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A Process Model of Situated Cognition in Military Command and Control

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Abstract

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 while designers tend to focus on the technological aspects of the system. The point of intersection between humans and technology has become a boundary with respect to evaluation. In addition, human factors practitioners have often studied the result of cognitive activity (e.g., a decision) rather than the processes that lead to the outcome. In this paper, the authors present a general model that combines the technological aspects of a system with the perceptual and cognitive processes of the humans embedded in the system. The model emphasizes that such systems are both process oriented and dynamic. The authors describe a process tracing methodology that can be used to investigate the flow of data and information through both the technological and human components of the system. The attack on the *USS Stark* is used as a case study to illustrate the model and the process tracing methodology. The results of the process tracing analysis have implications for the design of complex systems and the training received by those who operate such 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 system 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. For example, researchers who assess such cognitive processes as decision making and situation awareness (SA) in military command and control (C2) systems often rely on self-report measures, which can be suspect. Many techniques to evaluate SA involve disrupting the flow of activity, to the dismay of the decision makers. Several measures rely on subject matter experts to evaluate the responses of decision makers. Further, many researchers 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 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 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.

A Dynamic Model of Situated Cognition

Typical models of cognitive processing begin with the human receiving sensory input. These models also include modules which represent different types of memory, encoding, response selection and execution, and attention (Wickens, et al, 2004). Proponents of such models use controlled laboratory studies to study selected components of their model. While it is absolutely vital that such work be conducted, many of these studies use college students as participants and involve simple tasks for which no experience is necessary. Klein, et al. (2003) observed that the cognitive activities used by people in operational settings are much different than those studied in the laboratory. He has used the term ‘macrocognition’ to describe the types of cognitive activities that experienced people use in contexts with which they are familiar. He includes the following as macrocognitive activities: decision making, uncertainty management, mental simulation, sensemaking, situation awareness, attention management, problem detection, planning, and option generation. Suchman (1987) stated that “purposeful actions are inevitably *situated actions*.” She described situated actions as those “taken in the context of particular, concrete circumstances.”

The research cited above suggests that a model which integrates human and machine components need not be overly specified. Such a model is intended to describe what happens in operational environments with experienced people who are engaged in goal directed behavior rather than narrowly focused activity in a laboratory. Thus, their actions and their cognitive processes are situated in a particular context. That context is continually evolving (or dynamic) and, therefore, is continually influencing the cognitive activities of the humans in the system. In operational environments, it is often the technological portion of the system that triggers the activity of the human portion of the system.

The Dynamic Model of Situated Cognition (Figure 1) emerged as an attempt to illustrate the relationship between technological systems and human perceptual and cognitive processes. The model is described using the framework of a military C2 system. The large oval on the left side of the figure (Oval 1) depicts all data that exist in the environment. The blue rectangles and red diamonds represent individual data elements for friendly and enemy entities. While there are other types of data that would normally be present in the environment (e.g., noncombatants, weather, terrain, etc.) they are excluded from the figure for simplification.

