EXPLORING THE CONSTRAINTS OF HUMAN BEHAVIOR REPRESENTATION

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ABSTRACT

Human behavior representation (HBR) is an elusive, yet critical goal for many in the simulation community. Requirement specifications related to HBR often exceed current capabilities. There exist a number of tools, techniques and frameworks to model and simulate HBR, but they are constrained and do not generalize well. Even with a vibrant research community, certain HBR characteristics remain beyond our grasp, unless some unforeseen disruptive technologies emerge. We survey the state of the practice for HBR, discuss ongoing research, and identify what appear to be insurmountable challenges. Along with exposing the essential characteristics of HBR and their current level of maturity, we propose a generational framework for considering HBR capabilities. While a number of HBR issues have been addressed in the literature, there is no published discussion explicitly detailing its constraints and limitations.

1 INTRODUCTION

In concluding his seminal work *Computing Machinery and Intelligence* in 1950, Alan Turing noted with regard to machine intelligence that "we can only see a short distance ahead, but we can see plenty there that needs to be done" (Turing 1950). Over five decades later, this observation remains valid for a closely related field – human behavior representation (HBR). In this paper, we demonstrate that the challenges faced by the HBR community are of the same magnitude as the Imitation Game proposed by Turing (Turing 1950).

HBR refers to computer-based models that mimic either the behavior of a single human or the collective actions of a team of humans (Pew and Mavor 1998). Realistic representation of individual humans or groups of humans in computer simulations has served as an overarching goal for those considering next-generation simulations. In a number of cases, it's also been a nearly insurmountable challenge to the researchers, designers and developers of simulations, particularly in the military domain.

Over time, we have seen the emergence of numerous successful simulation technologies that have greatly improved the quality of simulation-based training and the sophistication of analyses derived from simulations. From immersive, networked aircraft and vehicle simulators interacting in a synthetic environment, to highly detailed simulations of entire manufacturing facilities, modern military and industrial planners have at their disposal a variety of simulation tools to augment training, guide decision-making and assist in refining control processes.

The Dagstuhl Conference Report illustrates both the significance and complexity of attaining convincing HBR when considering it as a grand challenge in the field of modeling and simulation (Ciancarini et al. 2002). The impact of HBR on future military operations will likely remain non trivial and probably increase in significance. Likewise, businesses are seeking more creative and realistic ways to interact with and serve their customers by using human-like automation systems. The ability to integrate models of human behavior that will underlie human-like agents, groups or instances of decision-making entities, or convincing yet autonomous human characters in simulations, is an increasingly critical objective.

While the simulation community continues to devise novel techniques addressing HBR, those seeking HBR in simulations must garner comprehensive insight into the limits of current capabilities. Such insight should manifest itself in requirement specifications that challenge developers, yet offer the potential for feasible implementations. We analyzed several requirement specifications for complex military simulation systems in search of HBR related requirements (USACOM 1999, STRICOM 2001, NSC 1998). Below are three examples representative of infeasible requirements relative to current capabilities. These examples are only a few of many and have been adapted for the context of this paper in order to reflect generalized elements of HBR.

- Provide the capability to model and simulate interactively the primary and follow-on effects of political organizations, social factors, psychological operations and civil affairs on the outcomes of simulated military operations

- Portray the effects of operations on the human condition as it relates to effectiveness and the ability to perform missions. At a minimum, the simulation must consider morale and cohesion, availability of religious support, attrition rate over time and rate of operations
- Have fully automated behaviors from the individual human to group level

To reach beyond current capabilities introduces significant risk. A clear articulation of the boundaries that constrain HBR models will lead to a more informed community that can make better decisions regarding the specification of requirements related to HBR in near-term simulation systems. Herein we characterize such constraints.

In this paper, we seek to inform the reader of the current bounds, both theoretical and practical, that limit a simulationists' ability to convincingly model human behavior, even when given no constraints on available resources. We survey relevant literature and assess the current state of HBR technology. Next, we discuss the failures of some simulation systems with prominent HBR requirements and propose what the literature demonstrates as the constraints of HBR. Then, we suggest a framework for considering attainable, generalized HBR requirements in near-term simulation development and pose likely topics for future work.

