Global Economics and Management Review 18 (2013) 33-39

Global Economics and Management Review

www.elsevierciencia.com/gemrev

Original

Got a problem? Agent-based modeling becomes mainstream

Rashmi Chaturvedi[a], Brian Armstrong[a], Alok Chaturvedi[b,*], Dan Dolk[c], Paul Drnevich[d]

[a] *Charles F. Day and Associates, LLC.,Technology Innovation Center, West Lafayette, USA*
[b] *Krannert School of Management, Purdue University,West Lafayette, USA*
[c] *Naval Post-Graduate School, Monterey, USA*
[d] *University of Alabama,Tuscaloosa, USA*

ARTICLE INFO

Article history:
Received 18 November 2013
Accepted 22 November 2013

Keywords:
Virtual worlds
Agent-based modeling
Game theory
Simulation
Emergent phenomena

JEL Codes:
C63
C53
C70

ABSTRACT

Agent-based modeling and simulation (ABS) is emerging as a key technology that is helping to enhance the understanding of social sciences. Systems ranging from organizations to economies and societies can be modeled to provide insights in ways that were previously not possible with quantitative approaches. The Sentient World Simulation (SWS) is an ultra-large-scale ABS developed to capture a comprehensive view of "Whole of Government" operations. The SWS supports a strategic geopolitical perspective that captures the interplay between military operations and the social, political, and economic landscapes. The SWS consists of a synthetic environment that mirrors the real world in all its key aspects. Models of individuals within the synthetic world represent the traits and mimic the behaviors of their real-world counterparts. As models influence each other and the shared synthetic environment, behaviors and trends emerge in the synthetic world as they do in the real world. The SWS reacts to actual events and incorporates newly sensed data from the real world into the virtual environment. Trends in the synthetic world can be analyzed to validate alternate worldviews. The SWS provides an open, unbiased environment in which to implement diverse models. This results in a single holistic framework that integrates existing theories, paradigms, and courses of action.

Introduction

Virtual worlds and their simulation platforms offer an increasingly popular and powerful alternative reality for research and practice in a number of disciplines. Some of the promise and popularity of such virtual worlds stems from the fact that they offer an alternative means to communicate, collaborate, and even organize economic, political, and social activities (Jarvenpaa, Leidner, Teigland, and Wasko, 2007; Lanchier, and Schweinsberg, 2012; Conte, Gilbert, Bonelli, Cioffi-Revilla, Deffuant, Kertesz, & Loreto, 2012). Despite the popularity of these alternative systems, we know little about them or their implications for social science research and practice. While the theoretical foundations of intelligent systems and their implications for practice were documented as far back as last century (Gregor and Benbasat, 1999), we know far less about the theoretical foundations and implications of virtual worlds and the technology and models that underlie them. For example, recent studies have been published on the effects of virtual reality on consumer learning (Kil-Soo and Young, 2005), and on the use of agents in product recommendation (Komiak and Benbasat, 2006; Bo and Benbasat, 2007) and supply chains (Nissen and Sengupta, 2006). However, much work remains to be done in this area, with a key question being whether virtual worlds simply represent another internet fad or bubble, or whether they offer viable new alternatives to the traditional econometric methods.

The importance of this question highlights a clear need for research that seeks to develop an understanding of such emerging virtual worlds, their dynamics, and potential issues regarding their design, application, and use. This paper examines the process of virtual world design, validation, and application by exploring the creation of the "Sentient World," an ultra-large-scale, multi-agent-based virtual world developed for the U.S. military. In doing so, we present an alternative and underutilized application of virtual world technology. This application demonstrates an effective convergence between the real and virtual worlds and offers a powerful IT-based platform for research as well as an "intelligent system" for applications to practice (Gregor and Benbasat, 1999).

The next section of the paper provides a brief background to some of the major technology underlying virtual worlds. We then introduce the "Sentient World Simulation" and discuss its develop-

* Corresponding author.
E-mail: alok@purdue.edu

ment, followed by a discussion of its validation and some of its applications in which virtual worlds facilitate real-world problem solving. We conclude with a discussion of the implications and contributions of virtual worlds for both management research and practice.

Background on virtual worlds

Some of the major technologies underlying virtual worlds (such as agent-based modeling and simulation) have been instrumental in the understanding of a wide variety of social science phenomena (Harrison, Lin, Carroll, & Carley, 2007). These technologies enable us to model systems ranging from organizations to economies and even whole societies. Such modeling provides new insights that are not possible using quantitative, analytical approaches based on archival data. At the core of these simulated virtual worlds lies agent-based modeling , which facilitates the autonomously managed artificial entities in virtual worlds that mimic the behavioral patterns of their real-world counterparts. These autonomous agents have control over their own behavior and can act without the intervention of humans or other systems. They can interact with other agents and communicate, negotiate, and cooperate with each other. Some of the applications of agent-based simulations include: computational experimentation, in which the consequences of decisions can be measured and analyzed; integration of multiple theories from various specialized disciplines for a comprehensive understanding of underlying phenomena; creation of agents with multiple decision strategies, both rational and non-rational; modeling of heterogeneous actors who can modify their behavior during the course of the simulation; and facilitation of a seamless and interchangeable integration of human and software agents.

