Metarecognition in Time-Stressed Decision Making: Recognizing, Critiquing, and Correcting

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We describe a framework for decision making, called the Recognition/Metacognition (R/M) model, that explains how decision makers handle uncertainty and novelty while at the same time exploiting their experience in real-world domains. The model describes a set of critical thinking strategies that supplement recognitional processes by verifying their results and correcting problems. Structured situation models causally organize information about a situation and provide a basis for metarecognitional processes. Metarecognitional processes determine when it is worthwhile to think more about a problem; identify evidence-conclusion relationships within a situation model; critique situation models for incompleteness, conflict, and unreliability; and prompt collection or retrieval of new information and revision of assumptions. We illustrate the R/M framework in the context of naval tactical decision making.

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ANALYSIS, RECOGNITION, AND METACOGNITION

A U.S. AEGIS cruiser was in the Gulf of Sidra below the “line of death,” in waters claimed as Libyan by Ghaddafi, when it detected a gunboat emerging from a Libyan port. The gunboat turned directly toward the cruiser and increased its speed. As the gunboat continued to approach, the Tactical Action Officer (TAO) and the captain had to decide whether or not to engage it.

One possible account of what happened is that the captain and TAO matched the cues and other available information to stored patterns. They might have recognized a pattern of cues as hostile and retrieved an associated response, e.g., to engage the gunboat. At the same time, there might have been partial matches to other templates, such as routine patrol. A growing body of research has supported a view of this kind in decision making and problem solving. For example, beginning with Chase and Simon’s (1973) work on chess, expertise has been equated with mastery of a large repertoire of familiar patterns and their associated responses. Klein (1993) has proposed a model of decision making based largely (but not entirely) on recognitional processes.

Pattern recognition is not the whole story, however. In particular, pattern matching does not explain how the captain and TAO handled the conflict between competing templates, neither of which perfectly matched the situation, or the relatively controlled manner in which they created a picture of the situation, evaluated it, and then created an alternative. And it does not say how they addressed the issue of thinking more about the problem versus acting immediately.

The captain and TAO dealt effectively and explicitly with uncertainty in a way that straightforward pattern matching does not capture. Yet they were hardly Bayesians. They did not attempt to assign a fixed set of possible meanings (with or without associated probabilities) to each individual cue, but considered different interpretations of each cue in the context of alternative situation pictures. And the end result was not an assignment of probabilities to the different hypotheses about intent, but a set of situation models together with an understanding of their strengths and weaknesses. A better description of the captain and TAO's processing is that they adopted a two-tiered strategy: (1) recognitional activation of expectations and associated responses, accompanied by (2) an optional process of critiquing and correcting. Together, these processes build, verify, and modify "stories" to account for a relatively novel set of events.

This article presents the outlines of an empirically based theory of the processes of critiquing and correcting. In describing these critical thinking skills, we emphasize the concept of metacognition, i.e., processes that monitor and regulate other thought processes such as memory, attention, and comprehension (Forrest-Pressley, MacKinnon, and Waller, 1985). Our findings suggest that metacognitive skills also include verifying and improving the results of pattern recognition, in support of decision making in novel and uncertain situations (Cohen, Adelman, Tolcott, Bresnick, and Marvin, 1993). Because of this interaction between recognitional and metacognitive processes, we call the framework the Recognition/Metacognition (R/M) model.

In particular, we will discuss evidence for a set of specific metacognitive skills in proficient decision making. They include: going beyond pattern matching in order to create plausible stories for novel situations, noticing conflicts between observations and a conclusion, elaborating a story to explain a conflicting cue rather than simply disregarding or discounting it, sensitivity to problems in explaining away too much conflicting data, attempting to generate alternative coherent stories to account for data, and a refined ability to estimate the time available for decision making.

In terms of training, the R/M model suggests that some crucial skills may not be as specialized as the task-specific structures emphasized in pattern-recognition, nor as general as the formal tools stressed in analytical models. In training based on these concepts, performance is improved by acquiring (a) effectively structured domain knowledge and (b) skills in questioning and revising that knowledge (Cohen, Freeman, Wolf, and Militello, 1995).

In the following sections we describe structured situation models, the arguments (or evidence-conclusion relationships) that are contained within the models, and a set of metarecognitional processes that modify and elaborate the stories by evaluating the arguments. Throughout the discussion, we draw on illustrations from the domain of ship-based tactical defense. These data are more fully described in Kaempf, Klein, Thordsen, and Wolf (this issue). The R/M framework, however, has also been applied in Army tactical battlefield planning (Cohen et al., 1993) and commercial airline pilot decision making (Cohen, 1993a). In the conclusion we briefly touch on how R/M concepts need to be expanded, refined, and tested in the future.

STRUCTURED SITUATION MODELS

When pre-stored patterns prove inadequate, decision makers draw on more abstract structures for organizing information. According to Pennington and Hastie (1993) comprehension of trial evidence by jurors is a constructive process, in which the jurors create explanatory causal models of the available facts in the form of stories. Stories also enable jurors to identify gaps where important pieces of the explanatory structure are missing and where inferences might be necessary. The R/M model posits a similar process. As decision makers become familiar with a domain, they acquire abstract knowledge about the types of events and relationships among events that are relevant in particular situations. In new situations of the same kind, decision makers use this generic knowledge to integrate the new information, and subject the results to repeated evaluation and modification. In particular, structural knowledge consisting of causal and intentional relations between events is used to construct narrative story structures. The main components of a story episode, according to Pennington and Hastie, are initiating events (which elicit) goals (which motivate) actions (which result in) consequences. Pennington and Hastie suggest that story construction is a general comprehension strategy for understanding human action. In tactical naval situations, officers construct stories to explain data about an approaching contact, corresponding to such possible intentions as reconnaissance, harassment, provocation, training, search and rescue, or attack.

Figure 1 shows the components and relations contained in a story structure for enemy intent to attack. The central element in this structure is the current intent of the enemy: to attack with a particular asset against a particular target. The left side of the structure represents prior causes of the intent, and the right side represents the effects of the intent in the current situation. Telling a story is not a rote process of filling in slots. The point is to try to make sense of the hostile intent assessment from the vantage point of each one of these possible causes and effects. For example, a plausible hostile intent story shows how high-level goals of the relevant country could have motivated an attack, how the contact was a logical choice as an attack platform given the overall capabilities of the attacking country, how own ship was a logical target for attack given the country's high-level goals and other opportunities, how the contact would have been able to detect and localize own ship, and how its observed actions make sense as ways of getting to an attack position quickly and safely. Figure 2 is an example of a hostile intent story at an early stage in the Libyan gunboat episode.

