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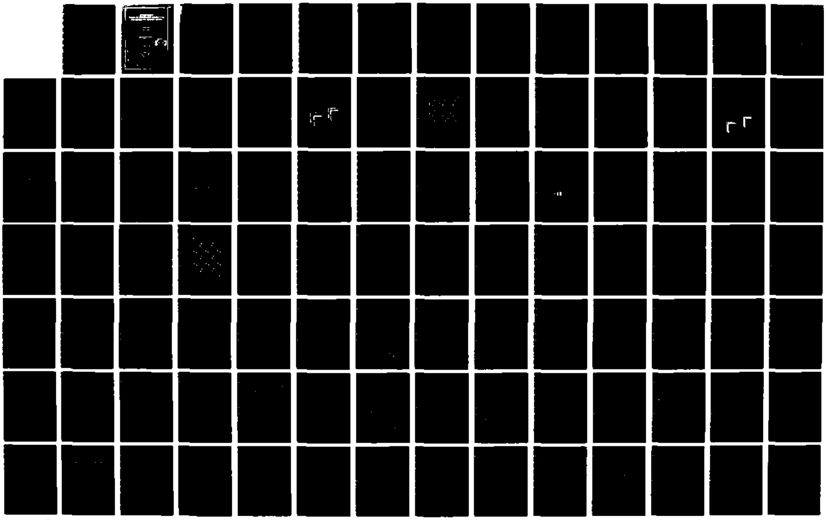

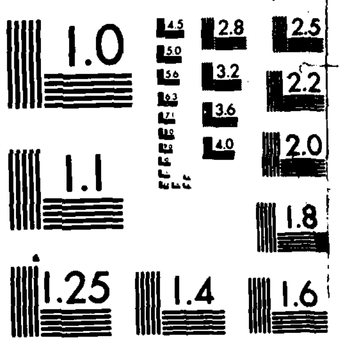

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The Schema-Based Theory of Information Presentation for Distributed Decision Making describes a schema structure appropriate for understanding connections between the way that information is presented and its impact on distributed decision making. The theory suggests a process for determining how information should be presented so that consensus and coordination will be improved and decision conflicts will be reduced.

The theory proposes that experienced decision makers select alternatives by mental processes that match the features of the current situation to features of reference situations for which possible alternatives are known to be appropriate. These reference situations may specify particular threat activities and dispositions, own Battle Group objectives, prescribed contingency plan action, and decision behavior of other decision makers to the group.

Information presented according to the principles derived from the theory will encourage each decision maker to more fully consider the impact of each action on the objectives of other decision makers. Applying the principles requires that the general schema used by decision makers be determined prior to the time when particular situation-specific information is presented. Given this prior determination, the principles suggest what emphasis needs to be given to specific features and feature relationships in the presentation of the current situation. Proper emphasis will facilitate understanding of the current situation, consideration of all appropriate action alternatives, and identification of priority information requirements.

The theory in this report was developed in the first year of a three year research program in distributed decision making. Subsequent research will test and refine the theory.

R-028-85

SCHEMA-BASED THEORY OF INFORMATION PRESENTATION

FOR DISTRIBUTED DECISION MAKING

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August 1985

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1.0 INTRODUCTION AND EXECUTIVE SUMMARY

1.1 Overview

This research is motivated by a question of central importance for C^3 applications. "Is there a set of principles for formulating plans and designing tactical information presentations which, if followed, would create an environment that fosters consensus, facilitates group decision making, and maximizes mutual support in execution of plans?" Plans and information presentations created according to these principles would encourage the proper information to be exchanged among decision makers, would encourage decision makers to consider a wider range of possible interpretations of situation data, and would encourage them to consider more fully the many potential consequences and interactions of decisions.

This work seeks to define and test such principles through a theory of distributed decision making centered on the concept of a schema. Schema have been used by cognitive and social psychologists to represent understanding. In this work, schema provide the structure through which properties of information presentations and plans can be linked to group decision making behavior.

The research plan defines three separate research issues. The first concerns the relationship between the schema used by different decision makers to understand a tactical situation and the ease with which decisions among these people may be coordinated. The second concerns the relationship between information presentations and schema that are used by decision makers receiving these information presentations. The last issue concerns the properties of plans that encourage different decision makers who receive the same information to interpret this information with schema that correspond to the same interpretation.

Work is underway in the first two of these areas. Chapter 2 reports the research that relates schema to coordination among decision makers. The research materials to be used in initial experiments in this area are presented in appendix A. Chapter 3 describes the schema structure developed to model how particular kinds of information presentations cause different kinds of schema to be used. Chapter 4 describes the principles of information presentation resulting from the schema model, and proposes a plan for testing these principles. Although the schema structure described in Chapter 3 is new, it has its roots in diverse research conducted by investigators in cognitive science and behaviorial decision theory and it relates to other decision models and theories. Appendix B describes the research data and theories of greatest importance to the theory presented here.

Because the theory developed here is intended to be capable of predicting explicit relationships between information presentation properties and decisions, it defines a detailed hierarchical schema structure. Consequently, much of the material presented in the body of the report is necessarily detailed and some is inherently complicated. To provide an orientation to this detailed material, the following section describes the most important concepts used in this research.

1.2 Principal Concepts Contributing to Theory of Information Presentation

This research is guided by four concepts which influence individual and group perceptions of decision situations. The first feature concerns the environment for distributed decision making within the Battle Group. The second is the structure of the building block schema used to represent a person's understanding of a tactical situation. The third concerns the importance of common situation understandings among people required to coordinate decisions. The fourth is the approach for modeling how different types of information presentations cause different understandings of a situation.

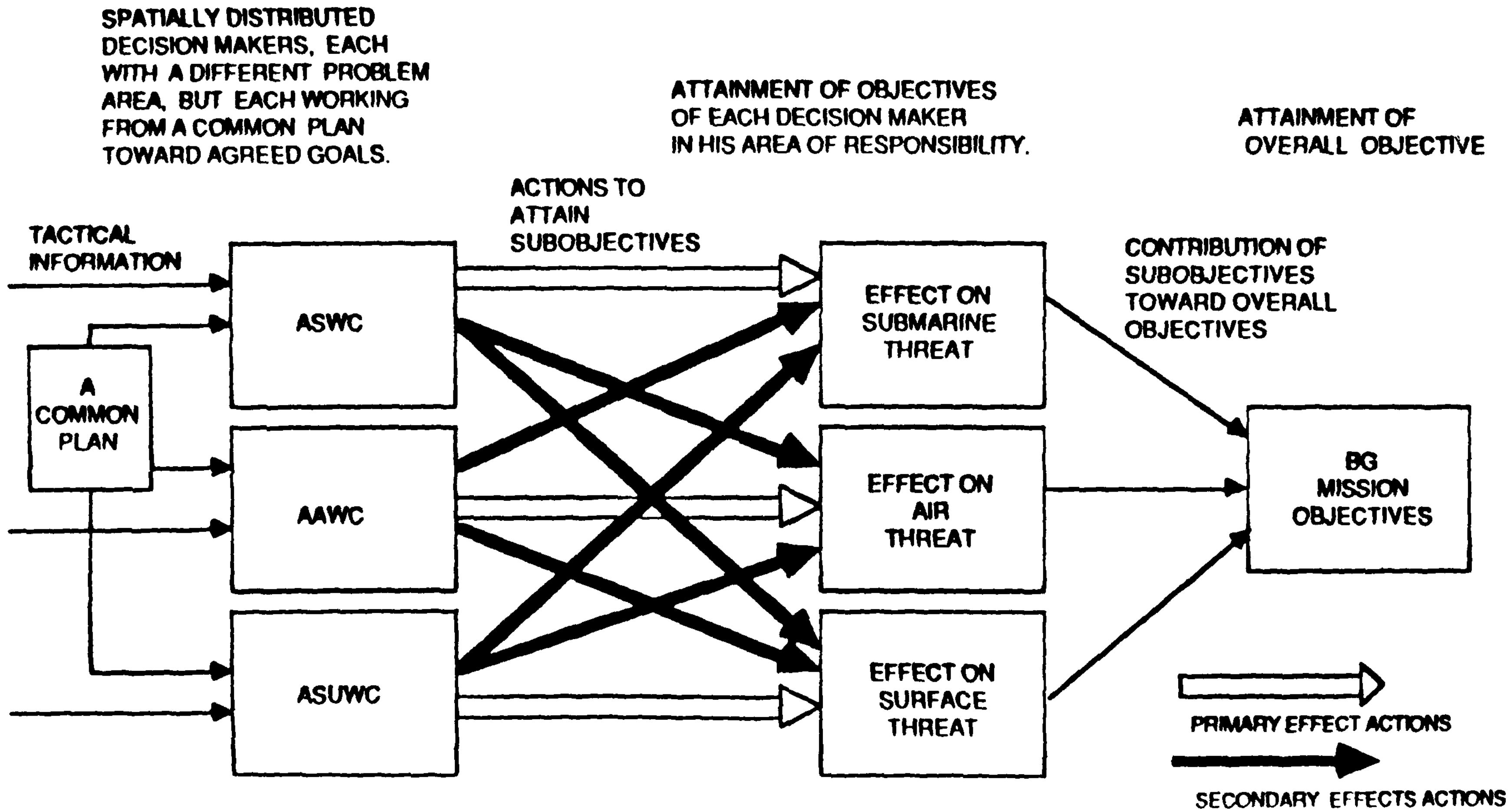
1.2.1 Distributed Decision Making in the Battle Group

The distributed decision making context for this research is the Navy's Battle Group Composite Warfare Commander (CWC) organization. Under the CWC concept, the Officer in Tactical Command (OTC) may delegate responsibility for countering the surface, air, and subsurface threats to three subordinate warfare area commanders: the Anti-Surface Unit Warfare Commander (ASUWC), the Anti-Submarine Warfare Commander (ASWC), and the Anti-Air Warfare Commander (AAWC). The three commanders work from a common plan toward the same overall Battle Group mission objectives, but they have different responsibilities, control different assets, and task different platform (ships, submarines or air craft) commanders to take different actions. The three warfare area commanders will often be on different ships.

Figure 1-1 represents the distributed decision making environment within the Battle Group. It indicates that the warfare area commanders are working from a common plan, and that each receives information about the tactical situation. Based on this plan and information, each commander tasks his assigned assets to take certain actions intended to achieve objectives within the warfare area of responsibility. Although the actions will affect primarily the warfare objectives of the tasking commander, the actions may also have side

FIGURE 1 - 1. DISTRIBUTED DECISION MAKING IN THE BATTLE GROUP

PRECONDITIONS FOR COORDINATION BY MEANS OF A COMMON PLAN, AGREED OBJECTIVES AND PROPERLY TAILORED TACTICAL INFORMATION.



effects on the objectives of the other warfare commanders. These side effects may enhance the effectiveness of the other warfare commanders or may reduce their effectiveness. Since attainment of overall Battle Group objectives depends on attainment of the warfare area subobjectives, actions that have positive side effects on other warfare commanders will contribute more to Battle Group mission than will actions that have negative side effects.

The research focuses on an important precondition for coordinated actions--a common situation understanding by the three warfare commanders. It is believed that warfare commanders with a common understanding will be more likely to consider actions with positive effects on the other warfare commanders than will warfare commanders with differing understandings of the tactical situation. In circumstances where time or communication limitations do not permit the warfare commanders to exchange information prior to taking action, common understanding increases the chances that actions taken will support the subobjectives of the other warfare commanders. In circumstances where warfare commanders are able to exchange information, a common understanding at the start of the exchange will enable a more rapid identification of effective coordinated actions.

Most actions taken in warfare are in accordance with a plan that specifies actions to be taken under various contingencies. A good plan will have anticipated and included as a contingency the situation that actually unfolds. It will ensure that warfare commanders can associate this unfolding situation with the correct plan contingency, and it will ensure that actions taken under the plan will be coordinated. Even a good plan, however, cannot ensure that actions will be coordinated if different commanders believe that different plan contingencies are in effect. Therefore, selecting actions specified by a plan does not reduce the importance of a common situation understanding to coordinated actions.

1.2.2 Basic Properties of Schema

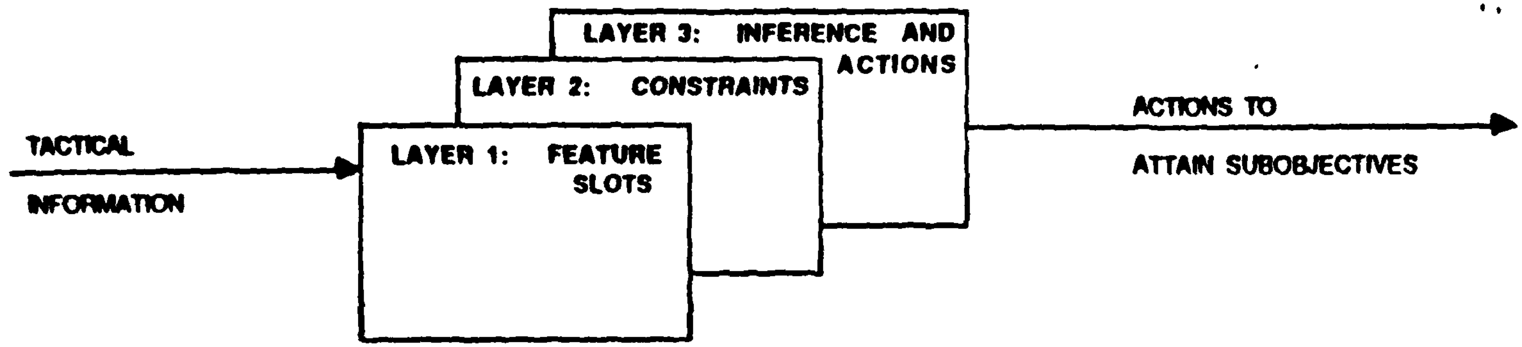
Schema theory proposes that people use schema to understand situations. This understanding encompasses much more than is contained in an accurate map of the situation. In military situations they would include, in addition to location and identification information, hostile intent, vulnerabilities, and possible future actions.

Schema have two functions: they enable situations, objects, and concepts to be recognized and classified; and they specify inferences and actions appropriate to entities associated with that schema. Schema represent classes of situations, objects, and concepts. Consequently, particular situations, objects, or concepts do not have their own private schema, but every familiar situation, object or concept will belong to some schema.

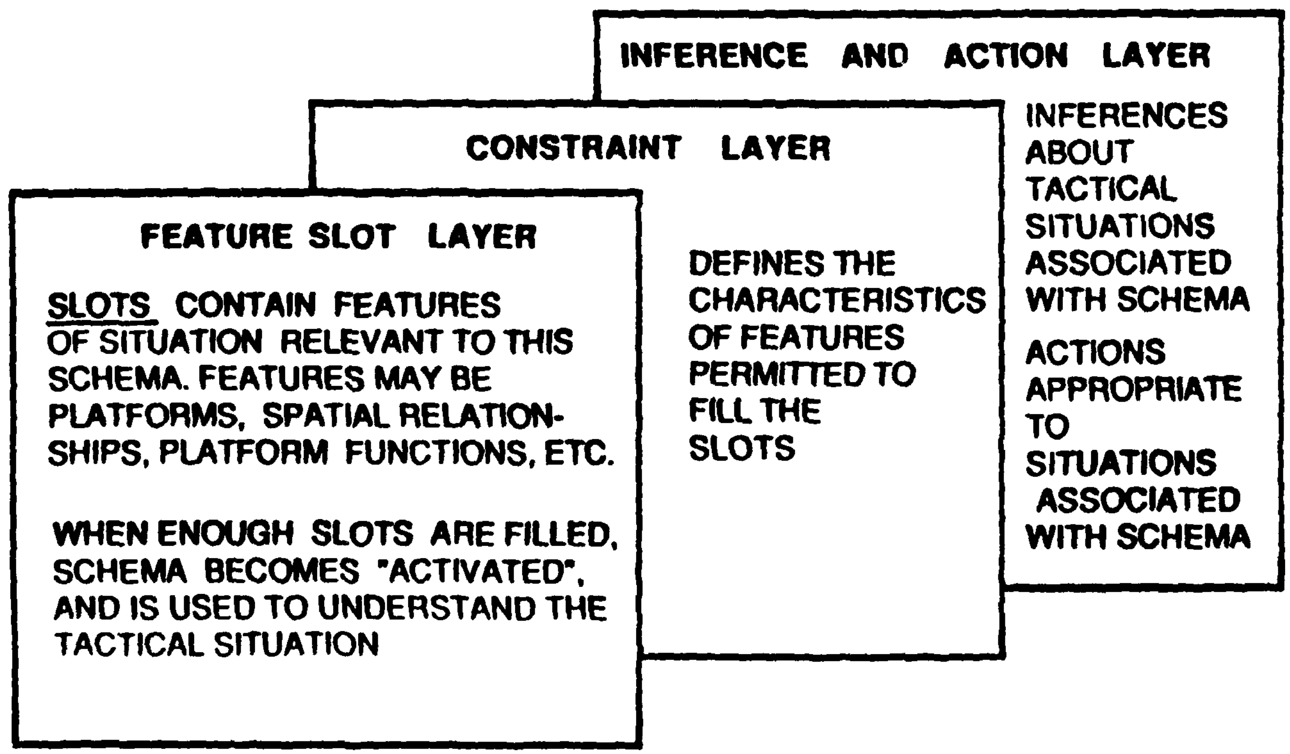
Figure 1-2 illustrates the schema structure used for the theory of information presentation. It has three layers: one for slots, one for constraints, and one for inferences and actions. A schema's feature slot layer defines situation, object, or concept features that are relevant for associating a particular instance with that schema. In the case of a tactical situation, features can include platforms' locations, platform types, spatial relationships among platforms, functional relationships among platforms, and patterns of communication, etc.

The constraint layer of a schema defines criteria on the characteristics of features that are permitted to occupy the feature slots. In this

FIGURE 1 - 2 SCHEMA: A CONSTRUCT FOR REPRESENTING SITUATION UNDERSTANDING



SCHEMA FOR A CLASS OF TACTICAL SITUATIONS



theory, these constraints are elastic. They permit different features to occupy slots to varying degrees. When enough selected slots in a schema are adequately filled, the schema becomes "activated". Activated schema represent the schema owner's current understanding. The theory permits multiple schema to be simultaneously activated to varying degrees. Simultaneous activation is expected when features of a situation are ambiguous, so that the situation may be interpreted in more than one way.

The third layer in a schema specifies the inferences and actions that are appropriate for this schema. Existence of the third layer is critical to the information presentation theory. This layer enables inferences to be made and actions to be selected based solely on activation of the schema. Thus, the theory assumes that most decisions follow directly from schema activation. The theory asserts that most decisions are not the product of a rational evaluation of the consequences should different alternative actions be taken. Rather, most decisions result from a recognition that the current situation is a particular type, or class, of situation for which certain standard actions are appropriate.

Although the theory stresses the prevalence of decisions based directly on recognizing that a situation corresponds to a particular schema, it does not assert that all decisions are of this type. When situations are ambiguous and correspond to several schema, or when situations do not fit any schema very well, the decision maker will need to use alternative methods for making a decision.

1.2.3 Role of Schema in Coordination Among Decision Makers

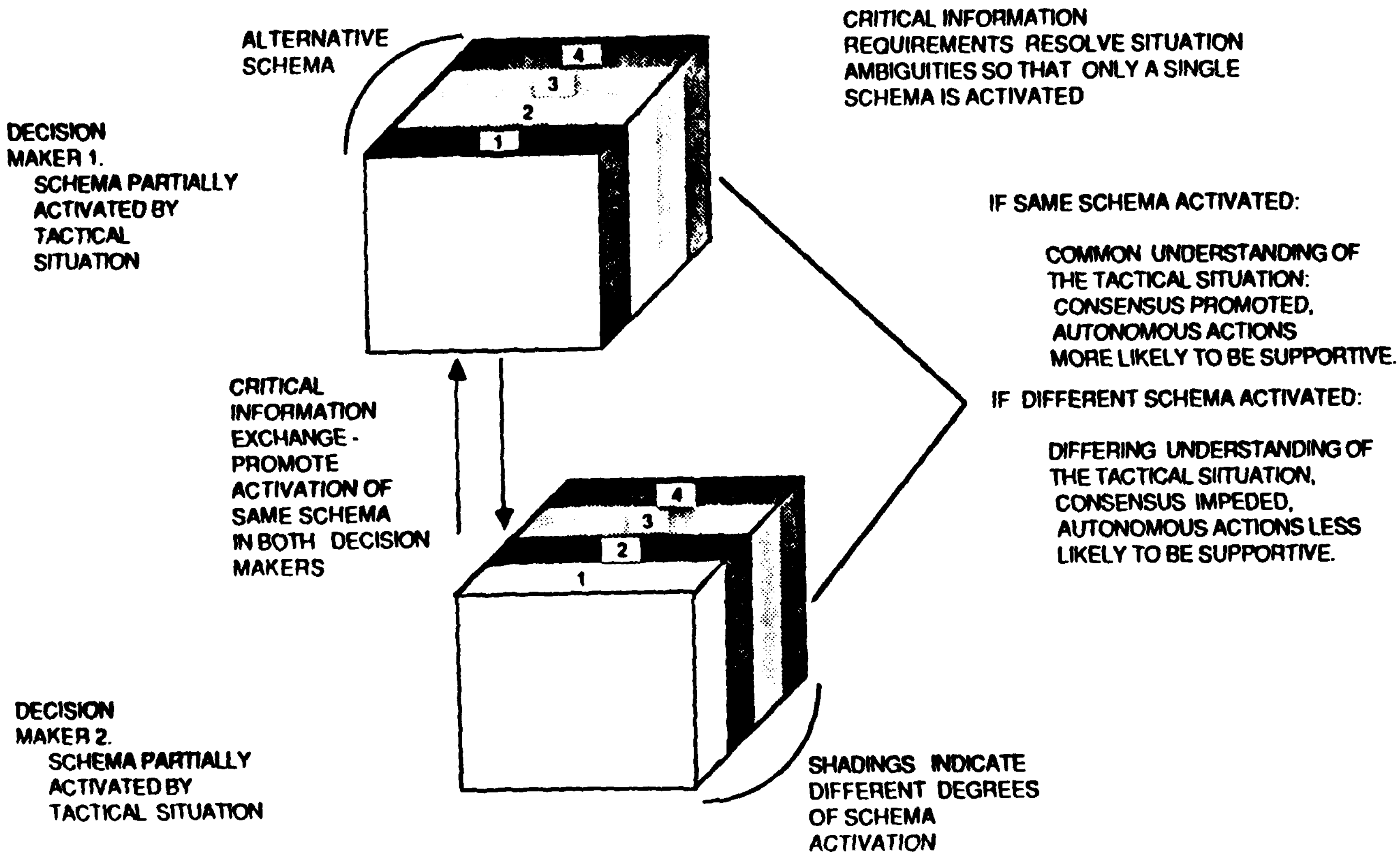
The importance of schema in distributed decision making follows directly from the importance of common situation assessments. Common situation assessments occur when the schema activated in different decision makers are "congruent," i.e., correspond to similar situations interpretations. Activation of congruent schema in different decision makers is, in this theory, a critical precondition to consensus and coordinated action.

There are numerous factors that can influence schema activation, and different decision makers may have different activated schema even if they work from the same plan and see the same information. In the case of the Battle Group, the differing roles and responsibilities of warfare commanders may color their perceptions of the tactical situation, causing each warfare commander to focus on those aspects of the situation of greatest possible impact on his responsibilities. This difference in responsibilities could bias each warfare commander toward different schema.

Figure 1-3 represents a pattern of schema activation of two decision makers who have different interpretations of a situation. The two blocks in this figure represent sets of partially activated schema. Each layer in the blocks represent a different schema. For the first decision maker, schema 1 is most activated, followed by schema 4, 3, and 2. For the second decision maker schema 2 is most activated, followed by 4, 3 and 1. Because different schema are active in the two decision makers, coordination and effective action may be impaired. A goal of situation assessment presentation, then, would be to activate congruent schema in both decision makers.