The sentient world simulation

The Sentient World Simulation (SWS) is an ultra-large-scale, multi-agent-based virtual world developed by Simulex, Inc. to capture an "effects-based" view of real-world intra and inter-country actions and reactions. It was developed for the U.S. Department of Defense and has been utilized to simulate U.S. military operations in other countries. In addition, large multinational firms have used the SWS in several private sector applications to simulate market entry and product acceptance in new markets. Unlike other types of simulations, which focus primarily on tactical dimensions (sometimes referred to as the "kinetics"), SWS supports a strategic, geopolitical perspective that extends beyond kinetics to consider the more subtle interplay between the player's operations and the real-world reflective social, political, and economic landscape in the virtual world. As such, the SWS consists of a virtual world that mirrors the real world in all of its key aspects – political, military, economic, social, information, and infrastructure (referred to collectively as PMESII.) Within the virtual world, models of individuals, organizations, institutions, infrastructure, and geographies represent the traits and mimic the behaviors of their real-world counterparts. As the models influence each other and the shared virtual world, behaviors and trends emerge in the virtual world as they do in the real world. In a sense, the SWS reacts to actual events that occur anywhere in the world and incorporates newly sensed data from the real world into the virtual world. This allows players and/or researchers to analyze the trends in the virtual world to validate alternate worldviews.

Developing a Virtual World

Unlike traditional approaches, in which a simulation supports only a single model, the SWS provides an open environment that operates on diverse multiple models. This approach makes it possible to integrate various existing theories, paradigms, and courses of actions within a holistic framework. In the SWS environment, this holistic framework consists of geographic entities (nations, provinces, cities), their infrastructures (electricity, telecommunications, transportation), political systems (types of government, political parties/factions), social systems (institutions, groups), economic systems (formal and informal sectors), and information systems (print, broadcast, Internet). Table 1 provides an example of this holistic framework.

Current versions of the SWS include virtual nation models for over 80 countries. To represent a virtual nation, individual citizen agents are constructed with behavioral, cultural and social traits to represent the societal makeup of the real nation. Such an 'agent architecture' uses a DNA-like double helix structure. In this architecture, one strand contains agent attributes and traits, while the other contains intelligence. The behavior strand of the double helix contains the various "genes." For example, each citizen agent is encoded with static traits such as gender, nationality, ethnicity, race, income, education, and religion, and dynamic traits such as political, societal, religious orientation, propensity to consume goods and service, and the will to fight. This architecture makes it possible to model intelligent agents for citizens, leaders, groups of individuals, organizations, and institutions.

Citizen agents. A citizen's well-being consists of the fundamental human needs, including basic health, security, religion, education, and freedom of movement. Citizens act based on their assessment of their perceived state of well-being. A citizen's emotional state is the second psychological parameter that the system tracks. Influences such as a leader or an event reported by the media can affect a citizen's emotional state. The role of the emotion is to capture the level of arousal and the intensity of the action in which the citizen engages.

Leader agents. Leaders represent the heads of organizations, institutions, groups, political parties, or have broad public following. In general, a leader's repertoire of knowledge and cognitive capability is larger than that of the citizen agent and includes such

Table 1.
Sentient World Simulation Agent Typology.

	Individual	Organization	Institution
Agent	Civilian | Leader	Social Group | Organization	Government Institution
Political	Political Leader	Political Organization	Political Institution
Military	Terrorist | Soldier	Terrorist Organization	Military Institution
Economy	consumer, Labor		Sectors, National Institutions
Society	Religious Leader	Religious Organization, NGOs, Charitable Organizations	Social and Religious Institutions
Information		Media-Print, Broadcast, Internet	News wires
Infrastructure	14 sectors		Infrastructure

traits as fundamentalism, nationalism, power base, and stances on domestic, economic, and social policies. Leader agents are categorized as social, religious, and political and are encoded with influence levels that reflect their power within groups, organizations and institutions. Leaders affect the political and social climate within the virtual world. They work to effectively impose their stances upon citizens and organizations in order to promote their goals.

