Modernizing Our Cognitive Model

David J. Bryant

Defence Research Development Canada – Toronto
Judgment and Decision-Making Group
P.O. Box 2000, 1133 Sheppard Ave. W.
Toronto, ON, M3M 3B9, CANADA
email: David.Bryant@drdc-rddc.gc.ca

Abstract

Although still popular, the Observe-Orient-Decide-Act (OODA) Loop is outdated as a model of human cognition. Based on advances in the cognitive sciences since the 1950s, the Critique-Explore-Compare-Adapt (CECA) Loop is proposed as a better descriptive model. The model puts two mental representations, the *conceptual model* established through operational planning, and the *situation model*, which represents the state of the battlespace, at the center of the decision making process. The four phases of the CECA Loop broadly correspond to the identification of information needs (Critique), active and passive data collection and situation updating (Explore), comparison of the current situation to the conceptual model (Compare), and adaptation to aspects of the battlespace that invalidate the conceptual model or block the path to goal completion (Adapt). The CECA Loop is intended to serve as a simple but widely applicable framework in which to study decision making in the context of Command and Control (C2). Some advantages of the CECA Loop over the OODA Loop are greater insight into the nature of perception and understanding, introduction of critical thinking elements, and exposition of the central role of planning and the mental representation of operational concepts in C2.

Introduction

The Observe-Orient-Decide-Act or OODA Loop has been popular in military circles as a descriptive model of human reasoning and decision making for roughly 50 years. By conceiving of friendly and enemy forces in terms of competing cycles of decision processes, military theorists have been able to identify ways of speeding up one's own decision making while interfering with and slowing down the enemy's. The key assumption is that completing one's own decision cycle faster than one's opponent will yield ever-increasing advantages in Command and Control (C2) effectiveness, which will, in turn, yield greater battle success (Alex, 2000).

To obtain positive combat effects from good decision making, it is necessary to have the best possible theory of cognition underlying one's concept of C2. A good cognitive theory is one that is most descriptive of how people actually think under various conditions and highly predictive of how people will think and act in any specific situation. Such a theory conveys a number of advantages. First, it informs military analysts and planners where support for command decision making is required and what kinds of support will be effective (Litherland, 1999). Second, it is needed to design training, doctrine, and procedures to be consistent with natural human reasoning and enhance its strengths and mitigate its weaknesses (Cunningham, 2000; Marr, 2001). Finally, by understanding how the mind works, one can decide what organizations, processes, and technology will most effectively aid decision makers deal with pressures of limited time and information overload.

The OODA Loop

The OODA Loop was first proposed by U.S. Air Force Colonel John Boyd in the mid-1950s in a study of air-to-air combat during the Korean War (Alex, 2000; Plehn, 2000; Sweeney, 2002). Boyd attributed the success of American pilots to the better visibility offered by their F-86 Sabre aircraft, which made it possible for American pilots to assess a changing situation quickly and manoeuvre in response. Boyd took from his observation the lesson that faster detection of the enemy's actions, assessment of their implications, and decision on how to respond could convey a significant combat advantage. From this, he derived four basic steps of Observe, Orient, Decide, and Act to describe cyclical decision processes (see Figure 1).

This idea resonated with military thinkers around the world and the notion of the OODA Loop entered doctrine in many countries without a great deal of critical examination (Plehn, 2000). Boyd's theory that conflict can be viewed in terms of a contest between time-competitive observation-orientation-decision-action cycles provided a powerful means for people to think about C2 (Alex, 2000). It must be noted, however, that Boyd himself made no effort to demonstrate the applicability of the OODA Loop to C2 contexts beyond air-to-air combat (Plehn, 2000).

