In Search of Interoperability Standards for Human Behaviour Representations

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ABSTRACT

There is a long history of research to create capabilities that address the need for human behaviour representations in training simulations and other M&S application domains. In training, human behaviour models have applications as synthetic teammates and adversaries, but can also be used as a representation of the state of the trainee and as synthetic instructors to increase the effectiveness of the training enterprise as a whole. They are essential components for achieving the goals for training simulations and for Live, Virtual, Constructive (LVC) training, including affordability, availability, and credibility. Over the last two decades, numerous formalisms and architectures for modelling cognition, performance, and other relevant characteristics of the human being have emerged, and the capabilities and applications have expanded dramatically. However, models vary along many dimensions, including fidelity, application domain, underlying modelling formalisms, and behavioural repertoire. This diversity leads to critical challenges with respect to interoperability and reuse, in particular the integration of component models into a comprehensive behaviour model, and the integration of behaviour models into simulation environments. The challenges are further complicated by a lack of standards for human behaviour modelling, leading to brittle models, lack of reusability, and increased costs driven by the requirements of model integration and reengineering. In this paper, we discuss the need for human behaviour modelling, its role in supporting affordable, available, and credible training experiences in simulation and LVC environments, and propose a reference architecture to enable interoperability standards that support a variety of models serving a diverse set of purposes, both within and beyond the training domain. The authors represent a North Atlantic Treaty Organization (NATO) Modelling and Simulation Group (NMSG) activity focused on developing a baseline reference architecture and interoperability standards for human behaviour modelling to facilitate the creation and integration of human behaviour representations into simulation.

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Steven de Jong obtained a PhD in human behaviour modelling in 2009. He subsequently did postdoctoral research at Maastricht University (The Netherlands) and Brussels University (VUB, Belgium). He focused on studying and modeling interactions between humans and/or virtual agents. Example topics included embodied networks, strategy spreading, fairness, and complex games. After initiating, directing and successfully selling an IT company working on smart applications for tourists, he now works at TNO, the Netherlands organisation for applied scientific research, as an expertise consultant in the modelling and simulation domain.

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INTRODUCTION

A human behaviour model (HBM) is a formal representation of the knowledge and information processing of an individual within a given context domain, task, or scenario. Given a constellation of inputs, a HBM generates representative behaviour as output. Interest in such models has a long history, and a number of references are available that describe parts of the research history that has contributed to advances in this area (e.g., Gluck & Pew, 2005; Pew & Mavor, 1998; Sun, 2008; Zacharias, MacMillan, & Van Hemel, 2008). On the one hand, HBMs are tools for understanding human cognition (e.g., McClelland, 2009); on the other hand, they can be applied as synthetic characters in simulated environments supporting a number of purposes, including training.

The *Interservice/Industry Training, Simulation, and Education Conference* (I/ITSEC) highlights the critical role of simulation in contemporary training and education. Simulation is an indispensable tool, which has benefited from the sustained pace of improvement in computational power and sophistication over the last 40 or more years. Throughout most of that history, the emphasis of technology development has been on improvements in the fidelity of simulations of physical systems – the appearance of the environments in which training occurs and the behaviour of the systems that people are learning to operate in those environments. Technology has advanced to a point where we can create photorealistic representations, which are nearly indistinguishable from the real-world environments they portray (see Figure 1). Similarly, we can simulate in extraordinary detail the physics of system interactions with the environment, weather, weapons, and other complex phenomena (e.g., ARL HRED STTC, 2014).