1.1 Terminology and Taxonomy

We define several terms that prove useful throughout our discussion and possess a generally accepted significance in the field of HBR. Furthermore, we draw from and expand upon Harmon's taxonomy of HBR requirements (Harmon 2002) as a means of lending a conceptual framework to the concepts we discuss.

Synthetic Forces- exist in military simulations, sometimes alongside real forces that have been instrumented and linked to the simulation. The physical aspect represents the movement and state of platforms (objects) in the simulation, including such aspects as maximum speed and the actions that can be performed in the world. The behavioral aspects of a synthetic force platform determine where, when and how it performs the physical actions, that is, its behavior (Ritter et al. 2002)

Semi-Automated Forces- simulation of friendly, enemy and neutral platforms on the virtual battlefield in which the individual platform simulations are operated by computer simulation of the platform crew and command hierarchy. The term "semi-automated" implies that the automation is controlled and monitored by a human who injects command-level decision making into the automated command process (Department of Defense 1998).

Intelligent Software Agent- an artificial agent that operates in a software environment and imitates human intelligence by mechanical means in pursuit of the goals of its clients (Franklin and Graessar 1997)

Human Cognition- the process of receiving, processing, storing, and using information in humans.

Based on these definitions, we see that synthetic forces are autonomous entities in a simulation lacking human-in-the-loop oversight. Their underlying structure, characteristics and behavioral doctrine are determined a priori, but behavior emerges as the simulation runs. Semi-automated forces require human-in-the-loop intervention, and offer greater flexibility and control over the behavior manifested in the simulation. Intelligent software agents are designed less formally than synthetic or semi-automated forces and may lack some of their structure or characteristics. We note that no published sources adequately describe and stratify these terms with regard to HBR.

In light of the Department of Defense's (DoD's) difficulty in crafting attainable HBR requirement specifications in the past, Harmon has proposed a taxonomy that partitions HBR into three branches: Non-Cognitive Factors, Cognitive Capabilities and Application Functions (Harmon 2002). Non-Cognitive Factors relate to the physical and psychological characteristics of the human body and mind. Cognitive Capabilities refer to situational awareness, planning and execution. Application Functions refer to the application-specific tasks under consideration.

Working in the context described by these definitions, we review literature related to our goal, which is the identification of HBR concepts that can be simulated, those that require more time, and those that, without a significant disruptive technology, appear unachievable.

2 BACKGROUND

Most agree that *Modeling Human and Organizational Behavior: Application to Military Simulations* (Pew and Mavor 1998) is one of the seminal texts concerning HBR. Ritter et al. (2002) offer a supplement to this text that includes frameworks or architectures that were not available at the time of publication and expanded discussion on the reusability of existing and emerging models.

A vast body of literature exists describing the implementation of the architectures and frameworks described by Pew and Mavor and subsequently Ritter et al. (2002). Those mentioned most frequently include Soar, Atomic

Components of Thought – Rational (ACT-R), and COGNET. Soar is a cognitive architecture for developing systems that exhibit intelligent behavior (Laird, Newell and Rosenbloom 1987). Similarly, ACT-R is a cognitive architecture for simulating and understanding human cognition (Anderson 1993). COGNET is a framework for modeling human cognition in the context of systems operation (Zachary, Ross and Weiland 1991). These tools have been used to design and implement software agents with human-like characteristics. In constructing such agents to model human performance and emotion applied to a Military Rehearsal Exercise (MRE), Gratch employed Soar, a cognitive architecture, as the basis of emotional appraisal and human-interactive agents (Gratch and Marsella 2001). ACT-R, has been used to model such diverse characteristics as a fighter pilot's target identification, prioritization and selection processes (Doyal and Brett 2003) and the effects of cell phone interfaces on driver behavior (Salvucci 2001). Human operator multi-tasking capability in a simplified air traffic control domain has been modeled using COGNET (Zachary et al. 2001).