Figure 1-3 also relates information acquisition and information exchange issues to the goal of activating congruent schema in all decision makers. The theory proposes that activation of such congruent schema is an important precondition for consensus. In terms of this goal, it is most impor-

FIGURE 1 - 3 ACTIVATION OF CORRESPONDING SCHEMA IN DIFFERENT DECISION MAKERS A KEY TO COORDINATED DECISION MAKING



tant to 1) obtain clarifying information that causes deactivation of all but a single schema, and 2) exchange with other decision makers information that causes activation of congruent schema in both decision makers.

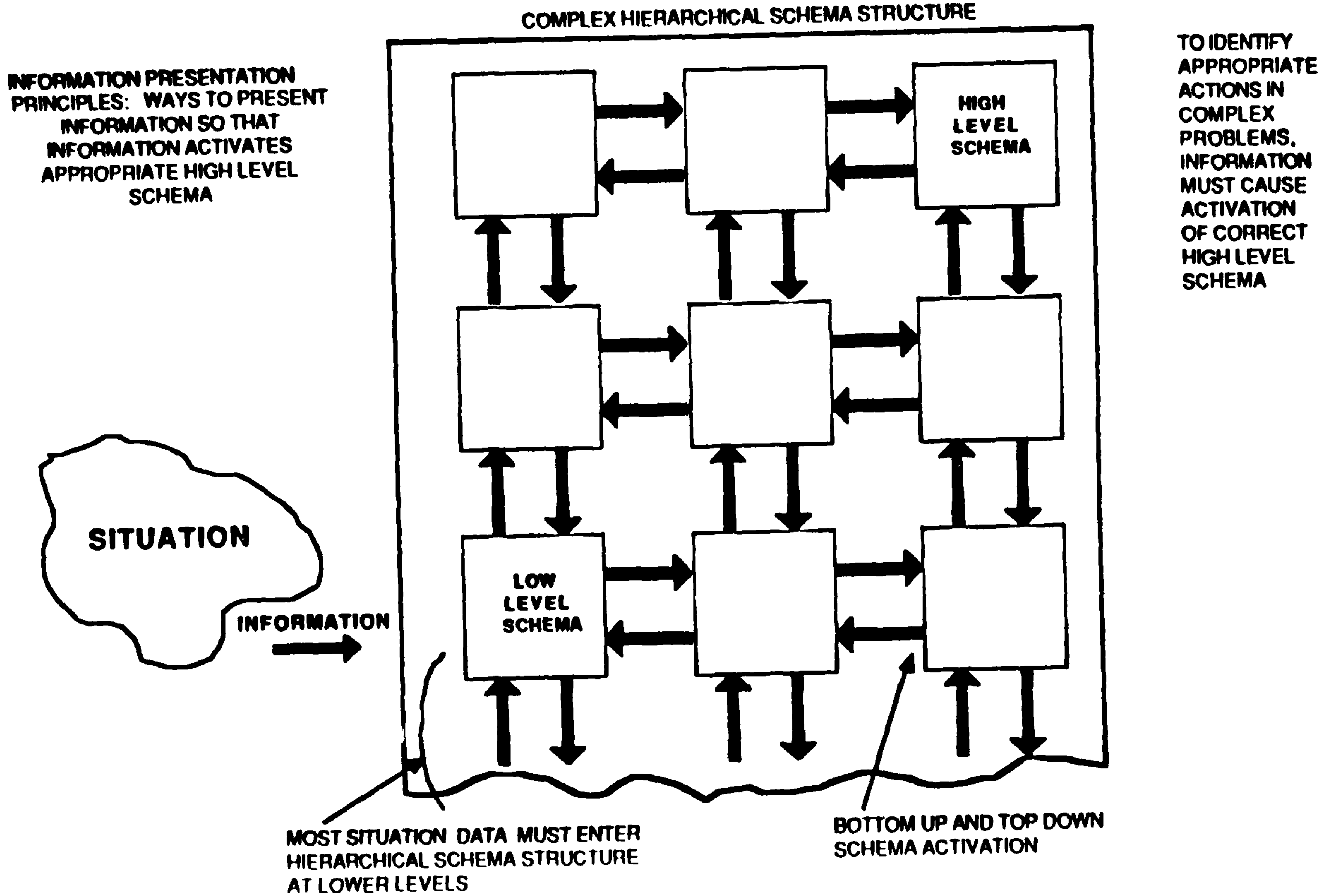
1.2.4 Relationship Between Presented Information and Schema Activated by That Information

The theory of information presentation defines principles that facilitate activation of the desired congruent schema in the different decision makers. The principles are developed from a detailed model of interacting schema outlined in Figure 1-4.

In this model schema necessary for understanding complex situations are arranged in a two dimensional hierarchy of schema types. One dimension is taxonomic, in which lower schema are a "kind of" of the higher schema. The other dimension is attribute amplification, in which each lower schema provides detailed information about a slot in a higher schema.

The schema at different levels in this hierarchy have different properties and serve different purposes. Those at the highest levels represent the "deepest" understanding, for they concern the more abstract and general principles applicable to a situation. Those at lower levels are concerned with concrete aspects of a situation. Their slots correspond to observable features of a situation. The schema at different levels in the hierarchical structure interact with one another. Schema lower in the attribute amplification hierarchy can, when activated, fill the slots of higher schema, thereby tending to activate these higher schema. Activated higher level schema prime unactivated lower level schema that feed them, thereby enabling those lower schema

FIGURE 1 - 4 INFORMATION PRESENTATION PRINCIPLES - PRINCIPLES FOR ACTIVATING DESIRED SCHEMA



to more easily recognize situation features corresponding to their slots. In terms of this schema structure, information leads to understanding when situation data entering lower level schema establish an activation flow through the hierarchy that succeeds in activating more general schema.

The information presentation principles described in Section 4 below, are derived from this model. These principles specify what aspects of information should be emphasized in order for that information to most readily activate the desired higher order schema. All principles reference a map of the schema hierarchy most likely used by a target community of decision makers. Such maps are to be developed from interviews with people in the target community. The five principles (which are explained fully in Chapter 4) are:

1. Presented features should be congruent with schema slots.

2. Presented features should reflect their diagnosticity (ability to differentially activate promising schema).

3. Reference expectation values should accompany presented features.

4. Information presentations should emphasize the function of situation parts and functional relationships among the parts.

5. Information presentations should include with situation details schema-related summarizing information relevant to situation details.

1.3 A Note on Terminology

The terms used by different investigators of schema theory can be confusing, because people have used the terms schema, scripts, frames, and templates to mean the same thing. The terminology used throughout this report, and to be used in the future, is as follows:

Schema: Schema are the tri-layer structure that was described in Section 1.2.2. Schema are cognitive structures that represent understanding. They modeled the organization of knowledge in the mind.

Scripts: Scripts are a specialized kind of schema that represent time-event sequences in familiar situations, such as going to a restaurant. Many of the slots in scripts are events.

Frames: The term "frame" originated in the artificial intelligence community and is still used by that community to describe a computer-based knowledge representation. It is used here only to refer to computer-based data structures.

Templates: The term "template" is not used in this report. This term will be used to describe a particular type of information layout on a computer screen. Information in template format will emphasize the ordered slot structure characteristic of schema.

2.0 INITIAL INVESTIGATIONS: THE ROLE OF SCHEMA IN DISTRIBUTED DECISION MAKING

This chapter describes the first experiments to be conducted under this research effort. These experiments will examine the potential contribution of schema for understanding issues in distributed decision making. Section 2.1 describes the theoretical issues addressed by the experiments, Section 2.2 summarizes short term research objectives associated with these issues, and Section 2.3 outlines the experimental approach. Appendix A.1 exhibits a preliminary version of the experimental materials to be presented to subjects, and Appendix A.2 provides schema and decision conflict interpretations of these materials.

2.1 The Role of Schema in Distributed Decision Making

Figures 2-1a through 2-1c emphasize different aspects of the simplified model of distributed decision making to be used in the initial experiments. Figure 2-1a presents a conventional description of command and control for the ASW and ASUW commanders. This figure shows each commander working from a common plan and each receiving information about the tactical situation. In these experiments, the tactical situation information received by both is the same, though in reality the two warfare area commanders would receive information tailored to their needs. Based on the plan, their estimate of the tactical situation, and their evaluation of the consequences of alternative actions, both commanders select a set of actions. They may coordinate with one another if time and communications constraints allow. Otherwise, they select their actions without further coordination.

Figure 2-1b recasts this conventional description to emphasize the role of schema in situation assess and action selection. In this diagram, the

FIGURE 2 - 1 A BATTLE GROUP MODEL (SIMPLIFIED) CONVENTIONAL INFORMATION FLOW

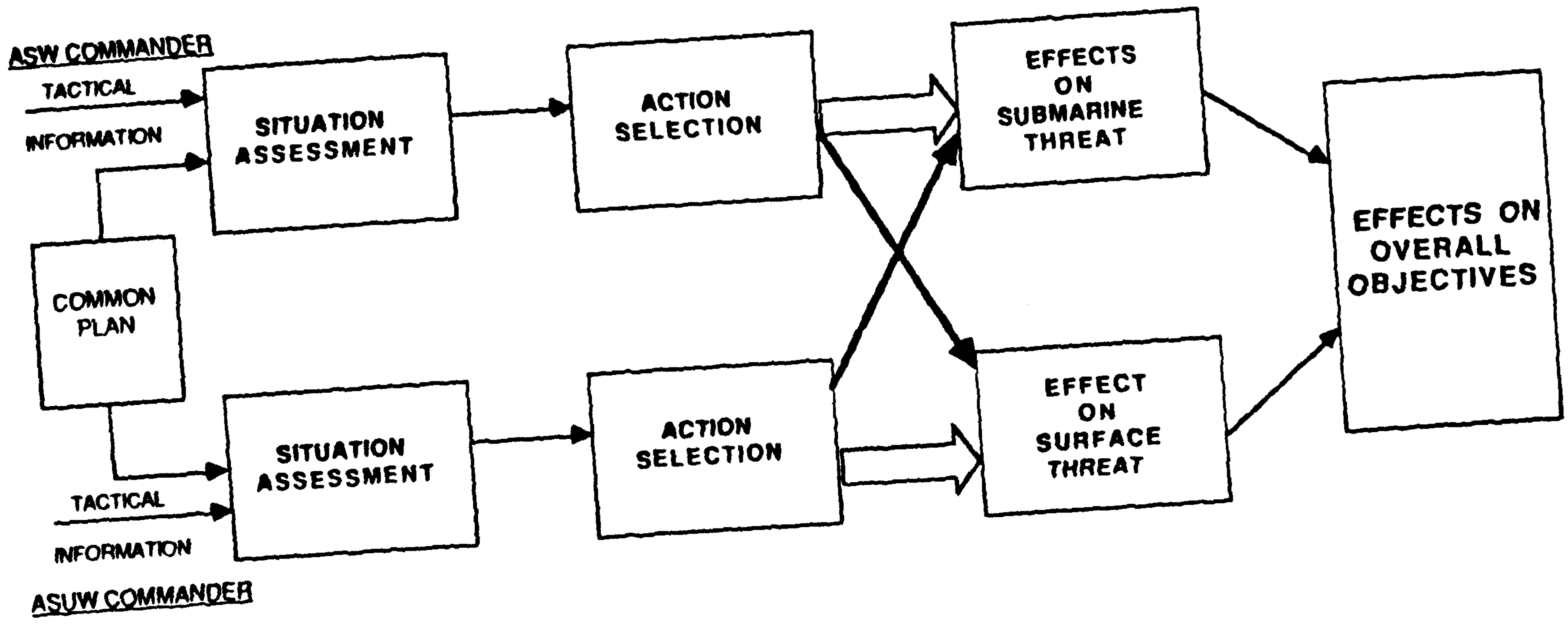
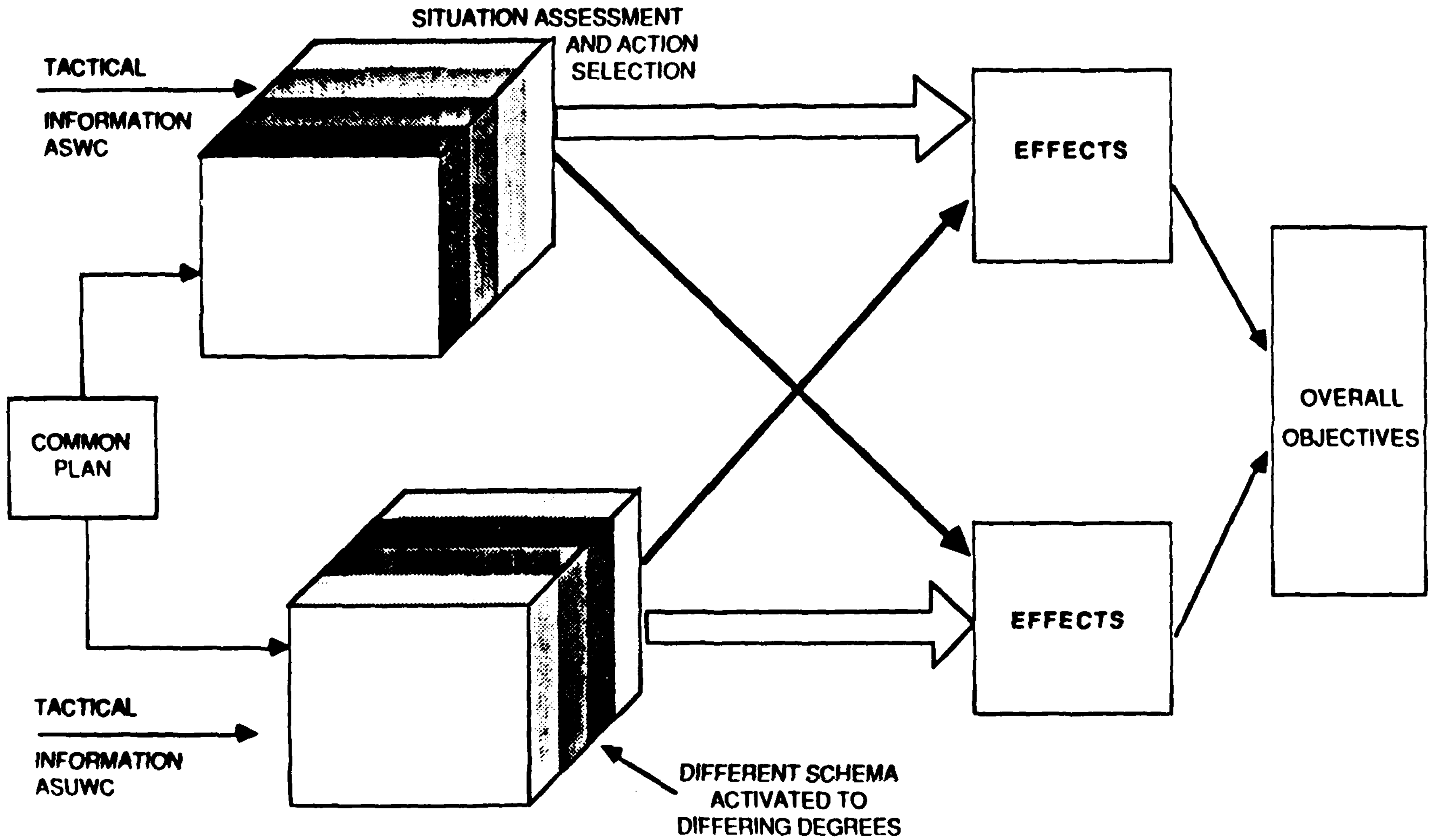


FIGURE 2-1 B THE BATTLE GROUP MODEL SCHEMA SELECTION EMPHASIZED

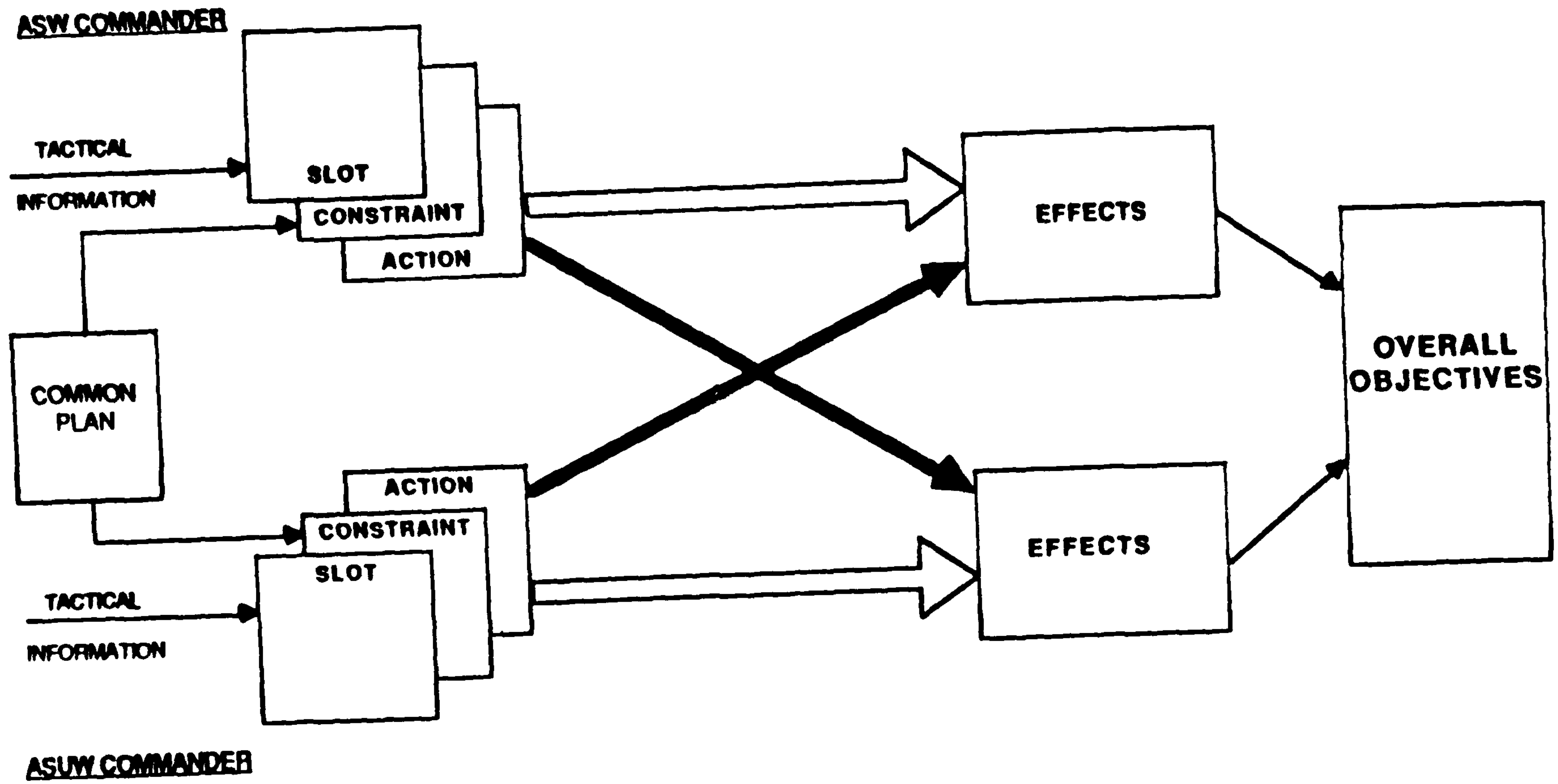


situation assessment and action selection blocks are replaced by a collection of schema. Each of the schema in this collection represents a different interpretation of the situation and the actions that are appropriate for that interpretation. For example, one schema may represent a situation in which an adversary intends to launch an intense attack while another may represent a situation in which the adversary intends to intimidate by appearing to be ready to launch such an attack. The degree to which each of these schema is activated, as indicated in the figure by its degree of shading, reflects the extent to which the commander believes each of these situations is currently plausible. The similarity of the shading patterns for the two decision makers indicates similarity of their situation interpretations.

The intimate association of situation assessment and action selection within a schema is an important aspect of the schema theory. This close association is assumed to be appropriate whenever the actions to be taken become evident once the nature of a situation is correctly understood. These associations develop through time from training and experience and in an expert are extensively developed within his domain of expertise. The present model emphasizes this mode of action selection, but does not require that all actions be selected in this way. When no single alternative is easily associated with a perceived situation, schema theory assumes that more formal analytic methods can be used to select an action.

Figure 2-1c redraws the command and control flow to emphasize the internal structure of a single schema rather than the relative activations of individual schema within a collection of schema. It shows the three schema

FIGURE 2 - 1 C THE BATTLE GROUP MODEL - SCHEMA STRUCTURE EMPHASIZED



layers for slots, for constraints, and for action specifications. Tactical information is shown entering the slot layer because slots are receptors for information currently being received and evaluated. The plan is shown entering the constraint layer, because, like schema constraints, a plan provides a comparison reference needed for interpreting the situations. According to the proposed schema theory of decision making, dynamic task-specific adjustment of schema constraints occurs frequently in decision making. As explained in Section 3.5, decision task specifications affect the schema-based decision process by adjusting the constraint layers of schema potentially relevant to a decision task. Actions are shown leaving the action layer because actions to be taken are identified in this layer.

2.2 Objectives of the Initial Experiments

The initial experiments are designed to explore different empirical methods for examining a schema-based model of distributed decision making, and to examine key issues central to the theory. The experiment's five objectives are:

1. Develop research methods needed for investigating schema-related issues. These involve reliable and consistent ways to interview a person in order to construct a representation of the schema that person used to understand a situation.

2. Using these methods, examine the pattern of different schema that are activated by ambiguous information.

3. Examine the extent to which the decision roles that are assigned to people affect the schema that are activated.

4. Examine the correlation between actions which are selected and the schema which are activated.

5. Examine the correlation between the activation of dissimilar schema and the selection of conflicting actions.

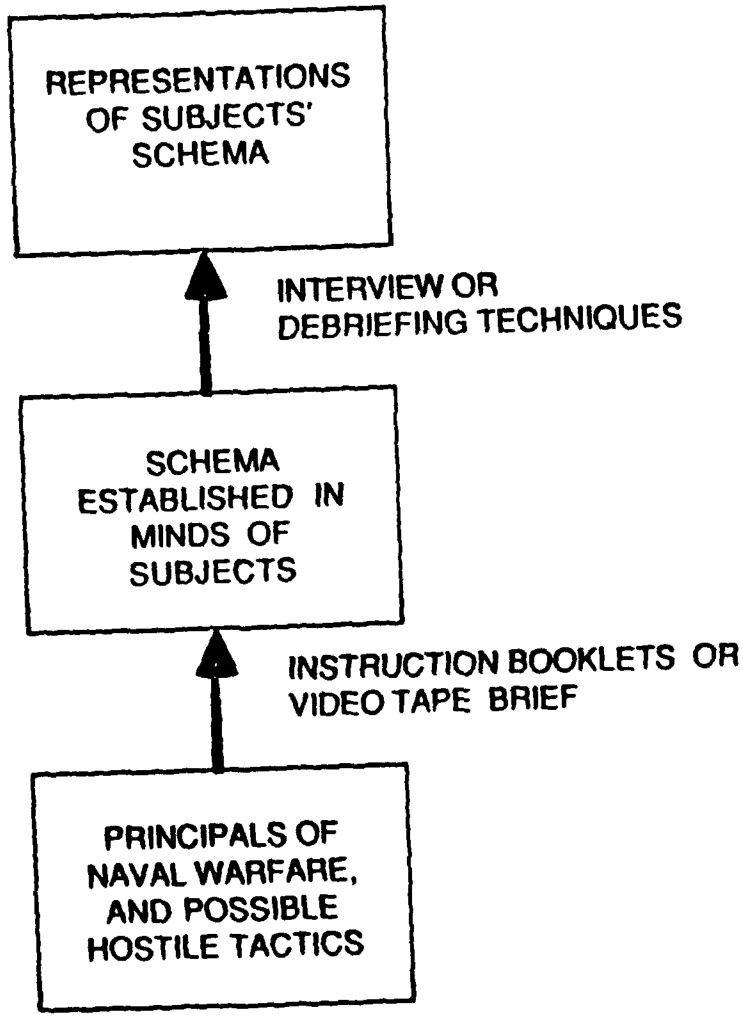
2.3 Experimental Approach to Attain Initial Objectives

The approach to attain the initial experimental objectives has three phases, which are summarized in Figures 2-2a, b, and c. Experimental materials to implement this approach have been developed, and are included in Appendix A.

