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IT²EC Extended Abstract *Presentation/Panel*

Digital Twin-Inspired Models of Socio-Technical Systems: A New Implementation of Work-Practice Modeling for Air Combat Simulation

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Abstract — This paper presents an enhancement to the digital twin approach that models work practices such as interactions between manned and unmanned aircraft; or across air control agencies deconflicting a busy battlespace. Our premise is that such methods can overcome limitations of current approaches that fail to properly simulate denied or disrupted environments, by capturing work practices of the socio-technical environment. We extend the digital twin construct to capture multiple entities and how they systemically interact and are interdependent. Our work is premised on the Brahms model and its underlying theory of work practice modeling of socio-technical systems, but we introduce a modern computational engine to scale this technique to broader digital twin interpretations, which can support richer Reality-Simulation-Reality cycles and more effectively support Train, Reflect, Learn and Train Again. We review the Brahms approach and how our extension of digital twin models is applied to socio-technical systems. We discuss Brahms-Lite and present an application to air combat simulation. We conclude with a discussion of how this technique can be applied more broadly to extend digital twin approaches in simulations of complex environments under nominal and denied conditions.

1 Introduction

Simulating how people and systems work together under both nominal and denied conditions requires new approaches that build on and expand "digital twin" constructs. Simulations must, for instance, train operators in detecting, countering and fighting through the adverse effects of communications disruptions. This paper explores a modeling approach and computational tool designed to capture and reflect socio-technical processes needed to train today's forces to be proficient in denied or contested environments.

2 Digital Twin Approach

A digital twin is a virtual model that mirrors physical world persons, devices, systems or processes. We expand this view to model not only individual entity behaviors but also the processes and data that capture their *interactions* and *interdependencies*. For instance, training scenarios should model how denial effects can disrupt not only a discrete digital twin, but also simulate and predict the adverse effects of coordination lapses on the systemic effectiveness of operators and their intelligent systems.

A premise of this work is that a socio-technical modeling enables digital twin approaches to more richly capture how people's understanding of context develops during activity and through interactions with other actors and information sources. Our approach reflects a broad meaning of "context" that includes what a digital twin is doing physically and mentally, how it is conceiving what it is doing (often less defined than tasks and procedures), what it is perceiving in the environment, and how the digital twin moves and interacts in the simulated setting.

We implement this enhanced digital twin approach using an agent-based modeling framework, developed by the US Government, called Brahms. Brahms is based on socio-cognitive theories of perception, inference, communication, and collaboration, and employs an activity-based approach that represents how functions are carried out in practice [1]. Brahms emphasizes the interactive behavior among people, systems, and the environment to understand and simulate emergent outcomes.

3 Brahms-Lite: A Re-Implementation

While the underlying process models and data structures in Brahms are well-suited to our enhanced notion of a digital twin, the Brahms computational environment's realtime performance is limited by a resource-heavy architecture, which was well-suited for the purposes it was originally designed to fulfill, but is inadequate for developing digital twin, socio-technical models of complex, realistic tactical scenarios. Legacy Brahms also supports visualization of a single "run", generating inspectable log files from one scenario, executed from a specific set of initial conditions. A robust exploration of the space of training scenarios, however, requires visibility into the aggregated findings from collections of runs that the legacy Brahms software does not support.

