Human Behavior Models for Adaptive Training in Mixed Human-Agent Training Environments

Joost van Oijen
NLR – Royal Netherlands Aerospace Centre
Amsterdam, the Netherlands
Joost.van.Oijen@nlr.nl

ABSTRACT

Current trends in simulation-based military training show an increasing demand for artificial intelligence (AI) and data science technologies to offer more flexible and adaptive training solutions for military personnel in rich simulated training environments. This requires technologies capable of (1) measuring and assessing performance of trainees in real-time, and (2) simulating role-playing agents that can replace human role-players and adapt their behavior to guide learning experiences for a trainee.

The above requirements pose two challenges. First, current training systems often lack an understanding of the dynamic context of a trainee's behavior, which is required to judge its performance during training of specific missions, (part-)tasks or tactical situations. This context is typically only available in the head of an observing instructor. Second, behavior models for simulated role-players are often black boxes from the point of view of an instructional system and cannot easily be adapted for instructional purposes (e.g. exhibiting degraded performance or making deliberate mistakes).

In this paper we present a unified human behavior modeling (HBM) approach that addresses the above challenges. It is based on the idea that HBMs can be used to model roles for both human trainees and agents. For an agent, it acts as an AI model that produces behavior, equipped with predetermined adaptive variables. For a trainee, it acts as an observer that tracks and measures behavior being performed by that trainee. As a computational HBM approach, we examine the use of the Context-based Reasoning (CxBR) modeling paradigm, allowing context-specific behavior and performance modeling. The HBMs (1) support instructor-based and automated tutoring, (2) promote collaborative design of instructional systems between training designers, subject-matter experts and behavior modelers, and (3) allow for interchangeable roles between trainees and agents in training. We demonstrate a proof-of-concept of the HBM approach in the scope of a training system for military aircrew training.

ABOUT THE AUTHORS

Joost van Oijen, PhD is a Senior Scientist at the Royal Netherlands Aerospace Centre (NLR). Having a background in Computer Science and Artificial Intelligence, he has over ten years of experience in AI for modeling & simulation, both in the industry and academia. At his current position, Joost leads several R&D projects focused on human behavior modeling for training and decision support. Having a strong software engineering background, he is actively involved in the development of multi-agent systems and behavior modeling tools for military simulation systems.

Human Behavior Models for Adaptive Training in Mixed-Agent Training Environments

Joost van Oijen
NLR – Royal Netherlands Aerospace Centre
Amsterdam, the Netherlands
Joost.van.Oijen@nlr.nl

INTRODUCTION

Current trends in simulation-based military training show an increasing demand for artificial intelligence (AI) and data science technologies to offer more flexible and adaptive training solutions for military personnel in rich simulated training environments. Such technologies contribute to adaptive training in several ways:

- First, one can benefit from the use of simulated AI role-players (hereafter named agent role-players) that are capable of taking on the role of adversaries or team-members. In the context of military simulation, these are also known as Computer Generated Forces (CGF). The use of simulated role-players has the benefit of being able to replace human role-players, allowing for more flexible training schedules, requiring fewer personnel, and thus saving costs.
- Second, data analytics can be used to measure and obtain real-time objective data on trainee performance in the simulation, in regard to tasks or skills to be trained. Currently instructors often rely on subjective self-observations in order to assess trainee performance, either real-time during training or during after-action-review based on replays.
- Finally, there is a desire to tailor training scenarios to the skill level of the individual trainee, in line with upcoming training methodologies such as performance-based and adaptive training. This includes the ability to adapt the behavior of agent role-players for instructional purposes in order to guide the learning experiences for a trainee. Currently, agent role-player behavior models are often 'black boxes' from the point of view of an instructional system and are not always designed to be externally adapted.

In this paper we present a unified human behavior modeling (HBM) approach that combines the above capabilities in a synergetic modeling approach for adaptive training systems. The approach is based on the idea that HBMs can be used to model roles for both human trainees and agent role-players. For an agent role-player, it acts as a behavior model that *produces* behavior, equipped with predetermined adaptive variables for instructional control. For a human trainee, it acts as an *observer* that tracks and measures behavior being performed by a trainee in the simulation. The proposed approach (1) supports instructor-based and automated tutoring, (2) promotes collaborative design of instructional systems between training designers, subject-matter experts and behavior modelers, and (3) allows for interchangeable roles between human trainees and agent role-players in training.

In the remainder of this paper we start by sketching a background based on related work, followed by our contributions in subsequent sections:

1. We describe the theory of the HBM approach and its relation with instructional systems.
2. We examine a computational approach using the context-based reasoning (CxBR) paradigm.
3. We show how the approach can be used in conjunction with training design by using a case study in the domain of military air combat training.
4. We present a technical proof-of-concept for integrating HBMs in an existing training system.