The first phase (Figure 2-2a) seeks to establish the methods for examining schema in empirical investigations of distributed decision making behavior. In this phase subjects will be given briefings about selected principles of naval warfare and about hypothetical hostile tactics. These briefings are intended to evoke decision-relevant schema in the minds of the subjects. The kinds of schema that might be generated from the material presented in Appendix A.1 are shown in Appendix A.2. Methods to identify actual schema generated will be developed from the subject-interaction techniques described in Section 4.1. Because reliable methods for reconstructing the schema used in decision making is so important to the total research program, considerable care will be taken to develop these methods.

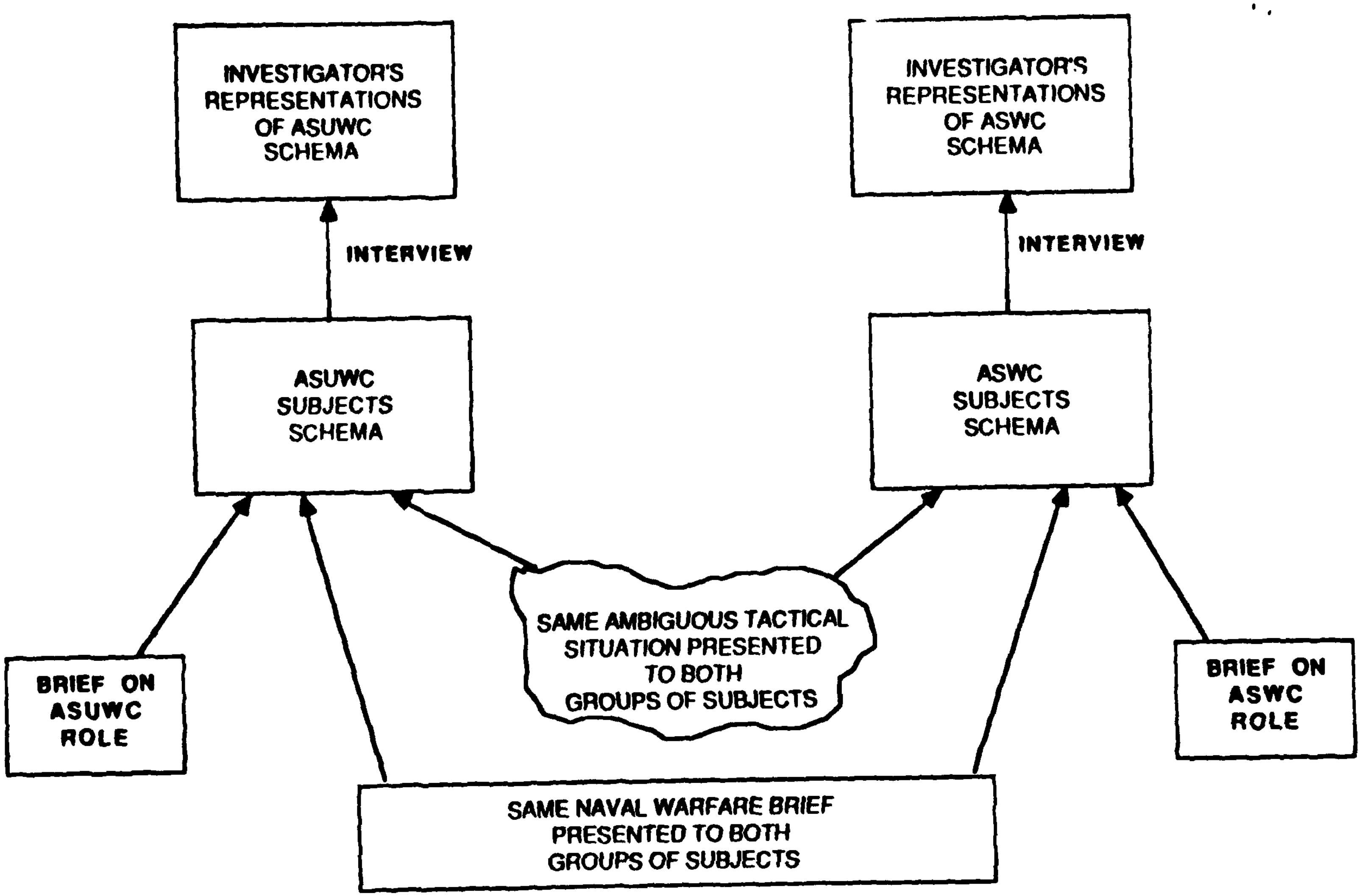
The second phase of experimentation (Figure 2-2b) examines the types of schema activated by an ambiguous situation description, and examines the relationship between the Battle Group role assigned to a subject and the type of schema activated by the ambiguous situation. It is anticipated that the schema activated by the information presented (reproduced in Appendix A.1) will either be one of the three schema generated by the background material on naval warfare or else can be interpreted as a weighted combination of these schema. It is also anticipated that the subject's warfare commander role influences the type of schema activated by the ambiguous information. For example, it is possible that subjects who are assigned the role of the Anti-Surface Warfare Commander will

FIGURE 2 - 2A PHASE 1 OF INITIAL EXPERIMENTS



PHASE 1 ESTABLISH METHODS TO DETERMINE SCHEMA PUT IN PLACE BY PRESENTED INFORMATION.

FIGURE 2 - 2 B PHASE 2 OF INITIAL EXPERIMENTS



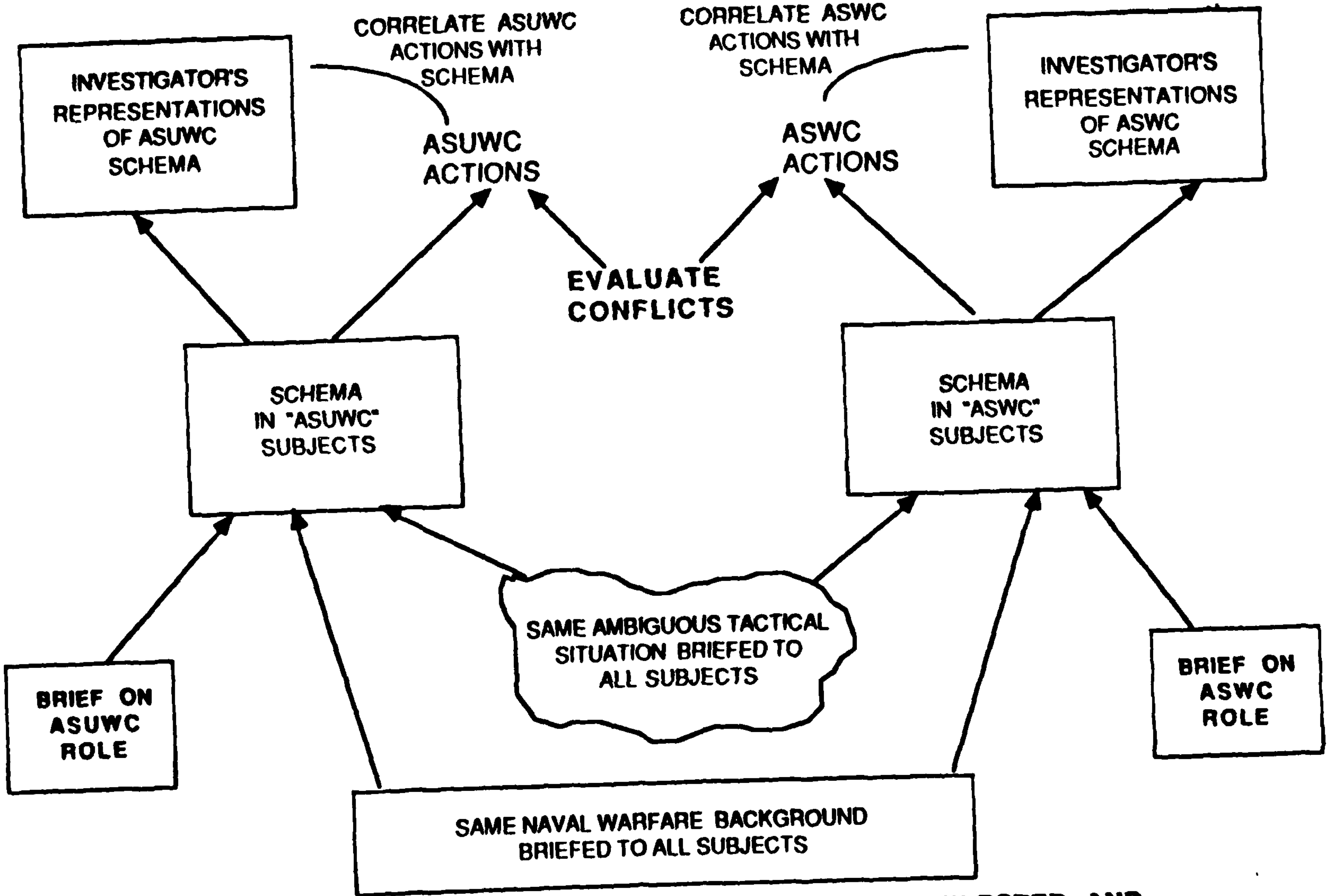
PHASE 2 DETERMINE EFFECT OF SUBJECT'S ROLE ON SCHEMA ACTIVATED BY AMBIGUOUS TACTICAL SITUATION DATA

interpret the information in a way that gives them more importance in the scenario. Alternatively, they might interpret the information in a way that makes their subsequent decisions easier.

The third phase of experimentation (Figure 2-2c) examines two relationships. The first is the relationship between activated schema and selected action options. The second is the relationship between the congruence of the schema activated in different decision makers and the inherent conflicts in the action options selected by these decision makers. In the initial phase three experiments, as in the second phase experiments, subjects will be briefed on naval principles and adversary tactics as well as on their roles as either ASWC or ASUWC, and will be presented with an ambiguous tactical situation. The subjects will then be given a list of possible action options (listed in Appendix A.1), and will be asked to select the best option. The lists given to the two warfare commanders will contain different action options, with the ASWC options being directed against the submarine threat, and the ASUWC options being directed against the surface threat. The material is designed so that the option that is appropriate against a particular adversary tactic should appear logical to a subject who understands (possesses schema for) the hostile tactics, but there will be no explicit direction anywhere in the instructions or briefing stating that particular action options are appropriate against various hostile tactics. Subjects will also be debriefed to determine which schema were activated.

The schema-based theory of information presentation for distributed decision making would anticipate that there will be both a high correlation between action options selected and schema activated and also a high correlation between similarity of activated schema and prevalence of conflicting decisions.

FIGURE 2 - 2 C PHASE 3 OF INITIAL EXPERIMENTS



PHASE 3 DETERMINE CORRELATION BETWEEN SCHEMA SELECTED AND ACTON OPTION SELECTED.
DETERMINE CORRELATION BETWEEN CONGRUENCE OF ACTIVATED SCHEMA AND SYNERGY OF ACTIONS.

After the data from the *initial experiments are* evaluated, subsequent experiments will be designed for examining different factors that can affect which schema are activated. It is anticipated that these factors will focus on the properties of presented information. Experiments to examine these properties will be based on the schema theory and methodology described in the next two sections.

3.0 DESCRIPTION OF THE THEORY

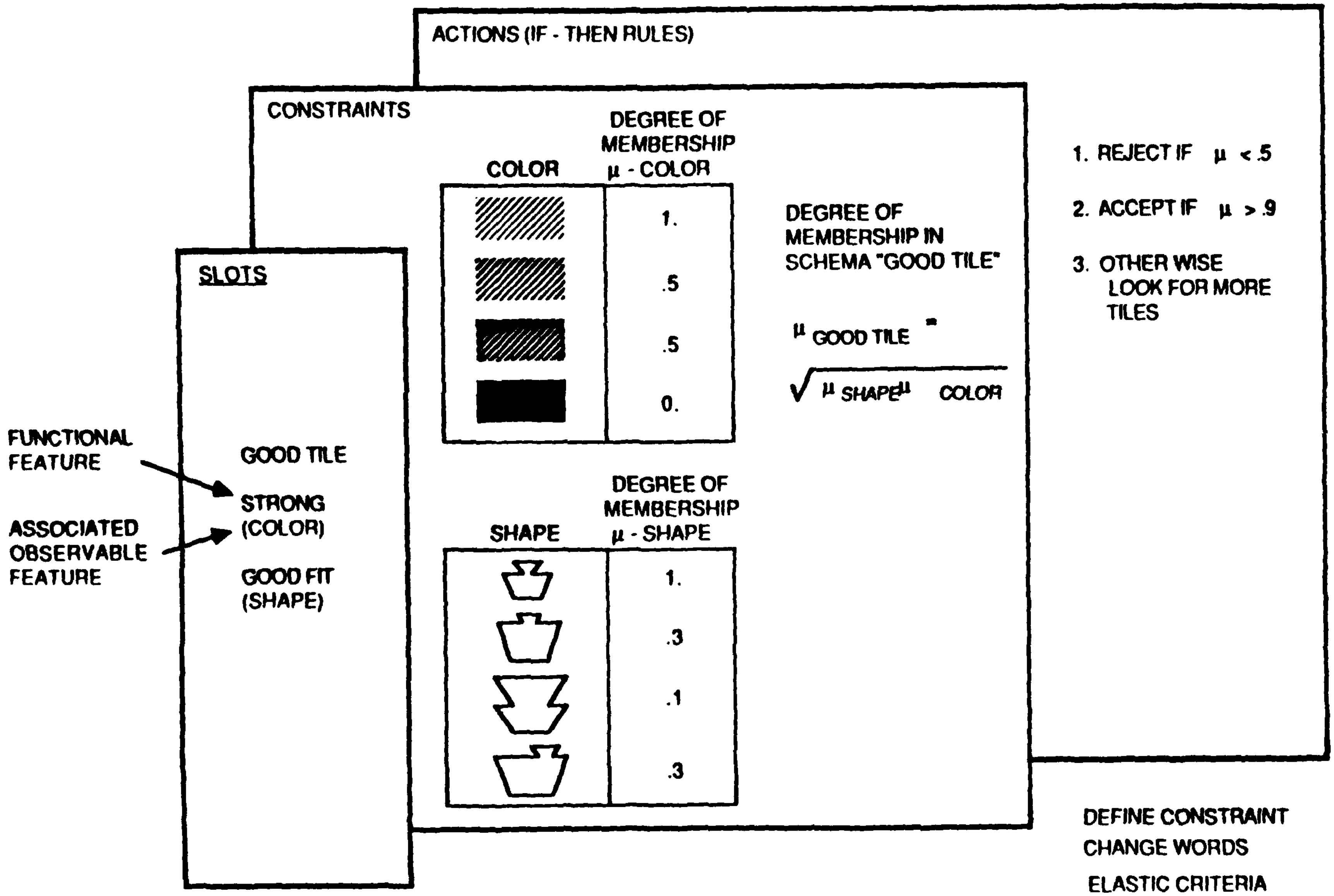
The previous chapter outlined a proposed relationship between schema and decisions, and suggested that consistency of activated situation schema among decision makers is an important precondition for consensus. This section describes the schema-based theory that relates properties of presented information to the situation schema likely to be activated by such information. Section 3.1 describes the structure of the individual schema which are the building blocks of the theory. Sections 3.2 describes how the schema are arranged into a hierarchy needed for understanding complex situations, and Section 3.3 describes how information flows through this hierarchy. Sections 3.4 digresses momentarily, to review important relationships between schema and categories. Section 3.5 enlarges the scope, discussing how the decision task and decision processes dynamically influence the schema used for decision making.

3.1 The Structure of a Schema

There are many kinds of schema, including the time-event schema usually referred to as scripts, and the part-whole schema which characterize objects. Despite some superficial differences, different types of schema are fundamentally the same. All types of schema represent classes of objects, concepts or situations rather than a particular instance of an object, concept or situation. Further, in the present theory of information presentation, all share a particular general structure.

This general structure may be described in terms of the very simple schema for a "good tile", illustrated in Figure 3-1. This schema is based on an experiment by Zimmermann and Zysno 1. In their number experiment, Zysno and

FIGURE 3-1. STRUCTURE OF A SCHEMA FOR A "GOOD TILE"



Zimmerman told subjects that tiles were needed to build a furnace, and that they were to rate the goodness of tiles that could be selected for the furnace. Furthermore, they were told that good tiles would fit well with other tiles and would be strong. "Good fit" and "strength," they were told, could be estimated from the tile's shape and color respectively. This particular example is useful for explaining the proposed schema structure because: 1) it is simple; 2) it illustrates the most important schema properties; 3) this schema will be used in Section 3.5 to illustrate the general information presentation theory,; and 4) data on feature combination for this schema have been obtained by Zysno and Zimmerman.

The schema for a good tile has the three parts that are characteristic of all schema: a set of slots that correspond to features; a set of situation-specific constraints that define what may occupy each of these slots; and a set of actions that are appropriate for the schema.

The schema for a "good tile" has two slots, one for each of the two functional features "good fit" and "strength" relevant to tile quality. Each of these functional slots has associated with it the observables "shape" and "color" that serve as indicators of "good fit" and "strength". Usually the slots for such observables would appear in separate embedded schema. In the present case, to simplify this explanation, both functional and observable features are shown in a single schema. When this schema is used to evaluate a particular tile, representations of that tile's shape and color are inserted into these slots. Note that both of the slots in the tile schema can be associated with the features of some particular tile. According to the proposed theory, a "feature" that cannot be associated with any particular tile, such as the frequency of tiles with cracks, cannot be a slot in classification oriented schema, such as this one used for tile evaluation. This restriction on schema will account for several of the judgmental biases discussed in Appendix B.2

The second characteristic part of the schema are the slot constraints. These constraints provide schema reference values that specify the range of features that may occupy the slots. Schema match logic uses these reference values to compute the degree of match between each feature being evaluated and its corresponding schema slot. The match logic also computes an overall schema match score which reflects the overall match between all the evaluated features and the schema as a whole. The interplay between these constraints and the schema feature slots is extremely important in the theory because this interplay is the basis for the "feature match" step in recognition and classification.

The present theory differs from other schema theories in that constraints that correspond to schema slots are possibility functions for fuzzy sets. In the tile example, the fuzzy sets are "good shape" and "good color". When a candidate feature attempts to occupy a slot, the constraint logic compares that feature against samples in an "explanatory data base", and estimates the candidate feature's degree of membership in the fuzzy set defined by the slot constraints. As indicated in Figure 3-1, for the tile example the explanatory data base consists of two tables, one containing sample shapes and associated degrees of membership, and one containing sample colors and degrees of membership. These constraints are "elastic" because they allow a broad range of shapes and colors to occupy the slots. Rather than rejecting completely a feature with a moderately poor fit, these constraints permit that feature to occupy the slot, but note that the fit is poor.

After a slot is occuppied by a candidate feature and its degree of fit is computed, the schema constraint logic updates its estimate of an aggregate tile for the schema as a whole. In this example, the schema tile represents the extent to which a particular tile is a good tile; i.e. the degree of membership of the tile in the fuzzy set "good tile". Data collected by Zysno and Zimmerman suggest that in this case a tile's degree of membership in the fuzzy set "good tile" is the geometric mean of its features' degree of membership in the fuzzy sets "good shape" and "good color".

The final characteristic part of the schema are the inferences and actions which are appropriate for this schema. The inferences are the unobserved qualities of a situation or object associated with a schema. The actions may be "if-then" production rules, triggered by "procedural attachment." Figure 3-1 suggests three such rules for the tile schema: reject the tile if tile is less than .5; accept if tile is greater than .9; try to find a better tile if tile is between these values.

In general, there can be a very wide variety of action heuristics associated with a schema, and they can range considerably in appropriateness. These action rules are generated from the dynamic interplay between schema and decision task described in Section 3.5. One of the goals of an information presentation theory is identification of effective methods to discourage use of "improper" judgmental heuristics.

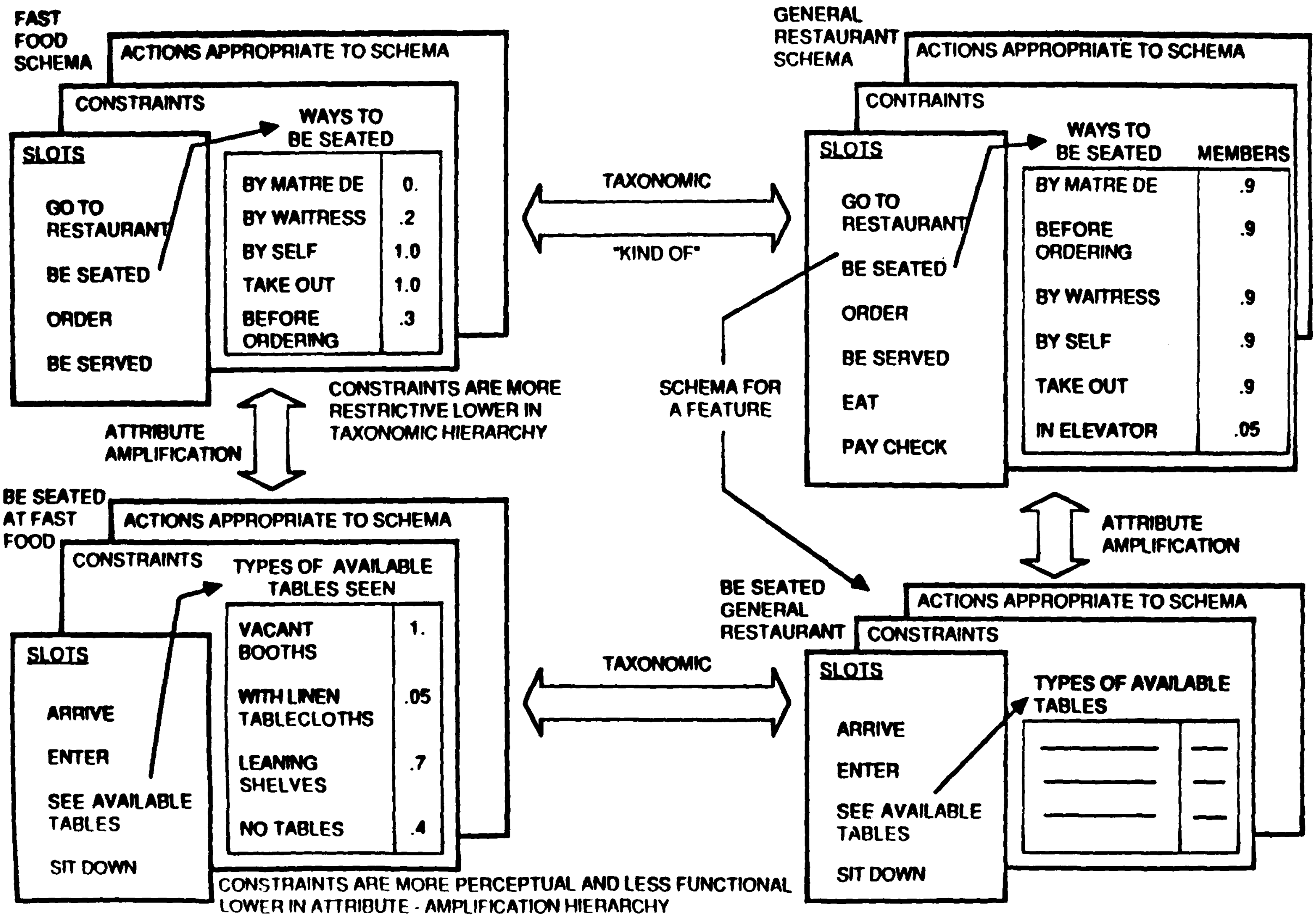
3.2 The Hierarchical Relationships Among Schema

Although selecting a good tile could conceivably require only a single schema, most judgmental and decision problems require the use of a complex network of interrelated schema. Two types of schema relationship most important to the present theory are taxonomic ("kind-of") and attribute amplification (typically "part-whole"). This section will describe the relationships, and indicate their importance to the theory.

