Rapid Adaptive Realistic Behavior Modeling is Viable for Use in Training

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ABSTRACT: *For many years it has been recognized that the design, development, and execution of adaptive threat generation systems and the use of rapid modeling techniques within applied research and training environments poses many methodological and integration challenges. With support from the Air Force Research Laboratory, 711th Human Performance Wing (711/HPW) Warfighter Readiness Research Division (WRRD) at Wright-Patterson Air Force Base, Ohio, through collaboration with Tier1, Aptima, Charles River Analytics, CHI Systems, SoarTech, Alion, and Stottler-Henke, and AFRL's Performance and Learning Models (PALM) branch, Phase I of the "Not-So-Grand Challenge"(NSGC) was launched to assess the critical issues facing current and future threat generation systems, the models used in them, and the extent to which current behavior and systems modeling architectures could provide military training with flexible, adaptable accurate/credible models of human behavior and realistic threats.*

1. Introduction

The current and future logistical and fiscal constraints within the Department of Defense (DoD) will drive the technological developments in simulation-based warfighter training. Today's strategic environment, in support of national security, mandates a paradigm shift toward a more modular, interoperable, scalable, and adaptive mindset (United States Air Force, 2004). To achieve such, the DoD is working to transform education and training through development, deployment, and utilization of adaptable, modifiable, capabilities-based training programs. Faced with rapidly evolving, asymmetric warfare, training systems and programs need to facilitate a warfighter's ability to respond quickly and adapt effectively. Therefore, the new dictum is that future threat generation systems, modeling techniques, and performance measurement methods must be agile and respond realistically enough to cultivate, in kind, a similar rapid responsiveness from the warfighter (Doyle and Portrey 2011); enabling forces to take an adaptive stance (Grisogono, 2010). After all, while "we train like we fight", we also "fight like we train." This research serves as a foundation in the development of more adaptive, less-scripted and more realistic constructive forces for increased dynamic capabilities in training scenarios for use in Distributed Mission Operations (DMO) Live Virtual Constructive (LVC) training and research environments as well as operational communities.

To facilitate this need, the Warfighter Readiness Research Division (WRRD) organized a Not-So-Grand Challenge (NSGC) with selected industry and internal partners. The challenge: to come up with solutions to the modeling architectural challenges facing current and future simulation training systems. The approach used to develop and assess the agent models consists of three stages: 1) development of data and integration methods for modeling, 2) integration of data into the models, and 3) evaluation of the models when integrated and used in full-up existing constructive environments.

2. Approach

For Phase I of the NSGC effort the Training Research Team's primary objective was to evaluate the capability of government and commercially available architectures to enhance military training with believable behavior models that can either measure and/or mimic human behavior. A simple example would be real-life enemy aircraft maneuvers recorded, passed through a modeling architecture which then translates it into a Computer Generated Force (CGF) for use in a training simulator. This would save scripting time of the maneuver into a threat system.

In this phase, it was determined that various architectures are able to use virtual and real world information to rapidly generate situational responsive, realistic red force behaviors. Another objective was to research the possible types of assessment criteria (i.e., Verification and Validation; V&V) needed to define levels of successful model integration within a threat generation system.

2.1 Approach to V&V

The Training Research Team adapted a model, integration, interoperability, and V&V process based on methods from Petty (2010) and Wang, Tolk, and Wang (2009). Initial specifications and requirements for the use, purpose, and function of the models and corresponding metrics were also used to determine training usefulness. Typically the purpose of a model drives the validation criteria of that model. In this case though, in order to make the development and assessment of these models tractable and repeatable, two common scenarios where put forth for the teams to design toward and stakeholder centric metrics were used to determine the utility of each modeling approach.

Assessment criteria (not all inclusive)

- Promote the use of a modular system design
- Use common applications, references, and operational capabilities
- Develop for usability, reusability, and generalizability
- Sufficient level of operational realism (realism/validity)
- Interoperability of models and systems in preparation for a federation of models in Systems of Systems (SoS); and scalability
- Composable by common users without the need of specialized skills or use of propriety software/systems outside AFRL systems.
- Allows for incorporation of changes to doctrine, i.e., new Tactics, Techniques and Procedures (TTPs) derived from lessons learned.

