Convergence between Real and Virtual Worlds:

Exploring Emergent Design in The Sentient World Simulation

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ABSTRACT

In this paper, we advocate that Virtual Worlds may serve as a viable vehicle for scientific inquiry in certain modern contexts. We explore the arguments for Virtual Worlds, and evaluate what it takes to build such a virtual world that may facilitate both convergence with the real world and support rigorous scientific inquiry. A central issue we address is the need to reexamine the design science paradigm to facilitate the development, validation, and use of scientifically viable Virtual Worlds. In doing so, we develop a theoretical paradigm of "emergent design" and illustrate this design process through the development of the Sentient World Simulation. We then explore the validation of this virtual world through a detailed case analysis. We conclude with a discussion of the generalizability of our work to other contexts and of the contributions of this paper and their implications for informing and guiding future research.

Keywords: Virtual Worlds, Emergent Design, Intelligent Agents, Agent-based Simulation, Generative Models

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INTRODUCTION

A "Virtual World" is a computer-based simulated environment, which offers an increasingly popular and powerful alternative reality for both management research and practice (Jarvenpaa, Leidner, Teigland, and Wasko, 2007). Virtual world applications come in many shapes and sizes (e.g., video games, Second Life, flight simulators, Internet social networks, computer models, etc.). These "alternate realities" carry the potential to change dramatically the ways in which we interact with each other in both the real world as well as in these virtual environments. In fact, some of the promise and popularity of virtual worlds lies in their ability to offer an alternative means to communicate, collaborate, and even to organize economic activity (Jarvenpaa, et al., 2007). One of the interesting phenomena of virtual worlds is how the boundary, or interplay, between the real and virtual environments changes depending upon the application of the virtual world. For example, applications designed for entertainment such as computer games require internal consistency to maintain participants' interest but not necessarily a strong correlation with the real world. Flight simulators, on the other hand, are designed to promote learning which will hopefully carry over to a significant degree to situations the training pilot may encounter in the real world. Somewhat similarly, one can view social network sites on the Internet as proxies for face-to-face relationships in the real world.

Alternatively, our focus in this paper is on the use of virtual worlds to support real world decision-making, specifically through the design and implementation of constructive or generative models. In this mode, there is a fairly crisp requirement for not only delineating virtual and real worlds, but also for aligning them in a way that allows for analogical reasoning to occur. This process, which in the case of conventional analytical models, is akin to model validation and verification, is a much more dynamic, fluid, and user-directed process when dealing with emergent, computational models. Our premise is that virtual worlds are becoming increasingly integral to scientific inquiry, and by implication, to the science of design. In building a virtual world we argue that the real world is network-centric, emergent, non-reductionist and inherently unpredictable. Therefore, to emulate such real phenomena, the convergence of real with virtual worlds requires that we capture this net-centricity, emergence, and non-reductionism in our virtual artifacts. Thus the process of design itself is significantly more emergent for virtual worlds than for conventional information system and model development. Likewise, these factors also render the processes for synchronizing real and virtual worlds more complex.

In this section, we present an argument that the design of virtual worlds must be an emergent process. Later, we illustrate this process through exploring a very large-scale, multi-agent, human-in-the-loop virtual environment we call the Sentient World Simulation. We designed this persistent, dynamic, continuously updated, generative social science virtual world to support military decision-making and the strategic planning of military operations. The major challenge in design is in the realization that the social, political, and economic ramifications of military action are more far reaching and long lasting than the immediate effects of any particular battlefield operation.

A major contribution in this study is the explication of the bi-partite design process of generative virtual worlds, consisting of the static agent-based, developer-driven platform coupled with the dynamic, user-generated experimentation of emergent systems. In the static, software-driven dimension, agent development is critical, and the construction of agents is driven by, and calibrated to align with, micro social science theory. The dynamic, user-driven dimension of emergent processes requires a much more fluid concept of validation which is itself an emergent process based upon macro social science theory incorporating equifinality and multifinality. Our overall argument is that virtual worlds are evolutionary, user-driven information eco-systems which extend the boundaries of what we have previously called the science of design. The basic argument is that traditional system design and development (e.g. Hevner, March, Park, & Ram, 2004) is required to establish a platform for facilitating emergent processes, which, in turn, then transforms design into an emergent process of its own.

This paper proceeds as follows. In the next section, we explore the applicability of virtual worlds to the process of scientific inquiry and discuss the challenges such application pose to the traditional science of design. Next, we explore the design and development of the Sentient World Simulation as a means of illustrating the science and process of emergent design. Then, we examine the validation process in emergent design through the application and testing of one of the models in the Sentient World Simulation. We conclude with a summary of the contributions of this paper, the generalizability of our work to other contexts, and the implications for informing and guiding future research on virtual worlds as vehicles for rigorous scientific inquiry and real-time decision making support.

VIRTUAL WORLDS, SCIENTIFIC INQUIRY, AND THE SCIENCE OF DESIGN

We begin by examining the role of modeling, simulation, and virtual worlds in the scientific method. Hamming (1997) partitions the evolution of scientific inquiry into three eras which we depict in Figure 1. In Figure 1a, we show the traditional interplay between theory and experiment which earmarked science from the beginning of the Enlightenment until the advent of digital computers.

INSERT FIGURE 1 ABOUT HERE

The advent of digital computers in the mid 20th century altered the landscape dramatically and led to the ascendance of modeling and simulation as an integral part of scientific investigation as we show in Figure 1b. In this scenario, a Model is a formal representation of reality which implements a Theory, and a Simulation elicits the behavior of the Model, usually over time, thus corresponding to an Experiment. Models in this context have largely been what we call analytical models in that they are primarily mathematical and equational in nature (e.g., systems of partial differential equations or mathematical programming[1]). We use the term simulation in the larger sense of an experimental design for solving and analyzing a model using various forms of sensitivity analysis and/or goal-seeking, as opposed to the more specific context of various simulation technologies such as discrete or continuous event simulations. Since their

[1] One may rightfully protest that mathematical models were prevalent in science well before 1950s, Maxwell's equations of electromagnetism, Schrödinger's wave equations and Einstein's relativity equations being just a few striking examples. We argue, however, that simulation capabilities other than direct experimentation were by and large not available.

introduction at Los Alamos over a half century ago for modeling turbulent flow in hydrodynamics (Pasta and Ulam 1953), simulation methods have become a pervasive part of the scientific method. In fact, many scholars view simulation in scientific research (e.g., numerical experimentation, sensitivity and process studies, etc.) as the first major step forward in the basic method since the seventeenth century. (Robinson 1987).

Computers have also become increasingly indispensable in scientific endeavors, and in some cases, such as the four color map theorem (Appel et al 1977), they enable proofs that may otherwise not have been possible. Similarly, virtual worlds, including those emerging from networks of collaboration as we depict in Figure 1c, may very well be the next transformative stage in the scientific method. For example, projects such as the Linked Environments for Atmospheric Discovery (LEAD) effort use grid technology to execute “on demand” multi-model simulations of weather forecasts (Plale et al. 2005). Such applications indicate that the increasing availability of data and models can nurture and accelerate the process of scientific collaboration and inquiry.

Computational Modeling and Computational Experimentation

The most widely used technology to date for building virtual worlds based upon emergent phenomena has been agent-based modeling and simulation (ABMS). ABMS is a constructive, or generative, modeling methodology as opposed to the more analytical descriptive, predictive, or normative modeling paradigms. We assume the reader has passing familiarity with the fundamentals of ABMS technology; please refer to (Gilbert 2006; Miller and Page 2007; North and Macal 2007) for any required introductory material. Virtual worlds rely heavily upon computational modeling and computational experimentation as shown in Figure 1c. We make a distinction between analytical and computational modeling whereby the former we refer primarily to mathematical models in the disciplines of the physical sciences, management science, and operations research. These typically assume the form of systems of differential equations, multiple regressions and optimization models, for example. Computational models on the other hand we view as primarily simulations whose objective is to capture emergent system properties. Computational experimentation is a research methodology conducted essentially via computer simulations to either generate hypotheses and/or, in concert with traditional field and laboratory experimentation, to confirm or refute hypotheses (Nissen and Buettner 2004). Virtual worlds and computational experimentation go hand-in-hand and one of the strengths of virtual world modeling and experimentation is that unforeseen, counter-intuitive emergent system properties and outcomes may arise.

Generative Social Science

Generative social science (GSS) is an exemplar of the use of virtual worlds, in the form of agent-based simulations, in scientific inquiry (Epstein 2006). GSS is the attempt to "explain the emergence of macroscopic societal regularities…from the decentralized local interactions of heterogeneous autonomous agents." (Epstein 2006, p. 5). This argument is congruent with the goals of the virtual worlds with one notable exception. Much of the computational experimentation done in GSS is data-free in that agents require only attributes and rules of engagement for interacting with nearby agents and the environment in order for a simulation to be run. However, many virtual worlds are more complex in that they are driven by dynamic data and models supplied in near real time mode which cause simulations to change in ways even more unpredictable than the static counterparts typically dealt with in GSS.