Insert Figure 1 about here

Insert Figure 2 about here

In some theoretical contexts, patterns stored in long-term memory are represented as unstructured lists of features; when some of the features are activated by matching cues, the pattern generates expectations for the other features. In the R/M model, however, causal relations among the elements in a knowledge structure are crucial for critical thinking. For example, in critiquing the hypothesis of enemy intent to attack, the decision maker will look for alternative causes of the gunboat's actions and alternative effects of enemy goals, capabilities, or opportunities. If the hypothesis regarding enemy hostile intent is to be accepted, the slots must not only be filled in; the links to other slots must be plausible—i.e., the decision maker must be able to tell a convincing story.

METARECOGNITION

Metacognition has been defined as "individuals' knowledge of the states and processes of their own mind and/or their ability to control or modify these states and processes" (Gavelek and Raphael, 1985, p. 105). It has primarily been studied in the context of cognitive development (e.g., Forrest-Pressley, MacKinnon, and Waller, 1985), on such topics as how children learn to monitor and control the cognitive activities involved in reading, comprehending, memorizing, and paying attention. We will extend some of the concepts in that research to the process of understanding a dynamic, uncertain situation and finding an appropriate action.

One source of insight in the child development literature is <u>metacomprehension</u>, which has to do with the way readers learn to extract meaning from a text. Baker (1985, p. 155) attempts to organize these processes into two broad categories of metacomprehension skill: "...evaluating the current state of one's ongoing comprehension" and regulation, in which the reader who "has evaluated his or her understanding and found it inadequate...selects and deploys some sort of remedial strategy." Evaluation includes such skills as being sensitive to problems in comprehending a unit of text such as lack of congruity, formulating questions to test understanding, and accurately characterizing the problem (Gavelek and Raphael, 1985). Regulation includes skills like determining the correct source of information (e.g., parts of the text that will fill the gap in comprehension), searching these sources of information, constructing an answer, and comparing the answer to a criterion to determine its adequacy (Gavelek and Raphael, 1985). Similarly, Kuhn, Amsel, and O'Loughlin (1988) discuss the importance of metacognition in the emergence of children's scientific thinking skills: for example, the ability to distinguish what one has inferred (conclusions) from what one has actually observed (evidence), and to recognize the possibility of alternative explanations.

We argue that analogous metacognitive skills are crucial in proficient problem solving and decision making. The R/M model refers to the metarecognitional skills involved in evaluation as <u>critiquing,</u> and the skills involved in regulating as <u>correcting</u>.

There is evidence in problem-solving research that experts are more skilled than novices in critiquing and correcting. For example, Patel and Groen (1991) found that expert physicians spent more time verifying their diagnoses than did less experienced physicians. Physics experts, according to Larkin, McDermott, Simon, & Simon (1980), are more likely than novices to utilize abstract physical representations of the problem to verify the correctness of their method and result, e.g., by checking whether all forces are balanced, whether all entities in the diagram are related to givens in the problem, and so on. In correcting, physics experts change their representation of the problem until the solution becomes clear or, if this process fails, resort to more general-purpose strategies, such as means-ends analysis (Larkin, 1981). Chi, Glaser, and Rees (1982) found that experts returned to and refined their initial representation throughout the course of the problem.

A third category of metarecognitional skill is also required: an ability to determine when critiquing and correcting are worth performing, and when the current solution must suffice. In the R/M model, we call this process the quick test. Something like the quick test also governs reading comprehension: Collins, Brown, and Larkin (1980) show that proficient readers vary the effort devoted to comprehension according to the purpose with which they are reading. In decision making, Beach and Mitchell (1978) and Payne, Bettman, and Johnson (1993) have explored how time, payoffs, and task complexity affect strategy selection.

Figure 3 depicts the key metarecognitional components of the R/M model:

1. Evidence-conclusion relationships (or arguments) are identified within the evolving situation model and plan. This is simply an implicit or explicit awareness, for example, that cue A was observed on this occasion, while intent to attack along with expectations of observing cues B, C, and D were inferred. On some other occasion cue B might be observed and cue A inferred.
2. Processes of critiquing identify problems in the arguments that support the situation model or plan. Critiquing can result in the discovery of three kinds of problems: incompleteness, unreliability, or conflict. A model or plan is incomplete if expected arguments are missing; that is, information has not been considered that might confirm or disconfirm a key element of the model or plan. Understanding and

planning may be complete but conflicting if there are arguments with alternative, conflicting conclusions that better account for some of the data, or alternative actions that better achieve some of the goals. Finally, even if understanding and planning are complete and free of conflict, they may be unreliable if arguments that link evidence and conclusions, or actions and goals, are conditional on doubtful assumptions.

3. Processes of correcting respond to these problems. Correcting may instigate additional observation, additional information retrieval, and/or revision of assumptions. These processes fill gaps in models or plans, resolve conflict among arguments, and bolster reliability.
4. A higher-level process, called the quick test, controls critiquing and correcting. The quick test considers the available time, the costs of an error, and the degree of uncertainty or novelty in the situation. If conditions are appropriate, the quick test inhibits recognitional responding and interposes a process of critical thinking. If conditions are inappropriate, it allows immediate action based on the current recognitional response.

Insert Figure 3 about here

In sum, the meta-level (the shaded portion of Figure 3) monitors the object-level (situation models and plans), maintains a model or description of it (i.e., identifies arguments and problems of incompleteness, conflict, and unreliability), and modifies object-level activity (by inhibiting overt action, adopting assumptions, and producing queries to recognitional processes).

Two possible misunderstandings of this framework should be dealt with, however briefly. First, the R/M model does not imply that metacognitive processes are localized in a different processor (e.g., an "executive") or in a two-tiered physiological architecture. It merely asserts that recognitional and metacognitive processes may be distinguished functionally (rather than structurally) in many instances of problem-solving or decision making. The core of the functional distinction is stated by Nelson & Narens (1994): Object level processes provide information about themselves to meta-level processes, while meta-level processes exert control over object level processes. Second, the framework does not assert that all decision processes require a meta-level process, and thus does not imply an infinite regress of metacognitive processes, meta-metacognitive processes and so on. The primary function of cognition is adaptive action in the real world. There are persuasive arguments that an efficient solution to this problem is a first-level recognitional capability supplemented (optionally) by a second-level process of critiquing and modifying. Additional levels provide rapidly diminishing returns and increased costs; we would not expect such "skills" to be acquired. In sum, the R/M framework does not imply a "homunculus." It makes testable predictions about the conditions under which second-order processes occur.

