An Interdisciplinary Approach to the Study of Battlefield Simulation Systems

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ABSTRACT

There are numerous advantages for conducting computer simulations that model wartime operations, which underlie the popularity in implementing them. Among them are: the ability to easily model the variables the researcher is interested in, the ability to control the experimental scenario, and the ability to add or change variables as the need arises. A simulation environment's success may be enhanced by considering questions not normally at the center of simulation research. We consider a case study: situation awareness and how it may be useful in validating the effectiveness of new sensor technologies; the role cognitive psychology has in measuring situation awareness and how it may be compared to the Joint Urban Operation (JUO) exercise.

This paper will propose an interdisciplinary approach to the study of battlefield simulation systems, Joint Semi Automated Forces (JSAF). It will show that the approaches and implementation of these systems up until now have been grounded in the computer science discipline. We will explore what cognitive science has to say about the simulation driven approaches. Integrating the viewpoint of fields such as cognitive science can provide valuable insights as to the effectiveness of these approaches by substantiating the validity of the system and increase the fidelity of the synthetic to real life experience.

ABOUT THE AUTHORS

John J. Tran is a researcher at the Information Sciences Institute, University of Southern California. He received both his BS and MS Degrees in Computer Science and Engineering from the University of Notre Dame, where he focused on Object-oriented software engineering, large-scale software system design and implementation, and high performance parallel and scientific computing. He has worked at the Stanford Linear Accelerator Center, Safetopia, and Intel. His current research centers on Linux cluster engineering, effective control of parallel programs, and communications fabrics for large-scale computation.

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INTRODUCTION

Problem description

Tasked as the transformation laboratory within USJFCOM the Joint Experimentation Directorate (J9) is using modeling and simulations as one of its major tools for developing, exploring, testing and validating 21st-century war fighting concepts [JFCOM2004, 1]Specifically J9 has been developing the Joint Semi-Automated Forces (JSAF) simulator, and using it within the Joint Urban Operations (JUO) Urban Resolve experiments to develop urban war fighting concepts using surveillance and reconnaissance technologies in the 2015 timeframe. One of the key questions that the experiment will address is how to measure effectiveness in urban environments [JFCOM2004, 2].

To derive this measurement of effectiveness in this paper we argue for a multi-faceted and inter-disciplinary approach that specifically should incorporate analysis techniques from cognitive psychology and applied cognitive psychology. One key measurement of interest within Urban Resolve is the effectiveness of the 2015 surveillance and reconnaissance technologies. Drawing upon disciplines of physics, engineering, computer science and operations research, one may use these following factors to evaluate the sensor technologies, such as determining the range and accuracy of the sensors, the environmental conditions in which the sensors can operate, the mobility and ease of placement of the sensor platforms, the idea sensor deployment patterns, sensor data communication requirements and so on. But, more importantly we argue that it also should include how effectively the soldiers are exploiting the data provided by these technologies. That is how soldiers utilizing the sensor data to improve their battlefield situation awareness and to carry out the operational task at hand. During battlefield situations, or during experimentation trials, the soldiers may be deluged with data, and they may be overly tasked in performing their operational duties. They must parse and assess potentially conflicting data in real time, and arrive a correct understanding battlefield situation. The additional data provided by the sensors should be measured with respect to how they help the soldiers.

JSAF, or Joint Semi-Automated Forces, is a modern system for conducting synthetic battlefield experiments and is used to simulate human operators participating in a human in the loop (HITL) simulation. JSAF has adequately modeled organic and inorganic entity behavior, (the physical model) [Ceranowicz, 2000] but lacks adequate techniques for measuring players' internal behavior. However, taking into consideration the player's state of mind during the analysis stage would increase the fidelity of the system.

JSAF uses a network of computers to model forces and conflicts. JSAF includes entities, environmental behavior, such as weather, and terrain. In its current state, we have the tools and experience to model physical behavior which answers the question: what is going on with the system? One example of the tools is the ability to conduct extensive logging of all simulation states. We do not have the adequate tools to answer what is the state of mind of the players. How do they relate to the environment?

Meeting the above goals will help us understand and validate the effectiveness of: (1) Doctrine and policy, (2) Simulation tools and environment, and (3) Sensor technology. In the next section we consider how the methods of cognitive science may provide potential tools to meet our goals with the specific focus on situation awareness (SA).