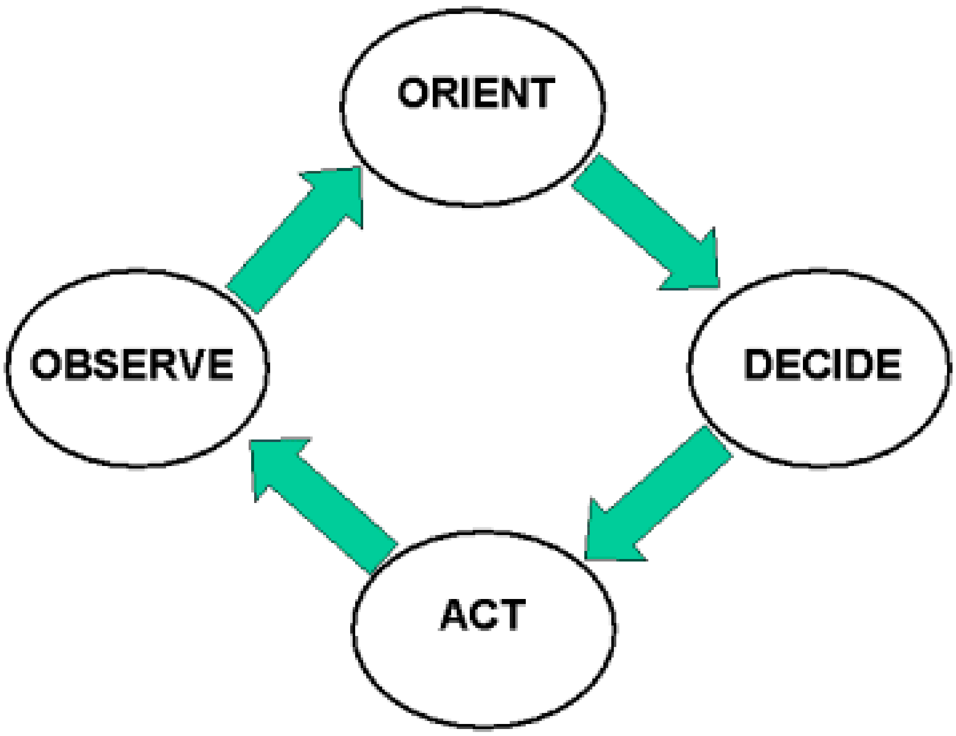

Figure 1. *The OODA Loop*

Because the stages of the OODA Loop are intended to describe decision making processes in general, across contexts, each level within a command hierarchy is assumed to perform its own OODA Loop. Figure 2 illustrates this idea; decision making at a given level of command is represented by a loop, with the decision making of lower levels of command contained within it.

Likewise, the decision loop of any given level of command is subsumed within the decision loop of the next higher level in the command hierarchy. These multiple decision loops are assumed to proceed simultaneously and interactively, such that performing the decision cycle at a given level depends on the performance of decision cycles below and, in turn, constrains the performance of the decision cycle above (Sweeney, 2002).

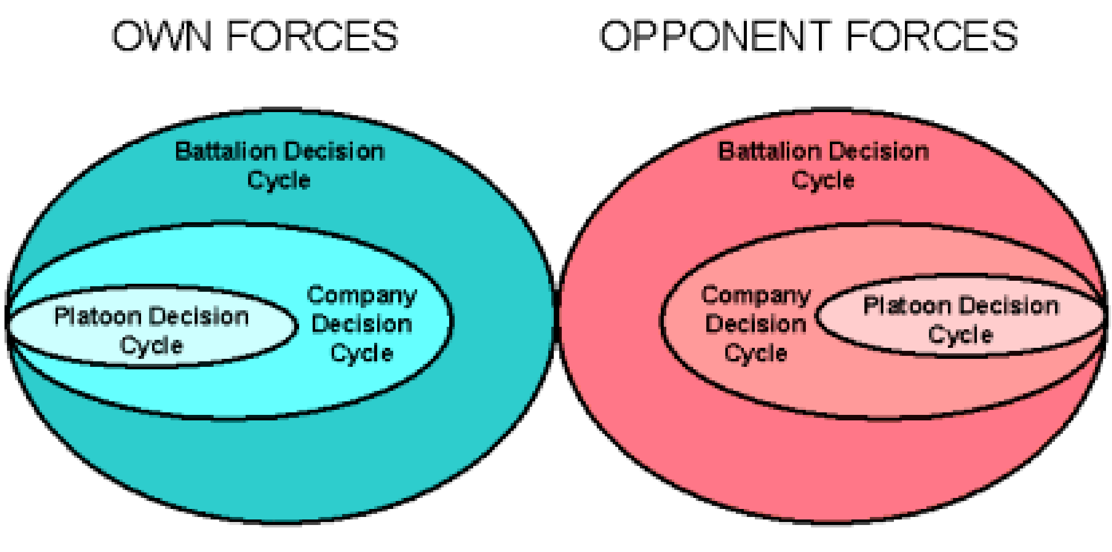

Figure 2. *Subset of Hierarchically Embedded OODA Loops for Own and Opponent Forces*

Figure 2 also illustrates the competitive aspect of the OODA Loop model. Just as one's own forces perform decision cycles within the command hierarchy, the opponent is assumed to perform the same decision cycles. In this context C2 superiority is achieved by performing decision cycles faster than the opponent at every level of command (Plehn, 2000). With shorter decision cycles, the own forces can select an action and implement it before the opponent is able to adequately observe, orient, and decide, conveying the initiative to the own forces. Moreover, speed in decision cycles at lower levels of command will convey advantages to higher levels of command that depend on information moving up the command hierarchy.