This paper describes the first phase of a study towards the implementation of the HBM approach for adaptive training, focusing on the theoretical and technical framework. In the next phase of the study we will apply the framework using expert-validated adaptive training scenarios in the air combat domain, from a more sound instructional design point of view.

BACKGROUND

The work presented in this paper touches upon three areas of related research. The first area is concerned with behavior modeling techniques for CGFs. The second area is concerned with techniques for measuring and analyzing performance of human trainees in simulations. The third area relates to techniques for using adaptive agents in systems known as Adaptive Instructional Systems (AIS). Below these areas are shortly described, followed by a reflection on the relation to our work.

Computer Generated Forces

Computer Generated Forces (CGF) are autonomous military actors that are used in military simulation for training or decision-support applications (Abdellaoui et al., 2009). There is a wide range of different behavior modeling techniques and paradigms that have been used to model CGF behaviors. Techniques range from more practical control-based techniques such as scripts, state machine or behavior trees; to more behavior-oriented approaches based on human notions such as goals, beliefs an plans (e.g. the belief-desire-intentions (BDI) paradigm); to approaches that aim to simulate human cognitive processes, based on cognitive models and architectures (e.g. ACT-R, SOAR). Within NATO, several studies have been performed on human behavior representation and models for simulation, both from an engineering perspective (Lewis, 2019) and human factors perspective (Lotens et al., 2009). Specific to the air combat domain, behavior modeling for fighter pilots in simulation-based training is a well-researched topic (Doyle & Portrey, 2014), (Dong et al., 2019).

Performance Measurement in Simulation

The increase of simulation-based training facilitates the implementation of training methodologies such as performance-based or adaptive training where instruction can be tailored to the performance of an individual trainee. Human-in-the-loop simulations provide a controlled training environment where data can be gathered in real-time on the task performance of humans in a simulation, as well as on psychophysiological states they experience. Based on collected data, performance analytics can give insight into a trainee's technical and non-technical skills during training, and serve as a motivation for adaptations of the training environment. There exists many theories and methodologies for performance measurement in simulation-based training (Salas et al., 2009). Specific to the air combat domain, numerous studies have addressed performance modeling for both technical and non-technical skills and competencies of fighter pilots. For instance, (Arar & Ayan, 2013) proposed a framework for automated measurement of task performance, based on air combat performance metrics obtained from a simulation system. Tools such as PETS™ (Portrey et al., 2006) have been developed for collecting performance metrics from simulations to support pilot assessment research (Rowe et al., 2008) (Freeman et al., 2020). In (Mansikka et al., 2021), a performance model is introduced that integrates measures such as situation awareness and mental workload, in addition to objective task performance measures. In other studies, sensors external to the simulation have been employed to measure mental states such as cognitive workload using EEG (Mohanavelu et al., 2020), or engagement using data from head-mounted displays (Bell et al., 2021). The latter demonstrated a policy for adaptive instruction that can be used by instructors to restore detected lapsed engagement.

Adaptive Agents in Adaptive Instructional Systems

An Adaptive Instructional System (AIS) is "a computer-based system that guides learning experiences by tailoring instruction and recommendations based on the goals, needs, and preferences of each learner in the context of domain learning objectives." (Sottilare & Brawner, 2018). The use of adaptive agents as role-players in an AIS has been addressed in recent studies. (Freeman et al., 2019) describes a testbed for developing and evaluating adaptive agents for pilot training. A set of functions are identified for agents to enable them to be employed effectively in an AIS, related to tactical proficiency and instructional efficacy capabilities. In (van den Bosch et al., 2020), a framework is presented for an AIS that uses adaptive agents whose adaptations are controlled by a director agent. (Bell & Sottilare, 2019) examine the use of agent-based services to fulfill different functions within an AIS, one of which addresses adaptive role-players as constructive behavioral services.

Concluding

In relation to our work, the presented HBM approach does not conflict with specific technologies addressed in the above research. As a design construct, it is independent of a particular implementation for adaptive CGF behaviors or performance measurement models in a simulation. Rather, it focuses on unifying the HBM design of individual role actors to support instructional systems in (1) modeling task behaviors for agent role players, (2) modeling performance measurements for trainees and (3) integrating adaptive behavior variables for instructional purposes. We examine an approach to integrate these capabilities in a computational HBM using the Context-based Reasoning (CxBR) modeling paradigm (Stensrud et al., 2004). This paradigm allows breaking down complex behaviors into smaller units of behavior through compositional and hierarchical design, such that behaviors and performance measurements can be addressed in a context-specific manner, relating to specific training tasks, skills or competencies for a particular role. When combining these capabilities in a single model, the same model can be used interchangeably for driving role-player behaviors or measuring trainee performance.

A UNIFIED HUMAN BEHAVIOR MODELING APPROACH

In this section we describe the rationale of a unified human behavior modeling (HBM) approach to facilitate adaptive training in a mixed human-agent environment. To explain the role of an HBM for an adaptive training system, the illustration in Figure 1 is used. Below, we first sketch the adaptive training system. Afterwards we describe the HBM approach and motivate its role.