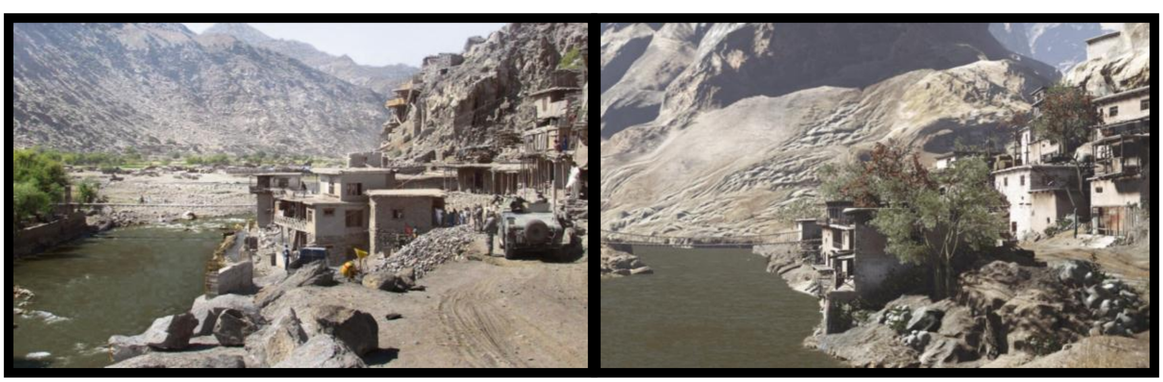

Figure 1. Comparison of real (left) and simulated (right) scene, demonstrating the realism of simulated environments.

These capabilities are impressive, and have greatly enhanced the value of training conducted in virtual environments, while decreasing costs through the reduced need for live assets to accomplish training goals. However, there has been substantially less investment and progress in creating high-fidelity representations of people to populate the virtual environments that are now taken for granted in many sectors represented at the I/ITSEC conference.

The relative lack of sophistication of technologies for developing human behaviour representations is not due to a lack of perceived utility. The experience of the authors has shown that virtual training exercises require human representations, including enemies (red forces), teammates (blue forces), non-combatants and support personnel (white forces) to provide real-time interaction, information, and other essential training functions. In addition, the value of synthetic instructors, or intelligent tutors, has been demonstrated in academic settings (e.g., Van Lehn, 2011), and in some specific areas beyond traditional academic applications (e.g., Van den Bosch, Harbers, Heuvelink, & Van Doesburg, 2009). Not only do HBMs offer the possibility of reducing training costs, but their importance is increasing in many areas where personnel have limited availability to support training exercises due to operational tempo and reductions in personnel that create further constraints.

Despite consistent interest, and a long history of research in relevant domains, substantial progress is still needed on multiple fronts to realize the full potential of the application in training simulations. In a National Research Council report, Zacharias et al. (2008) described the situation in this way:

> *"It is important to recall that the predecessor report in this area (Pew & Mavor, 1998, p. 8) noted that, 'the modelling of cognition and action by individuals and groups is quite possibly the most difficult task humans have yet undertaken. Developments in this area are still in their infancy.' This situation has not changed significantly in the mere 10 years since the publication of that report. But the world has, and, as a result, it has become even more clear that human behavioural modelling at all levels is critical to DoD specifically and to the nation more generally." (p. 20).*

As this quote implies, much research remains to fully realize the vision for HBMs, and the applications extend beyond both defence and training applications – a situation that has not changed since the book's publication. Those application opportunities include policy development, e.g., fatigue risk management, (Gunzelmann, Moore, Salvucci, & Gluck, 2011); organizational design (e.g., Sun & Naveh, 2004); system and interface design (e.g., Hornoff, 2001); training purposes (e.g., Ball et al., 2010); and task support (e.g., Salvucci, 2006). HBMs are most often used to generate behaviour of virtual humans in simulations and games to create training opportunities in representative and controllable virtual environments (e.g., Gratch & Marsella, 2004; Jones, et al., 1999).

Given the increasing demand for realistic HBMs, there is a need for flexible and generic architectures that support behaviour generation across a diverse set of tasks, domains, and applications. A HBM architecture must address a variety of factors determining and affecting behaviour, like physical properties (e.g., strength, endurance); cognitive properties (e.g., memory, reasoning); and social properties (e.g., cultural norms, role in social group). Whether a particular factor is relevant or not depends upon the task. A flexible architecture allows for easy inclusion and exclusion or tailoring of such factors in the development of HBMs and should provide standardized interfacing to other behaviour models and simulations.

