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A Dynamic Process Model for the Design and Assessment of Network Centric Systems

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Abstract

Modern warfare has witnessed the proliferation of coalition efforts to contain terrorism. To be successful, these efforts rely upon the effective integration of human and technological agents. Typically, models and analyses of network centric warfare (NCW) focus on technological aspects of a system, eschewing the roles, contributions and decisions made by humans. The Dynamic Model of Situated Cognition (DMSC) emerged as an attempt to represent relationships between technology and humans in a system. The model has been applied in a variety of contexts: individual performance, military command and control, naval operations, human error in military mishaps, and, most recently, to modeling team behavior in complex organizations (Miller & Shattuck, 2004, 2005a, b; Shattuck & Miller, 2004, 2005; Miller, Shobe & Shattuck, 2005). During the 2004 CCRT Symposium, we introduced "A Process Model of Situated Cognition in Military Command and Control." We have expanded and refined the model over the last two years and it continues to be well received. In this paper, we review these changes and extend the Dynamic Model of Situated Cognition to serve as an aid for system designers as they consider how individual and team behaviors emerge and interact with complex technology in a system context.

Introduction

The enormous advantages expected to accompany Network Centric Warfare (NCW) have not yet been realized (Cebrowski & Garstka, 1998). Reliance upon advanced technology has thus far failed to defeat an agile and illusive enemy in the asymmetric warfare waged now in Iraq and Afghanistan. It appears that the post 9/11 War on Terror combat models employed by the Department of Defense (DoD) have not yielded their predicted results, leaving strategists and politicians wondering how to improve them. These models may be inaccurate, incomplete, or flawed. Perhaps part of the reason for the disappointing results of our combat models is their incapability to represent the entirety of an NCW organization, including both the humans and the technological components which comprise any complex system. Failure to address the human side of the equation will result in inaccurate predictions. Such inaccuracy was evident in the first week of Operation Iraqi Freedom (OIF) when the inability of the humans in the system to operate 24-7 was not considered in the initial ground war calculations. The fierce dust storms that arose a few days into the operation provided much needed rest for the U.S. forces. In addition to addressing both humans and technology, a strong model must be dynamic, representing the way in which natural processes occur, mirroring the ebb and flow of information and entities on the battlefield.

In 2003, we introduced the Dynamic Model of Situated Cognition (DMSC) which differs from other models in that it assumes a dynamic process and examines the roles of both humans and technology and the interplay between them. Since its introduction, we have continued to improve the model, presenting it to various groups who have received it favorably. We have incorporated their comments and suggestions, adding to its utility. The model started as a simplistic representation of a single individual's viewpoint but it has now developed to represent the process by which a commander or even a team acquires information needed to assess a situation and make decisions. The model has recently been used by researchers of the DARPA M&D C2 Experiment 7 in their human-in-the-loop simulations, using it to determine how and why events, with both positive and negative outcomes, have occurred. It is currently being used in a series of field experiments at the Naval Postgraduate School to demonstrate how various data elements travel throughout the battle space, arriving in the command and control center, where they inform the commander who makes decisions regarding disposition of troops and resources.

Review of the model circa 2004

The model sprang from a command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) war game conducted at FT Knox in the Army's Unit of Action Mounted Battle Laboratory (UAMBL). It was an attempt to define a common framework with which groups of operations research analysts and human factors engineers could communicate effectively. Situation awareness or "SA" was a term invoked by both groups of researchers but it was clear that the two groups defined the term differently. Human factors researchers described SA as something that resulted from human cognition, (that is, SA resides in the human at all times, with varying levels of accuracy), whereas the operations analysts used the term to describe the number of red forces, for instance, that had been discovered by their technological sensors. To further muddy the waters, the US Army had begun using the term "Situational Understanding" to refer to an advanced level of SA, analogous to Endsley's Levels 2 & 3 SA in the scientific literature (Endsley, 2000). The two groups of researchers attempted to arrive at a shared understanding of events in the scenarios which were being simulated but each failed to appreciate the other perspective's significance and contribution. Hence, the model was created to illustrate the role played by humans and technology, demonstrating that appropriate consideration of *both humans and technology* is necessary to understand the process by which an event unfolds.