Groups of agents. Clusters of individual citizen agents form groups, organizations, or institutions. Groups can be formal or informal. In the virtual world, formal groups and factions operate overtly, while informal groups, such as terrorist cells, operate covertly. Organizations and institutions are legal entities that provide structure to the virtual world. The stances and resulting behavior of groups and organizations adapt as individuals join or leave and leadership changes. Institutions are more formal than organizations in terms of policy development, implementation, and adjudication capabilities. Some institutions have the right to use force. Traits for groups,organizations, and institutions include political orientation, freedom of opinion, societal orientation, economic policy, openness to foreign investment, and control over resources Certain fundamental or experimentally developed theories are explicitly encoded in these agents, such as well-being and set point theories from psychology and production and consumption theories from micro-economics. Other theories, such as social networks from sociology and macro-economics involving GDP and unemployment that capture emergent behaviors, are observed and validated based on the calibration of the agents. Table 2 provides an overview of the types of agents, agent behaviors, and theoretical grounding in SWS.

One of the key contributions of SWS is that it offers a platform for addressing issues when there is no set of formulae to describe the flow of information, the interactions between the key actors, and the cascading effects of events that lead to complex phenomena, such as civil conflicts (Epstein, 2002). The SWS can be used to fill in these gaps by experimenting with the solitary and collective behaviors of the individual, group, organizational, and institutional agents described above. This use of virtual worlds represents a unique and underutilized application of virtual world technology, an application that demonstrates an effective convergence between the real and virtual worlds and offers a powerful IT-based platform for management research and practice. Such uses of virtual world modeling can have an immense impaction the social sciences, which are still concerned primarily with how macrolevel phenomena emerge from micro-level actions.

Design Principles for SWS

A key objective of the SWS is to maintain a tightly coupled, 'near-real-time' connection between the external geopolitical environment and its SWS virtual counterpart. We maintain this critical role by using an extensible net assessment (xNA) knowledge base to create and sustain this coupling between the real-world and virtual-world environments in SWS. xNA is highly distributed big data repository that is fed from three primary sources: knowledge obtained from semantic data and text mining from the Internet, subject matter expertise provided by analysts, and domain experts via the Analyst Workbench interface, and feedback from SWS simulation updates. Each unit of data in xNA is tagged by three dimensions: source, point of view, and a time/date interval. Figure 1 conceptually depicts the critical role of the xNA knowledge base in creating and sustaining this coupling.

The modeling and simulation component of SWS is supported by the Synthetic Environment for Analysis and Simulation (SEAS) platform, which was initially developed at Purdue University and is now a proprietary system of Simulex, Inc. (Chaturvedi and Mehta 1999; Chaturvedi, Dolk, Mehta & Ayer 2005). The SEAS platform has served as the support environment for a number of innovative large-scale agent-based simulations, including an artificial labor market for military recruiting (Chaturvedi et al. 2005) and a bio-terrorist simulation that integrates epidemiological, traffic evacuation, and mass psychology models at the local, state, and federal levels (Chaturvedi et al. 2005; Drnevich, Mehta & Dietz. 2006; Drnevich et al. in-press). (For specific information regarding the technical and architectural details of SEAS, see Chaturvedi and Mehta (1999) and Chaturvedi et al. (2005)). Figure 2 conceptually depicts the SEAS architecture.

The SWS is a large-scale multi-agent model implemented on the SEAS platform. The SWS consists of over 12 million intelligent agents representing the virtual populations, organizations, institutions, and leaders of over 60 nations. These agents represent an overall population of approximately one billion people, with an agent compression ratio of 100:1. In order to model a system of this complexity, it is necessary to pay careful attention to the design process. Some of the guiding design principles to control this

Table 2.
Models for Determining Sentient World Simulation Agent Behaviors.

	Individual	Organization	Institution
Agent	Civilian Behavior Model, Wellbeing	Family, friends, informal groups	
Political	Citizen Organization Subscription Model, Political Leader	Political Organization, Recruiting, *Training, and Retention*	Political Parties, CX Government, COI Government, *International Organization – United Nations, NATO*
Military	*Insurgency Model*, Global Terrorism Progression Model, Terrorist Leader Model, Combatant Model, Will to Fight (WTF)	Terrorist Organization, WTF, Militaria, Paramilitary, Rebels, Secessionist, Multi-national	WTF Model
Economy	Leaders, *Influencers,* Labor, Consumption Model, Production Model, *IO models*	Economic Sector, Business Organizations, *Multinational Corporations, Informal Economy*	Global Economy Model, *World Bank, MF, Trade Regimes (WTO, NAFTA)*
Society	Social Group Model, Citizen Organization Subscription Model, Citizen Unrest Model Epidemiological Model, Religious Leader Model, Social Leader Model	Religious Organization, Social Network, Charitable Organizations, Humanitarian Organizations, *Anti-social (Organized crime, syndicates)*	*Social & Religious institutions (churches, mosques, temples)*, Non-governmental organizations (UN, Red Cross), Education
Information	Citizen Perception Model, Rumor Propagation Model, Media Subscription Model	Print Media, Broadcast Media, Online Media (Blogs)	*Information and Broadcasting, Entertainment*
Infrastructure	Individual Infrastructure, Infrastructure Dependence	*Multinational Corporations*	Cultural

