Creating a Tactical Pilot's Assistant for Combat Operations in Contested Denied Environments:

An Overview of Three Different Approaches

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ABSTRACT

As our adversaries become more capable in their development of advanced systems for combat, those systems themselves are becoming increasingly complex as well. The future battlespace is expected to be one where the mechanisms and tools we depend on today for the execution of a combat mission will not be reliable in terms of the real world representations they provide, given creative manipulation of sources and data. Less elegant approaches to contesting and denying operations merely take a given source of data or capability away. A far more sophisticated approach is one that does very subtle manipulation of key data and representations, such that even the ops systems may not detect miscorrelation or suspect data, thus requiring the human operator, under stress to do those detections and assessments. There may also be such a variety of information that the human operator will not be able to evaluate the quality or "truth" of the data in real time, and may be forced to make decisions on deficient or suspect sources and data. Further, the density of data from the variety of sensors and sources at hand will potentially overwhelm human operators just dealing with the regular influx of data. With this in mind, a major goal of this effort is to examine the extent to which we can use emerging human behavior and machine learning models to create software-based pilot's assistance that can help offload some of the source and data monitoring from the human operator and to alleviate cognitive bottlenecks in the midst of a combat engagement. Three different approaches to the development of an agent-based assistant will be described and discussed across this and the three other companion papers. This initial paper will serve to frame the other presentations and provide a practical foundation for the approaches that have been undertaken. This presentation will highlight the key activities, challenges and development efforts and will describe the applications spaces we used for demonstration. The capstone demonstration where each of the approaches will be evaluated will be described and

discussed. Our future plans for integrating the approaches and developed models into an F16 tactical training environment will be discussed as well.

THE PROBLEM

The end state for near-peer adversary operations is one that is considered to at least initially be contested with degraded operations on our side. Along the way to actual combat, there is an expectation that a number of the systems and the data they provide will be compromised at some level. For over a decade there has been increasing recognition of the need to support pilots and other operators in assessing the potential degradation to key systems and data and to assist in the analysis of alternatives and contingencies for mission success.

BACKGROUND

From a training and rehearsal perspective, the demand signal for more realistic training that represents as the operational state of combat in a near peer fight is persistent and growing. Currently, our range infrastructure cannot provide the breadth of realism at the right level of operational security of the future fight. Further, we cannot simply add more actual humans to the training construct to get to more realistic training and exercise as those same humans are needed in their multi domain areas of specialization, not as training and exercise aids.

The goal of the current tactical pilot assistant effort is to create and demonstrate software agents that can support humans operations in contested and degraded tactical environments we are creating in the virtual and constructive environment. These agents are being developed to help human operators to gain and maintain greater awareness of the data integrity and quality being delivered by the aircraft navigation and sensor systems. Many of the future combat systems we are developing have processes “baked in” that can correlate data from a variety of sources and provide the operator with an assessment of the quality and fusion of the multi source data for their decision making. We wanted to assess the feasibility of using machine-based agents as data assessors and monitors supporting the human operators in current fourth generation aircraft simulation systems.

For the current effort, we evaluated each of the models independently. However, it would be desirable for a future end state that the models all reside in a portable device that can be interfaced with just about any operational system and provide support to the operator of that system with just a little up front integration work on the systems and data for that system and the character of the data in its normal state.

APPROACH

For the present exploration, we identified three candidate agent model development frameworks for use in the development of an agent to support the analysis of alternative course of action in a degraded environment. Each of them has a different approach both theoretically and practically. We fully expect each approach to be useful in the exploration and that each one will be able to support a human machine team in a degraded environment. We further anticipate that elements of each can work in concert with the other two approaches, so that an eventual outcome would be a new synthesis.