Validation has two main components: 1) structural validation; an internal examination of the assumptions, architecture, and algorithms in the context of intended use; and 2) output validation; how well the results compare with the perceived "real world." In this case, validation mostly examined the representational accuracy of the executable model's ability to produce and reproduce realistic adversarial behavior in context.

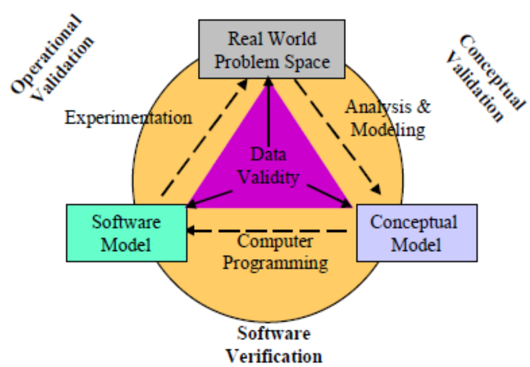

Figure 1. Essential Techniques for Military Modeling and Simulation (Smith, 1998).

The verification process, partially executed in NSGC Phase I, is used to determine if a models' functional requirement/s actually meet the need of a specific well-defined function or purpose. When using models for measurement, as agents in simulation and training systems, the verification examines transformational accuracy through the model development process; from concept to the actual use in context. Simply expressed this is the transformation of requirements (functional need) into a conceptual model (descriptive functional properties), then into an executable actionable model (executable functional properties), like software engineering (See Figure 1). For a sample list of the Model and Architecture Viability measures used see Table 1.

Table 1. Measures of Architecture and Model Viability for use in Training Systems.

Architecture
Architecture stability
Available to the public (non-proprietary and modifiable)
Usability (ease of integrating existing performance data into the modeling architecture)
Adaptability (time to develop/update and implement a human behavior into the model)
Network protocol requirements met (Distributed Interactive Simulation ; DIS, High Level Architecture; HLA)
Model
Capacity to generate believable CGFs
Realistic model behaviors measured against intended use
Re-usability of the model
Fidelity - model's ability to accurately represent specified behaviors
Generalizability of the model (i.e., to what level is the model agnostic with respect to a Framework or Architecture?)
Under what conditions does a model's credibility, believability, and reliability break down?
How easily can data be injected–is the model highly data base structure dependent
Is the model's behavior transparent to users not involved in the core modeling process

Note. Candidate Measures of Architecture and Model Viability for use in Training Systems. Modified from Department of the Air Force, 1996; Petty, 2010; Department of the Army, 1999.

2.2 Not So Grand Challenge

In Phase I, the Training Research Team, along with the NSGC partners, defined a set of requirements for rapid development modeling systems that could be used in threat generation systems and for adaptive training and research systems.

To create a tractable, traceable problem space, the team, along with F-16 SMEs, chose, defined, and facilitated the use of two F-16 air-to-air scenario scripts, which used three common adversarial maneuvers. These scripts were documented in detail and provided to the NSGC partners. Maneuvers were recorded in Distributed Interactive Simulation (DIS) protocols where objective measurements such as time, space, and positional information (TSPI) could be collected by the models or through the Performance Evaluation Tracking System (PETS). A modular, multi-threaded application, capable of robustly handling high volumes of networked entities via various simulation protocols (e.g., DIS, High Level Architecture; HLA) which calculates measurements at the team, inter-team (package), and teams-of-teams (force) level of analysis (Watz, Keck, & Schreiber, 2004; Portrey, Keck, and Schreiber, 2005; Schreiber, Stock & Bennett, 2006).