The example for this discussion is based on the restaurant script investigated by Bower, Black, and Turner 2. Scripts are a particular type of schema in which many of the schema slots are event slots and many of the constraints concern temporal relationships among events. Figure 3-2 shows four related restaurant schema: a "general restaurant" schema (upper right); a "fast food" schema (upper left); a "be seated in a general restaurant" schema (lower right); and a "be seated at a fast food restaurant" schema (lower left). The schema for general and fast food are related taxonomically, as are the schema for "be seated in a general restaurant" and "be seated at a fast food restaurant." The two "be seated" schema are related by "attribute amplification" to the two restaurant schema. The events (schema slots) for the general "restaurant" and general "be seated" schema are those identified by Bower, Black, and Turner.

The general restaurant schema has slots "go to restaurant", "be seated", "order", "be served", "eat", and "pay check". The explanatory data base for the constraints enumerates different ways that the constituent events can take place, and assigns membership scores to each of the different ways for each of the events. For example, constraints for the "be seated" slot assigns a "be seated" membership score for the different ways one could be seated in a restaurant. Because the general restaurant schema spans so many different kinds of restaurants, the constraints permit high memberships scores for many different ways to be seated. The actions appropropriate for being in a restaurant specify many behaviors that are acceptable in a restaurant, but might not be acceptable in other social situations. For example, it is appropriate to ask the waitress in a restaurant to bring a menu, but it is not appropriate to ask the same woman at the beach (where she is not a waitress) to bring a menu.

FIGURE 3-2. HIERARCHICAL ORGANIZATION OF RELATED SCHEMA



Because these schema specify actions that are appropriate to the schema, many decisions become very easy once one realizes that a particular schema applies to a particular situation.

The fast food restaurant is a "kind of" restaurant. As a kind of restaurant, it tends to have event slots similar to the general restaurant schema, but the constraints on these slots would tend to be much more restrictive. Thus, while being seated by a maitre d' is entirely consistent with the "be seated" slot in the general restaurant schema, it is inconsistent with the "fast food" restaurant schema. Actions that are associated with the fast food schema augment and qualify those specified for the general restaurant schema. Decisions concerning appropriate actions in a fast food restaurant depend on accessing both the fast food and the general restaurant schema.

The schema for "*be seated in a general restaurant*" contains more detail about the process of being seated than does the general restaurant schema itself. As a general schema, its slots and constraints, however, may be rather abstract. Consequently it may be difficult for a person to determine a degree of fit between observed features in a situation and the constraints on these slots. Rather, it is expected that this degree of fit would be calculated for the slots in the less general "be seated at a fast food restaurant". At this level of specificity, the constraints information may contain concrete detail that enables a person to match his perceptions against the slot constraints.

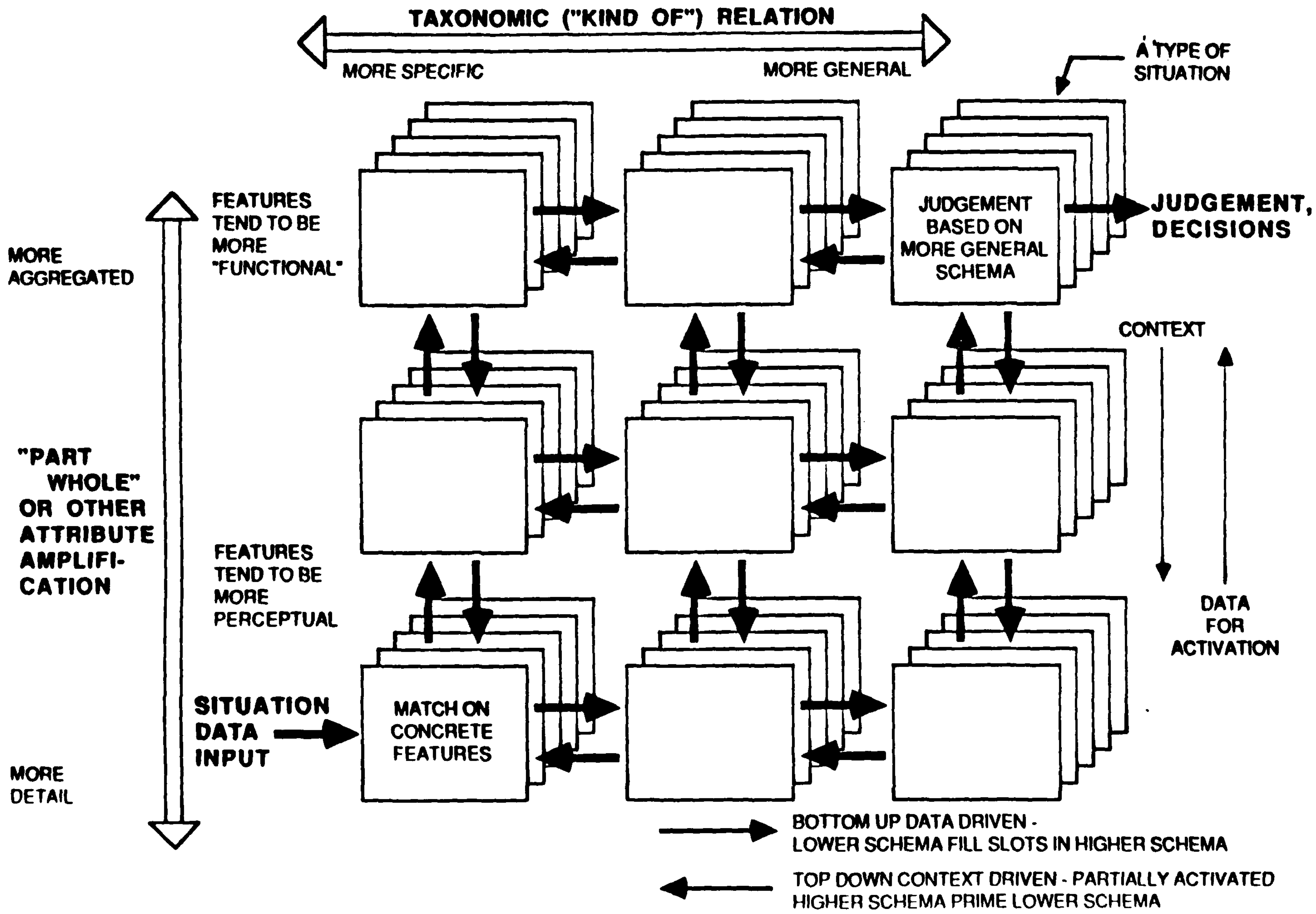
3.3 Significance of Schema Relationships to Situation Recognition, Understanding, and Actions

Situation recognition, understanding, and actions depend on the interplay among many related schema. The nature of this interplay is important to the theory, and generates several of the hypotheses concerning the relationship between information presentation properties and activation of schema based on that information. Figure 3-3 summarizes the interplay among schema relevant to the current work. In this figure, each cube represents a set of related schema, each having the three layers described earlier. These layers are not indicated here; the divisions in each cube delineate different schema.

There are four important schema-related issues pertinent to the theory of information presentation: 1) the way that actions relevant to a situation are distributed among the schema in the hierarchy; 2) the variation of schema slot characteristics as a function of the schema's level in the hierarchy; 3) how the slot characteristics at different hierarchical levels affect schema effectiveness as data entry points into the hierarchical schema structure; 4) the nature of the interplay between schema at different levels and how this interplay enables schema recognition.

Actions relevant to a situation are attached to schema throughout the schema hierarchical structure. It is assumed in schema theory that actions (or properties of actions) are attached to schema at the highest level in the hierarchy for which they are appropriate. For example, those actions which are appropriate in restaurants in general (paying for food) are attached to schema for restaurants in general or rather than being attached to each of the schema for specialized types of restaurants. Those which are appropriate only at lower levels in the taxonomy (ordering food at a counter) are attached to schema at a lower level. It is expected that the more general (and usually more fundamental) properties of a situation will tend to be specified by schema high in the schema hierarchy (the upper right hand corner of Figure 3-3). It is also assumed that actions or properties of actions specified by these schema are most critical to sound decisions whenever selecting the right actions depends on recognizing the fundamental principles or properties of a situation. For dif-

FIGURE 3-3. THE ACTIVATION OF SCHEMA WITHIN THE HIERARCHICAL STRUCTURE



ficult problems, in which identifying actions appropriate for a particular situation requires use of the more general schema, identifying proper action depends on the ability of situation data to activate these more general schema.

It may be hard for situation data to activate these schema because such general schema cannot be activated directly by perceptual cues. Generally, slots in the more general schema (the "meta-scripts" of Abelson 3), correspond to abstract aspects of situations that cannot be directly observed. For example, an important property of restaurants is that the food that can be prepared and served is limited to items listed on the menu. This relationship, though a property of restaurants and perhaps a slot in the restaurant schema, cannot be directly observed. Because perceptual data cannot directly occupy their slots, schema high in the schema hierarchy cannot be activated from data provided directly by perceptual systems. Rather, perceptual data must activate them indirectly by activating schema lower in the hierarchy, which in turn can activate the higher schema. Such perceptual data can activate schema low in the taxonomic and attribute amplification hierarchies because these schema have slots for perceptual data. The issue relevant to the theory of information presentation concerns how data capable of activating only low level schema directly can be structured to most effectively facilitate the subsequent activation of the more general schema.

In terms of Figure 3-3, the problem of activating the general schema necessary for understanding fundamental and abstract aspects of a situation may be understood as the problem of activating schema in the upper right hand box of Figure 3-3 using data that activates only schema in the lower left hand box. The theory assumes that information presentations which facilitate this process will enable a more rapid and more accurate activation of the general schema needed for situation understanding.

The flow of activation through the schema hierarchy is mediated by an iterative bottom-up and top-down feedback mechanism. In the bottom-up activation, data filling the slots of schema lower in the schema hierarchy affect schema higher in the hierarchy. When enough of the slots in a lower level schema are filled, the schema containing these slots become "activated". Since such activated schema can act as data capable of filling slots in all schema at adjacent higher levels, these lower level schema can partially activate higher schema. In this way, each lower level schema that becomes activated partially activates many adjacent higher schema. When several of the slots in the higher order schema are filled by different lower order schema, this higher schema also becomes activated.

The top-down activation increases the efficiency of the lower-level data collecting schema by providing context. Partially activated higher schema will "prime" relevant lower schema to facilitate their further activation. This priming helps these lower schema recognize data potentially capable of filling their slots. More importantly, it ensures that data relevant to situation understanding will be recognized as relevant and embedded within the system of activated schema. This priming of subordinate schema may be very important for data retention because there is evidence 4 that memory can retain at one time very few peices of data which have not been embedded into a schema system.

In summary, the schema feedback loop is assumed to work as follows. Perceptual data activates a low level schema. Since this schema can fill the slots of several higher level schema, the activation of the lower schema causes these slots in the higher schema to be filled, and causes the higher schema to be partially activated. Each of these higher schema has several additional slots besides the ones initially filled, and these other slots are fed by sets of lower schema. Once any of the slots in a higher schema is filled, this higher schema primes all the other lower schema connected to it. These lower schema search for additional perceptual data capable of filling their slots. Those schema for which such data are found are activated further, which then activate some of the associated higher schema sufficiently for these schema to fill the slots of yet higher schema. In this way, data entering at the lowest levels works with contextual information provided by the higher levels in an efficient data processing and recognition system.

The material presented so far in this section describes the "match" logic by which perceptual data in a context can activate the higher level schema needed for situation understanding and action selection. This match logic is critical to the theory, and the model described here will be used in Chapter 4 to generate hypotheses concerning the relationship between how information is presented and which of several possible decision related schema are activated.

The match logic, though central to the theory, is not the only process in the theory. This process is embedded within other processes which address how schema related to a decision task are retrieved or developed at the time of the decision task. These issues will be described in Section 3.5. Before describing it, however, it is important to discuss the relationship between schema and categories. This relationship provides the rationale for the theory-based methods of evoking schema described in Section 4.1.

3.4 The Relationship Between Schema and Categories

A natural category is a collection of objects, situations, or concepts which are sufficiently related so that all members of the category share many properties. This property sharing enables people to use category membership to reach conclusions about unobserved or unobservable properties of objects or situations from observed properties. According to the probabilistic featural view of categories, one of several discussed by Smith and Medin 5, all categories are defined in terms of a set of features shared by the members of that category. An object's membership in a particular candidate category is determined by matching the features of an object against the features of a category prototype. An object is classified as a member of the category if enough of the features of the object match the features of the category prototype well enough.

The activation of schema, as defined in the previous section, is very closely related the classification process proposed by the "probabilistic featural view" of natural categories. This relationship between categories and schema was discussed in the review paper by Abelson 3 and was earlier noted by Bower, Black, and Turner 2 in their classic work on scripts, a specialized form of schema with script events being a kind of schema slot. Bower, Black, and Turner explicitly equated the events in a script with category features. For example, the event "be seated" in the restaurant script can be interpreted as a feature in a restaurant category. The only significant difference between the schema in this theory and "probabilistic feature" categories is the existence of the third schema part which specifies actions and inferences appropriate to that schema. The other differences between the schema and these categories are details, such as the exact nature of the match process, that do not affect the conceptual similarity between schema and categories and, more importantly, do not affect the relevance of experimental data attained in category research to the present work.

The present theory of information understanding, though developed in terms of schema, suggests specific models that address several undeveloped issues in category theory. It suggests that the "prototype" for a category is not an average or highly typical member of the category, but is instead a set of fuzzy sets defined on the category features 6. It interprets the feature match process as a membership assessment in a fuzzy set. Finally, it interprets the category membership decision rule as a threshhold of a function of the feature membership degrees. In the example of the tile described in section 3.1, this function was observed to be the geometric mean. In other cases, other functions may be more appropriate.

Because of the similarity between theories of classification and theories of schema activation, research data attained by investigators of the categorization process can be applied directly to the present research. Thus, by drawing on the categorization research, the theory can take advantage of important relationships between similarity judgments, comprehension difficulty, typicality judgments, and family resemblance scores 5. Furthermore, this similarity implies that situation assessment can be viewed alternatively as situation classification or schema selection. This relationship is the basis for the schema mapping process outlined in Section 4.1.

3.5 The Development and Activation of Schema for Decision Making

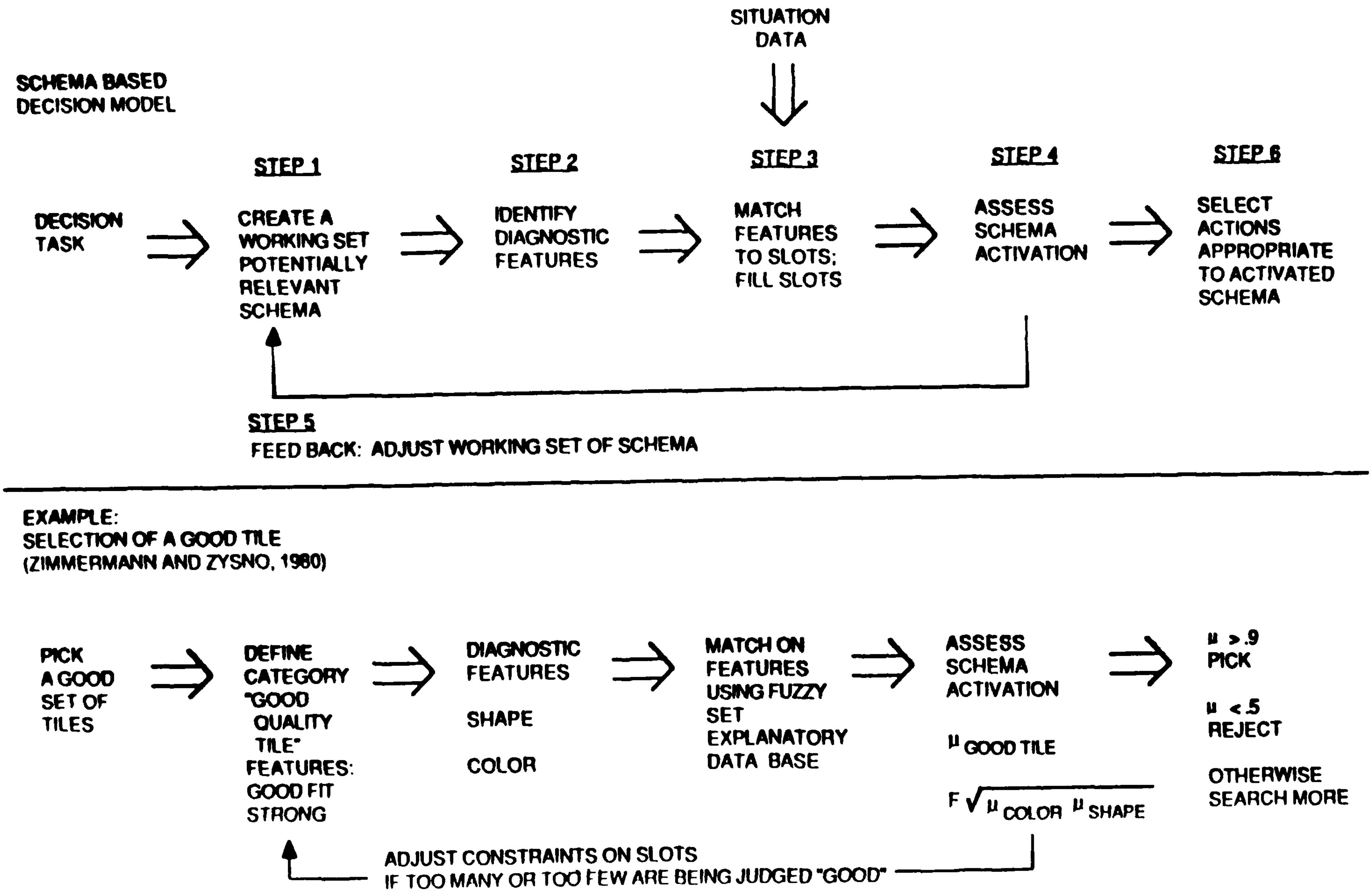
The previous material described how situation data interacts with a hierarchical system of schema to activate high level schema used for understanding the data. Though not emphasized in that discussion, different hierarchies are used in different decision tasks, and the schema in these hierarchies may be dynamically adjusted throughout the decision process. This section describes this schema adjustment process, and indicates how the model logic described previously fits within a broader schema based decision model.

This model of schema-based decision making focuses on the problem structuring phase of the decision process. This phase begins when a decision maker becomes aware of a decision task in the context of a general situation. It concludes when he identifies one or more reasonable alternatives, a set of attributes on which these alternatives will be evaluated, and a set of criteria for evaluating each alternative on each attribute. When this process produces a single alternative, the output of the model is a decision. For more difficult decision problems where no single alternative emerges as the clear choice, the process feeds subsequent steps for additional alternative evaluation.

The decision model (Figure 3-4) contains six steps: 1) the recognition of a problem as a decision task and the creation of a working set of schema potentially relevant to a presented decision task; 2) the identification of diagnostic features (slots) contained by this set of schema; 3) the match of these diagnostic features against situation data; 4) the tentative selection of schema based on this match; 5) feedback and modification of the working set of potentially relevant schema; and 6) the selection of an alternative associated with a selected schema.

The decision model will be explained in terms of the tile selection experiment described by Zimmerman and Zysno 1. As described earlier, subjects in that experiment were asked to rate the goodness of tiles based on their shape and color. Though not clearly a decision task as specified in that

FIGURE 3-4. SCHEMA - BASED DECISION MAKING



experiment, this task would be made into one if the subjects were asked to select tiles for a furnace to be built rather than just to rate the tile goodness. In that case, the subjects would be making a decision about each tile based on its "goodness". They would have to decide if the tile is good enough to select, bad enough to reject, or should be set aside for future consideration.

The first step of the decision model involves the recognition of a problem as a decision task and the creation of a set of generic schema embodying this task. With the Zysno and Zimmerman instructions extended as discussed above, the decision task is "pick a good set of tiles."

The decision maker next creates a working set of schema potentially relevant to the decision task and the general situation. The schema placed into this working set are those that are potentially relevant for understanding issues related to the decision task. The schema in this working set are assumed to be situation and decision task specific. Some of these are retrieved from long term memory, while others are built on the fly from other schema in memory. The nature of this process which generates a a working set of schema appropriate to a decision task is not a focus of this research, but is discussed briefly in the "Linda" example in Appendix B-1. In our tile example, the decision task requires only a single schema, the "good tile" schema described earlier. It is generated by adjusting the fuzzy constraints "good shape" and "strong" to be appropriate for the tile's expected use.

The second step is the identification of "diagnostic" slots. Diagnostic slots are the schema slots that are determined to be the best discriminators among the schema in the working set. These slots are predicted to be the most useful for enabling the decision maker to determine which of the schema in the working set is the most appropriate interpretation of the situation. The schema slots which are diagnostic in a particular schema depend on the entire working set of schema. A schema slot that is diagnostic for one problem may be irrelevant for another problem. In the tile example, tile shape and tile color are the diagnostic features.

The third step is the examination of a current situation, and the matching of the situation features with the slots in the working set of potentially relevant schema. This match process was detailed in Sections 3.1 through 3.3, and can involve complex interactions among schema at different levels in the schema hierarchy. As a result of this process, some of the slots in some of the schema are filled to varying degrees by situation features or by schema activated by these features. In the tile experiment, the results of this match process was made explicit. Subjects rated each tile, on a zero to one scale, for goodness of fit based on shape and strength based on color. In that experiment, as in the present theory, goodness of fit numbers were interpreted as degrees of membership in the fuzzy sets "good shape" and "good strength."

In the fourth step, the patterns of filled slots in the various candidate schema in the working set are assessed in order to determine the degree to which each schema is activated by the situation data. Those schema most consistent with the situation data will be most activated. Sometimes, only a single schema will be activated. In that case, the situation data is adequately explained only by that schema. At other times, several of the schema will be activated, indicating that several of the schema are consistent to varying degrees with the situation data. In still other cases, no schema is activated, indicating that none of the schema in the working set is appropriate for that situation. In the tile example, each examined tile activates the "good tile" schema to the extent that that tile is estimated to be good, as assessed by tile shape and tile color. For the Zysno and Zimmerman experiment, this degree of goodness approximately equaled the geometric mean of the goodnesses for the degree of fit and the degree of strength.

When the situation data activates only a single schema or when there is no time for additional evaluation, then the final step, action identification, occurs. Otherwise, a fifth feedback step to restructure the original working set is invoked. In the case when the situation data were consistent with many schema so that many schema are partially activated, the feedback process identifies those unfilled slots which if filled would be capable of resolving the ambiguities. These unfilled slots define information requirements important for resolving the schema ambiguities. If the situation data did not activate any schema very much, then the feedback process adjusts current schema or generates additional schema. These adjustments aim to improve the working set of schema so that the situation data will be able to adequately activate one of the schema. In the tile experiment, if there were no tiles that seemed to fit the schema for a "good tile", the feedback adjustment could develop a new schema by redefining the shape and color criteria for a good tile.

In the final step, actions associated with the activated schema are identified. Sometimes, when only a single schema is activated, there may be only a single action identified as appropriate. This outcome is usually the case for most routine and familiar tasks. It was also proposed to be the case in the tile example. The action associated with each tile followed directly from the degree of tile activation, and could be expressed as a simple decision rule: pick the tile if   good tile exceeds .9, reject the tile if   good tile is less than .5, and put the tile aside for future consideration if good tile is between .5 and .9.