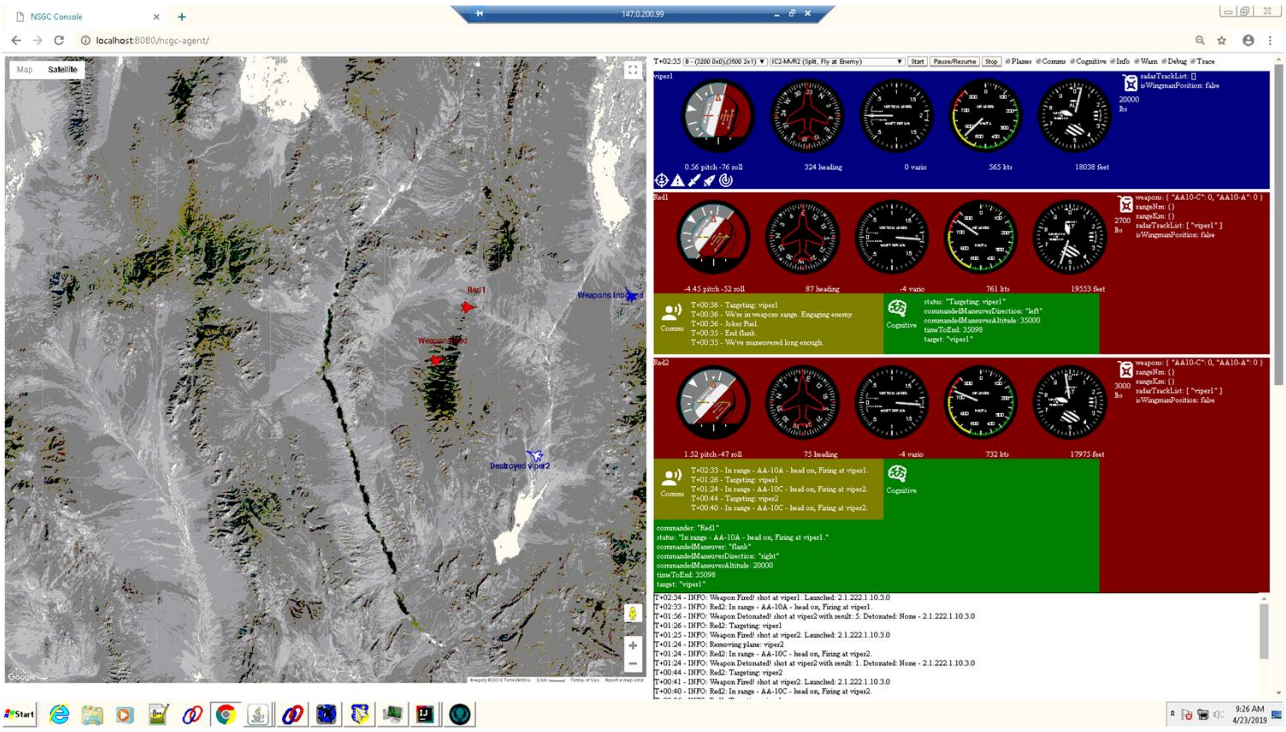

Fig. 1. Brahms-Lite dashboard.

To address these limitations, we developed Brahms-Lite, a modeling and simulation environment that: (1) supports collecting and visualizing aggregated data from multiple runs; and (2) encapsulates the Brahms model in a modern, supported, efficient and interoperable computational framework. Brahms-Lite preserves the activity-based theoretical construct and basic data structures and process models that power the legacy Brahms environment.

We developed the original Brahms models to demonstrate simulating anti-access/area denial (A2AD) attacks in air-to-ground attack scenarios [2]. Our subsequent implementation resulted in an aggregation and visualization tool to analyze findings collected over multiple runs [3]. This work was the foundation of Brahms-Lite. In the next section we summarize recent work applying this framework for air-to-air combat scenarios to illustrate a broader interpretation of digital twin to model socio-technical systems.

4 Case Study: Brahms-Lite for Air-to-Air Combat Agents

The U.S. Air Force Research Laboratory (AFRL) has been developing a simulation testbed to experiment with new techniques for creating computer-generated forces (CGFs). The Not-So-Grand-Challenge (NSGC) project (also called the “Rapid Agent Development Framework”) is developing a common context for model development and demonstration, with a goal of using real world data in the model development process. The approach is to explore and demonstrate efficient methods of constructing realistic behavior models in a manner that is generalizable across individual agent architectures [4]. The domain for NSGC is air-to-air combat, using 2-v-2 tactical scenarios.

The Brahms approach to work practice modeling is well-suited to this application because of the multiple interdependencies that obtain in a tactical combat sortie among pilots in the element and systems (sensors, weapons, navigation and communication) and Brahms’ capacity to capture these factors in a socio-technical model. To employ Brahms-Lite, we replicated Brahms’ data structures (work frames, thought frames) and process models (beliefs, actions) (see [1]) to create models of realistic pilot behaviors and integrate the models with the NSGC testbed described in [4]. Our dashboard (Figure 1) presents a tactical map and individual panels revealing system status information as well as digital twin actions (Figure 2) and communications (Figure 3).