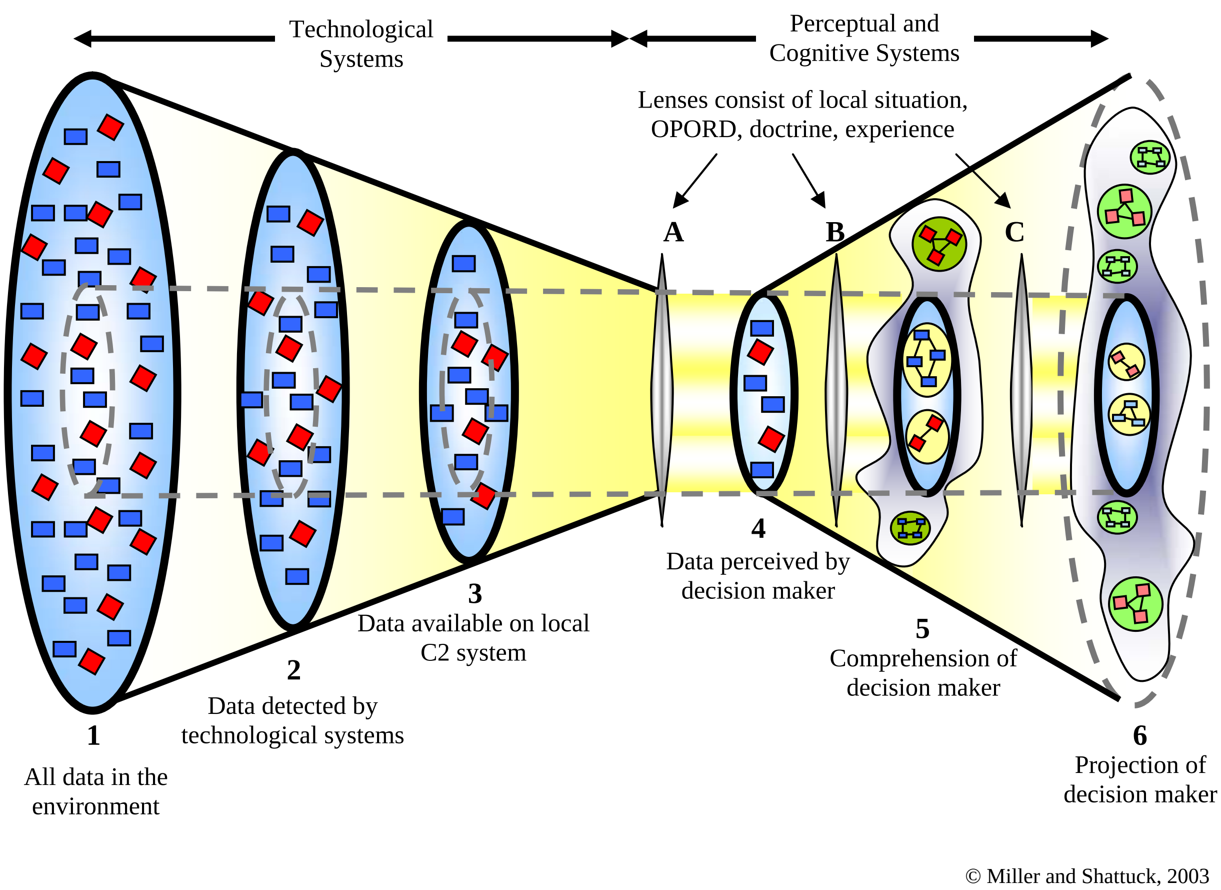

Figure 1. Dynamic Model of Situated Cognition.

The next oval (Oval 2) illustrates those data elements detected by the technological systems. Note that this oval is a subset of the first oval. However, it is not necessarily apparent what portions of the environment are being detected and what items remain undetected. Oval 2 is a subset of Oval 1 for a variety of reasons.

- There may not be enough sensors available to cover the environment.
- The technology may not be sensitive enough to detect certain classes of data
- The technology may not have the specificity required to identify certain classes of data.
- Enemy activity may be designed to deceive friendly sensors (spoofing).
- Sensors embedded in friendly forces may malfunction.

Oval 3 depicts the data displayed on the local decision maker's workstation. These data are a subset of what is detected by the available technological systems. In current and planned C2 systems decision makers are able to tailor their displays to suit their individual preferences. The capability to tailor what is displayed is one way designers may attempt to assist decision makers in coping with data overload. The drawback in this approach is that it is not obvious to the decision maker which data have been excluded by the individual's preferences. In addition, individuals may have different preferences selected, resulting in divergent and possibly confusing views of the environment.

The three ovals discussed thus far represent the technological portion of the model. Data displayed on the local C2 workstation are not just a function of how the decision maker has configured the screen; the configuration is also based on how the system designers have constructed the tools employed by the decision maker to cope with data overload. What is displayed on the screen may or may not represent the most important data detected by the sensor array. And since the decision maker's knowledge of the environment is directly related to what is displayed on the workstation, that knowledge may or may not be an accurate reflection of the actual activity in the environment. Further, the sensor array is only a sample or a subset of all the data in the environment. That which is sensed is incomplete and the awareness constructed from it will be incomplete. Incomplete does not necessarily mean inaccurate. If the right data are sampled, the awareness constructed will not be complete but could still be accurate. However, since decision makers usually do not know where the 'holes' are in the friendly and enemy sensor coverage, they are ignorant of how their mental model differs from the actual activities and events of the environment.