At other times, especially if several schema are partially activated, there may be no single action identified as the best. In that case, the structuring phase of the decision process described in the previous five steps may be followed by a structured evaluation phase. In this phase, the decision maker may use various formal methods to evaluate which of the alternatives identified by the schema process is the best. These formal methods require, in addition to a promising set of actions, a set of attributes, criteria for evaluating each alternative on each attribute, and an evaluation procedure. It is possible that attributes and criteria are identified by the same schema that identified the alternatives. If the more fundamental issues in a schema theory of decision making are substantiated, then it may be desirable to investigate the role of schema in the formal phase of decision making.

4.0 HYPOTHESES CONCERNING THE RELATIONSHIP BETWEEN INFORMATION PRESENTATION PROPERTIES AND ACTIVATION OF DECISION RELATED SCHEMA

Chapter 4 described the schema-based information processing theory. This chapter describes a three part approach for substantiating the theory. The first part concerns methods for mapping the hierarchical schema structure used by a person in a decision task. It addresses the kinds of questions that might be asked or exercises that might be given in order to permit the postulated hierarchical schema structure to be mapped. The second part concerns methods for using this hierarchical schema map, in combination with the information processing flow modeled by the theory, to predict certain relationships between information presentation properties and the schema activated by these presentations. The last part concerns the specific hypotheses capable of testing these predicted relationships.

4.1 Methods for Mapping the Hierarchical Schema Structure

Since methods for mapping this structure have not previously been developed for decision research, the mapping approach discussed here will apply techniques developed for other cognitive research issues. The methods proposed exploit the close relationship between schema used for understanding and categories used for classification. They draw on techniques used for evoking scripts and for revealing the features used for categorization.

The kind of hierarchical schema map to be sought was summarized in Figure 3-3. This map has two hierarchical dimensions: a taxonomic dimension in which schema are related by the "kind-of" relationship (a chair is a kind of furniture) and an attribute-detail dimension in which subordinate schema are the details of slots in the higher schema. Each schema in the map will be characterized by a set of slots. These slots have the same relationship to schema as features have to categories.

The schema evocation procedure may require three phases: a "free association" schema and feature listing phase; a prompted schema and feature listing phase; and a consistency check phase. In the free association phase, people will be asked to list the different types of situations where particular kinds of actions would be appropriate and to list the features of these situations. After doing so they will be asked to specify different sub-types of these situations along with their distinguishing characteristics. Finally, they will be asked to list the observable features that enable one to know whether they are in one of these situations of another.

In the prompted elicitation phase, people will be asked questions intended to elicit answers in "schema hierarchy format". As in the free association phase, people will be asked to list different situations in which various actions might be appropriate. In the naval example of Chapter 2 and Appendix A, these situations might correspond to the different types of hostile tactics. In that case, they would be asked to list the characteristics of these different types of attacks, the different types of events that occur, and the different kinds of objects involved. For each of these entities listed, they would be asked to list characteristic events, parts, and distinguishing aspects of these events or parts. In addition, they would be asked about the function of these parts, significant functional relationships between parts, and general principles of operation important to the tactic or event. They would also be asked if these tactics are a kind of more general tactic with similar events and parts, and if so to describe the same characteristics for these more general tactics. Finally, they would be asked if there are important subtypes of these tactics which differ in some of the details, but basically attempt to achieve the same sequence of subobjectives in somewhat different ways.

The answers to these questions are used to develop a tentative hierarchical schema map. The consistency check phase tests the adequacy of this tentative schema map. According to theories of categorization, the assessment of similarity between two objects is increased by each feature that they share and is decreased by each feature which is different 7. To test the tentative schema map previously developed, objects or situations that have different subsets of features corresponding to the schema slots will be constructed. If the assessments of similarity between these objects follow the expected pattern, so that objects sharing more features will be judged more similar than objects sharing fewer features, then the set of slots in the schema will be confirmed. If the similarity assessments do not follow the expected pattern, then it can be assumed that there exist additional significant features that were not identified in the earlier phases. In such cases, there will be attempt to find these features.

Another consistency check involves judgements of typicality. According to theories of categorization, exemplars of a category that are judged typical of the category have high "family resemblance scores". These scores are developed by assigning to each category feature a weight proportional to the fraction of category instances having that feature. The family resemblance score for any member of the category is the sum of the weights of the features that particular member has. Research in classification has shown that judgments of typicality correlate highly with these family resemblance scores. In this consistency check, categories corresponding to schema in the hierarchical map will be identified, and the family resemblance scores of several exemplars of this category will be estimated. Subjects will be shown these exemplars and will be asked to judge how typical they are of the category. If the typicality assessments correlate with the family resemblance scores, then the schema will be considered to be well characterized. If they do not, then the schema probably contains additional significant slots.

4.2 Predicted Relationships Between Information Presentation Properties and Evoked Schema

Given an adequate schema hierarchy map, the theory can predict a clear relationship between certain properties of presented information and the schema that are activated by this information. These relationships are direct consequences of the properties of schema and the nature of the feature-slot match process in the hierarchial schema map. This section discusses five properties of information presentations. Three of these stem from the nature of the feature-slot match process within an individual schema; one derives from the changing character of schema slots within the schema hierarchy; the last derives from the feedback loop bewteen different levels of the hierarchy.

Property 1: Congruence of displayed features to slots used in schema.

The schema map attained using the interview and consistency checking procedures described above specifies the features that people use for classification. The theory proposes a direct correlation between such features and the slots in schema. This property states that if the features selected to be shown in information presentations are that same as the features that people say they use for classification, then such classification is easier. Accordingly, the schema used for such classification would be expected to be activated from these features more easily.

Figure 4-1 provides two simple examples of information presentations, one that was designed to emphasize features that parallel the features used for classification and another that was not. Both examples have the same information content because the information in one can be derived from the other. This example supposes that a large number of people in a particular culture were asked to list the features of a "desirable family", and that nearly all responded that a desirable family was one with a very large number of sons and an equal number of daughters. Suppose that an information system were to be designed which supported decisions requiring estimates of family desirability. This information presentation property features the number of sons and equality of sons and daughters will more readily activate to an appropriate degree the "desirable family" schema than information presented in the format of the other table, which features total family size and the fraction of children that are sons.

Property 2: Vividness of features of varying diagnostic value.

The impact of a particular feature, its ability to activate a schema, depends on how much this feature is noticed. Features are noticed both because they are actively sought for and because they impose themselves passively on the perceiver. The former factor depends on predicted diagnosticity, the awareness of the perceiver that a *potential* feature is useful for discriminating among schema in the current schema working set. The latter factor depends on feature vividness.

This information presentation property suggests that if a feature's vividness is adjusted so that its impact is appropriate to the feature's mathematically estimated diagnostic value, then the information presentation will

FIGURE 4 - 1 ALTERNATE INFORMATION PRESENTATIONS ABOUT FAMILY COMPOSITION

CANDIDATES FOR "FAMILY OF THE YEAR" - FAMILY COMPOSITION DATA

FAMILY	BOYS	GIRLS
1	6	2
2	1	1
3	3	0
4	2	6

INFORMATION FORMAT TO BE USED IF CULTURE VALUES FAMILIES WITH MANY SONS, FEW DAUGHTERS

CANDIDATES FOR "FAMILY OF THE YEAR" - FAMILY COMPOSITION DATA

FAMILY	CHILDREN	FRACTION OF CHILDREN THAT ARE BOYS
1	8	3/4
2	2	1/2
3	3	1
4	8	1/4

INFORMATION FORMAT TO BE USED IF CULTURE VALUES SMALL FAMILIES WITH EQUAL NUMBERS OF SONS AND DAUGHTERS

(OTHER INFORMATION ABOUT THE FAMILY WILL ALSO BE CONSIDERED IN SELECTING THE "FAMILY OF THE YEAR") more easily evoke the appropriate schema. The mathematical diagnostic value can be estimated from the hierarchial schema map, for this map records the pattern of slots throughout the set of working schema. Diagnostic value can be estimated from this pattern from the degree to which different sets of features, were they perceived, would enable discrimination among the set of schema in the working set.

There are many examples where this information presentation property was the key to an accurate interpretation of a situation. In the "Hound of Baskervilles", for example, the critical clue to inferring a murderer's identity was a dog that failed to bark. Not barking is a feature of very low vividness. Presumably information presentations capable of highlighting such clues of high significance and low vividness would be very helpful for correctly interpreting situations.

A "dog not barking" is an example of a feature that is not vivid because the feature is the absence of something. A second and equally important reason why features are not vivid is that the feature is an abstract functional relationship among objects, rather than a perceptual property of the object. For example, a very important feature of a chess board is "pin potential". This feature is characterized by two pieces of high value being in the same row, column, or diagnal. Since exploiting pin potentials can lead to the capture of a piece, recognition of this abstract and not very vivid feature is often important for selecting a next move.

Property 3: Explicitness of feature reference values.

The extent to which a feature should select a schema depends on the degree of fit between the detailed characteristics of that feature and the kinds of characteristics permitted by the slot constraints corresponding to that feature. These slot constraints define feature reference values. The constraints normally do not define a clear cut set of characteristics which fit very well, with all others not fitting at all. Rather, reflecting their fuzzy set origin, they define a broad range of characteristics and a degree of fit for particular characteristics within this range. Accordingly, feature reference values also appear as a range of feature characteristics and an indicator of degree of fit for that characteristic.

The best way to convey this degree of match is not yet identified. On modern high resolution color graphics displays, it may be possible to show the match in novel ways. For example, match quality may be indicated by color saturation. Very good matches would be shown in highly saturated colors, poor matches would be shown in grayish hues, and features inconsistent with a schema could be shown in a saturated black. Match quality can also be shown by opacity. Very good matches would appear solid, poor matches would appear wispy, and features inconsistent with the schema would appear solid but in a counterindicator color.

Property 4: Use of features related to part function, functional relationships between parts, and principles of operation.

The possible value of showing explicitly features related to function, functional relationships between parts, and principles of operation was suggested by Rasmussen 9. The present theory suggests that such features can be used in a way to increase schema selection efficiency.

The current theory explains the possible beneficial effect of displaying these abstract features in terms of the schema hierarchy and the variation of schema slot properties as a function of the schemas' hierarchial position. According to the theory, the deeper understanding required to select alternatives in difficult problems requires the use of general schema high in the taxonomic and attribute amplification hierarchy. To use these schema for any particular situation, their relevance to that situation must be recognized. It is assumed here that such relevance is recognized when the schema is activated by filling its slots with the situation features or with activated schema lower in the hierarchy. If the match has to work its way up from schema low in the hierarchy to the general schema, the activation may be difficult. On the other hand, if the activation can be facilitated by displaying directly the special kinds of features associated with higher levels in the hierarchy, then the activation should be easier. Since the theory proposes that these higher level schema have slots corresponding to part functions, functional interactions, and principles of operation, the theory implies that displaying such types of features eases the activation of the higher level schema.

It should be possible to display these types of features without much difficulty. For example, all of the feature types can be employed in information presentations that represent the hostile attacks on the aircraft carrier described in Appendix A. Features conveying function can be icons indicating whether a platform is a bomber, fighter, or support aircraft. A feature conveying a functional relationship would be missile launch range circles centered on the aircraft carrier. A feature conveying a principle of operation would be an indicator that hostile missiles cannot be launched until a targeting update is received while the launching platform is near the missile launch point.

Property 5: Presentation order of detailed and summarizing information.

The presentation order of detailed and summarizing information affects a person's ability to integrate details and to understand the reliability and range of applicability of the summarizing information. According to schema theory 4 the number of details that can be retained depends on whether or not schema for interpreting these details are available. If such schema are not available, then very few of these details can be remembered and used for understanding. Presentation of summarizing information along with the details can help activate the schema needed for embedding these details. Such summarizing information cannot be presented indiscriminately, however, because they may activate schema which are not appropriate for a particular situation. Information that causes incorrect schema to be activated can seriously degrade decision making. Schema, once activated are not easily deactivated by data that is inconsistent with the schema. Such incorrect schema, once in place, tend to stay in place. Furthermore, as discussed previously, incorrect schema which causes situations to be misunderstood can cause very poor decisions to be made.

The theory suggests how summarizing information should be presented so that details may be integrated into higher schema while avoiding activation of inappropriate higher schema. In this theory, summaries are not a review of data highlights. Rather, they are interpretations of the possible meanings of the data and the contexts for the data. These data summaries are descriptions of the higher schema into which these data fit, and possibly the schema that are one level higher in the schema hierarchy map. In order to aid integration of the detailed data, summaries may be shown that describe all of the relevant schema that have slots for these data. The set of relevant schema can be determined from the schema hierarchy map and the situation data so far attained.

Schema deemed to be relevant are those which fit into slots of partially activated higher level schema, and those that are partially activated themselves.

4.3 Hypotheses for Testing Theory-Based Information Presentation Principles

Each of the information presentation properties described in the previous section linked the way that information is presented to the schema that are activated by that information. These hypotheses can test these information presentation principles in experiment that manipulate information presentation properties to cause different schema to be predictably activated.

For any particular experiment, these hypotheses will be expressed in terms of particular schema in the schema hierarchy map, particular features to be manipulated in specific ways, and particular dependent schema and decision variables.

The independent variables relate to the five information presentation properties: features related to certain selected schema are made congruent to the slots of these schema but features associated with other schema are not made congruent with schema slots, the vividness of certain features associated with some schema is increased relative to the features associated with other schema, feature reference values are made available for the features of some schema and not for the features of others, abstract features (function, functional relationships, and principles of operation) are available for some higher level schema and not for others, and summarizing information will accompany the detail information associated with some schema and not for details associated with other schema.

An important variable is the representation of the schema that is activated after presentation of the information stimulus. Because this schema itself is not an observable, these schema are intervening variables. Consequently, the experiments must rely on the representation of schema attained by the investigators using the methods of Section 4.1. Additional dependent variables will rely on the correlations to be established between selected schema and decision related behavior. This correlation will be tested in earlier experiments. In addition, the experiments will test for certain other expected effects. These are the incorrect schema, and the ability to recognize the value of potential information.

Each of these other effects are closely related to the schema activated. For any experiment, one particular schema can be designated to be the "correct" interpretation of presented information. This "correct" schema will be the one which is most consistent with the data provided, and in these experiments will probably be the only schema which is consistent with all the data provided. To test the timeliness of schema activation, subjects can be asked for their assessment of a situation after varying amounts of information have been presented. To test for accuracy of schema activating and the resistance to activating and incorrect schemam the number of correct and incorrect activations can be compared. To test the ability to recognize the value of potential information, information which subjects identify as most helpful during an experiment can be compared with information determined to be most diagnostic in terms of the schema hierarchial map.

APPENDIX A

EXPERIMENTS

A.1 Illustration of Experimental Materials to Test Schema Based Distributed Decision Making

Section A-1 illustrates the materials to be presented to subjects in experiments testing schema-based theory of distributed decision making. Section A-2 illustrates a postulated schema structure that could represent the information in these materials. This schema structure will not be presented to subjects. It is included here to clarify the kind of schema which the information presentation may produce. The experiments will investigate the actual schema produced by the presented information.

In the first phase of these experiments, subjects will be given identical briefings on selected principles of naval warfare and on different hostile tactics employing these principles. This material is illustrated in section A.1.1. Its purpose is to establish schema in the minds of the subjects. Subjects will then be interviewed to determine whether the understanding that they acquired from the briefing is can be easily represented as a schema structure. In the next phase of the experiments, subjects playing the roles of either the Anti-submarine Warfare Commander (ASWC) or Anti-surface Warfare Commander (ASUWC) will be given, in addition to the initial briefing, briefings on the roles and responsibilities of the ASWC and ASUWC and a description of an ambigious tactical situation. The subjects playing the different roles will be given separate and different briefs on these different roles, but the situation description will be the same. This material is illustrated in Section A.1.2. In the third phase, subjects will be asked to select actions appropriate to this situation from the prepared list of alternatives shown in Appendix A.1.3. These subjects will then be interviewed to determine which schema they consider to best fit the situation discription.

A.1.1 A Briefing on Selected Principles of Naval Warfare and Their Application to Selected Situations

Note: The principles of naval warfare presented here as well as the organizational relationship of a Battle Group have been simplified to facilitate the conduct of experiments using undergraduate students as subjects. The tactics, scenario and details of information presented would be expanded for experiments using naval officers as subjects.

The experiments that you are participating in concern the connection between the way that information is presented and the degree of cooperation that results among decision makers that are responsble for different aspects of a common problem. In these experiments you will be asked to identify actions that you think are most appropriate for a situation that will be described to you. So that you can make informed decisions, we will explain to you certain principles of naval warfare and will apply these principles to three different hypothetical kinds of situations. After we explain this to you, we may ask you questions about these principles and situations. The purpose of these questions is not to test you, but to gather the data necessary to test our theory.

A Few Principles of Naval Warfare

Ships, submarines, and aircraft are used to control an area of the ocean. With this control, they can destroy hostile ships, aircraft, and submarines that try to transit this area. The ships, submarines, and aircraft have different capabilities concerning their weapons, vulnerability to detection and destruction, operating time between refueling and communication capabilities.

Ships have several important advantages over submarines and aircraft in naval warfare. They can have substantial numbers of weapons capable of engaging surface, sub-surface and air targets, can stay in one area for long periods of time, can provide platforms for helicopters and other aircraft, and can be used as symbols of intention. In addition, ships are good communications nodes, and consequently the afloat commander of a battle can command from a ship. Ships have some disadvantages, however. Because they cannot move very fast and because they are relatively difficult to hide-once ini-tially detected ships can be vulnerable to attack. In addition, the presence of certain kinds of ships can signal a ship's mission.

The advantage of submarines is their ability to remain hidden for long periods of time, to sneak very close to a target, and to launch a surprise attack at a range which is hard to defend against. Once detected, however, submarines are vulnerable to attack. (They move slowly, and cannot defend themselves very well.) Because a submarine's ability to stay hidden is so critical to its success actions which may make the submarine more detectable should be undertaken only when necessary. Submarines are detected when they make noise. Because they make more noise when they move faster, faster moving submarines are easier to detect than slower moving submarines, and stationary submarines are very difficult to find. Submarines use sonar in the "active" mode (i.e., transmit noise signals and receive echos) in order to find other silent submarines. Sonar transmissions, however, can be detected and their source located by listening ships, aircraft and submarines. Likewise, radio transmissions from submarines can reveal their presence and location. The requirement for submarines to remain undetected even complicates the submarines ability to receive radio communications from other vessels of from shote stations.

The advantage of aircraft is their speed and mobility. Groups of aircraft can take-off from a single airfield, split into several groups, and attack their target from several directions at once. Aircraft do not have to fly over their targets to attack them. Rather, they can launch highly accurate missiles from "launch points" more than a hundred miles away from their target. Aircraft have two disadvantages. First, since they can be detected by radar at long distances, they can give the first definite warning of an impending attack. Second, since they have very limited fuel capacity, they have little endurance. A single aircraft has time for only a very few shots before being forced to return home. Communication with aircraft is relatively easy. Because their flight path is so long, messages to aircraft commonly originate from shore.

Ships, submarines, and aircraft, when used in different combinations to support one another, can be much more effective than when used alone. One such combination, in which platforms stay close to each other, enable different platforms to "cover" one another, with each platform providing a protective cover for the other. Another combination, in which platforms spread out on "multiple axes" to surround a target, is used for attacking a target from many directions at once. When all the platforms in these combinations attack a target nearly at the same time, the total attack can overwhelm the defenses of a target. The advantages of these combinations are so great that ships, planes, and submarines rarely fight alone. These combinations, however, do have some disadvantages. Combinations can require complicated methods to control and coordinate, and characteristic combinations of ships, submarines, and aircraft may convey intent, making surprise attacks more difficult to execute.

The principles of naval warfare you have just read wll be applied to the tactical situations that follow.

A "Friendly" Naval Mission and Three Different Ways That a Hostile Naval Force Can Defeat the Mission.

In this mission, a "our" Battle Group has been ordered to transit a part of the ocean whose control is being contested, and to rendezvous in two days with other Battle Groups. We have been told why the groups need to join, that timing is critical, and arriving even a day late could undermine a very important operation.

This mission is occuring during a war, and we must expect that our adversary will try to stop us from completing our mission. We do not know the tactic they will use against us but it will depend upon their overall strategy for this stage of the war, the resources they want to commit to immediate action, and how much they want to hold in reserve for later actions. We do know, however, that there are three basic tactics that this adversary would use against missions like ours: they can mount a massive attack and try to destroy us before we can rendezvous, they can mount a limited attack to reduce our strength enough to jeopardize the success of our mission, or they can attempt to delay us with a barrier to prevent the scheduled rendezvous. Each tactic requires a different amount of resources and presents different risks to their forces.

We have studied these tactics over the years, and have developed ways to recognize early signs that each of these tactics is underway. In addition, based on this study we understand both the strengths of these tactics--the main dangers each presents, and the weaknesses, and what we can do about them. The following material reviews each of these hostile tactics so that you can make decisions about proper actions to take when one of these situations is encountered.

Situation 1: The maximum power attack.

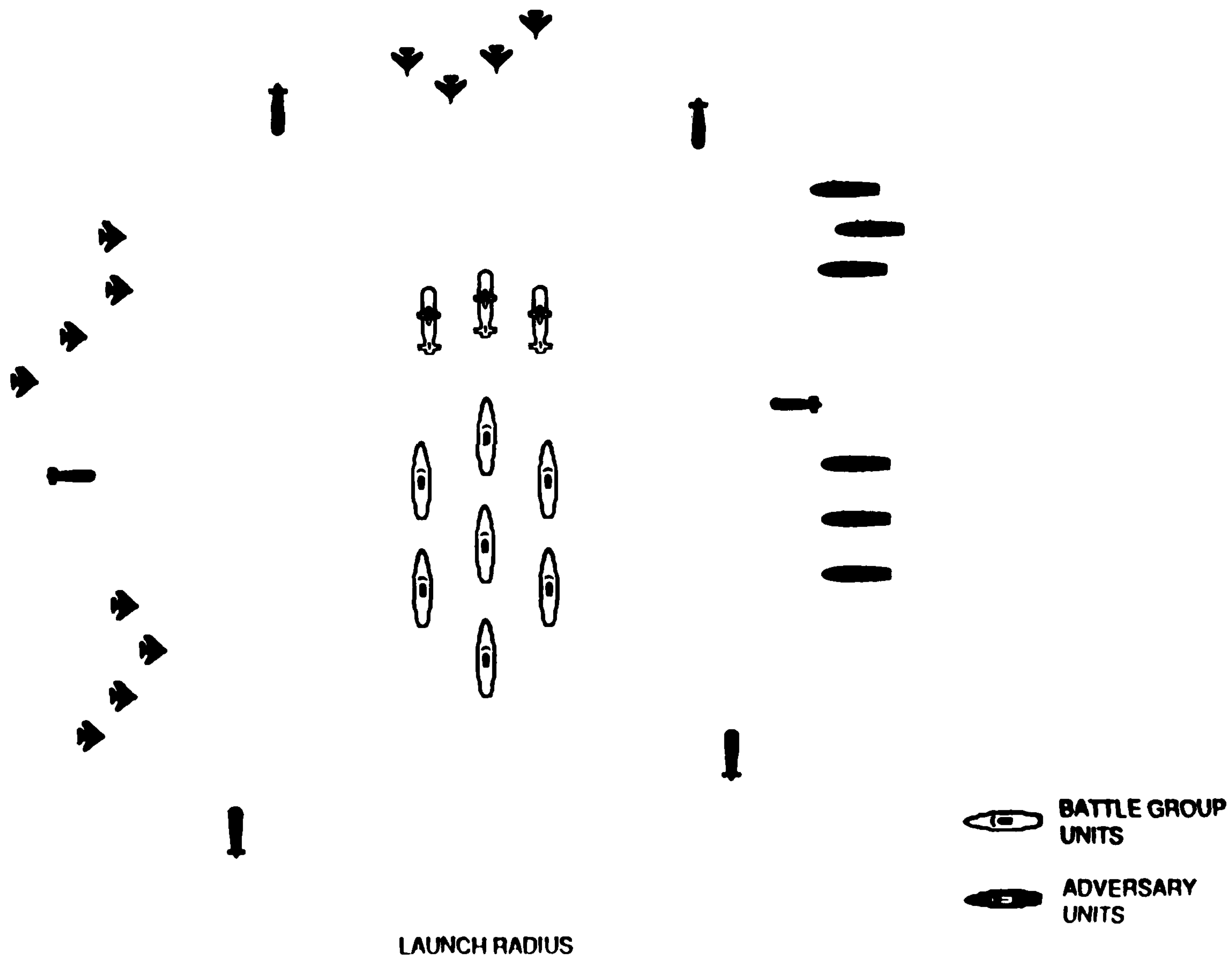
In this attack the adversary attempts to destroy the Battle Group in a massive strike from many directions at once. This strike is intended to overwhelm our defenses by firing more missiles than we can defend against.