As first conceptualized, the DMSC was introduced as a series of six ovals of varying sizes and three lenses (see Figure 1). The three ovals on the left side of the model (1, 2 and 3) represent the technological side of the system while the three ovals on the right (4, 5 and 6) represent the human perceptual and cognitive processes. Oval 1 is ground truth and in the simulated laboratory scenarios where it was first used, contains all the data from enemy, friendly and neutral forces as well as terrain features and the location of all sensors. In the simulation, Oval 2 is always a subset of Oval 1, including only those things that are detected by sensor systems.

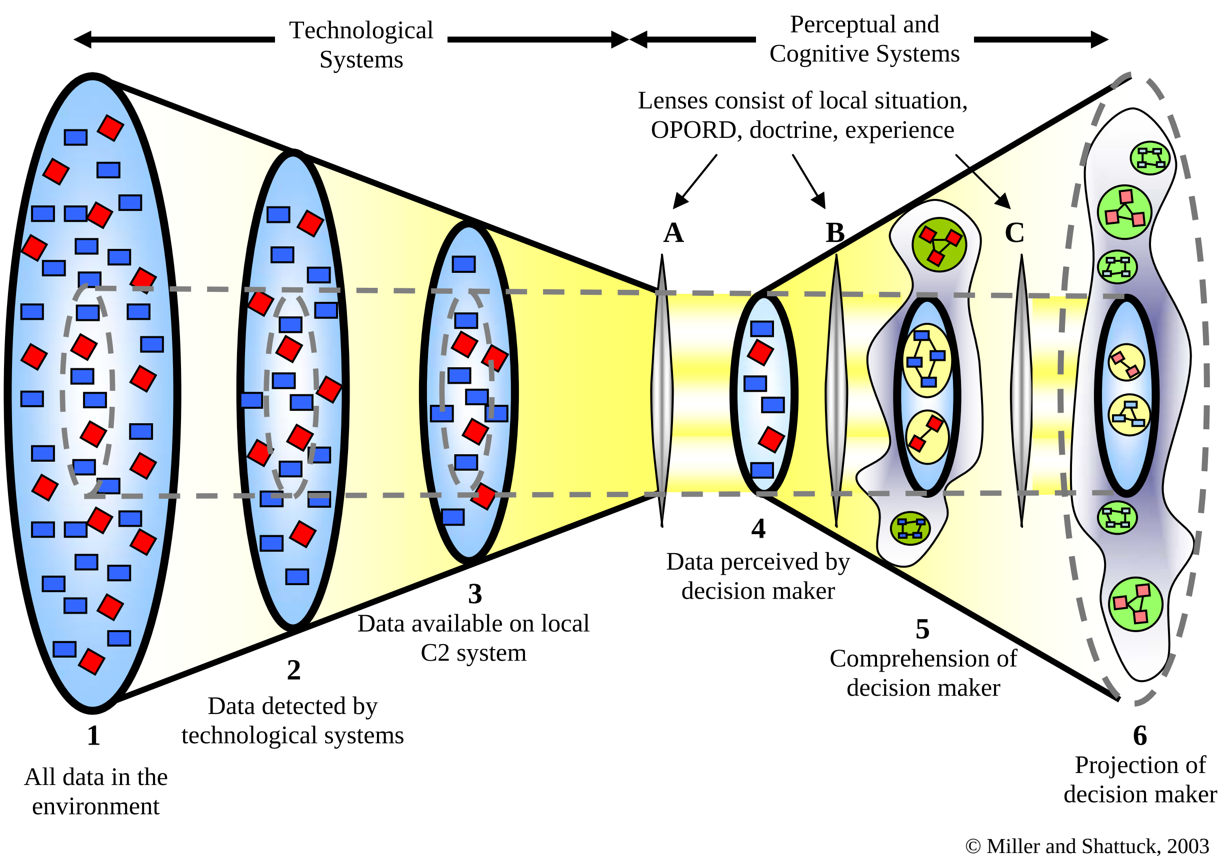

Figure 1. Dynamic Model of Situated Cognition

Oval 3 represents the subset of information that is displayed on the command and control screens of the individual operator. Oval 3 will vary depending on the settings of each screen and may change multiple times over the course of a scenario as an operator makes adjustments to features such as field of view, map resolution or range rings. Ovals 4, 5 and 6 on the right side of the model represent the *perception* of data elements, the *comprehension* of the current situation (sometimes called a mental model) and the individual's *projection* of current events into the future. These three ovals correspond to situational awareness Levels 1, 2, and 3 in the scientific literature (Endsley, 2000). When the model was first introduced as a tool to assist in understanding laboratory simulations of military scenarios, the three lenses (A, B, and C) consisted of only four things: the local situation, the military operational order (OPORD), military doctrine, and the experience of the operator.

There was an acknowledgement that distortions in the lens could result in inaccurate perceptions (Oval 4), comprehensions, (Oval 5), or projections (Oval 6). Such a distortion is illustrated in Figure 2. It was recognized that once inaccurate data were accepted into any stage of the model, this inaccuracy would be propagated throughout the remaining ovals, leading to inaccurate conclusions and potentially faulty decisions.