Objectives and Focus

This paper focuses on two important issues that currently limit the role of HBMs in training and other simulation environments. The first is the definition of a reference architecture to organize efforts to develop HBMs. The second is the development of interoperability standards, built upon the reference architecture, that facilitate development and integration of HBMs into simulation environments. We start from the position that there is an underlying framework that is shared across HBMs, regardless of their application. Most generally, they access information from the simulation environment (*perception*), make decisions based on some internal information processing mechanisms (*cognition*), and produce behaviours within the simulation (*action*).

This common framework can be, and has been, formalized in a variety of different ways, reflecting different emphases, representations, and applications (Gluck & Pew, 2005; Ritter, et al., 2003). Unfortunately, this can serve as a barrier to progress. The current state of HBMs typically leads to hand-crafted models for specific purposes. These models are often brittle and fail to generalize beyond their original scope. In addition, they are cast in proprietary formats that limit reuse and create sole-source requirements for maintenance, updates and extensions.

In the remainder of this paper, we describe current efforts by a North Atlantic Treaty Organization (NATO) Modelling and Simulation Group (NMSG) task group (MSG-127) to address these issues through the development of a reference architecture and standards for interoperability. The authors are members of this task group, focused on helping to drive the training and simulation communities toward best practices that improve transition opportunities. We begin with a brief overview of the origin and mission of MSG-127. We then describe the foundation of a reference architecture and the way forward for developing interoperability standards. We close with a discussion of the potential benefits of this effort for HBMs.

MISSION OF NATO MSG-127 TASKGROUP

The NATO Modelling & Simulation Group

The NMSG task group MSG-127 was formed around the topic of a Reference Architecture for Human Behaviour Modelling. It is a task group within the NATO Modelling and Simulation Group (NMSG), which is part of the NATO Science and Technology Organisation (STO)[1]. The NMSG is assigned responsibility for coordinating and providing technical guidance for NATO M&S activities undertaken by 28 NATO and partner nations and various NATO Bodies.

The mission of NMSG is to promote cooperation among Alliance bodies, NATO, and partner nations to maximise the effective utilisation of M&S. Primary mission areas include M&S standardisation, education, and associated science and technology. The activities of the Group are governed by the NATO M&S Master Plan. The group provides M&S expertise in support of the tasks and projects within the STO and from other NATO bodies. Importantly, the NMSG was officially named as the Delegated Tasking Authority for NATO M&S standardization.

MSG-127 Objectives and Approach

A starting point for increasing the generalizability and reusability of HBMs is the development of standards that capture requirements at multiple levels and thus facilitate HBM integration and interoperability within militarily relevant simulation environments. NATO MSG-127 is building upon current HBM research to develop a taxonomy of requirements for HBM integration into simulation environments. That taxonomy is being used as the basis for proposing standards to promote interoperability and reusability of HBMs. The focus is on maximizing flexibility (e.g., ease of integrating new components or omitting existing components), universality (e.g., ease of adding, removing, or changing components across applications and domains) and efficacy (e.g., savings in time and resources for developing HBMs) in simulated training environments and elsewhere.

Depending on the application, HBMs must incorporate a range of human aspects (e.g., perceptual, cognitive, physical, emotional) and consider the relationships between these underlying faculties and the interactions between the human and the simulated environment. In addition, HBMs may attempt to incorporate social and cultural influences into behaviour. All of these areas must be represented in an appropriate reference architecture and a set of interoperability standards to support a capability to generate behaviour for military training applications. It is the objective of MSG-127 to provide NATO with recommendations that will support greater use and reuse of HBMs in these environments.

