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SYNERGISTIC DECISION-MAKING SYSTEMS: USING MODELS OF DECISION-MAKING BEHAVIORS AND RESOURCES TO DESIGN BETTER DECISION-MAKING SYSTEM

by

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Despite advances in decision-making systems, many practical issues remain unaddressed and much of the computer's potential for supporting decisions is unrealized. The existing systems are often limited to specific decision-making activities or domains, and they force the decision-maker to adopt a closed and inflexible way of doing things. What is needed is a new approach to building decision-making systems, one that is not focused on how decisions should be made, but on the behaviors and resources involved in decision-making and how they affect the results. This paper explores such an approach. It examines how models of decision-making behaviors and resources can be used to design more open and flexible decision-making systems. The resulting systems are referred to as Synergistic Decision-Making Systems because they unite people and computers for the purpose of making better decisions in less time and human effort. To demonstrate the validity of this new approach, a prototype system was built and evaluated. The evaluation was unable to show the desired improvement but, rather, provided valuable information on ways to improve the design of both the evaluation experiment and prototype.
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CHAPTER I

INTRODUCTION

The American Heritage Dictionary (1992) defines synergy as "The interaction of two or more agents or forces so that their combined effect is greater than the sum of their individual effects." Systems that achieve synergy are more than combinations: they are wholes, their individual behaviors and characteristics unite in a way that creates something new. The interacting systems tend to build on individual strengths and compensate for individual weaknesses--achieving what they cannot do alone or do alone as well. The following research is an exploration of ideas for creating computer-based decision-making systems that work synergistically with human decision-makers. The goal is to create decision-making systems that: (a) interact more naturally with human decision-makers, (b) encompass all decision-making activities and domains, (c) help define and manage the decision-making process, (d) improve coverage of the decision space, and (e) build on the individual strengths of computers and people while compensating for individual weaknesses. Decision-making systems that emphasize these goals will be referred to as Synergistic Decision-Making Systems. The research explores using a process as a model for decision-making behavior and it develops a new model for human decision-making resources. It then reviews the effects of human resources on decision-making, explores the use of
patterns to improve coverage of the decision space, and suggests ways that decision-makers and decision-making systems can work together to produce better decisions with less time and effort. The research concludes with the design and evaluation of a prototype Synergistic Decision-Making System.

Using Models to Build Synergistic Decision-Making Systems

This research was born of frustration with existing decision-making systems that require extensive training or problem translation, are unresponsive to the decision-maker's needs, and apply only to limited decision-making activities or domains. The existing systems seldom consider decision-making as more than a single isolated activity, and they provide little support for the discovery, refinement, and reuse of patterns that occur repeatedly in decisions. Ideally, decision-making systems should help decision-makers move from a vague notion of some problem to a solution. They should guide the problem translation if needed, provide support and direction as needed, be unobtrusive, adapt themselves to changing activities and informational needs, and move easily between specific instances and more abstract, reusable, patterns.

The limitations of existing decision-making systems may stem from the approach typically used to design them: (a) define the system objectives, (b) determine what activities people engage in while making decisions, (c) design tools to support each activity while satisfying the system objectives, and (d) integrate these tools into a single system. Decision-making systems designed this way are bound to
be too granular, inflexible, and unresponsive to the variety of ways people approach
decision-making. They will be limited by how the designer perceives the complex
interaction of many simple behaviors as separate decision-making activities. An
alternative approach—the one taken here—is to create models of fundamental human
decision-making behaviors and resources and then develop systems that interact with
the decision-maker using these models. Decision-making systems designed this way
should be able to achieve a more synergistic relationship with the decision-maker.

Matching Fundamental Decision-Making Behaviors and Resources

One goal of a Synergistic Decision-Making System is to interact more
naturally with the human decision-maker. That is, the decision-making system should
conform to the way the decision-maker works rather than the other way around. To
accomplish this goal, the underlying models of decision-making behaviors and
resources should closely match the fundamental behaviors and resources of human
decision-makers. The closer this match the less the decision-maker will have to fit his
or her knowledge and behavior to the system’s. This fitting diverts attention from the
decision and leads to imprecision and translation errors that result from simplifying
assumptions and the mapping of representations to elements in the decision space.
Another reason for a close match is that it improves the mutual “understanding”
between the decision-maker and system. The decision-making system’s behavior and
representation of the decision will be closer to that of the decision-maker’s so that
each can more easily follow and guide the activities the other. Finally, a close match
should result in decision-making systems that are able to encompass all decision-making activities and domains. Since the resulting systems are based on models of human decision-making behaviors and resources, they should be able to support whatever the human decision-maker does.

**Using Models That are Scaleable and Expandable**

Some goals of Synergistic Decision-Making Systems can be met by using models that are scaleable and expandable. Scaleable models support horizontal and vertical partitioning of the decision space. In horizontal partitioning, decision elements within the same level of perception are differentiated into groups. The same elements can be differentiated in many different ways, depending on the sets of characteristics and relationships the decision-maker wants to emphasize. This type of partitioning helps the decision-maker manage the decision-making process by breaking the decision into smaller well-defined parts. It also helps improve coverage of the decision space by reducing demands on the decision-maker and allowing alternative sets of resources to be emphasized at different times. Vertical partitioning, in contrast, involves replacing one or more decision elements and their relationships with a single representation at a higher level of perception. Vertical partitioning can result in a loss of information, as in the case of abstraction, and/or a gain of information, as in gestalt perception where “the whole is greater than the sum of the parts.” The loss of information helps improve coverage of the decision space by concentrating decision-making resources on what remains. It also helps eliminate
information that is specific to an instance, revealing patterns that can be reused in new instances. These patterns later improve coverage of the decision space by directing attention to information and activities that have been used in other decisions. The gain in information from gestalt perception helps improve coverage of the decision space by bringing new informational resources to the decision. For example, recognizing a decision element as an outcome brings knowledge and behaviors associated with outcomes to the decision. The other attribute desired for models used by Synergistic Decision-Making Systems is expandability. Expandable models have the ability to declare representations and behaviors that are made available by other systems. Each system is isolated from the methods used by the other systems to invoke the declared representations or implement the declared behaviors. This allows each system to take advantage of the strengths the other systems have to offer.

Using Separate Models for Behaviors and Resources

Some goals of Synergistic Decision-Making System are better addressed by using separate models for behaviors and resources. Models of decision-making behaviors emphasize the interaction between a decision-maker and his or her environment. They describe behaviors that are largely independent of the underlying resources and may involve a sequence of related events. In contrast, models of decision-making resources focus on the internal behaviors and changing characteristics of resources in response to individual events. This second type of model defines the capabilities, limitations, and state of decision-making resources in
terms of defined resource characteristics and behaviors. Since decision-making involves an on-going interaction with the environment and is affected by the internal characteristics of decision-making resources, Synergistic Decision-Making Systems can benefit from using separate models to emphasize these different areas.

**Models of Decision-Making Behaviors**

Models of decision-making behavior can address at least two goals of Synergistic Decision-Making Systems. The first of these goals is that the systems help define and manage the decision-making process. To address this goal, the models must declare representations for the different parts of a decision and define the relationships between these parts. These models must be defined so that decision-making systems built from them are able to perform much of the routine work of the decision, and help in (a) defining objectives, (b) providing motivation, (c) managing the external and internal resources needed by each activity, and (d) designing activities that maintain a smooth continuous flow toward a conclusion. By helping to define and manage the decision-making process, the decision-making system frees the decision-maker to concentrate on less defined aspects of the decision. This also helps maintain the decision-maker’s interest in the decision and ensures that the important parts of the decision are not missed. Another goal of Synergistic Decision-Making Systems is to optimize coverage of the decision space. Models of decision-making behavior can help address this goal by incorporating the use of multiple perspectives on, and translations of, the decision. Perspectives bring complementary sets of
knowledge, behaviors, and motivations to bear on the decision. They invite the
decision-maker to assume a new role: making one set of resources more readily
available than others while simultaneously reducing competition among thoughts for
the decision-maker’s attention. By encouraging the decision-maker to assume
different perspectives at different times, the decision-making system can ensure that
more of the decision-maker’s knowledge gets his or her attention. Thus, more of the
decision space is covered. Translations, in contrast, are alternative ways of defining or
partitioning the decision space. Each translation activates new associations which
reveal knowledge about the decision that is not apparent from other translations.
Translations differ from perspectives in that they use the external representation of the
decision to stimulate ideas. Perspectives emphasize internal resources. Decision-
making systems can improve coverage of the decision space by encouraging the
decision-maker to experiment with alternate translations.

Models of Decision-Making Resources

An important way of interacting more naturally with the decision-maker is
being able to collaborate with the decision-maker on the decision. This collaboration
requires the decision-maker and decision-making system to have a shared
representation of the decision knowledge and a set of rules for manipulating this
representation. This shared representation and set of rules are defined in terms of the
characteristics and behaviors defined by models of decision-making resources. That
is, the models of decision-making resources provide a foundation for explaining how
knowledge about the decision is shared. By using these models, decision-making systems can accumulate decision knowledge and assist the decision-maker in remembering, manipulating, expanding, and classifying this knowledge. Models of decision-making resources also describe the capabilities and limitations of the resources and how the resource characteristics change with time and use. Decision-making systems can use this information to compensate for resource limitations.

Another way to collaborate with the decision-maker is to help with evaluating and comparing the attributes of each alternative and then with aggregating the results. This requires support for absolute and relative valuations as well as maintaining separate aggregations for positive and negative results. Models of decision-making resources describe how values are assigned to attributes and how these values are aggregated and compared. They allow the decision-making system to take advantage of the computer’s strengths in numerical analysis without interfering with the decision-maker’s natural approach to making decisions.

Organization of the Research

This chapter introduced the goals of Synergistic Decision-Making Systems and described how systems built from models of decision-making behaviors and resources could achieve these goals. It identified the characteristics of these models, showing that they must: (a) closely match the fundamental behaviors and resources of human decision-makers, (b) be scaleable and expandable, (c) identify the parts of a decision and the relationships between these parts, and (d) describe how knowledge
about the decision was shared and evaluated. The next two chapters describe models of decision-making behaviors and resources that have these characteristics. Chapter IV uses the model of decision-making resources, along with research in decision-making, to explain the effects of human resources on decision-making. Chapter V introduces the concept of Patterns and shows how they can be used to improve decision-making. Chapter VI reviews the previous chapters and their application to the design of decision-making systems. The remaining chapters describe a prototype Synergistic Decision-Making System and evaluate the prototype's effectiveness at producing better decisions with less time and effort.
CHAPTER II
THE PROCESS AS A MODEL OF DECISION-MAKING BEHAVIOR

Decision-making systems are often built around implicit or explicit models of decision-making behavior. These models give decision-making a tangible structure and define how the decision-maker will work with the system. A good model will also break the decision into a set of focused activities with clear goals that direct the decision-maker toward a solution. One candidate for such a model is the process model. This model is routinely used to improve business and manufacturing processes, and it works for decision-making processes as well. The process model is a general purpose model that captures the essential elements of decision-making while supporting the limitless construction of new ways to make a decision. It provides a structure and direction for decision-making activities while encouraging the decision-maker to consider and improve the way decisions are made. The process model also provides a formal approach to refining and reusing decision-making processes that result in better decisions with less time and effort. This chapter examines the process model, its benefits as a model of decision-making behavior, and its application to the design of decision-making systems. The arguments for using a formalized decision-making process are also considered, and an established decision-making process is examined to identify the major parts of a decision.
A process can be described as a series of operations that transforms resources into a product. The model of a process consists of the series of operations, or flow; the operations, resources, and product. One advantage of this model is that its parts are what Lakoff (1987, p. 51) refers to as basic-level categories:

Perhaps the best way of thinking about basic-level categories is that they are "human-sized." They depend not on objects themselves, independent of people, but on the way people interact with objects: the way they perceive them, imagine them, organize information about them, and behave toward them with their bodies.

The process flow can be perceived as physical movement in a direction, operations as movements in place, resources as the tools and materials used, and products as the rewards for completing the process. Basic-level categories exists at the most general level of human categorization. They are the easiest categories to learn, remember, and use (Lakoff, 1987). Decision-makers can easily "walk through" a decision-making process by gathering the resources they need for an operation, performing the actions involved in the operation, “walking” to the next operation in sequence, and so on until the decision is made. The process model is so basic that it is all too easily taken for granted. People repeatedly make serious mistakes by failing to properly identify and carry out the parts of a decision-making process.

Further examination of the parts of a process reveals characteristics that are helpful in understanding how a process works. The process flow defines a sequence of operations that reveals the dependency of subsequent operations on the completion
of previous operations. The type and nature of these dependencies are important to understanding and improving the process. The process operations are units of work that move the process closer to completion. Operations need certain resources, create resources for subsequent operations, and produce byproducts. They describe how the process achieves its goal and what it needs to do so. Process resources are the things that go into making a product. Some resources do the work of the process while others are used or produced by the process. Some resources are consumed while others are shared. Some are produced by one operation just to be used by another. Resources have costs, quality, capacity, availability, and life-cycle needs. The characteristics of resources reveal the cost of the process in time, material, and effort.

Benefits of the Process Model

One of the benefits of the process model is that it defines a context for decision-making activities. It defines what is needed to start each operation, what must be done to complete each operation, and what the decision-maker will have when the whole process is complete. A decision-making system can help maintain and verify this information, freeing the decision-maker to concentrate on completing each operation with the resources available. The decision-maker can query the system to find out what the immediate goal is, what the larger goal is, what resources are still available, and how far along in the process he or she is. Furthermore, the process model can be used to partition the decision so that the operations "provide a continual feeling of challenge, one that is neither so difficult as to create a sense of hopelessness
and frustration nor so easy as to produce boredom." (Norman, 1993, p. 35) These conditions are necessary for achieving an optimal flow experience: an enjoyable state of focused concentration on the task being performed. (Csikszentmihalyi, 1990, p. 42) Flow can reduce the time needed to make a decision and ensure that each part of the decision gets the attention it needs.

Given that "people are not good at keeping to a single task for long durations," (Norman, 1993, p. 36) it should be possible to increase their productivity by letting them change tasks when their attention falters. The process model supports this ability by breaking processes into smaller self-contained operations that can be suspended and later resumed. The decision-making system could maintain a number of processes with different goals, or motivations, as well as track operations that need specific types of resources at different degrees of readiness. The decision-maker would then be able to choose the process and operation whose goal and resource requirements best fit the decision-maker's current state of mind.

Closely related groups of decision-making activities are often combined into a single operation of a more abstract process. This "higher-level" process is more removed from the actions a person would take to complete it and may therefore be somewhat harder to grasp initially. Decision-making systems using the process model can "explode" operations into their component parts when requested, helping the decision-maker to understand the operation as the sum of its parts. Combining activities into a single operation also has two other benefits. First, it can enhance
overall comprehension of the decision by reducing the number of independent
elements the decision-maker must deal with at a time. The decision-maker can see the
process flow and how each operation contributes to the completion of the whole
process. The second benefit is incidental. By replacing a group of activities with a
representation of those activities, the decision-maker’s attention is directed away from
the specific method of performing the operation. This opens the door to replacing the
group of activities with an alternative. Decision-making systems can assist the
decision-maker in defining alternative process flows, identifying operation
interdependencies, and defining the costs of the operations and resources used. From
yet another perspective, operations—having removed their ties to any specific
implementation—may prove useful in designing other decision-making processes.

Formal Versus Informal Decision-Making Processes

In a given day, a person may make hundreds of decisions ranging from what
to have for breakfast to what his or her company's strategy will be for gaining market
share. The vast majority of these decisions will be made using informal processes or
heuristics. Informal processes can be managed almost entirely "in the head." They can
be used almost without thinking about them. There is little attempt to identify the
parts of the process or determine their effectiveness. Because they are used often,
informal processes are readily available in memory and ideally suited for making
quick decisions in common situations. Informal processes can be used when the
consequences of a poor decision are minor and the effects are short-term. In contrast,
formal processes usually cannot be managed in the head. The decision-maker often has to pay more attention to the process itself. Formal processes are used less often and are more difficult to recall from memory. Fortunately, they can be written down or even automated. Formal processes usually apply to complex decisions and are identified by the characteristics of those decisions. Formal processes should be used when the consequences of a poor decision are great and the effects are long-term. The process model of decision-making applies best to decisions that benefit from formal decision-making processes.

The advantage of a formal process is that it can be designed to expand on human abilities while minimizing the effects of human biases on decisions. A formal process can distribute functionality across operations and externally maintain more information than can be effectively handled by the unaided mind. Its operations can be defined to focus decision-making resources on a part of the decision while ensuring that the essential parts of the process are completed in the proper order. In addition, the exercise of defining the parts of a process reveals many opportunities for improving its results. Flows can result in queues or delays that not only affect the time taken to finish a process, but also affect the state and quality of the decision-making resources being used. Operations can be improved by reducing their resource requirements and side-effects while improving the quality of the resources they produced. Finally, a formal process can improve decision-making by making better use of decision-making resources in two different ways. One way is through the better
management of the resources to ensure their quality, availability, and that they are used in the most effective way. The other way is to use lower-cost, higher-quality, higher-capacity resources that have greater availability. Decision-making systems that use the process model can help decision-makers improve their decisions by taking advantage of the many benefits offered by formal decision-making processes.

Understanding a Decision-Making Process

Many of the ideas expressed in this research are based on an analysis of a decision-making process called—appropriately enough, the Decision Process. The Decision Process was developed, over many years, as a generic process for improving the quality of decisions. It was not created using Decision Theory or a scientific analysis of human cognitive abilities. It was developed from experience with processes that work and from reflection on where errors frequently occur. Another process, the Engineering Design Process (Tompkins and White, 1984, p. 9) is very similar. The Decision Process consists of the following seven steps:

1. Identify the problem.
2. Specify objectives and the decision criteria for choosing a solution.
3. Develop alternatives.
4. Analyze and compare alternatives.
5. Select the best alternative.
6. Implement the chosen alternative.
7. Monitor the results to ensure that desired results are achieved.
(Stevenson, 1990, p.42)

The Decision Process will be used below to identify the parts of a decision and to provide insight into how formal processes can be used to improve decisions.
The steps of this process are equivalent to the operations of the process model, so the process model will be used to explain how the Decision Process works. The structure provided by the process model will help define the operations of the Decision Process, identify the objectives of each operation, the resources needed, and the interaction between the operations.

Before the first step of the decision-making process can occur, the problem must first be perceived. This point is important because some problems are more readily perceived than others, and some mask deeper, more subtle problems. The perception of a problem is affected by a person's knowledge, state-of-mind, and inherent sensitivity to events as opposed to gradual changes in the environment. Perhaps recognizing the limits of human perception, many people follow routines to bring out problems that would otherwise go unnoticed. These routines typically check the state of things against external measures such as market position, milestones, or goal images. Other techniques for improving perception include getting views from different people or setting the problem aside to return to it with a fresh or different perspective. Thus, the true first step to making a decision may be to establish routines that help reveal when a problem exists.

The first step of the Decision Process is to identify the problem. To complete this step, the decision-maker gathers the resources needed, then transforms those resource into the step's output and verifies the result. The resources needed include
information about the problem and a set of techniques for problem identification. The output or goal of this step is a definition of what the problem is.

Once the parts of the first step are defined, the methods used to improve processes can be applied. For instance, checks can be put in to ensure the quality of the information used and the definition produced. One check for a good problem definition is given by McConnell (1993, p. 27):

A problem definition defines what a problem is without any reference to possible solutions. It's a simple statement, maybe one or two pages, and it should sound like a problem. The statement "We can't keep up with the orders for the Gigatron" sounds like a problem and is a good problem definition. The statement "We need to optimize our automated data-entry system to keep up with orders for the Gigatron" is a poor problem definition. It doesn't sound like a problem; it sounds like a solution.

This statement also points out that when people perceive a problem, they have a tendency to define it in terms of a preferred solution. Some reflection will show how this affects the decision outcome by prematurely eliminating potentially better alternatives. A related problem is plugging in, or "Beginning to gather information and reach conclusions without first taking a few minutes to think about the crux of the issue you're facing or to think through how you believe decisions like this one should be made."(Russo and Schoemaker, 1989, p. 4) The use of a formal decision-making process, which focuses attention on the steps required, helps prevent these problems from occurring. It is also worth noting that traditional decision-making systems would have difficulty dealing with these human tendencies. They might be able to point out
the lack of alternatives considered or the biases in numerical evaluation, but not the fact that the problem was defined wrong in the first place.

The second step of the Decision Process is to specify the objectives and decision criteria for choosing a solution. During this step the decision-maker must transform the problem definition into one or more objectives and define the criteria that will be used to measure how well the objectives are met. The output of this step is a set of objectives and criteria that will guide the next few steps of the Decision Process.

One advantage of defining objectives and criteria is that it helps avoid a problem with hindsight:

To some small extent, we may actually understand a situation better when we think about it in hindsight.... But in general, the clarity of hindsight is an illusion. And it often hampers learning from experience. Like claiming credit falsely for successes and rationalizing mistakes, the false clarity of hindsight creates the illusion that there is no lesson to be learned. (Russo and Schoemaker, 1989, p.183)

Russo and Schoemaker explain that the problems associated with hindsight result from the way people originally edit events and then reconstruct them later on. New knowledge builds on top of existing knowledge so that is impossible for people to "see" the problem as it originally presented itself. Defining objectives and criteria up front ensures that the success of the decision-making process can be determined objectively. This is necessary if the process is to be improved.

The second step is also a good example of a formal process's ability to anticipate future needs and distribute functionality across operations. The objectives
and criteria defined here are used to guide the search for alternatives in the next step, evaluate and select alternatives in the two steps after that, and finally verify the success of the decision-making process in the final step. All of this occurs without the decision-maker having to pay attention to it. Informal processes, in contrast, have difficulty looking ahead. They tend to be self-contained, unable to see future consequences or to change from uncertain feedback.

The next three steps to the Decision Process generate, analyze, and select among alternatives that meet the defined objectives. These steps tend to overlap and could be defined as one step, “find a solution to the problem.” One reason they are performed separately is so that more decision-making resources are available for working on smaller parts of the problem. In addition, each of these steps needs specialized resources and may benefit from changing the set resource used before the next step. This way each step need only be concerned with the resources it needs. There may also be cases where the decision-maker combines only the generate and analysis steps for each alternative. Many problem solving techniques recommend against analysis until all the alternatives are generated. One reason for this is that the thoughts invoked by the previous step, “defining the problem,” are still fresh in mind and can help in coming up with alternatives. That is, by performing the steps in the order defined by the Decision Process, the decision-maker is able to take advantage of the state of resources after each step. Another reason is that the effort to analyze an alternative may bias or deplete resources used to generate other alternatives. As a
result, a potentially better alternative to solving the problem may be missed and effort may be wasted on analyzing a less promising alternative. In summary, the operations of a decision-making process can be designed to focus resources and take advantage of the state of the resources used in previous operations. These benefits arise from applying the techniques of process analysis to decision-making.

The final two steps of the Decision Process are to implement the chosen alternative and monitor the results. These steps get results and compare them against the original criteria to see how well the decision-making process worked. They are necessary for learning from the solution so that the process can be change to improve the results the next time it is used.