The OODA Loop has seemed intuitively accurate and fit well with emerging concepts of control and information warfare (Loffert, 2002; Sparling, 2002]. Despite its popularity, however, the OODA Loop is flawed as a model of human decision making. Although it identifies broad aspects of decision making, the model provides no indication of *how* one should go about performing these processes. The deceptive intuitiveness of the OODA Loop obscures the underlying processes that people use to effectively seek information and use that information to generate and select from courses of action. Possibly worse, the OODA loop does not capture the essential goal-directedness of command decision making. This makes the OODA loop *reactive* rather than proactive as it suggests that decision making occurs only in reaction to environmental events. Without clear specification of basic perceptual and information processing processes, the OODA Loop is too vague to help one understand the interplay of planning and implementation in hierarchical C2 organizations (e.g., Plehn, 2000). One consequence of this is that the OODA Loop provides no guidance on how to define information needs from the commander's perspective or procedures for managing information (Cook et al., 2000).

The OODA Loop also tends to give the impression that perception and understanding are driven exclusively by bottom-up processes. A tremendous body of cognitive research however, makes clear that perception depends on pre-existing knowledge and concepts. People require pre-existing concepts to guide their interpretation of what they perceive. Such pre-existing concepts not only distinguish the most plausible interpretation of an observation but also guide us as to what portion of all the available sensory data is relevant and will direct our attention to important objects and events in the environment.

This point is important because we generally take perception for granted because it seems so automatic; we are not aware of the complex top-down cognition involved in directing our attention and interpretation of perceptual data (Rock, 1993). But when we consider information gathering and decision making in complex, socio-technological systems, problems are not so structured. In particular, command of military forces is likely to present highly unstructured problems in which a commander must formulate concrete objectives. It is not always clear what aspects of the environment (especially enemy forces) are relevant or useful in assessing the situation at a given moment of time. A commander must think about what he/she wants to do, what resources are available, what the enemy might do, and what data *should* be collected to assess all this. That is, the commander must define the concepts that will be used to guide data collection and picture building (perception) for the C2 organization. Whereas the OODA loop leaves these issues implicit in its "Observe" and "Orient" stages, it is vital when working in complex C2 environments to make these issues explicit. That is, we must specify the role of the operational plan or the commander's intent in defining the "rules of the game," that indicate the basic sets of factors that govern how one will search the environment and use data to assess the status of one's own goals and potential actions of the enemy.

The mistaken emphasis on information gathering as a "bottom-up" process may be partly responsible for the over-emphasis on technology as a solution to C2 problems (see Coakley, 1992, pp. 73-74). When decision making is viewed primarily as a problem of obtaining as much information as possible, it is easy to conceive of automation as a solution. It should become clear in subsequent sections, however, why simply expanding the capacity to collect more, and more precisely resolved, data does not itself aid human decision making.

Modern Perspectives on Cognition

A great deal of progress has been made in the cognitive and behavioural sciences since Boyd formulated the OODA Loop in the mid-1950s. At that time the mechanistic information processing view was becoming prominent. In the intervening 50 years, however, four perspectives have become extremely influential in shaping our understanding of cognition. These perspectives should be addressed in a model of decision making for C2.

Goal-Directed Cognition

The OODA Loop does not include an explicit role for plans, intentions, or goals, although people are clearly independent, self-directing creatures. Intentionally or unintentionally, the information processing perspective from which the OODA Loop arose creates the impression that people are largely passive reactors to external events as it focuses on gathering information about the world and deciding what to do in response to that information. The importance of goals and intentions to understanding cognition has been amply demonstrated in numerous studies that have shown that success in solving complex problems or controlling complex systems depends on clearly identifying goals and subgoals and effectively planning means to achieve them (e.g., Jansson, 1999; Newell & Simon, 1972).

Constructivist Theories of Understanding

The view of perception as active "sense-making" owes a great deal to the work of Irving Rock, whose general framework describes perception as an inferential process. Rock (1993) argued that the cognitive system works to determine what situation in the external world could have produced the given pattern of sensory stimulation. This implies a strong interaction of bottom-up and top-down processes, which work to select, modify, and interpret sensory data to create a coherent and meaningful understanding of the physical world. In this sense, we see the analogy of C2 to perception (Coakley, 1992); just as the commander must try to create a picture of the battlespace based on finite sensor data, so too every human creates an internal model of the external world based on his or her own finite sensory data.