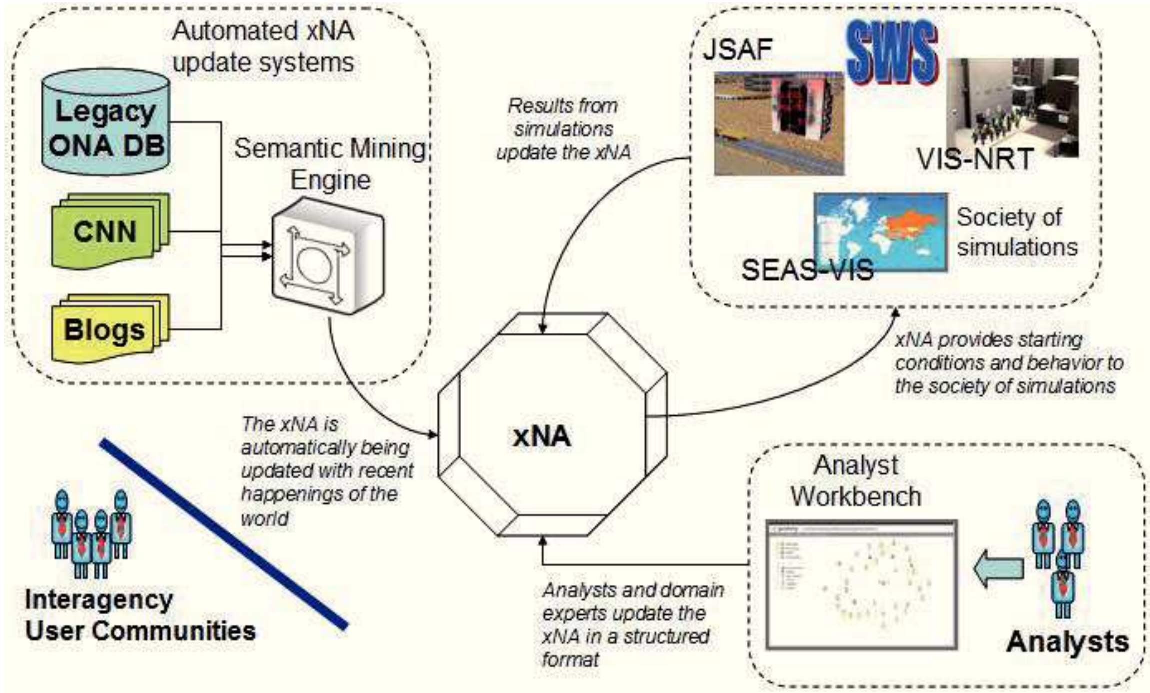

Figure 1. Conceptual Schema for the Sentient World Simulation Environment.