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. Lens A, the lens between Ovals 3 and 4, directs attention to selected incoming stimuli. These stimuli are, in most cases, either visual or auditory. Between Ovals 4 and 5 is Lens B, which influences how data are organized into information. The lens between Ovals 5 and 6, Lens C, guides the process of extrapolating current information into predictions about the future.

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.

The oval to the immediate right of the first lens (Oval 4) represents all the data actually perceived by the decision maker. The small gray dashed ovals embedded in Ovals 1, 2, and 3 portray the idea that data perceived in Oval 4 are only a portion of data available in previous ovals. Perceived data are a small subset of the data available in the environment, the sensor array, the configuration of the local C2 display, and are based on the characteristics of the lens. The data perceived may be a result of active or passive processes. Active processes refer to data requested or 'pulled' by the decision maker and, therefore, a result of goal-directed behavior. Passive processes refer to data provided or 'pushed' to the decision maker without a request and, therefore, may not be relevant to goal accomplishment.

Perceived data are of little value to the decision maker until they are processed. The term comprehension is used generically in this paper to refer to cognitive processes such as fusion, integration, analysis, explanation, interpretation, and pattern recognition. Comprehension is illustrated in Oval 5. The same lens components (e.g., local situation, OPORD, doctrine, and experience) that directed attention and led to perception also influence comprehension. The friendly and enemy icons in this oval have been linked and reorganized, suggesting that they have been processed. This oval represents the comprehension of the data elements that were perceived. The oval is embedded in an amorphous shape. This shape suggests that there are other possible ways the data could be linked and reorganized that would lead to alternative mental representations of the data. The  figure near the bottom of the amorphous shape represents one possible organizational structure of the friendly data. Note that the configuration of friendly icons (e.g., ) within the oval is not necessarily correct. The  figure may actually be the more veridical comprehension with respect to the environment depicted in Oval 1. The same situation may be true with respect to the configuration of the enemy icons inside and outside Oval 5.

The final oval (Oval 6) represents the projection or prediction of the decision maker. This prediction is based solely on what has been comprehended by the decision maker (Oval 5). Alternate views of the battlefield (e.g., ) within the amorphous shape but outside of Oval 5 do not contribute to or influence the prediction of the decision maker. As an example, note that the comprehension of the enemy in Oval 5 (e.g., ) has been transformed and is shown as  in Oval 6. Some of the attributes of the enemy that are transformed may be location, capabilities, and intentions. Other comprehension elements (e.g., friendly forces, weather, terrain, etc.) are transformed according to their own set of criteria. The transformation from comprehension to prediction is also influenced by the same lens effect that influenced perception and comprehension. Note that the amorphous shape that surrounds Oval 6 is larger than that which surrounds Oval 5 and contains even more alternatives. This representation depicts the idea that there is much greater uncertainty associated with prediction. Thus, what is actually predicted by the decision maker is only one possible view of the future.

The Dynamic Model of Situated Cognition combines the technological portions of a system with the perceptual and cognitive components of human cognitive processing. An element that is not included in the Figure 1 (again, for the sake of simplicity) is a feedback loop or some indication that situated cognition is iterative and dynamic. For example, decision makers continuously interact with their environment, which updates the lenses, thereby altering perception, comprehension, and projection. Additionally, the sensor coverage and communications network are dynamic; the sensor coverage is shifting constantly as sensors move or fly about the environment, resulting in changes to coverage. And every time a decision maker modifies the local workstation, perception will be affected. Thus, situated cognition is not a state that is achieved but a dynamic, ongoing process. Having described the Dynamic Model of Situated Cognition, the next task is to describe a methodology that be used to trace the flow of activity through the model.