Emergence

Since emergence is a main theme of this paper, let us be precise about what we mean and don't mean about this concept, particularly in light of the cavalier usage this term often receives. We see emergence as a bottom-up approach consisting of functions and computations applied to lower level units that capture their interactions. The effect of local interactions at the microscopic level results in macroscopic patterns, or in genetic algorithm terms, the resulting behavior is displayed at the phenotype rather than the genotype level. Let us elaborate on a few of the properties of emergent systems: 1) Self-organization is a collective phenomena and represents collective behavior (Forrest 1990); 2) Macro phenomenon may be greater than the sum of its micro components (Gero and Schnier 1995); and 3) An external observer is required to interpret the emergent pattern, and for whom the emergent pattern makes sense.

Science of Design

The Information Systems (IS) discipline views itself as positioned at the 'confluence of people, organizations, and technology', and characterized by the dual research paradigms of behavioral science and design science (Hevner et al 2004). The former is dedicated to development of theories concerning phenomena related to business needs whereas the latter is concerned with the construction and evaluation of artifacts which satisfy these needs. Behavioral science is empirical in nature with a goal of truth, whereas design science is primarily a constructivist activity whose goal is utility.

We examine the science of design in the context of constructing and maintaining virtual worlds. At first glance, "design of emergent processes" may seem oxymoronic if we ask "how can we design outcomes of processes which we claim are inherently unpredictable from their initial conditions?" However, while virtual worlds are undoubtedly artifacts in the Simon sense (Simon 1996), they are artifacts which require a unique, bi-partite process to design. We argue that virtual world artifacts are a hybrid of conventional top down design of agents as a first phase and an evolutionary, user-driven bottom up process during the emergent second phase.

THE DESIGN ARTIFACT: THE SENTIENT WORLD SIMULATION

The Sentient World Simulation (SWS) is a heavily data-driven virtual world whose primary objective is to examine how the interrelated effects of nation dynamics, socio-economic geopolitical situations, leader predispositions, and citizen expectations, goals, and desires for well-being. The specific purpose for which SWS was developed is to aid strategic decision-making in any countries in which the United States is involved militarily, adopting a holistic, social science perspective of which military operations constitutes only one dimension of the complex landscape.

Requirements of SWS

SWS is an ambitious experiment in generative social science, which presents formidable design challenges. The high level requirements of this complex system are:

- Capture social, political, and economic dimensions of countries.
- Support strategic military decision-making within theaters of operation, providing support for maintaining situational awareness, and generating and evaluating possible courses of action (COAs).
- Maintain near real-time fidelity. A crucial goal of SWS is to exhibit "near real-time" accuracy and timeliness in its underlying knowledge bases so that the state of SWS environment is not far removed from the geo-political realities which it emulates. This tight coupling between the real and virtual worlds bears a significant decision-making payoff by shortening the decision loop between problem identification and the evaluation of alternative courses of action.

- Support multiple levels of spatial and temporal granularity, which can range from regions encompassing multiple countries to provinces and cities within countries, and temporal levels of analysis from hours to months.

- Support human-in-the-loop (HITL) participation.

Design Objectives

The overall design objective for SWS is to develop a framework for designing high-performance controlled systems to emulate highly uncertain environments in which not only may the relative, Bayesian probabilities of possible outcomes be unknown, but even the outcomes themselves may not be predictable a priori. This framework has two elements – a static, deep structure level for building and testing agents, and a dynamic, transient, user-generated level for generating and interpreting the emergent, macro-level behavior manifested in the virtual world.

Deep Structure: Synthetic Environment for Analysis and Simulation Platform

The modeling and simulation component of SWS is supported by the Synthetic Environment for Analysis and Simulation (SEAS) platform (Chaturvedi and Mehta 1999; Chaturvedi et al. 2005). The SEAS platform has served as the support environment for a number of innovative large-scale agent-based simulations (see Chaturvedi et al. 2005; Drnevich et al. 2006; Drnevich et al. 2009). For specific information regarding the technical and architectural details of SEAS see (Chaturvedi and Mehta 1999; Chaturvedi et al. 2005). In Figure 2 we depict conceptually the SEAS architecture.

INSERT FIGURE 2 ABOUT HERE

Transient Structure: Sentient World Simulation

SWS is a large-scale multi agent model implemented on the SEAS platform (Figure 3). SWS consists of over 12 million heterogeneous, intelligent agents representing the virtual populations, organizations, institutions, and leaders of over 60 nations. These agents represent an overall population of approximately a billion people, with an agent compression ratio of 100:1.

INSERT FIGURE 3 ABOUT HERE

A key objective of 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 through the use of an external Net Assessment (xNA) knowledge base to create and sustain this coupling between the real-world and virtual world environments in SWS. xNA is a very large, highly distributed data repository 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 atom of data in xNA is tagged by three dimensions: Source, Point of View, and a Time/Date interval. The society of simulations component comprises the virtual world dimension of SWS wherein users employ computational experimentation to leverage the xNA knowledge base by creating and executing either historical or futuristic simulations.

Convergence of SWS and Second Life Virtual World Paradigms

SWS and Second Life (SL) are both large scale virtual worlds that have many complementary aspects. As we show in Table 1, they approach the process of mimicking the real world from differing perspectives. Whereas SWS focuses on detailed realism of the world, SL approaches it from an embodiment and self expression perspective. SWS implements micro-level theories as a forward problem where we observe the emergence of macro behaviors. It then uses macro-level theories to calibrate and validate the emergent phenomena. It is a dynamic data-driven system that continuously ingests data from thousands of sources, including real time sensor feeds, to parameterize entities within SWS, decode "playbooks" of actors, and to assess the outcome of events, actions, and interactions.

INSERT TABLE 1 ABOUT HERE

Second Life, in its current form, is primarily an environment for shared immersive experience. It is a social place where people meet other people through their respective avatars in the virtual world. People indulge in self expression through the embodiment of their avatars, their names, appearances, profiles, scripted actions (dancing, laughing, etc.), presents an experimental setting to study a wide range of micro-level behaviors in the areas of communication, psychology, social psychology, economics, etc.

Peering into the future, large-scale Dual Reality is not that far away. In Dual Reality an entity co-exists in the real world and the virtual world simultaneously and can have two-way communication between both the worlds. A convergence of SWS and SL can lead to the development of such dual reality. For example, in the context of a homeland security scenario, an island could be built in SL based upon direct feeds from SWS. Individuals, organizations, institutions, and infrastructure could be configured in SL. First responders, wired with sensors and actuators, could continuously feed their location, movements, and actions to their corresponding avatars in SL. Avatars in SL could then fly over a building, walk through fire and report 360 degree surveillance information back to the responder in the real world.

AN APPLICATION OF THE SENTIENT WORLD SIMULATION

Because of limited space and the research nature of the paper, we provide only a truncated, capsule version of SWS' overall features and interfaces in the form of a thumbnail use case.

Upon a request from the commander of International Security Assistance Force (COMISAF), SWS-Afghanistan was field tested in Afghanistan from March 1, 2007 until March 31, 2008. The purpose of the field experiment was to assess the applicability of a comprehensive modeling and simulation system with a reach-back capability and to provide detailed analytical support for planning and decision making in execution of Stability Operations in the theatre. SWS provided a planning and decision support framework appropriate for today's complex operational environment with regard to Diplomatic, Information, Military and Economic (DIME) actions on Political, Military, Economic, Social, Informational, and Infrastructure (PMESII) dimensions of operations using the comprehensive Whole-of-Government Approach (WGA). SWS incorporated multi-scale, multi-sided perspectives of the combined operational environment to highlight the economic, political, and cultural factors that influence military and non-military outcomes at the district, province, national, and the regional levels. Over 6,000 events and 53,000 actions were executed on 398 Afghanistan districts with a total of approximately 18,000 named entities and over 2.5 million agents representing citizens of Afghanistan.

The remainder of this section presents a case study of the efforts to rapidly deploy SWS to support a multi-national staff that rotated every 3-6 months in the operational theatre. The discussion focuses on the challenges related to business process, project management, technology deployment, and operational support as well as on the solutions to these challenges. COMISAF concluded from the field experiment that SWS is sufficiently robust to support course of action (COA) development and analysis from multiple, culturally relevant viewpoints SWS provided institutional memory of plans as well as the persistence of results to explore alternatives when assumptions or conditions changed. The insights gained in this effort to prototype and field a dynamically updating, web-based synthetic environment can serve to enhance support to operational commanders as well as make contributions to the art and science of agent-based modeling and computational social science. There are two general modes of usage in SWS: (1) assessing situational awareness by searching for, and possibly updating, knowledge from the xNA knowledge base, and (2) game-playing decision scenarios in the form of Excursions which allow decision-makers to inhabit SWS' virtual countries in any combination of past, present, and future timelines.