Defining a Model of the Decision-Making Process

The Decision Process identifies the parts and relationships that define the structure for a model of decision-making behavior. It does not, however, identify the attributes that ultimately affect the behavior of this model. After reviewing the parts and relationships of decision-making processes, this section turns to a summary of research on decision-making biases to identify the decision attributes.

The Parts of a Decision and Their Relationships

The basic parts of a decision include a problem definition, objectives, criteria, problem description, alternatives, factors, and outcomes. The problem definition sets the stage for the rest of the decision by concisely defining an undesirable situation. It
provides a context and focus for identifying the decision objectives and criteria. The
decision objectives are desirable situations that reduce or eliminate the defined
problem. They are defined in terms of decision criteria that measure the outcomes of
various alternatives. The problem description fills in all the background information
about the problem. It identifies the factors leading to the problem and helps to
generate alternatives for solving the problem. Decision alternatives are mutually
exclusive solutions to the problem. Each alternative is a set of actions that links
factors to outcomes. Decision factors are simply inputs to the problem that have a
significant affect on outcomes. Other inputs may be described in the problem but do
not significantly affect the outcome as measured by the criteria. Outcomes are the
expected results of performing alternatives. Each outcome varies in its ability to meet
the defined criteria.

In addition to the basic parts of a decision, there are the relationships that tie
these parts together. There is a factor-outcome relationship that describes the affect of
changes to factors on the outcomes of a given alternative. Each alternative is defined
by sets of these relationships. The other relationship is the outcome-criteria
relationship. This relationship defines the criteria addressed by a particular outcome.
The ability of the outcome to address a set of criteria is dependent on the alternative
used to generate the outcome.

The basic decision elements and their relationships define the structure for a
model of decision-making behavior. Synergistic Decision-Making Systems can use
this structure to help the decision-maker define and manage the decision-making process. The structure also defines the links that tie factors to outcomes and outcomes to decision-making criteria. Decision-making systems can use these links to help the decision-maker compare and evaluate the effectiveness of various alternatives.

The Attributes of a Decision

The attributes of a decision are the different types of values that can be assigned to the parts and relationships of a decision. Decision attributes ultimately determine the decision results, and they can be used to check how well the process is being carried out. One way of discovering what the decision attributes are is to think of each decision element and ask what can be said about it that will affect the outcome. Another way is to analyze the results of research on decision-making biases. Sanders and McCormick (1993, p. 68) provide a summary on the effect of biases on decision-making. This summary includes a short list of biases that will be referred to below. Both these approaches will be combined to compile a partial list of attributes for the parts and relationships of a decision.

Decision-makers are limited in the number of topics they can pursue at one time. As a result, some information will be considered earlier in the process and some will be considered later. Decision-makers often place “more weight on earlier information than on subsequent information.”, Sanders and McCormick, 1993, p. 68) This contrasts with Russo and Schoemaker (1989, p. 85) who state that decision-
makers place more weight on recent information than on earlier information. In either case, the time of review or analysis is one attribute that can affect a decision's outcome.

Two other attributes are the depth and breadth of search. Decision-makers are limited in how long or how far they will explore a particular resource. They tend not to "extract as much information from sources as they optimally should" (Sanders and McCormick, 1993, p. 68). The depth of search refers to the amount of information extracted from a particular resource. It is the compliment of the breadth of search, which refers to the number of resources used. Decision-makers often limit their search to preferred or more available resources.

The breadth and depth of search are similar to the breadth and depth of comparison. The breadth of comparison refers to the number of alternatives considered. Decision-makers may limit their comparison to preferred alternatives or alternatives that are more readily available to memory. One factor contributing to this problem is that decision-makers "have a limited ability to entertain a maximum of more than a few (three or four) hypotheses at a time." (Sanders and McCormick, 1993, p. 68) The depth of comparison refers to the number of attributes (i.e. desirable features) by which alternatives are compared. Research in decision-making has shown that decision-makers tend to "focus on only a few critical attributes when choosing between alternatives". (Sanders and McCormick, 1993, p.68)
Other attributes that stand out from the list in Sanders and McCormick (1993, p. 68) include preference, competence, reliability, certainty, and importance. Preferences refer to the decision-maker’s feelings for or against specific decision elements. Preferences affect what decision elements are considered and how the values of attributes are weighed. Competence refers to the decision-maker’s experience or aptitude in an area of decision-making. It is a measure of the decision-maker’s ability to estimate the values of other decision attributes. Reliability refers to a factor’s ability to behave as expected or to be measured accurately. Unreliable factors increases the chances of a bad decision and should be eliminated by choosing alternatives that are not affected by them. Certainty reflects the likelihood that a factor will affect an outcome. An uncertain affect can result in bad decisions and should be eliminated if possible. Importance refers to how great an effect a factor has on the outcome. Unreliable factors with uncertain effects on the outcomes can be used in a decision if their effects are unimportant.

The identification of the decision attributes completes a model of decision-making behaviors. Synergistic Decision-Making Systems can use this model to help the decision-maker define and maintain the decision-making process, compare and evaluate decision alternatives, and review the decision-making process for improvements.

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Chapter Summary

Research in decision theory frequently mentions the decision-making process but seldom considers what this means. This chapter took decision-making as a process literally and demonstrated that a process can be used as a model for understanding and improving decision-making behavior. The decision-maker can break a complex decision into a series of focused operations that use known resources to solve a well defined problem. This chapter also used the process model to analyze the Decision Process, which was then used to build a model of decision-making behavior. The model of decision-making behavior will enable Synergistic Decision-Making Systems to assist the decision-maker in defining and managing the decision-making process.
CHAPTER III

DEFINING A MODEL OF DECISION-MAKING RESOURCES

To create better decision-making processes and build decision-making systems that work more synergistically with human decision-makers, it is helpful to have a model of the human resources involved. This model will provide a better understanding of the effective use of human resources and of the resource characteristics that can lead to non-optimal decisions. It will also provide a framework around which decision-making systems can be built. The main objective for the model of human decision-making resources will be to show how knowledge can be represented externally so that the decision-making system can help the decision-maker capture, analyze, and apply his or her knowledge. The model should also explain how the parts of a decision are evaluated.

The Functional Division of the Brain

The search for an appropriate model of decision-making resources began with a cursory review of the current techniques used to represent knowledge and of the models of decision knowledge used by existing decision-making systems. The search ended with an analysis of research in neurobiology which provided an understanding of how knowledge might form and behave within human memory. The resulting
model divides the human brain into three broadly defined systems: associative memory, working memory, and emotional memory. It places high-level knowledge and perceptions in associative memory, and feelings and instinctual behavior under emotional memory. The model views working memory as the "master controller" that listens to and directs the two other memory systems. Working memory includes a type of short-term memory for remembering recent events and maintaining contexts, and a long-term memory for knowledge about procedures that have been effective in manipulating associative memory to achieve the goals set by emotional memory.

It is important to understand that this model does not view memory as a "box" where information is stored and retrieved by some external agent. The model views memory as three interacting systems that respond to external and internal events; invoke perceptions, behaviors, and feelings; and generate events of their own. The three memory systems are composed of billions of functionally similar neurons that respond to selected input events and if the inputs exceed a threshold, generate an output event. What makes each system unique is the organization and characteristics of the neurons contained within.

Of the three memory systems proposed, only associative memory is modeled in this thesis. One reason for this is that this thesis is primarily concerned with the organization and behavior of high-level knowledge. The other reason is that too little is known about working and emotional memory to come up with credible models for their behavior. However, the model of associative memory does interact with these
other systems and the nature of this interaction is discussed. This interaction will provide important clues into how the other systems might work.

The theory upon which the model of associative memory is based is not tested in this thesis. Its validity will be based on its ability to explain observations from research in decision-making and cognitive science, and on the effectiveness of decision-making systems that are based on the model's design. The neurobiological and anatomical foundations for the model are described in Appendix A. This chapter provides a description of the model and the model characteristics that can affect decision-making. It begins by describing the structure and behavior of knowledge, continues with a description of neural behavior, and concludes with information on the overall behavior of associative memory as a separate system within the brain.

The Structure of Knowledge

The main objective of the model of associative memory is to provide a way of representing knowledge externally so that decision-making systems can help decision-makers capture, analyze, and apply their knowledge to decisions. The structure for this knowledge representation was created by mapping the basic relationships found in many "pen-and-paper" representations over neurological foundations. The result is a dynamic form of knowledge representation that involves momentary events bound together across time.

The model of associative memory defines knowledge as a structure composed of representations and relationships. Representations stand for perceived things that
come into existence for a brief moment in time and then quickly fade away if not continuously stimulated. They correspond to the events generated by memory systems. Relationships, on the other hand, are concerned with how representations are bound together. The model defines three different types of relationships: combinations, connections, and collections. The combination relationship generates an event when a specific set of events occurs close together in time. It creates a new representation by combining representations that frequently occur together. Anytime a group of things is perceived as a whole, a combination is involved. The connection relationship ties two representations together so that when one representation occurs the other is invoked a moment later. If the connection goes only from one representation to the other, it is called a link. If is goes either way, it is called an association. Connections help direct attention from one representation to a another. The third relationship, a collection, creates a context or precondition in which representations exist. The collection must be active for the representations within it to occur. Things within a collection are perceived as individual entities that are part of a whole. Figure 1 provides an example of the three different types of relationships.

In summary, the model of associative memory represents knowledge as a structure composed representations bound together by three different types of relationships: combinations, connections, and collections. The representations correspond to events generated by memory and the relationships bind these events together across time.
Combinations
Four separate representations combine to create a "face" representation.

Connections
Links and associations direct attention from one representation to another.

Collections
Three separate representations are related by their containment in a fourth representation.

Figure 1. The Three Basic Knowledge Relationships.

The Model of Associative Memory

The human nervous system, including the brain, has over 100 billion nerve cells, called neurons (Stevens, 1985). Some of these neurons generate events in response to external stimuli or changing conditions in the body. Some release neurohormones that cause muscles to contract or regulate various systems in the body. The remaining neurons--a vast majority, send events to and receive events from other neurons. Many of these neurons provide the basis for knowledge--their events correspond to representations and their interconnections define relationships. These neurons will be collectively referred to as associative memory. The model of associative memory includes two broad types of neurons along with the general organization of neurons within and between various regions of the brain. The behavior and organization of these neurons provides insight on the behavior of associative memory and how it affects decision-making.
The Neural Foundations for Knowledge

To explain how the behavior of individual neurons can affect decision-making, it is first necessary to show how systems of neurons store the knowledge used for decisions. This will be done by presenting a theory on how combinations, connections, and collections are formed using neural connections and of which neural events correspond to representations.

There are two general types of neurons packed into separate but adjacent layers of associative memory. The neurons in the first of these layers combine events coming from other regions of memory and—after a short delay—pass the results to neurons in the second layer. These first layer neurons learn to combine events that repeatedly occur at the same time or very close together in sequence. They respond to just one set of events and require most of their events to generate an output. The neurons in the second layer receive events from the first layer neurons as well as from other regions of memory. These second layer neurons initially learn to generate an event in response to one or more similar events from the first layer neurons. Later on, if an event from another region of memory repeatedly arrives just before a second layer neuron generates its event, the second layer neuron learns to generate its event in response to the new incoming event. Second layer neurons generate an event in response to the combined events of first layer neurons or the single events coming from other regions of memory. The event generated by a second layer neuron then goes out to other regions of memory.
The two general types of neurons work together to form the three types of relationships needed for storing knowledge. The first type forms new combinations and passes them on to the second type which forms connections with neurons from other regions of memory. The output of the second type of neuron corresponds to a representation. This output leaves the region of associative memory to form connections with other representations in memory. This explains combinations and connections but not collections. Collections from when an event entering the first layer of neurons spreads out to provide a single input to many neurons. If this event is active while other events arrive, some of the neurons receiving the event will learn to combine the incoming events but only when the first event is already active. In effect, the first event enables other event combinations to occur. This forms the basis of collections. Thus, the three types of knowledge relationships: combinations, connections, and collections can be explained in the way neural connections form within and between various regions of associative memory.

This completes the theory of how knowledge is mapped directly to neurons and their interconnections. In essence, the theory suggests that the occurrence of a representation can result from a single neuron firing and that relationships arise from the direct connections between neurons. This theory will provide a way of explaining how the characteristics of individual neurons affect the behavior of associative memory.
Neural Characteristics and the Behavior of Associative Memory

Now that the neural foundations for knowledge have been set, it is possible to understand how the characteristics of individual neurons can affect the behavior of associative memory. Most of these characteristics will be introduced by describing the learning process. It will be shown that some characteristics of learning continue to affect the behavior of associative memory long after the learning has occurred. The remaining characteristics will be introduced by explaining how they affect the response of neurons to inputs. This explanation will shown that the neural response varies with increasing or continuous levels of input, and with the frequency of activation. The description of neural characteristics provided below will eventually be used as a guide for designing better decision-making processes and systems.

The Learning Characteristics of Neurons

The learning process creates new knowledge by building new relationships between existing representations. These new relationships form when existing neural connections are strengthened by events that repeatedly occur close together in time. The strengthening of connections is the result of neurobiological processes that affect the characteristics of neurons and add their own characteristics to the behavior of neurons. Together, these learning characteristics help determine the behavior of associative memory which ultimately affects decision-making.
The learning process begins when an event generated by one neuron arrives at a weak connection with another neuron. This event raises the activity level of the receiving neuron and creates a short-term increase in the connection strength between the two. The higher the activity level of the receiving neuron after the event arrives and the stronger the existing connection strength is, the more the connection strength is increased. The activity level of the receiving neuron depends, in turn, on the strength of the existing connections to the neuron, the number of other events arriving at the neuron, and the intensity of each event arriving. When the activity level exceeds the neuron's activation threshold, the neuron generates an event, or fires. The intensity, and to some extent the duration, of the generated event increases with the difference between the neuron's activity level and its activation threshold. The initial activation threshold and structure of most neurons are such that two or more events are needed to cause the neuron to fire. Thus, two or more simultaneous events are needed to initiate the learning process.

The initial short-term strength increases decay over a period of time ranging from minutes to weeks. However, once the neuron starts to fire, it begins reinforcing the events that caused it to fire by creating more persistent increases in the strength of the corresponding connections. At the same time, the events that are not active when a neuron fires slowly lose their connection strength. The neuron's firing also raises its activation threshold somewhat, which compensates for the stronger incoming events. This higher threshold also makes it harder for weakly connected events to fire the
neuron out of sequence with strongly connected events. In effect, once a neuron starts
to learn one set of events it stops learning others. The final connection strengths and
activation threshold become stabilized when the event generated by the neuron
strengthens its connections to other neurons. It is through these outgoing connections
that the neuron's event gets its meaning. This completes the learning process for the
first type of neuron.

The second type of neuron can continue learning new events provided the
events repeatedly occur along with other events that already cause the neuron to fire.
This happens because the second type of neuron continues to reinforce connections
that were active just before it fired. Eventually, the weak connections are strengthened
enough so that an event arriving at them can cause the neuron to fire. In fact, the
structure and activation threshold of this second type of neuron is such that a single
strongly connected event is enough to cause the neuron to fire. This strongly
connected event can invoke the representation in the absence of the combined events
that originally created it.

The learning process identifies a number of characteristics that affect the
behavior of associative memory. These characteristics include the number and
strength of connections to a neuron, the neuron's activation threshold, the intensity
and duration of received events, and the time interval over which short-term strength
increases decay. All of these characteristics affect the intensity of events generated
by neurons and associative memory, and--according to the model of associative
memory--more intense events receive more attention and invoke stronger emotional values.

The intensity of a generated event increases as the neuron's activity level exceeds its activation threshold. In the medium to long-term, the neuron raises its activation threshold to compensate somewhat for higher than average activity levels. However, any short-term increases in connection strengths or the number of incoming events will cause the neuron to fire above its average intensity. This has two effects on the behavior of associative memory. First, it means that recent events—which initiate short-term connection strength increases—can affect the attention and emotional value given to subsequent events. Second, it means that variations in the number of active incoming events can also affect attention and value. Similar results occur when the events arriving at the neuron have a larger than average intensity. In fact, this later effect could be used by working memory to raise the events generated by associative memory to the conscious level. The event intensity generated by a neuron can also be decreased by changes induced by learning. In the medium term, frequent activation may cause a neuron to raise its "steady-state" activation threshold so that it becomes increasingly difficult to fire the neuron. This decreases the generated event intensity which reduces the attention and emotional value given to its representation. In short, the characteristics of neurons that are affected by learning can increase or decrease the intensity of events generated by associative memory.
Other Characteristics of Neurons

Some neural characteristics are not directly related to the learning process but relate, instead, to the physical and biological makeup of neurons. These characteristics affect how the neural response changes with increasing or continuous levels of input, and with frequent activation. They affect the intensity and duration of events generated by associative memory and ultimately the attention and emotional value given to representations.

One important characteristic of a neuron is how it responds to increasing levels of input. This response is a function of the difference between the neuron's activity level and its activation threshold. The neuron's activity level, in turn, depends on the accumulation of ions in the neuron's cell body. This ion accumulation gradually reaches a saturation point such that proportional increases in input tend to produce decreasing gains in output. The result is a neural response curve where proportional increases in input weigh increasingly less in output intensity. This translates to decreasing gains in attention or the emotional values associated with representations.

There are also neural characteristics that decrease event intensity. The biological processes that strengthen connections, release ions into a neuron at connections, and propagate an event to other neurons; all require certain resources that can be depleted with repeated or continuous use. Some of these resources may be depleted rapidly, requiring a moment of rest to restore them. It may be difficult, for
example, to fire a neuron that has just fired or to strengthen connections through repetition without taking a break once in a while. Other resources may take much more time for depletion. For example, once fired many neurons can continue firing for some time but their event intensity will decrease over time. An initially intense event will eventually lose the attention it gets to a more recent event.

The physical, biological, and learning characteristics of neurons can increase or decrease the intensity of generated events. This behavior, in turn, affects the attention and emotional values given to representations. The knowledge of how these characteristics affect associative memory will be used to design more effective decision-making processes and systems by maximizing or minimizing their effects to support the decision-maker.

The Role of Working and Emotional Memory

Associative memory can perform most of its functions without interacting with working or emotional memory. Its main limitation is that it can only process events that occur close together in time. That is, associative memory has little facility for recalling, holding, or synchronizing events that were once distributed in time. It also has little control over attention, choosing priorities, and evaluating representations. These tasks require the involvement of working and emotional memory. The different roles of associative and working memory are described by Goldman-Rakic (1992, p. 111):
According to present thinking, a form of memory known as associative memory acquires facts and figures and holds them in long-term storage. That knowledge is of no use, however, unless it can be accessed and brought to mind in order to influence current behavior.

Working memory compliments associative memory by providing for short-term activation and storage of symbolic information, as well as by permitting the manipulation of that information.

This thesis does not attempt to create a model for working or emotional memory. However, it does try to model the interaction of the three memory systems. Knowledge of this interaction will define how decision-makers can interact with decision-making systems designed around the model of associative memory. This interaction includes invoking representations and keeping them active, holding on to or remembering recently occurring representations, moving attention from one representation to a related representation, and evaluating the emotional value associated with a representation.

Goldman-Rakic (1992) associates two structures of the brain, the hippocampus and prefrontal cortex, with working memory. She refers to some of the ways in which these structures interact with associative memory in the following:

My co-workers and I think that the primary role of the hippocampus is to consolidate new associations, whereas the prefrontal cortex is necessary for retrieving the products of such associative learning (facts, events, rules) from long-term storage elsewhere in the brain for use in the task at hand. (Goldman-Rakic, 1992, p. 114)

Consolidating new associations and retrieving the products of associative learning requires a way of invoking the representations contained in associative memory. Goldman-Rakic (1992) observed this ability in the neurons of the prefrontal
cortex. Therefore, the interface between working and associative memory includes a way of invoking the representations within associative memory.

Another function provided by the interface between working and associative memory is a way of directing attention between related representations. Before describing a model of how this might occur, it is important to clarify how the term "attention" will be used. Attention is a characteristic of human thought that is strongly associated with a sense of Self. After all, what a person pays attention to has a lot to do with how well that person, or Self, does. However, experiments such as those involving binocular rivalry show that some forms of attention have very cellular origins (Crick and Koch, 1992). They are not necessarily directed by a Self. The term attention as it is used below simply refers to some mechanism by which a system selects one thing to focus on out of all the competing alternatives.

The model of associative memory assumes that working memory has some mechanism for controlling attention that selects one representation out of the active pool of representations generated by associative memory. It proposes that representations whose corresponding events are firing more intensely, or whose firing invokes stronger emotions, tend to get attention more readily and for longer periods of time than other representations. Intense events get attention by exceeding working memory's attention threshold. Working memory uses this effect to stimulate a selected representation, raising the connected representations above competing alternatives. Working memory can also stimulate whole areas of memory to increase
awareness of any events in those areas. In the case of emotions affecting attention, the strength of an emotion is an indication of its significance to the person "feeling" the emotion. More attention will be spent on representations that invoke strong emotions since the person is likely to spend more time trying to resolve or remember them. Note, however, that the events invoking the emotions may not be intense enough to exceed working memory's attention threshold. Thus, while intense events enter awareness immediately, events invoking strong emotions may not enter awareness at all.

The attention mechanism used by working memory invokes a selected representation to keep it active. While working memory's attention is focused on the representation, the pool of active representations changes--dropping off some representations while keeping or adding representations that are connected to the selected representation. Working memory can then navigate patterns of connections by moving attention from the selected representation to another representation in the pool. Moving from one representation to another in this manner is referred to as a horizontal transition in attention. Working memory can also hold a collection of neurons active while moving its attention to a representation within the collection. This is called a vertical transition. It involves moving attention from a collection to a member of the collection. Using horizontal and vertical transitions, working memory can direct its attention to follow the patterns of knowledge stored in associative memory. Decision-making systems that are based on the model of associative
memory will provide similar methods for navigating the knowledge maintained by these systems.

The last function of interest provided by working memory is a way of valuing the representations in associative memory. This can be done by measuring or comparing the emotional values associated with the representations. The types of emotional values can range from basic emotions such as pain and pleasure to more abstract combinations such as worth and significance. Their values become associated with representations through the connections that form between associative and emotional memory. The model of associative memory assumes that working memory senses the sum of emotions associated with all active representations and can weigh the emotions associated with a particular representation by focusing attention on that representation until the other representations fade away. Emotional values are just another type of representation and are subject to the same factors that affect the intensity of events (or representations) in associative memory. Decision-making systems must take these factors into account when helping decision-makers evaluate and choose between alternate representations.

Chapter Summary

The model of associative memory describes how the characteristics and behaviors of human memory can affect the use and evaluation of decision knowledge. It argues that decision knowledge is composed of representations and three kinds of relationships: combinations, connections, and collections; and suggests that the
occurrence of representations corresponds to the firing of individual neurons. The model identifies several factors that can affect decision-making, mostly by affecting the firing intensity of neurons. These factors include the interval between activation, recency of activation, frequency of use, number of active inputs, and the saturation effect. In addition, the model shows that associative memory is event based and depends on events occurring close together in time. Finally, the interface between associative, working, and emotional memory was described. This interface provides the mechanisms for attention and the evaluation of representations—both playing significant roles in decision-making. With the model of associative memory done, it is possible to build decision-making systems that capture decision knowledge externally and help the decision-maker work with it. This possibility will be explored in Chapter V, "Using Patterns to Analyze the Decision Space." The model also explains the characteristics of human memory that can lead to decision-making errors. These errors will be explored in more detail in the next chapter.
CHAPTER IV

THE EFFECTS OF HUMAN RESOURCES ON DECISION-MAKING

One way to make decision-making processes and systems better is to minimize the harmful effects of, or eliminate, factors leading to non-optimal decisions. This chapter describes some of the human factors that can lead to non-optimal decisions. It is organized into three sections that describe evaluation, attention, and knowledge biases. Each section includes insights from the model of associative memory and discusses biases revealed by research in decision-making. The research discussed expands on the insights given by the model and extends the discussion into areas not covered by the model. The objective of this chapter is to develop a general feel for the effects of human resources on decision-making.