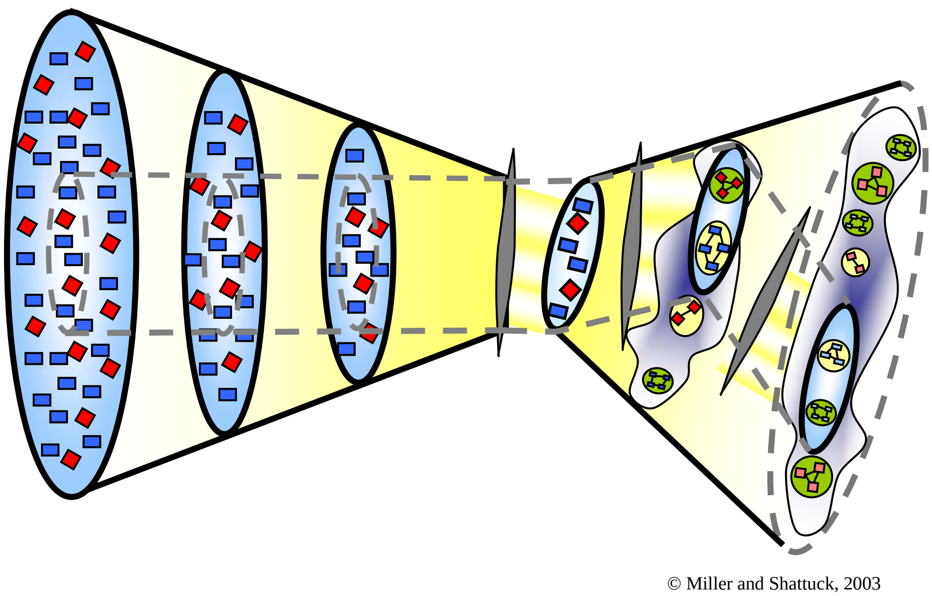

Figure 2. Distortions in the lenses lead to inaccurate perceptions, comprehensions, and projections

Changes to the model since its introduction

In the time since its initial introduction, the DMSC has changed, in many cases expanding to reflect the comments and observations of the audiences and our own observations when we applied it in different venues. The composition of the lenses has changed to include the individual's indwelling traits (e.g., intellect or personality) and temporary states (e.g., fatigue or fear), further emphasizing the dynamic, continuously changing nature of the lenses as well as the ovals.

There have also been changes to the sources of uncertainty in the model with the recognition that Oval 1, ground truth, is completely accurate while it is also constantly being updated. However, at a given point in time, Oval 1 will be identical for any and all individuals involved. Inaccuracies can enter the model at any point after Oval 1 and once inside the model, may propagate throughout it with unexpected or even disastrous outcomes (see the example of the *USS Greeneville* in Miller, Shobe & Shattuck, 2005). Data may also be morphed incorrectly based on erroneous algorithms, also misleading decision makers or giving them a false confidence in the accuracy of the data they are viewing. Spoofing, or active efforts by the enemy to mislead, appears as inaccuracy in Oval 2. For example, the red force has a single tank positioned in friendly territory but has three decoys also positioned nearby. Ground truth would indicate one enemy tank and three decoys. If the decoys are sufficiently realistic and can deceive the sensor systems, Oval 2 would indicate four enemy tanks. This misinformation would continue to propagate throughout the model.