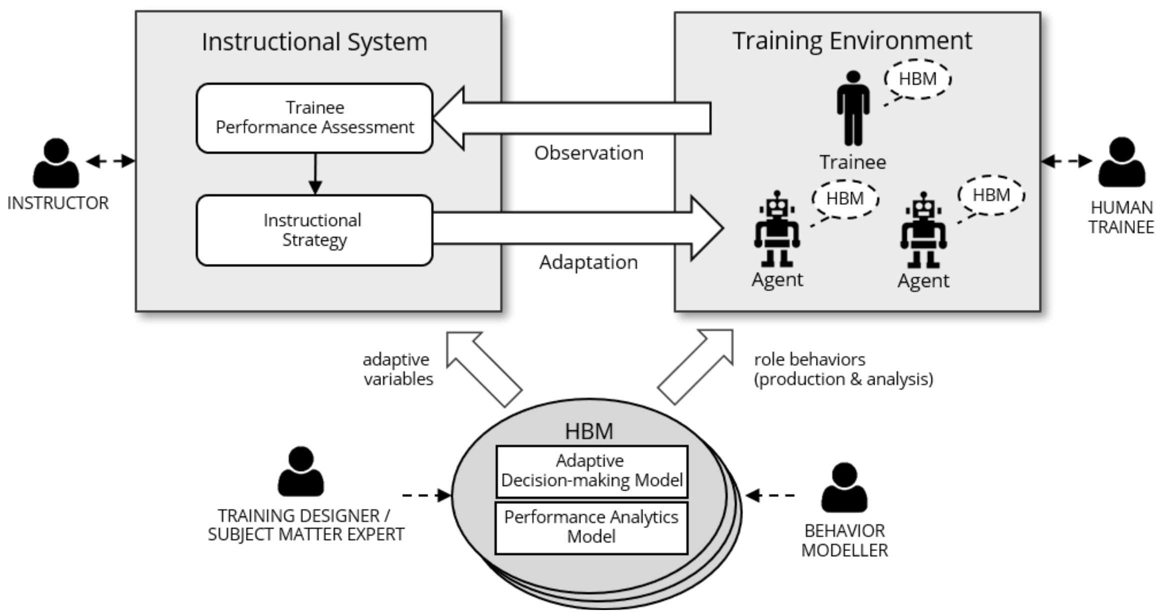

Figure 1: HBM Role in an Adaptive Training System

Adaptive Training System

The top half of Figure 1 sketches a basic adaptive training system, consisting of a Training Environment (on the right) and an Instructional System (on the left).

The training environment represents a (human-in-the-loop) simulation environment that can be populated by intelligent actors. These actors can represent human trainees or agent role-players. The agent role-players are capable of expressing task behavior in line with their assigned role in the environment (e.g. different team-member roles). They are driven by computational behavior (AI) models capable of replacing the role of human role-players in training.

A human trainee controls the behavior of a trainee actor that represents it's virtual embodiment in the simulation (e.g. through human machine interfaces offered by a simulator or virtual reality application).

The instructional system represents a computer-based training system that can observe and control the training environment in order to provide (adaptive) learning experiences for a trainee, in line with certain training objectives such as being trained on certain tasks, skills or competencies. The instructional system interfaces with the training environment by (1) being able to observe the behavior of trainees in order evaluate their performance, and (2) being able to adapt the training environment for instructional purposes (e.g. adjust the complexity of a training session). Such adaptation can relate to changing the state of physical elements of the environment, as well as changing the behavior of role-players (i.e. changing the cognitive state of agents).

The function of the instructional system is summarized by two processes shown in Figure 1, namely *Trainee Performance Assessment* and, based on the outcome of that assessment, the implementation of an *Instructional Strategy*, whose outcome orchestrates adaptations. The instructional system can be either be fully automated (also known as an Adaptive Instructional System), or controlled by a human instructor through an interface like an operating station (IOS) or dashboard.

Human Behavior Models

The bottom half of Figure 1 shows a set of HBMs where each HBM can be associated with an intelligent actor in the training environment (i.e. human trainee or agent role-player). The purpose of an HBM is to provide a single, unified computational model that combines two capabilities required for the implementation of the described training system:

1. **<u>Adaptive Decision Making model:</u>** An HBM includes a decision-making model that can be used to drive the behavior of an agent role-player in the training environment. Additionally, explicit adaptive variables can be defined that are used to control or influence the decision-making process during training. These variables can be exposed to an instructional system that can use them to initiate available adaptations.
2. **<u>Performance Analytics model:</u>** An HBM includes a performance analytics model that can be used to measure behavior performance of an actor role through quantifiable metrics related to performance indicators. For an instructional system, it provides real-time observation of trainees' performance measurements.