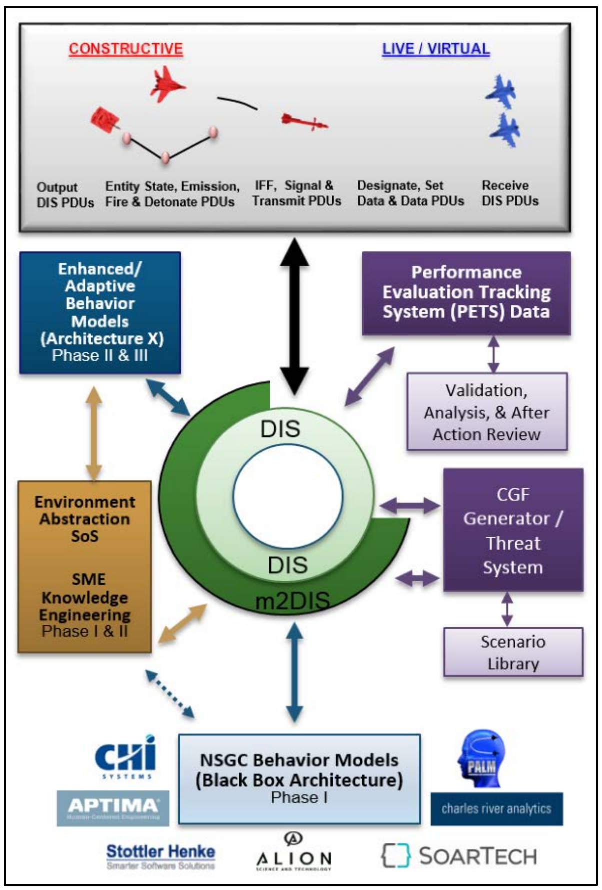

Figure 2: NSGC LVC DMO Modeling, Testing, and Training Environment (Doyle et.al. 2014).

NSGC was envisioned to contain three or more Phases (see Figure 2 and Table 2). In future Phases of NSGC, DIS data will be collected, via a distributed network, from a manned threat simulation system as experienced 'adversary' pilots fly against 'friendly' pilots. This information will be used to further test and evaluate the validity of the models for use in stakeholders serving as experienced observers, along with training pilots, will experience both modeled and live adversaries. Then assessments will essentially seek to determine if stakeholders were able to tell the difference between adversary models and live pilots executing adversarial maneuvers, essentially a version of the Turing Test.

While early design concepts and metric development worked to take into consideration as many of the stakeholder's needs, wishes, and desires as possible, developers were busy dealing with the reality and physics of it all. It was recognized early on that since there are differences between the development and proposed uses of most physics-based systems and that of behavior-based or cognitive-based systems, there too must be differences in development, modeling and measuring such systems. Sometimes in the cognitive, behavior, learning, training, and the research and performance modeling realms, metric strength can be lost in the process of translation. Determining causation by tracing particular event outcomes, in a one-to-one fashion to the original causal factor, or set of culminating events, can be less than a straightforward process; probably the single greatest challenge during validation.

So, during the initial design phase, it was decided that, at least in the case of realistic red force development, testing, and use, the team would separate agent behavior/cognitive-based model functions and the modeling process from the platform flight model and flight model development process. Separating the cognitive/behavior models from the physics-based models allowed for a black box method of development, integration, and testing, ensuring partners could keep their proprietary information while still following the common protocols for development and output. Naturally bounding behaviors modeled by the laws of physics/virtual physics through use of the Networked Integrated Combat Environment (NICE) threat system.

Table 2: NSGC Phases and current status (Doyle et.al. 2014; Mittal, Doyle, & Portrey, 2014)

NSGC Phases	Objective	Status
Phase I	Evaluate multiple behavior modeling approaches for constructive entity modeling in complex air combat systems in LVC domain at AFRL	Successfully completed
Phase II	Develop Environment Abstraction for advanced situation awareness and semantic interoperability	In process
Phase III	Invite various participants to display advanced constructive entity behavior for maximum combat realism	Planned

The NICE constructive threat system is a real-time software simulation for modeling constructive forces (i.e., CGFs) in a virtual environment. NICE performs physics-based modeling of real world systems in areas such as platform motion, weaponry, and sensor operations. NICE interfaces are designed to support DMO, primarily focusing on the LVC exercises. The system is compatible with standard data formats used to communicate between applications during these exercises, outputting and receiving network data packets in accordance with the DIS Standards as documented in IEEE 1278.1-1995, IEEE 1278.1a-1998, and IEEE 1278.1-20XX Draft 15 (Hofer and Loper, 1995). This new threat system architecture is modular to promote flexibility for integration with future projects and better support software maintainability.