Mental representations guide perception and information gathering activities – essentially telling us how to observe the world, discern what is and is not relevant, and relate observed phenomena to our goals. Knowledge is used to direct sensory systems, identifying the kinds of objects and events that are likely to be of interest, setting thresholds on the various kinds of phenomena that might attract attention, and so forth. Knowledge is also used to assemble gathered sensory data into a coherent and plausible *interpretation* of the state of the world around us (Rock, 1993). This is a key premise of the constructivist perspective, that our experience and understanding of the world is not an absolute truth; it is, instead, our best attempt to explain the data our senses have gathered and provide a mental model that can be used to plan actions to be taken in that world. We may not be aware of the hypothetical nature of perceptual experience, but that is only because our cognitive systems are an evolutionary legacy highly tuned to our natural environment. When we step into an unnatural world, such as that of modern warfare, however, it is critical to bear in mind that data are simply building blocks and the value of the end product, our understanding, depends also on the concepts and knowledge brought to bear in interpreting the data.

Mental Models

Concepts of mental representation are critical to understanding the overall decision making process. Among the most important class of representations studied is the mental model, which was developed as a means to describe complex and rich mental representations used in reasoning (e.g., Johnson-Laird, 1983). The defining characteristic of a mental model is that it maps elements of an external system (a problem, situation, or event) and the inter-relationships among those elements onto a conceptual structure (Moray, 1999; Rouse et al., 1992). Mental models are situational representations – that is, they take their structure from the structure of the system modeled. Consequently, mental models of different systems will exhibit different characteristics depending on the complexity of the system and the demands of the individual's task (which will make some elements more relevant than others) (Moray, 1999). In addition, mental models are transient and dynamic representations that continually adjust to represent the current state of the system or situation (Hatano & Inagaki, 2000).

If problem solving is viewed as the exercise of control over a complex system, the mental model plays a key role as the indicator of the current state of the system, the "here and now" (Jansson, 1999). This situation representation can be used to evaluate the current state in relation to desired goal states and serve as a working model for simulating the effects of potential actions.

Critical Thinking

Critical thinking, broadly defined as the systematic questioning and evaluation of one's own reasoning strategies, is known to be crucial to successful problem solving. This has been demonstrated in studies of decision making conducted in both military (e.g., Cohen et al., 1998; Emilio, 2000; Riedel. 2001) and non-military contexts (e.g., Green, 1990). Insufficient critical thinking has been identified as one common maladaptive aspect of decision making (e.g., Jansson, 1999).

Critical thinking is akin to hypothesis testing in science. A scientific theory serves as the best causal explanation for some phenomena until evidence is found that contradicts predictions of that theory. When this happens, the theory must be revised or replaced to produce a better explanation. Through continual testing and revision, science progresses towards better explanations with the understanding that perfect explanatory power is unachievable. In a similar sense, our mental models act as the best explanatory theory available when solving a problem (e.g., Brehmer, 1986). Critical thinking performs the role of hypothesis testing by calling into question elements of the mental model and motivates one to look for evidence that could potentially contradict what one believes. This leads to potentially disconfirming evidence and necessitates some revision or re-thinking of the problem or one's strategy for solving it.

The CECA Loop

The Critique-Explore-Compare-Adapt (CECA) Loop is a new model of decision making intended to serve as a general description of decision making by individuals and by the C2 structure. As a model of individual decision making, the CECA Loop captures the central importance of mental models as the means to represent and make sense of the world. It also demonstrates the necessity of top-down guidance of perception. To be useful in considering C2, however, the model must apply to social cognition, in which decisions are made by multiple persons working on a large problem. In the case of a C2 organization, the model describes information gathering and processing carried out by distributed units in which a single conceptual model (perhaps what is meant by the idea of the recognized picture) is created and maintained at the organizational level, although any individual within the organization may have knowledge of only a portion of the conceptual model.

At the core of decision making by an individual is the mental model that guides perception and action. Similarly, the C2 organization requires a conceptual model, which is a shared representation of the plan of operations over time. The model also applies to the entire C2 organization because in a distributed force all individuals must operate with respect to the same concept of the operation. Thus, the conceptual model developed through planning by the commander and staff must be disseminated in a way that allows every member of the force to internalize an accurate representation of at least those aspects of the conceptual model that can be affected by that individual.

Overview

The CECA loop, shown in Figure 3, begins with planning activities that establish the initial *conceptual model* (illustrated in the top-most box in Figure 3), which is a mental model of the plan. Action without a well-defined model of what is to be accomplished and how it is to be accomplished cannot lead to desirable outcomes. The conceptual model is parenthetically described (in Figure 3) as "how you want it to be" because this model maintains the goals of the operation as well as a representation of how to achieve them. Throughout an operation, the conceptual model will be a representation of how the operation is intended to proceed and, thus, is closely aligned with the commander's intent.