Applying Process Tracing to the Assessment of Human - System Performance (HSP)

Technologists and human factors practitioners tend to approach the assessment of human - system performance from different perspectives. Technologists want to compare the difference between the data available in the environment (Oval 1) with what the sensor array has detected (Oval 2). At best, this could be described as ‘technological performance’ but it is not human – system performance. Even a comparison between the data available in the environment (Oval 1) and what is displayed on the decision maker’s workstation (Oval 3) misses the mark. It is tempting for technologists to make these comparisons because, the contents of Ovals 1, 2, and 3 can be measured with precision - at least, this is the case in simulations. However, such comparisons lead to an inaccurate assessment of a decision maker’s situated cognition.

In recent years, human factors practitioners have developed a variety of methods to assess situated cognition and situation awareness (see Gawron, 2000). The methods vary in their degree of subjectivity, rigor, and intrusiveness. Some methods attempt to compare the data available in the environment (Oval 1) with the decision maker’s perception (Oval 4), comprehension (Oval 5), and projection (Oval 6). These comparisons can result in a more accurate assessment of a decision maker’s mental model of the environment than the methods proposed by technologists. However, they are still problematic. They do not describe *how* the decision maker’s understanding evolved. They do not account for the technological processes (Ovals 2 and 3) that contribute to situated cognition. Rather than adapting either a technological or a perceptual/cognitive approach to assessing cognition, what is needed is a human – system performance (HSP) approach. Process tracing provides such a comprehensive approach to assessing HSP, as well as situated cognition.

Woods (1993) describes process tracing as follows. “The goal in these methods is to map out how the incident unfolded including available cues, those cues actually noted by participants, and participants’ interpretation in both the immediate and in the larger institutional and professional contexts. This is called process tracing or protocol analysis method because it focuses on how a given outcome came about.” In addition, he states, “The specific techniques within this family are all oriented towards *externalizing internal processes or producing external signs that support inferences about internal workings*.”

Process tracing involves using multiple data collection methods throughout the human – machine system (Ovals 1 through 6). These data collection methods should be as continuous as possible. Admittedly, this approach is easier to implement during simulations than during free-play field exercises or actual operational settings. However, with recent improvements in data collection techniques and monitoring devices, it is becoming easier to collect continuous data even in operational settings.

Researchers need access to all data in the environment (Oval 1). In simulations, this can be done in real time; in operational settings this can be done after the fact. Researchers also need access to sensor data (Oval 2). These data include where the sensors are located, their operating characteristics (i.e., sensor type, range, etc.), and the data they are collecting. The data detected by the sensor array place an upper limit on human cognition. A decision maker's knowledge of the environment can be no better than what has been detected by the sensors. Investigators should know how the decision makers' local workstations are configured (Oval 3). Further, they need to understand why the decision makers configured the workstations in that way and know what data are (and are not) available to the decision makers because of those configurations. Again, Oval 3 represents a further constraint on human cognition. At any given point in time understanding can be no better than the data they are able to access.

Data collection in the technological portion of the system (Ovals 1 through 3) involves closely monitoring activities as they unfold and harvesting data from the system after the fact. Researchers can greatly improve the quality of data they will harvest if they work with designers and engineers before the data collection event to ensure that the appropriate activities are recorded and in the correct format and that timing devices are synchronized. Data collection during the perceptual and cognitive portion of the system (Ovals 4 through 6) involves monitoring and measuring the behaviors of the decision makers with as little intrusion as possible.

Researchers must determine the contents of each decision maker's lens. This can be done with interviews before and after the activity being investigated. Eye tracking technology can be used to help determine where decision makers were focusing their attention. Physiological monitoring can identify changes in stress levels of the decision makers. Voice and text transcripts can be used to determine how data were integrated into comprehension and how comprehension led to projections about the future. Activities such as asking decision makers to briefly sketch the most important aspects of the environment they are monitoring can be done quickly with minimal disruption but will provide rich insight into the focus of attention and other thought processes of the decision makers.