The relationship between accuracy and certainly has also been explored in another expansion to the model (Miller & Shattuck, 2005b). An individual needs to have both a high level of certainty and a high degree of accuracy to have the best possible comprehension and projection (Ovals 5 and 6). In the worst case, an individual would feel certain but would be wrong. Figure 3 shows a matrix with the relationship between accuracy and certainty, also showing a representation of Oval 5 with each of the four conditions. In the matrix, a high level of accuracy (condition B or D) is required for Oval 5 and 6 to be accurate, whereas conditions A and C indicate inaccuracy.

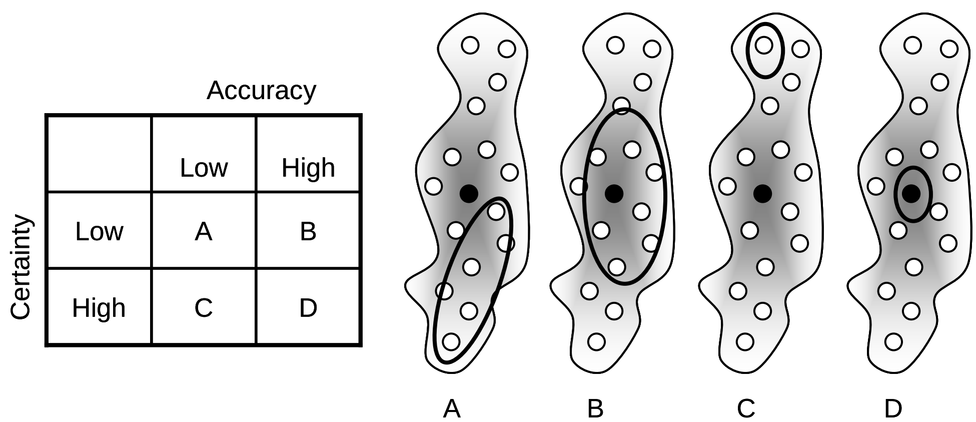

Figure 3. Matrix of accuracy and certainty as it applies to the model

Feedback loops have been introduced to better illustrate the dynamic nature of the model. These feedback loops are seen in Figures 4 and 5. In Figure 4, they feed from Ovals 5 and 6 to the preceding ovals (Ovals 1 through 4). To some extent, these feedback loops represent decisions made by individuals. Examples of such decisions may include repositioning their forces, changing the sensor coverage, adjusting the C2 screens, or shifting their focus from one portion of the battlefield to another. These feedback loops or decisions emanate from a human operator whose comprehension (Oval 5) or projection into the future (Oval 6) compels them to take action. These feedback loops happen continuously and can be observed directly by watching the operator’s actions and by listening to the communications with other individuals.