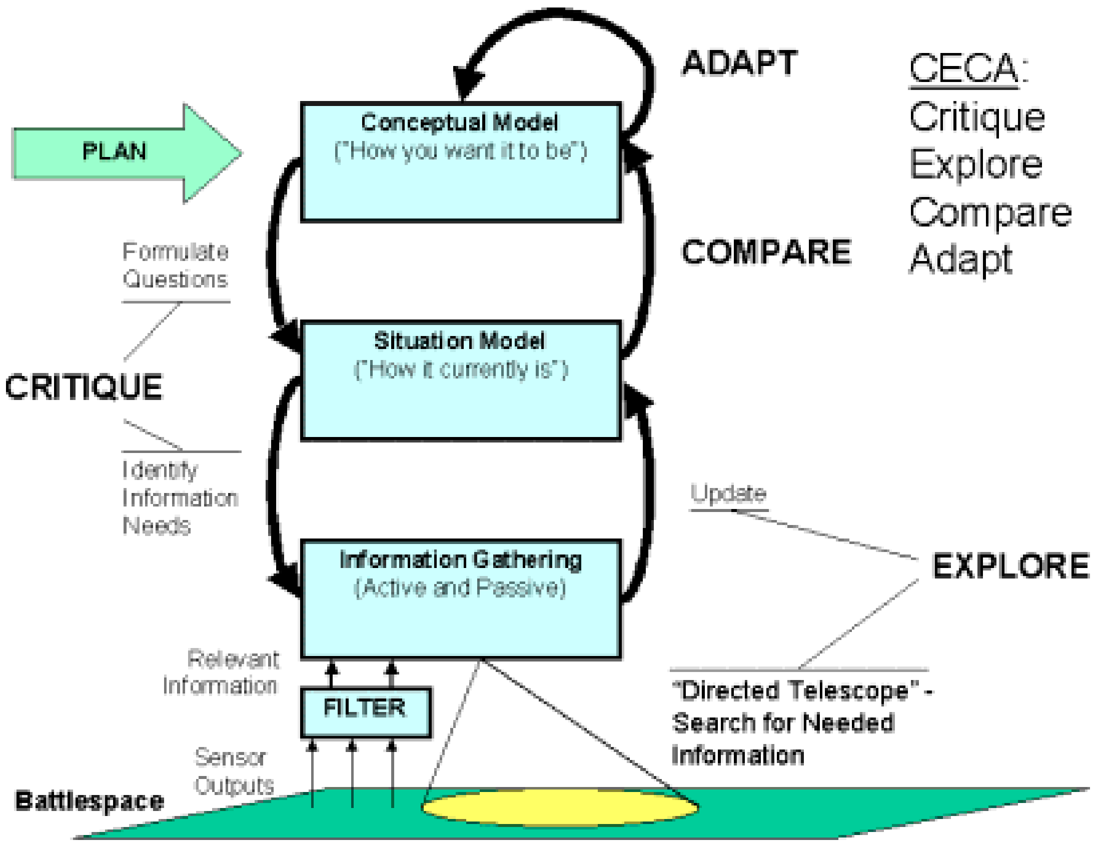

Figure 3. *The Critique, Explore, Compare, and Adapt (CECA) Loop*

The conceptual model must be goal-directed and describe the *states* of the battlespace one wants to achieve across a specified period of time. This is much more important than describing what *actions* one believes should be performed to meet operational goals. Detailed specification of desired battlespace states is crucial for a) devising appropriate actions, b) assessing the effectiveness of actions in achieving desired battlespace states, and c) assessing the relevance and effectiveness of the plan itself (and goals) in meeting higher-level operational aims.

The conceptual model can be thought of as a working description of the intended states of the battlespace as well as the ultimate desired end-state. As such, the conceptual model must be open to revision so that the desired transition states, and perhaps even the desired end state, can be changed in response to changes in the battlespace. This is illustrated in Figure 4 where the conceptual model is depicted as a series of battlespace states, established through planning, and ending with the desired end-state comprising the operation objectives. In between are a series of desired transition states that define the path from the initial to desired end-state.