An HBM for an agent role-player can be said to play an *active* role in the simulation, as it uses its decision-making model to *produce* behavior. An HBM for a human trainee plays a *passive* role, as it is used to *observe* behavior using the performance analytics model. As a special case, another type of actor can be considered, namely an agent learner. An agent learner uses a decision-making model with machine learning capabilities. For instance, a reinforcement learning (RL) algorithm is employed to learn certain behaviors or tasks in the environment (a policy in RL terms). In this case, the agent can be considered as the 'trainee' in the context of an instructional system, requiring learning guidance through feedback signals (rewards in RL terms). The use of agent learners will not be addressed further in this paper. The concept of using human-inspired adaptive instructional systems (AIS) for RL agents has been explored in an earlier study (van Oijen et al., 2021).

The key motivations for combining the above capabilities into a single HBM design construct are as follows:

<u>*Capturing the cognitive dimension of the environment*</u>
The collective of all HBM-based actors in the environment can be seen to represent the *cognitive environment*, encompassing all intelligible actors in the environment. It exist together with the *physical environment* consisting of all physical elements such as terrain, infrastructure, weather, equipment and the physical embodiments of the actors. Many current instructional systems can only observe and adapt the simulation environment at the physical level: for instance, observing the physical state of a trainee or adapting the physical state of environmental elements. The additional cognitive level offers instructional systems a more 'intelligent' level of observation and adaptation. For observation, it can observe the active behavior of a trainee and potentially the (inferred) intention behind that behavior, associated with metrics on the behavior's performance. Consequently for control, it can adapt and influence the internal decision-making of agent role-players, allowing more intelligent adaptations in support of training.

Intelligent adaptivity by design

In the HBM, the extent of the level of adaptivity for an agent role-player is explicitly grounded in the behavior model through explicit adaptive variables. From an instructional design point of view, these variables can be seen as the 'control dials' for the system to adapt agent role-player behavior. The requirements for adaptive variables need to be taken into account at the start of the development process of an agent's decision-making model, as it can be hard to add adaptivity at a later stage when the models may have already turned into 'black-box' solutions. When agents are not able to support the desired adaptivity, the alternative approach (which is commonly used) is to perform a (temporal) manual take-over of an agent actor in the environment. However, as agents become temporarily 'disconnected', this can lead to inconsistencies within the agent's decision-making model when control of execution is returned back to the agent.

Promotes collaborative design

The design of an adaptive training system as sketched above is generally a collaborative effort between instructional designers, behavior modelers and subject matter experts (SME). Behavior models cannot easily be designed fully independently from instructional design. Designers and SMEs need to collaborate on (1) defining appropriate task models for actors; (2) on translating task performance indicators to measurable and quantifiable metrics in the simulation; and (3) on translating instructional needs for adaptivity to adaptive variables for role-players. These design aspects are addressed in more detail later in this paper. As the HBM combines these design efforts, this makes efficient use of required SME resources and makes it easier to support interchangeable roles between agent and human trainee actors.

APPLYING THE CONTEXT-BASED REASONING PARADIGM

A computational approach was investigated for the implementation of the proposed HBM design. The approach is based on the Context-based Reasoning (CxBR) paradigm (Stensrud et al., 2004). CxBR is an agent modeling paradigm for intelligent agents that focuses on tactical-oriented behaviors. It was originally proposed for modeling agents in environments where tactical expertise is required. CxBR is based on the idea that humans at any time only use a fraction of their knowledge, and that situational awareness (SA) and decision-making processes are highly driven by situational contexts.

Behavior models in CxBR are defined through a collection of contexts and transitions between those contexts. Within an active context, specific knowledge requirements and decision-making rules apply, tailored to that specific context. In CxBR, a top-level context is said to represent a *mission*. Consecutively, contexts can represent e.g. mission phases, tactical situations or (part-)tasks, which, if needed, can be decomposed further into sub-contexts. As an example, Figure 2 illustrates an example context topology for a CxBR model for an actor performing a mission in the air combat domain. It shows a decomposition of tasks related to achieving a particular mission.

