "consumers will evaluate fewer brands when using imagery processing rather than discursive," or language-like, processing. Thus we must be wary that if imagery leads to fewer options in the evoked choice set as hypothesized, it may also lead to fewer options when generating new ideas.

d) Present examples of options framed in a different way: We have already discussed altering the framing of an attribute to stimulate new options. The framing of the reference point and sunk outcomes has also been shown to alter choices, perhaps because different frames lead to different node activation patterns. The reference point, target level, or neutral level on an attribute can greatly alter perceptions of an option if changing the reference level leads to changing the perception of an outcome from being a gain or "good" to being a loss or "bad." For example, Fischhoff [19] experimentally investigated different framings of outcomes in a civil defense problem. In a problem of choosing between equal chances of losing 40 lives and 60 lives versus a sure loss of 50 lives, a different frame was achieved by setting the reference point at the 50 sure lives to be lost in the second option. Then the new frame for the first option leads to equal chances of saving 10 additional lives or losing 10 additional lives. Similar transformations of example options can be done and presented to the decisionmaker to activate nodes in slightly different regions of the cognitive network. This should lead to maximizing the number of reasonable options generated.

Sunk outcomes are costs or benefits of a problem situation which have already been experienced and which may or may not be perceived as relevant to the current decision problem. It is important to consider whether sunk outcomes will be included in the model of the problem. More generally, the time horizon (both backwards and forwards in time) which is spanned by the model must be specified. Laughhunn and Payne [47] demonstrated that when making choices without a formal decision aid, some people use a minimal account (ignoring sunk losses or gains) and some use a psychological account (including sunk outcomes). They presented several possible determinants of the framing of sunk outcomes. Thus presenting example options with and without sunk outcomes may lead to different new options.

5) General creativity techniques: In addition to the specific techniques which are listed in the preceding subsections, some other general creativity techniques may be useful in generating novel options.

Examining the problem from the point of view of different experts, different interested parties, and different levels of an organization may lead to more creative options. The software package DECISION AIDE II [12] prompts the user to repeatedly "think of alternatives that a ··· would suggest," each time filling in the blank with one of a large number of nouns such as boss or ant. The world view a person has can often be a constraint on developing options. Initiating such an alternate context search is likely to lead to lateral traversal of the cognitive network. Similarly, an interdisciplinary team of analysts may generate a more complete set of options than a group of people from one shared background (Phillips [63], Fisher and Ury [20]).

Methods for releasing self-imposed constraints can enhance creativity, see, e.g., Adams [1]. For example, when confronted by the problem of the ostensibly broken doorbell, one of the authors thought of the "creative" option of trying to open the door (it was locked), but she failed to relax the implicit constraint imposed by the written note that ringing the doorbell would not work.

Brainstorming involves the rapid generation of ideas, by building upon previously generated ideas or diverging onto new topics without concurrent evaluation of the ideas (Fisher and Ury [20]). MacCrimmon and Wagner [50], [51] have designed the INVENTOR software to stimulate option generation by prompting a user to brainstorm. The ods/CONSULTANT software also supports brainstorming. A group of individuals separately brainstorming may lead to more breadth of options than if the same people do it in a group, which may lead to depth by following a specific idea with a related one. Training subjects to follow a diverging–converging two-step process called "ideation–evaluation" (in problem finding, solving, and implementation) led to higher use of ideation in problem finding and solving and better performance in problem finding in a field experiment by Basadur *et al.* [6]. Engelmann and Gettys [16] showed that divergent thinkers had greater ability to generate alternative options. Also, Isen and Nowicki [34] found that inducing a good mood in subjects (by having them watch a funny movie) helped stimulate the creative generation of options for solving the problem of affixing a candle to a wall in a room with miscellaneous objects.