These data collection methods, if used to methodically trace the flow of data through the technological and human portions of a system will not only describe how the decision makers came to understand what was happening in their environment but how that understanding went awry (if it differed from what actually happened). These methods are consistent with Woods' view of process tracing: "Process-tracing techniques primarily use data from verbal reports or from records of problem-solver behavior to build protocols that describe the sequence of information flow and knowledge activation" (Woods, 1993). Results of this process tracing method are also useful for informing designers where problems exist in the technological portion of the system. The next section illustrates the utility of the Dynamic Model of Situated Cognition by applying it to the attack on the *USS Stark*. In retrospect, the flow of data is traced through the technological and human components of the Combat Information Center (CIC). This case study not only describes what the crewmembers knew but also how the technology prevented them from knowing any more.

Application of the Dynamic Model of Situated Cognition to the *USS Stark* incident

On the evening of May 17, 1987, the *USS Stark* was patrolling international waters in the Persian Gulf off the coast of Bahrain and Saudi Arabia. On station for nearly two months, she had left port that morning from the island nation of Bahrain. The mission of the *Stark* and six other nearby Navy warships was to protect Kuwaiti and Saudi oil tankers and the vital shipping lanes in the Straits of Hormuz. These international shipping lanes were threatened by escalations in the ongoing seven year military conflict between Iran and Iraq. This most recent escalation, dubbed the "Tanker War", started in 1984 when both Iran and Iraq began employing a strategy of firing on oil tankers from Kuwait, Saudi Arabia, Iran, and Iraq. While multiple warnings had been given to the *Stark's* captain and crew about the imminent danger posed by "inadvertent" attacks from the two warring countries, no one anticipated the tragic turn of events that unfolded over the next few hours.

At 2109 that evening, the *USS Stark* was struck by the first of two Exocet AM-39 anti-ship cruise missiles, fired from an Iraqi F-1 Mirage fighter. The first missile penetrated the berthing spaces of the Oliver Perry class frigate and failed to detonate although it broke up and sprayed burning propellant throughout the ship before portions of the missile exited some 80 feet aft. Shortly thereafter, the second Exocet missile hit the frigate and detonated, engulfing the ship in sulfurous flames, ultimately resulting in the deaths of 37 crewmembers. The frigate suffered severe damage, although the heroic actions of her crew resulted in her eventual successful repair and recovery. Subsequent inquiries, investigations and court trials opened the case to intense scrutiny, raising questions about the roles played by her captain and crew and the effectiveness of the technological warfighting systems available to the *Stark.*

Information Resident in the Model

Using the model described previously, the following information resides in the various ovals and lenses for the *USS Stark* at five distinct slices in time. While information listed here appears static, the authors acknowledge that the information flow is dynamic, continually being updated as it flows and feeds back through the model.

1955 Hours, 17 May 1987 (Time 1)

Among the data contained in Oval 1 (ground truth) is the fact that the *USS Stark* is 12 nautical miles west of the Iraqi exclusion zone. Other U.S. Naval vessels are in the area. A single U.S. Air Force Airborne Warning and Control System (AWACS) aircraft is aloft, relaying radar information about the air picture. An unknown radar signature, track number TN2202, located approximately 200 miles from the *USS Stark* is detected by AWACS sensors. The AWACS has tentatively identified this as a French-made F-1 Mirage fighter and labels it as "friendly". This friendly designation is automatic even though the pilot is probably Iraqi and the aircraft is flown by the Iraqi Air Force. Oval 2 (data detected by sensors) also includes TN2202. Sensor coverage on the *Stark* is degraded due to poor weather (radar detection is 70 miles as opposed to 100) so they must rely on information from the airborne radar of the AWACS. The information displayed in the CIC, also referred to as Oval 3, includes track TN 2202. The track is listed as "friendly." The crewmember who is operating the SLQ-32 (the airborne "fuzz buster") has set the console to the "inhibit all" setting, causing audible alarms not to sound (Levinson and Edwards, 1997).