Assessing Situational Awareness in SWS

The use case described in the following tables and figures describes a subject matter expert (SME) located in USCENTCOM who has been tasked by his commander provide 1) a situational understanding for what's happening in CENTCOM, and 2) recommendations for what should be done next. Situational awareness is provided via a number of visual displays available in SWS, coupled with the ability to search and annotate relevant headlines gathered dynamically from the Web and stored in the xNA knowledge base. In Tables 2 and 3 below we present a simplified use case for this mode of operation. In Figure 4 we show representative SWS user interfaces for assessing situational awareness and understanding.

INSERT TABLE 2 ABOUT HERE

INSERT TABLE 3 ABOUT HERE

INSERT FIGURE 4 ABOUT HERE

Excursions: Decision Scenarios in SWS-Afghanistan

The full virtual world aspect of SWS comes into play in the form of Excursions. Users can embark upon Excursions into any country supported by SWS and can designate either an historical or a future-based timeline for the simulation. We describe a sample use case in Table 4. In Figure 5 we capture the major user interfaces for this mode of operation.

INSERT TABLE 4 ABOUT HERE

INSERT FIGURE 5 ABOUT HERE

In this section we have provided just a brief overview of a use case to help ground the decision-making context for which SWS is used, and to show how this agent-based system is deployed to support the strategic component of effects-based military decision-making. In the following sections, we address the formidable challenge of the underlying design of this dynamic, data-driven agent-based simulation.

MICROLEVEL DESIGN: THE SIMULATION OF AFGHANISTAN

Capturing the socio-politico-economic climates in nations has until recently been beyond the capabilities of most simulation technologies. Although economies lend themselves readily to mechanistic and quantitative representations, the social and political dimensions of countries do not. The ability of ABMS to better capture the fuzzier, more qualitative aspects of social relationships, i.e. to support generative social science, is becoming recognized and embraced, and is amply demonstrated within SWS. In order to support the strong requirement of near real time verisimilitude between the agent-based virtual world simulation of SWS and the real world, it is of critical importance to model the agents accurately and realistically. Getting the design "right" at this micro level is essential if we are to have any chance of meaningfully interpreting the macro level behavior of the emergent simulations. Agent behaviors must be well grounded in theory, while simultaneously satisfying the age old modeling requirement of representing structure and behavior at the appropriate level of abstraction. For a simulation this large with millions of agents, it would be disastrous from a performance standpoint, for example, to adopt too fine a spatial or temporal granularity. Equally critical in this phase of the design is the calibration of agents so that their behaviors align with how the theory predicts. In this section we describe SWS agents in terms of the underlying theory, structural design, and subsequent calibration. We have designed two broad classes of agents in SWS: social agents designed to capture the socio-political dimensions of a country, and economic agents to represent a nation's economy.

Social Agents

There are three major classes (IOI) of synthetic social agents: Individuals (Citizens and Leaders), Organizations, and Institutions, which are hierarchically arranged. Organizations and Institutions consist of Citizens and one or more Leaders, and may themselves be comprised of other Organizations. Each social agent is a 4-tuple {G, T, S, A(T)} where:

G	purpose in the form of one or more goals;
T	a set of traits or attributes, the values of which determine action(s) the agent takes;
S	one or more sensors through which an agent forms perceptions of the external social, political and economic environment;
A(T)	actions, or rules of engagement, which an agent may take within its environment.

The general, overriding goal for all agents, regardless of their respective level of aggregation, is to maintain and enhance their well-being. Employing the model of subjective well-being identified by (Kahneman 1999), we code an agent's perception of well-being based upon its desire for nine basic needs, and the degree to which it perceives these desires as being fulfilled. Sensors provide information from the socio-politico-economic environment from which each agent assesses its perceived well-being, measures the degree to which its basic needs are not being met, and depending upon the magnitude of this discrepancy, in concert with the particular traits of the agent, may take one or more actions in an attempt to reduce this difference. In Table 5, we provide an overview of SWS social agent structures.

INSERT TABLE 5 ABOUT HERE

Economic Agents

The other major class of agents is used to model the economy in each country that populates SWS. A synthetic economy provides a model of a domestic economic system and of an international economy within SWS, and is represented by fifteen sector agents, thirteen of which are **production** sectors. These include oil, power, natural gas, water, telecommunications, transportation, manufacturing, agriculture, finance, education, military-industrial, labor and capital, and all but the last two are also modeled as infrastructure. The final two sectors, consumers and government services, represent **consumption** sectors. A macro-economy emerges from the interactions of these fifteen sectors. A synthetic economy can represent either a country or a province within a country. In addition, synthetic economies can engage in bilateral trade with other economies. Each sector is interdependent with the other sectors via several propagation mechanisms through which effects percolate throughout the system. First-order dependencies are present whenever one sector uses the output directly from another sector as an input into its own production process. Second- and third-order effects as well as indirect cause-effect relationships emerge.

SWS presents a mechanism for exploring the micro-foundations of macro-level economic phenomena (which themselves proceed to feedback and influence microeconomic behavior). Once consumer, government and business infrastructure agents begin to stimulate demand within an economy, the production sectors begin to produce output according to their production functions. Economic agents within an economy engage in international trade if they cannot satisfy their demand and/or sell all of their supply domestically. International trade patterns change as domestic and international conditions fluctuate, and macro-level variables (such as GDP) emerge from micro-behavior while also influencing the latter in an iterative process. In Table 6, we provide an overview of SWS economic agent structures.

INSERT TABLE 6 ABOUT HERE

Media Agents as Sensors

Media organizations consist of television and radio stations, newspapers, and magazines. They make choices about what information to cover, who to cover, what statements to report, what story elements to emphasize and how to report it. Media organizations are able to set the agenda for domestic and foreign policies. Incidents are framed on well-being components, and formalized in a media report. For example, if the media's agenda is to arouse the public against the government and if basic needs are below a certain threshold level, then the media may frame relevant stories in a manner that blames the government for the dire conditions of the people. Citizens subscribe to a media organization based on their ideological bent. Subscription to a particular media is dependent upon the congruence of the ideology of the media with the ideology of the citizens subscribing to it. Media organizations are primarily focused towards framing the issues for their audiences in such a way that they increase their viewership as well as their influence. When the media infrastructure agents are reduced in their capacity to report, then the media conglomerates have a reduced capacity to spin reports.

Summary

We've described the basic agent structure underlying SWS. This is the more traditional part of the virtual world design process, but one that is critical to the eventual verisimilitude of the simulation, and central to verification and validation. In the next section, we discuss the calibration of these agents as well as the dynamic validation processes necessary to maintain the evolving knowledge base and support meaningful excursions in to SWS' virtual countries.

MACRO-LEVEL DESIGN: EMERGENT PROPERTIES AND VALIDATION

We have argued so far for the value of virtual worlds in the process of scientific inquiry, and the use of emergent design as necessary instrument in the modeling of network-centric living systems. We have shown how the development of agent structure and behavior is critical to this modeling process, but this aspect is not sufficient unto itself. Although it will help us build a system with emergent properties, it does not in and of itself ensure that these emergent properties are relevant to our application. Indeed, how do we know that our emergent system is any good, particularly with respect to capturing such a complex, interdependent environment as a country and a population?

There are two key differentiators between the validation of agents and the validation of the overall system behavior to which they give rise: continuous dynamic data and model updating, and the iterative participation of a large community of interest in performing these dynamic activities. The data-driven nature of SWS distinguishes it from the more localized agent-based simulations such as we typically find in generative social science research. Continuous validation, as we refer to it, is tightly coupled with the concepts of multifinality and equifinality described below.

Multifinality and Equifinality

In order to grasp the complexities associated with macro-validation, it is necessary to grapple with the conditions of equifinality and multifinality. Equifinality is the phenomenon when a specific emergent end state of an open system can result from multiple, different sets of initial conditions. For example, the Linux operating system is a single emergent operating system which has converged from the inputs of hundreds, even thousands, of open source contributors. Multifinality is the converse situation wherein different open system end states may arise from identical initial conditions. For example, the dissemination of a single version of Unix source code may result in the generation of multiple versions of the operating system as users adapt it to their specific requirements.

One of the greatest challenges of validating emergent systems is that cause and effect chains between open system initial conditions and end states are difficult, if not impossible, to trace. This forces us to rely upon interpretative rather than positivist analysis. In the SWS environment, our desideratum is "constrained emergence" facilitated by continuous validation wherein users leverage a deep structure platform (SEAS in this case) to generate dynamic alternate realities, but within a finite bandwidth of possibilities arbitrated by a community of subject matter experts.

Continuous Validation for SWS - Afghanistan

The emergent validation process as applied to SWS - Afghanistan consisted of a two tier process: a) validation of the initial configuration of Afghanistan, and b) continuous validation of SWS-Afghanistan, with data updated, refreshed, calibrated, and validated within one month of the current date.. Once these steps were completed (with step b occurring iteratively), various courses of action were submitted, evaluated and refined as necessary (see Figure 6 below).