The first approach is the development of a novel software infrastructure that supports interoperability among cognitive architectures. The DREAMIT (Design, Reconfigure and Evaluate Autonomous Models in Trainings) Workspace is a collection of software tools that allows existing agent or cognitive models to be combined to produce more complex behaviors. Our motivation is to allow the analyst to choose the right tool for the job, so to speak, by promoting the decomposition of agent behaviors so that different architectures can be applied in a piecemeal fashion. This approach puts a premium on the development of modular and reusable models. Toward that end, we are also developing a generic planning model that can be deployed with the DREAMIT Workspace. This model will provide basic agent behaviors that will be combined with another model to produce a more complete representation of the tactical situation a pilot might face in a contested environment.

The second approach involves simulation at the level of people working with each other and with their automated systems. Using a Government-developed work-practice modeling framework called Brahms, this approach considers the communications, coordination and interdependencies at play during tactical missions. In particular, the Brahms Contested Airspace Simulation Toolkit (Brahms-CAST) enables detailed analyses and simulations of activity under both normal and denied conditions. This approach will provide insights into the socio-technical dynamics of operations in contested environments. In support of alternative course of action analysis, Brahms-CAST can model the probabilistic outcomes associated with a given set of initial assumptions, such as the location, efficacy and likelihood of threats and corresponding countermeasures.

The third approach can be considered as a form of "models of models". The Configurable Adversary Response Prediction (CARP) framework aims to enable the accurate and efficient development of causal expectation representations. Our vision is that the Pilot's Assistant can rapidly pattern-match mission observations to these expectation models in order to detect anomalies. The expectation models provide efficient mission-time matching by compiling thorough off-line analyses derived from mission and behavior-model simulations. CARP exploits behavior-model abstractions for interoperability and parameterization, of the types investigated by the first two approaches. CARP uses these abstractions to collaboratively support an analyst in the processes of generating and sampling a sophisticated set of predictive scenarios, and then mining the simulation data for regularities, causal relationships, and mission expectations.

DISCUSSION

The approaches we have explored have significant promise to support the end state and support operational personnel in their missions. The initial plan will be to integrate and evaluate them inside combat relevant simulation environments with operational subject matter experts to refine the models, predictions, and alternatives analysis. To our mind, this is a unique exploration and we are very excited to put these papers and our work out in the larger communities of interest for feedback.

FINAL THOUGHTS AND RECOMMENDATIONS

There is significant evidence for a need to better support human operators on contested environments. We believe there is no one single approach that is best for this and the approaches we have chosen are both scientifically and commercially viable. This is important because the science foundation is solid and commercial viability ensures that the capabilities in these approaches will continue to evolve with new applications and customer demand. The approaches are also evolving as three cooperative initiatives, so that potential synergies are identified early and explored collectively. It is also the case that the approaches are modular enough that they could be woven into the actual software on a current or future operational platform or hosted on a portable flight board or pad to accompany the operator in flight.

Approach 1: Tactical Pilot Assistant and Denied Environments: Incorporating Socio-Technical Factors in Simulations

Tactical pilot assistants will incorporate artificial intelligence (AI), advanced human-systems interaction, and networked access to data and sensors to provide decision aiding of unprecedented sophistication. In conventional air combat scenarios, a tactical pilot assistant could, for instance, monitor aircraft systems, interpret and carry out pilot commands, and advise the pilot as to systems status, mission progress, and threats. Such agents are particularly valuable during operations in contested environments, where pilots may be subject to denied communications, spoofed navigation systems, and other forms of electronic warfare (EW) disruptions. In Anti-Access/Area Denial (A2AD) contexts, the tactical pilot assistant could alert the pilot when denial attacks such as datalink jamming or GPS spoofing are detected and recommend countermeasures. A2AD effects could also degrade the integrity of the tactical pilot assistant itself, motivating systemic simulations early in design.The functions of a tactical pilot assistant and the pilot go well beyond the mechanics of maneuvering the aircraft. Tactical pilot assistants and their human pilots are part of a socio-technical system, where people and agents are inherently part of a network of operations that may involve ambiguous communications and dynamic roles and responsibilities. Combat sorties, for example, require considerable interaction within and across aircraft and remotely with people and agents on the ground.