In Oval 4 (Perception), crewmembers detect Track 2202 after it is relayed from the AWACS, and identify it as friendly (the radar on the *Stark* did not pick up the Mirage for a considerable period of time). Oval 5 (Comprehension) shows that, while an Iraqi fighter is airborne, is the crew does not believe there is anything happening out of the ordinary and consequently, there is no reason to be concerned about the current situation. This is the first time that the model will be seriously distorted. The projection offered in Oval 6 shows that everything appears within normal limits and the ship is not in any known risk.

Information in the Lenses

The following information will set the stage for the individual actors in the scenario and can be thought of as residing in their respective lenses. For this paper, we divide the lenses into these somewhat arbitrary classifications: Experience (societal, cultural and individual), States or Performance Characteristics (system/team and individual), and Doctrine and Rules of Engagement (ROE) (macro level - the temporal context in the months preceding the incident; micro level - the temporal context in the days and hours preceding the incident).

<u>Experience (societal, cultural level)</u>. Iran and Iraq are at war and have been since 1980 when Iraqi president Saddam Hussein invaded Iran's oil fields. Nearly half of the world's oil comes from the Middle East, transported by vulnerable oil tankers through the ports located in the Persian Gulf. The United States has sided with Iraq in this conflict, probably due to the Iranian hostage conflict in which the Iranian militants held 66 U.S. Embassy personnel hostage for a period of 444 days.

<u>Experience (Individual level)</u>.

- Captain Brindel had been in command of the *Stark* for over two years since January, 1985. This was his final cruise aboard the *Stark*, with his change of command scheduled for 23 May, less than a week later. Captain Brindel had previously been given awards for his outstanding peacetime "administrative" victories, including the Federal Energy Efficiency Award.

- LCDR Gajan was the new Executive Officer (XO) of the *Stark* and had not been present at intelligence briefings. He had reported to the *Stark* on 8 April, 1987, just 5 weeks before the incident. LCDR Gajan was new to the crew and was previously unknown to Captain Brindel.

- LT Moncrief was the Tactical Action Officer (TAO) of the *Stark* and was standing watch in the CIC on the night of the attack. LT Moncrief was also absent from the two intelligence briefings. LT Moncrief later stated that he was not expecting an attack from Iraq. (His lens may have differed from that of the captain and other crewmembers.)

States or Performance Characteristics (system/team and individual). The crew of the *Stark* was in the middle of preparing for yet another engineering inspection under Captain Brindel and this was to be his final inspection as the commanding officer of the *Stark*. Manning was reduced in the CIC. Two crewmembers usually served as the CIC Watch Officer and the Weapons Control Officer. Responsibility for both these positions was assigned to a single crewmember due to reduced manning. During critically important times during the evening, another crewmember had left his post to visit the head. When an additional crewmember was sent from the CIC to go find this missing person, the CIC was undermanned by three positions. The crew had departed port from Bahrain that morning so acute or chronic fatigue should not have been an issue. Temperatures in the region were high although with nightfall, the thermal burden on the individual crewmembers was reduced.

Doctrine and ROE (macro level, the temporal context in the months preceding the incident). In December, 1986, five months before the tragedy, U.S. Naval Forces Central Command gave a security briefing to the *Stark* captain and crew stating that "the greatest threat was Iraqi aircraft shooting at unidentified radar contacts in the northern Persian Gulf at the maximum range of their Exocet missiles" (Levinson and Edwards, 1997). The *Stark* crewmembers were further warned that they were going into harm's way and they were told to be "ever vigilant." The crew was also told that AWACS aircraft would be supplying them with information at all times regarding enemy and neutral aircraft. The ship would then be expected to lock their fire control radar onto the threatening aircraft to serve as a warning signal to the approaching aircraft. This briefing was repeated for the *Stark* commander. At an in-theater briefing on Feb. 27 by CMEF (Commander, Middle East Forces) the Iraqi threat was again discussed and the threat from Iran was emphasized. The threat posed from an inadvertent attack to their ship was also stressed.