Figure A-1 represents a typical maximum power attack. No actual attack of this type is likely to be exactly like this one, but all will be more or less similar. This attack is characterized by large numbers of adversary surface ships, submarines, and missile-carrying aircraft spread out over several axes. There will be typically six to eight surface combatants, including two or three ships with long range missiles at two different axes; 20 or more aircraft attacking in waves, with each wave breaking into groups of 3 or 4 aircraft directed to different axis; and about six submarines each operating independently on a different axis.

In a maximum power attack, all of the different forces attempt to attack at once. A maximum power attack is especially dangerous to us, and our best defense against it is to "preempt"--to attack them before they attack us. To do this successfully, we must recognize the signs of the impending attack and must understand the points of this type attack.

There are several indicators of the maximum power attack. Most significant are the large numbers of adversary ships, submarines, and aircraft. The ships are usually aircraft deployed in more than one group, and situated somewhat outside the missile launch range of their aircraft. Because the submarines will be maneuvering into position before the attack, they will be moving fairly noisily, and should be easier to detect. Typically, if the Battle Group is looking hard for submarines, we should see about half the total number of hostile submarines. Finding three or four at different axis near the bomber launch radius is a good indicator that this attack may be imminent. Of

FIGURE A-1. MAXIMUM POWER ATTACK
TYPICAL GEOMETRY AT LAUNCH (NOT TO SCALE)



course another good indicator are confirmed reports that waves of missile carrying aircraft have taken off and are heading in our direction.

A pattern of observed adversary communications can also provide warning of impending attack. Because this type attack is so complicated, the targeting instructions and timing actions are rather extensive and requires special coordination. The transmission of these complicated instructions are reflected by a pattern of increased communications at unusual times, and by the control of the attacking aircraft and submarines shifting from commanders ashore to control by the afloat commander.

Our best opportunity for a preemptive attack is to exploit weaknesses in the maximum power attack plan. First, we can exploit the fact that the submarines are isolated and noisy. We can agressively search for, track, and destroy hostile submarines. Second, we can exploit the dependence of this attack on extensive coordination. We can station a submarine close to the adversary commander, and as part of our preemption, destroy his ship.

Situation 2: A limited attack.

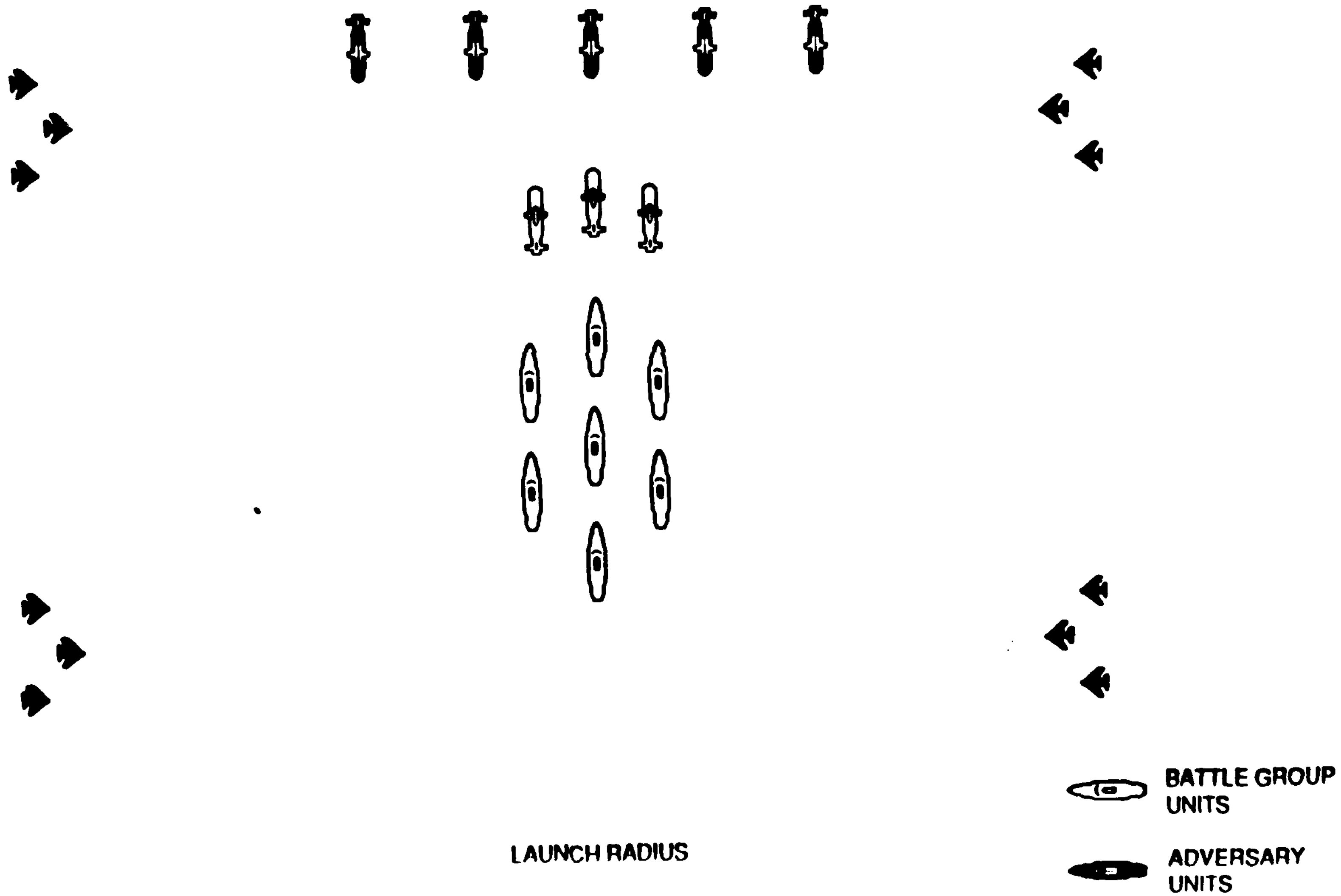
Another basic hostile plan is a limited attack. This attack, while not nearly as intensive as the maximum power attack, is intended to inflict enough damage on the Battle Group to defeat our mission. Furthermore, it can do so using far fewer hostile assets and placing them at much less risk.

In the limited attack the adversary will typically station submarines in the path of the Battle Group at a point that can be reached by hostile missile-carrying aircraft. These submarines do not move to the Battle Group, but wait for the Battle Group to come to it. When the Battle Group reaches a trigger point, the hostile aircraft take off. Shortly thereafter, the submarines launch a surprise missile attack, followed by a combined attack of aircraft missiles and additional missiles from the submarines.

Figure A-2 represents a typical limited attack. It is characterized by about six submarines, lying in a row in front of the Battle Group, and by twenty or more aircraft attacking as they did in the maximum power attack, in raids breaking into groups of 3 or 4 aircraft directed to different axes.

The indicators of this attack are not very easy to recognize. Only about one is likely to be detected since they are not moving and of submarines are very hard to detect. One indicator is that aircraft are reported to be flying in our direction. But unlike the maximum power attack, in which the attack did not begin until the aircraft reached the missile launch point, this attack begins when the aircraft are still enroute. Overall, this attack is characterized by a lack of definite indicators. Few submarines will have been detected, and no surface forces are involved. There likely will be, however, reports of the aircraft launch, perhaps associated with some unusual shore-based communications.

FIGURE A-2. LIMITED ATTACK
TYPICAL GEOMETRY AT LAUNCH (NOT TO SCALE)



It is difficult to preempt this attack because it is so hard to see it coming. Fortunately, this attack is not nearly as dangerous as the maximum power attack, and it is possible to "ride out" the early phase of the attack and to counterattack in later phases. The actions to counter this attack are based on the assumption that the hostile submarines are isolated (having no cover from surface ships), and that once these submarines launch a missile, they reveal their position. Accordingly, our plan to counter this attack is to vigorously search for submarines, to extrapolate the possible positions of other submarines from any that are detected, to position our own submarines near these anticipated positions, and to use these submarines to destroy the hostile submarines as soon as they reveal themselves through a missile launch. The defense against this attack also includes standard anti-air warfare postures.

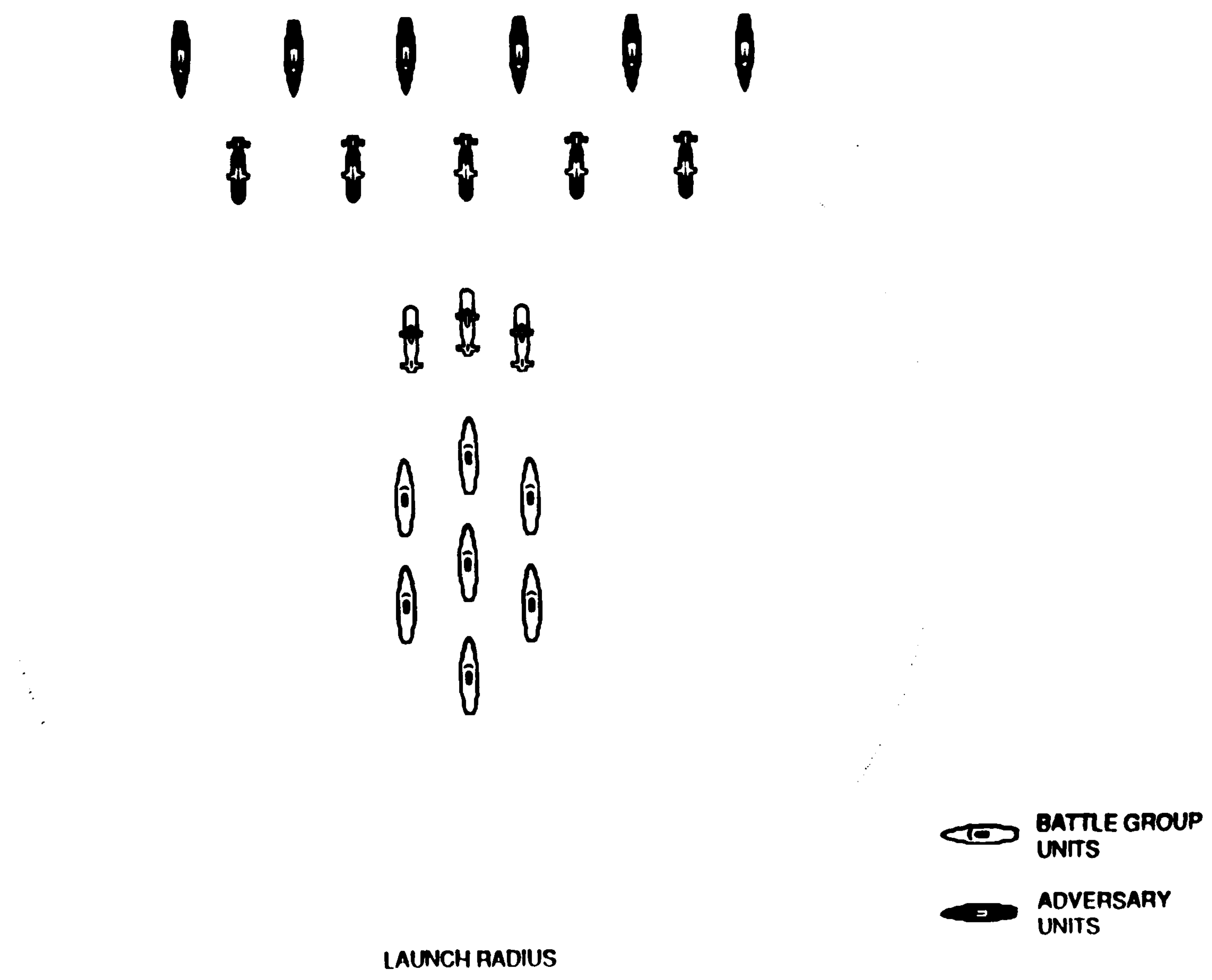
Situation 3: The barrier defense.

It is not certain that the adversary will attack the Battle Group at all. If they have advance knowledge of our mission they may merely try to block our way with a barrier in order to delay our progress and cause us to miss our rendezvous. Under this tactic, the adversary may attack us if we try to pass the barrier, but they also may choose not to attack. The adversary may adopt this plan if they have an overall strategy for limiting their immediate losses, hoping to attack later when better tactical opportunities are available.

Figure A-3 illustrates a typical barrier. It is characterized by a row of adversary ships, each about thirty miles apart from the nearest neighboring ship. It is also characterized by a row of adversary submarines closely associated with these ships. These submarines will be practically impossible to detect, because they are nearly stationary and hence very quiet, because any noise they do make will be masked by the nearby ships, and because it is hard to search for submarines so close to hostile ships. Some adversary aircraft will be evident in this tactic but they will not approach the Battle Group close enough to fire or be fired upon. Their role is to enhance our belief that an attack is imminent.

Because the adversary's ships and submarines are so near one another, they provide each other with firepower coverage. Consequently, it is very difficult to advantageously attack the barrier. It is, instead, much more prudent to go around the barrier, taking defensive precautions should they choose to attack, but also taking care not to inadvertantly provoke any unnecessary attack. The precaution that we take exploits the geometry of the hostile barrier and their reliance on centralized afloat control. Because these ships and submarines are aligned along a single axis, we can attack them in a surprise cross fire if we secretly send submarines to the West as the Battle Group passes the barrier to the East. We can also exploit their reliance on a central command afloat. This tactic, in which the adversary hopes to stop us without engaging in a major attack, relies on continual situation monitoring by the afloat commander and on detailed engagement instructions from this commander to his platform commanders. Consequently, jamming the commander's communications may be effective against this tactic. Destroying the commander's platform will also be

FIGURE A-3. BARRIER
TYPICAL GEOMETRY AT LAUNCH (NOT TO SCALE)



effective, but would of course end all attempts to limit the size of the engagement.

An engagement with a barrier force is likely to begin as our Battle Group comes within the range of their missiles and attempts to pass around the barrier. Although it may begin as an intense surface and subsurface attack, it may also begin with a limited number of "warning" shots. Because the adversary's actual objectives are not known, these warning shots may or may not be followed by more intense fighting if we persist passing around. Finding the right response to warning shots requires a careful calibration of counterresponse, managed by our afloat commanding officer.

A.1.2 Roles of ASW and ASUW Commanders and Description of Shared Assets

The following material explains how responsibilities are divided among the ASW and ASUW commanders and presents an ambigious situation. In the initial experiments, subjects designated as ASW commanders will receive a different brief than those designated as ASUW commanders. Both briefs will be consistent, but will emphasize the different areas of responsibilities. Both groups of subjects will receive the same situation report. The following material will denote those parts of the brief that differ for the two groups of subjects.

Our Battle Group is commanded by the Officer in Tactical Command (OTC). The OTC delegates major command authority to three subordinate warfare area commanders. Each subordinate commander is responsible for reacting to a different part of the hostile threat, but all share the common responsibility of ensuring that the Battle Group attains its mission objectives. The ASW commander is responsible for actions taken against hostile submarines. He is responsible for detecting, identifying, tracking, and if appropriate, destroying these submarines. The ASUW commander is responsible for actions taken against hostile surface units. The AAW commander is responsible for countering hostile aircraft. He is also responsible for countering missiles fired from any platform, including surface ships and submarines.

The assets of our Battle Group are aircraft, submarines, helicopters, and surface ships. The OTC assigns to the warfare area commanders those Battle Group assets needed for carrying out their responsibilities in their assigned threat area. Because ship, aircraft, submarine, and helicopter assets are all useful for combating both hostile submarines and hostile surface ships, both the ASW commander and the ASUW commander may desire to use some ships, some aircraft, some submarines, and some helicoptors. Ships, aircraft, submarines, and helicoptors which are potentially available for use by more than one warfare commander are shared assets.

These shared assets can be a source of contention and the cause of considerable confusion. In order to avoid confusion during a battle only one of the warfare area commanders is permitted to control any particular asset at one time. This control is determined prior to the battle by the OTC. Based on requests from the warfare area commanders, the OTC will assign temporary control over the shared assets.

Warfare area commanders are expected to request control of assets both on their own needs and also on the recognized and anticipated needs of the other warfare commanders. For example, in a situation with a minimal surface threat, the ASW commander might be expected to request control over most of the shared assets, and the ASUW commander would be expected to request control over very few of these assets. Such a situation is the "surprise" tactic described previously.

In our Battle Group, there are only two types of shared assets, submarines and search/attack aircraft. There are three submarines and three squadron of search/attack aircraft to be shared. The submarines are very useful for attacking other submarines and surface ships. They can be stationed close to their target, and can attack in a way that provides very little warning. Submarines are also useful for detecting and tracking other submarines. The search/attack aircraft are more effective for detecting and tracking submarines than are other submarines because they can search a much larger area. Once they find these submarines, they can attack them with their anti-submarine missiles. Because these aircraft are armed with anti-ship missiles as well as anti-submarine missiles, they are often assigned on missions against surface ships. When submarines and aircraft are on anti-submarine missions, they are controled by the ASWC; when they are on anti-surface ship missions, they are controled by the ASUWC.

It is now assumed that our Battle Group is underway to the rendezvous point, and has encountered signs of hostile activity. This activity will be described in the following paragraph. After this description, you will be asked to select from a list a set of actions that you believe is most appropriate for this situation. As ASW (ASUW) commander you are responsible for countering the submarine (surface ship) threat in a manner that best ensures that the Battle Group attains its mission. In selecting the set of actions, you should consider which resources it is appropriate for you to control, how much autonmoy you wish to give to your platform commanders, and what you should direct these commanders under you to do.

Figure A-4 summarizes the tactical situation. There are signs of hostile submarine, aircraft, and surface ships. The signs include:

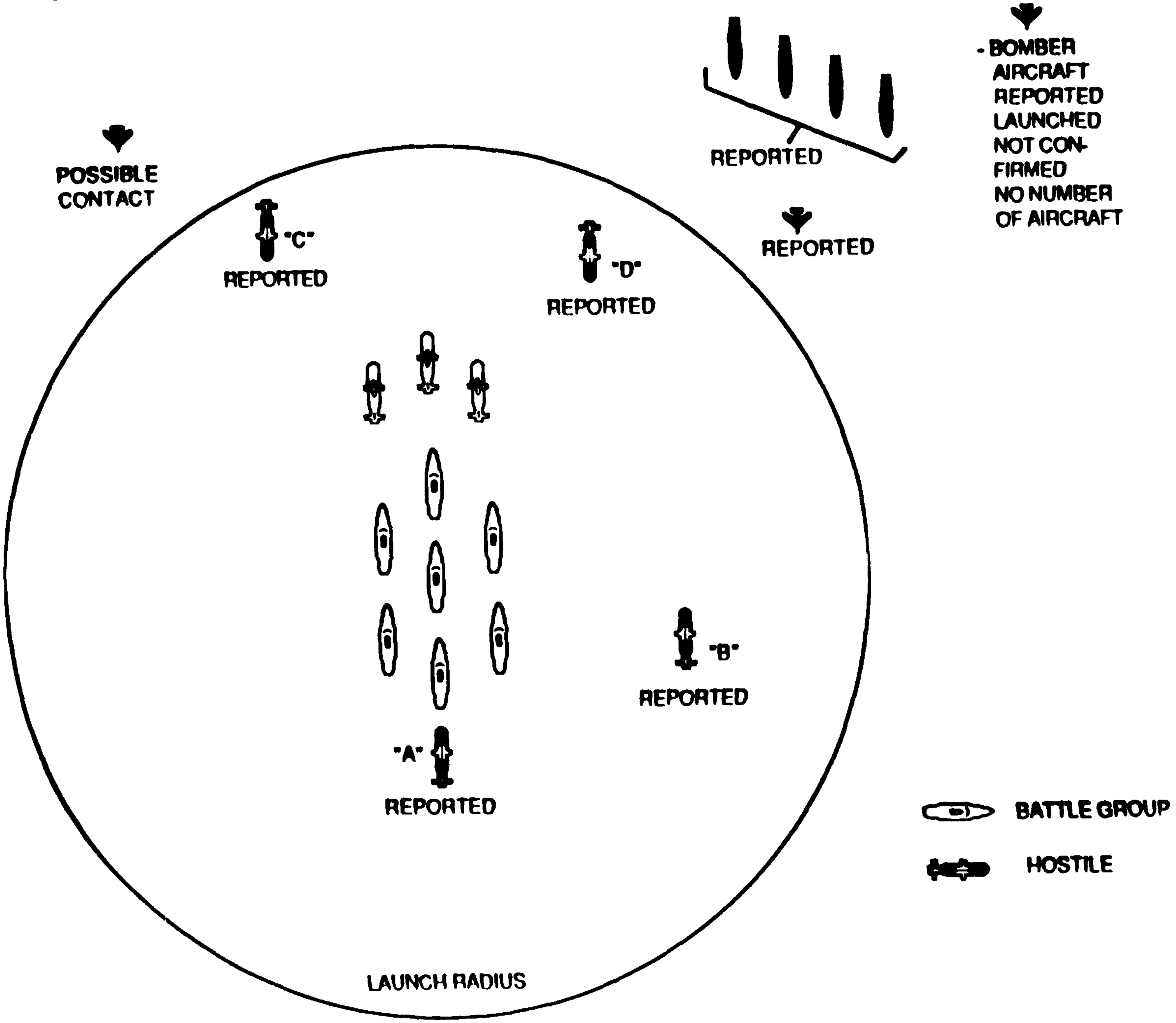
1. One of our submarines detects a submarine at location "A".

2. One of our aircraft detects a submarine at location "B".

3. Two submarines are detected by listening devices at locations "C" and "D"

4. An unconfirmed report of an unknown number of their aircraft have taken off.

FIGURE A - 4 TACTICAL SITUATION (NOT TO SCALE)



5. An aircraft's radar and radio communications are detected at one location.

6. Another aircraft's radar and communications are detected at a different location.

7. Four ships are detected. Their location is uncertain but they are beyond the hostile aircraft missile launch position.

Based on this situation description and your understanding of the three different hostile tactics described previously, please interpret these indicators and assess the situation.

A.1.3 ASUW and ASW Action Alternatives

Set of actions for subjects playing ASWC role

Alternative 1. Task all three groups of search/attack aircraft to conduct a maximum intensity continuous search for hostile submarines. Direct all three submarines to search for hostile submarines, searching in a way to minimize their own detection. The commanders of these submarines are directed to attack only upon positive evidence of hostilities.

Alternative 2. Task two of the three groups of search/attack aircraft to conduct an intense continuous search for hostile submarines. Direct two of the three submarines to pursue any reported submarines, and give them maximum authority to attack.

Alternative 3. Task two of the three air groups to conduct a moderate continuous search for submarines. Direct one submarine from the Battle Group to the West. The commander of the submarine is directed not to attack unless explicitly directed to do so.

Set of actions for subjects playing ASUWC role

Alternative 1. Task surface ships to search for and track surface ships. Do not include engagement instructions.

Alternative 2. Task two submarines to depart from the group and move to the West. They are directed to be as quiet as possible. The commander of the submarine is not to attack unless explicitly directed to do so.

Alternative 3. Direct one air group to monitor communications from hostile surface groups. Task a submarine to approach the suspected hostile command ship, and give them maximum authority to attack.