2.3 NSGC Phase I V&V

Validation answers the question: "Did you build the right thing?" and Verification answers the question: "Did you build it right?"

Validation and verification (V&V) studies were done at two levels. The first level was at the level of physics (i.e., the airframe), because it is important that the modeled red forces and their vehicles do not violate the natural laws of physics. The next level is at the psychological, performance, conceptual modeling of the constructive entity. Taking a dualist approach to the design allowed for first level physics-based requirements and assessment to be addressed by the NICE infrastructure, therefore the NSGC Phase I effort focused on the V&V of conceptual modeling of constructive entity behaviors. Validation tested constructive entity behavior as implemented by the agent models

The agent models were to demonstrate behaviors associated with the two scenarios: Visual Identification 6 (VID-6) and Sweep-2. Since modular design was used, each team's model is being treated like a black box. Therefore during Phase I, Verification studies primarily amounted to testing the implementation of conceptual models to executable code. The responsibility to execute software-related verification methods, for the moment, rested with each team. However, part of the verification was done through use of the model-to-DIS (m2DIS) Interface, described in more detail in the next section, which abstracts away some low-level functionality that typically would be implemented in a constructive entity behavior. All the participants were mandated to use the m2DIS Interface to enable their constructive entities to execute behaviors with the NICE infrastructure (Watz, 2012).

2.3.1 Summary of Desired Red Force Behavior

Per the F-16 SMEs, listed below are a summary of desired red force behaviors that would increase believable behavior during a scenario (not all inclusive):

- Prosecuting local numerical advantage: the Red group should attack the nearest Blue player and exhibit Radar Warning Receiver (RWR) awareness
- Building Blue formation picture awareness: If RWR no longer indicates a Blue radar lock and picture situation awareness (SA) indicates no Blue player in position to immediately fire, a Red player would turn to recommit.
- Influencing turn direction: When pursuing a cold Blue player, Red forces should attempt to influence a Blue turn into a cooperating wingman or element. If two or more Red entities are chasing a cold Blue player, they should open in azimuth so the Blue player must assess turn direction, cannot turn hot and threaten both, and may not be able to preserve minimum desired range from both.
- Splitting defenses: Red strikers should sometimes attack from different axes, attempting to divide the attention of Blue defenders. Undetected striker groups should lean away from Blue defenders if aspect indicates Blue forces are pursuing Red counter-air forces; such a maneuver avoids Blue radar search and typically, opens range against the defenders.

The next section elaborates on the NICE to m2DIS application-programming interface, and concepts like Environment Abstraction that allows accessing information in the environment in a semantically rich manner.

2.4 The Integration Environment

In order to use and integrate any modeling architecture and the specified agent model in an adaptive constructive training environment, by default, each modeling team accounts for interoperability at three levels. That is the syntactic, semantic, and pragmatic (Doyle et. al., 2014; and Mittal, Doyle, and Portrey 2014; Mittal et. al., 2008). (See Figure 3).

Collaborators typically complied with syntactic interoperability, largely technical integration with the DIS layer of the network. Even though almost all of the modeling teams already have mature proprietary DIS adapters and a semantic perception layer, in order to achieve semantic interoperability, a common understanding and shared meaning of various data elements, was needed.

In order to facilitate semantic interoperability with the NICE infrastructure, the Training Research Team developed an m2DIS Application Programming Interface (API) that provides a common terminology. The objective of m2DIS API was twofold. First, it served as a starting point to introduce semantics and additional abstractions over the DIS Protocol Data Units (PDUs). Second, while each team was free to subscribe to DIS through their proprietary middleware, publishing to the NICE infrastructure over the DIS network mandated the use of the m2DIS publishing API, by default ensuring semantic interoperability at a partial level (publish), making the m2DIS API the only mechanism by which modelers could leverage the NICE physics-based environment (Doyle et.al., 2014; Mittal, Doyle, and Portrey, 2014).