CYCLES OF CRITIQUING AND CORRECTING

The R/M model provides a highly dynamic view of decision making. Problems exposed by critiquing lead to correction steps, which involve the modification and elaboration of situation models and plans. Critiquing and correcting for one problem can lead to the creation and detection of other problems, triggering new cycles of correction and evaluation. The process stops when the quick test concludes that the model or plan is satisfactory, or that the costs of further thinking outweigh the potential benefits. In this section, we will explore both the component processes in the R/M model and the manner in which they interact.

Arguments

The first step of metarecognition is awareness of which elements of the story (e.g., the gunboat's turning toward own ship) support the key conclusion (e.g., that the gunboat is hostile). We call these evidence-conclusion relationships arguments. An argument (Toulmin, Rieke, and Janik, 1984) is a structure with slots for grounds, conclusion, backing (the basis for the linkage between grounds and conclusion), and rebuttals (conditions under which the linkage might not hold). A way of summarizing this structure is: Grounds, so Conclusion, on account of Backing, unless Rebuttal.

Arguments may proceed from effects to causes (e.g., the arguments based on actions of the gunboat in Figure 2), from causes to effects (e.g., the argument in Figure 2 based on Ghaddafi's goals and opportunities), or from effects to other effects within a causal story structure. Understanding of justification relationships is needed as an input to metarecognition.

Understanding the backing of an argument can guide metarecognition in choosing which arguments to critique and what kinds of problems to look for. For example, the backing might be experience in analogous situations (Were they similar enough to the present situation? Is my experience representative?); the backing may involve an analytical technique (Is each step of reasoning valid? Does this method agree with other methods?); or it may involve the authority of an expert (Is this source really knowledgeable?).

Rebuttals are specific ways that the link between grounds and conclusions in an argument could be broken. If the direction of an argument is from cause to effect, a rebuttal might involve an alternative possible effect; if the direction of an argument is from effect to cause, a rebuttal might involve an alternative possible cause. In critiquing arguments, metarecognition looks for rebuttals and then assesses their plausibility.

Critiquing and Correcting Incompleteness

Cues in a situation can recognitionally activate story structures, and these structures in turn may recognitionally activate additional information that fills their slots. Critiquing goes beyond this relatively automatic retrieval. In critiquing the completeness of a story, the decision maker focuses attention on specific components of the structure (i.e., the key conclusion, such as hostile intent, and a possible cause or effect) and queries for information regarding the cause or effect that would provide the grounds for an additional argument regarding the conclusion.

In Figure 2, for example, the story is incomplete because the TAO has not fully considered the factor of capability. Does the choice of a gunboat as an attack platform really make sense? The gunboat has weapons capable of damaging the cruiser, but this is at best a weak argument for hostile intent, ignoring other assets that might have been used instead of the gunboat. In addition, the TAO has not fully considered the factor of opportunity. The cruiser is below the line of death, but again this is a weak argument. Does the choice of the cruiser as a target make sense given other possible opportunities? Finally, the TAO has not considered how the gunboat might have detected the presence of the cruiser. As we shall see, filling these gaps led to a serious reconsideration of the initial hostile intent assessment.

A key factor in judging the completeness of a situation model is that it provide adequate arguments for action. In anti-air warfare there is typically a relatively small set of available options (e.g., sending other aircraft to intercept the contact, warning it, illuminating it, setting internal alerts, and engaging). The situation model needs to be elaborated in sufficient detail to justify one of these possible actions. For example, when hostile intent is a precondition for engagement, situation understanding is incomplete until a convincing story describing intent has been constructed. Similarly, jurors decide between guilty and not-guilty by applying verdict categories to stories that they construct (Pennington and Hastie, 1993).

In other domains the relevant courses of action are not so simple. In Army battlefield planning, for example, plans are multidimensional and unique. In that case, the evolving plan may be subjected to metarecognitional critiquing for completeness. If the plan is incomplete, the decision maker returns to situation assessment, and tries to construct arguments for elements of the situation model that further constrain the plan. Situation assessment and planning are intertwined. Examples of this process are given in Cohen et al. (1993) and Voss et al. (1991).

<u>Critiquing and Correcting for Conflict</u>

In fleshing out a story, the decision maker may find new arguments whose conclusions contradict the conclusions of existing arguments. This is conflict. Both conflict and unreliability involve discovery of rebuttals to arguments, often in the form of alternative causes or effects. Unreliability requires only that an alternative cause or effect be <u>possible</u>, thus neutralizing the effect of the argument. Conflict goes two steps beyond this: First, there must be an argument for the alternative cause or effect, i.e., positive grounds for believing that it is the case. Second, the alternative cause or effect must be <u>incompatible</u> with the original conclusion. For both of these reasons, conflict is typically a more troubling problem than unreliability.

In the Libyan gunboat incident, filling the gaps in the hostile intent story led to the discovery of conflict (Figure 4). First, the Libyans had an air capability that would have been much more effective than the gunboat. The inferiority of the gunboat provides grounds for an argument that its intent is not to attack. Fleshing out the opportunity component of the story produced a second conflicting argument: Another U.S. ship was both closer to the gunboat and farther below the Line of Death. Finally, the TAO and captain believed that the gunboat could not have detected the cruiser at the range at which it turned. This provides an even stronger argument against hostile intent.

Insert Figure 4 about here

One way to correct for conflict is to retrieve or collect new information that tips the balance in favor of one of the conflicting conclusions. Such information is not always available, however, and decision makers are not always satisfied to resolve conflict by sheer weight or number of cues. Correcting steps may also include a reassessment of the original conflicting arguments. If two arguments conflict, then one or both of them must be wrong. The assumptions underlying those arguments can be identified and evaluated. If one or more of the assumptions can be judged implausible, the conflict is resolved. Conflict resolution thus leads naturally to critiquing the conflicting arguments for unreliability.

Critiquing and Correcting Unreliability

In some cases, the unreliability of an argument is recognized immediately. Rebuttals may be so familiar that they are retrieved automatically, virtually at the same time the argument is identified. For example, failure to respond to an identification-friend-or-foe (IFF) challenge is a cue suggesting hostility. Yet officers had frequently experienced friendlies' failing to respond to IFF challenges, and as a result readily identified this as an unreliable argument. In other cases, however, an argument may appear plausible at first blush, but has weaknesses that are only revealed by more deliberate critiquing. It is as if the decision maker adopts a devil's advocate strategy: He temporarily assumes that the argument is false, i.e., the grounds are true but the conclusion is wrong, and queries for an explanation.