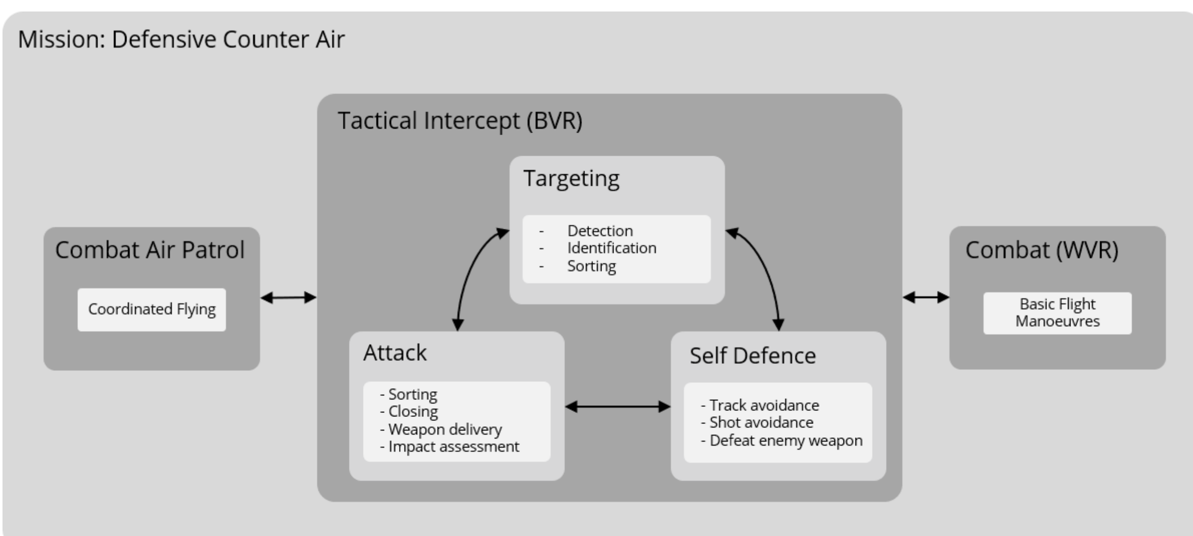

Figure 2: Example Task Model as a Context-based HBM.

The use of contexts provides a structured analysis and common language for a task domain and can easily be understood by designers and SMEs. E.g. in related work, CxBR has been employed in a graphical design tool to facilitate the acquisition of knowledge for military tactics (Castro et al., 2002). An attractive property of the CxBR paradigm is that it does not enforce any specific technology for the implementation of behaviors within a context. Behaviors can be implemented e.g. using scripts, finite state machines, cognitive models or machine learning approaches. Additionally, contexts can be reused across CxBR models.

In this study the CxBR paradigm is used to implement the two capabilities of the HBM approach that were presented in the previous section: providing (1) an adaptive decision-making model, and (2) a performance analytics model:

CxBR for Adaptive Agent Role-players

In its original design, the CxBR approach specifies the inclusion of context-specific decision-making models for agents. Additionally, it provides a built-in mechanism that can be used to define adaptive variables. In CxBR, these are denoted as so-called *moderators* that can be defined for contexts or their transitions. Moderators have been proposed to model aspects such as human mood and emotions that can affect decision-making rules and alter behaviors in a particular context (Stensrud et al., 2002). It is the responsibility of the behavior modeler to reflect the effect of moderator changes within the decision-making model. The moderators can be exposed to an external instructional system for (real-time) control in order to achieve an instructional intervention.

CxBR for Trainee Performance Measurement

Besides the original purpose of the CxBR paradigm to model agent behavior, we propose to employ the paradigm also for the measurement of behavior performance. From a training point of view, instructors would typically also employ some form of context-based reasoning when assessing the performance of a trainee, in the context of a specific mission phase, procedural task, or tactical part- or whole-task. For instance, when a trainee is currently performing a tactical maneuver (a context), an instructor would pay attention to specific behavioral cues or performance indicators that are relevant to that maneuver. In many training systems, contexts are usually only implicitly available in the head of an instructors. The CxBR approach can make these contexts explicit and capture performance measurements specific to individual contexts, consequently making these available to an instructional system.

Context Determination

As a computation model, a CxBR model has to determine which context or sub-context is currently active during execution, in order to execute the appropriate decision-making or performance analytics model specific to that context. Active contexts are determined by the context transition rules that can exist between contexts, or by universal transition rules that can be triggered from any context. It is up to the behavior modeler on how to define and implement transition rules, whether they are based on knowledge-based conditions or more advanced classifier algorithms. In conclusion, a well-design context topology serves as a reference task model for an actor’s role behavior, benefiting both the implementation of behavior production and measurement models.

TOWARDS INSTRUCTIONAL DESIGN

In order for CxBR-based HBMs to be used effectively for an adaptive training system, one needs to take into account instructional design aspects. To illustrate this, consider an example of an adaptive simulation-based training system to train fighter pilots in the air combat domain. In the system, human trainees can be trained in a simulator on tactical behaviors such as combat maneuvers, tactical intercepts or specific missions. In the training environment, agent role-players can act as virtual team-members or adversaries. From an instructional design point of view, designing CxBR-based HBMs requires translation from (often) informal, qualitative knowledge used by instructors, to more formal quantitative knowledge to be embedded in an HBM. Below, three of such required translations are discussed.