The m2DIS API achieved syntactic interoperability and partially achieved semantic interoperability. Current plans envision further development of the m2DIS layer which will further promote semantic interoperability via Environment Abstraction (EA; Mittal, Doyle, and Watz 2013; Watz and Doyle (TBD). A process which also supports mimicking the behavior of the Air Battle Management (ABM) role in a mission; effectively creating Tactically Aware Agents (TAAs), also providing CGF Red Force agents with the tactical picture. EA is geared to achieve complete semantic interoperability at the agent-platform-system level. If NSGC partners are supplied with current taxonomic information about all possible and probable actions that can be acted out in a scenario, semantic interoperability could more readily be displayed by each modeling team in future Phases of NSGC activities. Then we will work toward achieving pragmatic interoperability in a training context.

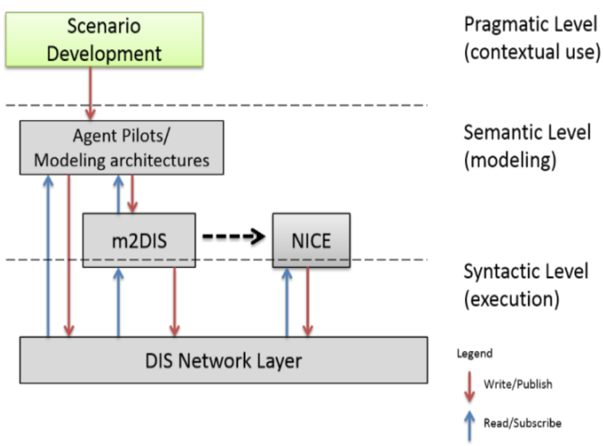

Figure 3. Towards Semantic Interoperability (Mittal, Doyle, and Portrey 2014)

3. Future Directions

The current state of affairs, with respect to behavior modeling and automated real-time metric collection in the development of constructive models as well as the need for dynamic adaptive systems for training is growing. While there is a need to create believable constructive entity behaviors to improve the immersive learning experience of users, researchers must also strike a balance to retain sufficient tractability and traceability in order to effectively evaluate training outcomes in an objective manner. A capability, which until now, has proven difficult because natural acting systems produce behaviors that "seemingly" emerge from complex dynamic agent-agent and human-agent interactions. Therefore to retain tractability/traceability our current strategy is to develop and use modular tractable behavioral components (Doyle et.al, 2014).

The team views the steps taken in the Phase I and the subsequent Phase underway as very exploratory in nature. However, the venue in which to integrate these processes, to further research in training, is very dynamic and complex, so the team is driven to continue formulating and using formal and semi-formal methods of evaluation and integration of models for use in applied training and research environments. The team plans to continue their venture into rapid modeling development assessment by tackling the questions listed in Table 3.

Table 3. Future Candidate Measures

Candidate Measures
If needed, can the models output be traced to input to determine a logical chain of causality
Can the model perform without creating interferences in a federation of models—Is the model compatible with other models with respect to interoperability and sharing functional capacities when required to do so
What is the model's level of domain independence
Can the model support data acquisition and understanding of an individual's intent, behavior, or response
Can the model pass a Wizard of Oz or Turning type test —when replacing AI with Human SMEs and comparing results
Does the model support or exploit automated measures capture
Does the model support real-time or near real-time data analysis
Does the model execute, fine grained critical mission actions accurately
Can the model, when used for an intended purpose, positively affect training outcomes

Note. Summary of Future Candidate Measures of Model Viability for use in Training Systems, modified from By Order of the Secretary of the Air Force, 1996; Petty 2010; Department of the Army, 1999.

4. Summary

The Training Research Team set out to support the development of a process, and set of design and testing methods, the larger DoD Modeling and Simulation community would embrace and expand upon by providing contributions. Our desire to provide a platform and process for modelers from various theoretical and methodological backgrounds to come together and aid the development of what the warfighter so clearly needs (i.e., more realistic and highly adaptable modeling approaches), could not have been met with more enthusiasm.