Doctrine and ROE (micro level, the temporal context is the days and hours preceding the incident). Iraqi-piloted aircraft had begun flying further south over the past few days and the pace of Iraqi attacks had increased substantially. These changes, both the air routes being flown and the tempo of operations, marked a significant departure from normal Iraqi flight operations, resulted in two intelligence advisories dated 14 and 16 May that warned the *Stark* of the change in the Iraqi tactics.

Changes to the Model over Time

2058 Hours, 17 May 1987 (Time 2)

A little more than an hour later, the following data have entered various ovals in the model. In Oval 1 (ground truth), the Iraqi fighter executes a sharp left turn and increases speed in the general direction of the *Stark*. In Oval 2 (sensor information), sensors on the AWACS and the *Stark* detect the Iraqi fighter's turn toward the ship, indicating potentially hostile intent. The data pass into Oval 3 (information displayed in the CIC), where the information about the enemy aircraft is displayed. This critical information regarding the Iraqi F-1 is perceived by the CIC crew on the *Stark* (Oval 4). Between Oval 4 (perception) and Oval 5 (comprehension), an error is made, leading to an inaccurate comprehension. The hostile intent demonstrated by the maneuvers of the Iraqi aircraft is not picked up by the CIC crew. At the time, the comprehension in the CIC is that while there is an Iraqi fighter in the air, it does not seem overly important to the ship's safety. This inaccurate comprehension results in an inaccurate projection (Oval 6). The CIC continues to believe that everything is under control and the CIC should continue monitoring conditions.

2105 Hours, 17 May 1987 (Time 3)

Seven minutes later, the pilot of the Iraqi F-1 turns directly toward the *Stark*. The information about this final turn toward the *Stark* is picked up by sensors located both on the AWACS and the *Stark* (Oval 2) and is displayed in the CIC (Oval 3). This piece of information is vital to events that transpire although the course change information is not detected by the CIC crew (Oval 4) causing even more inaccuracies in Ovals 5 and 6. Had the crew noticed the course change, established radio contact with the Iraqi fighter and used the fire control radar to warn the Iraqi aircraft, the tragedy might still have been averted.

2107 Hours, 17 May 1987 (Time 4)

Two minutes later, the Iraqi fighter is 22.5 nautical miles from the *Stark* and fires the first of two Exocet missiles toward the vessel. In Oval 2, sensors fail to detect the launch of the missile and in fact, the missile launch may not have been detectable by sensor systems on the AWACS or the *Stark*. In Oval 3, there is no information available on the inbound missile although the information about the Iraqi aircraft is still being updated. The SLQ-32 operator had earlier turned down the volume on the auditory warnings that may have served to warn the crew about the approaching missile. At 2108, LT Moncrief, the TAO in the CIC, observes the Iraqi aircraft course movement and gives the CIC crew orders to notify the *Stark* captain and to issue warnings to the Iraqi aircraft. Of course, by this time, it is too late to avert the impending disaster. A radio warning to the Iraqi aircraft is issued around 2108, although no response is received. A second Exocet missile is fired from the warplane around this same time. A second warning is sent to the incoming aircraft; again there is no response. The SLQ-32 operator turns up the volume on the unit and there is now confusion over the alerts that are emanating from the SLQ-32 unit. Radar lock-on by the Mk-92 radar on the F-1 Mirage occurs only after both Exocets have been launched and the hostile aircraft is approximately 10 miles from the *Stark*.

The forward lookout on the *Stark*, Seaman Robert Williams, sees the missile launch and spots the first Exocet off the port bow about 2109, relaying that information to the bridge, then to the CIC. The information does not reach the CIC before the missile impacts the ship. In fact, for most of the crewmembers on the *Stark*, the first indication that there is a problem is when they hear and feel the first missile impact the hull (Oval 4). Following the impact of the first missile, the approach of the second missile is detected and an auditory warning is issued over the ship's PA system. In Oval 5, many of the ship's crewmembers know that it has been struck by a missile although in Oval 6, there is a state of confusion on the ship. No one knows exactly where the missile came from and, for many crewmembers, there is even confusion about whether they have been struck by a missile. The second Exocet missile strikes the ship shortly thereafter, adding to the general confusion.