Motivation

Cognitive science and applied cognitive science refer to the umbrella disciplines that seek to understand both how the mind works (cognitive science and applied cognitive science), and how such knowledge can provide useful applications (applied cognitive science). These disciplines include, but are not limited to, cognitive psychology, artificial intelligence, and cognitive ergonomics. By taking into consideration the capacities of what the mind can process, we hope to develop methods and models that more accurately assess and represent players' performance.

To do so, we will rely primarily on cognitive psychology and applied cognitive psychology because they are pioneers among these disciplines in subject matter and in the use of objective measures to infer behavior, they provide experimental frameworks that may be useful for testing theories, and they have existing cognitive models that may be used for comparison.

We are interested in the case of situation awareness because SA researchers address the same issues we are trying to address, namely what is the participant's state of mind and their relationship to the environment and how is this relationship quantified? In addition, the abstract definition of situation awareness does not favor any particular field, although in practice much research effort has been devoted to aviation, pilot, and emergency crew SA. We are proposing to extend this study to synthetic battlefield simulations in the context of cognitive psychology by providing a:

1. Background for situation awareness and JSAF simulation,
2. Taxonomy of situation awareness,
3. Draw upon cognitive methods to increase the accuracy of situation awareness measurement
4. Accurate measurement of situation awareness increases the ability to evaluate sensor effectiveness

BACKGROUND

Background on JSAF

JSAF, a joint semi-automated force simulation system that models battlefield environment, is federated [Williams2003] and has many components working together to create a synthetic battlefield and conflict simulation environment. These components, together, operate to model the JSAF system's physical and behavioral realism. The JSAF software serves as modeling and simulation tool for training and doctrine development purposes.

The most recent JSAF mission is the Joint Urban Operation (JUO) exercise and its key objective is to test sensor effectiveness for the year 2015. This may be done by taking situation awareness (SA) into account.

Table 1 outlines a perspective on the progression of JSAF development driven by the needs to have data logging, complex tool development, and functional requirements. The Joint Experiment Scalable Parallel Processor (JESPP) and the Future After Action Review System's (FAARS) effort, led by a group at the Information Sciences Institute (ISI) and the Topographical Engineering Center (TEC), approaches on the ability to collect for the first time all simulation event data, and with this capability, the JSAF team approaches the ability to measure situation awareness. Moving forward, understanding and measuring situation awareness in JSAF requires a cognitive perspective.

Table 1. Evolution of behavior modeling and analysis in JSAF

Needs driven impact	Development Efforts	Logging capability
Tactics and doctrine development & needs for training	Earlier development of sims	Early stage with minimal logging facility
Add realism Improvement to the system	Model Behavior & Sensors Technology	Disjointed logging facility
Higher fidelity	Scalable system (JESPP)	Unify Logging more than needed
Situation awareness	Analysis tools *Mental Models*	Analysis of log

Background on Situation Awareness

An area of intense research interest and although several definitions for the term exists one that is commonly accepted refers to SA as the perception and comprehension of surrounding environment that allows for a projection of the future states of affairs [Endsley 1998]. The term *situation model*, which is distinct from mental model of how a system operates, has also been used to refer to SA.

In military terms, SA is a static spatial awareness of friendly and enemy troop positions [Pew1998]. With regards to JSAF, it is not to clear to researcher whether or not JSAF has SA properties that correlate poor SA to poor planning, and therefore deprive players of comprehension and perception of simulation environment.

In JSAF, any relevant discussion of SA must be framed in the context of the concept of "cells" of which there are three: red (hostile), blue (friendly), and white (neutral omnipotent observer). Each cell is made up of a group of players on the same side (with the same military mission), and for red and blue cell, each of which has some level of collective situation awareness of the opposing force. In particular, the game-play objectives of the Joint Urban Operation (JUO) exercise are: (1) for the red force to evade the blue force, and (2) for the blue force to capture the red force.

Situation awareness is inherently a cognitive construct. It involves perception, memory, interpretation, reasoning and problem solving capabilities. The soldiers must use their senses to gather data from multiple sources about the current state of the battlefield. The data sources may include their physical environment, computer terminals, sensor readouts, and fellow soldiers. They must be able to recall the relevant data when needed. They must match data against their mental models of the situation to either accept or reject the data. They may use the data to update and adjust their mental models. Aspects of the battlefield situation the mental models represent may include the geophysical locations of the friendly and opposing forces, temporal aspect of force movements, and the goals and intentions of the forces. Then, they must reason using their mental models to plan their actions. For example, during their understanding of opposing force's goals and the current troop locations, they can better predict future opposing force movements and act accordingly.