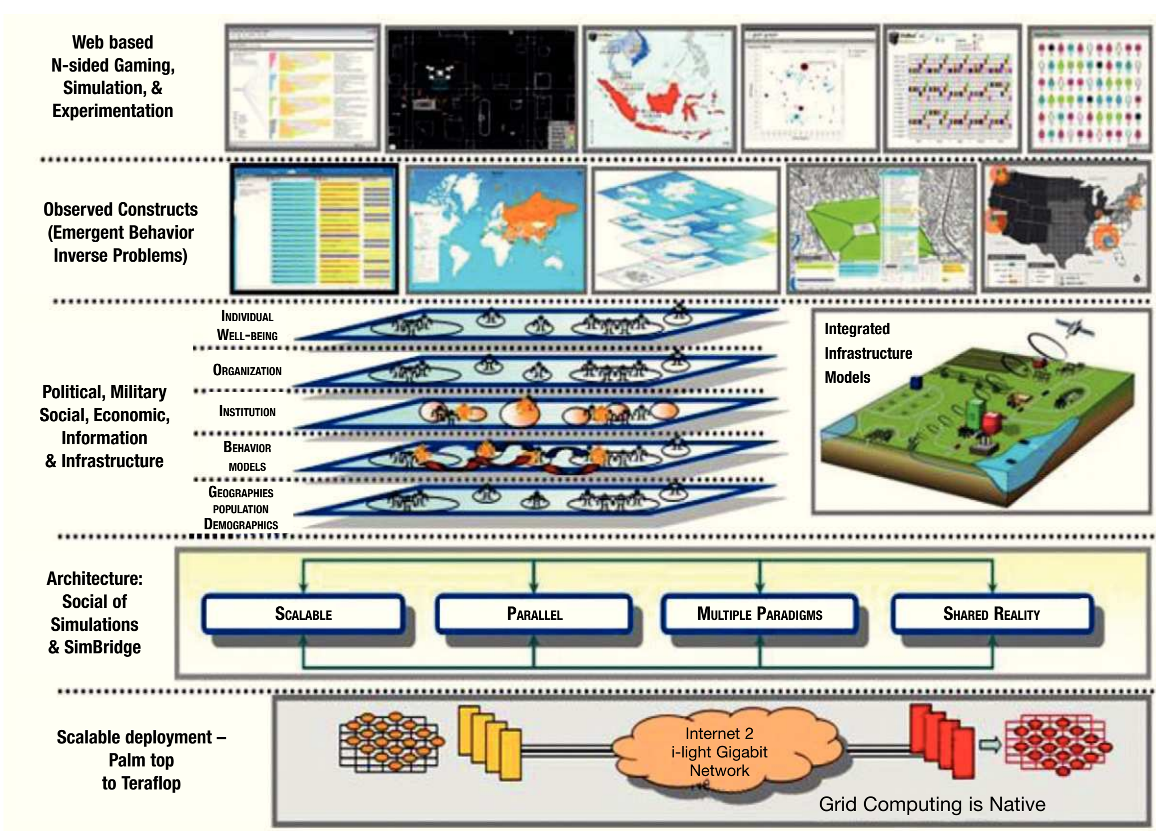

Figure 2. Conceptual Architecture for the Synthetic Environment for Analysis and Simulation.

complexity include decoupled data and models; multiple model views; transparent assumptions, rules, and algorithms; and "on-demand" modeling to handle time granularity; modularity via self-assembling societies; and a Model Bullpen for the modular testing of sub-models. We discuss these guiding design principles in more detail below.

Decoupled data and models. One of the primary design protocols in model management involves logically separating the model representation from its associated data and solver. SWS allows for models and data to be independent so that data sets can be linked dynamically with the models that need them.

Provide multiple views of models. SWS is designed for n-sided participation, which means we must support a multiplicity of interpretations for the same event. Different players, or teams, may view an event, such as the bombing of a religious place, from diametrically opposed perspectives. The organizations responsible for the bombing may see the event as an act of revenge; the organizations that own the structure may see it as an act of aggression that requires an immediate response; NGOs may see the event as requiring an emergency response; the news media may see the event as a newsworthy incident; and so on. Agent behaviors must be able to capture and reflect all of these various viewpoints.

Provide transparency of assumptions, rules and algorithms. The multiple views described above must be traceable to the underlying assumptions, rules, and algorithms that define agent behaviors. Our xNA knowledge base makes these definitions visible and manipulable to system users via the Analyst Workbench.

"On demand" modeling to handle time granularity. Simulations of this scale typically support many different time granularities (Figure 3), and one of the greatest challenges in system design is keeping these granularities synchronized. To address this problem, SWS adopts concepts from Web-based services in the form of "on demand" modeling. SWS typically runs continuously at the coarsest level of granularity. If a model, or process, is required from a finer level of time granularity, it is executed only "on demand"; otherwise the model with its associated agents remains inactive. In this way, SWS can support millions of agents, since typically only a relatively small percentage of them will run simultaneously. Figure 3 conceptually depicts the temporal granularity in SWS.

Modularity via self-assembling societies. Public and private sector organizations have long struggled with the problem of simulation reusability and the associated problem of integrating large-scale, multi-genre simulations (Davis and Anderson, 2003). SWS adopts a society of simulations (SOS) approach as a modular way of addressing the system of systems challenge inherent in this undertaking.

Briefly, SOS provides an environment in which simulations interact as collaborating members in a common society. Member simulations share certain aspects of what they model with other members of the society using a common, ontology-based knowledge repository that is referred to as Shared Reality, via member-specific liaisons. New members can join an existing society, while current members can disengage or be removed from a society without requiring the society to stop and restart (Chaturvedi 2005).

Model bullpen for the modular testing of sub-models. The SOS approach allows heterogeneous models to be developed independently and concurrently while retaining high fidelity and scalability to the global scope. The model bullpen is the part of the SOS architecture in which models that have been developed and tested off-line can be tested in context before being admitted to the model society.