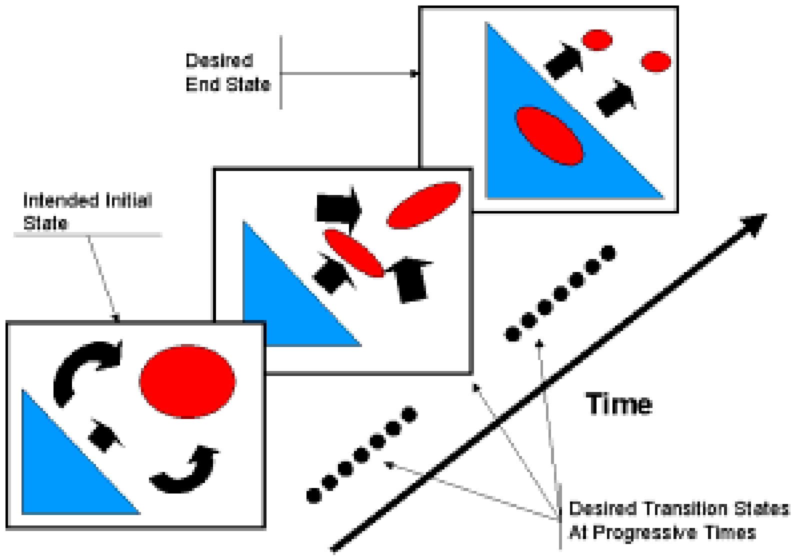

Figure 4. *The Conceptual Model Describes Intended States Over Time*

To know when and how to adapt one's conceptual model, one must have a *situation model* (illustrated by the middle box in Figure 3), which is a representation of the current state of the battlespace ("how it currently is") in a form that can be understood with respect to the conceptual model. In particular, the situation model must identify aspects of the current state of the battlespace that differ from the desired state of the conceptual model because an adequate understanding of the implications of the situation for the plan cannot be gained passively.

The situation model should represent all aspects of the battlespace that affect the validity of the conceptual model but not aspects that are irrelevant (as determined by the conceptual model specifically and doctrine generally). The key to effective information management depends on minimizing attention devoted to information that does not have the *potential* to invalidate the conceptual model. This is a critical point – disconfirmatory evidence, which can indicate ways in which the conceptual model is not an accurate representation of the situation, is more valuable than confirmatory evidence. Evidence that disconfirms one's beliefs and plans forces one to change them and, hence, one's actions to be more adaptive to the actual conditions of the battlespace.

The Decision Making Process

Because the conceptual model of the plan is goal-oriented, information gathering must be directed toward determining the ways in which the current situation is facilitating the achievement of goals and more importantly the ways in which it is thwarting the achievement of goals or putting one's own forces at risk. Thus, information needs are established in the "Critique" phase of the CECA Loop (consult Figure 3) by questioning the conceptual model to identify critical aspects that, if invalidated, would render the plan for the operation untenable in some respect. From these questions, one can identify specific kinds of data types that will contribute to answering the questions. Specific information needs are promulgated down to the sensor level so that the battlespace is searched with a kind of modern day "directed telescope" (see Figure 3) that provides desired information quickly.

The “Explore” phase of the CECA Loop (see Figure 3) comprises the active and passive collection of data from the battlespace. Active collection is guided by the information needs developed in the Critique phase and thus is directed to answering questions of the conceptual model’s validity. The directed telescope is a concept, described by Martin Van Creveld, that refers to the means used by commanders to obtain tactical information and disseminate critical orders (Van Creveld, 1979). Historically, the directed telescope has been implemented by specially selected and trained officers or agents who were directly responsible to the commander and performed a range of information gathering functions. Critically, these aides were also able to take back information concerning events or conditions that went counter to the commander’s intent and signalled the need for some adaptation (see Builder et al., 1999). The concept of the directed telescope falls in line with what we know of constructivist knowledge acquisition. It essentially takes of place of the top-down processes of perception in guiding the commander and C2 structure in its bottom-up information gathering. The directed telescope is akin to selective attention in humans, and serves to make optimal use of limited processing capacity to rapidly obtain relevant information.

A second means of information gathering involves the continual reception and filtering of sensor data according to intelligently determined criteria. This is illustrated by the box labeled *filter* in Figure 3, although the filter actually refers to all the mechanisms in place to block irrelevant information from further processing. Passive collection is a filtering process in which events in the battlespace are monitored to determine whether unassessed aspects of the battlespace should receive attention. Events triggering a response in the filtering system can be actively processed and incorporated in the situation model. The criteria used to filter ambient sensor inputs must depend on the conceptual model, through analysis of the factors that can affect the achievement of goals or the safety of the force, as well as an understanding of the principles of warfare. A filtering process is necessary to prevent the decision maker and C2 organization from becoming overwhelmed by the volume of data that can be collected. It represents a compromise between the need to be responsive to unforeseen events and limitations on the volume of data that can be processed at any given time.