Developing, testing and integrating a tactical pilot assistant requires simulations that capture the complexities and vulnerabilities of an information-rich, networked, digital, automated world. Simulations that reflect socio-technical processes are needed to model the effects of human-automation interaction under both nominal and off-nominal conditions. Socio-technical context is not just a backdrop for simulation, but must be an explicit factor in a tactical pilot assistant’s threat assessments and course of action recommendations. Detecting and overcoming problems with socio-technical lapses, whether benign or the result of hostile action, is one example. Communications and data disruptions, as in combat forces operating under conditions of denied access to information, can also have devastating emergent effects on the way people and intelligent systems work together.

Simulating how people and automated systems interact in an uncertain, dynamic environment provides analysts and planners with a tool to assess risk and design and evaluate countermeasures, in particular, a tactical pilot assistant that enables a pilot to fight through such events. Simulations are thus needed that can properly capture work practices of the socio-technical system.

To address this need, we adopt a socio-technical approach to simulating activity, namely situated, interactive behavior that includes a spatial/geographical model, cultural features and objects, and - information systems. In this paper, we present our simulation methodology that captures the activities of individuals and the socio-technical context. We describe current research in support of a tactical pilot assistant that employs this simulation approach for predictive analysis and constructive agent control in simulations of uncertain, complex threats. This work, in concert with related research contributing complementary capabilities, will accelerate the development of a robust tactical pilot assistant.

Approach 2: Configurable Adversary Response Prediction: Building Efficient Expectation Models from High-Fidelity Behavior Simulations

The Air Force has an interest in a run-time mission pilot’s assistant that will support tactical pilots in the rapid assessment of information quality and reconsideration of decisions that the information supports. Such a capability requires an efficient, predictive knowledge base that enables rapid situation assessment and decision support. The Configurable Adversary Response Prediction (CARP) project addresses two key technical challenges to the development of the pilot’s assistant. The first is to extend and exploit the state of the art in modeling and simulation, particularly in the modeling of human decision making, to support simulation of scenario and mission outcomes that provide the analytical forecasts necessary to perform situation assessment. The second is to represent the results of these analyses in an efficient knowledge base that can create assessments in real time, overcoming the difficulty of running large-scale analyses during mission execution.

The output of the CARP application will be sets of behavior envelopes that align expected observations with assumptions about adversary goals and tactics. These envelopes will provide a knowledge base that allows the pilot’s assistant to rapidly identify mismatches between assumptions, awareness, and observations. CARP will produce this efficient knowledge base through collaborative exploration of predictive behavior spaces, using a guided user interface for experimenting with realistic simulations and summarizing their predictive outcomes. CARP’s simulation testbed will be a robust integration and adaptation of predictive simulation systems and models. The testbed provided by CARP will allow the use of the most accurate available models, together with tools to support and adapt model parameters to improve predictions, and then to aggregate simulation results into behavior envelopes, which encapsulate expected observed behaviors in varied situations. To prove the concept, we are working in collaboration with TiER I and EduWorks, who are developing innovative technologies for high fidelity simulation-based modeling of adversary decision making. The paper describes our work to date, including challenges met and advances made. It also discusses our integration plans for the tactical environment evaluations, which will be the capstone event to the efforts.

Approach 3: Toward a Tactical Pilot's Assistant: A Framework for Integrating Agent-Based Models