Translating task models to behavior contexts

Training scenarios are designed around a certain training objective for a trainee (or team of trainees). A training objective can relate to training certain competencies that can be trained through job-specific training tasks in a scenario. Competencies are the knowledge, skills and abilities (KSA) that are required to perform a job well. These may originate from an established competency model or a competency profile obtained from a training needs analysis (TNA). For instance, competencies for a fighter pilot relate to flying skills (e.g. aircraft handling, anticipation, scan pattern), information handling (e.g. maintaining situation awareness, sensor handling), weapon system handling (e.g. game plan execution, target identification, maneuvering), or communication. Training tasks are so-called part- or whole-tasks that represent concrete (mission-related) activities. Part-tasks are the tasks that can be trained in relative isolation of a mission context, such as basic flight maneuvers (BFMs), take-off/landing or refueling. Whole-tasks group a set of part-tasks that can be trained together, such as a tactical intercept or full missions such as a Defensive or Offensive Counter Air (DCA/OCA). In the design of a CxBR-based HBM, training tasks can be defined as individual contexts and composed in a context topology to represent the behavior in a mission. An example of such a design was given in Figure 2. The tasks can then be individually tracked and measured computationally during a training session.

Translating complexity factors to adaptive variables

From a training perspective, *complexity factors* are the factors that can shape or adapt a training environment in order to adjust the level of complexity of a training session or individual training tasks. In the example domain, complexity factors can relate to environment conditions (e.g. night time, visibility); equipment state (e.g. fuel, weapon load), threats (amount, tactical performance), contingencies (e.g. failures, damages, mission changes) or team-work (e.g. team-members' individual, collaborative and communicative abilities). Some of these factors relate to physical aspects in the environment, whereas other factors relate to cognitive aspects of intelligent role-players. Adaptation requirements for the former need to be translated to adaptive variables that are to be supported by the environment simulation system that is used. Adaptation requirements for the latter should be translated to adaptive variables for CxBR-based HBM models. Behavior modelers can then take them into account in the development in order to prepare the behavior models for real-time adaptation.

Translating performance indicators to measurable metrics

Performance indicators are the qualitative or quantitative measures that are used to judge the performance of a particular training task or competency. In order to measure performance indicators computationally within an HBM, they need to be translated to metrics that can be observed and measured in the simulation. In the example domain of air combat, for some training tasks this can be achieved with relative ease, especially for tasks that are subject to clearly defined rules or protocol, such as defined in the Tactics, Techniques, Procedures (TTPs). For other training tasks, the identification of quantitative metrics can be more challenging for SMEs or instructors, as 'good performance' in complex situations can depend on many contextual factors. For instance, to what extent was a tactical intercept task performed effectively or optimally? In CxBR-based HBM design, performance indicators represented by measurable metrics can be defined for individual contexts, ranging from metrics at the mission level, to whole-task level, to individual part-tasks.

Concluding

Above we have sketched the steps for designing HBMs for adaptive training from an instructional design point of view. In the next section, a proof-of-concept technical demonstrator is described that shows an application of an adaptive training system using CxBR-based HBMs in the air combat domain.

PROOF-OF-CONCEPT SYSTEM

A technical proof-of-concept demonstrator was implemented for an adaptive training system for fighter pilot training. It employs the presented HBM approach for modeling both a human trainee and agent role-players.

In this phase of the study the focus was on the technical infrastructure for the adaptive training system, based on the model described in the beginning of this paper in Figure 1. The demonstrator is built from an existing simulation infrastructure for the air combat domain. The technical framework that was realized is illustrated in Figure 3.