Along with these and other tools, some generalized techniques have resulted in successful HBR modeling, albeit under constrained conditions. Performance moderator functions have been used to model the impact of values, emotion, physiology and stress upon individuals and groups in decision-making, yet researchers note the need to reduce computational requirements by at least an order of magnitude to make this technique practical (Silverman, Cornwell and O'Brien 2003). A Markov dynamic model (MDM) framework has been used to model and predict driver actions with 95% accuracy. MDMs are similar to hidden Markov models, but include a dynamic predictive process like a Kalman filter (Pentland and Liu 1999). The command and control decisions of a submarine commander have been modeled using Bayesian networks (Yu 2003), which are also useful for assessing knowledge gaps in human subjects (Chung et al. 2003).

A number of experimental implementations have demonstrated the practicability of HBR in simulations, notwithstanding constraints on design parameters and system performance. One of the most notable successes is the aforementioned MRE, an immersive, interactive, scenario-based simulation. The MRE incorporates agent-based virtual humans in a synthetic environment that can include an interacting human (Swartout et al. 2003). Also, researchers at Sandia National Laboratories have embarked upon an effort to craft a virtual human - machines with an embedded, highly realistic computer model of the cognitive processes that underlie human situation awareness and naturalistic decision making (Forsythe and Xavier 2002).

3 HBR DESIGN FAILURES

One could presume that inherent complexity and lack of a comprehensive generalized framework would limit aspirations, but such is not the case. Recently, several military simulation systems with HBR requirements have failed during development. While we cannot precisely link these requirements to the cause for failure, it is notable that such incidences have recurred while the efforts to surmount HBR challenges continue.

Perhaps the most dramatic example of such a failure is the cancellation of the Joint Simulation System (JSIMS), a program plagued by cost overruns, organizational challenges and complexity issues (Tiron 2003). Along with JSIMS, attempts to model human behavior in the highly complex domain of Air Traffic Management have proved problematic, largely as a result of the inflexibility of the software agents designed to perform ATM tasks normally handled by human operators (Callentine 2002).

These design failures, and those not discussed in the literature, should not preclude the continued development of technologies supporting HBR in the near or long term. Instead, they should stand as pedagogical references for simulationists to consider when crafting requirements for future systems possessing HBR capabilities. As exemplars of inherent constraints, these failures serve as the foundation for the characteristics we describe in the subsequent section and lend credence to the generalized requirements we outline after that.

4 HBR: CHARACTRISTICS, CAPABILITIES AND CHALLENGES

In this section, we discuss the bounds imposed by the state of technology, contrasted with the unrealistic expectations of those who seek HBR in their simulations. These expectations persist even though the tools to realize them may be immature or nascent. We do this by articulating what can currently be accomplished in HBR as demonstrated by the current state of the practice, describing current research thrusts, and proposing existing constraints that can only be overcome with infinite time and resources, or be enabled by an emergent disruptive technology. Our enumeration should prove useful to those who request, develop, manage or employ simulations.

4.1 Current State of the Practice

Attaining certain aspects of HBR can be accomplished without great difficulty. Depending on the scope and complexity of the behavior to be modeled, designers and developers have been quite successful in incorporating HBR in their work. For example, elements of "natural language", namely speech recognition, parsing and generation can be accomplished under constrained conditions and in limited domains. This is demonstrated by the work of Garfield et al. (2003) in designing and implementing a Natural Language Vocal Interaction tool for use with computer generated forces and other synthetic agents, in work on MRE discussed earlier (Traum et al. 2003), and by the successful prototype of an Intelligent Tutoring System featuring dialog agents in the context of military health awareness (Luperfoy et al. 2003). In all of these implementations, utterances were restricted to a limited vocabulary germane only to the respective domains or context.

Rudimentary emotion modeling has been implemented as well. Biddle and colleagues discuss and compare a number of techniques to do this, and partition them according to biological, cognitive, and rational/social categories. This partitioning underscores the absence of a unifying framework for complex emotion modeling, as does their conclusion advocating "the pursuit of hybrid emotion architectures that weave the primary theoretical framework" (Biddle et al. 2003). In the MRE, "there are a number of limitations in how the system infers emotional state that need adjustment or re-thinking" (Gratch and Marsella 2001).