The design, evaluation metrics, techniques, and methods used increased the viability and validity of using behavior models within synthetic training environments. The modular, adaptable, usable, generalizable approach taken also enhanced the impact of recent theoretical and methodological advancements made in modular systems design, semantic interoperability, and behavior modeling (Doyle et.al., 2014; Mittal, Doyle, and Portrey 2014; Mittal, Doyle, Watz 2013); stigmergy and the importance of instance based interaction when modeling behavior in systems (Doyle and Kalish 2004); dynamism, Discrete Event Simulation for Complex Adaptive Systems (DEVS-CAS; Mittal 2012; Wang 2009); theories concerning properties of weak and strong of emergent behaviors in systems (Doyle and Kalish, 2004; Mittal, Doyle, and Watz 2013, Mittal 2013, Mittal, Doyle, and Portrey 2014); and the use of affordances by observers to discern activities/events in systems that are seemingly intelligent or useful when matched with the roles and goals of artificial intelligent agents (Mittal, Doyle, and Watz 2013; Mittal, Doyle, and Portrey 2014). As well as the ability of models and systems developers to design systems in a straight forward manner which capitalizes on the reuse of underlying system components/methods in development of new systems. Meaning, similar methods and frameworks can be used across many domains and platforms, with a need to only ground the system within the domain semantically via a taxonomy that is platform, domain, and situation, and process dependent via SME knowledge elicitation.

The purpose of the Phase I activity was to lay a foundation for the design processes of future training research experiments using behavior modeling and intelligent constructive adaptive architectures/agents to enhance individual and team performance while training to accelerate the development of adaptive knowledge and skills in warfighters. This effort also determined what the interface and model execution controls needed to be between models developed outside an existing constructive environment, and for use in an LVC context or event. It also informed about the scope of the models' world and how that could be made into an interactive, intuitive development process; more accessible to the non-modeler SME, so they too can organically and intuitively make rapid adjustments to the models. The methods and tools developed and used in NSGC will also direct development and integration of adaptive tutors/mentors and synthetic wingmen in Learning Management Systems.

In the future, such a system could consist of on-line adaptations performed using an intelligent agent framework to respond and adapt to the warfighter's actions during a real-time LVC DMO training exercises as well as an off-line Global Tactic Aware Agent executing algorithms to effectively search through the space of adversary behaviors collected and stored in a database, exploiting information about what the 'adversary' resolute to expose fundamental weaknesses in warfighter's strategies and tactics when wargaming against a warfighter model. This type of information could be extracted from traces of simulation events from past/present training sessions or information gathered from the operation environment; i.e., real live adversary

There is a rich, unexplored field of intelligent training systems development processes that can support a whole host of new capabilities for the warfighter. We, as a community, should be able to continually leverage upon a parallel development and testing of systems to explore uncharted whitespace needs to be filled with various types of model and system based agent technologies. There is enough whitespace that almost every approach in our current sights will have an opportunity to fill some niche to enrich the training experience for the operator.

Along with the purpose of the NSGC, the team sent this challenge out to the larger community; "when working on the edge of new vistas in science and engineering, rarely does one individual or one team discover truth in theory or solidify methods or discover unifying processes that support the unveiling of ground truths or confidently determine what the new findings can and should be used for. It is usually only through collaboration, cooperation, and/or our own competitive nature that these very same scientific/engineering communities break new ground and gain stability in process, methodology, and use of new tools" (Doyle et. al., 2014).

If the current shortcomings are recognized, and consequently the collaborative teams ability to overcome such hurdles is any indication of our capability to conquer challenges of this nature in the near future, the state of the art for the use of behavior models in building realistic adaptive training systems will have achieved an evolutionary leap in practice through a technological and methodological paradigm shift in the application, integration, and semantic interoperability development and evaluation process.

The Training Research Team as well as many Industry teams now recognize that, in this realm of inquiry, while there may have been little if any agreed upon theories, methods, or validation approaches in use, for what was just attempted, at the onset of this venture, we as a community of practitioners are both enriched and codified in the knowing, that we do, as a larger community, have the capacity to do the seemingly impossible and take on many of these Not-So-Grand-Challenges in the future.

5. Acknowledgements

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