For example, in the Libyan gunboat incident, the captain and TAO critiqued the argument against hostile intent based on the inability of the gunboat to localize the cruiser. They temporarily assumed this argument was false, and generated several possible explanations: The gunboat might have new training, new equipment, or Russian advisors. Similarly, they looked for rebuttals to the argument against hostile intent based on capability. The gunboat might have been chosen instead of superior air assets if the Libyans were desperate to inflict harm and unconcerned about their own survival. Finally, the choice of the cruiser as a target might have involved either lack of awareness of the other U.S. ship or unknown Libyan objectives. Figure 5 shows the rebuttals that were generated for each of the conflicting arguments.

The captain and TAO may explore new assumptions such as these to patch up the attack story. If they wish to retain the assessment of hostile intent, rebuttals like those shown in Figure 5 must be accepted. There is a traditional but oversimplified point of view according to which attempting to explain conflicting data is a case of the confirmation bias (e.g., Lord, Ross, & Lepper, 1979). In many of the situations we have looked at however, no familiar pattern fits the data; there are data that appear to conflict with every reasonable hypothesis. In such situations the traditional view either paralyzes decision makers or forces them to construct an unrealizable statistical average of the possibilities. Expert decision makers, by contrast, try to make sense of the data by constructing coherent stories. They do not stop there, however. After explaining conflict, they initiate a new cycle of critiquing, in which they assess the explanation. If it contains too many unreliable assumptions, a variety of corrective methods are available. They may collect or retrieve new data to confirm or disconfirm the assumptions: they may drop the unreliable assumptions and look for other explanations; or they may explore an alternative conclusion, generating a new story that requires fewer or more plausible assumptions (Cohen, 1986, 1993b). Cohen, Freeman, Wolf, & Militello (1993) found that training in story construction actually led to a reduced tendency to ignore conflicting data.

Insert Figure 5 about here

After critiquing and correcting the hostile intent story, the captain and the TAO turned to the task of constructing a patrol story. This required critiquing the reliability of cues that originally suggested hostile intent. They temporarily assumed that the gunboat was on patrol despite its presence in dangerous circumstances, its heading toward own ship, and its high speed, and queried for an explanation. First, the gunboat might be out in harm's way if its crew were not aware of the presence of U.S. ships. Second, there were so many U.S. ships in the area that almost any heading would have meant turning toward one of them by coincidence. Third, perhaps what the captain and TAO regarded as high speed was actually the gunboat's standard patrol speed. The new story—that the gunboat was on patrol—depends on the assumption that these explanations or other equivalent ones are true.

In this incident, both of the candidate stories, hostile intent and patrol, involved questionable assumptions. This is typical of situations in which no standard pattern perfectly fits the data, and in which, as a result, metacognitive processes are required. Through critiquing and correcting, however, the officers had become aware of the assumptions underlying both stories. This awareness enabled them to design a new, more robust story about the gunboat's intent. According to this new story, the intent of the gunboat was opportunistic attack. The opportunistic-attack story does not require assumptions about localizing the cruiser or selecting it as a target, as required by the attack story, since the gunboat was coming out to engage any U.S. ships it could find. And it is no longer necessary to assume a surprisingly high normal speed or extremely poor situation awareness, as in the patrol story, since the intent was hostile. As a result, the opportunistic attack story became the officers' working theory of the situation.

Assumption-Based Reasoning in Critiquing and Correcting

Critiquing and correcting for one problem can lead to the creation and detection of other problems. Figure 6 summarizes how steps of critiquing and correcting can be linked in the R/M framework. The three types of problems explored by critiquing are shown as three points on a triangle, representing: model incompleteness; the existence of conflicting arguments that contradict the key conclusion (e.g., hostile intent); and unreliable assumptions in arguments for the key conclusion or in rebuttals of arguments against the key conclusion. The arrows showing transitions from one corner of the triangle to another represent correcting steps. It is these correcting steps that may sometimes (but not always) produce new problems. For example, correcting incompleteness in the situation model, by retrieving or collecting data or by making assumptions, can lead either to unreliable arguments or to conflict with other arguments; resolving conflict by critiquing a conflicting argument can lead to unreliable assumptions in rebuttals; dropping or replacing unreliable assumptions can restore the original problems of incompleteness or conflict. These new problems may then be detected and addressed in a subsequent iteration of critiquing.

Insert Figure 6 about here

It is important to note that correcting does not always lead to new problems: Additional data may sometimes confirm rather than disconfirm an initial conclusion, and assumptions may turn out to be plausible, coherent, few in number, and consistent with the data. We can represent these outcomes by shrinking the size of the triangle in Figure 6. The smaller the triangle, the less the total uncertainty, whether it happens to be represented by incompleteness, unreliability, or conflict. Also, the smaller the triangle, the less leeway or need for corrective measures.

Proficient decision makers try to construct complete and coherent situation pictures, within the constraints of the quick test. Thus they often appear to advance from the upper right or left corners of the triangle down to the bottom. They try to fill gaps and explain conflict, if possible by means of newly collected or retrieved information, but if necessary by adopting or revising assumptions. As we saw, this process does not force decision makers to accept the resulting story. But it tells them what they must believe if they do accept it. Evaluation of situation models is reduced to a single common currency: the reliability of the assumptions that they require.

CONCLUSIONS

Proficient decision makers are recognitionally skilled: that is, they are able to recognize a large number of situations as familiar and to retrieve an appropriate response. Recent research in tactical decision making suggests that proficient decision makers are also metarecognitionally skilled. In novel situations where no familiar pattern fits, proficient decision makers supplement recognition with processes that verify its results and correct problems. The Recognition / Metacognition framework suggests a variety of metarecognitional skills that may develop with experience or serve as the objectives of training and as guidelines in the design of decision aids:

(1) More experienced decision makers are more sophisticated in their use of the Quick Test. They buy themselves more time for resolving uncertainty by (a) explicitly asking how much time they have before they must commit to a decision, and (b) estimating the available time more precisely. For example, in the air defense domain, less experienced officers were ready to shoot as soon as an approaching contact was within its nominal weapons range of the cruiser. More experienced officers considered the actual ranges at which such contacts had fired in the past, specific conditions that might affect firing range in the present situation (e.g.,

weather, visibility), and potential warning cues (e.g., changing altitude, using radar).