INSERT FIGURE 6 ABOUT HERE

The first stage consisted of the configuration and validation of provincial-level data, which included demographic data (traits such as ethnicity, religion, sect, tribe and sub-tribe, well-being and attitude), data on key leaders and organizations (types and attitudes), and data on information and infrastructure nodes (capacity). An important aspect of the configured data set was the attitudes of leaders and organizations toward key chosen entities. Five significant sides were chosen as “Human-in-the-Loop” players: Government of USA, Government of Afghanistan, ISAF, Taliban (Afghanistan), and Al Qaeda (Afghanistan). This stage also consisted of validating aggregate emergent statistics at the provincial level.

The second stage focused on continuous validation, specifically tracking changes in Afghanistan in SWS from its initial configuration in March 2007 and comparing it with actual data, while attempting to ensure that no more than 30 days separated the simulation output and the real-world data. Significant Diplomacy, Information, Military, Economics (DIME) events were injected weekly along the simulation timeline, and the resulting simulation outputs were evaluated against reported field/third party data. Validating system outputs also required that we validate system inputs. While inconsistencies between synthetic and real-world data may be due to the calibration of various models, it may also be due to a reliance on a non-representative set of DIME inputs across all HITL players used to run the system forward. Thus, validating the set of

DIME actions injected into the system was also a critical aspect of the continuous validation process. Tracking Afghanistan had some inherent challenges, such as the paucity of data on Afghanistan as well as inconsistencies in the format of the available data. Nonetheless, available field data was used to configure and validate data in both stages of the continuous validation process. We begin with a description of the first stage of this process: the initial configuration of the reference world.

Creating the "Reference World" Starting Point

Creating "virtual" Afghanistan's initial conditions required representing and validating economic, political, and demographic data for Afghanistan as well as the initial emergent statistics. The goal was to provide a valid explanation for SEAS parameters and outputs based on the best-known field/third party data and subject matter expert (SME) conclusions. We collected data at the national, provincial (34) and district (398) levels for all PMESII categories that were then mapped to SEAS IOIIG (Individual, Organization, Information, Infrastructure and Geography) categories. The type of data that was collected and verified consisted of economic data (GDP, production, sector output, etc.), demographic data (population, ethnicity, religion, tribe/sub-tribe, income class, etc.), political data (national and provincial government ministers and officials, insurgent groups and leaders, strength of government institutions, etc.), public opinion data (public attitudes towards central and provincial government, Taliban, USA, etc.), and information on key organizations and infrastructure nodes (public and private organizations, Kajaki dam in Helmand province, etc.).

Gathering and verifying all of this data to initially configure the reference world at different granularities was the critical first step, which essentially required the successful completion of three main tasks: (1) identifying and documenting relevant sources of data and information; (2) developing a parameterization methodology to configure the traits and parameters of SEAS agents; (3) and the validation of the initial emergent data. It should be noted that the amount of data that was initially collected and configured numbered in the thousands of data points, and therefore we were not able to validate each data point produced by SEAS to initially configure the reference world. Thus, our validation efforts in this stage were focused on validating profiles for each of Afghanistan's 34 provinces.

The first step in creating the initial configuration of the reference world was identifying and qualifying useful sources of data and information. Given its status as a very poor country, Afghanistan has limited capacity and resources to gather, synthesize and disseminate data. As a result, we relied upon a number of sources to populate the initial configuration of the reference world. Key sources included the World Bank, the International Monetary Fund, the CIA World Factbook, Afghan government agencies such as the Central Statistics Office, academic studies, as well as reports and data produced by think tanks and research units, such as the International Crisis Group, the Center for Strategic and International Studies (CSIS), and the Afghanistan Information Management Service. We also relied upon public opinion surveys sponsored by organizations such as the Asia Foundation, Charney Research, the Environics Research Group and the Senlis Council. These surveys provided data on Afghan attitudes regarding the central and provincial governments, the U.S., NATO, the Taliban and Al-Qaeda at a specific point in time, and they proved to be immensely valuable.

Unfortunately, surveys of Afghan attitudes occur relatively infrequently, and we usually had to work with only one or two data points per year.

The next step in creating the reference world involved the development of a parameterization methodology to populate the traits and parameters of the various agents within SEAS. There were two key aspects in regards to this step. First, we had to translate existing field data into SEAS formats. Key parameters such as public opinion towards various entities, and citizen well-being, are populated on a 0 – 7 scale in SEAS, with higher numbers representing greater satisfaction or approval. Most field data, however, exists in a different format. For instance, public opinion surveys measuring public attitudes towards the national government typically report the percentage of those surveyed that either support or disapprove of the way the government is governing. These percentages had to be converted to a 0 – 7 scale.

Other examples of mapping survey results into SEAS were less straightforward, making it necessary to develop explicit ranking methodologies that mapped survey data to a 0 – 7 scale. For instance, the National Risk and Vulnerability Assessment (NRVA) is a report published by the Afghan Ministry of Rural Rehabilitation and Development (in conjunction with various international agencies) that contains a plethora of demographic and socioeconomic data on Afghanistan at the provincial level. Pollsters questioned Afghans regarding the amount of travel time required to reach public transportation, with responses ranging from “In the community” and “Less than ¼ day” to “1/2 to 1 day” and “More than 1 day.” Freedom of Movement needs in SEAS was populated based upon the reported distribution of a province’s population across these categories. Specifically, the higher the percentage of a province’s population that had to travel a longer distance to access public transportation, the lower the parameterization for the Freedom of Movement needs fulfilled for the agents representing citizens in that province. Thus, one of the challenges that had to be overcome in configuring the initial instance of the reference world was the development of an appropriate methodology that mapped reported field data into a format usable by SEAS.

"Data triangulation" was another important aspect of the parameterization process. We compared data from a variety of sources with multiple perspectives to overcome the weaknesses and/or intrinsic biases that may exist in single-method, single-observer, and single-theory studies. Parameterization of traits, attitudes, and other parameters proceeded after multiple sources of information and data were compared, qualified, and synthesized. For example, we relied upon a number of public opinion polls to parameterize attitudes towards the Taliban. For instance, a December 2006 poll published by World Public Opinion.org noted that 90% of Afghans have a negative attitude towards the Taliban, while 94% have a negative attitude towards Al-Qaeda and its leader Osama Bin Laden. This report noted that "*Ninety-two percent of the Afghan people said their opinion of the Taliban was unfavorable, up four points from 88 percent in 2005. The numbers expressing a 'very unfavorable' view increased the most, rising 9 points from 62 percent to 71 percent. Only 7 percent expressed somewhat (5%) or very favorable (2%) views of the Taliban.*" Other surveys conducted by the Senlis Council and the United States Institute of Peace showed disapproval by approximately 72% of the population. From these three sources, data triangulation was used to deduce that between 72 - 92% percent of the population opposed the Taliban.

We also consulted other surveys to further parameterize attitudes across ethnicities, sects, and tribes/sub-tribes. For instance, a February 2007 CSIS report noted that "*most of the (Taliban) leadership is from the Ghilzai Pashtuns, including the charismatic leader Mullah Mohammed Omar, and its principle areas of operation coincides with the Ghilzai's largest population centres in Uruzgan, Zabul, Ghazni, Dai Kundi, and Paktika.*" This information was used to parameterize attitudes towards the Taliban for non-Pashtun ethnicities, such as Tajiks, Hazaras and Uzbeks, non-Ghilzai Pashtuns (i.e. Durrani), and Pashtuns located in the northern parts of the country. Thus, the consultation of numerous sources of information facilitated data triangulation as well as parameterization at a fine level of detail.

Validation of generated data was the final step in the creation of the reference world starting point. This step was critical, because much of the detailed data produced by SEAS to populate the reference world does not have real-world counterparts for Afghanistan. We focused our validation efforts at this stage on the macro-level outputs for each of Afghanistan's 34 provinces. For example, Figure 7 below shows the SEAS provincial profile for Helmand province.

INSERT FIGURE 7 ABOUT HERE

We validated macro-level synthetic data using separate sources that we did not rely on initially to create the generated data. For instance, we initially utilized data from the CIA World Factbook, Afghanistan's Central Statistics Office and detailed National Geographic maps to determine provincial-level population as well as the religious and ethnic distribution within each province. We cross-referenced our initial calculations with the district-level profiles produced by the Office of the United Nations High Commissioner for Human Rights (UNHCR) as well as reports put out by think tanks such as CSIS. Any notable discrepancies were set aside for further review and evaluation. Thus, the creation of the starting point for the reference world required the successful completion of three main tasks: (1) identifying, qualifying and synthesizing relevant sources of data and information; (2) developing a parameterization methodology to configure the traits and parameters of SEAS agents; (3) and validating the initial emergent data. We now turn to a description of our continuous validation effort.