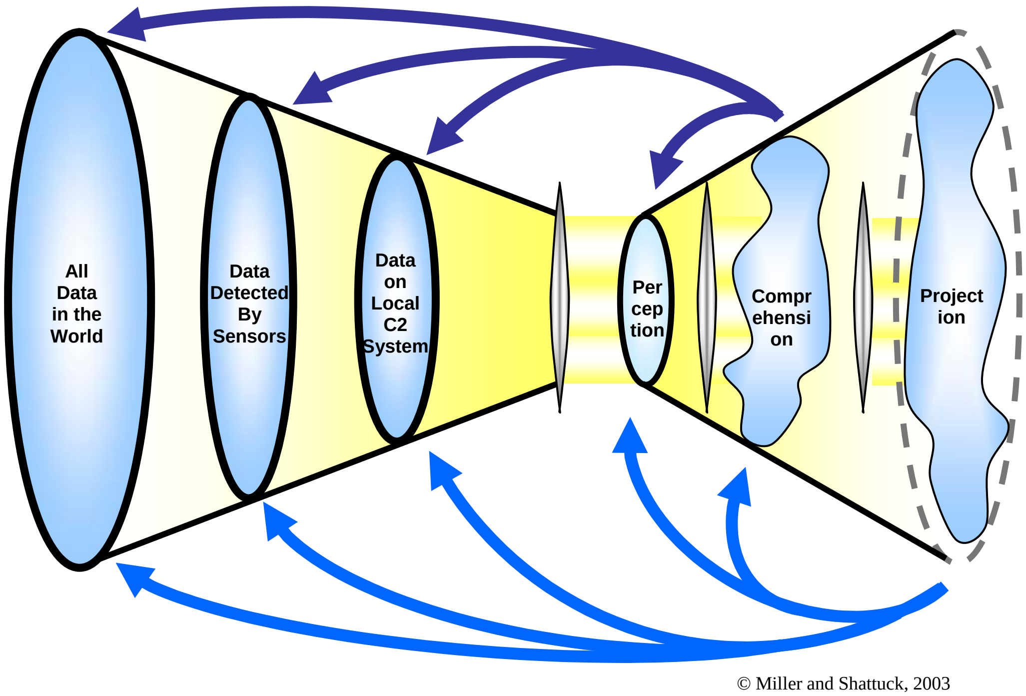

Figure 4. Feedback Loops in the Model from Ovals 5 and 6 to Ovals 1 through 4

The feedback loops seen in Figure 5 represent adjustments or accommodations to the lenses. Comprehensions and projections serve to alter the lenses.

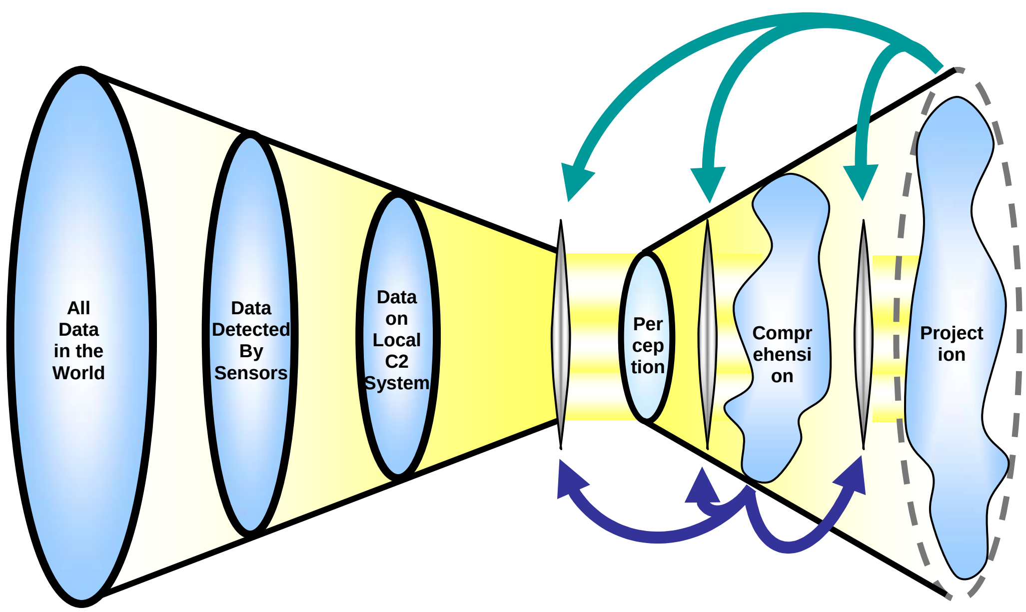

Figure 5. Feedback loops from Ovals 5 and 6 to the lenses.

We have also explored how the DMSC applies to teams. When extending the model from individuals to teams, Ovals 1 and 2 are the same for all team members but Ovals 3 through 6 differ among the individual members of the team. Figure 6 illustrates this idea of a common Oval 1 and 2 and diverging Ovals 3 through 6. This finding assumes that information in Ovals 1 and 2 is shared equally by all team members. In a situation involving diverse coalition partners, it is possible to imagine a scenario in which Oval 1 is identical for all members, but intelligence information is not shared equally among all partners. In that case, Oval 2 would show divergence between coalition partners.