A REFERENCE ARCHITECTURE FOR HUMAN BEHAVIOR REPRESENTATIONS

Human behaviour representations are models that perform in humanlike ways in specific contexts. A model, more generally, is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process (Glossary US Defence Modelling & Simulation Office; MSG-131, 2014). According to Schmidt and Schneider (2004),

[1] The STO was known as the Research and Technology Organization (RTO) before July 2012.

reference models are development guidelines providing standardized solutions for certain modelling problems of a (homogeneous) class of real systems. They are usually characterized by the two main attributes: *universality* and *recommendation character* (Thomas, 2006).

- *Universality* refers to the idea that a reference model should be applicable not only in one special case, but across problems of a certain class.
- *Recommendation character* refers to the idea that a reference model should serve as a blueprint, or even as a default solution, for certain problems.

In general, a reference architecture can be considered to be a special kind of reference model. Reference architectures reflect strategic decisions regarding system technologies, stakeholder inputs, and product lines. They render user requirements, processes, and concepts in a high-level solution from which individual projects can be identified and initially programmed. Their primary focus is on services, processes and component functionality, and they provide the basis for the development of specific instantiations, referred to as *Target Architectures*. Reference architectures may be characterized in the same way as reference models, i.e., using the attributes *universality* and *recommendation character*.

It could be seen as bold to propose a standardized reference architecture for human behaviour representations, given the current state of the science. However, we believe that a carefully articulated reference architecture, described at the appropriate level of abstraction, could provide a specification that promotes greater interaction, integration, and reuse of specific models and formalisms in the development of human behaviour representations for a variety of applications. Our proposal for this architecture is illustrated in Figure 2. It is not intended to embody a detailed theory of the human information processing system. Rather, it is a structural description of the cognitive system at a relatively high level of abstraction. The structures are intended to reflect components of cognition for which there is relatively broad consensus within the scientific community. These features are intended to address the universality attribute described above.

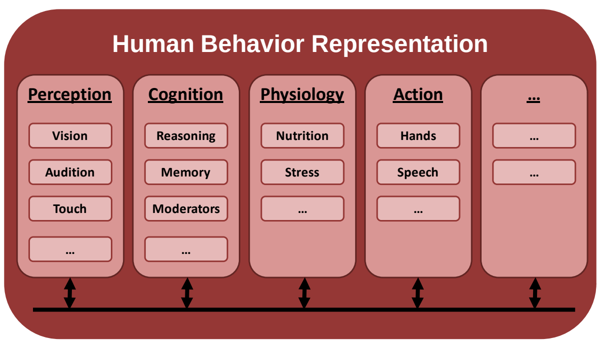

Figure 2. Proposed reference architecture for human behaviour models

Because it is a structural description, the reference architecture does not identify the internal mechanisms that drive the information processing within each of the components. Lively scientific debates still flourish on these issues, and myriad theories exist that provide useful accounts of many cognitive and behavioural phenomena. A structural description allows for diversity in theoretical claims, as well as specifications that operate at different levels of abstraction. That is, it may serve as a kind of default architecture (reference character), but is flexible enough to allow numerous specific instantiations.

Key Characteristics

The architecture in Figure 2 serves as a stable foundation for thinking about the development of HBMs. It specifies some of the basic aspects that HBMs may involve, without overly constraining the particular representations and mechanisms that are used to develop them. Broadly, the architecture divides human behaviour representation into perception, cognition, and action – a taxonomy that is prevalent in conceptualizations of cognition and behaviour. In addition, we have included an aspect for physiology. As our understanding of the relationships between physiology and cognition improves (e.g., Dancy, 2014; Gunzelmann et al., 2009), it is increasingly apparent that the physiological state of individuals has significant and systematic influences on cognitive functioning and behaviour. Although such physiological mechanisms are usually not incorporated into HBMs today, we expect that these mechanisms will become increasingly prevalent for some applications.