Classes of Decision-Making Biases

Much of the emphasis in decision-making research is placed on identifying decision-making biases. Decision-making biases emerge as tendencies toward or against specific decision elements, or as anomalies in the evaluation of alternatives. They are a sign of the affects of human resource characteristics on decision-making. Researchers have many ways of classifying decision-making biases: ranging from naming specific biases such as the Anchoring Bias (Kahneman, 1992) to more general
classes of biases such as Input, Output, and Operational Biases (Haley and Stumpf, 1989). This thesis introduces a new classification that emphasizes the different ways in which human resource characteristics affect decision-making. The new classification consists of Evaluation, Attention, and Knowledge Biases. Evaluation biases are defined as decision-making biases caused by human resource characteristics that affect the values assigned to things. Attention biases, in contrast, result from human resource characteristics that affect the attention given to a thing or its attributes. The final class, Knowledge biases, covers decision-making biases caused by the structure or limits of a decision-maker's knowledge.

The Effects of Evaluation Biases on Decision-Making

Decision-makers use an evaluation process to estimate and compare the value of things. This process may include operations to (a) assign values to things along one or more dimensions, (b) aggregate the values for different dimensions, (c) compare alternatives along a given dimension, and (d) select the dimensions for evaluation. When human resource characteristics affect these operations or their results, they lead to evaluation biases. Evaluation Biases lead to non-optimal decisions by affecting the values assigned to things.

Insights on Evaluation Biases From the Model of Associative Memory

According to the model of associative memory, a decision-maker assigns a value to a thing by forming a connection between its representation and a
representation in emotional memory. Once this connection is made, the decision-maker can "feel" the thing's assigned value by simply invoking its representation. The main function of the evaluation process is to make this connection by invoking the representation for a thing just as the emotional representation occurs. The emotional representation can be made to occur by invoking other representations that are connected to it. Therefore, the value assigned to a thing comes to be defined in terms of values originally assigned to other things. Evaluation Biases occur when the characteristics of associative memory affect either the assignment or invocation of these values.

Characteristics that affect the response of neurons to incoming events often lead to Evaluation Biases by affecting the magnitude of values assigned to representations. The strength and number of connections received by the neuron and the neuron's current activation threshold are all characteristics that affect its response. The more events arriving at the neuron and the stronger their connections are, the larger the invoked value will be. For example, the more arguments made that support a particular conclusion and the stronger those arguments are, the stronger the value associated with the conclusion. Unfortunately, the decision-maker may not invoke all of the relevant representations at the time of evaluation and may have stronger connections with some representations. Evaluation Biases will then occur because the magnitude of the assigned value does not reflect all the relevant information with equal representation. Another factor affecting the response of neurons is that the
neurons gradually reach a saturation point such that proportional increases in their input result in decreasing gains in their output intensity. Thus, proportional increases in gains or losses are weighed increasingly less in an evaluation. The decision-maker will ignore small gains or losses in an “all-or-nothing” decision that he or she would not ignore if the gains or losses were distributed across a number of decisions.

Evaluation biases can also be caused by variations in the weights assigned to the evaluation criteria. Evaluation criteria have representations with assigned values that affect the evaluation of other representations. For example, the decision-maker may use perceived product quality as a criterion for evaluating the alternatives in a decision. He or she will associate a certain value with the representation for quality that affects how values assigned the alternatives when quality is considered. The larger the value associated with quality, the more weight assigned to alternatives that meet this criterion. This can lead to non-optimal decisions when the decision-maker has a bias toward a one criterion over others. Alternatives that emphasize the preferred criterion will be valued more than other. Variations in assigned weights lead to more subtle problems when the evaluations use opposing criteria that should be weighed the same but are not. Decision-making research discussed in the next section describes the problems that occur when losses are weighed more heavily than gains.

The evaluation process is also susceptible to the effects of short-term variations in connection strengths. Every time a representation is invoked just prior to a value, the connection between the two is strengthened. The strength of the
connection is affected by the intensity and repetition of this representation-value correlation. Therefore, a decision-maker that repeatedly evaluates some representations of a decision more often than others is likely to assign those representations higher weights. The decay of the short-term component of the connection strength contributes to this effect: representations that are not regularly visited lose their decision weight. The result is that the magnitude of values assigned to representations will depend on how frequently the representation is paired with the value. Simply invoking the representation once in a while may be enough to maintain its assigned value.

There are a number of factors that can cause Evaluation Biases while aggregating the values for each dimension of a representation. The evaluation process can either assign values to the representation as each value is determined or as a group by invoking all of the values within a short period of time. Either way, the aggregated value assigned to the representation is likely to be inaccurate for a number of reasons. First of all, it is unlikely that the combined effect would accurately account for the variations in weights associated with each dimension or for the interactions between the dimensions being considered. Second, successive contributions may contribute proportionally less to the combined value because of the saturation effect. Finally, the dimensions that are evaluated early in the evaluation process may weigh less in the decision because of the short-term decays in connection strengths.
Insights on Evaluation Biases From Research in Decision-Making

Kahneman (1992, p. 298) describes a function that summarizes results from many experiments on the value decision-makers assign to things:

(i) The value function is S-shaped, concave in the domain of gains and convex in the domain of losses; this shape favors risk aversion for gains and risk-seeking for losses. (ii) The value function is loss averse, steeper in the domain of losses than in the domain of gains.

Figure 2. A Function Showing the Bias in Weights Assigned to Gains Versus Losses.

Figure 2 shows the value-function described by Kahneman. It has gains and losses marked at one, two, and three units. The function result can be any measure upon which a decision is made such as worth, significance, or likeness. This function shows that a gain of one unit is valued less than a loss of one unit. That is, losses weigh more heavily in the decision than gains of the same magnitude. The decision-maker is said to be loss averse in this case. Using the second unit as a reference point in the domain of gains shows that a further gain of one unit weighs less than a possible loss of one unit. The decision-maker is said to be risk averse in the domain of
gains. If the second unit in the domain of losses is used as a reference point, further gains are shown to weigh more than possible losses. In this case, the decision-maker is said to be risk seeking.

The value-function can be extended to multiple dimensions by accumulating the values of separate evaluations. Kahneman (1992) provides an example that not only demonstrates this, but shows how the same dimension can be valued from different reference points at different times. His example is based on reversible figures, such as the Necker cube, that can only be seen as one thing at a time. He suggests that "although no weighted average of reversible figures is ever perceived, the proportion of time that each percept is seen provides a natural metric for the relative strength of the competing interpretations." (p. 306) If two competing interpretations result in negative and positive valuations, the process can result in mixed feelings which results in ambivalence toward the option. (Kahneman, 1992)

The value-function depicts evaluation biases that occur when assigning values to things. There are several other biases that originate in other operations of the evaluation process. One of the best known biases involves the use of norms. Norms are ad hoc representations constructed from memory that are considered normal or acceptable for the things they represent. (Kahneman, 1992) They are used for evaluating the normality or fairness of an option presented to the decision-maker. An evaluation bias known as the anchoring bias is caused by anchoring effects that "will be explained as cases in which a stimulus or message that is clearly designated as
irrelevant and uninformative nevertheless increases the normality of a possible outcome." (Kahneman, 1992, p. 308) For example, a commercial may first introduce a product at a ridiculously high price and then reduce the price to within expectations given the potential buyer's norm for similar products. Even though the buyer is aware of this sales gimmick, he or she may still consider the purchase a better deal than if the high price had not been mentioned. The reason for this is not clear, but it is possible that just considering extreme values shifts the scale or increases the size of the scale used for valuing an alternative. The lower price may suddenly seem more affordable, for instance, on this new scale. Another possibility is that some validity is given to the higher price so that the decision-maker actually integrates some weighted value of the price with the norm raising its value.

Another evaluation bias can occur when the decision-maker makes a choice between two or more options that are compared relative to each other. Relative valuations compare pairs of options along each dimension, coding each comparison as an advantage for one alternative and a disadvantage for the other. Tversky and Simonson (1993) observed an evaluation bias they call "extremeness aversion" that results from these valuations. One effect of this bias is to cause decision-makers to choose an option with a value in the center of two extremes. Tversky and Simonson suggest that this occurs because the relative disadvantages assigned to each option outweigh its advantages. That is, the value-function weighs disadvantages more heavily than advantages. As a result, the smaller disadvantages of the center option compared
to the extremes make it the lesser of three evils. They call this effect compromise. In a second case, the third option is placed close to one of the two extremes. This had the effect of creating a bias against the extreme closest to the option. Subjects tended to go with either the middle option or the other extreme. Tversky and Simonson called this effect polarization.

The Effects of Attention Biases on Decision-Making

The model of associative memory uses attention as a means of synchronizing the resources of the brain and of selecting or emphasizing some representations over competing alternatives. Such a neurological device must exist because there is only one set of resources--eyes, arms, legs, and such--to pursue the many alternatives a decision-maker is confronted with at a given point in time. Attention is therefore bound to time and the amount of attention given to a thing refers to the amount of time that the brain's resources are allocated to it. This is usually a very short time period. Although, it varies with the intensity of the event representing the thing, the emotional value associated with the thing, and the effect of recent events on the decision-maker's state of mind. These factors affect what gets attention, how long it gets attention, and how attention is shared between alternatives. They are the source of Attention Biases.
Insights on Attention Biases From the Model of Associative Memory

The behavior of neurons in associative memory, the event processing behavior of working memory, and the short-term variations that occur in memory are the three main sources of attention biases. The behavior of neurons cause one type of bias by ignoring elements of a decision that do not change. "Neurons fire when something different happens and don't respond significantly when they are continuously stimulated." (Ornstein, 1991, p. 105) Large quick changes capture a person's attention while small gradual changes go mostly unnoticed. As a result, decision-makers fail to notice factors that change slowly over time and falsely attribute outcomes to more conspicuous events. One may wonder: if neurons respond only to events, how do people see things that are stationary in their environment? The answer is that the eyes are continuously moving. "If, by one means or another, the image on the retina is held completely stationary, it fades from consciousness after a second or two." (Crick, 1994, p. 123) Thus, the brain has evolved its own mechanism to maintain awareness of stationary objects.

The model of associative memory suggests that decision-makers give more attention to intense events. In general, this causes decision-makers to miss competing alternatives or make false correlations between events that receive more attention. The intensity of an event is affected by factors such as the clarity, number, recency, and duration.
Event clarity refers to how easy it is for a neuron to detect the event. For example, while describing neurons that detect bars of light or dark in the retinal image, Crick (1994, p. 142) writes: "For any particular neuron there is one particular orientation of the line or bar to which it fires most vigorously. If the orientation deviates from this by as little as 15 degrees, the firing rate is usually much slower." In other words, the neurons tend to fire more intensely when their inputs are less ambiguous. The end result being that the decision-maker will pay more attention to less ambiguous events, except when his or her objective is to resolve the ambiguity.

The number of events contributing to the invocation of an event can also affect the event's intensity. More contributing events generally increase intensity. If there are many active representations connected to one representation, that representation is likely to get the decision-maker’s attention. This leads to non-optimal decisions when the set of contributing representations includes or excludes representations whose absence or presence would affect the decision by changing which representations got the decision-maker’s attention.

Recent events produce short-term increases in connection strengths that can lead to Attention Biases. These increases lead to temporal sensitivity in memory recall. The recent events invoke clusters of connected knowledge—often subconsciously—that strengthen connections and increase the firing intensity of the neurons on subsequent activation. The resulting temporal sensitivity helps: (a) increase the "window of knowledge" immediately available to the decision-maker;
(b) focus attention on related knowledge; (c) draw attention to events that are more likely to be correlated (i.e. the less events are distributed in time, the less that can happen between them, the more like they are to be correlated); and (d) improve access to the most likely future events given the events that have occurred recently. Temporal sensitivity causes attention biases by improving access to knowledge that may not be relevant to the problem while inhibiting access to knowledge that may be relevant.

The final Attention Bias caused by event intensity relates to the duration or frequency with which an event occurs. Neurons tend to fire more intensely at the start of an event and decrease intensity as they continue to fire. They may also decrease their firing intensity if the event repeatedly occurs within a short period of time. Continuous or frequent firing may be said to cause wear in the neuron. Wear has the opposite effect of the other intensity factors. It makes it difficult to focus on one thing for long periods of time and causes the decision-maker to seek new activities or stimuli.

The model of associative memory also suggested that decision-makers will pay more attention to events that invoke stronger emotions. This is based on the assumption that the decision-makers are driven to resolve or avoid negative experiences, seek positive experiences, or remember emotionally charged experiences. The emotions felt may be higher-level emotions such as worth, significance, or likeness. Emotions cause biases by directing more attention to some
events than others. They tend to suffer from being associated with specific experiences and momentary events. That is, decisions based on emotions are rarely able to account for their effects on future decisions. Emotions are specific to the individual's behavioral strategies, personality traits, and current interpretation or perspective of events. As a result, emotions encourage a rather narrow view of decisions and frequently lead to errors.

Insights on Attention Biases From Research in Decision-Making

One group of errors revealed by research in decision-making is caused by a tendency to attend to more salient events. These events are more likely to be remembered or stand out over less salient events, and are consequently more likely to be connected with other events. Chapman and Chapman (1969) identified a class of decision-making errors caused by "illusory correlation," which "causes individuals to build up erroneous linkages around salient events" (Haley and Stumpf, 1989) Illusory correlation causes decision-makers to connect outcomes with the wrong causes or causes with the wrong outcomes.

Another group of errors shows a tendency to focus attention on the current problem. Kahneman and Lovallo (1993) observed that "people tend to consider decision problems one at a time, often isolating the current problem from other choices that may be pending, as well as from future opportunities to make similar decisions." Failure to recognize the consequences of the current decision or the ability to delay a decision may trade short-term savings for long-term losses.
Much of the research in decision-making seems to focus on errors caused by the decision-maker's preferences for or against certain inputs, procedures, or outcomes. Preferences are feelings about what works and what does not: what information is important, what procedures should be followed, and what outcomes are desired. Preferences show up in decision-making as a tendency to use, attend to, accept, or ignore some things more than others. Haley and Stumpf (1989) classify decision-making biases as either input, output, or operational. Their model suggests that errors occur because of preferences for certain inputs or outputs, or from biases resulting from operations. They describe input and output biases as follows:

Input biases form when decision-makers selectively rely on data, such that they give some classes of data more weight than others. Input biases activate inappropriate schemas to deal with information. Input biases are data biases that occur because of the availability or saliency of some information (p. 481)

Output biases reflect response preferences [Italics added]. Decision-makers labouring under output biases fail to evaluate data [inputs] appropriately: they supply guesses in the absence of data, or pad insufficient data. (p. 482)

Thus, response preferences result in errors by causing decision-makers to ignore inputs. Haley and Stumpf (1989) also describe how Jung's personality types, which show preferences for different styles of data and ways of making decisions, result in decision-making errors.

Many people have a preference for a positive self-image and optimism about the future. This can lead to decision-making errors by influencing their interpretation of events. Taylor and Brown describe "three main forms of pervasive optimistic bias:
(i) unrealistically positive self-evaluations, (ii) unrealistic optimism about future events and plans, and (iii) an illusion of control" (Kahneman and Lovallo, 1993, p. 27) The illusion of control is frequently mentioned in articles on decision-making. It may result from a desire to feel that one is in control of their environment. This bias causes decision-makers to overestimate their personal control over outcomes. (Schwenk, 1988) It may be accompanied by a tendency "to seek out information that supports their hypothesis while innocently ignoring disconfirming evidence." (Langer, 1983, p. 24)

Motivation can be described as a preference for a positive outcome or against a negative one. Research in decision-making has identified a number of decision-making errors that might be attributed to attention biases caused by motivation. The status quo tendency in decision-making provides some examples. "The status quo tendency refers to the inclination of decision-makers to continue with existing goals and plans beyond the point at which a neutral observer or statistical model would recommend a change in course." (Silver and Mitchell, 1992, p. 35) One reason for this is that "people feel stronger regret for bad outcomes that are the consequence of new actions than they do for similar bad consequences that result from the status quo." (Silver and Mitchell, 1992, p. 42) People may also prefer not to be personally responsible for a possible failure. Once a bad decision is made, motivational factors may lead to further mistakes that reinforce the original.

Staw's research demonstrates that within investment-decision contexts, initial negative feedback may actually cause decision makers to
increase their commitment of resources to the current plan, especially when they are responsible for the negative consequences. Decision makers discount negative feedback as a temporary aberration,...(Silver and Mitchell, 1992, p. 40)

And once a decision-maker realizes the status quo plan will not achieve its goals: "The decision maker changes the goal to fit the outcome of the current plan instead of sticking with the original goal and changing the status quo plan." (Silver and Mitchell, 1992, p. 40)

There are a number of other ways in which preferences can affect decision-making. Preferences for positive feelings lead to "positivity biases" where positive, confirming information weigh more heavily than negative, disconfirming information with respect to given alternatives. Positivity biases generally operate when little specific data exists. If new information resembles certain categories, decision-makers affected by positivity biases may assign it more importance... (Haley and Stumpf, 1985, p. 485)

Some preferences have social foundations: "Managers enact social-desirability biases when they do what they think other people want them to do, rather than what they actually feel." (p. 486) Preferences may even reflect awareness of "us versus them" situations. "Reactive devaluation is confirmed by showing that supporters of a party in negotiations will judge a settlement less favorable if it is made by the opponent than by their own side." (Kahneman, 1992, p. 301) "Concession aversion, [causes] a systematically different evaluation of concessions made and of concessions received." (p. 301)
The Effects of Knowledge Biases on Decision-Making

When people learn, they add to their knowledge by building new relationships between existing representations. Over time, this process establishes a foundation of knowledge through which individuals experience and interpret the world. This foundation is influenced by both inherent and developmental learning factors. The inherent factors are the result of built-in human limitations and personality traits. Developmental factors are the result of new knowledge being built on and interpreted through existing knowledge, and the affects of personal experience and learned behavioral strategies. The structure of knowledge resulting from both inherent and developmental factors often causes decision-making errors to occur. These errors and those that result from the application of specific knowledge are said be the result of Knowledge Biases.

Insights on Knowledge Biases From the Model of Associative Memory

The model of associative memory explains some of the inherent and developmental factors that can affect the structure of knowledge. One inherent factor is the limit to the number of representations that can be integrated as a whole. To integrate representations, they must be invoked close together in time in order for associative memory to form the necessary relationships. There must be some limit to the number of representations that can be invoked simultaneously or to the number of representations that can be combined. Such a limitation was described by G. Miller
and is called the 7±2 principle. Taylor (1995, p 25) provides an excellent summary of this principle:

One of the "laws" of experimental psychology is that human beings cannot integrate more than seven to nine unrelated concepts. This limitation appears in every measurable aspect of human cognition, including visual perception, short-term memory, and cognitive analysis. Moreover, it has survived many hundreds of experimental tests conducted over a period of a hundred years, so there can be no question that the limitation is both real and pervasive.

Because of the 7±2 principle, people are forced to create groups to simplify complex information. These groups are mental constructs that stand for collections of related or strongly interconnected things. Once created though, these groups take on their own identity. They start to lose their attachment to the things they were created from. The groups can be connected with other representations and can take on new properties of their own. Decision-making errors often occur when these groups hide the significant properties of their members or imply properties that do not follow the original intent of the group. Decision-making errors also occur when one group affects the definition of related groups so that certain properties and interactions become emphasized over others. Ironically, the limitations that force people to create groups also drive their intellectual abilities. People are forced to abstract the world, helping them discover patterns that occur over and over again in many different situations.

Another inherent factor that affects decision-making is blocking. Blocking occurs when the same knowledge is needed to do two or more things at the same
time. Minsky (1986, p. 33) put it this way: "We often find it hard to think two
different thoughts at once, particularly when they're similar, because we get 'confused'
when the same agencies are asked to do different jobs at the same time." Blocking
physically prevents access to alternative thoughts, as opposed to attention biases
which simply direct attention away from them. Blocking interferes with decision-
making by preventing alternatives from being considered.

Beyond the inherent factors, there are developmental factors that affect the
structure of knowledge built by the learning process. The learning process builds new
representations by forming new relationships between existing representations. This
process is complete when these new representations are connected back to the
existing knowledge structure. But, the new representations depend on a person's past
experience and they are "seen" through the existing knowledge. The person's ability
to understand the world is both biased and limited by what the person already knows.

Our view is limited to what can be expressed in the terms we have
adopted. This is not a flaw to be avoided in thinking--on the contrary,
it is necessary and inescapable. Reflective thought is impossible
without the kind of abstraction that produces blindness. Nevertheless
we must be aware of the limitations that are imposed. (Winograd and
Flores, 1986, p. 97)

The knowledge a person has, the events he or she attends to, and the strategies
he or she uses to deal with the world, all affect the learning process and ultimately the
structure of knowledge with which decisions are made.
Insights on Knowledge Biases From Research in Decision-Making

Research on the effects of knowledge and its use in decision-making include work on decision heuristics, strategies, and schemata; and on the application of analogies, metaphors, scenarios, and frames to the decision space. The former group directs the decision-making process and affects decisions by affecting this process. The latter group is used to identify and extend decision knowledge. It affects decisions by affecting how the available information is interpreted.

Heuristics are simple rules-of-thumb used to evaluate options in a decision. In general terms, they involve knowledge about what works and what doesn’t. Heuristics generally cause decision-making biases by favoring some information, procedures, or objectives over others. "Managers use heuristics as filtering and organizational devices, thereby reducing the complexities of decision situations. But sometimes heuristics may lead to systematic errors or biases." (Haley and Stumpf, 1989, p. 481)

Availability, perseverance, and information gathering heuristics provide examples of the range of heuristics applied to decision-making. "Managers use availability heuristics when they estimate the occurrences of problems and the feasibility of solutions by the ease with which they can bring these problems and solutions to mind." (Haley and Stumpf, 1989, p. 486)

Using this heuristic, decision-makers judge a future event to be likely if it is easy to recall past occurrences of the event... Generally, frequently occurring events are easier to recall than infrequently occurring events so availability is a good way of judging probability.... However, other things besides frequency can increase the availability
of certain types of events in memory. Dramatic vivid events may be easy to recall even if they occur infrequently. Also, recent events may be easier to recall. (Schwenk, 1988, p. 43)

The availability heuristic favors knowledge that is easy to recall.

People often put their faith in a chosen course of action. When they discount or undervalue evidence that goes against their faith, decision-makers are enacting perseverance heuristics. "Individuals enact perseverance heuristics in data gathering when they adhere to their prior beliefs and ignore subsequent disconfirming evidence" (Haley and Stumpf, 1989, p. 485) Perseverance heuristics favor information that supports a person's prior believes.