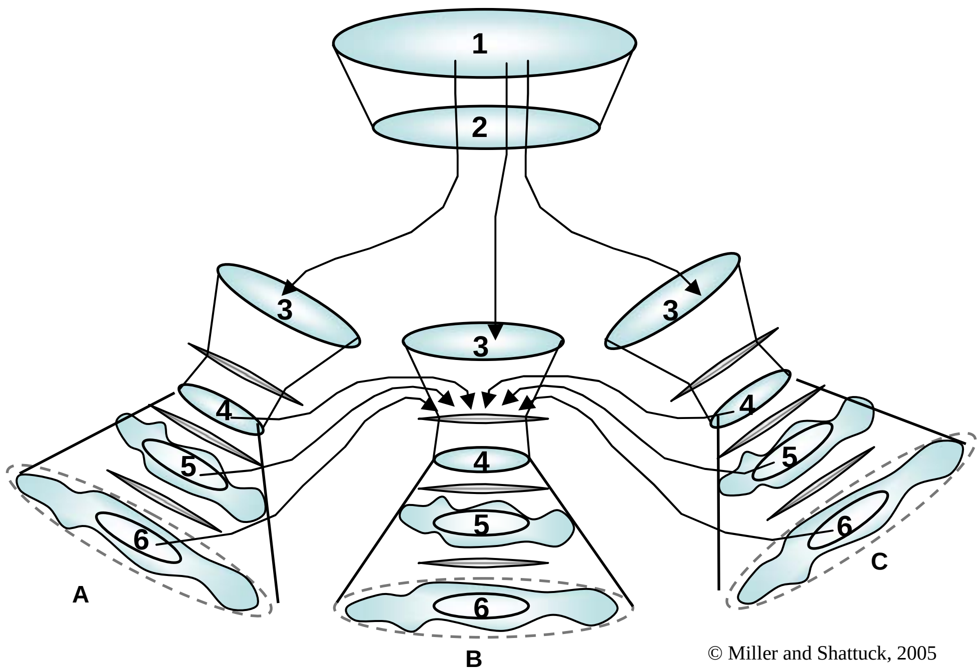

Figure 6. The DMSC applied to teams

Figure 7 represents how information received from other humans is assimilated into the human side of the DMSC. The information may be a perception ("I just spotted enemy combatants moving through the northern corridor"), it may be a comprehension ("I just saw a bunch of civilians running toward the embassy and the patrol in that area is reporting a lot of shouting. I think we have an angry mob on our hands"), or it may be a projection ("I saw men digging at the side of this road. I believe they may be setting up an ambush for our convoy"). The human information is first filtered through Lens A and only then may enter Ovals 4 through 6. Depending on what is known about the human who is supplying the data, the input may be accepted ("Yeah, Joe always know what he's talking about. I'll do exactly as he requests.") or it may be rejected ("Dave is always jumping to the wrong conclusions—and it usually gets us in trouble."). The level of trust in the human reporting the data is calibrated and enters the model accordingly.