Within each of the broad categories, we have nested some particular functions. The list is not exhaustive, but it provides further specification of where components of cognition and behaviour can be captured in the overall architecture. Some of these functions seem obvious and intuitive. For instance, including opportunities to represent different sensory modalities within perception is a natural way of understanding how they fit in cognition and behaviour. In other cases, our distinctions may become more contentious. For instance, we have included “moderators” as an aspect of cognition in the representation. We do this based on research that has looked at topics such as fatigue (e.g., Gunzelmann et al., 2009) and emotions (e.g., Marinier, Laird, & Lewis, 2009; Gratch & Marsella, 2004), which has represented those mechanisms in terms of their role in influencing ongoing cognitive activity. There is also evidence that such moderators can impact other aspects of the cognitive system (e.g., Kase, Ritter, Schoelles, 2009). The direction of some of these relationships is also a subject of debate in the literature.

Open scientific issues like cognitive moderators are precisely the reason for making the architecture extensible. By allowing the architecture to be adapted for particular purposes, there is flexibility in conceptualizing how various aspects of the overall system fit in and exert their influence. So, factors like emotions, fatigue, culture, and other important influences could be represented in multiple ways, depending on how the reference architecture is instantiated for a particular purpose.

Another important characteristic of the reference architecture is that is does not specify a particular level of fidelity that must be represented within any component of the system. This is critical, because the required level of fidelity in the simulation of human behaviour depends on the application (e.g., Beaubien & Baker, 2004). For instance, the level of fidelity required for a HBM to function as an adversary in a training environment is different than one that has to function as a teammate. Similarly, HBMs that support training of different skills will require that different cognitive functions be emphasized in their development. In fact, the architecture supports variable levels of fidelity across components. In fact, there is no requirement that all aspects be represented in any particular HBM. The objective of the reference architecture is to provide a stable framework for organizing cognitive mechanisms. This is the critical function that is needed to support the development of interoperability standards for HBMs.

Finally, rather than specifying a set of direct connections among components we propose that information from different aspects of cognition be made available to the system using a publish/subscribe mechanism, allowing other components to use or not use that data and be agnostic about the specific provider of that data. This increases the flexibility of the system overall, by making minimal commitments about information passing/sharing. These principles are based on the High Level Architecture (HLA) concept that is the accepted M&S interoperability standard in NATO. Similarly, the information exchange between the components will be defined by a data model. The data model approach as used in HLA is a modular and hierarchical structure that supports base objects and derived or specialised objects. These principles allow flexibility in the specific information and the level of detail that a component subscribes to.

Examples of Applying the Reference Architecture

One reason why applications of the reference architecture (or comparable architectures) are not more prevalent is the complexity of the knowledge, skills, and abilities required to be proficient in many areas. This challenge stems partly from the knowledge engineering required to make a functional system that scales to these domains. It also derives from the state of the science of human cognition. There are simply no computational theories that capture the complexity of human cognition in enough breadth and depth to address the challenges.

Despite the limitations, examples of human behaviour and computational cognitive modelling have demonstrated the potential value for military training. We mention two examples below from our own experience, which help to highlight the potential utility of a reference architecture for such models.

Example 1: Training of Helicopter Directing Officers

One application of human behaviour representation is to generate the behaviour of virtual humans (*agents*). This has been done, for instance, by Bell and Short (2009), who developed a behaviour model of an air controller (AC) to enable student-pilots to train tactical procedures and communication. In line with this, The Netherlands Institute for Applied Scientific Research (TNO) developed a behaviour model for the Royal Netherlands Navy of a helicopter pilot, applied to the training of Helicopter Directing Officers (HDOs) (van den Bosch & Boonekamp, 2013).

The Belief-Desire-Intentions (BDI) concept was used to implement a HBM that behaves appropriately in the scenario (e.g., the Virtual Pilot adheres to procedures, but will not crash into an oil rig when the HDO-trainee gives incorrect directions). The task model produces expert pilot behaviour by default, but it can be configured to generate alternative behaviours, such as errors, depending on the training objectives. The rapid and time-critical nature of communications sets high demands on the human-agent interaction. A designated grammar was developed, capturing all allowed communications and its variations. A commercial high-quality speech interface was used for the implementation of the speech system.