Continuous Validation

Once the initial state of the reference world was populated, parameterized and validated, the next step was to run the synthetic world forward in time with the injection of real-world events from March 2007 on, followed by an analysis of output data to determine the consistency between synthetic data and the actual state of the world.. At this point the validation phase was continuous, since end-users required that the synthetic environment accurately reflect real-world conditions within a 30-day period. The continuous validation effort, as indicated in Figure 8a below, consisted of two main tasks: "significant event" validation and output validation. We defined a "significant event" as a diplomatic, informational, military, or economic (DIME) action taken by one of the five Human-in-the-Loop actors configured for the SEAS virtual Afghanistan (Figure 8b).

INSERT FIGURES 8a & 8b ABOUT HERE

The first step, therefore, was to identify and gather as much information as possible on the variety of DIME actions across all five HITL players. We consulted a number of sources to obtain data on significant events, such as the ISAF Press Office, the websites of the U.S. Embassy in Kabul and the Afghan Embassy in Washington, DC., Afghan government websites (Ministry of Foreign Affairs, Office of the President, etc.), Afghan news services (Pajhwok, Bakhtar News Agency), and Afghan-specific websites (Afghanistan page of IRIN, e-Ariana, Agha.com, etc).[2] In addition, we utilized daily situational reports from consultants based in Afghanistan to populate "M" (military) and "I" (informational) actions for each of the five HITL players.

It quickly became apparent, though, that even with our best research efforts, we would not be able to capture every single significant event across all DIME actions and HITL players. The main problem was that many events, particularly those related to Taliban and Al Qaeda actions, are simply not reported with a sufficient degree of specificity by news services, websites, and other sources of information. For instance, the following excerpt from a May 2007 article in the *New York Times* noted how the Taliban were able to siphon off profits from the opium trade in Afghanistan to fund their activities: "*Farmers growing poppies in Taliban-controlled areas pay a tax to the insurgents, who then hire "day fighters." For their part, drug traffickers pay the Taliban for security……In Nimruz province, in southwest Afghanistan; the Taliban demanded that traffickers provide $4,000 a month and a Toyota Land Cruiser to support 10-man fighting units, according to United Nations officials. An Afghan official said Taliban forces were given five Land Cruisers for attacking the Afghan border police so traffickers could move drugs more easily....*" This excerpt does provide some detail as to the location of these extortionist actions by the Taliban (Nimruz province), but our analysts deduced

[2] The Integrated Regional Information Network (IRIN) is the humanitarian news and analysis service of the U.N. Office for the Coordination of Humanitarian Affairs.

that these actions were likely to be widespread in opium growing areas controlled by the Taliban. Based on an extensive review of available research and news reports, we also determined that other actions, such as Al Qaeda technical/media support to the Taliban, as well as the Taliban engaging and receiving support from friendly sub-tribes, were also likely occurring with a high degree of frequency despite the lack of media coverage or specific information in the media reports that did address these topics. Thus, the set of DIME actions used to run the referent world forward in time was adjusted to take account of events deemed by our analysts to occur with a high level of frequency, despite the fact that such actions, due to their secretive nature, did not receive extensive media coverage.

The next step in the continuous validation process was to upload and translate these events into a format compatible with SEAS. Formal procedures were established to handle both of these tasks. We uploaded events into SEAS using the SEAS Significant Event Inject tool and the SEAS Action Planner. Both were used to create a number of discrete and continuous events in SEAS for which information was collected. For instance, the website of the Office of the President of Afghanistan disseminates news releases describing meetings between President Hamid Karzai with a variety of foreign dignitaries and officials. These types of events were entered into the SEAS Action Planner described in the Use case as an “Engage” action.

The insertion of a significant quantity of events was handled by the SEAS Significant Event Inject tool, a spreadsheet-based database of specific classes of events and their associated metadata. This tool was designed to work with databases providing information on thousands of significant events. For example, on the website of the Afghan Ministry of Rural Rehabilitation and Development, one can access files showing the status of thousands of development projects carried out from 2002-2008. The SEAS Significant Event Inject Tool was designed to handle files such as these as well as similar files and databases from other sources.

We also needed to develop procedures for translating real-world events into comparable SEAS actions. As previously noted, the website of the Office of the President of Afghanistan provides information regarding meetings between President Karzai and foreign leaders. These events were translated as an “Engage” action in SEAS. But SEAS actions are also characterized by the numeric “resource level” associated with them (in the case of the “Engage” action, the resource level reflects the degree to which one actor tries to sway another actor to adopt attitudes favorable to the former). Each action resource level has been calibrated for a specific real-world semantic, so each event was mapped to a resource level in SEAS accordingly. For example, if three or more diplomatic engagements occurred within a week, the resource level for the “Engage” action for that week represents a 2; otherwise it represents 1. Similarly, we also developed procedures to overcome other types of translation issues as well, such as allocating responsibility for military actions undertaken by “Coalition Forces” to the U.S., ISAF, or the Afghan government.

The final, iterated stage of the continuous validation process was the evaluation of the goodness of fit between synthetic data and actual data and, if necessary, the recalibration of models and the resubmission of SEAS Action Planners for subsequent simulations over the desired timeframe. The key aspect of this step was the comparison of synthetic data from March 2007 to the present with actual data, and as a result the major challenge presented during this phase was the paucity of detailed, current data describing the economic, political, and social conditions in Afghanistan, both nationally and at the provincial level. Some of the critical values that we reserved for closer scrutiny included GDP growth and public opinion. We were not able to find GDP growth data for individual provinces, so we were left with validating GDP growth at the national level. We used real GDP growth rates from IMF country reports as our benchmarks, and calibrated the synthetic Afghan economy so that synthetic growth rates matched the growth rates reported by the IMF. There was also a paucity of public opinion data. As previously noted, we relied upon surveys sponsored by several organizations, but these surveys occurred relatively infrequently (about every 8-12 months). Therefore, we had to rely on only one or two data points per year, and as a result our strategy of validating public opinion data essentially consisted of comparing trends in synthetic data with those seen in what actual data was available. In Figure 9 below we show a comparison of synthetic public opinion data with actual public opinion nationwide in Afghanistan as well as in Kabul, Kandahar and Helmand provinces.

INSERT FIGURE 9 ABOUT HERE

Inconsistent trends between synthetic and actual data were set aside for further review. If the synthetic data could not be validated, subsequent iterations of model recalibration and the resubmission of courses of action ensued, with the current iteration of the continuous validation process ultimately ending only upon the validation of the generated data.

CONCLUSIONS

This paper describes how we used a Virtual World as an instrument of scientific inquiry for near real-time decision making in a theater of conflict. The thirteen month of field experiment in Afghanistan marked the first ever application of a Virtual World in a theater of military operation and effectively demonstrated the value of SWS as a decision support virtual world for the U.S. military. The team, the tool, and the underlying database developed during the project reached the level of sophistication needed to support military and non-military operational planning. Planning at International Security Assistance Forces (ISAF), where SWS was used, became a scientific endeavor – a computational experimentation where numerous lessons learned developed demonstrating an effective convergence between real and virtual worlds.

Planning as scientific investigation: SWS is a high fidelity synthetic environment that enabled military and non-military planners to rapidly acquire a significant domain knowledge related to social behavior, military operations, and the model process and procedures to generate meaningful plans from different perspectives (US, Taliban, Afghan Government, etc.). The planning process involved users to translate operational plan (OPLAN) planning guidance, course of action design, or requests for information from graphics and written word to SWS Course of Action (COA) plans. These plans were then executed in SWS. Different branches were created in order to refine the COAs and alternative options were presented to the commander. Based on commander's orders, operation orders (OPORD) were created. These orders were executed in the field as well as in SWS. The desired and actual outcomes were monitored and data were collected. Actual and SWS outcomes were compared. More than 50% of the variables tracked showed significant convergence between the real world and the virtual world. Much of the divergence was associated to the planners' inability to anticipate the other sides' (Taliban, Al Qaeda, and local governments) actions.

Virtual Worlds as a vehicle for organizational learning and memory: Virtual worlds play a significant role in organizational learning and provide organizational memory in a situation where teams rotated in and out of Afghanistan every 3-6 months. SWS provided rapid, on-demand projections to enable planners to confidently consider impacts outside their areas of expertise (for military officers – social and economic impacts) and, for all planners to discover and anticipate potential unforeseen consequences of planned actions.

Emergent Design: Virtual worlds require capturing nonlinear, non-reductionist, network-centric behaviors of "real world" entities, and their interrelationships. Virtual worlds by definition address the needs of a diverse group of users. Individual users are both consumers and producers of content. Requirements are not known a priori as users dynamically reveal current requirements, which also evolve over time. Building a virtual world requires "citizen programmers" to contribute content – data, models, scenarios, courses of actions, and intervention plans. While traditional IS is developed by a few expert programmers, the bulk of the content of virtual worlds come from the end users. As such the discipline of the structured methodology must come from the platform itself. Emergent design extends the science of design to enable the development of interacting components by "citizen programmers." Using a hybrid approach, a combination of top down and bottom up views, SWS provides a platform on which large numbers of users can build and share their own custom content.