THE CHALLENGE

Taxonomy of situation awareness

Domain Behavior Depth

There has been much work devoted to classifying SA and the various segments of military and aviation simulation. To this end, we focus on how an alternative taxonomy of SA affects the use of cognitive psychology methods for a better quantitative evaluation of players' internal state. Pew (1997) suggests the need to have in depth domain of behavior classifications, and breaks down as followed: (1) the organizational level SA, which is guided by doctrine and policy, and (2) the individual level SA, which is guided by tasks. He added that common to both, the process for obtaining information is based on psychology [Pew1997].

Table 2. Taxonomy of the Domains of SA

	Individual	Group
Micro model	F15 fighter pilot	C130 Crew
Macro model	JSAF red player	JSAF red cell

We further expand on Pew's classification with a two dimensions: (1) along the first dimension, a distinction is made between "micro" and "macro" model of SA, and (2) along the second dimension, we retain Pew's distinction between individual and group SA levels. Together, they form the four quadrants of SA taxonomy. Table 2 illustrates some examples of the quadrants of SA taxonomy.

Table 3 highlights a comparison of characteristics between the micro and macro model. The intimacy between the players and their environment sets the distinction between the micro and macro model. Additionally, the locality of awareness also points out to another difference between the two models. The following examples speak more to the specifics of this classification.

Figure 1. Example of Micro Model SA; analogous to first person shoot 'em gaming**.**

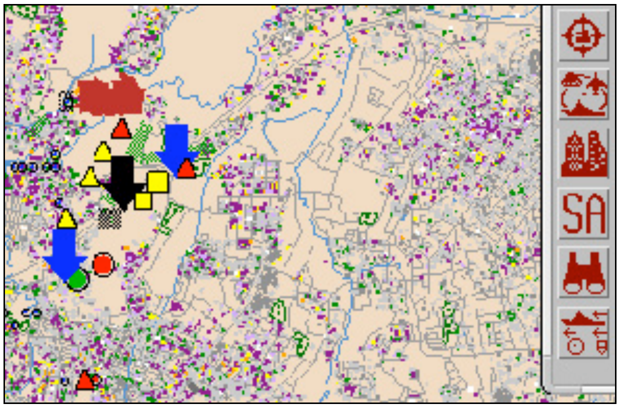

Figure 2. Example of Macro Model SA; this is a screen capture of how the red players place their Situational Objects on a PVD (game console).

Micro Model

The individual level SA of the micro model is defined as task oriented SA of participant with minimal communication flow, and the focus is on individual cognitive processes. For example, a pilot in a cockpit of an F15 fighter jet (figure 1) has an SA level that is only relevant to his or her environment, namely, the instruments, the weather, the altitude and enemy positions and possibly tactics. In a similar sample space, a group level SA of the micro model would be the crew of a C130 airplane; and the active participants communicate their collective SA.

In the above examples, the micro model SA at both the individual and group level demonstrates the close relationship between the participants and the entity (air plane).

Table 3. Comparison of Characteristics of the Domains of SA

Micro Model	Macro Model
Fine grain relationship between subject and environment	Coarse grain relationship between subject and environment
Higher local awareness	Lower local awareness
Lower global awareness	Higher global awareness
Greater psycho-physiological impact	Less psycho-physiological impact

Macro model

For the macro model of SA, we note that both individual and group level the participants exercise control over more than one entity or scenario.

In JSAF, at the individual level, a player can control a range of tasks (figure 2). For example, a blue player can engage in a *mano-a-mano* confrontation with a red player; and in a different setting, a different player can commandeer a battalion of tanks engaging in full-scale combat.

At the group level (within a cell), the players can collaborate their SA through the exchange of information and together meeting a common mission objective. This objective can be for example, a red force eluding the blue force, and vice versa for the blue force to capture the red force.

JSAF: a macro SA model

The proposed taxonomy is consistent with Endsley's view of situation awareness. It further organizes SA roughly in terms of how many entities are controlled by the player(s). Much research has been focused on the micro model, e.g. aviation and flight simulators. The above example places JSAF in a macro model SA category, and calls on researchers to explore SA and its impact on meeting mission objectives.