Historically, cognitive modeling has been an exercise in theory confirmation. "Cognitive architectures" were advanced as computational instantiations of theories that could be used to model various aspects of cognition and then be put to empirical test by comparing the simulation-based predictions of the model against the actual performance of human subjects. More recently, cognitive architectures have been recognized as potentially valuable tools in the development of software agents—intelligent routines that can either mimic or support human performance in complex domains. While the introduction of cognitive architectures to what has been regarded as the exclusive province of artificial intelligence is a welcome turn, the history of cognitive modeling casts a long shadow. In particular, there is a tendency to apply cognitive architectures as monolithic, one-off solutions. This runs counter to many of the best practices of modern software engineering, which puts a premium on developing modular and reusable solutions. In this paper, we describe the development of a novel software infrastructure that supports interoperability among cognitive architectures. Our motivation is to allow the analyst to choose the right tool for the job, so to speak, by promoting the decomposition of agent behaviors so that cognitive architectures can be applied in a piecemeal manner with the requirements of the behavior driving the choice of architecture. In this way, we stand tradition on its head and compel the analyst to think carefully about the various ways a behavior might be modeled and, by extension, how those models are best encapsulated so that they can interoperate. After describing the infrastructure, we report on an ongoing effort to use it for the development of a complex "tactical pilots assistant." We are collaborating with researchers at Soar Technologies and Eduworks to understand how otherwise distinct agent technologies might be combined. Specifically, we are exploring how a model of agent perceptions can be combined with a diagnostic reasoning module to assist a pilot in generating and verifying expectations about a tactical situation. In addition to overcoming the practical challenges of model integration, this effort entails a richer theoretical challenge of determining a useful division of labor among agent models and the human pilot they are designed to support.

Author Bios

Dr. Winston Bennett, Jr. is the Technical Advisor for the Warfighter Readiness Research Division located at Wright Patterson AFB Ohio. He is an Air Force Research Laboratory Research Fellow and a Fellow of the Association for Psychological Science, the Society for Military Psychology and the Society for Industrial and Organizational Psychology. He is currently leading research developing methods to monitor and routinely assess individual and team competencies and performance across live and virtual environments and evaluating game-based approaches for training, work design, and job restructuring. He is an Associate Editor for the journal Military Psychology and serves as a contributing editor and/or as a reviewer for other professional journals. He received his Ph.D. in Industrial Organizational Psychology from Texas A&M University in 1995.

Randolph M. Jones is a co-founder and Senior Artificial Intelligence Engineer at Soar Technology. He has over 25 years of experience building scientific and applied human behavior models, including psychological/cognitive models and human-like intelligent agents. He has led the development of several knowledge-acquisition and high-fidelity behavior modeling techniques, as well as knowledge-representation schemes for knowledge-rich, efficient, interactive, intelligent systems, which have produced a wide variety of cognitive models and intelligent agents for Air Force, Navy, Army, DARPA, and other defense agencies. Dr. Jones received his PhD in Information and Computer Science from the University of California, Irvine.

Robert Bechtel is a Lead Scientist with Soar Technology, Inc. He has over 35 years of experience applying advanced computing technologies to problems in the defense and commercial sectors. At SoarTech, he is a principal investigator and project manager in the Unmanned Platforms business area. Prior to joining Soar Technology, he was Senior Scientist at Eclectic Computing Concepts, leading projects in battle effects assessment for JWAC and CENTCOM, and directing a team in creating an intelligence analyst workstation for a non-US intelligence service. Dr. Bechtel's PhD is in Information and Computer Science from the University of California, Irvine.

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Walter Warwick is a Principal Scientist at TiER1. He brings a deep interdisciplinary perspective to the development human behavior representations. One of his first efforts was to implement a framework for representing Recognition Primed Decision making in task network modeling environments. Later, Walter led a series of efforts to integrate the ACT-R cognitive architecture within the task network modeling tools IMPRINT and C3Trace. The research supported task decomposition to the "cognitive level" while providing a uniform and intuitive development environment for two otherwise disparate modeling methodologies

Matthew Walsh is a Senior Scientist at TiER1. He is an expert in cognitive science with over 10 years of experience modeling learning, memory, and human performance. He has developed computational models of knowledge acquisition, retention, and re-learning. Matt has also implemented more applied models including a computational cognitive model to perform functions of the Air Tasking Order Manager in Air Force training exercises.

Stu Rodgers is a Managing Director at TiER1. Stu has participated in research projects across multiple Department of Defense services laboratories, NASA, and DARPA. These projects have focused on human performance modeling and analysis. He has expertise in heuristic search, computational cognitive process models, human performance modeling, and knowledge representation.

Key Words

Agent-Based Modeling, Human Behavior Representation, Model Integration, Tactical Pilot's Assistant

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