Stability: Despite its size, (over 12 million interacting agents), SWS is remarkably stable. We can explain this behavior through the principle of complexity theory that postulates that systems are ordered, and exhibit regularities in structure. Considered over time, SWS entities/agents do not proceed from one random state to another, but move from one relatively stable pattern of interrelationships among their components to another. Over time, SWS exhibits a subset of potential patterns of its subcomponents such as economy, social networks, and organizational membership. These particular patterns are reference states. Probabilities of changes of system components toward those present in reference states are greater than probabilities of changes away from them. A given system may oscillate between two or more reference states; the intervening patterns that are less likely are "boundary" areas. This principle has also been observed in social and psychology.

Multifinality and Equifinality: Open systems exhibit characteristics of multifinality and equifinality. That is, a given set of system conditions can lead, over time, to a multitude of end states (multifinality), and many different system conditions may lead to the same endstate (equifinality). These principles are applied to virtual world design, as one way to integrate data on different trends and individual differences. Intervention pathways, in this view, show characteristics of multifinality and equifinality, whether the "start" states consist of a set of environmental and / or socio-psychological conditions, and whether the "end" states consist of normative and/or individual or group well-being desires. The influences of internal and external interventions on users may also occur through multifinal or equifinal pathways.

Continuous Validation: Deployed on a NATO Secret Wide Area Network (NSWAN) SWS supported NATO-led ISAF from March 2007 until March 2008 for operational planning. One of the goals in support to the theater was to continuously track the current political, economic, and cultural climate of the observed world by keeping SWS data current. In order to accomplish this, a process of continuous validation was developed and implemented in which the "Reference World" tracked the real world by extracting data from multiple heterogeneous sources on a daily basis, injecting real-world events into SWS over the recent timeline, and using referent data sources to provide assessments of SWS outputs.

Virtual worlds and the multi agent-based simulation platforms on which they exist are becoming integral to the process of scientific inquiry. We hope this paper may encourage and motivate other scholars to join us in this pursuit.

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Table 1. Comparison of SWS and Second Life Virtual Worlds

Property	Second Life	Sentient World Simulation
Focus	Embodiment	Detailed realism
Construction	User created	Automated, semi-automated foraging of textual content
Primary Use	Self expression, social place, entertainment, fantasy	Decision making, Situation understanding, information
Convergence	Behavior, social interaction	High fidelity reconstruction of the real world
Primitives	Land, Avatars, Objects, and Scripts	Individuals, Organizations, Institutions, Infrastructure, Geography
Social interaction	Emergent, real-time, initiated by people	Hybrid – may be mapped from real world data mining; generative at the run time, multi-scale
Avatar/Agents	User created	Named agents – represent their real world counterparts; large number of profile based agents
Execution	Primarily human in the loop	Primarily self executing, with human in the loop
Size	9 million registered, 50K online anytime	Over 12 million artificial agents

Table 2. Use Case for Situational Awareness via Map Visualization

User Intent	SWS Action(s)
Develop situational understanding: Option 1	
At the beginning of my (work) day I look at the reference world interface and see what is happening in my theater	
- I want to look at the "hot" areas in CENTCOM, such as Afghanistan and Iraq	
- I start with the map visualization.	
- I want to get the most recent situational awareness, so I click on the timeline to the most recent time.	>"Map" & "Statistics" panes;
- The map visualization allows me to overlay statistics from the world on this map over time.	> "Feb 1,2009" on timeline;
- Here we see the population's average perceived well-being of the 55 countries in this configuration from the reference world database.	> "Well-Being";
- Selecting Attitude towards National Govt shows the average public opinion of the population towards their national government.	> "National Gov't Attitude"
Now, to provide my commander a report on what's happening today, how can I determine what's happening of significance in USCENTCOM?	
- One Answer: I can look at what's happening in USCENTCOM by clicking on the Headlines statistic to see relatively where the news sources are reporting	
- I note that in USCENTCOM that Iraq, Afghanistan, and Pakistan are being reported on more than other countries in my area, since they are a lighter shade of orange	
- I look at Afghanistan in order to gain a little better situational awareness. Here, a dashboard, or GeoInformationPanel pops up (Figure 4A) which shows more specific information on a geographical region	> "Headlines Statistic"
- I see the distribution of the population's well-being from extremely unhappy to very happy.	>"Afghanistan" on map
- I see some trend statistics over time, such as well-being	>"GeoInformationPanel"
- I also see trend statistics and the latest data on the average perceived well-being needs values. For example, the population's average perceived Health Needs Fulfilled right now is a 1.93.	
I also note that each population agent evaluates his/her own well-being across nine well-being components.	

Table 3. Situational Awareness Via Headline Tag Search

User Intent	SWS Action(s)
Develop situational understanding: Option 2	
- Another Answer for how I can assess what's happening in Afghanistan is to look at the Events pane	
- The Events pane lets us look at storylines that have been automatically mined from the web over time. Here we see real headlines that have been mined from sources such as AP, Reuters, and CNN.	>"Events pane" of "Headline" tab
- Each headline is listed in the "Headline" tab, and I can search for headlines through the search menu	
- For example, if I enter "Afghanistan" in the search box on the "Headline" tab, I see many results that match either in the plain text or the machine and human-tagged information.	> type "Afghanistan" in Search box
- Now, let's consider the other tabs in the Event pane. Each tab allows us to filter headlines based on the selected tags	
- The "Country" and "City" are tabs are populated with machine tags that allow us to see headlines with just the selected country or city.	>"Country" tab >"City" tab
- The "Person" tab has to do with specific people that have been machine-tagged in news reports.	>"Person" tab
- The "Subject", "Verb" and "Object" tags are also machine tags that allow us to filter the headlines.	>"Subject" >"Object" >"Verb"
- Now, the "Tag" tab is reserved for human tagging. If I click on this tab, it shows me the human-generated tags.	> "Tag" tab.
- I also see that one of my SME co-analysts, Tom, in USCENTCOM has tagged another article as important. I want to see what he has tagged that is important to him.	>USCENTCOM_SME_Tom_important tag
- Now I go to the "Headlines" tab and see that Afghanistan attacks are up 31 percent, an important headline indeed.	>"Headline"
- So now I have been able to get some good analysis on what's happening recently in the headlines. I can provide my commander a good situational understanding of Afghanistan in CENTCOM as well as report on several of the headlines.	>provide a cursory narration on it

Table 4. Use Case for Excursion into Afghanistan – 6 Months into the Future

User Intent	SWS Action(s)
Develop situational understanding: Option 2	
I would like to create an *Excursion* from the Reference World database in SWS from the *perspective of the Afghanistan National Government* from the *current date* out *six months* into the future. I would like also to play from *the perspective of my greatest adversary* in country, the Taliban	
I create an Excursion by selecting the geographies, player perspective, and time. From this, I get a generated Excursion Portal pane. This pane shows us how historical and current news stories have been parsed into events that can be injected into a SWS excursion. It reports that Afghanistan has taken 40 actions internally within their country as well as many other actions elsewhere in the world.	>Excursion Pane (Figure 4B)
I use these events *if* I were to take a historical simulation, *or if* I want to continue and inject actions from players into the future using the status quo from historical activity. Since I am projecting into the future and I would like to develop my own intervention strategy, I choose not to use these events.	>Activity Summary pane (Figure 4B)
I select Afghanistan in the Activity Summary, and it shows up Afghan Government events that have been automatically parsed and are available for SWS excursions.	
I use the Excursion Portal to access SWS visual tools. In February 2009, overall well-being in Afghanistan is very low. The southern and eastern provinces are slightly lower in well-being compared to the northern provinces. The Afghan state has little presence in the south and east, and attitudes towards the national government in those areas are low.	>Excursion Portal
Acting from perspective of the GoA, I see that my adversary, the Taliban, are deeply unpopular in most of the country. The main exception is Helmand province (and, to a lesser extent, Kandahar), where frustration with civilian casualties and kinship/tribal loyalties generate more positive attitudes towards the Taliban.	> Map Visualization
In February 2009, Poor Sunni Pashtuns constitute the largest population subgroup in Paktika province. Overall attitudes of Poor Sunni Pashtuns in Paktika towards GoA and the Taliban are slightly negative.	> Glyph Graph
The media nodes that Poor Sunni Pashtuns in Paktika heavily subscribe to include Pajhwok Afghan News, Radio Afghanistan, Radio Liberty, and BBC.	> Information Gralaxy
As GoA player, I want to develop an overall intervention strategy of Armed Nation-Building by building the capacity and legitimacy of the Afghan state, while defeating a revolutionary insurgency. Goals: Enhance well-being, Build popular support; Deter, dissuade and/or Engage Taliban (especially fence sitters), Extend presence of government beyond provincial and district capitals, Rebuild, reconstruct infrastructure.	>Action Planner
As Taliban player, I anticipate my adversary has the following overall objectives: Overthrow the Karzai government, dismantle its political and social institutions, Disrupt Afghan nation-building efforts, Delegitimize Afghan government, and Build popular support, especially among friendly sub-tribes.	>SWS Action Planner
Run simulation 6 months into the future. GoA public opinion sees a marked improvement in northern and eastern provinces but mixed results in southern provinces. Targeted media campaign (Pajhwok Afghan News, Radio Afghanistan, Radio Free Europe, etc.) and economic reconstruction lead to improvement in well-being and attitudes to GoA in Paktika.	>Map Visualization
Refine Course of Action: Observe relatively little combat in Paktika province; more intense kinetic activity in Oruzgan and surrounding provinces; economic reconstruction and relief aid in Oruzgan and nearby provinces not sufficient to compensate for higher level of military activity. Conclude that ore aggressive media campaign required: some, but not all, of the main media nodes in Afghanistan targeted. Candidates include BBC, Afghanistan National Radio, and Radio Arman. More extensive use of information operations and shuras should be attempted to counter Taliban night letters and other propaganda.	>Glyph Graph
Refine Action Plan and rerun simulation.	