Use of SA to evaluate the effectiveness of sensor technology

Computer generated force simulations represent the real world at the entity level. For example, entities can be humans and vehicles, like aircraft, ground vehicles and surface vessels; Or, they can be embedded systems, like IFF, radio transmitters and sensors. Or, they can even represent the environment, like fog, precipitation and cloud layers. These simulated entities interact with each other by sending messages. They periodically emit *state* messages reporting their internal state attributes, such as their location, movement, damage state, camouflage state, and so on. Also, they emit *interaction* messages indicating what they did, for example, an aircraft can send a weapon fire message, and a radio transmitter can send a radio signal message. The entities are always truthful in the messages, so the entire set of

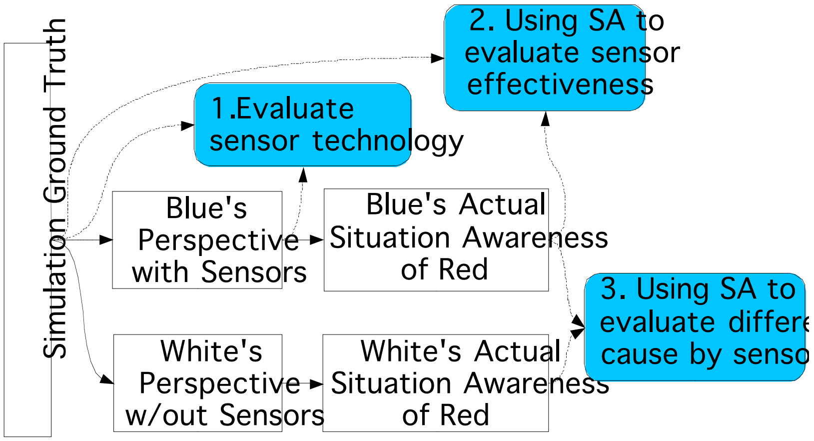

Figure 3. Evaluating sensor effectiveness using multiple situation awareness viewpoints.

the state and interaction messages during a simulation defines the *simulation ground truth*.

Typically human simulation players do not directly see the state and interaction messages of the opposing forces or even all the messages from their own force. The players rely on simulated observer entities, such as sensors and human intelligence, to provide them with a *perspective* on the contents of the simulation. Using this perspective the players develop their situation awareness, see Figure 1. With respect to the simulation ground truth, the players' perspective is partial, approximate and delayed. The players do not have enough wherewithals to deploy observers everywhere and all the time. Even if observers were deployed, their observations are not exact. For example, due to the inaccuracies of the sensor technology (as simulated by the observer sensor entity), an observer may misclassify a heavy truck as a tank. Also, the observation message send to the players maybe delayed. This delay sometimes is an artifact of the underlying computing infrastructure, or sometimes it is inserted on purpose to emulate actual time delays that are consistent with the real world.

Currently, we are participating in the Joint Urban Operations (JUO) Urban Resolve exercises. One of the key objectives of the exercises is to determine in complex urban battle environments the potential effectiveness of proposed 2015 sensor technologies [Denhke2003]. From the point of view of the Blue force against the Red force, Figure 1 illustrates three potential methods of evaluating the contribution of sensors. One is to compare the Blue force perspectives against the simulation ground truth; two is to compare Blue SA against simulation ground truth; and three is to compare the Blue players' situation awareness against the White cell's situation awareness. In this case we define that the White cell formulates its situation awareness without using the proposed new sensor technologies.

Evaluate Sensor Technology

Method one, perspective versus ground truth, provides an absolute measure of usefulness of the sensor technology. This method utilizes all available data using all the messages from the underlying simulation and all of the sensor data output. Comparing these two types of data, we can determine exactly which entities were detected, and which were not. Of the detected entities we can determine which sensors did the detection, for how long, and if the entities were classified correctly. Of the undetected entities, we can determine if the failure to detect was due to sensor technology, or because no sensors were deployed near the undetected entities. These types of measurements are very useful in determining the usefulness of the sensors and the sensor deployment patterns. Indeed within JFCOM J9 we are developing a range of tools using this method [Graebner2003]. Tools we have developed include sensor-target and truth-perception scoreboards. Sensor-target scoreboards indicate which sensor types are more adept at recognizing which entity types. Truth-perception scoreboards indicate the frequency that tracked targets are classified correctly and incorrectly. If targets are classified incorrectly, they indicate the distribution of category types in which the targets are misclassified.