(2) More experienced decision makers adopt more sophisticated critiquing strategies. They start by focusing on what is wrong with the current model, especially incompleteness. Attempting to fill in missing arguments typically leads to discovery of other problems (i.e., unreliable arguments or conflicts among arguments). These problems then motivate the elaboration of the current model or its replacement by an alternative. Less experienced decision makers are more likely to consider an alternative hypothesis at the start of their thinking and then to prematurely reject it in the face of any conflict.

(3) Experienced decision makers adopt more sophisticated correcting strategies. They try to modify a story in order to explain conflicting evidence, rather than ignoring or discounting it. They evaluate the assumptions required by alternative stories, rather than comparing the data to fixed patterns or checklists. They try to construct a more plausible story by revising the most unreliable assumptions in the current stories.

The R/M model explains how experienced decision makers are able to exploit their experience in a domain and at the same time handle uncertainty and novelty. They construct and manipulate concrete, visualizable models of the situation, not abstract aggregations (such as 55% hostile, 45% not hostile). Uncertainty is represented explicitly at the metacognitive level, in terms of incompleteness, conflict, and unreliability attributed to components of the first-level model.

The Recognition/Metacognition model needs to be tested and refined in research that spans several domains and that involves a variety of converging methods. For example, critical incident interviews and think-aloud problem-solving sessions can be coded and analyzed to identify types of situation model structures and metacognitive processes, and to test their correlation with experience (e.g., Cohen, Thompson, Adelman, Bresnick, Tolcott, & Freeman, 1995). Specific predictions about decision making behavior can be tested experimentally (for example, the interaction of the "confirmation bias" with the number and plausibility of assumptions required to explain conflicting evidence). A computational implementation of the R/M model in a hybrid neural-symbolic architecture might permit more extensive investigation of its implications and empirical validity (e.g., Thompson, Cohen, & Freeman, 1995). The R/M model might also be extended and tested in the context of team and distributed decision making (for example, where different team members or geographically separated subteams must monitor one another's performance and respond by adjusting their own performance). Finally, the R/M model might be tested further as a basis for improving performance, in the training of critical thinking skills and in the design of decision support systems (e.g., Cohen, Freeman, Wolf, & Militello, 1995).

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LIST OF FIGURES

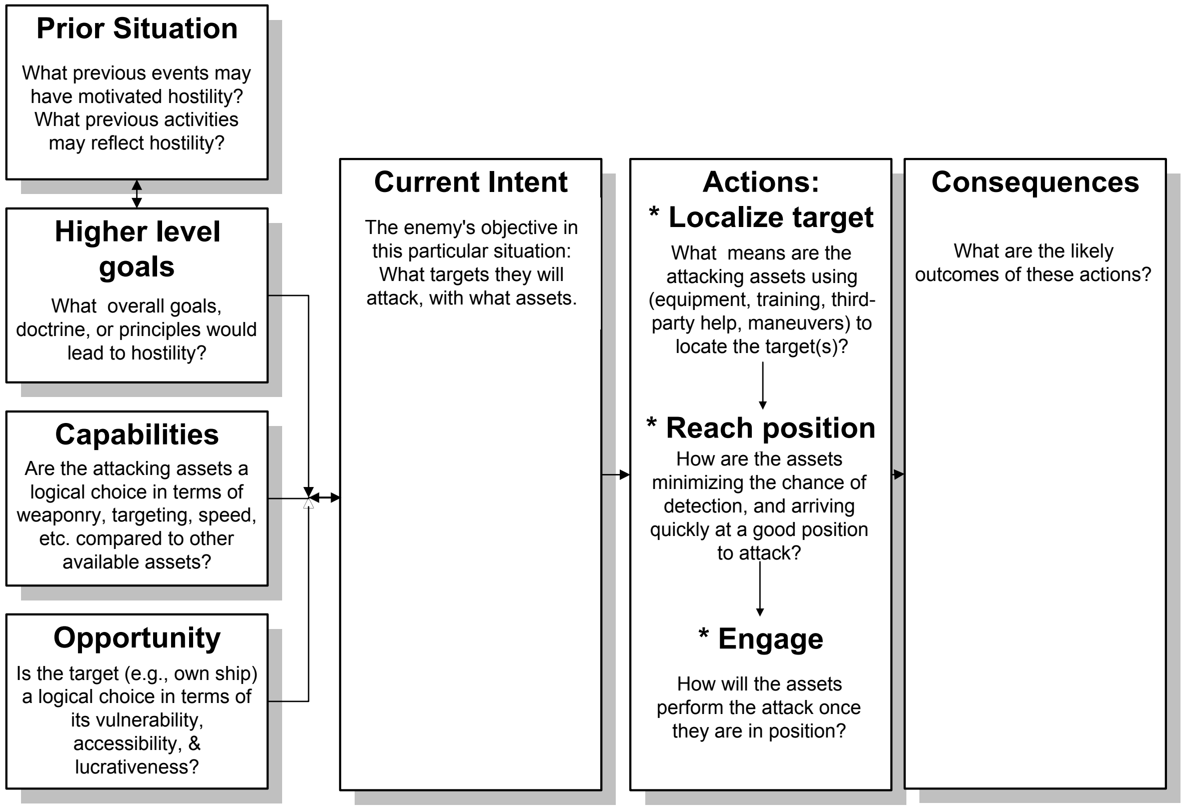
Prior Situation
What previous events may have motivated hostility? What previous activities may reflect hostility?
Higher level goals
What overall goals, doctrine, or principles would lead to hostility?
Capabilities
Are the attacking assets a logical choice in terms of weaponry, targeting, speed, etc. compared to other available assets?
Opportunity
Is the target (e.g., own ship) a logical choice in terms of its vulnerability, accessibility, & lucrativeness?
Current Intent
The enemy's objective in this particular situation: What targets they will attack, with what assets.
Actions:
* Localize target
What means are the attacking assets using (equipment, training, third-party help, maneuvers) to locate the target(s)?
* Reach position
How are the assets minimizing the chance of detection, and arriving quickly at a good position to attack?
* Engage
How will the assets perform the attack once they are in position?
Consequences
What are the likely outcomes of these actions?

Figure 1.