The simulation of human performance for analysis and prediction has taken the form of probabilistic models of cognitive processes in a number of domains, like train control system modeling (Joshi, Kaufman and Giras 2001) and air traffic management (Corker 1999). Similarly, human performance attributes, like workload, have been modeled for analytic purposes (Keller 2002). As part of their Agent-Based Modeling and Behavior Representation program, the Air Force Research Lab provided an opportunity for multiple developers to create different models of the same human operator activities. Subsequently, the development teams compared their results between models and with human participants performing the same activities (Tenney et al. 2003). In cognitive performance, course of action (COA) evaluation and selection has been implemented using rule sets coupled with fuzzy logic (Vakas and Burdick 2001) and as noted earlier, with Bayesian networks (Yu 2003).

These examples are in no way exhaustive, but they indicate what designers and developers are currently capable of implementing, and they give the reader a clear sense of the bounds imposed by the tools that are currently available. Most techniques discussed in this subsection have been extended beyond the simulation domain, thus exemplifying the acceptance and applicability of these technologies. While these tools are available, they are not comprehensive or generalizable solutions for the sophisticated requirements of some in the community. If the user is willing to accept simplifications and restricted domain specificity in exchange for reasonable results, then success can be achieved. As demand for a model more closely assimilating human cognition increases, so does the complexity of the problem and the risk associated with successfully achieving valid HBR.

4.2 Areas Where Research is Ongoing

In order to portray increasingly complex behavioral characteristics, researchers have pursued an agenda aimed at providing the generalizable frameworks needed for more compelling HBR. This research has been ongoing within academia, industry, and the military, and experimental results have been widely published. Integrating the human performance attributes, natural language processing (NLP), cognitive processes and emotional characteristics described above, embodied conversational agents have been the focus of work for those striving to create virtual humans (Allbeck and Badler 2002). Likewise, appropriate and adaptive individual behaviors reflecting emotion, mood and personality are being considered (Kshirsagar 2002), along with models of autonomous and convincing group behaviors (Nakamura 2001). A comprehensive, adaptive architecture to support multiple reasoning and agent migration and vehicle dynamics has been proposed (Stytz and Banks 2001).

A number of tools and frameworks exist for modeling human cognitive processes and behavior, and while they have been reviewed in detail (Pew and Mavor 1998, Ritter et al. 2002), researchers continue to seek novel means for applying these tools and extending HBR capabilities. For example, the virtual humans in the MRE are implemented in Soar, rendered graphically with PeopleShop™, and make use of the Hidden Markov Model Toolkit for dialogue (Hill et al. 2003). The literature clearly indicates that researchers are seeking to employ a combination of techniques and approaches in order to produce simulations that depict a broad range of convincing human characteristics and higher levels of simulated cognition. Their success has been incremental and partitioned across domains and phenomena. Furthermore, there is little to suggest that the components required to craft simulations including the convincing HBRs that requirements developers desire are about to emerge from the research community. While there is much promise in the ongoing research, findings to this point do not indicate the attainment of generalizable results for successful, high-fidelity HBR. In fact, a number of grand challenges remain, and in the subsequent section, we pose those characteristics that are beyond reach at this time.

4.3 Characteristics Requiring Infinite Resources or Disruptive Technologies

Despite vibrant research efforts, several elements of HBR either cannot be achieved in a tractable manner – they either require unacceptable time or resources – or there is no known way to accomplish them. In both cases we posit the need for the occurrence of suitable disruptive technologies (Christensen 1997) to enable their successful implementation. Researchers have continually advanced the state of speech recognition and synthesis. NLP, however, is known to be a hard problem, but is still a requirement for fully conversant synthetic agents. The cognitive architectures we have described thus far, and their various implementations, are constrained to specific domains or are limited in their scope.

A single framework for modeling human behavior across multiple levels of resolution, encompassing the individual, the small team, group, crowd and then population or culture, has not emerged and appears beyond our grasp. Neural networks have demonstrated a rudimentary form of machine learning, but learning must be coupled with human-like reasoning, emotion and planning of significant complexity. This has yet to be demonstrated as tractable. If HBR is ever successfully codified, there must be models that can accurately predict behavior. The sheer complexity of the human's universe of discourse, together with their ability to act rationally or irrationally, with adaptability and innovation, prevent this capability from being accomplished. The realization of these attributes will likely remain relegated to science fiction.