Using SA to evaluate Sensor Effectiveness

Method two, Blue's SA versus ground truth, provides measurements based on how effectively the sensor information is being used. During the exercise the players are typically overloaded with data and with operational tasks that they must perform, such as controlling the entities. In real time they need to sift through the data, understand it and act upon it. Method one assumes unlimited computing resource and unlimited processing time. For example, generating the scoreboards requires examining Gigabytes of data. The ability of the players to analyze the data is necessarily constrained by the cognitive limits of human memory, attention focus, multi-tasking under workload, and pattern/schema matching ability. So, in terms of information content Blue's SA is necessarily a *subset* of the information content of Blue perspective. Blue's SA is not a strict set, since the players may misinterpret the information within the Blue's perspective. By comparing the Blue's SA against the ground truth we are able to determine how effectively the sensor data is being used.

Use of Control Group in Assessing Sensor Effectiveness

Method three, Blue's SA versus provides a potentially a fairer way to judge sensor effectiveness. Here we propose a Blue Cell control group, which with the exception of not using the new sensor technologies, are the same as the Blue players. The Control group still receives all the data from traditional observers and sensors, and it still must perform the operational tasks of the Blue players. This measurement helps to quantify the advantages offered by the new sensor technologies, and if the advantage is offset by the extra cognitive load imposed upon the players.

Use of cognitive methods to increase accuracy of SA measurement

Objective Measures

In general, it is much more desirable to obtain objective measures but because of the difficulty in doing so researchers investigating situation awareness tend to rely on subjective measures. Our goal is to develop quantitative measurements of situation awareness for the various levels in our domain. Although our present focus is on Level 1 SA, SAOs that measure Level 2 and Level 3 SA are in development. Currently, JSAF records player's situation awareness by having them annotate "Situation Awareness Objects" (SAOs) on the computer screen during the exercise. SAOs are pointers that indicate the presence and direction of movement of the opposing force. When the exercise is complete, overall SA is evaluated by comparing the total SAOs recorded against the opposing forces' activities. As it stands now, the process is manual and subjective, which allows for error in measuring SA. Our goal is to minimize this error.

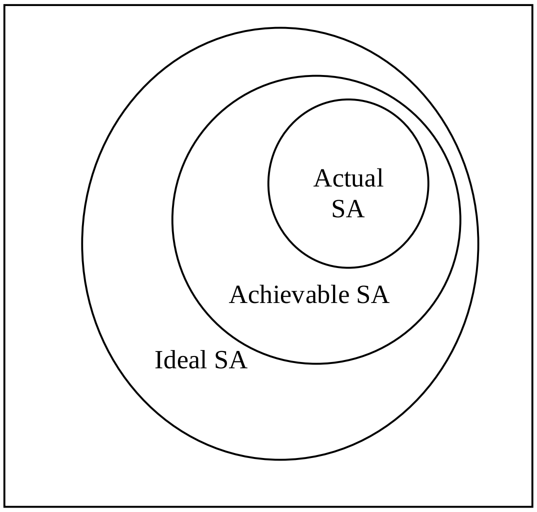

Figure 4. Venn diagram of idealized, achievable, and actual SA, adapted from Pew 2000.

Ideal, Achievable, and Actual SA

What can be considered another source of error in SA measurement is the difference between actual SA and what is believed to be achievable with regards to ideal SA [Pew, 2000]. Ideal SA is defined in terms of expert evaluation or on the basis of some upper boundary. Here, for example, ideal SA might be defined as Blue's perspective. The achievable ideal is a subset of the Ideal and depends on design considerations and processing limitations. Here, the achievable ideal might be some point between Blue's perspective and Blue's SA (actual SA). The actual location of this value is difficult to pinpoint and involves a consideration of the display design as well as the player's cognitive limitations. If there is a meaningful difference between actual SA and achievable SA (large error), then better training opportunities may be developed that minimize this difference. Or it may be the case that perceptual limitations were not adequately considered and may involve redesigning how the information is presented. Evaluating individual differences may also prove useful but may not be feasible here with such a small sample size.