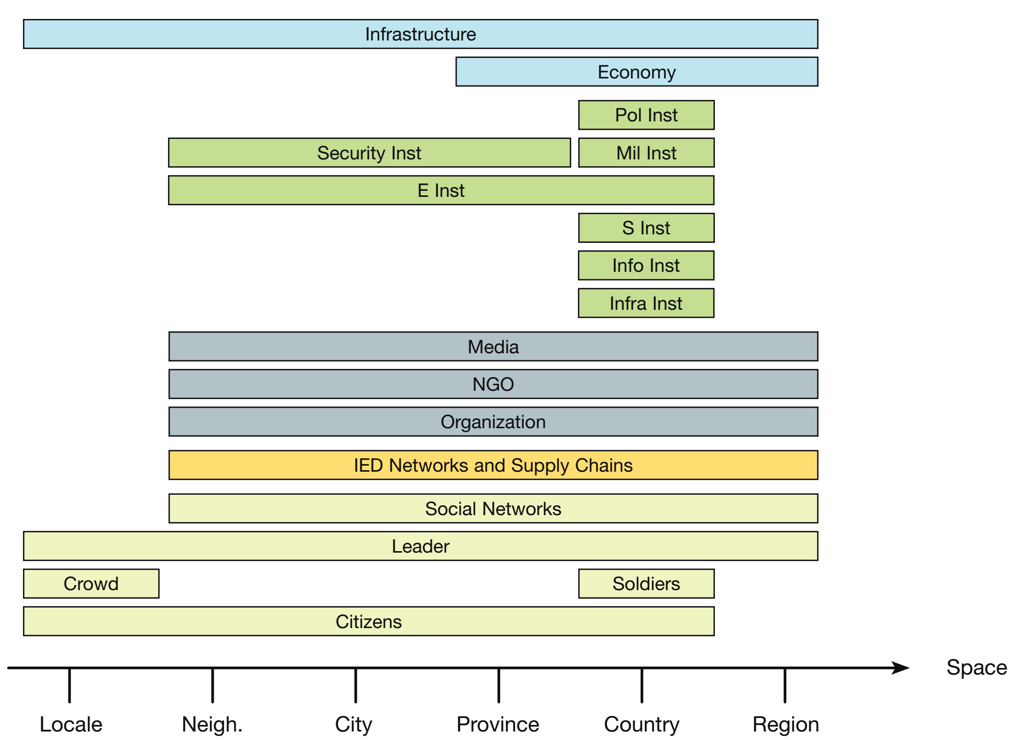

Figure 3. Temporal Granularities in the Sentient World Simulation.

Validating the virtual world

Validating a virtual world simulation of this scale is a daunting task. Given that simulation validation is one of the greatest challenges facing simulation-based research (Harrison et al., 2007), we have taken care in the development of the SWS to ensure the validity of the simulation. To this end, we have employed a variety of methodologies and philosophies throughout the development, validation, and testing process, including: testing agents strenuously (micro-level validation); inverse problems and social constructs (macro-level validation); iterative participatory modeling; and calibration with the real world. These aspects of the SWS development, validation, and testing process are discussed in greater detail below.

Test agents strenuously (micro-level validation). The agents are the lowest-level and most critical elements of the system. If the agents are not modeled accurately, the overall emergent properties of the system cannot be trusted. Therefore, it is essential to capture and test agent behaviors as rigorously as possible and to ensure their conformity with known theoretical models. The model bullpen feature provides modular testing of sub-models, which substantially facilitates this process.

Inverse problems and social constructs (macro-level validation). Emergent macro-level behavior must also be tested rigorously against known theories and frameworks. The problems of equifinality (in which an emergent phenomenon may result from several different causes) and multifinality (in which a single initial condition may lead to multiple emergent phenomena), must be addressed.

Iterative participatory modeling. The simulation must be continuously run, tested, and refined in game-playing mode with subject matter experts as the players and/or analysts of the game outcomes. A strategic feature of SWS is that it provides n-sided perspectives, which must be actively exercised. This iterative participatory modeling approach consists of repeating cycles of study and data analysis, role-playing games, agent-based model design and implementation, and intensive computational experiments (Barreteau, 2003).

Calibration with the real world. Since SWS is intended to be a near-real-time, continuous-feed simulation, there is always the unfolding of real-world events against which to calibrate the simulation. In this context, the major challenge is to be able to identify and repair discrepancies in a short enough time to maintain the currency and relevancy of the persistent system.

Applications of virtual worlds in practice

The SWS was developed by the Joint Forces Command (JFCOM) in concert with Simulex, Inc., for use by the U.S. Department of Defense, and has been utilized to simulate U.S. military operations in other countries. The SWS has also been used in several private sector applications by large multinational firms to simulate market entry and product acceptance in new markets. These specific examples of the SWS applications to the public and private sector are discussed below.

Public Sector Applications

The U.S. military has utilized the SWS to simulate U.S. military operations in other countries. The SWS has evolved from several generations of computational experimentation involving large-scale simulation exercises – the most notable of which was Urban Resolve 2015 (UR 2015) – and to support the International Security Assistance Force (ISAF) in Afghanistan.