Synectics is a set of techniques which rely on metaphorical thinking and thinking with analogies to create new ideas. Training subjects via a nominal group technique procedure to use either an organistic (forest-like) or a mechanistic (machine-like) mataphor for an organization led to different interpretations and solutions for the same problem [8]. Isenberg [35] found that the "strongest predictor of an action plan's effectiveness was ··· analogical reasoning, or using personal experience" to understand the problem situation of a manager in a hypothetical case. When told a story of a military general who divided his men into small groups and had them follow many roads simultaneously to converge on a fortress, many experimental subjects [27] were able to use this remote analogy in generating a solution to a problem of not being able to administer a high-intensity X-ray to destroy a tumor due to the dangerously high intensity level. Glass and Holyoak [27] describe this experiment and explain why the similar abstract structure of the two contexts stimulated subjects to think of the idea of administering low-intensity rays from multiple directions simultaneously. MacCrimmon and Taylor [49] and Taylor [72] describe other creativity techniques for use in structuring decisions, including the relational algorithm and the Maltzman technique to reduce functional fixedness (by presenting a stimulus and giving a different association each time it is presented).

V. SUMMARY AND IMPLICATIONS FOR FUTURE RESEARCH

This paper presents an integrative framework of procedures for generating alternative action options, based upon an associative network model of knowledge representation. Procedures were divided into five categories: attribute-based, state-based, composite, option-based, and creativity procedures. The different option-generation procedures are seen as different strategies for traversing the cognitive network to search for and/or create new options. The approaches differ by the type of cognitive unit (decision problem attribute, state, or option) to be brought into short-term memory to stimulate further search.

Compared with other areas of decision research, there is a relative paucity of research on how we can improve option generation. The integrative framework presented here can be used to guide further research. First, additional methods falling into the five categories should be developed. Second, future research should investigate which option-generating procedures are most appropriate for various types of options, this will lead to modification and elaboration of the integrative framework. Third, the appropriateness of different methods may vary due to individual differences in cognitive architecture, especially between experts and novices (Isenberg [35], Frederick and Libby [22]). Experts tend to develop a whole picture and to first use a breadth search strategy in problem solving (MacCrimmon and Wagner [51], Bouwman [9]). Fourth, the effects of extrinsic versus intrinsic incentives on the quality of options should be investigated, as well as how differing levels of cognitive effort may influence memory search strategies. Finally, Pitz [64] advocates making a clearer theoretical distinction between procedures designed to retrieve options from memory and those designed to creatively produce new options. Production of options could occur when an associational cue (e.g., an attribute) is combined with a rule (such as focus on one attribute at a time) to elicit a new option.

One promising general approach to problem structuring is the use of decision "templates" of generic problem structures which are augmented with information from a specific problem, as suggested by Weiss [76] and Weiss and Kelly [77]. This is similar to von Winterfeldt's [78] suggestion to identify prototypical decision problems as an aid to structuring future problems. It may be possible with our expanding capabilities for computerized storage of large knowledge bases and development of expert systems to combine some of the option-generating procedures described in this paper with a memory of options generated for similar problems in previous analyses. Humphreys and Wisudha [33], Humphreys and McFadden [32], Humphreys [30], Weiss [76], Leal and Pearl [48], Kirkwood [44], [45], Merkhofer *et al.* [56], Selvidge [67], and MacCrimmon and Wagner [50], [51] discuss computerized aids for various parts of the problem structuring process. Elam and Mead [14], [15] present a framework for enhancing creativity via decision support systems, and specifically evaluate the ods/CONSULTANT [61] software's performance.

In the not too distant future this line of research should result in aids for option generation in various significant problem areas. The development of domain-specific computerized problem structuring aids has probably advanced the furthest in the military arena, where the results are often proprietary, see Tong *et al.* [73], Barclay and Randall [5], Madni *et al.* [53], [54], Arbel *et al.* [4], Chu *et al.* [11], and Chong and Courand [10]. For a nonmilitary example, consider the problem of aiding an emergency services director in generating options following a severe earthquake. The director might be able to use a decision-aiding software package on a battery-operated personal computer. There could be a knowledge base of options considered in previous disasters and disaster drills. Updated information on facilities and resources which have not been destroyed by the earthquake would be entered into the system, and suggested options would be generated by the decisionmaker in response to helpful prompts from the decision-aiding software. After feasible options are generated, elements of the options could be rapidly evaluated by decision analysis and management science techniques embedded in the software package. The framework of option-generating procedures presented in this paper lays an integrated foundation for the development of these computerized problem structuring aids.

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