Gathered data are used to update the situation model of the battlespace, reflecting changes that have occurred in the battlespace, corrections of errors in the situation model, the addition of missing elements, and the enhancement of relevant detail. All changes to the situation model must bear on the validity of the conceptual model to prevent the situation model from becoming overly complex with irrelevant information.

In the “Compare” phase (see Figure 3), the situation model is compared to the conceptual model to determine what, if any, aspects of the conceptual model are invalid (i.e. inconsistent with the current situation). The emphasis should be on identifying ways in which the current state of the battlespace does not correspond to the state described by the conceptual model for this time period of the plan. In particular, the answers to the high-level questions used to direct information gathering must be explicitly considered to ensure that the validity of critical aspects of the conceptual model are tested.

Based on the differences between the situation and conceptual models, the conceptual model will require some degree of revision. It is then up to the decision maker to determine what to do in response to inconsistencies in the “Adapt” phase (see Figure 3). In general, the decision maker has three options, to a) ignore the inconsistencies if they are deemed of low consequence (i.e. inconsistencies with the conceptual model have little practical impact), b) alter the means by which the goals of the operation are to be achieved, or c) alter the goals themselves if the most basic assumptions of the conceptual model are invalidated.

How Does the Organization Act?

Unlike the OODA Loop, the CECA Loop does not have "action" embedded in the loop itself. There is a good reason to consider the information gathering/decision making loop in parallel to action. The OODA Loop places action at the end of a sequence of information processing activities and before the beginning of the subsequent sequence, implying a strict linearity to decision making. Such linearity is rare in any system but especially so in a chaotic system like warfare, in which numerous streams of activities occur simultaneously.