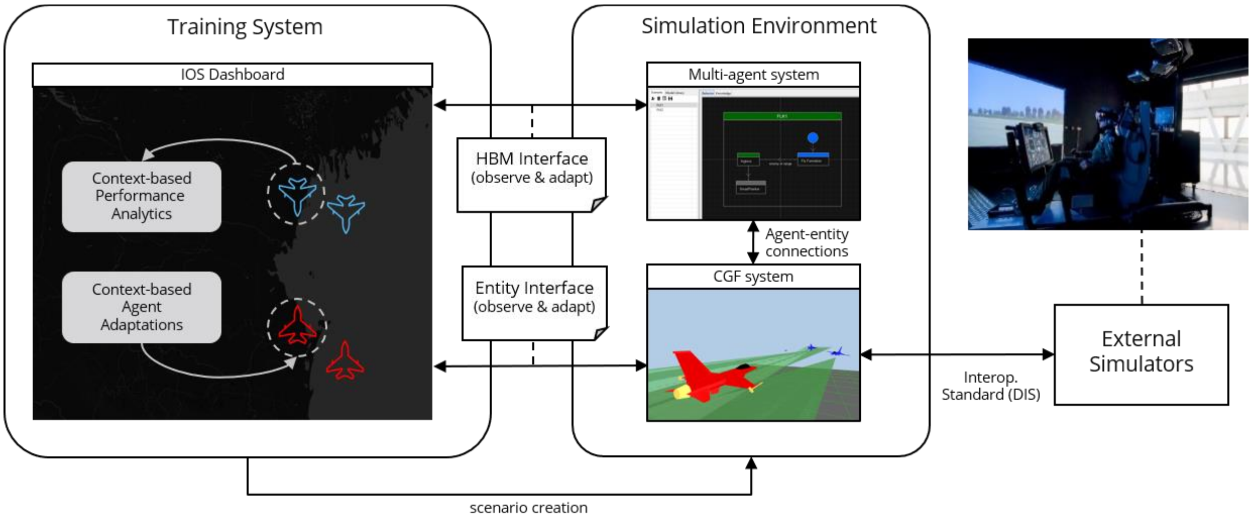

Figure 3: Proof-of-concept Adaptive Training System

The existing simulation infrastructure consists of four (in-house built) components. On the right shows a human trainee interface, representing a research simulator for fighter pilots, designed for tactical training. The simulator connects to the simulation environment (in the middle) through standard interoperability standards such as DIS. The simulation environment consists of two applications: a CGF system (bottom) and a multi-agent system (top). The CGF system is a light-weight air combat simulator, simulating fighter aircrafts with basic platform dynamics, sensor and weapon systems. The multi-agent system is a behavior modeling tool for CGF behaviors. It allows behavior models to control aircrafts in the CGF system (i.e. agent role-players). On the left is the instructional system as an Instructor Operating Station (IOS) that includes functionality for air combat scenario creation, execution and observation through a map-based interface. The system is currently used for fighter pilot and fighter controller training.

For this study we added the following capabilities:

- The multi-agent system was augmented with the capability to develop agents based on the CxBR-based HBM approach. HBMs were developed for the human pilot trainee and agent pilot role-players.
- The IOS was extended to receive real-time contextualized performance measurements from individual HBMs. During training, an instructor can select an aircraft and track current mental states (as contexts) and associated performance metrics, as tracked by the trainee's HBM.
- The IOS was extended to send adaptations to individual agent HBMs. During training, an instructor can select an aircraft and initiate one or more available adaptation for that aircraft.

The above capabilities were demonstrated in a basic air combat scenario: a 2v2 Defensive Counter Air (DCA) mission. Blue force is represented by a human trainee as flight lead, assisted by an agent wingman. Red force is represented by two agent enemy aircrafts. In this scenario, all actors share a comparable HBM design, in line with the CxBR example from Figure 2. The HBMs have contexts for technical-oriented tasks (e.g. formation flying, offensive/defensive maneuvers) and tactical-oriented tasks (e.g. target identification, tactical intercept), based on existing expert models. For each context, several example performance metrics and adaptation variables have been implemented. In the next phase of the study we will focus more on the HBMs' implementation based on expert-validated domain knowledge, concerning task models, complexity factors and performance indicators, following the instructional design steps that were described in the previous section.

The implemented system demonstrates a framework where an adaptive training system has a cognitive-level interface with the intelligent actors in the environment. This allowed operators to inspect and adapt the cognitive environment, as represented by the executing HBMs. This is provided alongside the already existing physical-level interface that allows operators to inspect and adapt the physical environment (e.g. aircraft positions, radar locks or missile positions). While in the current system, a human operator can use these interfaces to evaluate a trainee's performance and plan adaptation, the same interfaces can be used by an automated adaptive instructional system (AIS).

CONCLUSION

In this paper we presented an HBM approach to support the development of simulation-based, adaptive training in mixed human-agent environments. HBMs in this context are used to model both task behavior models for adaptive agent role-players, and task performance models for trainee actors. As a computational model, we examined the use of the context-based reasoning (CxBR) modeling paradigm to serve as a blueprint for an actor's task model, hereby enabling the implementation of context-specific decision-making and performance models. An HBM can then be employed in a training environment to either represent an agent actor (to drive its behavior), or represent a human trainee actor (to measure its performance). When appropriate HBMs are in place, flexible training environments can be established with interchangeable agent role playing and human trainee actors.

In a simulation-based training environment, the HBMs supports an instructional system by providing a cognitive-level interface with the intelligent actors in the environment: participating HBMs provide real-time observation of trainee performance measurements and expose available adaptations for agents that can be controlled during training for instructional purposes.

In the first phase of this study a technical proof-of-concept implementation of the HBM approach was demonstrated within an existing training system infrastructure for pilot training in the air combat domain. Existing task models were transformed into CxBR-based HBM models that were run in a simulated training environment, and externally interfaced with an instructor dashboard. In following steps we will conduct an instructional-driven design of HBMs by using expert-validated adaptive training scenarios for air combat situations. This allows an evaluation of the effectiveness of the HBMs in an operational training system: either for an instructor-based training system on how it improves trainee assessment and control over adaptive interventions, as for a computer-based AIS on how it supports implementing an instructional strategy.

REFERENCES

Abdellaoui, N., Taylor, A., & Parkinson, G. (2009). *Comparative Analysis of Computer Generated Forces' Artificial Intelligence*.

Arar, Ö. F., & Ayan, K. (2013). A flexible rule-based framework for pilot performance analysis in air combat simulation systems. *Turkish Journal of Electrical Engineering and Computer Sciences*, *21*(8), 2397–2415.