TABLE 5. Traits, Goals, Sensors, and Actions for Social Agent Entity Types

Agent	Entity Type	Traits	Goals	Sensors	Actions
Individual	• Citizens	• Age • Income • Education • Ethnicity • Religion • Ideology	• Maintain and enhance personal well being	• Leaders • Organizations/ media • Institutions	• Demonstrate • Riot • Join organizations • Leave organizations
	• Leaders	• Type (*Power oriented, Affiliation oriented, Responsive, Ideologue*) • Ethnicity • Race • Income • Education • Attitude towards group, state	• Maintain and enhance personal influence • Maintain and enhance the influence of their organizati on • Maintain and enhance well being of their members	• Followers' well being • Organizational power base • Control over resources	• External Consensus Collaborate • Internal Set agenda Unify Coerce
Organization	• Informal groups • Formal organization • Networks	• Type (*political, religious, social, economic, media*) • Size • Control over resources • Ideology • Ethnicity • Nationalism • Religion	• Survive • Maintain • Increase members hip • Seek influence	• Member well-being • Other organizations	• Demonstrations • Riots • Attacks • Set agenda • Collaborate • Unify • Seek consensus • Coerce
Institutions	• Government	• Type • Political • Military • Economic • Spatial • Central • Provincial • Local • Power Resource Competenc	• Policy implemen tation • Policy adjudicati on • Policy enforcem ent • Policy formulatio n	• Population's well-being component • Public's Confidence/legiti macy • Public's Trust • Resource availability • Other institution's actions	• Collaborate • Unify • Coerce • Enforce • Respond • Prepare • Recover • Reconstruct • Attack • Ally • Defend

		e • Nationalism	• Influence policies	• Incoming actions • DIME Actions	• Aid • Coerce • Trade

TABLE 6. Traits, Goals, Sensors, and Actions for Economic Agent Entity Types

Agent	Entity Type	Traits	Goals	Sensors	Actions
Production	• Oil • Power • Natural gas • Water • Telecoms • Transportation • Manufacturing • Agriculture • Finance • Education • Military-industrial • Labor • Capital	• Maximum production • Maximum exports • Maximum imports • Local inventory target • Unit production	• Maintain inventory at target levels	• Current availability • Global imports and exports • Trade blockade • Capital flight • Trade embargo • Boycott • Freeze assets	• Produce goods and services • Trade
Consumption	• Consumer • Govt services	• Initial demand • Unmet demand • Total consumption	• Satisfy all demand	• Consumer spending	• Rebuild infrastructure • Improve productive efficiency • Negotiate trade contracts • Regulate the black market • Stimulate the economy • Change tax rates

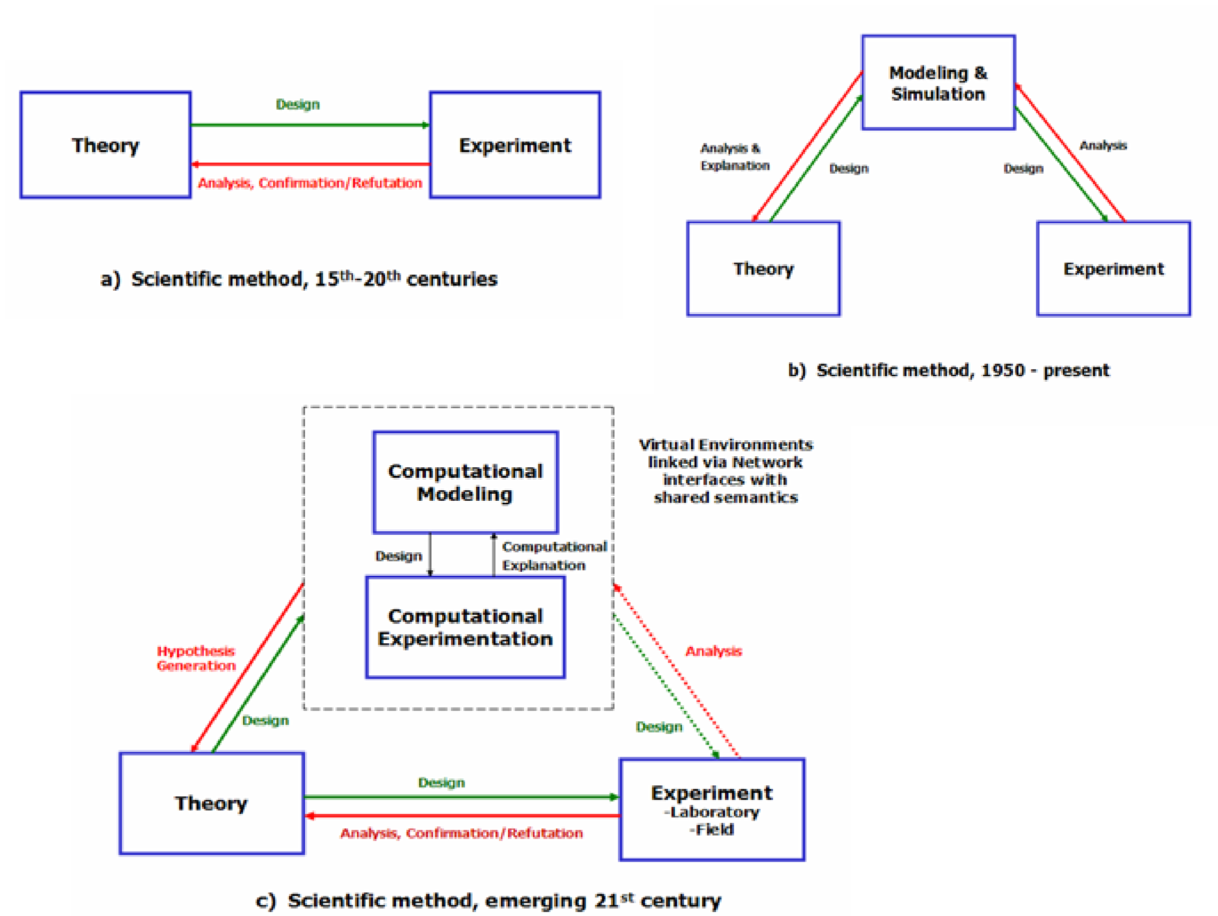


Figure 1. Modeling and Simulation in Scientific Inquiry (Hamming 1997)

