A Process Tracing Approach to the Investigation of Situated Cognition

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Technologists and human factors practitioners tend to approach the measurement of situation awareness from different perspectives. Technologists compare the difference between the data available in the environment with what has been detected by the sensors built into a system. Human factors practitioners focus on perception and cognition to the exclusion of the technological parts of the system. The authors propose a Dynamic Model of Situated Cognition and use it as a framework for analyzing both the technological and human aspects of a complex system. They employ a process tracing method in the analysis of a high fidelity military command and control (C2) simulation. Their results indicate that the model and the process tracing method are effective ways in which to investigate the development of situated cognition in complex systems. In addition, their results have important implications for designers of software, hardware, and training systems.

INTRODUCTION

Complex cognitive systems couple humans with machines for the purpose of accomplishing a specific goal. It is often the case that human factors practitioners focus their attention on the humans in the system while designers and engineers tend to focus on the technological aspects of the system. Human factors practitioners tend not to study or evaluate the technological aspects of a system because they may lack the necessary access or expertise. Systems analysts and engineers may try to reduce human behavior to a series of stochastic equations which may give the appearance of accuracy and precision but ultimately will miss the complexity, creativity, and variability of perception and cognition.

While systems analysts and engineers appear to have made progress in describing and evaluating the activity within the technological aspects of a complex system, human factors practitioners continue to wrestle with evaluating human cognitive processing in such systems. Further, many practitioners evaluate cognitive activities as if they were states rather than processes. They talk about cognition at a particular point in time in terms of percentages, comparing what was reported by the decision maker to what should have been known.

An alternative view, and one which is held by the authors of this paper, is that it is more appropriate to consider and evaluate cognitive activities as a process. For example, how much situation awareness (SA) a decision maker has at any point is important, but even more important is how the SA evolved over time, as well as when and how the SA deviated from ground truth. In this paper, the authors provide a new model - a Dynamic Model of Situated Cognition - that integrates human cognition with the technological systems that provide data and information to the decision maker.

The authors also present a process tracing approach for analyzing cognitive processes across the human – machine system. The process tracing method combines multiple measures that permit researchers to chronicle the changes in cognitive activities as events unfold, to highlight key events, and to identify points at which the understanding of decision makers deviates from ground truth and why those deviations occur. The authors applied both the Dynamic Model of Situated Cognition and the process tracing method to guide the investigation of human – system performance during a recent military command and control (C2) high fidelity simulation.

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In recent years, human factors practitioners have developed a variety of methods to assess human cognition and, in particular, situation awareness (see Gawron, 2000). The methods vary in their degree of subjectivity, rigor, and intrusiveness. One method simply asks decision makers to rate their situation awareness by referring to a behaviorally anchored scale. Other methods attempt to compare the data available in the environment with the decision maker's perception, comprehension, and projection. These comparisons will result in a more accurate assessment of a decision maker's mental model of the battlefield than the methods proposed by technologists. However, they are still problematic. One typical method, Situation Awareness Global Assessment Technique (SAGAT), involves stopping the flow of activity - to the dismay of the decision makers - at multiple points in time and asking them a series of questions. The questions normally are linked to the various levels of situation awareness (perception, comprehension, projection).

There are several sources of subjectivity in SAGAT. Developing the questions requires a keen understanding of both the command and control environment and the levels of situation awareness. Several questions must be developed for each level of situation awareness in order to conduct statistical analysis on the responses. The questions posed for each point in time must be different to prevent decision makers from artificially directing their attention in anticipation of the probe. Yet, the different questions within each level must be equivalent in difficulty or the results will be invalid. Scoring can also be challenging, whether the questions are verbal (i.e., short answer or fill-in-the blank) or graphical (i.e., placing unit symbols on a map). The researchers who score the questions must have access to the data in the environment to determine the correct answers at the time of the probe. Also, the scoring of the researchers must be calibrated to ensure their subjective judgments are similar.

SAGAT and related methods of analysis are heavily dependent upon subject matter experts (SMEs). Among the roles filled by SMEs are the following. SMEs:

- are intimately familiar with the domain being studied.
- serve as a guide for researchers into the domain of practice.
- can facilitate access to data.
- are able to formulate appropriate SAGAT questions.
- can assist researchers in understanding the behavioral responses of the study participants within the context of that domain.