Bell, B., Nye, B., Bennett, W., & Kelsey, E. (2021). Attention and Engagement in Virtual Environments: Measuring the Unobservable. *Interservice/Industry Training, Simulation and Education Conference (I/ITSEC)*.

Bell, B., & Sottilare, R. (2019). Adaptation Vectors for Instructional Agents. In R. A. Sottilare & J. Schwarz (Eds.), *Adaptive Instructional Systems* (pp. 3–14). Springer International Publishing.

Castro, J., Gonzalez, A. J., & Gerber, W. J. (2002). Design and Implementation of CITKA, a Context Based Tactical Knowledge Acquisition System. *Sweding American Workshop on Modeling and Simulation-2002*.

Dong, Y., Ai, J., & Liu, J. (2019). Guidance and control for own aircraft in the autonomous air combat: A historical review and future prospects. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, *233*(16), 5943–5991.

Doyle, M. J., & Portrey, A. M. (2014). Rapid adaptive realistic behavior modeling is viable for use in training. *Proceedings of the 23rd Conference on Behavior Representation in Modeling and Simulation (BRIMS)*, 73–80.

Freeman, J., Watz, E., & Bennett, W. (2020). Assessing and Selecting AI Pilots for Tactical and Training Skill. *NATO MSG-177*.

Freeman, J., Watz, E., & Bennett, W. (2019). Adaptive Agents for Adaptive Tactical Training: The State of the Art and Emerging Requirements. In R. A. Sottilare & J. Schwarz (Eds.), *Adaptive Instructional Systems* (pp. 493–504). Springer International Publishing.

Lewis, C. L., M. Alexander, T. Huiskamp, W. ,. Blais. (2019). *MSG-127 A Reference Architecture for Human Behaviour Representation*. NATO.

Lotens, W., Allender, L., Armstrong, J., Belyavin, A., Cain, B., Castor, M., Gluck, K., Käppler, W., Kwantes, P., Lundin, M., Thomas, G., & Wallin, N. (2009). *HFM-128 Human Behavior Representation in Constructive Simulation*. NATO.

Mansikka, H., Virtanen, K., Harris, D., & Jalava, M. (2021). Measurement of team performance in air combat – have we been underperforming? *Theoretical Issues in Ergonomics Science*, *22*(3), 338–359. https://doi.org/10.1080/1463922X.2020.1779382

Mohanavelu, K., Poonguzhali, S., Adalarasu, K., Ravi, D., Chinnadurai, V., Vinutha, S., Ramachandran, K., & Jayaraman, S. (2020). Dynamic cognitive workload assessment for fighter pilots in simulated fighter aircraft environment using EEG. *Biomedical Signal Processing and Control*, *61*, 102018.

Portrey, A. M., Keck, L. B., & Schreiber, B. T. (2006). *Challenges in developing a performance measurement system for the global virtual environment*. Lockheed Martin Systems Management MESA AZ.

Rowe, L. J., Prost, J., Schreiber, B., & Bennett Jr, W. (2008). Assessing High-Fidelity Training Capabilities Using Subjective and Objective Tools. *2008 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) Proceedings*.

Salas, E., Rosen, M. A., Held, J. D., & Weissmuller, J. J. (2009). Performance Measurement in Simulation-Based Training: A Review and Best Practices. *Simulation & Gaming*, *40*(3), 328–376. https://doi.org/10.1177/1046878108326734

Sottilare, R., & Brawner, K. (2018). Exploring standardization opportunities by examining interaction between common adaptive instructional system components. *Proceedings of the First Adaptive Instructional Systems (AIS) Standards Workshop, Orlando, Florida*.

Stensrud, B. S., Barrett, G. C., & Gonzalez, A. J. (2004). Context-Based Reasoning: A Revised Specification. *FLAIRS Conference*, 603–610.

Stensrud, B. S., Barrett, G. C., Lisetti, C. L., & Gonzalez, A. J. (2002). Modeling Affect in Context-Based Reasoning. *Proceedings of the Swedish-American Workshop on Modeling and Simulation (SAWMAS)*.

van den Bosch, K., Blankendaal, R., Boonekamp, R., & Schoonderwoerd, T. (2020). Adaptive Agents for Fit-for-Purpose Training. In C. Stephanidis, D. Harris, W.-C. Li, D. D. Schmorrow, C. M. Fidopiastis, P. Zaphiris, A. Ioannou, X. Fang, R. A. Sottilare, & J. Schwarz (Eds.), *HCI International 2020 – Late Breaking Papers: Cognition, Learning and Games* (pp. 586–604). Springer International Publishing.

van Oijen, J., Toubman, A., & Claessen, O. (2021). Teaching Reinforcement Learning Agents with Adaptive Instructional Systems. In R. A. Sottilare & J. Schwarz (Eds.), *Adaptive Instructional Systems. Design and Evaluation* (pp. 120–136). Springer International Publishing.