Baron, Beattie, and Hershey (1988) identified three biases resulting from heuristics used in gathering information. The first heuristic showed an Information Bias, where "Subjects evaluated questions as worth asking even when there is no answer that can change the hypothesis that will be accepted as a basis for action." (Baron, Beattie, and Hershey, 1988, p. 88) The second heuristic showed a Certainty Bias, where "Subjects overvalued questions that have the potential to establish, or rule out, one or more hypothesis with 100% probability." (Baron, Beattie, and Hershey, 1988, p. 88) Finally, a third heuristic resulted in Congruency Bias, in which "Subjects overvalued questions that have a high probability of a positive result given the most likely hypothesis." (Baron, Beattie, and Hershey, 1988, p. 88).

Strategies and schemata are structured collections of decision-making rules and knowledge. Strategies are concerned with identifying decision states and
selecting actions that direct the decision toward a desired goal. They are usually
tightly structured and well defined. Schemata will be described as loosely structured
collections of knowledge used for analyzing and solving a general type of problem.
Biases caused by strategies and schemata can result from the way these collections are
built. For example, decision-makers may unintentionally build strategies that are
dependent on a "one decision at a time" mindset. Haley and Stumpf (1989, p. 483)
noted that "when managers use certain heuristics in initial stages of decision-making
they rely on other, hinged heuristics in subsequent stages of decision-making. These
cognitive trails may result in systematic biases which increase gaps between intended
and realized strategies."

Analogies, metaphors, scenarios, and frames are abstractions built from one or
more decision-making situations that can be applied to a variety of other situations.
They are used to identify and extend knowledge about the decision. The "fit" between
these abstractions and the new situation can be a source of decision-making errors.
"Essentially, the decision-maker draws an analogy between the causes and solutions
for the current problem and those of past problems. Analogies then specify the ways
the problem should be solved." (Schwenk, 1988, p. 48) Haley and Stumpf (1989,
p.488) argue that "reasoning by analogies helps reduce environmental uncertainty,
and even yields creative solutions to problems however, this process may provide
extremely simplistic overviews for complex situations." Analogies and metaphors
cause biases toward or against certain aspects of a new situation and cause the decision-maker to identify representations and use relationships that may not apply.

Chapter Summary

The model of associative memory and the results of research on decision-making biases both provide numerous examples of the effects human resources can have on decision-making. These effects can be attributed to three broad categories of decision-making biases: Evaluation, Attention, and Knowledge Biases. Evaluation Biases affect decision-making by interfering with the evaluation process. Their effects can be reduced by building decision-making systems that provide support for the evaluation process. Attention Biases affect decision-making by affecting the amount of attention given to various parts of the decision. Decision-making systems can help decision-makers avoid Attention Biases by assisting decision-makers in the discovery and analysis of decision information. Finally, Knowledge Biases result from factors limiting the structure or application of the decision-maker’s knowledge. They can be addressed by building decision-making systems that help decision-makers break apart, recombine, and apply the knowledge structures used in decision-making.
CHAPTER V

USING PATTERNS TO DISCOVER, REFINE, AND REUSE DECISION KNOWLEDGE

The previous chapters discussed how models of decision-making behaviors and resources could be used to improved decision-making processes and overcome the effects of human resources on decision-making. These chapters dealt with the "human side" of decision-making. What is missing is a generalized strategy for dealing with the "world side" of decision-making--a strategy that leverages human strengths in uncovering knowledge about the world and using it to solve problems. This chapter describes a strategy based on repeating patterns that achieves this goal. It shows how people can discover, refine, and reuse patterns to make better decisions with less time and effort.

Definition of a Pattern

Christopher Alexander started a minor revolution in the way people think about design. His work in architecture has quietly spilled-over into the software community and made in-roads into the basic sciences and mathematics. Alexander writes about patterns and how people create and judge the quality of pattern languages. He summarizes the existence of patterns as follows:
We have a glimpse, then, of the fact that our world has a structure, in the simple fact that certain patterns of events—both human and nonhuman—keep repeating, and account, essentially, for much the greater part of the events which happen there. (Alexander, 1979, p. 69)

It is because patterns of events keep repeating that people are able to learn and use them. This repetition is precisely what is required to form connections between neurons. And, of course, it only makes sense to learn patterns that are repeated. What good is knowledge that is never used again? Unfortunately, events are never repeated exactly the same way twice, so people must abstract only those features that do occur repeatedly. This is precisely what happens when neurons combine events to create new representations. Only those events that repeatedly occur together form new combinations. Thus, patterns come to be stored in associative memory as connected sets of representations. These representations combine only those events or features of the world that repeatedly occur close together in time.

Associative memory's ability to store patterns does not explain how people can come up with an endless variety of new things. This requires the use of a pattern language.

In summary: both ordinary languages and pattern languages are finite combinatory systems which allow us to create an infinite variety of unique combinations, appropriate to different circumstances, at will.

<table>
<thead>
<tr>
<th>Natural Language</th>
<th>Pattern Language</th>
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<tr>
<td>Words</td>
<td>Patterns</td>
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<tr>
<td>Rules of grammar and meaning which give connections</td>
<td>Patterns which specify connections between patterns</td>
</tr>
<tr>
<td>Sentences</td>
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(Alexander, 1979, p. 187)
Pattern languages are simply patterns in the way patterns are combine to create new things. Each pattern used by a pattern language has an identity that defines its place within the language. For Alexander, this identity can be the name of the place where the pattern occurs: "Indeed, a culture always defines its pattern of events by referring to the names of physical elements of space which are 'standard' in that culture." (p. 71) The pattern's identity is, in essence, a name for an endless variety of variations of the same pattern—each instance affected by the patterns beside, below, and above it.

Ways of Navigating Patterns

Patterns are stored in associative memory as connected sets of representations which are, in turn, identifiers for yet other patterns. Decision-makers apply patterns to decision-making by invoking their representations in sequence, usually in the order established by the pattern. The representations activate behaviors and knowledge that help guide the definition of information in the decision space. By moving from one representation to another, the decision-maker can map out his or her knowledge of the decision. This directed movement from one representation to the next is referred to as pattern navigation. Pattern navigation can be used to direct thought processes or attention. However, the mechanics of pattern navigation are more easily understood in terms of attention so this form will be discussed below.

The decision-maker's attention can only be focused on one representation from a pattern at a time. The pattern member that has the decision-maker's attention
is called the primary focus, or focus. There can also be a secondary focus, or context, within which the primary focus exists. This context may change the interpretation of the primary focus but receives only background attention. The two types of focus, primary and secondary, result in two different types of attention transitions. The first type, horizontal transitions, involves changing the primary focus by following a connection from one representation to another. The two representations are clearly distinct from one another and exist at roughly equal levels of abstraction. The other type of transition is a vertical transition. This type involves changing the primary focus into the secondary focus while assigning a new primary, or changing the secondary focus into the primary focus. In contrast to horizontal transitions in attention, vertical transitions usually involve a change in the level of abstraction.

Horizontal and vertical transitions provide enough functionality to navigate the patterns contained in associative memory. Horizontal transitions support navigation within a pattern and vertical transitions support navigation between a pattern and a component pattern. By applying sequences of horizontal and vertical transitions, the decision-maker can use patterns to define information contained in the decision and later analyze this information for the knowledge it contains.

Techniques for Capturing Decision Knowledge

In order to use patterns in decision-making, they must first be discovered. The first step to discovering patterns is to gather as much information about a given situation as practical. The amount of information gathered for the same amount of
effort decreases as the decision-maker’s attention span decreases, as techniques for gathering information are exhausted, and as the information gathered becomes less significant to the decision. The time between "captures," or the recording of information, and the decreasing significance of information captured can be used as an indicator of when to change techniques or move on. The decision-maker should consider revisiting the information gathering step with a fresh or new perspective. Ultimately, the decision-maker must decide how much information gathering is practical.

There are a number of good techniques to help decision-makers capture their knowledge about a decision. Many of them exploit checklists, categories, or common relationships. Although useful for filling in details, these techniques generally cover only limited domains. What is needed is a set of techniques that works closer to the way people think. Six such techniques were developed by using the model of associative memory as a guide. Four of these techniques exploit the connection relationship to help map out knowledge contained in associative memory. The remaining two techniques use the collection relationship.

The first technique, free mapping, tries to capture as many different representations from the pool of active representations as possible. The model of associative memory states that focusing on a particular representation for too long tends to shift the active pool toward that representation. Most of the other representations tend to fade away. To capture the greatest variety of representations, it
is necessary to capture them quickly without focusing on them too long. Free
mapping involves recording representations externally and then ignoring them. It is
used to record as many thoughts as possible without considering the relationships
between the thoughts.

The second technique is focus mapping. This technique tries to capture all
representations connected to a given representation, particularly those that may be
hidden by stronger representations. The decision-maker starts by concentrating on the
focus representation and then externally records the next representation that comes to
mind. Afterwards, he or she returns to the focus representation and repeats the process
until all the representations connected to the focus have been recorded. Focus
mapping is used to uncover the thoughts connected to a single focus thought. It is
related to a breadth first search.

The third technique, flow mapping, captures representations that naturally
occur in sequence. The decision-maker starts by focusing on the initial representation
and then externally records the next representation that comes to mind. Afterwards, he
or she focuses on the new representation and repeats the process until the series of
representations comes to an end. Flow mapping is used to capture entire chains of
thought and is related to a depth first search.

The fourth technique, split mapping, tries to add detail to or break up
information that is too general to work with. It uses two representations to help search
for an intermediate one. Split mapping starts with an anchor and focus representation.
Then, the decision-maker tries to think of some representation that fits between the two. The intermediate representation is recorded externally and becomes the focus for the next repetition of this process. The decision-maker can move the anchor to a different representation between repetitions.

The fifth technique, group creation, is one of two techniques that use the collection relationship. It tries to define as many collections as possible for a given representation or group of representations. The decision-maker starts with one or more representations and tries to define collections that they might belong to. The collections are recorded externally as they come to mind. Group creation is used to find types or contexts for thoughts.

The sixth technique, group definition, tries to condense or abstract decision information by defining one or more representations as something else. In this technique, the decision-maker replaces one or more representations with a single new representation. The new representation is compared against the remaining representations in successive iterations of this technique. Group definition is used to identify one or more thoughts that form a whole.

Techniques for Discovering, Refining, and Reusing Patterns

Once enough information is gathered about the decision, the decision-maker can examine the information for patterns or use existing patterns to identify and expand the information. The patterns discovered through examination can be recorded for future use or immediately reused on other parts of the decision. Pattern discovery
involves identifying sets of representations that repeatedly occur together. The size of these sets should be large enough to be whole patterns, but not so large that they never occur in their entirety. The measure of completeness is somewhat arbitrary—being affected by cognitive limitations, but may be determined using the frequency of correlation between representations or an intuition about pattern usefulness or wholeness.

The initial information about a situation is usually too specific or detailed to reveal repeating patterns so it is necessary to abstract or partition the information first. This includes putting elements with similarities or lots of interaction into groups; and also defining types of elements, uses for them, and instances in which they occur. These activities add new, more abstract representations to the decision information. Patterns are then created by connecting these representations and defining groups for the results. These groups serve as the pattern’s identity. The pattern discovery process is characterized by questions about how and why representations are connected, what characteristics do they share, and what do they do as a whole.

Patterns need to be continuously refined by adding promising extensions and variations while letting disused pieces fade from existence. The decision-maker who recognizes this can benefit from a faster, more responsive approach to decision-making. He or she knows it is not necessary for the initial pattern to be perfect or to anticipate all contingencies—which cannot be achieved or known anyway. The decision-maker also knows that the pattern will produce different results in different
situations and from different viewpoints. This means that different scenarios and perspectives can be invented for the pattern to help refine the pattern before it is used and that the pattern must be revisited after it is used. Pattern refinement requires the decision-maker to "step into" different scenarios and perspectives before considering a pattern and to identify information that will be needed to improve the pattern.

Patterns become more valuable as they are reused in new situations. The decision-maker's first step is to identify which patterns are the most valuable in the current situation. This can require both generalization about decision characteristics and identification of characteristics that are unique to the decision. The decision-maker uses these characteristics to search for patterns that may apply. The patterns that are found can be used in two different ways. They can be used as processes to guide analysis of decision information or as structures to map out information. Process patterns work mostly in the background to activate the resources needed and establish process state, or contexts, and set objectives for process operations. Structural patterns work in the foreground to help identify information and search for missing pieces. The decision-maker applies a structural pattern by matching members of the pattern to elements in the decision.

Chapter Summary

This chapter defined what a pattern is and described a general strategy for using patterns in decision-making. While models of decision-making behaviors and resources address the human issues in decision-making, they do not address issues
that are specific to the types of decisions being made. Patterns provide a way of capturing domain specific knowledge and using it to produce better decisions in less time and effort. Patterns, combined with models of decision-making behavior and resources, provide a complete framework for building more effective decision-making systems.
CHAPTER VI

DESIGNING MORE EFFECTIVE DECISION-MAKING SYSTEMS

The previous chapters identified three general approaches to designing more effective decision-making systems. The approaches were to (1) use the process model to help decision-makers define and manage decision-making processes and resources; (2) use the model of associative memory to help decision-makers avoid Evaluation, Attention, and Knowledge Biases; and (3) use Patterns to help decision-makers discover, refine, and reuse decision knowledge. This chapter examines the application of these approaches to the design of decision-making systems.

Using the Process Model

One approach to producing better decisions is to improve the processes by which they are made. This means the decision-maker must occasionally shift his or her attention away from the decision and to the process being used. Decision-making systems can be designed to help the decision-maker make this shift by providing a “process view” of the decision. They can use the process model to make decision-making processes more tangible: breaking them into a sequence of operations that transform resources into a product, and can provide tools to help define and management the processes. Once a process is defined, the decision-making systems
can provide tools that help the decision-maker apply techniques that improve the process.

**Defining the Process**

The first step in using the process model is to help the decision-maker define the decision-making process. This definition includes a process statement, sequence of operations, set of operation descriptions, and a summary of the resources used. The process statement is a description of what the process does without describing how it is done. It considers the needs of a decision-maker looking for a solution to a problem and the need for flexibility in how that problem is solved. The decision-making system can query the decision-maker for the process statement, provide guidelines for its definition, and help file it for future reference.

The sequence of operations defines what each operation does including what it needs from other operations and what it supplies to other operations. There are two approaches to defining a sequence of operations. The decision-maker can either define operations that come before or after other operations or define the operations that come between other operations. If the decision-maker finds naming the operations difficult, he or she can use some other defining property of the operation instead. For example, the words “create the” can be prefixed to the process output to identify the operation. The decision-making system can help the decision-maker generate an operation sequence by repeatedly querying him or her for operation names while providing cues to what the next and previous operations are.
After the sequence and operations are identified, the operations need to be described. The operation descriptions include how the operations work, what resources they use, and what resources they produce. The decision-making system can help by querying the decision-maker for this information and using the process as a model to file the results. The decision-making system can also help by collecting information on the resources used including their most effective use, limitations, and costs.

To complete the process definition, the decision-maker should prepare a summary of the resources used. This is an accumulated summary of the resources used by all the process operations. It serves an informational need for the decision-maker thinking about using the process, sets constraints on the process design, and establishes a basis for measuring process improvement. The decision-making system can help the decision-maker prepare this summary by aggregating the resources used by each operation.

**Improving the Process**

Once the process is defined, the decision-making system can help the decision-maker identify opportunities for improving it. He or she will need to consider the sequence of operations as a whole as well as the individual operations. The decision-making system should provide separate views of the process to support these different needs.
One view should emphasize the overall choice of operations and the reasons for performing them in a given sequence. The decision-making system can then help the decision-maker identify and evaluate alternative series of operations for the same process. The overall, or process, view should include support for breaking the existing operations into functional parts, questioning the necessity of each function, and finding new ways to recombine or perform them. Some of this effort will be directed toward using predefined operations and adding auxiliary operations to control the process. The system should also help the decision-maker define operation boundaries that minimize interaction between operations while isolating groups of functions that are likely to have alternative implementations. Operations with fewer external interactions are easier to understand and usually easier to replace with alternatives. Criteria that can be used for isolating groups of functions includes functional similarity, degree of interdependency, degree of resource sharing, and the availability of functional alternatives. The decision-making system can help the decision-maker by showing the links between operations and resources, and providing guidelines for defining or locating functional groups.

The other view of a process focuses the decision-maker's attention on individual operations. This view helps the decision-maker "step into" a defined operation to work out its use of resources and interactions with other operations. The decision-making system can help with this process in two ways. First, it can guide the definition of the resources used and help point out issues regarding their effective use.
Second, it can show where interactions occur, guide their definition, and suggest ways to use them more effectively. The interactions defined should include those that occur through sharing resources. The definition of the interactions will be helpful in balancing the needs of the operation with the needs of other operations in the process.

**Applying the Process**

Once the decision-making process has been defined and improved, the decision-maker is ready to use it to make decisions. At this point, the decision-maker's attention can shift from the process back to the decision being made. The decision-making system can help accomplish this shift by managing much of the process for the decision-maker. It has information on the sequence of operations, the operation objectives, and the resources needed; and can use this information to guide the decision-maker, track the process's state of completion, and manage the process resources.

To guide the decision-maker, the decision-making system can point out the resources and objectives required for the current process operation. The decision-maker's task then becomes one of apply the available resources to achieve the stated objectives. He or she may transform some of the resources to intermediate states along the way. Rather than displaying all the resources available at once, the system should provide access to most resources based on the type of resource and frequency of use. The system may also provide features that help the decision-maker adopt a particular state of mind before performing an operation. And, it should track the
objectives completed so that it can provide information about the state of the overall process on demand. After completing an operation, the system should move the decision-maker to the next operation.

The decision-making system should also consider the need to schedule, suspend, and resume operations. If the decision-maker's attention falters or is directed elsewhere, the system may have to suspend the current operation and schedule a new one. The system can maintain a list of processes, or process objectives, to help the decision-maker find other activities when his or her attention falters. When an operation is suspended, the system should maintain enough information about the operation so the decision-maker can resume it latter. This may include the current state of the operation, the state of the resources used, and a record of the most recent actions taken by the user. Any other information that will help the decision-maker recall his or her state of mind when the operation was suspended should also be maintained. The system can query the decision-maker for this information when an activity is changed.

Avoiding Decision-Making Biases

Many decision-making errors result from the effects of Evaluation, Attention, and Knowledge biases. Decision-making systems can help avoid these errors by managing decision activities and information for the decision-maker, by drawing attention to possible biases, and by providing techniques to overcome them. The three types of biases emphasize different approaches to avoiding the errors they can cause.
Evaluation Biases

Decision-makers use the evaluation process to estimate the value or significance of things: including instances of information, actions, and outcomes. The evaluation process contains operations that (a) value items along a given dimension, (b) aggregate multiple values for an item, (c) select and group dimensions for evaluation, and (d) compare the values of different items. Evaluation errors result from an imbalance in weights given to values, the effects of using different perspectives or reference points on evaluations, the short-term effects of memory, and biases in attention given to alternative items or dimensions. The best approach to avoiding these errors is to have the decision-making system manage the evaluation process operations and the information collected.

Decision-makers typically weigh negative values higher than positive values and larger values proportionally less than smaller values. Decision-making systems can minimizing these biases by drawing the decision-maker's attention to them. This can be done while the decision-maker is valuing individual items or after all items have been valued. The system may simply ask the decision-maker to consider the possibility of a bias or provide controls that demonstrate the effect of a possible bias on the outcome. More complex systems could perform mathematical or statistical analysis on the results. In the case of pair-wise comparisons, the system can show whether the advantages assigned to one item are the same size as the disadvantages assigned to the other item along each dimension.
Imbalances in the weights assigned to each dimension also occur when the dimensions are valued separately. The decision-maker may have a tendency to value all dimensions on the same scale, even when some dimensions are clearly more important than others. One way to reduce this problem is to let the decision-maker enter a weight or priority for each dimension. However, this could be more confusing than helpful and it still suffers somewhat from the same problem. A better way is to line up the values for all dimensions of an item so the decision-maker can see them together and adjust them as needed. The values of all items may be adjusted together by letting the decision-maker adjust the average values for each dimension and then carry over these changes to the individual values.

Item valuations may be based on individual feelings about the items or on comparisons between them. These two types of valuations are referred to as absolute and relative, respectively. Absolute valuations simply measure the emotions associated with an item or dimension in a given situation. The feeling that quality is important is an absolute valuation. Errors in this type of valuation can be avoided by analyzing the reasons for the associated feelings. Relative valuations compare items against each other or against a reference point. Errors occurring when items are compared against each other can be avoided by using pair-wise comparisons. Errors caused by using reference points can be avoided in a few different ways--depending on the type of reference point being used. In cases where a situation changes gradually over a long period of time, the decision-maker may not be aware that the current
situation is being used as a reference point. He or she bases all valuations on the assumption that the current situation is the appropriate standard for measurement. The decision-making system should get the decision-maker to consider how the valuation would change if made from a different situation. A second case occurs when fixed reference points are used. Fixed reference points occur when the decision-maker is faced with a recent or likely changed in the situation. All valuations are based off this recent change rather than if the new situation had existed for awhile. For example, decision-makers may forego new opportunities for a raise in salary because of a recent raise when they would have taken the opportunity otherwise. The decision-making system should get the decision-maker to consider the new situation as separate from previous situations. The final problem occurs when a reference point changes from one valuation to the next. The same reference point may look positive from one point-of-view and negative from another. In this case, it may be necessary to value the item from each point-of-view and weigh their relative merits. The decision-making system may list each point-of-view as a separate dimension for valuing the items. In general, decision-making systems can improve valuations by helping the decision-maker reflect on the views, assumptions, and foundations behind assigned values, and encouraging the construction and use of alternative perspectives.

The short-term effects of memory cause problems in maintaining values for the duration of the decision. Even if these values are kept externally, the decision-maker may decide to adjust them based on more recent analysis while forgetting
things considered during the earlier analysis. To counter the effects of short-term memory, the decision-making system must maintain: (a) the values entered for items along each dimension, (b) the reasons for choosing each dimension, (c) the reference points and perspectives from which the dimensions were valued, and (d) the time at which they were valued. If the decision-maker decides to change a value, the system should force him or her to review the original analysis.

Attention biases affect many aspects of decision-making. In the evaluation process, they affect the time spent valuing different items and dimensions. The more time spent valuing something, the stronger the associated value will be. This is particularly true for items and dimensions that get more recent attention. The decision-making system can counter this effect by keeping track of when and how often a particular valuation is viewed or performed. It can then point out items or dimensions that have gotten less attention recently and ask if their values need to be adjusted.