Urban Resolve 2015 (UR 2015). UR 2015 simulated international operations of the U.S. military. Conducted in three two-week segments in the latter part of 2006. UR 2015 yielded a significant insight that urban combat is less about military tactics and terrain and more about infrastructure and population, dimensions that have not typically been focal points of quantitative-oriented combat simulation and modeling. UR 2015 led to the formation of three task forces, one of which used the SEAS platform to model political, economic, social, information and infrastructure elements of urban environments rather than conventional military-on-military operations. This effort became the genesis of SWS and proved sufficiently powerful during the experimental phase in which JFCOM accelerated its deployment in the theater upon the request of a field general. After continued experimentation in the field, this focused version of SWS was used to provide direct support to analysis, planning, and decision-making on behalf of the International Security Assistance Force in Afghanistan (Chaturvedi, Dolk, & Drenvich, 2011; McKay, Adams, & Chaturvedi, 2011; Lawlor, 2007).

Private Sector Applications

As mentioned above, SWS has also been used in several private sector applications by large multinational firms to simulate market entry and product acceptance in new markets. These applications include exploring the consumer market at the macro level for several large multinational firms with business interests in the consumer packaged goods (CPG) industry. In these private sector applications, SWS was used to represent the markets of China and India at the provincial level using a persistent synthetic environment built from a large amount of open-source data and publicly available reports. The model focuses on an understanding of the dynamics of government and private sector interactions on consumer spending behaviors in India and China. Key learning objectives of these applications included understanding the growth in consumer wallet sizes; understanding consumers' distribution of the shares of their wallet; and understanding the impact of environmental factors, such as actions by governments and other industries on household consumer packaged goods (CPG) spending behaviors. These specific examples of the SWS applications to the private sector are discussed below.

India. SWS was used to represent the market of India at the provincial level for a large multi-national firm in the CPG industry. Specifically, SWS was used to explore the introduction of the 'people's car'.[1] Among the main questions that were studied were: What economic impacts can be expected? How will this affect consumer behavior? What options does CPG have to maintain or expand its share of the consumer wallet?

Key insights of the SWS experimentation in India included: (1) CPG consumption remains relatively constant in the scenario; (2) as more people buy the 'people's car,' the transportation wallet share increases; (3) wallet share increase in transportation is mostly offset by a decrease in basic needs wallet share; and (4) the effect of the 'people's car' is more marked in highly urbanized states than in less urbanized states.

China. SWS was also used to represent the markets of China at the provincial level for a large multinational firm in the CPG

1. Tata Motor's no frill, modestly priced car, Nano, is popularly known as the peoples' car.

industry. In this private sector application, SWS was used to explore differences in consumer behavior among provinces. Among the main questions studied were: What provinces offer the greatest opportunity for market expansion? How effective is advertising in different provinces? How will changes in government policy impact the market?

Key insights of the SWS experimentation in China included: (1) advertising by the CPG industry is effective at increasing relative consumption of that industry, but only to a limited extent; (2) infrastructure expansion efforts in tier-three provinces may be effective at increasing overall consumption in those regions; (3) provinces moving to higher levels of urbanization are spending more on transportation and services; (4) advertising becomes less effective as lower-tier provinces move to higher-tier status due to saturation; and (5) consumption spending is increasing at a fast pace in tier-three provinces.

Discussion

This paper has examined the process of virtual world design, validation, and application by exploring the creation of the "Sentient World" Simulation, an ultra-large-scale, multi-agent-based virtual world developed for the U.S. military. In doing so, we demonstrated an alternative and underutilized application of virtual world technology. This application demonstrated an effective convergence between the real and virtual worlds, offering a powerful IT-based platform for both management research and practice. Some of these impacts of virtual world modeling are discussed below.

Near real-time decision support. Agent-based decision technology can provide analysis capabilities as part of an "in line", "near real time" decision-making process. The agent-based modeling and simulation involved in virtual worlds not only illuminates different decision choices and alternatives, but also critically reveals the potential impacts of these decisions. These illuminations and revelations reduce the guesswork required to evaluate decision alternatives, without in any way minimizing the need for human judgment. For example, SWS provided the staff and the commander with a set of insights and recommendations beyond the capabilities of traditional staff, based on the capabilities that emerged from UR 2015.

Generation of anticipatory, non-intuitive alternatives. One of the strengths of virtual world modeling and experimentation is that it may reveal otherwise unforeseen, counter-intuitive emergent system properties and outcomes. For example, in UR 2015 the commander's staff sometimes reversed recommendations reached by analysis and intuition because of consequences that SWS uncovered.

Improved reach-back capability. The success of the early version of SWS in supporting actual field operations in Afghanistan has naturally led to investigations of whether a broader, more general version of the system can be deployed in other military operations and other non-military venues. Previously, staff performing these kinds of analytical functions did so manually, which required them to be located at the operations site. The SWS allows a much smaller forward presence with the majority of analytical expertise located at a safe remove. The more ambitious, "parallel worlds" vision of SWS described herein reflects our thinking in this regard.