When used by themselves to assess human awareness and cognition in context, methods such as SAGAT still miss the mark. The most rigorous will compare the data available in the environment with the perception, comprehension, and projection. However, they do not account for the technological processes that contribute to human cognition. A possible reason for this shortcoming is that the models upon which these methods are based tend to be parochial. Methods that measure technological awareness are based on models that emphasize the software and hardware portions of the system. Methods that measure perceptual/cognitive processes are based on models that emphasize the human portions of the system. The model described below considers both the technological and human components of the system and, therefore, serves as a more viable representation from which to develop methods for assessing awareness and situated cognition.

A DYNAMIC MODEL OF SITUTATED COGNITION

Figure 1 depicts the Dynamic Model of Situated Cognition. The description that follows uses a military C2 context to describe the model, but the model is equally relevant in any domain in which humans and machines interact with one another to achieve a desired end state. Oval 1 contains all data available in the environment. The blue rectangles and red diamonds represent friendly and enemy data elements. (For simplicity, the figure does not include data elements that represent other physical characteristics of the environment such as non-combatants, terrain, and weather.) Oval 2 contains only those data in Oval 1 that are able to be detected by the sensors in the system. Oval 2 is smaller than Oval 1 because in most systems, sensors are insufficient, in quantity or

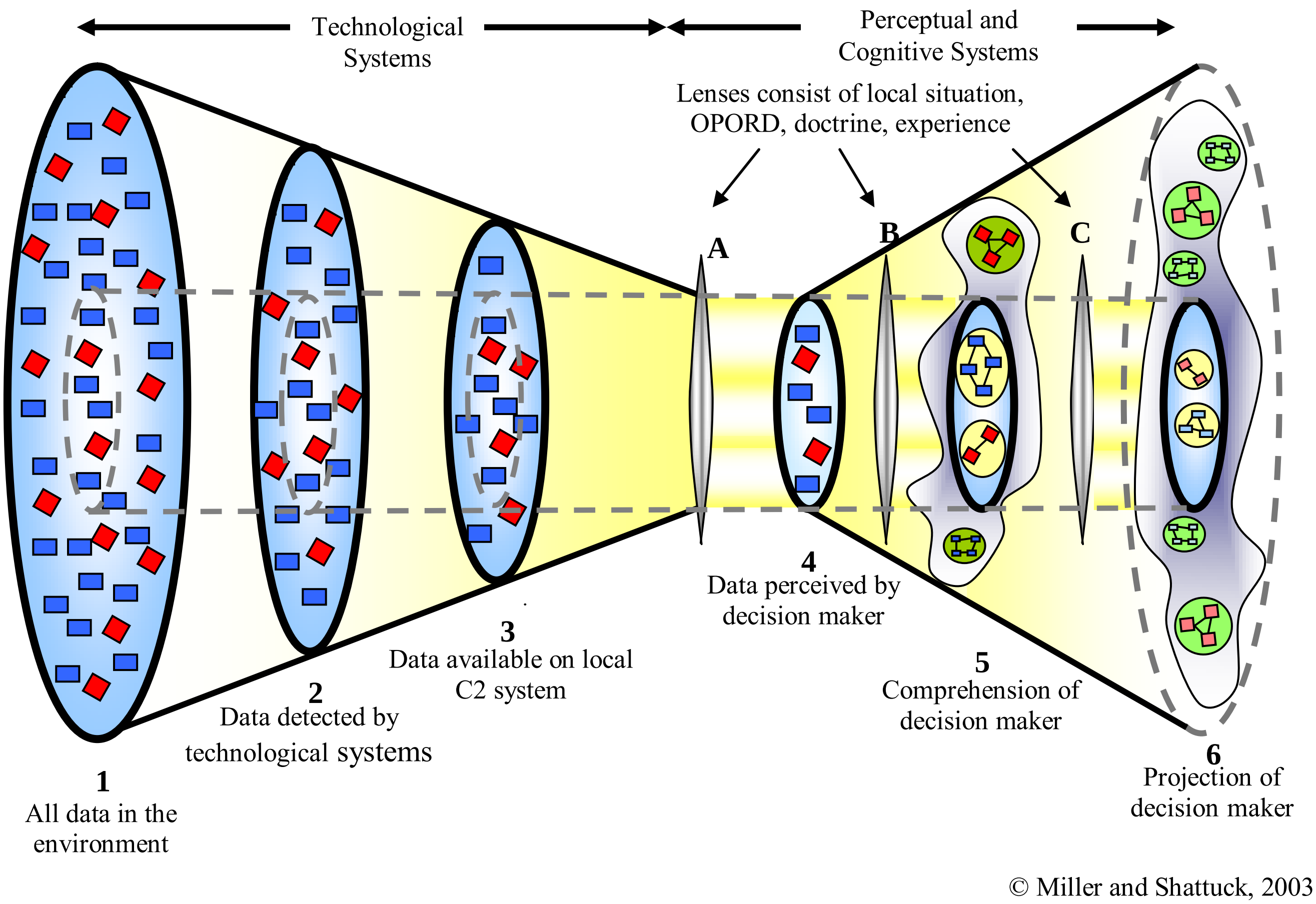

Figure 1. A Dynamic Model of Situated Cognition.

capability, to detect all data in the environment. In highly dynamic environments such as military C2, decision makers often are unaware of which portions of the system are 'covered' by sensors and which are not.

Oval 3 depicts those data that are presented to the decision maker, often on a visual display, but sometimes using auditory and haptic modalities. Although it may be possible for all data in Oval 2 to be presented, decision makers tailor their displays to reduce clutter. The display is, in essence, a keyhole through which the decision maker peers to gain access to the vast amount of data stored in the system. Ovals 1, 2, and 3 represent the technological part of the human-machine system.

Three distinct lenses are depicted in Figure 1. Although the informational elements are the same in each lens, the placement of the lenses in the model suggests that different functions are performed by each lens. As is the case with the human visual lens, perceptual distortions may result from asymmetries and flaws in the refining process.