Attention Biases

Attention biases are caused by the brain's sensitivity to events, event intensity, emotional associations, and recent events. Event sensitivity causes decision-makers to ignore things that are constant or change gradually over time. Decision-makers may attribute outcomes entirely to specific events when "background" conditions are a significant factor. The decision-making system can address this problem by prompting decision-makers to periodically assess the current situation and its effect
on the defined objectives. Sensitivity to event intensity means that decision-makers will pay too much attention to strong, clearly perceived, or less ambiguous events; and to events that are supported by many contributing factors. Again, these events may not be the most significant factors to a particular outcome. The decision-making system can help decision-makers identify alternative factors by getting them to set aside more intense events. Decision-makers also pay too much attention to events with strong emotional associations. These events can be dealt with the same way as intense events. Since emotions are directed toward more immediate and personal experience, their presence in decisions that can affect others should be a cause of suspicion and their influence on long-term decision strategies should be considered. The decision-making system should get decision-makers to periodically question their emotional preferences for events. The system should also encourage decision-makers to consider the effect of a decision on future decisions and assist in the development and use of decision strategies. The last type of attention bias is caused by sensitivity to recent events. Events that have occurred recently receive more attention than older events because short-term changes in memory increase the event intensity. The decision-making system needs to question the decision-maker on whether there are older events that may have contributed to an outcome.

**Knowledge Biases**

Knowledge biases occur when the structure of a decision-maker's knowledge forces events to be interpreted in specific ways or inhibits access to knowledge that
would otherwise affect the decision. To reduce the effects of forced interpretation, it is necessary to periodically break apart the existing structures and form new ones. The decision-making system can help with this process by capturing knowledge structures and then assisting the decision-maker in breaking them apart and recombining them. The decision-making system can help the decision-maker access unavailable knowledge by helping him or her build perspectives and then assume the different perspectives while revisiting parts of the decision.

Discovering, Refining, and Reusing Patterns

Another way to make decision-making systems more effective is to have them help decision-makers discover, refine, and reuse patterns that occur over a series of decision situations. The systems should include features to help capture knowledge, build and navigate patterns, apply process and structural patterns, store patterns along with information to help find them again, and recall patterns appropriate to the current decision. Decision-makers should be able to use free, focus, flow, and split mapping to capture and connect representations within the same level of abstraction. They should be able to define and create groups to collect representations and create new levels of knowledge.

The decision-making system should maintain an active pool of representations from which the decision-maker can build new connections and collections. The decision-maker should be able to focus on representations in the pool to reveal connected representations and move the focus to any representation in the pool.
Representations that do not periodically receive the focus should eventually fade from the pool. The decision-maker should also be able to lock potentially useful representations in the pool and recover representations that have recently faded from the pool.

The decision-making system can help the decision-maker apply process and structural patterns by displaying them simultaneously with the work being done by the decision-maker. Since process patterns normally work in the background, the decision-maker should be able to "load" them into the system interface. The structural patterns should be seen to coexist with the patterns being built from the representation pool. For both process and structural patterns, the system should provide features that let the decision-maker move from one pattern member to a connected member. For structural patterns, this requires a separate focus that the decision-maker can jump to from the work he or she is doing. The elements of structural patterns should gradually fade from view as their significance to the current task decreases. The system should also let the decision-maker define a secondary focus using a representation in the pool, or point out representations that belong to collections and let the decision-maker expand the collection to make it a secondary focus. The decision-maker should then be able to expand the collection by adding new representations, or selected representations from the work space.

The decision-making system needs to provide features that help the decision-maker store and recall patterns. Most of these patterns will be connected in a network
of pattern representations. The system can use active representations and their relationships with other representations to help narrow the network searched. The decision-maker may also define search categories and patterns to further narrow the search. Finally, the decision-making system should help the decision-maker build, append, store, and recall sub-networks of patterns that are useful in different decision situations.

Chapter Summary

This chapter described a number of ways that decision-making systems could help decision-makers (a) define, manage, and improve decision-making processes; (b) avoid Evaluation, Attention, and Knowledge Biases; and (c) use Patterns to discover, refine, and reuse knowledge about decisions. It provided a foundation for designing more effective decision-making systems that help decision-makers make better decisions using less time and effort. The next chapter applies some of the ideas described here to the design of a prototype Synergistic Decision-Making System.
ASSOCIATIVE MAPS: A TOOL FOR BETTER DECISION-MAKING

Associative Maps are computer-based tools that support the decision-maker by emulating associative memory. They help the decision-maker capture his or her thoughts, organize them into knowledge about the decision, and then apply this knowledge to the decision. This task is accomplished by exploiting patterns that repeatedly occur in decisions. Associative Maps help the decision-maker discover and refine these patterns and then use them to guide the decision-making process and map out knowledge contained in the decision space.

The Foundations of Associative Maps

Associative Maps are based on the model of associative memory and provide a user-interface that is based on the model of interaction between working and associative memory. The difference between Associative Maps and human memory is that the decision knowledge is maintained externally and the user-interface is external. This gives the decision-maker a unique perspective of what is in his or her head. It almost gives the decision-maker a dual personality that can be consulted with on decisions. This section describes how the interface between working and associative memory is represented externally.
Representations and Relationships

Many theorists argue that the most significant difference between humans and other primates is the human ability to use language (Leakey and Lewin, 1992). In fact, the human vocal cavities are uniquely shaped to generate a wide range of sounds. The model of associative memory suggests that people experience representations as through their percepts (e.g. images, sounds, emotions). These percepts are activated through connections when the representations are invoked. Therefore, the logical way to depict representations externally is to use words or short phrases; phrases being short-hand for depicting representations a person does not have a single word for. Associative Maps depict representations by enclosing a word or phrase in an oval on the display. This depiction is called a node. Because of the difficulty of representing a complete thought with a single word or phrase, Associative Maps also let the decision-maker enter text associated with the representation that is shown at the bottom of the display when the representation is displayed as the current focus. This text makes Associative Maps easier to use by increasing the granularity or density of the information presented at once.

Associative Maps only support two of the three types of knowledge relationships described in the model of associative memory, connections and collections. They depict connections by drawing a line between two representations, or nodes. The current version of the tool does not distinguish between associations, which are two-way connections, and links, which are one-way connections.
Associative Maps depict collections by showing the word or phrase used for the collection’s representation on the display without an oval around it. The collection is displayed in an area centered and above the collection members. Associative Maps do not include support for combinations, which combine events to invoke representations. This is because the decision-maker defines and invokes the representations, instead.

Representations Versus Instances

Every time a representation is used in a different way, a new "instance" of the representation must be created. This is because each instance of the representation has its own identity with its own set of connections to other representations or instances. The different uses of a representation are defined by collections. So, every time the decision-maker adds a representation to a collection, Associative Maps create and put an instance of this representation in its place. The tool also add a link going from the instance to its representation. However, this link does not shown on the map. Instead, the tool provides a special command that lets the decision-maker get to the representation from its instance. Instances are displayed in grey to distinguish them from representations which are displayed in black. All members of a collection are instances. The term "representation" refers to both instances or representations in this text unless otherwise noted.
Focus Control

As in the model of associative memory, there are primary and secondary foci in Associative Maps. The primary focus is the representation that has the tool's "attention." Most of the tool's operations are performed on this focus. To move through Associative Maps, the decision-maker moves the primary focus from one active representation to the next. When a new representation gets the focus, all the representations connected to it become active and are displayed. The connected representations become inactive again when the focus is moved to a different representation. If the primary focus is moved to an instance, the word or phrase representing the collection containing the instance is displayed nearby.

Collections define contexts, preconditions, sets, and so on. They must be made active for the instances they contain to become active. To make a collection active, the decision-maker expands its corresponding representation. This expanded representation becomes the secondary focus. The secondary focus is the collection that currently has the tool's attention. It defines the context for tool's interaction with the decision-maker. All new representations and representations "pasted" from the active set are inserted into the secondary focus. If the primary focus is moved to an instance, the collection containing the instance becomes the new secondary focus. The exception to this occurs when the decision-maker sets the secondary focus to a particular collection. In this case, neither changing or expanding the primary focus will change the secondary focus. However, expanding the primary focus will still
make its corresponding collection active if it has one. The name of the current secondary focus is displayed in a box at the top of the display area.

The current version of Associative Maps activates all instances contained in a collection whenever the collection becomes active. Ideally, only those instances connected to active representations (such as the primary focus) should be made active. The possible exception being instances with special significance to working memory such as the first instance in a collection. The current version makes the entire collection active to give the decision-maker a view of the whole collection at one time. This is akin to having all items in a menu displayed instead of just the current selection and selections above and below it. A better way to give the decision-maker a bigger view is to expand node activation beyond the representations connected to the primary focus. An even more sophisticated technique would assign intensity values to representations and maintain a display threshold. The intensity values would be based on the distance of a representation from the primary focus, and the recency and frequency of their activation.

**Associative Maps and Text**

The human brain can often assemble and disassemble groups of words and ideas much faster than it can deal with their individual representations. For this reason, Associative Maps let the decision-maker work with text in addition to representations and relationships. The text interface improves the flow of ideas from the decision-maker. After the text is entered, the decision-maker can analyze it for
content using Associative Maps to help with the analysis. The text interface provides features that let the decision-maker identify groups of words and ideas from text and create representations for them. Associative Maps also go the opposite direction. The word or phrase that names the primary focus can be pasted into the text interface where the decision-maker can fill-in and smooth-out the flow of ideas.

Modes of Operation

Associative Maps have two separate operational modes between which the decision-maker can toggle. The “build” mode accepts names for representations from the computer keyboard and creates nodes for the representations using the current tool settings. The “navigate” mode uses the keyboard for changing the primary or secondary focus, moving nodes around the display, and performing various tool operations on the focus. When the tool is in the build mode, a text cursor is displayed in a box that is located where the next node will be drawn. The box automatically expands to contain the characters typed by the decision-maker. The next node location is automatically updated using the location of the primary focus and the current tool settings. The decision-maker can change this location by using the keyboard arrow keys. The decision-maker uses the Insert key to toggle between the “build” and “navigate” modes. The text cursor disappears when the tool is in the navigate mode. In this case, the arrow keys move the primary focus from its current node to the nearest node in the direction of the arrow key pressed. The primary focus is given a thick node border to distinguish it from other nodes. One other important
key is the Tab key. This key "jumps" the primary focus from its current representation to the nearest asserted representation. Asserted representations are described below. Normally, the decision-maker uses the Tab key to jump between the process or structure pattern being used as a guide and the pattern he or she is building.

Using Associative Maps to Capture Knowledge About the Decision

Associative Maps use the four connection-based techniques described in the Chapter V, “Using Patterns to Discover, Refine, and Reuse Decision Knowledge,” to capture decision knowledge. The tool refers to these techniques as mapping modes and the current mapping mode is a tool setting. Associative Maps use Free Mapping to capture ideas that are supposedly unconnected. This mode is a type of brainstorming technique where the objective is to capture as many ideas as possible before exploring them further. Focus Mapping is used to capture all the ideas connected to a focus idea. This mode is a type of concentration technique where the objective is to identify as many connections to the focus idea as possible. Associative Maps use Flow Mapping to capture a sequence or chain of ideas. This mode is a process or event mapping technique that repeatedly prompts the decision-maker to come up with what comes after the last idea entered. The final mapping mode is Split Mapping. This mode requires the decision-maker to define an anchor representation. Its objective is to fill in the details that occur between the anchor and focus ideas. Split Mapping helps reduce the tension caused by the gap between the current and desired situation.
The decision-maker sets the tool's Free Mapping mode when he or she wants to generate an initial set of ideas to work from. Generally, this is done at the start of the decision-making process after defining the problem. The text interface can be used to create or load the problem definition. Free Mapping begins with the text box at some location in the display area. The decision-maker types a word or phrase for the first idea that comes to mind and presses the Enter key. The tool creates a node using the word or phrase, places the node where the text box was, and moves the text box to a random location in the same general area of the display. The random location emphasizes that the next idea entered should not be related to the first. This will be particularly important when the ideas are analyzed later on. At this point, the tool is waiting for the decision-maker to enter the next idea.

The decision-maker sets the Focus Mapping mode when he or she wants to identify all the connections to a focus idea. Focus Mapping is a good way to discover new relationships. Each connection represents a possible relationship between the focus idea and connected idea. This relationship can be identified and applied to other representations in the problem. Focus Mapping is also useful for mapping out structural patterns by simply moving the focus between representations in the pattern. It begins with the text box at some location on the display. The decision-maker types a phrase representing the focus idea and presses the Enter key. The tool creates a node using the phrase, places the node where the text box was, makes the node the primary focus, and moves the text box to a location surrounding the node. Next, the decision-
maker thinks about the focus node, types a phrase for the first idea that comes to mind, and presses the Enter key. The tool responds by creating the node, placing it where the text box was, drawing an arc from the focus node to the new node, and moving the text box to a new location surrounding the focus node. The decision-maker continues to enter new nodes until he or she runs out of ideas.

The decision-maker sets the Flow Mapping mode when he or she wants to identify a sequence of ideas. This mode is ideal for defining processes or creating "walk-throughs." Unlike Focus Mapping, however, the connections created with Flow Mapping do not represent relationships, except for possibly cause-and-effect chains. Flow Mapping begins with the text box at the top or side of the display area. The decision-maker types a phrase representing the initial idea and presses the Enter key. The tool creates a node using the phrase, places the node where the text box was, makes the node the primary focus, and moves the text box to a location below or beside the node. Next, the decision-maker thinks about what comes after the current focus idea, types a phrase for the first idea that comes to mind, and presses the Enter key. The tool responds by creating the node, placing it where the text box was, drawing an arc from the focus node to the new node, making the new node the focus node, and moving the text box to a new location below or beside the new focus node. The decision-maker continues to enter new nodes until he or she runs out of ideas.

Split Mapping mode is used to fill in the gaps between ideas. It is ideal for mapping the path between initial conditions to final objectives. This mode is also
useful for adding detail to processes and walk-throughs. Split Mapping begins with the text box at the top or side of the display area. The decision-maker types a phrase representing the initial idea and presses the Enter key. The tool creates a node using the phrase, places the node where the text box was, makes the node the anchor, and moves the text box to a location on the opposite side of the display. Next, the decision-maker types a phrase representing the final idea and presses the Enter key. This time the tool creates a node using the phrase, places the node where the text box was, makes the node the focus, draws an arc between the anchor and focus node, and moves the text box to a location between the anchor and focus nodes. Finally, the decision-maker thinks about what comes between the anchor and focus ideas, types a phrase for the first idea that comes to mind, and presses the Enter key. The tool responds by removing the arc between the anchor and focus nodes, creating the new node, placing it where the text box was, drawing arcs from the anchor to new node and new node to the focus node, making the new node the focus, and moving the text box to a new location between the anchor and focus node. The decision-maker continues to enter new nodes until he or she runs out of ideas.

Using Associative Maps to Organize Decision Knowledge

Once the initial ideas are entered into the software tool, the decision-maker starts organizing them to create knowledge about the decision situation. This includes picking out interesting representations, making new connections, defining types or uses for representations, partitioning representations into related groups, and creating
new groups of representations. Associative Maps provide a number of operations to help with these activities. There are unary operations that use the primary focus, binary operations that use the primary focus and anchor nodes, and multi-node operations that use selected nodes.

The unary operations include assert, set anchor, and select. The first of these asserts the focus node so that it stays active when the focus goes elsewhere. It is used for picking out interesting nodes while searching through the maps. The set-anchor operation makes the focus node the anchor node. The anchor node also stays active when the focus goes elsewhere, however, there can be only one anchor node. If another node is set to the anchor node, the current anchor looses this status. The select operation marks a node for a multi-node operation. Selected nodes remain active until the multi-node operation is performed.

The binary operations include connect and disconnect, which make and break connections between the anchor and focus nodes. In a typical situation, the decision-maker asserts one or more nodes during a search and then finds another node that he or she thinks is connected. The decision-maker then sets this node as the anchor, moves the focus to one of the asserted nodes, and invokes the connect operation. The disconnect operation simply undoes previously connected nodes. It may be used to disconnect nodes that should exist at different levels of abstraction. Associative Maps also provide an auto-connect mode so that the decision-maker does not have to invoke the connect operation. Auto-connect only works when the tool is in navigate mode. It
sets the current focus to the anchor and automatically connects the anchor to each node that becomes the focus, thereafter. If the focus mapping mode is set, the anchor remains where it was originally set after each connection. Otherwise, the anchor moves to the new focus. This may seem like a lot of modes to keep track of but it is fairly intuitive when used. The auto-connect mode is a natural extension of the mapping modes.

The multi-node operations include create, define, breakup, and delete. These operations work on the set of selected nodes. If there are no selected nodes, they use the focus node by itself. The decision-maker uses the create operation to create a new group for the selected nodes. This operation could be called the "these are also" operation. It attempts to define as many different groups for a set of nodes as possible. The tool prompts the decision-maker for the group name, creates a representation and collection for the group, and inserts instances of the selected nodes into the collection. Any connections between the selected nodes are also copied to the new collection. The selected nodes are not removed from any groups they are members of. The define operation identifies the selected nodes as something. The decision-maker uses this operation to define the selected nodes as a whole and for partitioning representations into related groups. The tool's initial steps for the define operation are the same as those for the create operation, except the selected nodes are removed from any groups they were in. In addition, any connections from the selected nodes to other nodes are removed from the selected nodes and reconnected to the
group representation. The final multi-node operation is breakup. The decision-maker uses this operation to break existing groups into their component representations so that new groups can be created from them. The component representations are copied to the collection defined by the current secondary focus if there is one. The selected groups are not deleted, so breakup does not actually break them apart. The delete operation is used to delete groups or representations that are no longer needed.

Using Associative Maps to Apply Decision Knowledge

The remaining decision-making activities supported by Associative Maps fall under the category of applying knowledge. These activities use patterns as processes to guide the decision-maker or as structures to map out information. The decision-maker must first search an existing knowledge map for the patterns he or she will use. Associative Maps maintain a list of map entry points and index structures to help the decision-maker find the best patterns for a particular decision. The entry points are actually representations that exist in the map and the index structures consists of collections and connections, also within the map. When the decision-maker finds a process to guide the decision, he or she uses the set-guide operation to make it a guide. The tool marks the primary focus as the guide and displays the text associated with it in a window at the bottom of the display area. The text explains what the guide is for and how to use it. To use the guide, the decision-maker expands the guide node to go to the first node in the guide collection. The text in the window now explains what the guide is for and how to use it. The decision-maker can go to the next step by
selecting the node connected to the first step and so on until the process is complete. Essentially, the same procedure is used to apply a pattern as a structure to map out information, except the decision-maker asserts the pattern's node instead of specifying it as a guide. Expanding the pattern node moves the assert setting to the first node in the structure. The decision-maker moves around the connections in the structure to reveal its parts. In either case, the decision-maker switches to build mode to perform the operations specified by the guide or to create the new pattern indicated by the structure. Leaving the build mode and pressing the Tab key moves the primary focus from one pattern to the next so the decision-maker can go from the new pattern to the structure pattern and finally the guide pattern.

Associative Maps also maintain a few lists that help the decision-maker find things. These lists are just collections that are part of the knowledge map. The entry point list has already been mentioned. The other lists are the working list, guide list, and reference list. The working list is a list of nodes the decision-maker is working on. The tool puts new nodes into this list if the secondary focus is not defined. The guide list is a list of other guides the decision-maker can go to. The tool puts the previous guide into this list each time the decision-maker sets a new guide. The reference list is actually generated by the tool every time the primary focus changes. It lists all the groups that contain the primary focus node. The decision-maker uses this list to return from a collection back to its representation.
Chapter Summary

Associative Maps use the model of associative memory and its interaction with working memory to create a unique environment in which the decision-maker uses patterns to capture information about the decision, organize it into knowledge about the decision, and apply this knowledge to solve the decision. The tool uses Free, Focus, Flow, and Split Mapping to help the decision-maker capture his or her thoughts on the decision, and Group Create and Define operations to identify and partition decision knowledge. Associative Maps help the decision-maker make better decisions by providing an framework through which the decision-maker and decision-making system can collaborate on the decision using the decision-maker’s knowledge.
The following experiment was performed to determine whether Associative Maps could help decision-makers capture knowledge about specific types of decisions while analyzing different decision situations. The main objective was to help decision-makers discover knowledge of processes, structures, and representations that could be refined and reused to make similar decisions more effectively in the future. The experiment also tested whether Associative Maps helped decision-makers identify knowledge that can affect the current decision.

Experimental Design

The experiment consisted of three problem situations in Facilities Planning and asked participants to list statements about the situations that could be helpful in solving problems similar to the ones described. Each statement is an expression of the participant's knowledge about the problem. The more statements written, the more knowledge the participant has captured regarding the situation described. It was hypothesized that Associative Maps would increase the number of statements listed, by helping participants exploit the information given to discover and apply their own knowledge about similar situations. The first of the three problems was a short 10
minute practice problem—designed to familiarize participants with the experiment and tool. After completing this problem, the participants were given five minutes to look over an answer sheet with some possible answers. The remaining two problems took 30 minutes each and were performed back-to-back without an opportunity to review possible answers. Each participant performed one of these two problems using Associative Maps and the other by hand. This approach was taken, rather than dividing the participants into two separate groups, so that none of the participants felt left out of the experiment. The order in which Associative Maps were used and the two test problems were performed was varied from one participant to the next in order to test the affect of these factors on the results. Because using Associative Maps might have had an effect on the participant's approach to subsequent problems, only half of the participants used the software on the practice problem. The other half would first use Associative Maps on either the first or second test problem. The independent variables in this experiment were the use of Associative Maps, the order in which this tool was used, and the order of the problems being performed. The dependent variable was the number of statements listed about each problem situation. The problem domain, test instructions, and familiarity of participants with Microsoft Windows applications were extraneous variables. Participants were recruited from a graduate course taught in the Department of Industrial Engineering at Western Michigan University's College of Engineering and Applied Sciences.
Experimental Results

Associative Maps represent an entirely new approach to decision-making--not only involving new concepts, but also the creation of new terminology, theories, and models. While Associative Maps borrow knowledge from many other areas of study, they are unique in their application of this knowledge and in the way they bring it together in one system. The final results appear similar to things the decision-maker has seen before and yet the system is fundamentally different. Early expectations were that the first version would not be successful but would serve as a basis for further exploration. This turned out to be the case. The vagueness in the theories, system, and experimental design, along with a larger than expected learning curve, made collecting statistically meaningful results difficult to obtain. However, much information was gathered from conducting the experiment and reviewing the results. The results discussed below will emphasize what was learned about this early version of Associative Maps.

Numerical Analysis of the Results

A total of 14 participants completed the evaluation research. However, the experiment and software were modified twice so that only six participants completed the final version. Observations of early experimental runs revealed that participants tended to use the tool for drawing hierarchies or diagramming complex patterns. They tended to work things out in their mind before recording the results. Some
participants even tried to explain to the investigator how he could convert their work into a solution for the problem. This tendency to use the software as a diagramming tool presented two problems. First, the software was not capturing representations and relationships as it was designed to do. The representations entered by the decision-maker were too ordered and provided little opportunity for further analysis. The diagrams were large—being complete solutions, and too flat—defining only one shared relationship for all the representations in the pattern. Ideally, the participants should define many different sets of relationships using smaller collections of representations. This would capture much more knowledge about the situation described. The second problem was that the software played too much of a passive role in the information gathering process: not guiding it or helping participants in any way other than recording the results. The modifications to the experiment and software during the first few runs tried to emphasize the software’s role in helping participants capture and work with representations.

Another problem that forced changes to the experiment was the concept of groups. Groups are the system's name for representations that are associated with collections. The group can be expanded to reveal the representations in the collection or the collection can be collapsed to return to the representation that refers to it. Groups generally play a bigger role during problem analysis which went beyond the scope of the experiment conducted. They were introduced in the first run in a "they are here if you want to use them" fashion. Unfortunately, this concept proved to be
too confusing for the limited training time available. Several of the early participants mentioned that the software would be much more useful after they had additional training and experience. The group features were also added to the software toward the end of its development so that their display behavior was designed well. A few participants were confused when large numbers of representations appeared or disappeared all at once. The use of groups was de-emphasized in the final version of the experiment.