2110 Hours, 17 May 1987 (Time 5)

The *Stark* is on fire, dead in the water with many casualties. The Iraqi fighter turns away and heads home (Oval 1). The on-board sensors fail due to loss of power (Oval 2). The CIC is full of smoke and is soon engulfed in flames (Oval 3). There is mass confusion on the ship with many senior enlisted petty officers dead from the two missile strikes. There is a loss of power and fire-fighting capability (Oval 4). There is a dawning comprehension by crewmembers that the ship is in grave danger (Oval 5). The projection is that efforts must be made to establish contact to acquire outside help or the ship and crew will be lost (Oval 6).

Over the course of this 75 minute scenario, massive deviations from ground truth led to skewed perceptions, comprehensions and perceptions of the crewmembers onboard the *USS Stark*. By tracing the path of these distortions over the five time slices represented in this case study, it is evident that at the beginning and the ending of the scenario, there is congruence with ground truth. By Time 5, the distortions in the model which are clearly illustrated in Time 1 through 4 have finally been rectified when the current situation is seen in stark reality without dependence upon technological means.

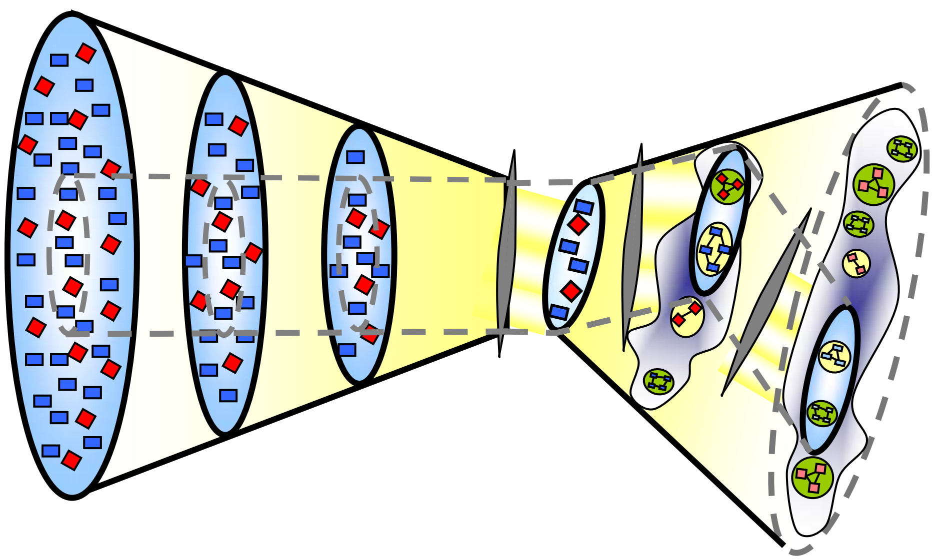

Figure 2. Distortions in the lenses lead to inaccurate perceptions, comprehensions, and projections

Figure 2 illustrates what happens when a lens is skewed or misshaped. For example, crewmembers did not believe that the Iraqi aircraft was hostile because of the relationship between the U.S. and Iraq and possibly because the track had been labeled “friendly.” The skewed lens caused the crewmembers to misperceive the data available to them and form a comprehension other than the correct one, which also led to an erroneous projection. In a sense, the crewmembers may have been ‘set up’ to make erroneous comprehensions and projections. Their failure may have been caused less by negligence and more by their lenses and the data that were not provided by their technology.

Conclusion

The Dynamic Model of Situated Cognition offers an innovative way to view complex systems in which humans and machines function as cooperative agents. It recognizes the unique contributions made by both the technology and humans. It also highlights the flaws inherent in adapting an analytical approach that focuses on either the human or the machine. Process tracing offers a viable method to determine how data from the environment are detected by sensors, displayed by machines, and processed by humans. Understanding how data flow through the system, where the data may have been blocked, and how lenses may be skewed is vital to knowing how to redesign systems and develop appropriate training. Future generations of warriors need not die because they are unaware of the dangers that lurk in the environment. Properly designed technology coupled with well-trained operators will result in optimal human – system performance.

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