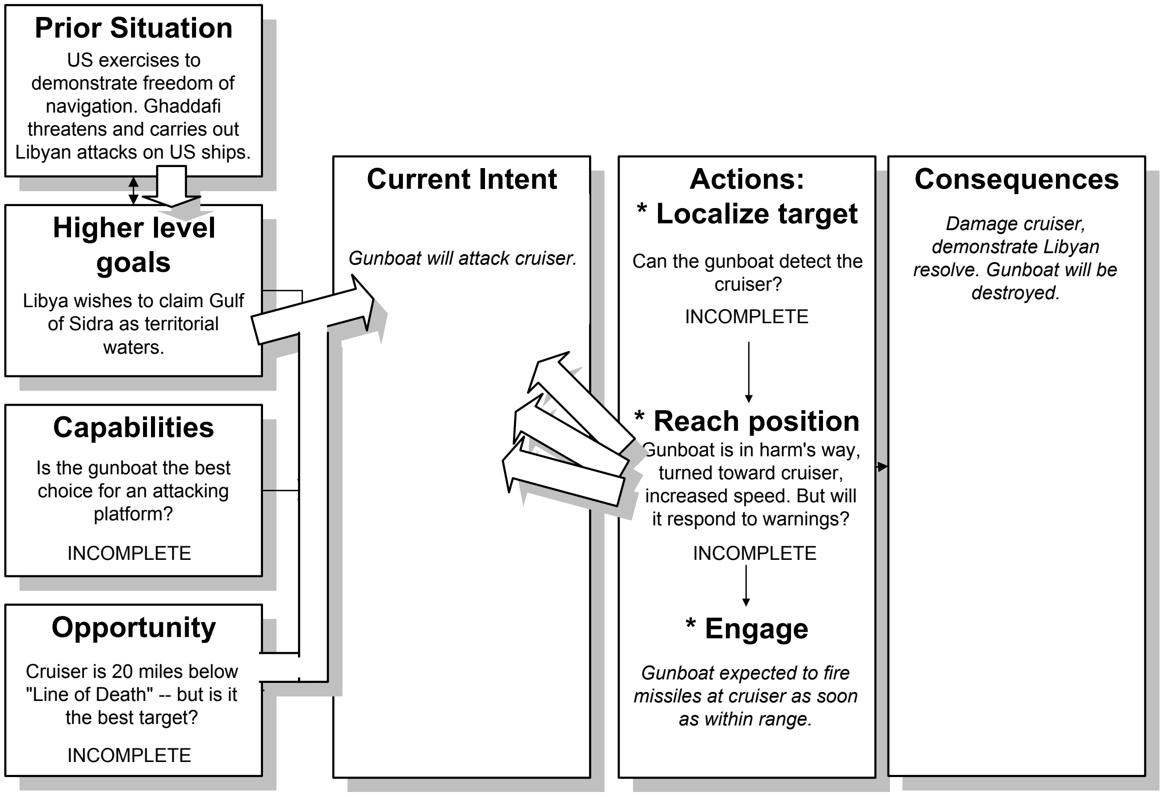
Prior Situation
US exercises to demonstrate freedom of navigation. Ghaddafi threatens and carries out Libyan attacks on US ships.
Higher level goals
Libya wishes to claim Gulf of Sidra as territorial waters.
Capabilities
Is the gunboat the best choice for an attacking platform?
INCOMPLETE
Opportunity
Cruiser is 20 miles below "Line of Death" -- but is it the best target?
INCOMPLETE
Current Intent
Gunboat will attack cruiser.
Actions:
* Localize target
Can the gunboat detect the cruiser?
INCOMPLETE
* Reach position
Gunboat is in harm's way, turned toward cruiser, increased speed. But will it respond to warnings?
INCOMPLETE
* Engage
Gunboat expected to fire missiles at cruiser as soon as within range.
Consequences
Damage cruiser, demonstrate Libyan resolve. Gunboat will be destroyed.

Figure 2

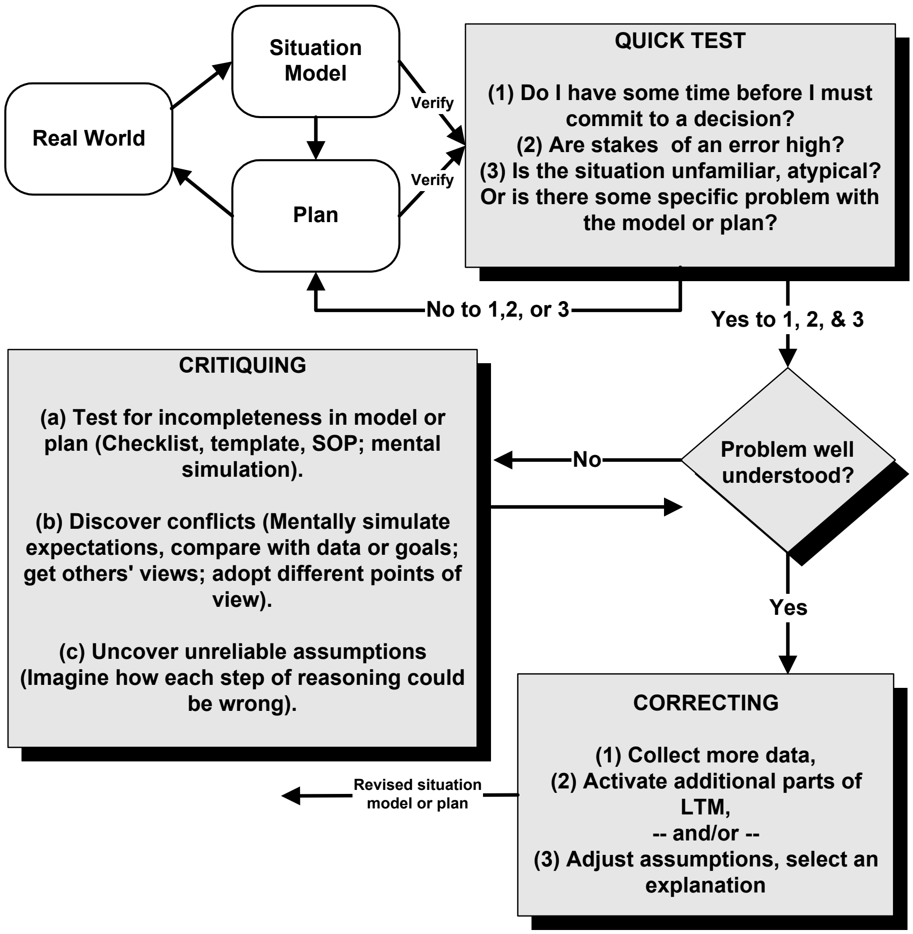
Situation Model
Real World
Plan
Verify
Verify
QUICK TEST
(1) Do I have some time before I must commit to a decision?
(2) Are stakes of an error high?
(3) Is the situation unfamiliar, atypical? Or is there some specific problem with the model or plan?
No to 1,2, or 3
Yes to 1, 2, & 3
CRITIQUING
(a) Test for incompleteness in model or plan (Checklist, template, SOP; mental simulation).
(b) Discover conflicts (Mentally simulate expectations, compare with data or goals; get others' views; adopt different points of view).
(c) Uncover unreliable assumptions (Imagine how each step of reasoning could be wrong).
No
Problem well understood?
Yes
CORRECTING
(1) Collect more data,
(2) Activate additional parts of LTM,
-- and/or --
(3) Adjust assumptions, select an explanation
Revised situation model or plan