Initial analysis of the results indicated that there was little difference in the number of answers given using Associative Maps and the number of answers given doing the problems by hand. If anything, fewer answers were given when the system was used. Table 1 lists the results.

Table 1

<table>
<thead>
<tr>
<th>Participant</th>
<th>Using Tool</th>
<th>By Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>94</td>
<td>111</td>
</tr>
<tr>
<td>Average</td>
<td>16</td>
<td>19</td>
</tr>
</tbody>
</table>
The tendency toward fewer answers given when using the system combined with the small sample size, problems with the testing procedure, and the assistance given by the investigator during the experiment made statistical analysis less useful than experimental observations and the system evaluation forms. The initial analysis did, however, reveal unanticipated problems with the test design. Participants were provided with a numbered answer sheet for each problem to encourage them to list their ideas. The first entry was filled in to give them an idea of what the problem expected. One problem showed up as a tendency of participants to fill in just over half the answer sheet and stop. The answer sheet had room for 25 answers and four of the six participants filled in just over half this number. They also came up with about the same number of answers for both problems, even though the nature of the two problems was very different. The investigator got the distinct impression while collecting one participant's results that he was happy to show that he got the same number of answers when using the software as he did in doing the problem by hand. Table 2 shows the relationship between the problem type, effect of using the tool, and the number of answers given. Underlined numbers are the rounded averages for the group.

The consistency in the number of answers generated for each problem suggests a possible lack of incentive for generating more answers. Unfortunately, the Human Subjects Institutional Review Board requirements makes it difficult to use performance-based incentives. The consistency may also be explained from the
experimental observation that participants often waited until the end of the test period to write their answers down. In their rush to get the answers down, they may have just listed what they felt was enough before turning the answers over to the investigator.

### Table 2

A Comparison of the Number of Answers Given by Problem Type

<table>
<thead>
<tr>
<th>Problem</th>
<th>Using Tool</th>
<th>By Hand</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>24</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>18</td>
<td>12</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>29</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>94</td>
<td>16</td>
<td>111</td>
</tr>
</tbody>
</table>

Among the two participants who showed a large variation in the number of answers given, they did much worse using Associative Maps than doing the problem by hand. Casual observation showed that many participants spent their time experimenting with the tool--trying out different things. This included participants who were trying to build complex patterns. They had to be constantly reminded to ignore how things were suppose to be connected and try to write some answers down using what they had done. Their experimenting with the software and tendency to build things may have contributed to the lower number of answers observed on problems done using the system.
Tables 3 and 4 show the effects of changing the order of the problems and the order in which the tool is used, respectively. The problem order had no apparent effect on the number of answers generated. Using the software on the first problem seem to increase the number of answers given on the second problem. When the tool was used on the second problem, the number of answers decreased. These results could suggest that using the tool gave participants ideas on how to generate more answers by hand or that the tool did not wear their concentration down as quickly as doing the problems by hand did.

Table 3

A Comparison of the Number of Answers Given by Problem Order

<table>
<thead>
<tr>
<th>Problem Used First</th>
<th>Using Tool</th>
<th>By Hand</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>12</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>25 16</td>
<td>29 18</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>B</td>
<td>18</td>
<td>24</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>15 15</td>
<td>14 20</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>94 16</td>
<td>111 19</td>
<td></td>
</tr>
</tbody>
</table>

One experimental result that is difficult to judge but worth noting is the variety of answers given. Problems done by hand should follow the problem description fairly closely while those done using Associative Maps should show more creativity. That is, participants doing the problem by-hand should focus more on information given in the problem description. There was no clear difference to
suggest this in the results observed. The knowledge capturing features of the tool did not appear to have their intended effect. This is probably due to the participants' inexperience with the features, particularly in their application to decision-making.

Table 4

<table>
<thead>
<tr>
<th>Tool Used…</th>
<th>Using Tool</th>
<th>By Hand</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>10</td>
<td>12</td>
<td>147</td>
</tr>
<tr>
<td></td>
<td>18 17</td>
<td>24 20</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>13</td>
<td>13</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>19 16</td>
<td>13 13</td>
<td>15</td>
</tr>
</tbody>
</table>

|               | 199 17     | 105 18  |

The participants did, however, show interesting variations among each other as each brought their own knowledge and perspective to the problems. Given problems in facilities planning, one participant noted the need for providing electrical service to the machines. None of the other participants recognized this need. The same participant repeated this requirement for the second problem, showing a tendency to carry recently used knowledge over to successive decisions. One of the problem descriptions was indirectly worded to imply a need to replace worn equipment. The objective was to get participants to think about the maintenance requirements for the equipment listed. In response, one participant suggested the use of Titanium Nitride coated drill bits to reduce the need for replacement. Variations
like these point out why it is important to bring many people into a decision. It may also show an advantage to having each person solve the problem separately. If they worked together, they might end up interpreting the problem the same way and would not have as much variety in their answers.

**Analysis of the Evaluation Forms**

Evaluation forms were given to participants in order to obtain qualitative results for the experiment. These forms provided information on effectiveness of the tool and the experimental design. The system evaluations were very positive. Participants felt the software was either helpful or very helpful in solving the problems. They also felt the software would be helpful in solving the types of problems they would face in their careers. Although, there was a tendency to lower their rating on this second question from very helpful to just helpful. The initial participants felt the tool was of average difficulty and complained about having to remember key strokes and operations. The tool demonstration for these participants focused on using key strokes and provided no help sheets for the tool. These participants were also the ones introduced to the group operations. Participants in the final experiment were shown mouse and menu equivalents to the key stroke commands with an emphasis on non-group operations. They were also given a help sheet that showed the commands and visual results of using each command. These participants found the software easy to use, although, they still felt more practice was needed.
The participants offered some general comments about the tool. One feature they felt was useful was the ability to arrange and group items on the screen. One subject commented that the "graphical presentation helps [you] to think better about these areas [of the screen] and classify them." Two subjects wanted pop-up text boxes that identified the names of items connected to another item or contained in a group. In general, a way to condense or overview an area of the map would have been helpful. Participants frequently got "lost" during the experiment. One participant brought up the difficulty of distinguishing between an independent node and the instance of the node in a collection. This participant suggested that the independent nodes have capital letters or use a different background shading. Another subject suggested the creation of a more advanced tool for reusing patterns. This tool would combine patterns of similar things and let the decision-maker select the combined pattern, delete elements that are not needed, and add elements that are missing. Most of the comments were about getting more practice with the tool or on providing tutorials and adding help features. These comments show one reason why the tool did not increase the number of answers given: participants needed more time to learn how to use the tool for problem solving.

Reflections on the Experimental and System Design

Associative Maps were designed to support the whole decision-making process in a manner that worked with and guided the decision-maker's natural tendencies. They were designed to capture, refine, and reuse knowledge over many
decision situations; to help the decision-maker build strategies and schemata for use in specific situations. A thorough evaluation of their effectiveness would require many hours or even days of participation. This would be inappropriate for the first test of an entirely new tool, so the current experiment was limited to a preliminary evaluation of one aspect of the tool. Its goal was to see whether the knowledge capturing features of Associative Maps could increase the knowledge captured by the decision-maker during analysis of a problem description. Even so, it was a difficult experiment to design and some problems did occur.

Problems With the Experimental Design

One problem with the experimental design occurred in writing the problem descriptions for subjects to work on. Although an adequate problem format was eventually found, the final problems were not ideally suited to the task. The difficulty was in writing descriptions that had enough missing information to require the participants to apply their own knowledge while not leaving out so much information that the participants had little to work from. Similarly, it was difficult to write descriptions that solicited knowledge at the appropriate level of detail. It was hoped that asking for statements that applied to "similar situations" would accomplish this task. However, one participant still listed "use Titanium Nitride coated drill bits" when the problem was looking for "allow space for servicing equipment." The initial experiment provided too much detail making the problem descriptions difficult to read and leaving the participants wondering what was expected of them. The final
experiment provided too little detail so that participants were either at a loss for ideas or provided too many details of their own.

Another problem with the experimental design was the pretest instructions. The participant's task was not made clear enough so that they ended up wasting too much time building patterns and experimenting with the tool. This problem was partially due to the lack of time needed for explaining the philosophy behind the tool. It was compounded by the fact that the system objectives were not entirely clear on how the tool would be used. An attempt to provide detailed step-by-step instructions failed because the instructions were not used. This approach might have worked if the steps were integrated with the problem description.

The problems with the experimental design can be attributed to three learning curves that the participants had to contend with at the same time. They had to learn how to use the tool, understand how the software was used to solve problems, and understand what the problem was asking for. During the initial experiments, participants spent most of their time learning how to use the tool and complained about having to remember key sequences. After changes to the experiment and tool to make things easier, participants had trouble understanding how to use the tool to solve the problems given. Rather than use the tool to come up with as many ideas as possible, participants would ask how to connect nodes together in a certain way. They were thinking about how to represent knowledge rather than trying to capture it. Finally, even when participants were not using the tool, it was evident that they had
trouble understanding what they were suppose to do to solve the problems. Changes
to the wording of what was asked for helped to reduce this problem. However, the
type of answers given and the difficulty participants had in generating them suggested
that they spent most of their time reflecting on the information given rather than
expanding on it to reveal new insights.

Problems With the System Design

The evaluation research revealed a number of areas where improvements
could be made to the system. These improvements address the first two problems
encountered in the research: learning how to use the system and understanding how to
solve the problems using the tool.

The two main problems encountered were (1) the tool did not assist the
decision-maker in deciding what to do next, and (2) the tool operations did not clearly
communicate what they expected the decision-maker to do. The tool required the
decision-maker to keep track of this information. This requirement violates the
objective of minimizing the cognitive load on the decision-maker by keeping track of
as much information externally as possible. One way to notify the decision-maker of
the operations available is to show the operations in some area of the display. A
participant suggested that the system display icons in the tool bar showing the current
mapping mode being used. Microsoft Window's applications use the tool and menu
bars to notify the user of the operations available. The problem with tool bars and
menus is that they are easy to ignore, especially if they have many options that are
continuously displayed. Another concern is that they generally display many types of
options, not just suggestions for what to do next. The ideal solution might be to have
a separate tool bar or box with fewer options that the decision-maker could look at
when he or she feels the need to do something else. This may be combined with a
feature that draws attention to the "option" bar after a period of inactivity by the
decision-maker.

The second problem with the system design, that of having operations
communicating what they expect, is specific to each operation. Associative Maps
were designed so the decision-maker could create and endless supply of operations
from just a few primitives. Since the primitives handle the screen display, the
software has a limited number of ways for operations to interact with the decision-
maker. Even so, the few primitives that do exist could be designed to communicate
the expected inputs better. For example, the current knowledge capturing modes have
one weakness: they do not bring the decision-maker's attention back to the focus
thought. They should be saying "here is the focus thought, what does it make you
think of?" After the decision-maker enters the next thought, the focus node should
flash once to draw the decision-maker's attention back to it--possibly repeating this
behavior again after a sufficient delay.

Another problem with Associative Maps is that the display area gets cluttered
with information of different types or information that does not apply to the problem
at-hand. Associative Maps treat processes as knowledge and store them with other
knowledge. They also display processes with other knowledge in the same area of the display. This arrangement is awkward when a process is being used to work on knowledge. It displays more of the process than the decision-maker is interested in and clutters the limited display area with distracting information. This is another violation of the cognitive load objective, the decision-maker should not be thinking about other parts of the process while performing a single operation. To solve this problem, the current operation should be integrated with the interface so that it is in a different display area than the work being done. The system should also provide an operation that displays the whole process in the central display area at the decision-maker's request.

The amount of information displayed can also be reduced by isolating percepts from other knowledge. Percepts are feelings, sights, sounds, and other experiences that are invoked by knowledge. Since Associative Maps deal strictly with text, the decision-maker must represent percepts with words or phrases. These words or phrases could be shown in their own area of the display so that they are not confused with the knowledge that invokes them.

Two other areas where extraneous information could be reduced or better organized involve the activation of connected nodes and the separation of groups on the display. When the decision-maker asserts the focus node to keep it displayed, all nodes connected to the asserted node remain displayed when the focus is moved elsewhere. This behavior lets asserted nodes act like menus with their options staying
displayed. However, it was distracting and inconsistent with the original model--only the focus node changes the event pool by activating connected nodes. The other problem was being able to make the distinction between two or more groups on the display. Normally, the groups occupied different areas of the display. However, a problem occurred when the decision-maker moves from one group to another and then started adding new nodes. It is not clear which group the nodes should be added to, if any. The tool should make it very clear when the decision-maker is adding nodes to one group or another, possibly by placing boundaries around the groups.

The tool could also aid the decision-maker by managing more of the decision-making process. Currently, when switching from one operation to another the decision-maker must manually select the resources (i.e. process and structures) available to the operations. This work is tedious and distracting for the decision-maker and could be managed by the tool. The tool could also show the resources in a separate area of the display or bring the information forward on command. The decision-maker could add or remove resources to these areas while letting the tool add them to the knowledge structures. Similarly, the tool can keep track of other process information such as the state of the process prior to being suspended and the first, next, and previous process steps.

One of the difficulties identified by participants in the experiment was finding the knowledge they had just entered into the tool. The tool could have made this task easier by making recent information more available, just as the human brain does.
There are a couple of reasons for doing this. First, it lets the decision-maker pursue thoughts until they are exhausted and then quickly return to them for analysis. Second, it helps the decision-maker expand his or her cognitive abilities. A person can quickly "juggle" recent information to get the best set of $7\pm2$ items to integrate. The tool could help the decision-maker to do this by keeping the best set of items displayed and let the decision-maker replace any of these items from a list of recently accessed information. This list should probably contain only items that were active for some period of time or received the decision-maker's attention for some reason.

The tool should also assist in the search for knowledge. One participant suggested the tool should display a list of the connected nodes in a hierarchical format. This was previously considered but left out of the tool because of the difficulty of supporting the complex structures that can occur in knowledge. The levels of a hierarchy are represented by collections in Associative Maps. However, there is no guarantee that all members of the collection will be active at the same time as is the case of a hierarchy. Other connections into the collection can activate only selected groups of members. The other choice was to list the nodes spreading away from the focus using a hierarchical display to show the spread. Unfortunately, this encourages the decision-maker to use connections when he or she really wants to represent a hierarchy. Connections should not be used to create hierarchies because connected representations do not necessarily share a common relationship as is the case for representations in the same level of a hierarchy. The best solution may be to
store search paths for knowledge within the knowledge. The tool can assist the
decision-maker by providing a hierarchical tool for building and searching these
paths. The decision-maker could drop and remove items from the hierarchy and the
tool would take care of building the necessary knowledge structures.

Participants also had a problem finding similarly named representations. This
is not a problem in human memory because invoking the name is the same as having
found it. However, the tool does not know whether the entered representation is one it
already has stored or something new. One thing it could do is check for a name with
the same spelling and ask the decision-maker if it is the same as the entered name. If
it is, the two names are treated as separate instances of the same representation. If the
decision-maker is not sure of a name, the system could provide an alphabetical listing
of names close to the one entered.

Suggestions for Additional System Operations

The operations provided by the tool either make routine tasks easier or
combine functions that cannot be broken into smaller parts. There are a number of
operations in addition to the ones mentioned that would make the Associative Maps
more usable. One operation would make it easier for decision-makers to compare,
evaluate, and classify items. The decision-maker would be able to choose the items to
compare, the dimensions along which they are compared, the reference points used,
whether the evaluations were to be made on a relative or absolute basis, and the
categories to place the results in. Another useful operation would help decision-
makers follow or apply patterns of connected nodes. The decision-maker would call up and move through the pattern occasionally selecting nodes. The tool would follow the user creating copies of the nodes in a new collection as the user selected them. The decision-maker could then add to and modify the new pattern while comparing it with the original. A third operation would help the decision-maker find or identify the current and final objectives. It might use a hierarchical tool to find the current and final objective or build them by accumulating conditions. Then, it would help the user accumulate, organize, and evaluate sets of operations that mapped between the current and final conditions. The final operation would let the decision-maker encapsulate outside tools within the framework of Associative Maps. This is needed so the decision-maker can bring specialized tools, such as spreadsheets, to bear on parts of the problem.

Chapter Summary

This chapter described an experiment to evaluate whether Associative Maps could increase the number of statements people made about a problem situation. While the results did not confirm this, a considerable amount of information was gathered on ways to improve both the tool and experimental design. The main problems with the tool design were its required learning curve and participants not understanding how it was used to solve problems. It was decided that the tool needed to take a much more active role in directing the participants actions--at least, for the time limitations given by the experiment. The main problem with the experimental
design was creating problem descriptions that provided enough information to stimulate ideas, but not so much that there was nothing left to be said or not enough time to say it in. The experiment needed to be done using real problem descriptions over a much greater time period than what was available. In the end, this experiment was successful at achieving its real objective: gathering information on ways to make Associative Maps more effective in real decision situations.
CHAPTER IX

CONCLUSION

Despite the popularity of computers and the availability of computer-based decision-making systems, many decisions are still being made without fully utilizing the computer's potential to improve them. The reasons for this are that the available systems apply only to limited decision-making activities or domains and they force the decision-maker to follow a closed and inflexible way of doing things. The motivation behind my thesis was a vague perception of many simple, open, and broadly applicable ways in which computers could significantly improve decision-making without being restrictive on the decision-maker. The difficulty was in defining why these ways worked, how they fit together, and how decision-making systems could be designed to use them. After considerable reflection, the goals of Synergistic Decision-Making Systems were established and a design approach was chosen that used models of decision-making behaviors and resources as the basis for building better decision-making systems. Chapter I introduced the goals of Synergistic Decision-Making Systems and described the characteristics of the models needed to build them.

One simple, open, and broadly applicable way of improving decision-making is to use a process as a model for decision-making behavior. The process model
provides a foundation for defining, understanding, and consequently improving the way decisions are made. Chapter II described the process model, argued the case for using formal decision-making processes, and used The Decision Process to identify the basic parts, relationships, and attributes of decision-making processes. This chapter laid the groundwork for building decision-making systems that could improve decisions by helping decision-makers define, manage, and improve the way decisions were made.

Another way decision-making systems can improve decisions is by assisting the decision-maker in collecting, identifying, evaluating, and organizing information about the decision. This requires that the decision-maker and decision-making system have a shared representation of the decision knowledge. Chapter III identified the structures needed for representing decision knowledge and described a model of associative memory that explains the characteristics and behaviors of these structures. This model later provided the foundation for understanding how memory resources affect decision-making. Chapter IV also described the interaction between associative, emotional, and working memory. This interaction served as a model for the interface between the decision-maker and decision-making system.

Decision-making systems can also improve decisions by reducing or eliminating the unfavorable effects of decision-making biases. Chapter IV used the model of associative memory and research in decision-making to identify factors that lead to decision-making biases and to describe the effect of these biases on decision-
making. The goal of the decision-making system is to address those factors that most contribute to unfavorable effects. Chapter IV organized decision-making biases into three categories that roughly determined the approach to dealing with them. Evaluation Biases can be addressed by using the parts, relationships, and attributes of a decision to assist in the evaluation process. Attention Biases can be addressed by using idea generation techniques, memory cues, and perspectives to reveal alternatives. And finally, Knowledge Biases can be addressed by using tools to analyze and synthesize knowledge structures, creating different translations of the decision.

While the previous chapters dealt exclusively with issues regarding all decisions, Chapter V introduced a generalized strategy that is capable of addressing specific types of decisions and problem domains. This chapter described techniques for capturing decision information and for discovering, refining, and reusing patterns that occur in this information. The ability to work with patterns changes a decision-making system from a general, but essentially closed system, to an open system that is capable of addressing application and domain specific issues.

Chapters VI, VII, and VIII applied the ideas discussed in the previous chapters. Chapter VI examined the application of these ideas to the design of decision-making systems. It looked at how decision-making systems can (a) use the process model to define, manage, and improve decision-making behaviors; (b) use the model of associative memory to help decision-makers avoid the three types of biases;
and (c) use Patterns to help decision-makers discover, refine, and reuse decision knowledge. Chapter VII described a prototype Synergistic Decision-Making System that is primarily based on the model of associative memory and the use of Patterns as described in Chapter V. The user-interface to the prototype system is based on the model of interaction between associative and working memory. Chapter VIII described an experiment to evaluate whether the prototype could increase the amount of knowledge gained from a problem description. This chapter also described the insights gained from the experiment and made suggestions for improving the prototype’s design.

This thesis started with a few vague ideas about ways computers could be used to significantly improve decision-making. It took what seemed to be three unrelated approaches to define these ideas, each failing in one aspect or another. Eventually, these approaches were seen as a complimentary set and the final version of the thesis came together. While the final results were not what was hoped, they were much better than expected. This thesis provides a good foundation for creating a new class of decision-making systems that: (a) interact more naturally with human decision-makers, (b) encompass all decision-making activities and domains, (c) help define and manage the decision-making process, (d) optimize coverage of the decision space, and (e) build on the individual strengths of computers and people while compensating for individual weaknesses.
Appendix A

The Model of Associative Memory
The Model of Associative Memory

This appendix contains an earlier version of Chapter 3, "Defining a Model of Decision-Making Behavior. This version provides more detail than was considered appropriate for body of this thesis.

The Structure of Knowledge

The structure of knowledge provides a framework for understanding the workings and organization of the human brain. It is composed of two parts, representations and relationships. Representations are things that occur, or come into existence for a brief period of time. They stand for objects, concepts, sensations, emotions, actions, and so on. Anything that can be perceived or performed is a representation. Relationships are concerned with how representations are bound together. Three different types of relationships can be identified by examining many different techniques for representing knowledge. The three types that repeatedly occur are combinations, connections, and collections.

Combinations are groups of representations that occur together and create the perception of a whole. They are often shown by creating a spatial or orientational relationship between the representations, or by placing a border around them. The defining characteristic of a combination is that there is something about the whole that is more than its parts. Thus, people recognize the contents of a picture rather than for the lines and colors used. The combination members define the whole. Although, many different combinations may be used to define the same whole.
The second type of relationship is the connection. The connection directs attention from one representation to another. Both representations are perceived as independent entities and a person's attention is focused on only one representation at a given time. If the attention is directed in one direction, the connection is a link; otherwise, it is an association. Connections show sequence or relatedness, but do not define what the sequence or relation is. They are usually represented by arcs drawn from one representation to the other. An important aspect of a connection is that the shift in attention occurs across time. In other words, connections capture small time intervals that separate representations but also tie them together. Connections can show a relationship between only two representations.

The final type of relationship is the collection. Collections are contexts or categories for representations. Unlike combinations, the members of a collection do not combine to create a new whole. The members are perceived individually while also being recognized as belonging to the collection. The collection members usually have little to do with defining the collection. In fact, new members can be continually added. It is more common for the collection to identify the shared properties of its members, such as in the classical definition of a category. Collections are often represented by aligning their members in rows or columns without using a border. In addition to serving as contexts or categories, collections are frequently used for showing stages or establishing preconditions for completing connections. Collections can show a relationship between many representations.
In summary, knowledge is composed of representations bound together by three different types of relationships: combinations, connections, and collections. It is a dynamic structure, involving both state and time, that provides a framework for fitting the work of researchers in neurobiology, brain anatomy, and cognitive science into a model of how associative memory works.