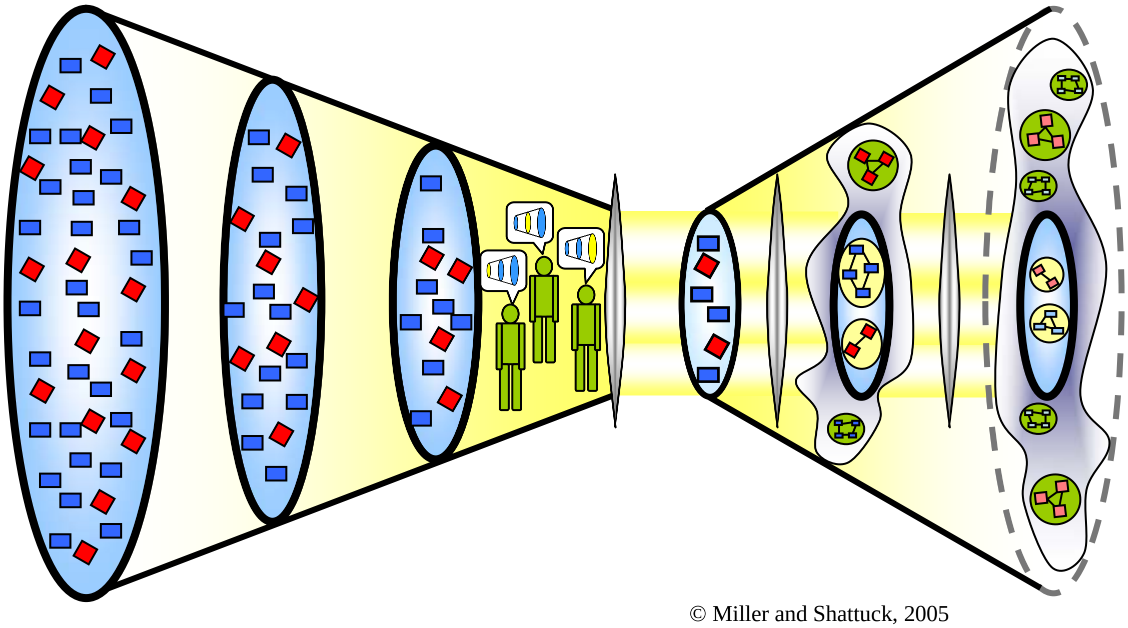

Figure 7. Input from humans enters the DMSC at Lens A

Applications of the model

Since its introduction in a laboratory-based military simulation, the model has been used by the authors in a variety of military applications. In the field of error analysis, it has been applied to the USS Stark incident (Miller & Shattuck, 2004), and to the mishap involving collision of the *USS Greeneville*, a US Navy Submarine, and a Japanese fishing vessel, the *Ehime Maru* (Miller, Shobe & Shattuck, 2005). In the *USS Greeneville* example, the information available to the crew members was modeled using the DMSC providing insight into the decisions made by the captain of the submarine. In another submarine mishap, the *USS Hartford* ran aground off the coast of Italy, causing millions of dollars in damage (Miller, Shobe & Shattuck, 2005). In January 2005, the nuclear-powered *USS San Francisco* collided with an uncharted undersea mountain, providing yet another example of a mishap involving a US Navy submarine whose crew was unaware of inaccuracies of data in Ovals 2 and 3, leading to erroneous comprehensions (Oval 5) and projections (Oval 6).

The model has also been used to assess how information flows among members of a team in a complex organization (Shattuck & Miller, 2005). The authors build on Naturalistic Decision Making (NDM) theories and use an actual military accident to trace the flow of information through the model, highlighting what decisions were made, how the decisions were made, and how the technological and human aspects of the system conspired to cause the accident. Thus, the model couples NDM theory with the DMSC model to provide a more robust insight into total system performance.

Lastly, we used have the model to provide developers of network centric operations and warfare systems (Miller & Shattuck, 2005b) with user-centered design principles. In that paper, we described Network Centric Warfare and introduced the Dynamic Model of Situated Cognition to serve as a design aid for developers who need to consider how individual and team behaviors emerge and interact with complex technology in a system context. Understanding how the components of these complex systems are integrated and designing robust and effective networks is vital if NCW is to succeed. The DMSC can be used to optimize total human system performance by forecasting excessively high workloads for an individual, potentially shifting tasks to team members who have a lower workload.

Conclusions

The changes and enhancements to the Dynamic Model of Situated Cognition make it a robust tool to assist in post hoc event analysis and predictive modeling efforts of complex systems such as network centric warfare. It has shown its usefulness in a variety of venues, both laboratory and field-based, as well as providing a predictive and retrospective tool for examining system strengths and weaknesses. It has been adopted by professionals in the field of combat modeling and continues to aid systems designers. Failure to adopt a dynamic and comprehensive model such as the DMSC may lead to inaccurate assessment of events or poorly designed systems. As seen with previous attempts to predict combat outcomes, inaccuracies can lead to disappointing or even disastrous consequences on the battlefield.

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