In a recent experiment, the NSGC testbed was used to run a series of 2-v-2 scenarios using models created from eight different agent architectures [4]. Agent performance was evaluated across nine dimensions. Although the experiment was not a competition, and the principal finding was that the testbed is an effective mechanism for accelerating agent development and model realism across multiple agent architectures, the Brahms-Lite model achieved the highest overall score and the highest categorical scores in 7 of the 9 dimensions.

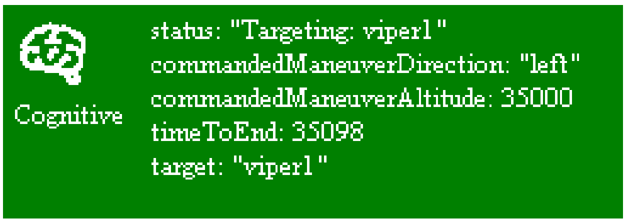

Fig. 2. Dashboard panel displaying agent actions.

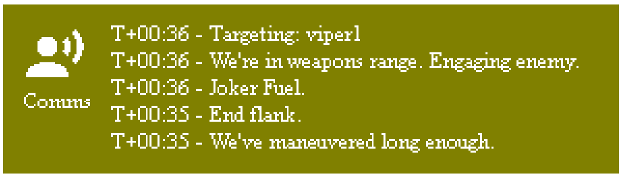

Fig. 3. Dashboard panel displaying agent communications.

5 Conclusion

The digital twin approach can be enhanced by modeling work practices such as interactions between manned and unmanned aircraft; or across air control agencies deconflicting a busy battlespace. Such an extension of the digital twin construct can overcome limitations of current approaches that fail to properly simulate denied or disrupted environments, by capturing work practices of the socio-technical environment. In this paper we describe an approach that models multiple entities and how they systemically interact and are interdependent. Though the work is premised on the Brahms model and its underlying theory of work practice modeling of socio-technical systems, we created a modern computational engine to scale this technique to broader digital twin interpretations. We applied this extension of digital twin models to air combat simulation, with preliminary but promising early results. This technique is not specific to air combat nor any other application domain and can be readily applied more broadly to extend digital twin approaches in simulations of complex environments under nominal and denied conditions. This paradigm can thus enhance Reality-Simulation-Reality cycles and more effectively support Train, Reflect, Learn and Train Again.

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Author/Speaker Biographies

Dr. Benjamin Bell is the president of Eduworks where he leads simulation, training, and decision support development. His research has addressed simulation for training and education for K-12, higher education, military, and national security applications. He has held faculty positions, chief executive positions in industry, and leadership roles for several international conferences. He is an adjunct professor at Embry Riddle, holds a PhD from Northwestern, and is a graduate of the University of Pennsylvania.

Fritz Ray is the CTO of Eduworks and lead contributor to the open source Competency and Skills System (CaSS) project. Mr. Ray is a periodic contributor to several learning specification bodies including IEEE LTSC, Schema.org, xAPI, and CTDL/ASN. He holds a B.S. in Software Engineering Technology from the Oregon Institute of Technology.

Kristin Wood is a Software Developer at Eduworks Corporation. Her work focuses on competency-based training and the use of technology to improve training development. She holds a B.A. in Anthropology and Spanish from the University of Tulsa, an M.A. in International Education from New York University, and is completing a Post-Baccalaureate in Computer Science at Oregon State University.

Dr. William J. Clancey is a senior research scientist at the Florida Institute for Human and Machine Cognition. His research relates cognitive and social science in the study of work practices and the design of agent systems. He has developed AI applications for medicine, finance, education, robotics, and spaceflight. He received a PhD in computer science at Stanford University and a BA at Rice University.

Dr. Winston "Wink" Bennett is the Airman Systems Directorate Readiness Product Line Lead. He is a Senior Research Psychologist in the Warfighter Readiness Research Division, 711th Human Performance Wing Air Force Research Laboratory. Through more than 25 years of service in the Air Force research community, he has achieved international recognition as a leader in education, training, and performance measurement research. He has led numerous research products that have since become part of the operational military community and have significantly improved mission effectiveness. He pioneered training, education, and measurement technologies and transitioned research results to operational military, scientific and commercial communities that have produced groundbreaking training technology and research and serve as a foundation for other researchers and practitioners to follow. He is a Fellow of three research societies and the Air Force Research Laboratory.