The Model of Associative Memory

The human nervous system, including the brain, has over 100 billion nerve cells, called neurons. Some of these neurons generate events in response to external stimuli or changing conditions within the body. Some release neurohormones that cause muscles to contract or regulate various systems in the body. The remaining neurons--a vast majority, send events to and receive events from other neurons. Their organization and behavior determine a person's thoughts, perceptions, emotions, and behaviors at any given moment. Many of these neurons form the basis for knowledge--they invoke representations and their interconnections define relationships. These neurons are collectively referred to as associative memory.

The model of associative memory includes models for two broad types of neurons, along with the general organization of these neurons within regions of memory and the general mapping of events between regions. The model will show how associative memory stores and recalls knowledge composed of combinations, connections, and collections. And, it will show that some of the functions of associative memory are mostly automatic while others are controlled by a system.
referred to as working memory. Finally, the model will describe the general interaction between associative memory and a system known as working memory.

**Neuron Learning and Behavior**

The event generation behavior of a neuron begins when the ion level at the cell body, or soma, raises the cell's potential above an activation threshold. This causes the neuron to initiate an event on its axon. The neuron is said to fire. The axon propagates the event from the soma to the dendrites of target neurons--splitting apart along the way, often a few times, to form many axon terminals that contact the branches of the target dendrites. The contact point between an axon terminal and a dendrite is called a synapse. When the event arrives at an axon terminal, it excites a target neuron by releasing neurotransmitters into the synaptic cleft between the cells. These neurotransmitters open gates on the neuron's dendrite that allow positive ions into the cell (In the case of inhibitory synapses, negative ions flow into the cell). The same target neuron may receive synapses from many different sources. If the combined activity of all these synapses raises the ion level above the target neuron's activation threshold, the cell fires. The build up of ions at the cell body may take a moment to occur so the cell's output is not instantaneous. The cell membrane slowly pumps the positive ions back out of the neuron until the cell is restored to its resting state.

Learning results from an increase in the number and strength of synapses that cause the neuron to fire. The first widely accepted postulate on how this occurs was
proposed by Donald O. Hebb in 1949: "When an axon of cell A...excite[s] cell B and repeatedly or persistently takes part [Italics Added] in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficacy, as one of the cells firing B, is increased." (Hebb, 1949, p. 34) This postulate is known as Hebb's Learning Rule, or Hebbian Learning.

The biological mechanisms of learning are very complex and not completely understood. The learning behavior varies from one type of neuron to the next and even within the same neuron over time. However, the types of changes that can occur are fairly well understood and it is possible to construct a model neuron and determine its behavior from the task it must perform. Figure 1, "Learning in Neurons", presents a model neuron.

A. Before Learning
Events a and b frequently arrive at the same time.

B. After Learning
The neuron fires only when events a and b arrive at the same time.

Figure 1. Learning in Neurons.

Part A of Figure 1 shows the neuron before learning occurs. The thin arrows touching the cell body indicate incoming events with weak synapses. The initial synaptic strengths may vary somewhat so that some neurons are predisposed to
learning specific events. The vertical bar drawn close to the incoming events represents the neuron's initial activation threshold. This threshold is high enough to keep events with weak synapses from firing the neuron. However, if two or more events arrive at the neuron together, they can strengthen each other's synapses by a process known as long-term potentiation (Levitan and Kaczmarek, 1991, pp. 419-422). This process can also occur with a single event in a few instances. Eventually, the mutually strengthened synapses help the combined events fire the neuron. The model neuron assumes that this action starts a second stage of learning as described by Kandel and Hawkins (1992, p. 86):

Experiments in both the Aplysia and mammals indicate that explicit and implicit memory storage proceed in stages. Storage of the initial information, a type of short-term memory, lasts minutes to hours and involves changes in the strength of existing synaptic connections... The long-term changes (those that persist for weeks and months) are stored at the same site, but they require something entirely new: the activation of genes, the expression of new proteins and the growth of new connections.

The first stage may be needed to "pick out" which set of simultaneous events will cause the neuron to fire. The second stage then reinforces the selected events. The model neuron further assumes that the neuron's firing begins a process that raises its "steady-state" activation threshold. This assumption is important in cases where a neuron can continue learning after it has learned the original events. It helps keep
weakly connected events from firing the neuron out of sequence with the original events, but lets the events strengthen their connections if they repeatedly occur in sequence with the original events. That is, it insures that the neuron represents one thing--the one it originally learned--but does not prevent other events from learning to invoke that representation. The second stage of learning comes to an end as the neuron connects its output to other neurons. At this point, the steady-state activation threshold and synapses become stabilized.

The actual cellular processes involved in learning probably overlap to some extent and may be triggered by events other than those mentioned. The intensity of events may also factor into the whole learning process. More intense events produce bigger increases in synaptic strengths and neurons probably fire with greater intensity as they progress through the learning process. The main requirements for learning are the repeated pairing of events and the eventual selection of one set of events over all others.

Two additional requirements are needed in part to address problems resulting from the high density of neurons packed together within the regions of the brain. The first requirement is that learning occurs only in the synapses that become active just prior to a neuron's firing. More specifically, learning does not occur in synapses that have been active for some time. If this requirement did not exist, a neuron could easily end up confusing the sequence of events. The second requirement is that a neuron needs a moment of rest to recharge the learning process. The repeated pairing
of events needed for learning must be distributed across time. This keeps feedback loops from forming unintentionally and ensures that events will settle down quickly if not maintained by external processes. In effect, the neuron "debounces" the learning process.

Some neurons can continue learning to fire to new events, provided the events repeatedly occur in sequence with events that already cause the neuron to fire. If this possibility did not exist, a person could only experience events as they happen. He or she would be unable to remember or associate things because these abilities require the invocation of representations in the absence of the events that originally created them. Figure 2, Continued Learning in Neurons, shows how a neuron might learn to fire to a new event.

![Diagram](image)

The neuron first learns to fire when events a and b occur together. Next, event c frequently occurs along with events a and b until event c can fire the neuron by itself. After learning, the neuron fires to events a and b, or event c.

Figure 2. Continued Learning in Neurons.

This second type of neuron requires a combination of its original events or any of the new events to fire. The activation threshold is drawn across the middle of the neuron to show that a single "strong" event is enough to fire the neuron. Strong
events are assumed to be events coming from other regions of the brain. Note that the first type of neuron probably stops learning when its few main dendritic branches are monopolized by different inputs. The effect of the branching structure on reducing the number of inputs is described by Levitan and Kaczmarek (1991, p. 357):

For example, on a cell that has a complex pattern of dendritic branches, competition may lead one cell to establish its terminals on one branch, at the expense of synapses from other cells. On another branch or a different region of the dendritic tree, the terminals of a different cell may gain precedence, and the mature postsynaptic cell will come to be innervated in different regions by different axons.

The requirements for learning do not apply to the behavior of neurons after learning occurs. The main distinction is that events do not have to occur at the same time to fire the neuron or keep it firing. One event can arrive early, maintaining the neuron's ion level above its normal level but below its activation threshold. Then, a second event can arrive to raise the ion level above the activation threshold causing it to fire. In other words, a cell can be prepped for firing. Another possibility is that the cell can start firing to one event and then let another event "take over." This may be how people remember things for a delayed response as described by Goldman-Rakic (1992, p. 113):

Using the eye-movement experiment, we have demonstrated that certain neurons in the prefrontal cortex posseses what we call "memory fields": when a particular target disappears from view, an individual prefrontal neuron switches into
an active state, producing electrical signals at more than twice the baseline rate. The neuron remains active until the end of the delay period, when the animal delivers its response. A given neuron appears always to code the same visual location.

The ability of a synapse to accept this kind of continuous stimulation and the ability of a neuron to continuously fire is probably restricted to the second type of neuron. If an event arrives at the synapse of the first type of neuron too soon, some degradation probably occurs that keeps the synapse from working for a short period of time. This behavior might have to do with the supply of positive ions at the synapse. The model makes this assumption so that it can use the first type of neuron to detect a sequence of events, such as a word made up of a combination of syllables. To detect a sequence, the neuron must be able to combine an event with another delayed event. The complex branching structure of the neuron's dendrite probably causes the delay.

Up to this point, neurons have been described as sending and receiving events. This is sufficient detail for describing most neural behavior but there are a few significant behaviors or effects that require a little more detail to understand. Neural events are actually abrupt changes in the frequency with which a neuron generates electrical spikes (Crick, 1994, p. 92). These changes begin when the ion level at the soma first exceeds the neuron's activation threshold. After the neuron fires, its activation threshold increases significantly to keep it from firing again. The threshold then decreases exponentially until it returns to its steady-state value. The higher the
ion level is, the quicker it exceeds the falling threshold value and the sooner it will fire again. The end result is that the higher the ion level is above the initial threshold, the higher the frequency of spikes generated (Levitan and Kaczmarek, 1991, pp. 37-41). That is, events fire with greater or lesser intensity. The neuron stops firing when ion level drops below the steady-state threshold. The model uses these behaviors to explain some effects of neural behavior on decision-making.

In review, the model of associative memory includes two types of neurons. One type, call it Type A; learns to combine events that occur close together in time, needs most of its inputs to fire, and effectively stops learning after its main inputs are used. The other type, that is Type B; learns to combine events that occur at the same time, but only needs a single strong event to cause it to fire and can continue learning new events if they initially occur in concert with existing events. The model also assumes that learning occurs only in synapses that become active just prior to the neuron's firing, although Type B neurons can be continuously stimulated by events. The model will show later on that the primary function of a Type A neuron is to combine time correlated events into a single new event, while the function of a Type B neuron is to echo these combined events to other regions of memory. The key feature of a Type B neuron is that it lets a new event invoke a representation in the absence of the events that originally combined to create the representation. Before these separate functions can be understood, the organization of neurons within a region of memory must be described.
Organization of Neurons

Ultimately, the role played by a particular neuron depends on its location within the general organization of the brain. The model of associative memory is primarily concerned with the organization of neurons in the cerebral cortex—a part of the brain associated with memory. The cerebral cortex consists of two large wrinkled sheets that line the surface of the skull on either side of the head. Researchers usually divide the cerebral cortex into regions associated with broad functional areas such as language or touch. The general architecture of all regions is the same, however, and it may be more meaningful to classify them by their main inputs. The following summary on the architecture of a region was derived from Crick (1994, pp. 94-95, 132-135).

The most studied region of the cerebral cortex is known as V1. V1 is comparatively easy to study because it receives a crude map of the image falling on the retina. That is, a neuron in a particular area of V1 responds to an event or events from a corresponding area in the retina's visual field. The main inputs from the retina enter region V1 at layer 4, one of the six layers of the cortex. Layer 4 is conspicuous among the layers in that it is the only layer containing spiny stellates, a small neuron with widely dispersed dendritic and axonal branches. The relatively short dendrites of the spiny stellates stay mostly within layer 4, while their axons may reach into other layers. Layer 4 is composed almost entirely of this type of neuron. Most of the other cells in the cortex are pyramidal cells whose dendrites and axons extend
vertically through the layers. The axons of some pyramidal cells may split off in horizontal directions within a layer, others may leave the cortex to reenter it elsewhere, and still others may leave the cortex entirely.

The neurons of layer 4 receive their inputs from the retina and send their outputs to the pyramidal cells in layers 2 and 3 which also receive inputs from other parts of the cortex. Some of the outputs from layers 2 and 3 leave the cortex to only to reenter it at other locations. The other outputs cross through layer 4 to the neurons of layer 5. The outputs from layer 5 either leave the cortex to non-cortical regions or spread horizontally some distance while sending axon branches into layer 6. Layer 6 sends many of its outputs back into layer 4 and other outputs to the thalamus and claustrum, two structures strongly bounded to the cortex. As Crick (1994, p. 279) describes them: "The thalamus is the gateway to the cortex, since all the senses (excepting smell) must relay through it to get to the cortex." The claustrum "receives an input from many cortical areas and may send connections back to all of them." (p. 250) The separation of the different types of inputs and outputs into different layers of neurons appears to be a common pattern in the brain.

The model of associative memory assumes that the inner layers: 2, 3, and 4 are the main processing areas of the cortex while the outer layers: 1, 5, and 6 are primarily concerned with communications and control. The inner layers are responsible for building the three relationships: combinations, connections, and collections. The neurons in layer 4 combine events and send their output to layers 2
and 3. Layer 4 is where new combinations are made using Type A neurons. The inputs from other cortical regions enter layers 2 and 3 to invoke representations independently of the combinations that originally created them. Layers 2 and 3 are where connections to representations are made using Type B neurons. The model explains the final relationship, collections, by observing that an incoming event can spread out to provide a single input to many neurons in layer 4. One event "enables" a group of Type A neurons that form the basis of a new collection. The output of the neurons in the collection eventually learn to invoke members of the collection which actually exist in other regions of the cortex.

Detecting Representations

The primary functions of associative memory are to learn, replay, and detect representations. The first two functions can be explained at the level of individual or small groups of neurons. They occur independently of, or in collaboration with, other systems of the brain. The third function, detecting representations, involves interconnected groups of neurons and is largely independent of other brain systems. It occurs in two stages: one that separates and abstracts aspects of a situation or thing and one that recombines specific aspects into new wholes. The process by which associative memory detects a representation is one of the most important processes performed by the brain. It can be seen most clearly in the processing of the retinal image.
The main events generated by the retina enter the cortex at layer 4 of region V1 where processing begins. Each event carries information on many different aspects of the image. Most of the events occur when a light or dark spot appears and disappears amid a small circular area of contrasting dark or light. The same axonal input delivers a separate event for both the appearance and disappearance of a spot within particular area of the retinal image. The event's intensity varies with the portion of the contrasting area covered by the pattern falling across the spot (Crick, 1994). Lines passing directly over the spot will result in fairly strong events since they cover little of the surrounding area. However, lines or other patterns that cover most of the surrounding area will generate only weak events. Many of these events also carry information on color, since their spots and surroundings are tuned to different wavelengths of light. "For example, the center of the receptive field of a P cell may respond well to green wavelengths whereas its antagonistic surround may be more sensitive to red ones. Because of this there are several subtypes of P cells, each interested in different color contrasts." (Crick, 1994, p. 125) Finally, the direct mapping of events from specific areas of the image to corresponding areas of region V1 provides information on simple patterns and movement within a local area. Therefore, a single event can carry information on the shape, color, position, and state of the pattern falling on a particular part of the retina.

Layer 4 of region V1 begins the process of separating and abstracting the aspects of the retinal image. It does this primarily by combining events that occur
close together in time and space. For example, a line that falls across an area of the retina will generate a set of simultaneous events. The neurons of region V1 corresponding to this area of the retina will learn to detect the line after repeated occurances. Some of the neurons in layer 4 learn to detect only a spot of light amid antagonistic surroundings, "most of the other neurons in area [region] V1 respond best to a thin bar of light (or darkness) or to an edge, rather than to a spot of light... For any particular neuron there is one particular orientation of the line or bar to which it fires most vigorously. If the orientation deviates from this by as little as 15 degrees, the firing rate is usually much slower." (Crick, 1994, p. 142) The response of individual neurons to lines shows that region V1 has started to separate and abstract patterns from the retinal image. V1 probably uses a similar process to extract other aspects of the image such as color and motion. The different color contrasts of the spots and their surroundings may help some neurons separate simple color patterns from more detailed patterns of light and dark. Furthermore, the complex geometries of layer 4 neurons may delay some inputs in a way that enables their neurons to detect motion in a given direction.

The outputs of region V1 go directly, or indirectly through region V2, to regions V3 through V5 (Zeki, 1992). Each new region integrates new inputs and adds new degrees of separation and abstraction that cover increasingly larger portions of the visual image. The layers within each region increase abstraction while the direct mapping of outputs from one region to the next help to increase separation. "The
forward projections are patchy and discrete, because segregated groups of cells in V1 and V2 send their outputs to specialized areas [regions] with the corresponding visual attributes." (Zeki, 1992, p. 76) The separation is probably initially laid down by genetics and then further refined by the learning process. By the time events leave regions V3, V4 and V5, the retinal image is separated into aspects of dynamic form, color and form-with-color, and motion (p. 72).

The last stage of detection recombines selected aspects of the image into a new whole. For example, if there is some special significance to a moving red box, the outputs of regions V4 (form-with-color) and V5 (motion) must be combined to detect this event. This could occur through reciprocal connections between these regions or in another region further on in the cerebral cortex.

For example, areas [regions] V4 and V5 connect directly and reciprocally with each other. Both of them also project to the parietal and temporal regions of the brain [cortex], but... the outputs from each area occupy their own unique territory within the receiving region. Direct overlap between the signals from V4 and V5 is minimal. It is as if the cortex wishes to maintain the separation of the distinct visual signals--a strategy it also employs in memory and other systems... Any integration of the signals within the parietal or temporal regions must occur through local "wiring" that connects the inputs. (Zeki, 1992, p. 75)

While the different aspects of an object may be combined in a new region, the model of associative memory assumes that the component aspects are "experienced"
in the regions in which they originally occurred. Thus, there must be return projections to the regions that detect these aspects. It turns out that such a system of projections does exist.

The return projections, however, are diffuse and fairly nonspecific. For example, whereas V5 receives input only from select groups of cells in layer 4B of V1, the return input from V5 to layer 4B is diffuse and encompasses the territory of all the cells in the layer, including ones that project into V3. This reentrant system can thus serve three purposes simultaneously: it can unite and synchronize the signals for form and motion found in two different pathways; it can refer information about motion back to an area with an accurate topographical map; it can integrate motion information from V5 with form information on its way to V3. (Zeki, 1992, p. 76)

**Thought Transitions**

Detection is one of two ways in which representations can be invoked, the other way is through relationships. Unlike detection which is mostly independent of other systems and almost instantaneous, relationships often require the slow incremental involvement of other systems. They define the most common paths by which thought moves from one representation to the next. This movement is referred to as a thought transition. Relationships embody two different types of transitions, horizontal and vertical. The horizontal transitions occur when a person goes from perceiving one entity to perceiving another. For example, when the person sees one city on a road map and then another. These transitions show the interaction of
independent things or events. Connections are used for creating horizontal transitions. Vertical transitions, on the other hand, occur when the person goes from perceiving a whole to perceiving things within the context of a whole. For example, when the person goes from seeing the road map to seeing a city on the map. The context of the map remains active while another part of the mind focuses on a detail. Collections are used to support vertical transitions. Thought transitions—which involve sequential processes, are the complement of detection which is mostly a parallel process.

The Role of Working Memory

Associative memory can perform much of its work without the support of other systems. Its main limitation is that it can only handle events that occur close together in time. That is, associative memory has little facility for recalling, holding, or synchronizing representations that occur at different times. It also has little control over attention, setting priorities, or evaluating representations. These tasks must be provided by some other system in the brain.

According to present thinking, a form of memory known as associative memory acquires facts and figures and holds them in long-term storage. That knowledge is of no use, however, unless it can be accessed and brought to mind in order to influence current behavior.

Working memory compliments associative memory by providing for short-term activation and storage of symbolic information, as well as by permitting the manipulation of that information. (Goldman-Rakic, 1992, p. 111)
In order to perform its tasks, working memory must be able to excite and inhibit the activity of associative memory. It must be able to choose the representations it is interested in and suppress those it is not. In her review of research on working memory, Goldman-Rakic (1992, p. 115) suggested that "the ultimate function of neurons in the prefrontal cortex is to excite and inhibit activity in other parts of the brain." The prefrontal cortex and the hippocampus are two areas of the brain she associates with working memory.

My co-workers and I think that the primary role of the hippocampus is to consolidate new associations, whereas the prefrontal cortex is necessary for retrieving the products of such associative learning (facts, events, rules) from long-term storage elsewhere in the brain for use in the task at hand. (Goldman-Rakic, 1992, p. 114)

The hippocampus's role may be to "rehearse" event combinations it wants associative memory to remember, since associative memory requires the repeated pairing of events. The hippocampus might be to blame for thoughts that people cannot get out of their heads. Without working memory, associative memory can only remember events that frequently occur close together in time.

Working memory must also have ways to choose among active or recent events, hold or remember events for further use, and move from one event to the next. These activities use the constantly changing pool of events generated by associative memory. The model of associative memory assumes that working memory divides its attention between the most intense events in the current pool. While its attention is
focused on a particular event, the event pool changes--dropping off some events and keeping or adding events related to the focus event. Working memory can then choose to hold a particular event active or just remember that the event occurred. It can also move from one event to the next by following the relationships that exist between representations.

The event pool may be divided into many domains, or regions of events, that have specific uses to working memory. For example, a given domain may keep track of procedure "entrypoints" that are associated with representations. By focusing on the events in this particular domain, working memory can initiate a procedure. It can use the same process to expand a collection to reveal its members. Other domains may provide only input to working memory. The most notable among these are the domains of emotion. Working memory can gauge emotions associated with an event, or representation, but it cannot focus on the emotions directly.

The model of associative memory suggests that emotions play an important role in attention, choice, and the evaluation of the events in the event pool. Emotions range from basic emotions such as pain and pleasure to more abstract emotions such as value and significance. Abstract emotions are built from basic ones. For example, things that are valuable avoid pain or provide pleasure, and significant things are valuable or satisfy goals. The model assumes that working memory "feels" the sum of emotions associated with all the active events in the event pool. It measures the emotions associated with a particular event by focusing its attention on the event until
most other events fade away. With this assumption, people can feel an emotion without being aware of what is causing it. They can also evaluate complex situations intuitively. If the focus event represents a choice, its feeling may be used as a basis for action. Events associated with strong emotions are assumed to get the more attention. They are the events a person believes to be of the greatest immediate consequence to his or her self.

Working memory may evaluate a representation by focusing on its event and measuring the emotions associated with it. It compares different representations by alternating between them--measuring the relative advantage or disadvantage of each representation. If the representations are to be compared along multiple dimensions, the dimensions must be aggregated first. This can be done by: (a) comparing individual dimensions against a neutral reference and summing the results for each representation, or (b) performing pair-wise comparisons along each dimension for the different representation pairs and coding the result as a gain for one representation and a loss for the other. The gains and losses of the pair-wise comparisons are then summed for each representation. In either case, each comparison results in an emotional value that is temporarily added to the emotions already associated with a representation. The strength of this associated value decays with time.

In addition to the constantly changing pool of events, the person's state of mind is constantly changing. Many of these changes show up as short-term increases in the connection strengths of neurons in both associative and working memory. In
associative memory, these increases mean that the neuron will fire more intensely next time it is accessed. Thus, the information is more likely to come to the attention of working memory.

Gaining access to new information, even accidentally, changes the mind; this is one reason small changes can make big differences in the way we operate. The immediate access to information shifts our ability to recall and our judgment. One study asked people to name any fruit that begins with the letter a; next, those that begin with p. The second question was answered faster. The first question summoned up the storehouse of information about fruits, making the names of fruits more readily accessible for the second question. (Ornstein, 1991, p. 108)

Short-term increases in the connection strengths of working memory probably act as a type of short-term memory. Working memory uses these changes to keep track of recent events and new or trial relationships before committing them to memory. Short-term memory acts like a place to collect resources before assembling them.