Each subjects will be asked to select the alternative which he feels is most appropriate for the ambigious situations described in the previous section.

A.2 Theory Interpretation of Experimental Materials

The experimental materials presented in the previous section are designed to test the schema theory for distributed decision making. The narrative is designed to induce schema used for comprehension, the description of an ambigious situation is designed to activate these schema to varying degrees; and the inference and action layer of these schema is designed to indicate actions appropriate against each hostile tactic. Section A.2.1 details possible schema that could be used by subjects to comprehend the presented material and to select appropriate alternatives.

Each of the actions and decisions associated with each schema are designed to be most effective against different hostile tactic. The alternative presented to the ASWC and ASUWC will work well together if both ASW and ASWC interpret the ambiguous situation the same way, but the alternatives will conflict or underutilize resources of the commanders intercept the situation differently. Section A.2.2 discusses the relationship between each hostile tactic and each alternative, and describes the sources of possible decision conflicts.

A.2.1 Schema Representation of Experimental Materials

The information presented to subjects about naval warfare principles, possible hostile tactics, and warfare commander roles is not organized to resemble schema. Rather, it is presented the way that such information would normally be available to decision makers as an illustrated narrative. Schema theory assumes that when such information is comprehended, it is converted into a schema format. Before performing the experiments it is not possible to know what specific schema the presented information will actually induce but their general form is predicted. The theory proposes that each schema have the layered structure of Figure 3-1 and that the set of schema be organized into the hierarchial structure of Figure 3-2. Figure A-5 illustrates a possible hierarchial structure containing general schema about naval operations, and attribute amplification schema for each of the slots in those naval operation schema. Tables A-1, A-2, and A-3 illustrate possible schema for part of this structure. Table A-1 details the slot and cnstraint layers for the hostile tactics schema, and Table A-2 suggests their possible inference and action layers. Table A-3 details the attribute amplification schema corresponding to the slots in the naval operation schema.

A.2.2 Relationship of Alternatives to Schema and Potential Conflicts Among Decision Makers

Each of the alternatives addresses three issues: how many shared assets (ships and helicopters) should each decision maker request, how should he deply these assets, and what rules of engagement should be conveyed to the platform commanders. The number of platforms to be tasked by the ASWC and ASUWC depends on the roles each is to play against each threat. In the extreme case, when there is no surface threat (the limited attack tactic), the ASWC should request all shared assets and the ASUWC should request none. Deployment depends on tactic also. Generally, in all situations helicopters and submarines must, to some extent, search for and track hostile submarines. Consequently, this action cannot be a discriminator for tactics. Nevertheless, in the different situations they may be used differently. For example, against an expected maximum power attack, hostile submarines must be used vigorously pursued, and detection-avoidance of own submarines is less important than against other hostile tactics. Against the barrier tactic, submarines must be deployed near the hostile force in order to enable a cross fire on hostile surface ships and

FIGURE A - 5 OVERVIEW - SCHEMA STRUCTURE FOR ASWC/ASUWC DECISION MAKING

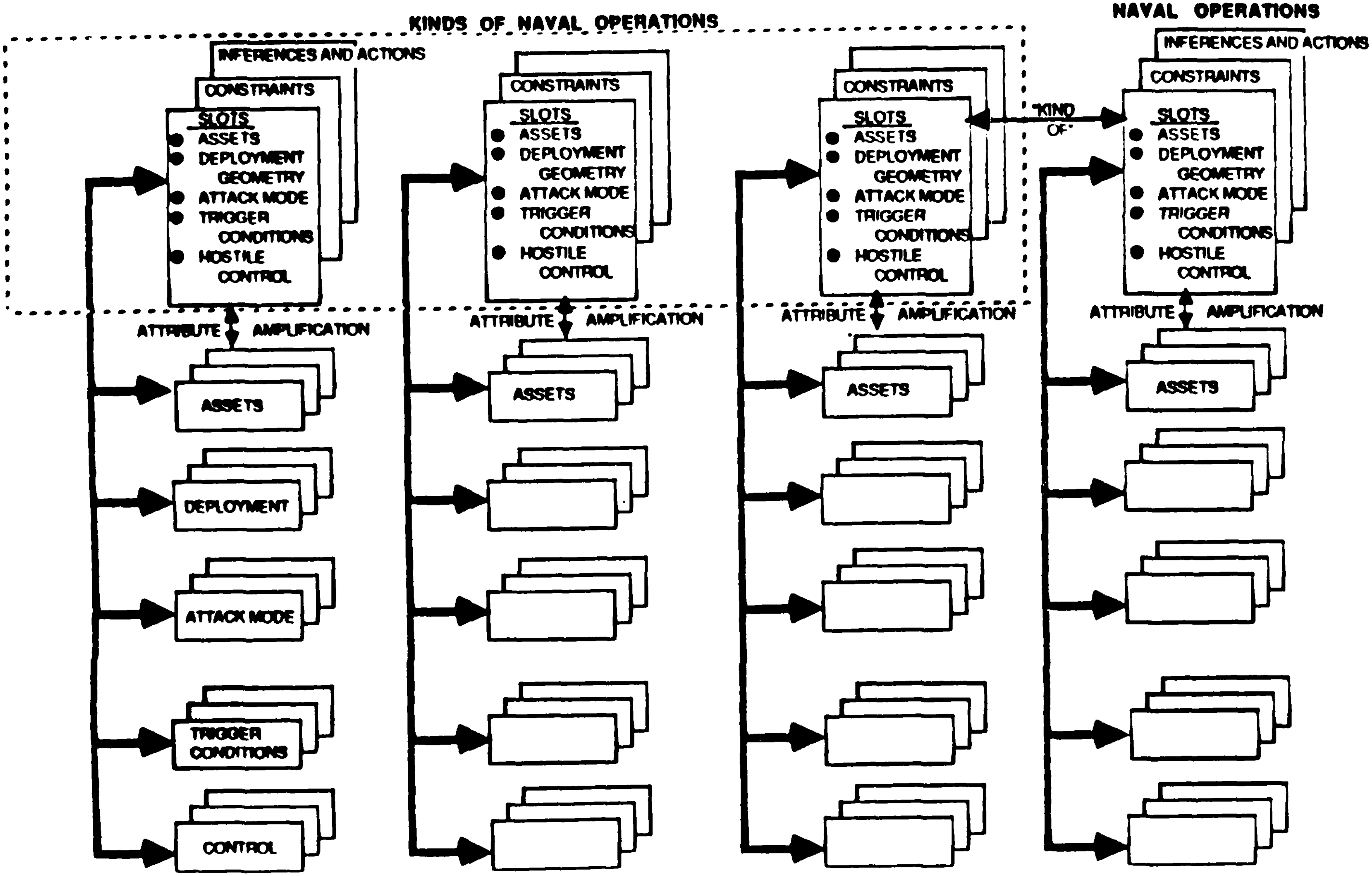


TABLE A-1 POSSIBLE SCHEMA FOR THE THREE HOSTILE TACTICS

SLOTS AND CONSTRAINTS

SLOTS	CONSTRAINTS: MAXIMUM POWER	CONSTRAINTS: LIMITED	CONSTRAINTS: BARRIER
NAME:	SURROUND, SATURATE, AND DESTROY	LIMITED, SURPRISE, DESTROY	DELAY, AND AVOID FIGHT IF POSSIBLE
ASSETS:	SUBSTANTIAL AIR, SURFACE, SUBSURFACE	SUBSTANTIAL AIR, SUBSURFACE	SURFACE, SUBSURFACE
DEPLOYMENT GEOMETRY:	SURFACE: 1 OR 2 GROUPS, ONE OR TWO AXES AIR: 2 OR 3 AXES, FLANKING SURFACE SUBSURFACE: SURROUNDING ISOLATED	NO SURFACE AIR: 2 OR 3 AXES SUBSURFACE: IN DIRECTION OF BG MOVEMENT; LYING IN WAIT	NO AIR SURFACE - ONE BROAD AXIS PERPENDICULAR TO BG DIRECTION OF MOVEMENT SUBS - CLOSE ASSOCIATION WITH SURFACE
ATTACK MODE:	SIMULTANEOUS, SATURATING	COORDINATED AIR-SUBSURFACE. AIR ATTACK LATER.	MAYBE NO ATTACK MAYBE SUB/SURFACE ATTACK
TRIGGER CONDITIONS:	ANYTIME, BUT FORCES MUST BE PUT IN PLACE	BG MOVING INTO SUB AND AIR MISSILE RANGE	BG ATTEMPT TO PASS BARRIER
HOSTILE CONTROL:	COORDINATED SHORE AND AFLOAT	ASHORE	AFLOAT

TABLE A-2 POSSIBLE SCHEMA FOR THREE HOSTILE TACTICS

INFERENCES AND ACTIONS

TYPE	MAXIMUM POWER	LIMITED	BARRIER
OUR VULNERABILITY	SATURATED ATTACK; VERY DANGEROUS	LESS INTENSIVE ATTACK: CAN RIDE OUT IF SUB RELOADS PREVENTED	DELAY DAMAGE EXPECTED IF ATTACKED
ACTION	DON'T GIVE THEM A CHANCE, PREEMPT	DON'T PREEMPT, BUT TRY TO PREVENT RELOADS	GO AROUND. TRY NOT TO PROVOKE AN ATTACK
THEIR VULNERABILITY	ISOLATED SUBS, MOVING INTO POSITION	ISOLATED SUBS IN DIRECTION OF MOVEMENT (SUBS VERY HARD TO FIND)	SURFACE GROUP MORE COMPACT. CAN BE SURROUNDED
ACTION	VIGOROUSLY SEARCH FOR SUBS, AND DESTROY	VIGOROUS, MAXIMUM SEARCH STATION SUBS TO DESTROY SUBS IF ATTACK BEGINS	SECRETLY SEND SUBS TO SET UP POTENTIAL CROSSFIRE IF THEY ATTACK
THEIR VULNERABILITY	COMPLEX CONTROL AND COORDINATION		COMPLEX CONTROL AND COORDINATION
ACTION	STATION SUB CLOSE TO THEIR COMMAND SHIP AND DESTROY		SAME COMMUNICATIONS

TABLE A-3 SLOT AMPLIFICATION: PHYSICAL FEATURES "OBSERVABLES"

SCHEMA SLOTS BEING AMPLIFIED	SCHEMA FOR MAXIMUM POWER ATTACK	SCHEMA FOR LIMITED ATTACK	SCHEMA FOR BARRIER ATTACK
PLATFORMS	MORE THAN 20 BOMBERS (12 PER RAID) 6-8 SURFACE SHIPS 2 or 3 LONGRANGE SHOOTERS 2 or 3 MEDIUM RANGE SHOOTERS 2 or 3 SURFACE TO AIR SUBS - SIX P_D = .5 WITH VIGOROUS SEARCH	SAME AS MAX INTENSITY SURFACE - FEW AND DISTANT SUBS - FEW DETECTIONS P_D = .1	NO AIR SURFACE - SAME AS MAX INTENSITY SUBS - FEW DETECTED (NOT SURROUNDING)
DEPLOYMENT	SUBS - MULTIPLE AXES EACH SUB ON SEP. AXIS SURFACE - AT LEAST TWO AXES AIR - 3 OR 4 AXES PER RAID 3 or 4 AIR PER AXIS	SUBS - MULTIPLE AXES, ISOLATED AIR IS SAME AS MAX INTENSITY	SUBS ARE ASSOCIATED WITH SURFACE PLATFORMS
ATTACK MODE	SIMULTANEOUS - SURFACE SUBSURFACE, LAUNCH WHEN ALL REACH LAUNCH POINT	SUBS FIRST, THE AIR CLOSELY FOLLOWING	"WARNING" SHOTS - CONTROLLED FIRINGS - TO WARN THEN TO DESTROY
TRIGGER CONDITIONS	AIR ATTACK REACHES LAUNCH POINT INCREASED COMMUNICATIONS TRAFFIC IN "NON-ROUTINE" PATTERNS SURFACE MOVEMENT MULTI-AXES GEOMETRY ATTAINED	AIR WAVE COMING WITHIN FIFTEEN MINUTES OF LAUNCH POINT	OVERT WARNING ACTIONS INCREASED COMMUNICATIONS TRAFFIC WHEN BG PASSING
POSITIVE CONTROL	SHORE SHIFTING TO AFLOAT	SHORE CONTROL	AFLOAT CONTROL

submarines. The rules of engagement are the clearest discriminator among tactics. Against a maximum power attack, preemption and launch on warning is necessary. Against the limited attack, submarines should attack when the hostile submarines reveal their positions with a missile launch. Against the barrier, when escalation control is paramount, the rules of engagement are most restrictive. All launches require explicit commands from the warfare commanders.

If the two warfare commanders perceive the situation differently and issue instructions or make resource requests in accordance with these different perceptions, then action conflicts will arise. Figure A-6 summarizes these action conflicts. These conflicts involve numbers of resources, non-synergistic use of resources, and inconsistent rules of engagement.

FIGURE A-6 POTENTIAL CONFLICTS AMONG DECISION MAKERS

IF ASWC BELIEVES SITUATION IS:

IF ASUWC BELIEVES SITUATION IS:	ASWC ACTIONS / ASUWC ACTIONS	MAXIMUM POWER	LIMITED	BARRIER
		TASK TWO SUBS TO ATTACK SUBS. VIGOROUS ASW SEARCH, EVEN IF MAKES OUR OWN SUBS MORE DETECTABLE ROE: FIRE UPON CONFIRMED HOSTILE ID	TASK ALL SHARED SUBS TO REMAIN UNDETECTED ROE: FIRE UPON EVIDENCE OF LAUNCH	TASK ONE SUBMARINE TO CROSS FIRE POSITION SUBS TO REMAIN UNDETECTED ROE: FIRE ONLY ON DIRECTION
MAXIMUM POWER	TASK ONE SUB TO TARGET HOSTILE OTC ROE FIRE UPON OTC WHEN HOSTILITES TO BEGIN	NO CONFLICT	CONTENTION FOR SUB TASKING ASUWC SUB MAY REVEAL ITS LOCATION WITH PREMATURE LAUNCH	ONE SUB NOT TASKED ASUW SUBS OUT OF POSITION FOR BARRIER CROSS FIRE ASUWC ROE INCONSISTENT WITH ASWC ESCALATION CONTROL ROE
LIMITED	NO HOSTILE SURFACE THREAT SEARCH FOR SUCH A THREAT	ONE SUB NOT TASKED PREEMPTION DILUTED SINCE ASUWC SUBS NOT PARTICIPATING	NO CONFLICT	TWO SUBS NOT TASKED
BARRIER	TASK TWO SUBS TO CROSS FIRE POSITION ROE: FIRE ONLY ON COMMAND	CONTENTION FOR SUB TASKING INCONSISTENT ROE: ASWC MAY PRECIPITATE BATTLE; ASUWC MAY WEAKEN PREEMPTION.	CONTENTION FOR TWO SUBS ASW ROE INCONSISTENT WITH ASUWC ESCALATION CONTROL ROE	NO CONFLICT

← CONFLICTS → (horizontal)

↕ CONFLICTS (vertical)

APPENDIX B

B. Relationship of the Theory to Other Behavioral Decision Research and Theories

The development of the theory described in Chapters 3 and 4 was guided by research results and theories developed in the fields of behavioral decision theory and cognitive science. The relationship of the theory to a few of these research results are reviewed in this appendix.

B.1 Key Research Data Motivating the Theory

The description of the key research results motivating this theory are organized around the six steps in the theory.

Step 1: Interpretation of a decision task.

A paper that suggests that decision and judgment tests may be converted into schema-based information processing problems is "Economic Theory of Choice and the Preference Referal Phenomenon" by David Grether and Charles Plott 9. This paper demonstrated that people who say that they prefer one kind of bet to another will consistently be willing to pay a higher price to participate in the less preferred bet rather than the more preferred bet. Because such behavior is inconsistent with "rational economic man", the authors attempted to discredit the experiments that had previously documented the preference reversal effect. In their experiments, they controlled for as many causes of the phenomenon as they could think of, but could not eliminate the effect. They concluded the effect was due to "information processing response mode". The present theory suggests a definite meaning for "information processing response mode". It postulates that subjects interpret "bet preference" and "bet participation price" as two different types of judgment, each making use of a different set of judgment-related schema. Because the slots in the two kinds of schema differ, the features used for judgments of preference and judgments of bet participation price differ. The preference effect is interpreted here as reflecting the fact that a bet that appears more attractive in terms of one set of features may appear less attractive in terms of another set of features.

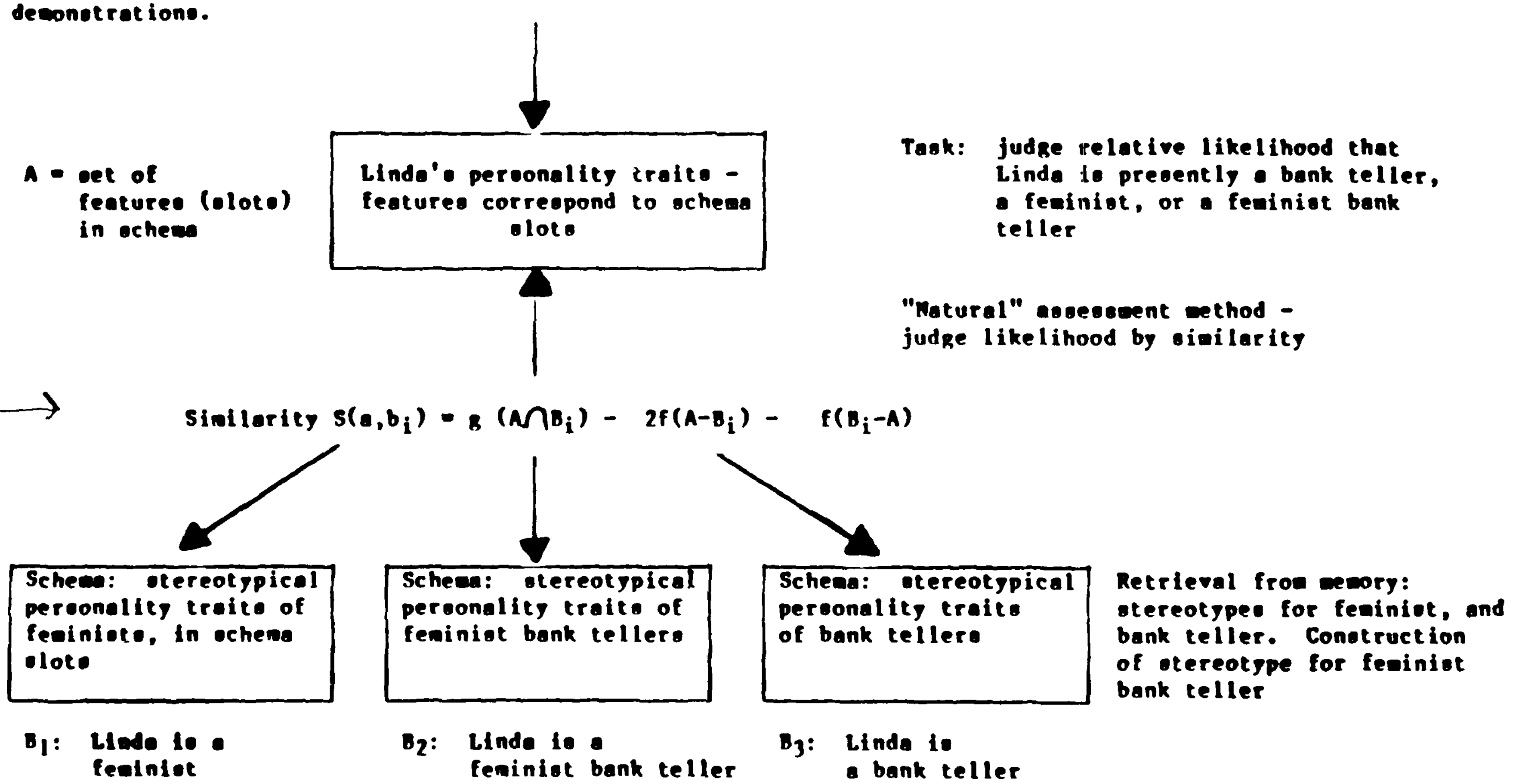
Step 1. Creation of a set of judgment related schema.

An experiment suggesting that people base judgments on the quality of a match to situation-specific schema is the example of "Linda", summarized in Figure B-1. This experiment is described in the paper "Extensional Versus Intuitive Reasoning: the Conjunction in Probability Judgment" by Amos Tversky and Daniel Kahneman 10. In this experiment subjects were given a description of a young woman, Linda, who fits the stereotype of a feminist, and were asked to rank the relative likelihood that Linda is a feminist, a bank teller, or a feminist bank teller. Nearly all subjects judged that Linda is more likely to be a feminist bank teller than to be a bank teller, despite the fact that "feminist bank teller" is a subset of "bank teller".

The proposed theory explains these results rather simply. The subjects interpreted the requested likelihood assessment task as a similarity assessment task, in which the likelihood that Linda belongs in each of the three categories "feminist", "bank teller", and "feminist bank teller" may be judged by the similarity between Linda and the stereotype of each of these categories. Interpreting a likelihood assessment task as a similarity assessment task accounts for the judgmental fallacy. According to the theory, each of these stereotypes are represented by a "schema" and the three schema constitute the working set of potentially relevant schema. Presumably, subjects had ready-made schema for feminist and bank teller, and created a new schema for feminist bank

FIGURE B-1: A SCHEMA-BASED MODEL OF REPRESENTATIVENESS HEURISTIC FOR JUDGING RELATIVE LIKELIHOOD (SCHEMA INTERPRETATION OF CONJUNCTIONS FALLACY)

Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.



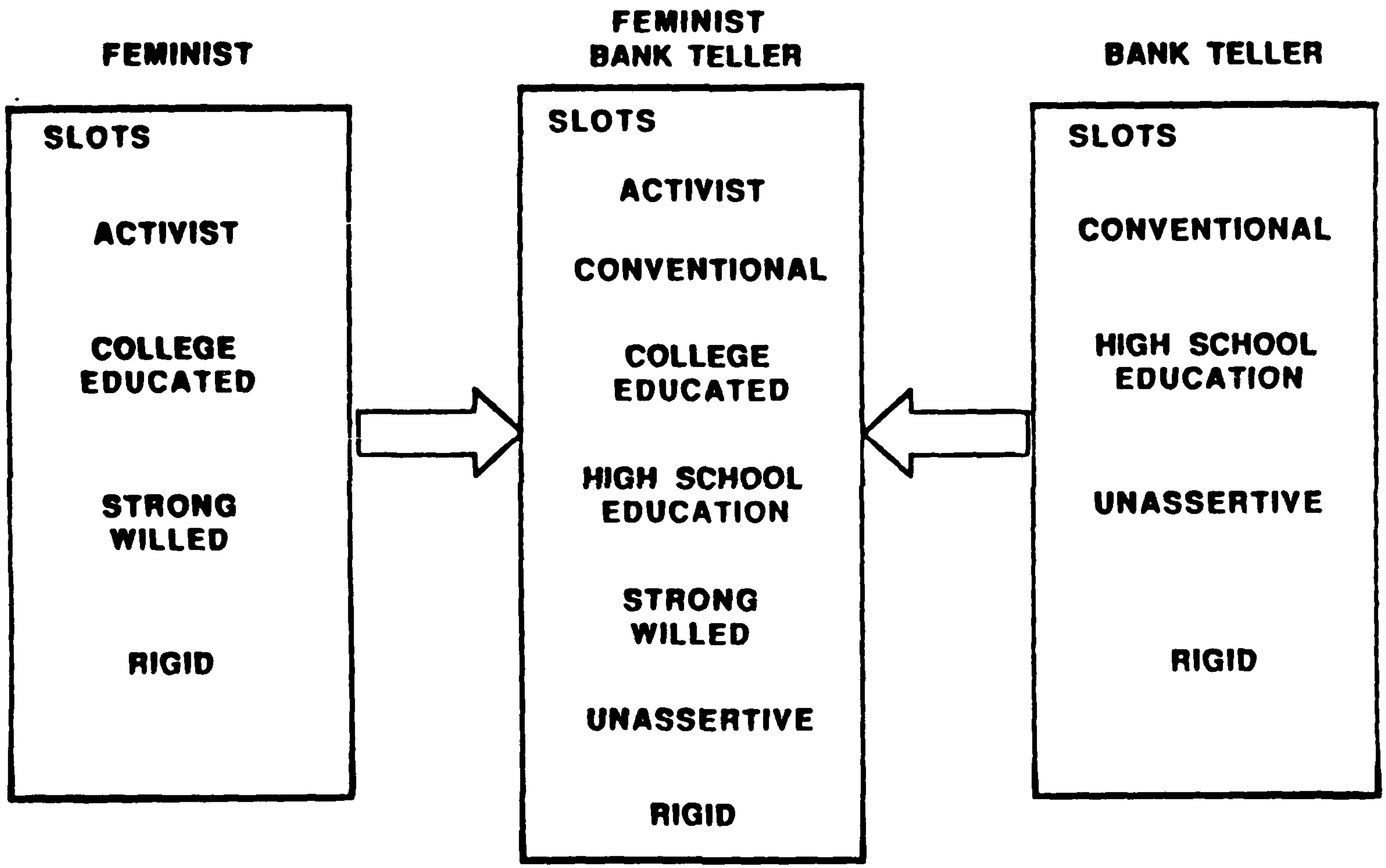
Example from: (Tversky, A., & Kahneman, D.,) "Extensional Versus Intuitive Reasoning: The Conjunction Fallacy in Probability Judgement", Psychological Review, 1983 teller using a slot merging process such as the one illustrated in Figure B-2 (not all investigators of categorization use this method for category formation, e.g., Osherson and Smith 11). After forming a working set of schema relevant to the task, subjects matched features of the description of Linda against slot constraints in each of the three schema, determined the degree of fit for each slot in terms of constraint membership function, and computed an overall degree of fit for each scheam. Relative likelihood was then assessed from overall degree of fit for each of the schema.