Figure 3

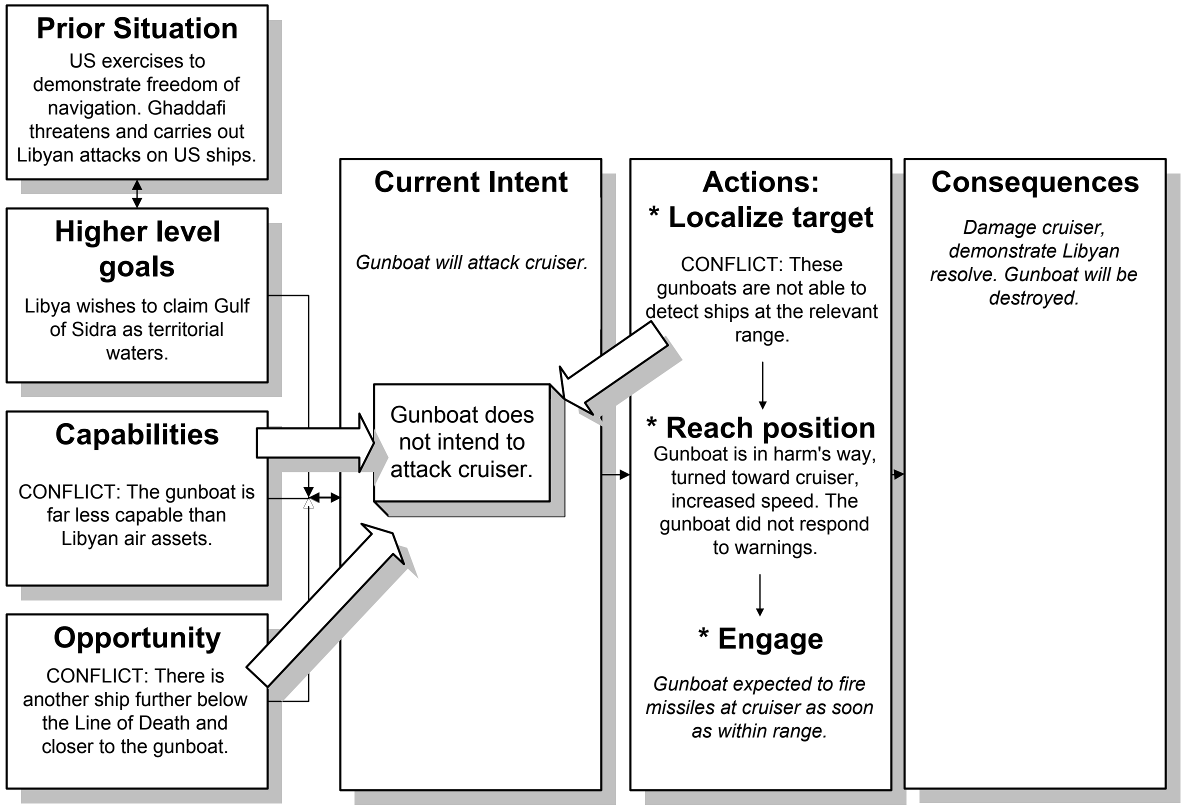
Prior Situation
US exercises to demonstrate freedom of navigation. Ghaddafi threatens and carries out Libyan attacks on US ships.
Higher level goals
Libya wishes to claim Gulf of Sidra as territorial waters.
Capabilities
CONFLICT: The gunboat is far less capable than Libyan air assets.
Opportunity
CONFLICT: There is another ship further below the Line of Death and closer to the gunboat.
Current Intent
Gunboat will attack cruiser.
Gunboat does not intend to attack cruiser.
Actions:
* Localize target
CONFLICT: These gunboats are not able to detect ships at the relevant range.
* Reach position
Gunboat is in harm's way, turned toward cruiser, increased speed. The gunboat did not respond to warnings.
* Engage
Gunboat expected to fire missiles at cruiser as soon as within range.
Consequences
Damage cruiser, demonstrate Libyan resolve. Gunboat will be destroyed.