Two other tasks performed by working memory are to build contextual frames for events and to integrate independent events into wholes. Frames are probably collections of events taken from short-term memory, joined together by common relationships such as the time-order of events. They can improve access to a person's past state-of-mind by accessing key information from which other information may be reconstructed. Frames provide access to only those events selected by working
memory. Because events can be added to a collection one at a time, frames can contain a considerable amount of information. Frames do not, however, automatically invoke the information they contain.
Appendix B

Test Instrumentation
Recruitment Script

Introduction

1. Christopher Alexander is an Architect who has started a minor revolution in how we think about design.

2. His work has quietly spilled over into the software community and has made inroads to the basic sciences and mathematics.

3. He talks about patterns and how we create and judge the quality of pattern languages.

4. What is remarkable about his work is that it applies to so many areas. It applies to pattern recognition in Artificial Intelligence, patterns of behavior in psychology, patterns in numbers that form the basis of mathematics, and even patterns in manufacturing or human factors--although we don't recognize them as such. This is how Alexander summarizes it.

(Show First Slide)
We have a glimpse, then, of the fact that our world has a structure, in the simple fact that certain patterns of events—both human and nonhuman—keep repeating, and account, essentially, for much the greater part of the events which happen there....

Indeed, a culture always defines its pattern of events by referring to the names of the physical elements of space which are "standard" in that culture.

"The Timeless Way of Building"

Alexander (pgs. 69, 71)
Patterns and Knowledge

5. The patterns to which Alexander is referring apply to patterns of states as well as patterns of events.

6. That is, things in our world always seem to arrange themselves in certain ways or states.

7. Just about everything we know involves patterns and the names we give those patterns become the categories we use to describe our world.

8. You can pick almost any word at random and identify the pattern it represents. As Alexander put it, (read the second quote).

9. And it makes sense to learn patterns that repeat themselves--what use to us is a pattern that is not repeated?

10. How could you teach someone anything useful if it did not follow a pattern that would repeat?

Design Goals for Associative Maps

11. This may sound like a very philosophical idea but it actually has a very practical value.

12. If you can identify the patterns that occur, you can use them to improve your designs and decision making.

13. That is the gist of Alexander's approach and it is why I created Associative Maps. I created them to help people discover, refine, and reuse patterns.

14. My second but closely related goal was to help people access what they already know to create a more detailed description of the problem they need to solve.

15. Associative Maps exploit the patterns and associations people have learned to help them access their knowledge.

16. Your participation in the experiment will help me determine if I have met my second goal. (Show the second slide)
PROBLEM STATEMENT

Diversity Food Stores is an organization that, in the past, has planned and operated food stores. The organization has decided to expand its outreach from a grocery store to a grocery-pharmacy-hardware one-stop shopping center. The objective of this new facility is to meet the day-to-day food, household, and medical needs for an average family living within a suburb of a large city. What requirements must be considered in the layout for this new facility?
Description of Experiment

17. In the experiment, you will be asked to solve problems like the one shown here.

18. The problem statement will describe a situation related to Facilities Planning.

19. The statement will not provide a complete description, so your main task will be to "fill in the blanks" with what you can think of.

20. Each sentence will deal with one or more aspects of the problem. You should find it helpful to explicitly state these aspects in your own words.

21. Significant words and phrases throughout the problem statement will provide clues to additional information you may need. There will also be cases where information provided on one part of the problem applies to another part but is not specified.

22. This will be particularly true if you identify more general forms of the information provided.

What the Participants will Do

23. Your goal will be to make as many statements on what is asked in the problem as you can in the time available.

24. Each statement must be expressed in one sentence that you can either write on a piece of paper or type into an editor that will be provided. You will have three problems to solve; one practice and two test problems.

25. After completing the practice problem, you will be given a possible set of answers to look over. You will then be given 30 minutes to solve each of the test problems.

26. You will be directed to use Associative Maps on only one of the two test problems.

27. The other problem will be solved by hand, using pencil and paper.

28. I will give you a demonstration of the Associative Maps prior to starting the experiment.

Ask for Questions
Sign-Up Sheet

Check-off an available time slot from the second sheet for the time you will attend. Write your name and the time slot in the space provided. Please include your phone number so that you can be notified if the time slot is canceled.

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Phone (Calling Times)</th>
<th>Time Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

Please remove time slot for the time you will attend.
<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Day and Time</th>
<th>Meeting Room</th>
</tr>
</thead>
<tbody>
<tr>
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<td>CAE Center</td>
</tr>
<tr>
<td>A</td>
<td>Wed (15th) 1:00-2:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>A</td>
<td>Wed (15th) 1:00-2:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>A</td>
<td>Wed (15th) 1:00-2:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>B</td>
<td>Thur (16th) 9:00-10:30 am</td>
<td>CAE Center</td>
</tr>
<tr>
<td>B</td>
<td>Thur (16th) 9:00-10:30 am</td>
<td>CAE Center</td>
</tr>
<tr>
<td>B</td>
<td>Thur (16th) 9:00-10:30 am</td>
<td>CAE Center</td>
</tr>
<tr>
<td>B</td>
<td>Thur (16th) 9:00-10:30 am</td>
<td>CAE Center</td>
</tr>
<tr>
<td>C</td>
<td>Thur (16th) 3:00-4:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>C</td>
<td>Thur (16th) 3:00-4:30 pm</td>
<td>CAE Center</td>
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<td>Thur (16th) 3:00-4:30 pm</td>
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<tr>
<td>C</td>
<td>Thur (16th) 3:00-4:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>D</td>
<td>Fri (17th) 10:00-11:30 am</td>
<td>CAE Center</td>
</tr>
<tr>
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</tr>
<tr>
<td>E</td>
<td>Mon (20th) 2:00-3:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>E</td>
<td>Mon (20th) 2:00-3:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>E</td>
<td>Mon (20th) 2:00-3:30 pm</td>
<td>CAE Center</td>
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<tr>
<td>E</td>
<td>Mon (20th) 2:00-3:30 pm</td>
<td>CAE Center</td>
</tr>
<tr>
<td>E</td>
<td>Mon (20th) 2:00-3:30 pm</td>
<td>CAE Center</td>
</tr>
</tbody>
</table>
Pre-Test Script

(Pass out the Informed Consent form)

1. Please take a moment to read and sign this form.

   (Wait for their attention)

2. In about 5 minutes we will go to the CAE Center and I will give you a
demonstration on how to use Associative Maps.

3. After the demonstration, you will be given 15 minutes to do a practice problem.

4. Your goal is to make as many one-sentence statements addressing what is asked
in the practice problem as you can.

5. Some of you will do the practice problem by-hand and the rest will try their luck
at using Associative Maps.

6. After the 15 minutes are up, I will collect your answers and give you a few
minutes to look over an example list of the answers I came up with. Note the my
answers are not necessarily the correct or only ones.

7. Next, I will give you the first test problem to do. You will have 30 minutes to
complete it. Some of you will be directed to use Associative Maps on this
problem and some of you won't.

8. After 30 minutes are up, I will collect your answers as I did for the practice
problem.

9. You will then be given the second 30 minute problem. Those who used
Association Maps on the first problem will not use them on the second and vice
versa.

10. After 30 minutes, I will collect your answers and give you an evaluation form to
fill out.

11. Are there any questions?
Demonstration Script

This script lists the actions taken during the software demonstration. The statement on the following page should be placed where everyone can see it and the Associative Maps software should be running on a PC workstation with the Insert Box displayed in the center of the screen. The demonstration shows how to create a group, how to use free, focus, and flow mapping; and how to simultaneously display one group while working on another.

Demonstration Overview

1. Use Free Mapping
2. Show the Entry Point List
3. Use Group Create

Use Focus Mapping

4. Change the focus node
5. Use Focus Mapping
6. Use Group Define

Use Flow Mapping

7. Show screen movement
8. Create a group for the flow
PROBLEM STATEMENT

Diversity Food Stores is an organization that, in the past, has planned and operated food stores. The organization has decided to expand its outreach from a grocery store to a grocery-pharmacy-hardware one-stop shopping center. The objective of this new facility is to meet the day-to-day food, household, and medical needs for an average family living within a suburb of a large city. List the layout requirements that should be considered for facilities similar to this one.
Demonstrate Using Associative Maps on the Problem Statement

Free Mapping to Enter Significant Words and Phrases

1. Enter "Day-to-Day Needs", "Grocery", "Household", and "Medical".
2. Enter "Average Family" and "Suburb of a Large City"
3. Select the nodes from step one.
4. Select Group/Create.
5. Enter "Facility Objectives"
6. Expand this group
7. Write down "Frequent visits",
8. Write down "Fast inventory turnover"
9. Write down "Different turnover rates for Grocery, Household, and Medical."

Focus Mapping to Generate Associations

1. Set map focus to "Average Family" and set Focus Mapping.
2. Enter "2.5 Kids", "Both Parents Work", "Total Income = 45,000", "Drive Station Wagon or Minivan"
3. Write down "Play center for kids", "Central meeting location", and "Toy department"
4. Write down "Times people come to the store"
5. Write down "Parking space for large vehicles"
6. Flow Mapping to Identify Processes
7. Set map to Free Mapping for first node
8. Enter "Drive To Store"
9. Set map to Flow Mapping

Collect these node in the "Shopping" group.

11. Write down "Entry from parking lot"

12. Write down "Space for grocery carts near entry"

13. Write down "Aisle space for carts"

14. Write down "Space for registers"

15. Write down "Space for loading and unloading cars."
Test Instructions

The general approach to solving the test problems is to (a) familiarize yourself with the problem and what it is asking for, (b) generate as many ideas as you can about the situation described, (c) ask yourself how each idea applies to what is asked, and (d) write down your response in terms that address what is asked. You can easily spend most of your time on step b and not have enough time to complete steps c and d. To get the most responses down in the time allowed, you should apply this approach repeatedly to small parts of the problem--generating a few ideas, formulating your response, and then writing it down.

The following steps outline the recommended approach for breaking the problem into smaller parts. You should think of each step as a separate problem to be solved. Do the steps in order and try to complete as many as you can.

Steps for Solving the Problems

Understand what the problem is asking for.

Identify what each sentence says about the problem.

Identify what the significant words and phrases say about the problem.

Describe any implied processes or procedures related to the problem.

Consider other situations that are similar to the one described.

Consider what parts of the problem can be applied to new situations.

General Approach for Each Step

Generate ideas using the software or a pad of paper, depending on which one the problem indicates.

Place the answer sheet so that your ideas and the sheet are both visible.

Try to think of statements using your ideas that address what is asked at the top of the answer sheet.

If you are not clear on the statements, try writing them on the pad of paper first.

Finally, write each statement you come up with on the answer sheet.
Focus Mapping

1. Click in an empty area of the screen.
2. Press F8 to start a new idea series.
3. Press F10 to select Focus Mapping.
4. Type the focus idea and press Enter.
5. Click in an empty space around the node.
6. Type an associated idea and press Enter.
7. Repeat step 6 until you are out of ideas.
8. Generate statements using your ideas and write them on the answer sheet provided.
9. Click on one of the ideas you generated. Repeat this procedure from step 5 until you are out of ideas.

Flow Mapping

1. Click in an empty area near the top of the screen.
2. Press F8 to start a new idea series.
4. Type the initial step and press Enter.
5. Click in an empty space below or to the right of the node.
6. Type the next step and press Enter.
7. Repeat step 6 until all the steps have been identified.
8. Generate statements using the process steps and write them on the answer sheet provided.
9. Repeat this procedure until you have defined all the processes you can identify.
Facility Layout

Diversity Food Stores is an organization that, in the past, has planned and operated food stores. The organization has decided to expand its outreach from a grocery store to a grocery-pharmacy-hardware one-stop shopping center. The objective of this new facility is to meet the day-to-day food, household, and medical needs for an average family living within a suburb of a large city. Use this problem description to help you identify the things that should be considered in the layout of facilities like this one.
Things to Consider in the Layout of a Supermarket

1. Space for Grocery Department

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Use the back of this sheet if you need to continue your response.
Things to Consider in the Layout of a Supermarket

1. Space for Grocery Department
2. Space for Hardware Department
3. Space for Pharmacy
4. Space for Toy Department
5. Make daily visits quick and easy
6. Design facility for fast inventory turnover
7. Have a central location for meeting kids
8. Have a play center for kids
9. Have a toy department
10. Support peak capacity during evening and weekends
11. Have parking space for large family cars
12. Have space next to car for loading groceries
13. Plan aisle space for grocery carts
14. Separate truck traffic from customer traffic
15. Use the back of this sheet to continue your response.

Use the back of this sheet if you need to continue your response.
Do this problem by hand.
1. Work the problem out on the pad provided.
2. Use the approach you are most comfortable with.
3. Formulate a response in terms of the statement at the top of the answer sheet.
4. Write the response on the answer sheet.

Use the software on this problem.
1. Pick a significant word or phrase from the problem description (e.g. Family).
2. Press F10 to set the Focus Mapping mode.
3. Type the word or phrase and press Enter.
4. Click in an empty space around the focus node.
5. Type a related word or phrase and press Enter.
6. Repeat step 5 until you are out of ideas.
7. Look at each idea you entered and try to formulate a response using the idea, that addresses the statement at the top of the answer sheet.
8. Write each response on the answer sheet.

Material Handling

Nonac is a leading manufacturer of fax machines and computer printers for the home and office environments. Their facility receives parts and components from other facilities, assembles and packages the products, and ships them directly to retailers. Since most of the products are similar in nature, they share many of the same parts. Certainly, the same nuts and bolts are used! Product cycles range from six months to one year, making automated assembly difficult and expensive. Most of the assembly work is done by hand at from twelve to twenty workstations per product. Each workstation is generally dedicated to one phase of a product's assembly for up to three months because of high product volume. Parts and components are received daily at one end of the facility and products are warehoused and shipped at the other end of the facility. All product assembly begins with a base unit that determines the general length and width of the product. Use this problem description to help you identify the issues that need to be considered in the design of any material handling system.
### Design Issues for a Material Handling System

1. Can it be configured to balance demand variations among product lines?

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25.

Use the back of this sheet if you need to continue your response.
Do this problem by hand.
1. Work the problem out on the pad provided.
2. Use the approach you are most comfortable with.
3. Formulate a response in terms of the statement at the top of the answer sheet.
4. Write the response on the answer sheet.

Use the software on this problem.
1. Pick a significant word or phrase from the problem description (e.g. Family).
2. Press F10 to set the Focus Mapping mode.
3. Type the word or phrase and press Enter.
4. Click in an empty space around the focus node.
5. Type a related word or phrase and press Enter.
6. Repeat step 5 until you are out of ideas.
7. Look at each idea you entered and try to formulate a response using the idea, that addresses the statement at the top of the answer sheet.
8. Write each response on the answer sheet.

Process Layout

A.R.C., Inc. produces plunger housings for air flow regulators. The manufacturing process consists of the five operations shown below. Operation 0104 uses eighty 1 by 12 foot aluminum bars that are manually loaded into a bin that feeds the screw machine. The Deburr and Blow Out operation removes small rough protrusions from holes drilled by the automatic drilling unit. Note that metal drilling operations tend to be rough on drill bits and require some method of cooling between operations. Also note that the operation times for operations 0104 and 0204 are almost twice the times of operations 0304 and 0404, so you may want to consider doubling resources on some operations. Use this problem description to help you identify the types of information needed to design any process layout.

<table>
<thead>
<tr>
<th>Oper. No.</th>
<th>Operation Description</th>
<th>Machine Type</th>
<th>Setup Time(hr.)</th>
<th>Operation Time(hr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0104</td>
<td>Shape, Drill, Cut Off</td>
<td>Automatic</td>
<td>5.00</td>
<td>0.0057</td>
</tr>
<tr>
<td>0204</td>
<td>Machine Slot and Thread</td>
<td>Screw Machine Chucker</td>
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<td>0.0067</td>
</tr>
<tr>
<td>0304</td>
<td>Drill 8 Holes</td>
<td>Auto. Drilling Unit</td>
<td>1.25</td>
<td>0.0038</td>
</tr>
<tr>
<td>0404</td>
<td>Deburr and Blow Out</td>
<td>Drill Press</td>
<td>0.50</td>
<td>0.0031</td>
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<td>SA1</td>
<td>Enclose Subassembly</td>
<td>Dennison Hydr. Press</td>
<td>0.25</td>
<td>0.0100</td>
</tr>
</tbody>
</table>
Types of Information Needed for Doing a Process Layout

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Space required for loading materials into a machine.</td>
</tr>
<tr>
<td>2.</td>
<td></td>
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Use the back of this sheet if you need to continue your response.
Evaluation Form

Thank you for participating in this experiment. The ability to help people identify the information needed to solve problems is just a small part of this software and is difficult to test completely in the time available. Therefore, your answers and comments on this form will be an important part of the software evaluation. Please take a moment to complete it.

1. Do you feel that the software was helpful in solving the problems you were given? (Circle one)
   - Very Difficult
   - More Difficult
   - No Effect
   - Helpful
   - Very Helpful

2. Do you think this software will help you solve the kind of problems you will face in your career? (Circle one)
   - Very Difficult
   - More Difficult
   - No Effect
   - Helpful
   - Very Helpful

3. How easy was the software to use and understand? (Circle one)
   - Very Difficult
   - Difficult
   - Average
   - Easy
   - Very Easy

4. How much did the test instructions or software demonstration affect your participation in the evaluation? (Circle one)
   - Very Much
   - Not Much
   - Not at All

5. Did you experience any problems while using the software? (Please comment)

6. Can you think of anything else the software may help you with? (Please comment)

Please comment on any additions or changes you think should be made to the software. (Feel free to use the back of this form.)
Appendix C

Project Description for the Human Subjects
Institutional Review Board
Project Description

Purpose

This research is being carried out to determine whether a new type of decision support system is effective in increasing the knowledge gained by a decision-maker during analysis of decision situations.

Procedure

Participants will meet in an available classroom and the testing procedures will be explained. A consent form will be handed out, signed by the participants, and returned. Then the group will proceed to the Computer Aided Engineering lab where PCs will be running the Associative Map software. A brief demonstration of the software will be given at one of the PC workstations. Number test packets, one for each participant, contain the test material and are stacked in a random order. Each packet includes one practice and two test problems. The problem descriptions indicate when the participant is to use Associative Maps. Participants will be assigned test packets in the order they choose PC workstations. The practice problem, an answer sheet, a problem solving guide, and a software hint sheet will be removed from the participant's packet and given to him or her. The participants will then have 10 minutes to work on the practice problem before they are given the answers to look at. After another 5 minutes, the practice problem and answers will be collected and the participants will be given the first test problem including another answer sheet from their packets. After 30 minutes, any work will be saved to disk or
collected. The first test problem will be collected and the second one handed out with the last answer sheet. Participants will have 30 minutes to work on this last problem before all test material is saved or collected and an evaluation form is handed out.

Research Design

Three problems will be prepared that describe a situation in Facilities Planning and ask the participant to come up with statements on some aspect of the situation that can be applied in similar situations. One of the three problems will be a 10 minute practice problem while the other two will be 30 minute test problems. A total of 16 test packets will be prepared from copies of the problem set. The order of the two test problems will be alternated every other packet so the effect of doing one problem before the other can be seen. Each problem will have a check box that will be used to indicate when the participant is to use the system. Every participant will use the system on one of the two test problems so that all participants feel they are participating in evaluating it. Half the participants will use the system on the first problem while the other half will use it on the second problem. This will show how the order in which the system is used on the problems affects the results. Half the participants will also use Associative Maps on the practice problem. The independent variables in this research are the system being tested, the order in which participants use the system on problems, and the order of the test problems. The dependent variable is the number of statements generated about the problem situation. The
problem set, test instructions, and familiarity of students with Microsoft Windows applications are all extraneous variables.

Location and Duration

The testing will be performed in the Computer Aided Engineering lab at Western Michigan University's College of Engineering and Applied Sciences. The software will be pre-set up to run on 4 Microsoft Window's 3.1 based IBM compatible PCs. Four testing sessions will be needed to complete the 16 cases. The test introduction will take 10 minutes, the practice problem will take 15 minutes, and the two test problems will take 30 minutes each. Administration and evaluation forms will take another 5 minutes for a total testing time of one and a half hours.

Subject Selection

Subjects will be recruited from the undergraduate courses taught in the Department of Industrial Engineering at Western Michigan University's College of Engineering and Applied Sciences. The student investigator will give a 10 minute overview of the research and offer participants a free copy of the software for participating.

Risk to Subjects

Many students are still unfamiliar with current graphical user interfaces. Even those who are familiar may have difficulty understanding how the system works. This may cause frustration while using the system. A more subtle risk is that the system may make the participants too sensitive to problem analysis. Unfortunately, a
system that encourages people to think about the problem also slows down their problem solving times by encouraging them to consider viable alternatives. This behavior can be a liability in environments where quick decisions are the measure of a person's ability.

**Protection for Subjects**

To reduce the possible frustration associated with using this system, students will be told that any difficulty they encounter is a weakness of the system, that they are volunteers and are not required to complete the problems, and that they will have an opportunity to explain the problem on the evaluation form. This information will be stated by the experimenter and on the Informed Consent form.

**Confidentiality of Data**

The experiment will be conducted by the student investigator who will not know the names of the students and agrees not to notify the instructors of any difficulty with a particular individual. Student names will not be recorded on the problem sets or evaluation forms. Subject numbers will be randomly assigned and there will not be a record of an individual's subject number.

**Instrumentation**

Copies of the consent form, problem solving guide, software hint sheet, practice problem, practice problem answers, test problems, answer sheets, and evaluation form will be prepared for each student. The subject number will be written on the problems and answer sheets. The three problems will contain a half page
Each description will conclude with the sentence "Use this description to identify issues worth considering in similar situations" or words to this effect. The answer sheets will restate what the problem asked for, include numbered lines for each answer, and provide one answer as an example. The practice problem answers will contain additional examples of the type of answers expected for the problems. The problem solving guide will instruct subjects on a strategy for solving the problems. It provides direction to cut down on the time wasted thinking about how to do the problem. The guide was designed to break the problem into increments so that participants would have at least some answers down at the end of the time period. The software hint-sheet lists the common operations and key presses needed to solve the problems using the system. It is designed around the strategy outlined in the guidelines. The evaluation form will: (a) thank students for participating, (b) ask them to rate the system on a five-point scale along several categories, (c) ask for comments on any specific problems encountered, and (d) ask for general comments.

Three scripts will be prepared for conducting the research. An oral recruitment script will be prepared that: briefly explains the motivation for creating the system, provides an overview of the software, discusses the research procedure, and finally asks for questions. The second script, to be read at the start of testing, will explain the test procedures. The third script will provide a brief demonstration of the software.
Appendix D

Protocol Clearance From the Human Subjects Institutional Review Board
Date: November 4, 1994

To: Ron Carter

From: Richard Wright, Interim Chair

Re: HSIRB Project Number 94-10-10

This letter will serve as confirmation that your research project entitled "A study on the effectiveness of associative maps in decision support" has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you must seek specific approval for any changes in this design. You must also seek reapproval if the project extends beyond the termination date. In addition if there are any unanticipated adverse or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: Nov. 4, 1995

xc: Bringelson, IENG
BIBLIOGRAPHY