The "Linda" example is very important to the current theory because it is explained very easily by the schema-based theory and because it seems very difficult to explain in terms of some alternative theories. For example, "Linda" seems difficult to explain by any theory that models people's judgments as approximations to formal logical methods. Section B.2.5 will discuss these difficulties in more detail.

Step 2. Identification of diagnostic features.

The product of the first step in the schema-theory of understanding is creation of a working set of potentially relevant schema. Each of these schema has a set of slots which correspond to possible features of an object or situation. Some of these slots may be important for discriminating among the different schema in the working set, and others may be unimportant. As an example, if an assessment task required grouping objects into subgroups, then those features which are shared by some of the objects but not by others become diagnostic of a subgroup. Since diagnostic slots are recognized as especially important to the assessment, the schema based recognition system attaches more importance to these features. The system seeks diagnostic features more than

FIGURE B - 2 CREATION OF A NEW "SCHEMA" FROM TWO EXISTING SCHEMA



THE SLOTS IN THE SCHEMA "FEMINIST BANK TELLER" ARE THE UNION OF THE SLOTS FOR FEMINIST AND BANK TELLER. IN THIS EXAMPLE, THE FUZZY SET CONSTRAINTS ON THESE SLOTS ARE NOT MODIFIED. BECAUSE SOME OF THESE CONSTRAINTS FOR THE SLOTS "BANK TELLER" AND "FEMINIST" TEND TO BE DISJOINT SETS, NO INDIVIDUAL IS LIKELY TO ACTIVATE THE SCHEMA "FEMINIST BANK TELLER" VERY STRONGLY.

other kinds, and after finding them weights them more heavily in assessing the overall degree of fit between a situation or object and the schema. A key point in slot diagnosticity is that such diagnosticity depends on context i.e. all schema in the working set. A slot that is highly diagnostic with one set of schema may not be diagnostic for another set. The classic paper "Features of Similarity" by Amos Tversky 12 demonstrates feature diagnosticity especially well. In this paper, subjects were asked to select which of three listed countries were most similar to Austria. In one case, the three countries were Sweden, Poland, and Hungary. In the second case the three were Sweden, Norway, and Hungary. Replacing Poland with Norway caused the percentage of subjects rating Hungary as most similar to Austria to increase from 36% to 60%, and the percentage rating Sweden most similar to Austria to decrease from 49% to 14%. The present theory explains these results in terms of the sets of country schema and an attempt by the subjects to group (categorize) countries by sets of common features. In the first set of four countries (including Austria), Hungary shared the feature "iron curtain" with Poland; consequently this feature became diagnostic of a subgroup of the four countries. Because this feature is not shared with Austria, the similarity assessment between Hungary and Austria is reduced. In the second set, the feature "Scandanavian" is diagnostic of a subgroup. Because Austria does not share this feature with Sweden, the apparent similarity to Sweden is reduced and the relative similarity of Hungary and Austria is increased.

Diagnosticity is an important concept in a schema-based theory of information presentation because diagnostic feature slots which so far have not been matched by any observed situation feature define information requirements. An awareness of unfilled diagnostic slots in a set of schema may be associated with an awareness of the value of information.

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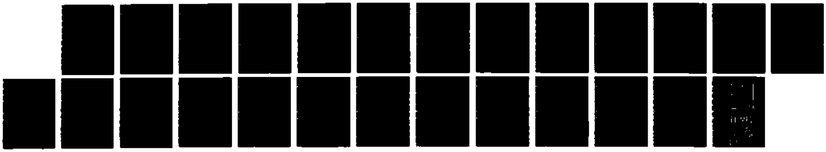

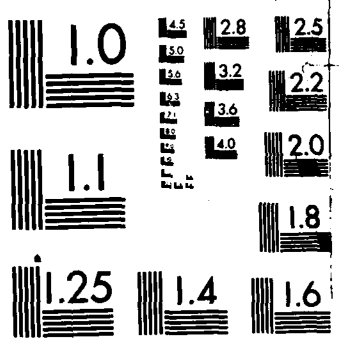

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Step 3. Estimation of degree of match between situation features and schema slots.

Many theories of categorization postulate that objects are placed into categories based on the match between features of an object to be classified and some kind of prototype object for the category. The book Categories and Concepts by Edward Smith and Douglas Medin 5 references numerous papers which provide data suggesting the importance of this match process. The general supposition of the current theory, that schema are selected based on the match between situation features and schema slots, follows in the mainstream of current categorization research.

The categorization literature, as summarized by Smith and Medin, however, does not emphasize hierarchical interplay between schema levels as an important aspect of the feature match process. The model of schema cooperation between higher level schema used to represent context and low level schema used to match concrete situation features has been adapted to the current theory from concepts developed by linguists and by cognitive scientists interested in story understanding. This idea of cooperating levels of schema is basic to the theory of comprehension described by Teun A van Dijk and Walter Kintch in their book Strategies of Discourse Comprehension 13. The interplay between levels of schema is described by David Rummelhart in numerous papers. For example, in "Schemata: The Building Blocks of Cognition" 14, David Rummelhart described schema as recognition devices whose "processing is aimed at the evaluation of their goodness of fit to the data being processed." Such recognition devices were assumed to include both bottom up (data driven) and top down (concept driven) processing, in which data generates possible explanatory schema that in turn specify other data needed for their confirmation or rejection.

The differing nature of schema at different hierarchical levels is suggested by some categorization data attained by Barbara Tversky and Kathleen Hemenway (T3). They examined the types of features characteristic of categories at different taxonomic levels, and found a general tendency for concrete features particularly parts, to dominate at the "basic" category level--the level of "chair", "bird", etc. Thus at lower category levels, features tend to be more specific. At higher, more abstract levels, such as "furniture" features related to functionality become more common. The increased prevelance of functional features at more general category levels is important to the information presentation theory, and is the data suggesting the fourth information presentation properly discussed in Section4.

The paper by Zysno and Zimmerman 1 provided the data suggesting that the fit between an observed feature match and feature reference in a schema may be characterized by degree of membership in a fuzzy set. Use of fuzzy sets in schema remains controversial and some researchers believe that fuzzy set concepts are inconsistent with the probabilistic featural model of categorization 11.

Step 4. Activate the schema whose slots best match the situation data.

Schema theory assumes that schema are activated based on overall match of between situation features and schema slots. There is reasonably good data substantiating that situation data activates schema selectively, but very little on the detailed mechanism of activation. One paper which relates schema activation to situation understanding is "Understanding Understanding" by David Rummelhart 15. In this paper, David Rummelhart tracked the evolution of subject's hypotheses about the meaning of a story. After each sentence of a story was related subjects were asked to interpret what the story was about. The number and variability of the hypotheses narrowed in a systematic way as clues about the situation were received.

Generally, the schema literature does not detail the mechanism by which such matches are made, and does not describe the way that evidence from different features are combined to provide an overall weight for schema selection. The "probabilistic featural" model for categorization assumes an explicit formula in which each observed feature which matches a category prototype contributes additively toward a threshhold needed for a classification. In contrast, for the tile problem investigated by Zimmerman and Zysno, people seemed to estimate an overall fit of a schema to an object by approximating the geometric mean of the fit between the schema slots and the object's features.

Step 5. *Feedback to revise the working set of potentially relevant schema.*

There are no papers so far reviewed that provide clear data for the proposed feedback in the schema recognition cycle, but the proposed theory seems to require such a mechanism. This feedback revises the working set of potentially relevant schema after additional information about the environment is available. Part of the reason that data for this mechanism may be scarce is that the notion of a flexible working set of schema, constructed on the fly in response to a decision task, is unusual.

The proposed theory assumes that new schema for a decision task may be developed quickly by modifying old schema in two ways. The first way assembles the new schema from old schema building blocks. Thus, the schema "feminist bank teller" is developed from permanent schema for feminist and bank teller. The second way adjusts the constraint fuzzy sets defining the match criteria. In the case of a schema for a "good tile", such schema adjustment would change the criteria for a tile to qualify as having a good shape or a good color. For example, if the first few tiles inspected all had excellent shapes and poor color, the schema might be adjusted so tighten the criteria for excellent shape and to relax the criteria for good color. The theory assumes that such adjustment refines the working set of potentially relevant schema so that the situation data will select exactly one of the schema.

Step 6. Selection of actions appropriate to a schema.

Schema, by definition, are structures which specify inferences and actions appropriate to that schema. A basic premise of the current research is that a person who is able to select a schema that is appropriate for a given situation will know what behaviors are appropriate for that situation. Conversely, a person who cannot match a situation to one of his schema will not be able to easily recognize which actions are appropriate for that situation. In fact, in terms of schema theory the difference between an expert and a novice is the possession of functional schema in an area of experise.

Because the relationship between schema and actions dictated by that schema is so critical to the theory as it applies to distributed decision making, the first experiments to be performed in this work examine this relationship in detail. These experiments were outlined in Chapter 2.

B.2 Relationship of the Theory to Selected Topics in Behavioral Decision Theory

This section reviews the relationship of the current theory to the works of Rasmussen, Janis and Mann, the SHOR paradigm, the general theory of "bounded rationality", and to decision making heuristics and biases. The theory is consistent with the first three topics and may provide a more fundamental explanation of these theories. In contrast, the theory proposes a completely different model of human cognition from some interpretations of "bounded rationality", and in some instances predicts qualitatively different behaviors from this model.

B.2.1 Relationship to Theory of Rasmussen

In his paper "Skills, Rules, and Knowledge: Signals, Signs, and Symbols, and Other Distinctions in the Human Performance Models" 8, Rasmussen developed a hierarchy of system properties that could be useful in operators' decision making. From the lowest to the highest, this hierarchy can be interpreted to consist of the following levels: physical form--the system parts and materials; physical functions--the function of these parts; generalized functions--the functional relations between parts; abstract functions--the physical principles behind the functions; and functional purpose--the application of the principles for an objective. Features in information displays may be designed to support all of these levels, and features directed toward the highest levels may convey the understanding necessary to help an operator identify solutions to unusual system properties.

The Rasmussen theory may be interpreted directly in terms of the proposed schema-based theory. This correspondence can be summarized as follows:

1. The hierarchical taxonomic levels of schema described in Section 3.2. correspond to the hierarchical levels specified by Rasmussen.

2. Higher level schema support deeper understanding based on more general properties of a system or situation, and such schema are valid for understanding a broader class of systems or situations than do schema lower in the hierarchy.

3. Slots in higher schema levels tend to be more abstract, corresponding to such features as those concerned with functional relationship between parts. In constrast, slots in lower schema tend to correspond to a physical description of the parts themselves.

4. Information presentations that can activate more abstract schema directly by portraying more abstract features will convey deeper understanding more efficiently than do information presentations that activate schema indirectly through schema lower in the hierarchy.

B.2.2 Decision Process Model of Janis and Mann

The decision process model of Janis and Mann (reported in Sage 16 specifies four steps in the decision making process: 1) appraising the challenge, 2) surveying alernatives, 3) weighing alternatives, and 4) deliberating and commitment. Their process flow consists of a sequence of adequacy tests and remediations should an adequacy test fail. The first test determines whether any potential risks are serious enough to warrent a change. If so, then an alternative course of action is assumed to be generated, and a test on the adequacy of the alternative is made. If the new course of action is satisfactory and the risks are not significant, it is adopted. if it is not satisfactory, another course of action is identified and evaluated according t the satisfying type criteria. After each alternative is generated, a third test evaluates whether a sufficient mumber of alternatives have been developed. If so, the alternatives are evaluated and prioritized. A fourth test then evaluates whether the best alternative can meet requirements. If not, a fifth test evaluates whether requirements can be modified. (This decision has omitted addition aspects of Janis and Mann, not important to the present discussions such as hypervisilance and decidophobia).

The schema decision making model presented here is consistent with and complements the Janis and Mann process model. The schema theory is more detailed than the Janis and Mann model, and can model each of the adequancy tests. Thus, the schema based model can examine the details of tests like "are the risks serious if there is no change?" and attempt to model the process by which particular aspects of a situation will cause the question to be answered one way or the other. According to schema theory, this question is answered by comparing the features of a situation to those features anticipated when the present course of action was determined, and to the slots of schema that are associated with certain standard "danger" situations. If there is sufficiently good match to the anticipated situation and sufficiently poor match to the danger schema, then the question is answered affirmatively.

The tests that evaluate alternative quality are assumed to use schema like the one for tile quality assessment described in Section 3.2. The slots of these schema correspond to attributes relevant to alternative quality, and the schema fuzzy set constraints provide criteria for characterizing the quality of the alternative attributes. An interesting feature of the Janis and Mann model is the feedback loop between altnerative evaluation and requirements. This loop permits requirements to be changed if no alternative can meet them. In the schema theory, this loop has the effect of changing the working set of schema by modifying the schema fuzzy set constraints.

B.2.3 The SHOR Paradigm of Joe Wohl (Report in Sage 16)

SHOR is an acronym for sense, hypothesize, option development, and response. This paradigm emphasizes the important difference between "sensing" and "hypothesizing", a difference which is also critical in the schema decision making theory. The product of "sensing" is a an estimate of the situation picture. It is an estimate of locations and identities of different objects in a situation. In contrast, the product of "hypothesizing" is an estimate of the meaning of the situation. This meaning is an explanation of the reasons for such a situation. In a military situation assessment it includes the adversary's intent, his principles of operation, and the logical connection between capability and tactics selection. The SHOR paradigm proposes that such hypotheses, rather than just an accurate situation map, are the proper basis for option development.

In the schema decision model the accurate situation map is an intermediate level schema in the overall schema hierarchy. Its slots correspond to parts of the situation such as the ships, aircraft, and land masses, and may also include certain spatial relationships between the parts. Schema theory assumes that most decisions require the deeper understanding associated with schema high in the schema hierarchy, it is also at this level that appropriate options are specified within the action specification layer of these schema. This level is the level that corresponds to the SHOR hypothesis level and would include the time-event schema that model adversary tactics associated with different objectives.

B.2.4 Judgmental Heuristics and Cognitive Biases

The proposed schema-based theory of decision making can account for the many diverse judgmental heuristics and cognitive biases documented in behavioral decision theory literature 5, 12. These biases, which can be understood by the way that they affect the schema selection process, may be traced to 1) the structure of schema; 2) the way that the initial set of schema are selected; 3) the way that diagnostic features are selected; 4) the way that the environment interacts with the feature-slot match process; 5) the way that the match results update the inital set of schema; and 6) the feedback process. Table B.1 summarizes the relationship of many of the judgmental biases to the theory.

Three biases that have potentially serious consequences to decision making are selective perceptions and overweighting of a small amount of data and

TABLE B-1: RELATIONSHIP OF JUDGMENTAL HEURISTICS AND COGNITIVE BIASES TO THE THEORY

THEORY ELEMENT	BIAS ORIGIN	RELATED BIASES *
1. Structure of Schema:		
a. Every slot must be potentially filled by an instance. Statistical properties over many instances (data reliability or base rate) require special processing to fill a slot.	Schema Structure	a. Law of small numbers, data saturation, ignoring base rate, overconfidence in low reliability data,
b. Schema tie slots together.		b. Illusion of correlation, hindsight
c. Information from slots in different schema is hard to combine.		c. Adjustment and Anchoring
2. Selection of Initial Schema for Working Set Not all potentially relevant schema are considered equally. Some are already being considered; others are easily recalled; still others are are repressed.	Selection of working set of schema	Availability, reference effect, selective perceptions, expectations, desire for self-fulfilling prophecy, fact/value confusion, habit, fundamental attribution error, casuality
3. Identification of Diagnostic Slots Only situation features actively looked for can be detected. Some of these features are searched for harder than others.	Selection of Features to be emphasized in match logic	Representativeness, selective perceptions, gambler's fallacy

* Primarily from Sage, Andrew. Behavioral and organizational considerations in the Design of Information Systems and Processes for Planning and Decision Support. IEEE Transactions on Systems, Man, and Cyberretics, 11 (1981.)

TABLE B-1: RELATIONSHIP OF JUDGMENTAL HEURISTICS AND COGNITIVE BIASES TO THE THEORY (CONTINUED)

THEORY ELEMENT	BIAS ORIGIN	RELATED PREVIOUSLY DOCUMENTED BIASES
4. <u>Match Logic</u> Match logic is the process underlying similarity judgments. It is affected by how easily various situation features may be observed.	Comparison of situation features with schema slots	Data presentation context, spurious clues, order effects, feature vividness
5. <u>Assessment of Schema Activation</u> Schema activation results from the feature match process. It is affected by context and aspiration levels.	Schema activation assessment	Reference effects, expectations
6. <u>Feedback Control</u> Updated schema in working set depend on the initial schema working set, and on the situation.	Feedback/Control	Regression effects, overconfidence in redundant information, conservatism

over confidence in unreliable data. These biases tend to cause people to select a wrong situation schema, and thus to misunderstand a situation. For example, troops assembled on a border can be associated with an "invasion" schema or with an "exercise" schema. A decision maker who incorrectly selects the exercise schema and does not consider or rules out the invasion schema can make inappropriate and possible diasterous decisions.

Selective perceptions arise when a person ignores certain important features of a situation, and pays attention instead to other less important features. It typically occurs, for example, when a person has an already activated schema to account for a situation, and ignores evidence that would indicate that this schema is incorrect. Thus, a supervisor who has decided that an employee is lazy will tend to assume that any work which is completed late is due to laziness, and will not notice nor look for evidence suggesting other possible reasons for late work. The bias of selective perceptions can be traced to poor performance in the schema decision model steps of "creation of a working set of potentially relevant schema" and "identification of diagnostic features." The model proposes that the features that a person pays attention to are diagnostic, i.e. are useful for discriminating among the set of schema in the working set. According to the theory, features of no value for discriminating among these schema will tend not to be noticed. Consequently, if the schema associated with particular features are excluded from the working set, then these features would be expected to be not noticed.

The "law of small numbers" (drawing conclusions from sample sizes that are not statistically significant) and "overconfidence in unreliable data" are attributable to the type of schema assumed by the theory and to the nature of the match process. The theory assumes that slots of schema must be able to be associated with features of a particular instance of the class of objects, situations, or events associated with a schema. For example, the schema for an automobile accident may have slots for vehicles involved, for damage and injuries sustained, and for the cause of the accident. However, cannot have slots for the fraction of all drivers currently on the road who are drunk because that fraction is a property of one particular accident. Therefore, because schema do not have slots corresponding to accident base rate, schema theory predicts that such statistics are difficult to incorporate into inferences about an accident. This disregard for base rate information is well documented in the literature 17. (Such information can be better used by people who have adopted special schema for appropriate statistical problems. Thus, a person with a Bayesian schema can better use base rate information since the structure of the slots the constraint associated with measurements of slot values, and the actions determined from these are all algorithmically correct. These Boyesian schema must have base rate slots because every instance of a Bayesian problem contains base rate information).

The schema theory suggests that people place too much emphasis on unreliable data and small samples of data because these data can activate schema nearly as well as can better quality data. The data themselves appear as features of particular instances of objects, events, or situations. When these features match slots in the schema, they cause the schema to be activated. Because the schema have no slots for data reliability or statistical significance, such activated schema do not contain data indicating that they were activated using unreliable data. Consequently, a schema selected by unreliable data can contribute to subsequent reasoning processes with as much weight as schema activated by reliable data.

B.2.5 Bounded Rationality

Bounded rationality is a description human cognition that assumes that thought process are people's rational and logical, but that human information processing limitations can cause the results of these processes to be suboptional. For example in bounded rational decision behavior people attempt to optimize a decision in terms of a set of utilities, but their performance falls short because they can consider only a few alternatives at one time and because they cannot estimate outcomes, probabilities, and utilities exactly. Thus, according to this theory one can represent cognitive processes as an optimization algorthm which performs suboptimally because of such factors as memory limitation and inadequate processing time.

The schema-based theory of cognition is different from bounded rationality. The schema theory asserts that understanding and decisions based on understanding arise from a complex interplay of schema based on a match process rather than by applying approximations to format logical inferences.

The difference between bounded rationality and schema can be understood in terms of computer chess algorithms. One optimizing algorthm for chess moves would examine every possible move, every countermove, every counter-countermove, and so on in a very deep and broad tree seach. A bounded rationality approximation to this algorithm would adopt the same tree search strategy, but because of limited processing capabilities would examine only a few of the layers of a few of the branches. A schema approach, on the other hand, would make use of a very large number of different chess board schema each associated with types of situations in which various classes of moves are promising. These schema would have slots for key types of relationships among a the chess pieces (such as "pin-potential" described earlier), and would specify types of actions associated with these relationships. The power of the schema approach derives from the availability of a large number of schema, each associated with key relationships (a number of pieces covering a square) among pieces, the relationship specifications; this approach does not require much move-countermove projection.

Very frequently, the judgments and behavi[illegible] resulting from this match-schema process is consistent what would be expected from bounded rationality. Sometimes, however, the observed judgments or behavior is qualitatively different from behavior easily attributable to bounded rationality. The results of the "Linda" experiment described earlier illustrates one case where bounded rationality and schema processing lead to different predictions of human performance. In the Linda example, people judged the probability that Linda would be a feminist bank-teller to be greater than the probability that she would be a bank-teller, despite the fact that feminist bank-teller is a subset of bank-teller. The discussion in Section B.1 explained this result in terms of schema theory. In constrast, it is not easy to explain the result in terms of any straight-forward model based on a bounded rationality in which correct rules of logic are being approximated. The judgments made in this case violate a simple logical principle: the probability of a subset is less than the probability of a superset that it is part of. Presumably any optimizing cognitive process would attempt to obey the rule, so a bounded rationality theory would attribute its violation in this case to information processing limitations. Yet the information processing required to recognize this relationship and apply it in the Linda experiment is so small that such limitations seem unlikely to be the cause of this error. Thus, it seems unlikely that the Linda results can be explained as an approximation to an optimal rational process, and some other model, such as the schema-based theory, seems necessary.

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