Figure 4

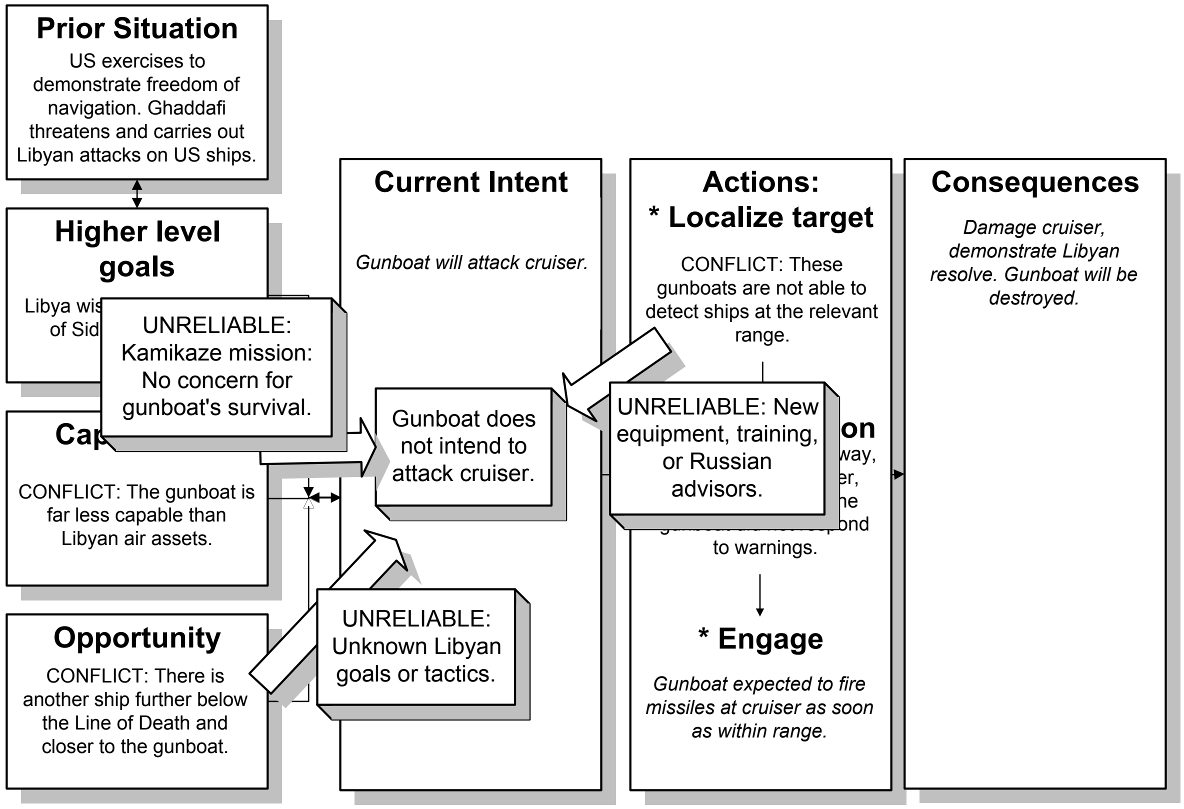
Prior Situation
US exercises to demonstrate freedom of navigation. Ghaddafi threatens and carries out Libyan attacks on US ships.
Higher level goals
UNRELIABLE: Kamikaze mission: No concern for gunboat's survival.
CONFLICT: The gunboat is far less capable than Libyan air assets.
Opportunity
CONFLICT: There is another ship further below the Line of Death and closer to the gunboat.
UNRELIABLE: Unknown Libyan goals or tactics.
Current Intent
Gunboat will attack cruiser.
Gunboat does not intend to attack cruiser.
Actions:
* Localize target
CONFLICT: These gunboats are not able to detect ships at the relevant range.
UNRELIABLE: New equipment, training, or Russian advisors.
to warnings.
* Engage
Gunboat expected to fire missiles at cruiser as soon as within range.
Consequences
Damage cruiser, demonstrate Libyan resolve. Gunboat will be destroyed.

Figure 5

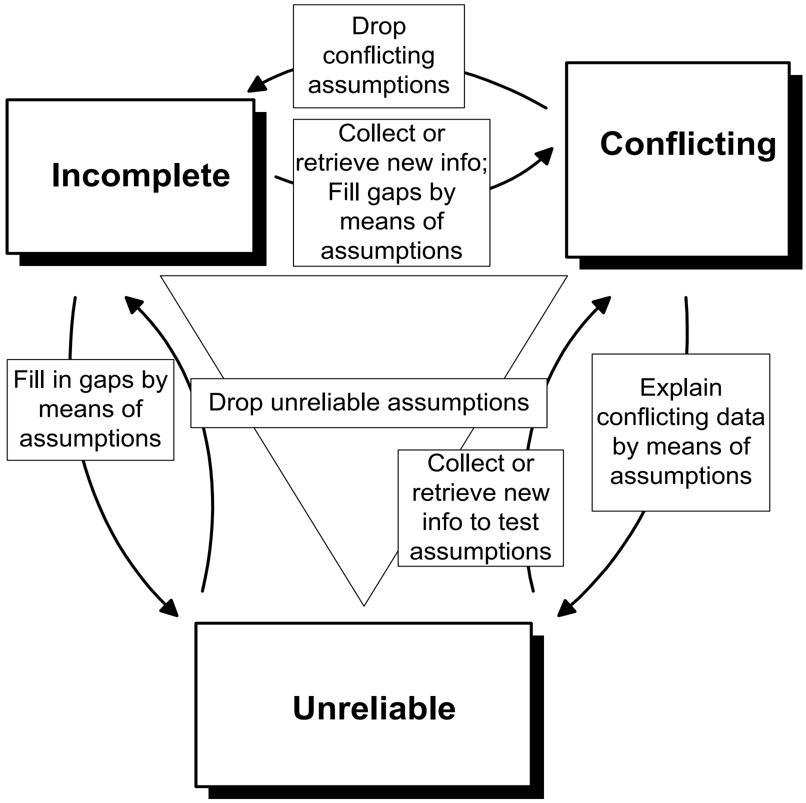
Drop conflicting assumptions
Incomplete
Collect or retrieve new info; Fill gaps by means of assumptions
Conflicting
Fill in gaps by means of assumptions
Drop unreliable assumptions
Explain conflicting data by means of assumptions
Collect or retrieve new info to test assumptions
Unreliable

Figure 6

MARVIN S. COHEN, JARED T. FREEMAN, and STEVE WOLF (Metarecognition in Time-Stressed Decision Making: Recognizing, Critiquing, and Correcting)

MARVIN S. COHEN is president of Cognitive Technologies, Inc. Dr. Cohen's work includes research on human reasoning and decision making in real-world settings, training cognitive skills, elicitation of expert knowledge, computer-based decision aids, human-computer interface design, and methods for representing and manipulating uncertainty. Current projects include modeling and training tactical decision making in Army and Navy domains, real-time capturing of battlefield mental models, hybrid neural and symbolic models of metacognitive processes, computer and human interactions in target recognition, and commercial airline pilot decisions. Dr. Cohen obtained his Ph.D. in experimental psychology from Harvard University.

JARED T. FREEMAN is a research scientist at Cognitive Technologies, Inc. He specializes in knowledge elicitation, cognitive task analysis, and training design for problem solving and decision making in naturalistic settings. He is currently participating in programs to identify and train situation assessment skills and critical thinking among commercial airline pilots and officers of the U.S. Army and Navy. Dr. Freeman received his Ph.D. in cognitive psychology from Columbia University.

STEVE WOLF is a research associate at Klein Associates, Inc.. Mr. Wolf has had a key technical role on projects concerned with expert knowledge and decision support, including training and decision support systems for the Navy, decision support requirements of airport baggage inspectors, helicopter pilot safety, Fire Direction Officers decisions, and human-computer interface designs for a surveillance platform. Mr. Wolf holds a B.S. in psychology from Wright State University, Dayton, OH.