There are at least four classes of information embedded in the lenses that influence how decision makers perceive, comprehend and make predictions about activities on the battlefield. The *local situation* influences the data to which a decision maker will attend. The *operation order (OPORD)* represents the specific plan a unit is attempting to execute. *Doctrine* represents broad guidelines to which decision makers may refer if the OPORD is underspecified. *Experience* refers to previous activities in which a decision maker has engaged that are similar to the current situation. Decision makers rely (either consciously or unconsciously) on these previous experiences to influence how they direct their attention. Data useful in previous situations may prove useful in the current situation. Together, these four classes of information influence what is perceived by the decision maker.

Lens A, the lens between Ovals 3 and 4, directs attention to selected incoming stimuli. Lens A will focus or direct attention to a subset of the data available in Oval 3. These data will be perceived in Oval 4 by the decision maker. Alternatively, data which would not normally be focused on by the decision maker but that are presented in a highly salient manner (e.g., bright or loud) may intrude upon the decision maker's cognitive processes and also will be perceived.

The data perceived by the decision maker are interpreted, organized, and integrated based on the contents of lens B, resulting in comprehension (Oval 5). The lens between Ovals 5 and 6, Lens C, guides the process of extrapolating current information into predictions about the future. Ovals 4, 5, & 6 and lenses A, B, and C comprise the human part of the system.

In general, it can be thought that data flow from left to right. Although not depicted in Figure 1, there are feedback loops that flow from right to left. Output from Ovals 4, 5, and 6 can influence the contents of preceding ovals. For example, if a decision maker perceives that an enemy vehicle has been detected (Oval 4) and comprehends it is a threat (Oval 5), then a decision to deploy a sensor could change what is detected in the environment (Oval 2), which could lead to changes in Ovals 3 – 6, as well as the lenses. Output from Oval 5 (comprehension) and Oval 6 (projection) can also affect the lenses. For example, understanding the outcome of a battle in which a particular maneuver was used could change the contents and the contour of the lens because the event has added to the experience base of the decision maker.