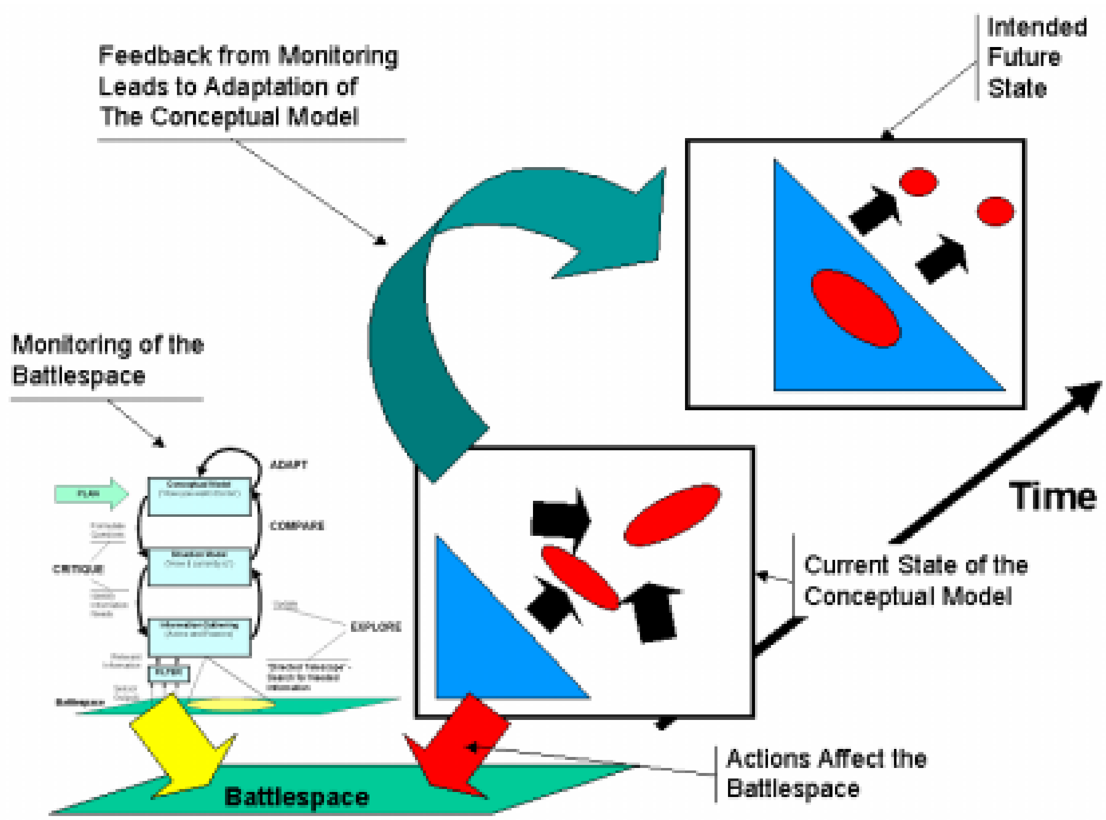

Figure 5. *Model-Guided Action and CECA Monitoring*

Rather than view action as a stage within the model, the CECA Loop treats action as a continuous process that is driven by the conceptual model. All actions are driven by the conceptual model, which lays out the rationale for each action the own force might take. As shown in Figure 5, the current state of the conceptual model (which depends on the data gathering and adaptation prior to this point) directs actions that affect the battlespace in some way. The CECA Loop proper is shown in the figure as running in parallel with the direction of action by the conceptual model. As the conceptual model drives action it also drives the data collection activities that allow the commander to assess the effects of those actions (as well as those of the enemy) on the state of the battlespace. An important consequence of this assumption is that action is not strictly tied to immediate observations of the battlespace. Rather, the conceptual model evolves in relation to *all* observed events as they affect the validity of the plan. Where the OODA Loop gives the impression of a commander constantly reacting to external events, the CECA Loop shows how a commander remains focused on achieving his/her own goals via a well-conceived plan while adapting appropriately to events in the battlespace.

With this distinction between reaction and proaction in mind, the CECA Loop makes clear that data cannot be treated as an infinitely valuable resource. Given limitations on the capacity to update mental models, human decision makers need to be economical in their use of data. Thus, to foster faster, better decision making actually requires a *decrease* in the amount of data that are passed through a C2 organization. Although the temptation might be to gather as much data as technology allows, that data will be of no use if there is not a concomitant capacity to process it into meaningful information that can be used to influence actions. The CECA Loop contains an explicit filtering function precisely to avoid overwhelming decision makers as they update their situation model. In concert with active search, the filter provides the capability for the C2 organization to react to unanticipated events but limits the expenditure of information processing resources on irrelevant data.

In using the conceptual model to define the kinds of information one will seek, one risks excluding key but unanticipated factors that will bear on the operation, leading to surprise, which is at least as equally undesirable an outcome as information overload. The role of the CECA Loop model is not to advocate the highest conceptual orientation to decision making. Instead, by describing how people naturally tend to think, it provides a framework for exploring the balance of risk of information overload and surprise.

Effective search and filtering of information depends on the sharing of the conceptual model among distributed units within the C2 organization. Sharing such a complex model is difficult and effort needs to be devoted to creating an external conceptual model to which everyone in the C2 organization can refer. The shared conceptual model is not meant to be a huge document explaining every detail of the operational plan. Such micromanaging has proven ineffective (e.g., Dumas, 2002). Rather, the conceptual model is meant to create a shared mental model among all members of the C2 organization and so must rely on extensive *implied intent* shared among those individuals (Pigeau & McCann, 2000). A shared conceptual model can only be established if members of the C2 team have a base of shared concepts and values with which to interpret explicit products (written or graphical) that layout the time line and critical points of an operational plan.

Conclusion

This paper has presented a new model of command decision making based on current concepts of cognitive psychology. The CECA Loop is more consistent with natural decision making than the OODA Loop that has been a popular model since the 1950s. The CECA Loop is not complementary to the OODA Loop in the way Allsion's three models for explaining governmental action are (Allison & Zelikow, 1999). Allison's models (rational actor, organizational behavior, and government politics) provide post hoc explanations that cover different aspects of governmental decision making. The CECA Loop is a new model of the same cognitive processes addressed by the OODA Loop and, hence, supplants it. The OODA needs to be replaced because it is accurate only at a more general level than the CECA Loop. Thus, the OODA Loop lays out four broad requirements for a decision making process and captures the cyclical nature of decision making in C2 but it fails to address questions of mental representation and constructive perception and understanding. The OODA Loop has served its purpose, primarily to provide a framework in which to address the time-sensitivity of decision making inC2, but a new model is needed to provide a framework in which to address emerging C2 issues such as information overload, propagation of commander’s intent, and efficiency of data gathering and processing.

It is intended that the CECA Loop provide a framework for discussing decision making in the C2 environment and bring to light important issues that have been neglected. Making better use of the organizational framework provided by a conceptual model, C2 is improved in two key respects. First, the amount of data gathered is reduced because the conceptual model clearly specified what data is relevant (worth gathering) at each point in the operation. Second, the amount of data processing is reduced because the conceptual model identifies critical aspects of the operation, allowing data to be processed in the most efficient manner to address critical aspects (avoid unnecessary processing). The CECA Loop makes clear that the amount of data is not the paramount factor but rather the *informativeness* of that data in terms of allowing the decision maker to evaluate the validity of his or her mental models. Work remains to be done to fully develop links between the CECA Loop framework and practical issues of command but greater progress will be made by explicitly confronting the issues of mental representation and communication raised in this framework.

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