While the pursuit of these characteristics is admirable, the likelihood of them being attained is miniscule without either infinite resources or disruptive technologies. Understanding what is not possible is just as crucial as envisioning what can be done with existing tools. Incomplete knowledge of the domain constraints can ultimately lead to the types of failures described in Section 3. Avoiding those failures while continuing to stimulate innovation and advancement in HBR should lead to the simulations that will prove most useful while serving as efficient, effective and attainable models from which the simulation community can benefit greatly. As a reference, Figure 1 articulates the characteristics discussed or referenced in the previous sections and portrays the state of success for each characteristic. Some characteristics in Figure 1 are portrayed as both developing and unachievable in practice. In these instances, we find that the work ongoing in these areas will not yield generalizable results without an enabling disruptive technology.

Software engineering issues play a significant role in any potential success of HBR. Of significant interest is the specification of requirements related to HBR capabilities. It has been noted that the requirements specification process for numerous military simulations has been flawed in this regard. It has been observed that many "requirements documents under-specified the HBRs they desired (Harmon 2002), with a ratio of direct to implied requirements of approximately 1:3. This observation underscores the poorly understood discipline of formulating HBR requirements and demonstrates the need to improve the process or risk continued failure. In the subsequent section, we discuss a more practicable framework for specifying and assessing HBR requirements.

Although the literature shows that incremental success is being made in addressing a number of HBR-related challenges, there is little to indicate that the disruptive technologies that need to be realized in a number of fields are about to occur. The ability to link all of the necessary components together in order to successfully yield human-like

	Mature	Developing	Unachievable in practice
Constrained speech recognition, parsing and generation	X		
COA analysis, selection and implementation	X		
Rudimentary emotions	X		
Human physiological characteristics	X		
Semi-automated coarse-grained behavior generation	X		
Probabilistic human performance simulation and prediction	X		
Autonomous, convincing group behavior		X	
COA generation		X	
Interdependence between physiology, emotion and cognition		X	
Behavior adaptation appropriate to dynamic scenarios		X	X
Speech generation w/ appropriate prosody		X	X
Pattern recognition coupled w/ appropriate decision-making		X	X
Generalized behavior prediction		X	X
A single framework for modeling human behavior at multiple levels of resolution		X	X
Complex cognition, reasoning and learning			X
Conversational dialogue			X
Synthesis of autonomous knowledge acquisition, planning and behavior			X
Complete integration between emotion, cognition and behavior			X

Figure 1: HBR Characteristics

models, that those who require HBR capabilities in simulations, also remains unfulfilled. That is not to diminish the work accomplished to date, but rather to underscore that the current technology is encumbered by limitations. This is demonstrated by the sizable community of researchers who continually strive to extend our ability to model human behavior.

5 FEASIBLE REQUIREMENTS FOR HBR IN NEAR-TERM SIMULATIONS

In providing the community with an HBR taxonomy, Harmon portrays the state of HBR requirements specification as lacking the necessary clarity, precision and depth to contribute to feasible near-term solutions. While a general theme may emerge from the analysis of simulation requirements pertaining to HBR, we expanded upon Harmon's work and present a more far-reaching assessment of the practice. Going further, we offer the reader examples of what is currently infeasible and describe a framework for considering the necessary evolution that HBR technology and requirements specification should follow.