C2 SIMULATION

Participants

Participants in the simulation consisted of four male active duty Army soldiers who occupied a high fidelity C2 mock-up. Three were officers and one was a non-commissioned officer. The simulation also included active duty and retired Army officers who role played the higher headquarters and the enemy.

Equipment

Each participant had his own workstation in the mock-up, which consisted of two computer monitors and a communications console. The mock-up also had a large screen centrally located, which any of the participants could use to display what was on either of their workstation monitors.

Procedures

The participants were given two weeks of training prior to the actual data collection. During these two weeks, the participants became acquainted with one another, were trained on the C2 software, determined the roles they would play, and developed their tactics, techniques, and procedures.

There were six 90-minute sessions that were conducted over four days. Aside from a software constraint that limited the size of the maneuver area, the simulation permitted friendly and enemy participants to exercise free play. Each 90-minute session was preceded by a period during which the participants received their mission from higher headquarters, analyzed their intelligence, developed a plan, and emplaced friendly units in their initial positions.

The authors used the Dynamic Model of Situated Cognition as the basis for tracing the flow of data and the development of awareness over time. This process tracing method relied on multiple data sources to construct a complete and accurate story of how the events unfolded (see Woods, 1993) across both the technological and the perceptual/cognitive components of the C2 system. Sources of data included:

- Videotapes of the eight computer terminals (two per participant).
- Voice transcripts.
- Database queries.
- Heart rate variability monitors (worn by each participant).
- Geographical Recall and Analysis of Data in the Environment (GRADE). At selected times through each session, participants were asked to sketch on a map what was happening on the portion of the battlefield on which they were focused and to predict what they thought would be happening thirty minutes into the future.

- Situation Awareness Rating Technique (SART). Participants rated their awareness along three dimensions: demand, supply, and understanding.
- Retrospective interviews.

Results of the study support using the Dynamic Model of Situated Cognition as a framework for analysis of the events in the C2 simulation. The authors were able to construct detailed chronologies by combining the various data sources. These chronologies describe the technological awareness (the data that were available in the environment, detected by sensors, and displayed on the workstation screens) and the human awareness (perception, comprehension, and projection). The chronologies demonstrate the influences the lenses had in directing attention and in interpreting the data. The chronologies also showed how feedback loops influenced the lenses as well as shaped the content of the ovals in the model.

In addition to the detailed chronologies that resulted from adopting the Dynamic Model of Situated Cognition as an analytical perspective, many other important findings emerged . Some of these findings include the following.

- *Collaboration*. The C2 system provided many ways in which the participants could collaborate. In spite of all the tools, participants often were unaware of what the other participants were doing.
- *Data Overload*. The C2 software can easily overload decision makers with data. Designers understood this and provided users the ability to tailor their workstations in a manner that reduced screen clutter. During one 90-minute session 9600 alerts were generated by the software. However, the vast majority of the alerts never were displayed because the participants had configured their workstations to filter them out. As a result, in some cases, important data detected by sensors were never viewed by the participants.
- *Attention Shifting*. An analysis of a 13 minute period of a session revealed that one participant shifted his attention 26 times for an average of once every 30 seconds. During a 16 minute period of another session the same participant shifted his attention 60 times for an average of once every 16 seconds. The frequency of attention shifts suggests that the level of processing performed by the participant was relatively shallow.
- *Redundant/Repetitive Activities*. Participants were observed to perform the same behavior multiple times. Participants also engaged in redundant behaviors, duplicating the efforts of other participants. These behaviors suggest the possibility that there may be some issues of display design, workload distribution, and coordination that need to be resolved in order to improve performance within the C2 system.

The study conducted by the authors demonstrates the utility of using the Dynamic Model of Situated Cognition as a framework for examining the development of cognition in context. Employing a process tracing approach to the analysis of complex systems facilitates the linkage of technological and human awareness, which, heretofore have been treated separately. By collecting data at each stage in the model, a detailed chronology of events is created which, when analyzed, provides invaluable insights into how cognition evolved. More importantly, this approach facilitates the understanding of when, where, and why the situated cognition of the decision makers differs from reality. These findings will lead to recommendations on the design of software, hardware, and training systems that will truly benefit future users of complex cognitive systems.

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