Conclusion

Virtual worlds and the multi-agent-based simulation platforms on which they exist are becoming an integral methodology in the process of scientific inquiry, particularly in the field of information science. The ability to create and inhabit virtual worlds can provide decision-makers with a way to anticipate and evaluate increasing numbers of possible outcomes, with wider variance than has typically been provided by conventional analytical modeling. The use of SWS in military staff decision analysis during actual operations is an early indicator of the value of this technology and methodology. We will continue to push the envelope of such large-scale agent-based virtual world simulations as a way to create more realistic and complex environments in which to survey and enlighten critical decision landscapes, and we hope that this paper may also encourage and motivate other scholars to join us in this pursuit.

References

Barreteau, O. (2003). The joint use of role-playing games and models regarding negotiation processes: characterization of associations. *Journal of Artificial Societies and Social Simulation*, *6*(2).

Bo, X., & Benbasat, I. (2007). E-Commerce Product Recommendation Agents: Use, Characteristics, and Impact. *MIS Quarterly, 31*(1), 137-209, March.

Chaturvedi, A. R., Dolk, D. R., & Drnevich, P. L. (2011). Design Principles for Virtual Worlds. *MIS Quarterly*, *35*(3), 673-684.

Chaturvedi, A. R., & Mehta, S. (1999, March). Simulations in economics and management: Using the SEAS simulation environment. *Communications of the ACM 42*(3), 60-61.

Chaturvedi, A., Dolk, D., Mehta, S., & Ayer, R. (2005, November). Agent-based simulation for computational experimentation: Developing an artificial labor market. *European Journal of Operational Research, 166*, 694-716.

Chaturvedi, A., Mehta, S., & Drnevich, P. (2005). Computational and live experimentation in bioterrorism response. In F. Darema (Ed.), *Dynamic Data-Driven Applications Systems*, (pp. 1-16). Kluwer Publications.

Conte, R., Gilbert, N., Bonelli, G., Cioffi-Revilla, C., Deffuant, G., Kertesz, J., & Loreto, V. (2012). Manifesto of computational social science. *The European Physical Journal Special Topics*, *214*(1), 325-346.

Davis, P. K., & Anderson, R.H. (2003). *Improving the Composability of Department of Defense Models and Simulations.* Rand National Defense Institute, Rand Corporation.

Drnevich, P. L., Ramanujam, R., Mehta, S., & Chaturvedi, A. In-Press. Affiliation or Situation: What Drives Strategic Decision Making in Crisis Response? *Journal of Managerial Issues*.

Drnevich, P., Mehta, S., & Dietz, E. (2006). Coordinating Effective Government Response to Bio-Terrorism. In Amass, S., Chaturvedi, A. & Peeta, S. (Eds.) *Advances in Homeland Security, Volume II: Guiding Future Homeland Security Policy – Directions for Scientific Inquiry*. Purdue University Press, West Lafayette, IN.

Epstein, J. (2002, May). Modeling civil violence: An agent-based computational approach. *Proceedings of the National Academy of Sciences, 99*(3).

Gregor, S., & Benbasat, I. (1999, December). Explanations from Intelligent Systems: Theoretical Foundations and Implications for Practice. *MIS Quarterly, 23*(4), 497-530.

Harrison, J., Lin, Z., Carroll, G., & Carley, K. (2007). Simulation Modeling in Organizational and Management Research. *Academy of Management Review,32*(4), 1229–1245.

Kil-Soo, S, & Young, E. L. (2005, December). The Effects of Virtual Reality on Consumer Learning: An Empirical Investigation. *MIS Quarterly, 29*(4), 673-697.

Komiak, S. Y., & Benbasat, I. (2006, December). The Effects of Personalization and Familiarity on Trust and Adoption of Recommendation Agents. *MIS Quarterly*, *30*(4), 941-960.

Lanchier, N., & Schweinsberg, J. (2012). Consensus in the Two-State Axelrod Model. *Stochastic Processes and their Applications, 122*(11), 3701-3717.

Lawlor, M. (2007, October). Military changes tactical thinking. *Signal Magazine*. Accessed on-line June 1, 2013 at: http://www.afcea.org/signal/articles/templates/Signal_Article_Template.asp?articleid=1403&zoneid=215.

McKay, S., Chaturvedi, A., & Adams, D. (2011). A Process for Anticipating and Shaping Adversarial Behavior. *Naval Research Logistics*, 58(3), 255-280.

Nissen, M. E. & Sengupta, K. (2006, March). Incorporating Software Agents into Supply Chains: Experimental Investigation with a Procurement Task. *MIS Quarterly, 30*(1), 145-166.

Wasko, M., Teigland, R., Leidner, D., & Jarvenpaa, S., , (2011). Stepping Into the Internet: New Ventures in Virtual Worlds. *MIS Quarterly. 35(3), 645-652.*