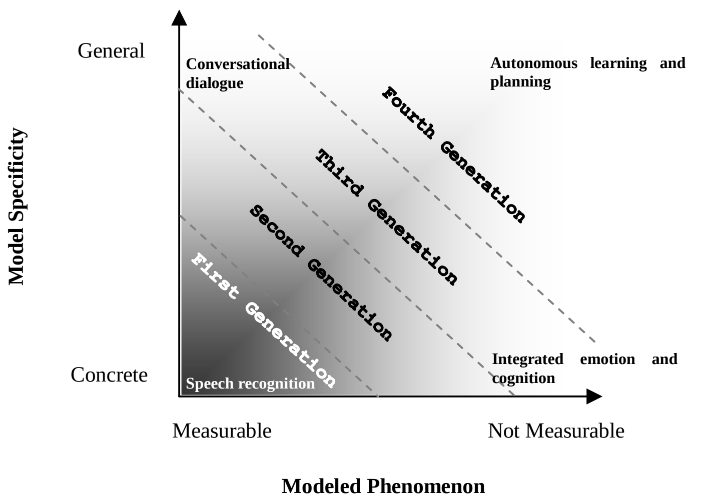

Figure 2 - Generational Framework for Considering HBR

Ignoring disruptive technologies, we propose a more incremental approach to specifying requirements with the intent of establishing successive building blocks upon which developers can generate increasingly improved HBRs. This approach balances the pragmatism of fulfilling requirements with the innovation inherent in research and experimentation.

Many are familiar with the canonical depiction of the chronological evolution of programming languages (Brookshear 2003). This description is based on the capabilities of languages, their features and an increasing abstraction away from machine details and towards a closer correlation with the application layer or human language. Similarly, we pose an HBR classification framework illustrating an evolution from low-level, specific cognitive components and interactions to more generalized, naturalistic human behavior. Moreover, each generation should build upon the success of the preceding generation, extending and generalizing specific capabilities. Requirement specification for HBRs well beyond the current generation should be considered infeasible and the risk associated with pursuing them should be viewed as high. This framework is depicted in Figure 2 and described below. The shaded area of Figure 2 corresponds to current, mature HBR capabilities.

Mature HBR capabilities are specified in Figure 1. This limited set indicates that we are currently in the first generation of HBR capabilities, and as ongoing research goals are realized, we may be approaching the second generation. Third generation HBR may be described as having:

- A single framework for cognitive, emotional, physiological and behavioral characteristics
- The ability to engage in domain-dependent dialogue
- Coupled pattern recognition, planning and decision-making capability
- An architecture for modeling behaviors at various levels of resolution

The fourth generation would approach human-like faculty – fully conversant, innovative in planning and sophisticated in behavior.

6 DISCUSSION AND CONCLUSIONS

We have investigated some prominent system failures related to HBR requirements and coupled the elements of HBR in those failed systems to a survey of the current state of technology for crafting HBRs. Moreover, we have characterized the domain constraints relating to HBR and proposed a feasibility framework by which the community can continually assess the current state of technology and predicate requirements specifications in a clearer, more precise fashion.

In an essay distinguishing between simulations and artificial intelligence, Crockett notes that:

> "simulation is designed to present a manipulatable image, portrayal, or representation, so that we can manipulate it and hopefully learn more about the phenomenon simulated. Here is the larger philosophic point: because the computer is so ideally suited to such simulations, we have to be careful not to mistake a computer simulation for that which is simulated. It takes some philosophical discipline, in short, to resist specious blurrings of differences between simulations and the phenomena they simulate" (Crockett 1994).

It is not the goal of simulationists to replicate humans in synthetic form. Rather, as synthetic agents become more human-like, their usefulness increases. While Turing poses that "we may hope that machines will eventually compete with men in all purely intellectual fields" (Turing 1950), HBR seeks to merely impart human characteristics in simulations to better serve their users, not compete with them. Despite this, we have demonstrated that the tools to address HBR related issues are constrained and there are likely more than a few intractable problems that must be solved for HBR to fulfill its expectations.

7 FUTURE WORK

In the future, we would like to revisit and extend the work accomplished by Pew and Mavor (1998), and Ritter et al. (2002) in order to more fully assess the capabilities, available tools, conceptual frameworks and advancements in incorporating HBR in simulations. Their work, while thorough and illuminating, is such that periodic examination of progress and setbacks would yield dividends to the community. Also, exceedingly thorough and detailed analysis of HBR successes would demonstrate the most promising avenues for further research in the field.

We have discussed some of the challenges facing those who specify HBR-related requirements. A comprehensive study of engineering requirements applied to this domain would illustrate not just the shortcomings, but the approaches that those who require HBRs should take during this critical phase of design. Accordingly, a greater degree of rigor and more formality in specifying HBR attributes would be of tremendous benefit.

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