Three Pronged Approach

An experimental approach adapted from research methods in narrative comprehension is the three-pronged approach. The first prong in this approach corresponds to a set of theoretical predictions. The second prong corresponds to the use of verbal protocols/ and or subjective measures. The third prong corresponds to the collection of online behavioral measures. The purpose of the two types of data will be to provide converging evidence for the theoretical predictions of the first prong, somewhat of a different use than in narrative comprehension.

This approach may be used to study situation awareness errors by formulating a set of hypothetical predictions based on intuition or experience about individual and group situation awareness. Subjective evaluation or measurement based on verbal protocols or interviews that are given after the exercise can include: (a) an effectiveness form, (b) individual or collective group discussion or "hot wash", and (c) a third party observer.

Objective measurements include the introduction of experimental probes into the exercise, at the group level situation awareness error is the number of situation awareness objects placed by each individual puckers compared between each SA object place and actual Red Force, at the collective/group level situation awareness error is meeting mission objective (normalized to a certain percentage for each player). Conducting the actual experiment is beyond the scope of this paper. We look to do this in the future.

Situation Models in Narrative Comprehension

One potential framework that may prove fruitful to look at in researching situation awareness in JSAF comes from research in situation models in cognitive psychology. By comparing how situations are defined within the two paradigms, we can identify general commonalities and differences that may increase our understanding of situation awareness in JSAF.

In cognitive psychology, a narrative comprehension paradigm has been used to study situation models. This typically consists of reading narratives on a sentence-by-sentence basis and answering experimental probe questions. Readers have no background knowledge of what the story is about until they start reading. As they read, the information they encounter can shift along a number of situation defining dimensions. Research using reading time measures has identified 5 dimensions to which readers are sensitive. These are entity, space, time, goal, and causality. In other words, readers construct a situation model that is updated to correspond to changes in the text’s situation. Finally, once the story has ended, readers have encoded a “global static summary” of the story, which corresponds to the completed situation model.

Table 4. Comparison between reading comprehension narrative and JSAF simulation along the five cognitive processes dimensions

Read Comprehension	JSAF Simulation
Read the story - No apriori knowledge of entities - Time can be told out of order - No spatial knowledge - Unknown goals - Causality is “fixed”	Initially Starts the Vignette Some background: - apriori menu of entities - no time shift expected - spatial boundary - 2 sets of goals - causality is dynamic
Information acquired throughout the reading process can cause shift along the five dimensions: - entity - space - time - goals - causality	Information acquisition = the game/experiment: - no time shift - sensors provide space and entity shift - inferential provide goals and causality shift
Completion State Global static summary - character summary - plots - space and time summary	End of Vignette Global static summary - effectiveness of mission - goals evaluated - effectiveness of sensors

Although quite different experimentally, the JSAF paradigm can be compared to the narrative comprehension paradigm. Reading is naturally a more passive activity than game playing. Players are provided with a vignette so there is some background knowledge. The knowledge includes information about the situation dimensions, such as an apriori menu of entities and spatial boundaries and geographical constraints. As the game progresses, situation information comes from various sources: entity and spatial information comes from the sensors, whereas goal and causal information is inferred the movements of the entities. Note that the game continues uninterrupted so there is no time shift. When the game is over, the result is a global static summary, analysis of the end result of the game in which the effectiveness of the strategy, the goals of the mission, and the effectiveness of the information provided by the sensors are evaluated. The challenge is to objectively measure situation awareness, probes, and causality shifts.

We can borrow known experimental techniques and apply them to simulation exercises. For example, techniques that measure shifts along the five dimensions may be used. We look to do this in the future.

CONCLUSIONS AND FUTURE WORK

In this paper, we laid the foundation for integrating mental models with physical models in the context of the JSAF experiment. Of specific interest is player’s situation awareness. An alternative taxonomy of situation awareness is proposed that positions JSAF in the proper domain of situation awareness. It is argues that cognitive methods play an important role in the measurement of situation awareness and the development of quantitative models in JSAF.

Conclusion and Future Work

Our future work will focus on developing model of situation awareness within the synthetic battlefield arena and incorporating quantitative and qualitative measures into our JSAF experiments. We will use the results to validate sensor technology, and with this commanding officers can train their players and develop doctrine for various engagement tactics.

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