This application demonstrates some of the power of HBMs for training: it reduces personnel requirements, thus making training more flexible and cost-effective. The current architecture of the model only uses cognition (being knowledge of procedures and knowledge of how to respond to a series of pre-defined events); however, it is conceivable that the Navy, at a later stage, may want to expand the qualities of the model. For example, they may want to incorporate the effects of prolonged task operations on the quality of performance, to facilitate training HDO's in assisting fatigued pilots. A challenge in this scenario is that the current architecture lacks the properties to incorporate a fatigue component into the model. A reference architecture would alleviate this challenge by allowing relatively easy expansion because the information exchange would be specified among behaviour components, as well as between behaviour components and the (simulated) environment.

Example 2: Synthetic Teammates

A second example is research at the United States Air Force Research Laboratory to develop a Synthetic Teammate to support training (Ball, et al., 2010). In this research effort, the Adaptive Control of Thought – Rational, or ACT-R (Anderson, 2007), cognitive architecture is being used to implement a psychologically valid model of a pilot for remotely piloted aircraft (RPA) reconnaissance operations. The model participates as part of a 3-person team, and must interact through text chat with live people that play the roles of mission planner and sensor operator.

The task environment is abstracted from actual RPA operations, but captures the communication and interaction dynamics required for effective team performance in the domain. The objective of the research effort is to demonstrate that the training value of the simulation with a synthetic teammate as the pilot will be as high as when a third human being plays that role.

In the context of the reference architecture proposed above, ACT-R illustrates one target architecture. ACT-R is modular, and includes modules for perception (audio and visual) and action. It also contains several modules that perform various cognitive functions, including central cognition, declarative memory, and imagery (e.g., Anderson, 2007). In addition, cognitive moderators have been explored in this architecture (e.g., Gunzelmann, et al., 2009), with mechanisms that relate fatigue to changes in the cognitive modules in the system.

DERIVING INTEROPERABILITY STANDARDS FOR HBMS

Based on the structure of the reference architecture outlined in the previous section, this section focuses on the information exchange among the main components of human behaviour. This expresses the way in which the components interact and communicate, and also how the HBM integrates into the simulation environment. We do not propose specific standards at this point but rather point to the potential benefits for standardization for HBMs in training simulations. This is an area where more debates are possible, since standards must specify what information is available. Again, however, extensibility should help to minimize these issues.

The NATO View on Standards

NATO recognises the International Organization for Standardization / International Electrotechnical Commission (ISO/IEC) concept of a standard as follows: "A standard is a document, established by consensus and approved by a recognized Body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context". It is noted that "a standard should be based on the consolidated results of science, technology, experience and lessons learned" (ISO/IEC).

The main qualities which make a good standard are the following (AMSP-01, Huiskamp et al, 2014):

- Relevant: a standard should be relevant to the targeted user/developer community;
- Substantive in content: a standard should provide meaningful information and/or results;
- Enabling timely production: a standard should provide timely production in an efficient manner, to ensure that the product is useful to the community;
- Reviewed: a standard should be reviewed by the technical community to which the product applies and have large acceptance;
- General: a standard should be as general as possible, while still maintaining usefulness, to support the broadest community of current and future users;
- Stable: a standard should be established and changed only as necessary. It should be prototyped and tested before being proposed for adoption to demonstrate its maturity;
- Supportable: a standard should maintain the integrity of the existing product suite and the needs of the user.

Standards must mature to meet changing requirements. When new requirements emerge or technical innovations become possible, new standards will likely be needed.

Interoperability and Standardization in Modelling & Simulation

Within the domain of Modelling and Simulation, substantial effort has been invested in the development of standards. The domain even has its own standards organization, known as SISO. This highlights the importance of developing useful standards for simulation. Simulations are complex to develop, and require extensive experience, knowledge and skill to design, develop and integrate systems into a federation that meets operational, functional, security and technical requirements. Interoperability among (distributed) systems is a multifaceted problem. It ranges from technical exchange of data through semantic issues dealing with a common understanding and use of information to mutually accepted security measures.

Interoperability is increasingly important as a means to facilitate effective simulation development, based on reusable components. Standards are the foundation of interoperability. We perceive six key advantages of standards in Modelling & Simulation:

- Standards reduce development complexity and risk; they allow producing more modular and reconfigurable implementations.
- Standards protect investment in content creation, as scenario descriptions, models and other databases may be reused in a variety of applications.
- Standards reduce costs and avoid duplication of efforts on new technologies.
- Standards are a natural way to share investments, while at the same time reducing ownership risk by allowing upgrades or replacement of part of an existing system.
- Standards allow people working with different systems to collaborate on training and experimentation.
- Standards allow upgrading to newer systems or changing to systems from another vendor.

It is interesting to note that interoperability and standardization are especially important to smaller nations. Using international standards makes it possible for smaller nations to acquire affordable interoperable systems from different vendors in a competitive market.

Toward Interoperability and Standardization in Human Behaviour Modelling

As established throughout this document, creating credible and adaptive human behaviour models is a substantial scientific challenge. Progress in human behaviour modelling has been slower than many other topics within Modeling and Simulation. Of course, the challenges are significant and the problems are hard, but the most prominent issue is that current work is isolated. It is difficult to use other models and build on existing results.

This issue is mostly caused by a lack of consensus on what models are supposed to simulate. Mathematical and computational modelling of human cognition has produced few, if any, agreed upon theoretical mechanisms, or laws, that govern the manner in which information is represented or processed by the human mind. From the perspective of creating interoperable HBMs, this is a substantial challenge. With little agreement on the fundamental aspects of human cognition, model developers are free to propose any combination of representations and processes that allow for the replication of critical capacities and limitations of human behaviour in particular settings.

There is significant diversity in the basic research community with regard to the nature of these foundations of human cognition (e.g., Gunzelmann, 2013; Sun, 2008). More importantly, this diversity expands when one considers application-oriented modelling formalisms and frameworks (e.g., Gluck & Pew, 2005; Zacharias, et al., 2008; Pew & Mavor, 1998). The process of standardization in Modelling and Simulation generally has greatly benefited from the existence of mature and validated theoretical mechanisms within the domains that are being simulated; those theoretical mechanisms can be instantiated in virtual environments to simulate physical processes. Because this is not the case for HBM, it is especially important that the reference architecture and the corresponding standards be flexible, so that they can evolve as our understanding of the human cognitive system matures.

DISCUSSION & CONCLUSIONS

Standards are necessary to facilitate progress in a variety of domains, and human behaviour modelling is no exception. In this paper, we have presented a framework for a reference architecture and described our efforts to use this foundation to develop standards for the interoperability of HBMs in training simulations. This is an important step in realizing the vision for how to apply the scientific understanding of human behaviour to the practical needs of simulation-based training.

We believe that making progress toward such standards will ultimately benefit the research community in a variety of ways. It will support reuse and integration across modelling formalisms by allowing component models to be combined to produce more sophisticated behaviour. Two benefits of this will be to reduce the cost of model development and also to increase the flexibility of using alternative modelling formalisms to meet the requirements for particular applications.

The NATO MSG-127 is making progress on addressing these challenges. In addition to increasing the pace of progress in research areas related to human behaviour modelling, it is hoped that the contributions of this group will help to better align HBMs with the simulation environments they are intended to augment. The MSG will further refine the proposed reference architecture and develop an initial proposal regarding standards over the course of the next two years, and develop the first set of interoperability standards within five years, all while engaging the community.

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