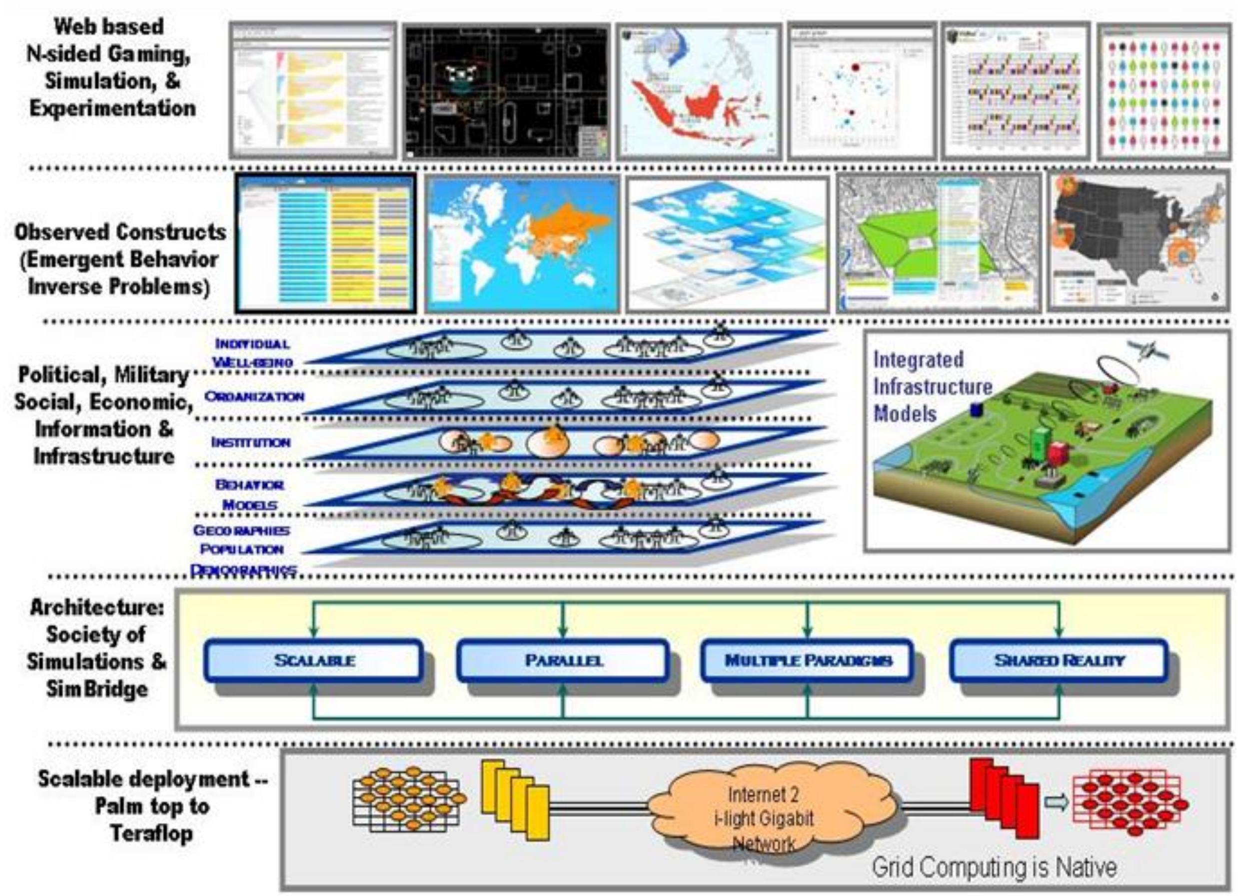


Figure 2. Conceptual Architecture for SEAS

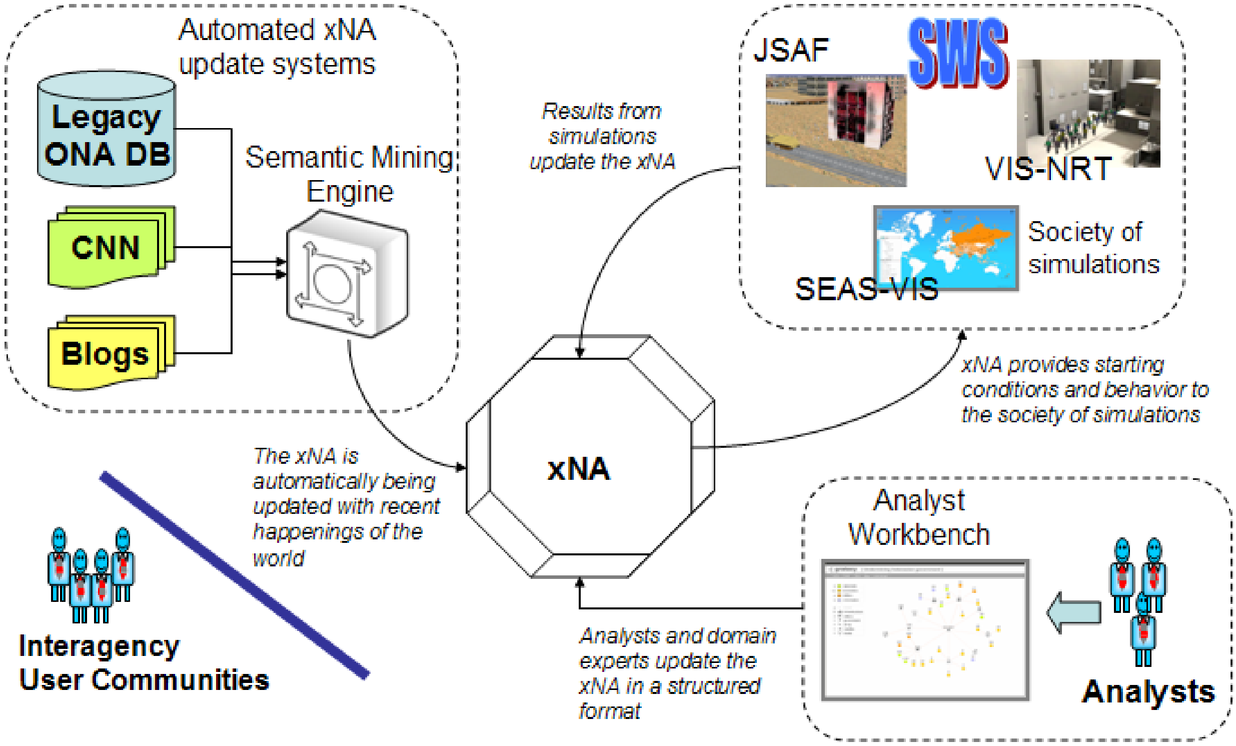


Figure 3. Conceptual Schema for the Sentient World Simulation Environment

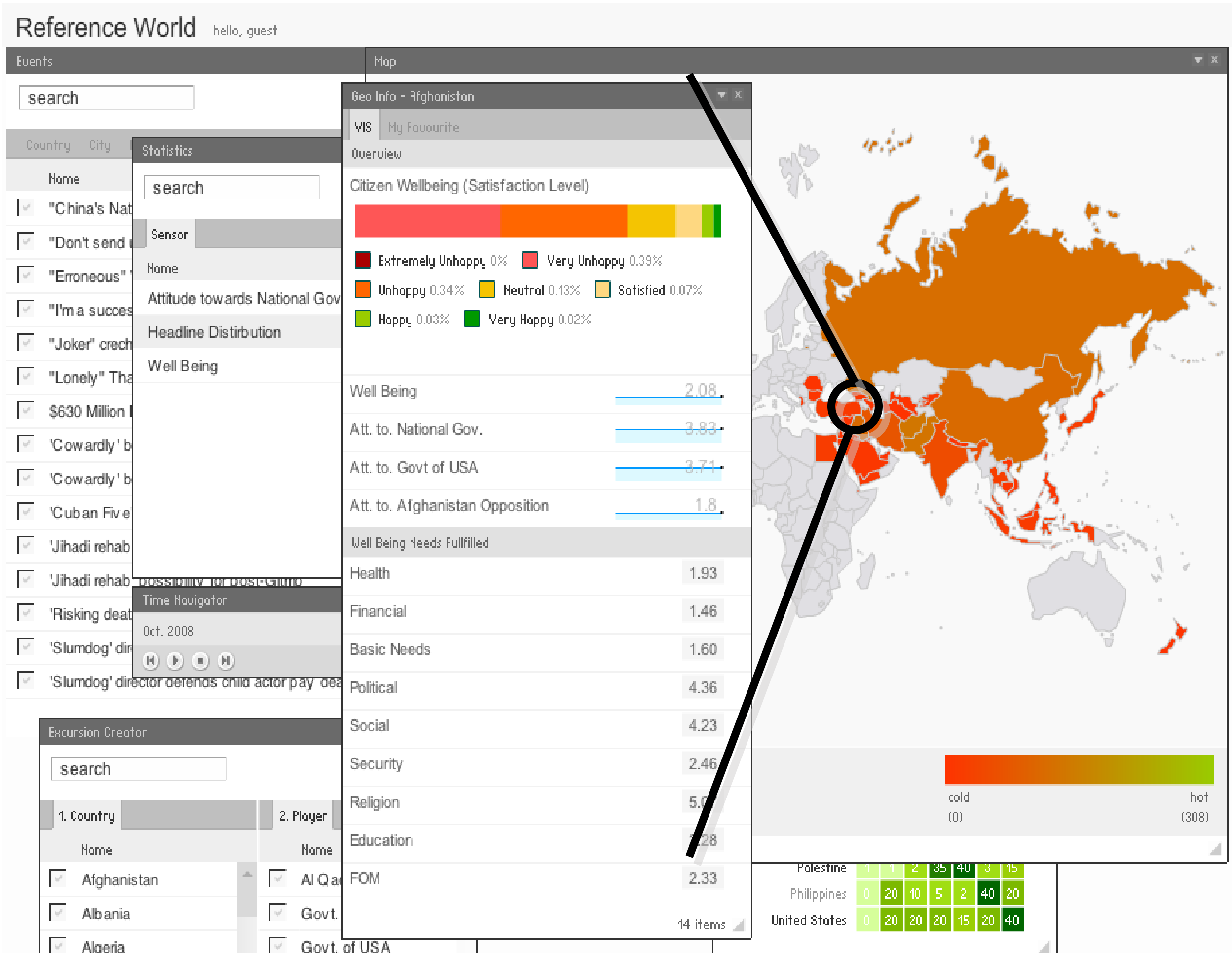


Figure 4. Population's Perceived Well-Being for Afghanistan

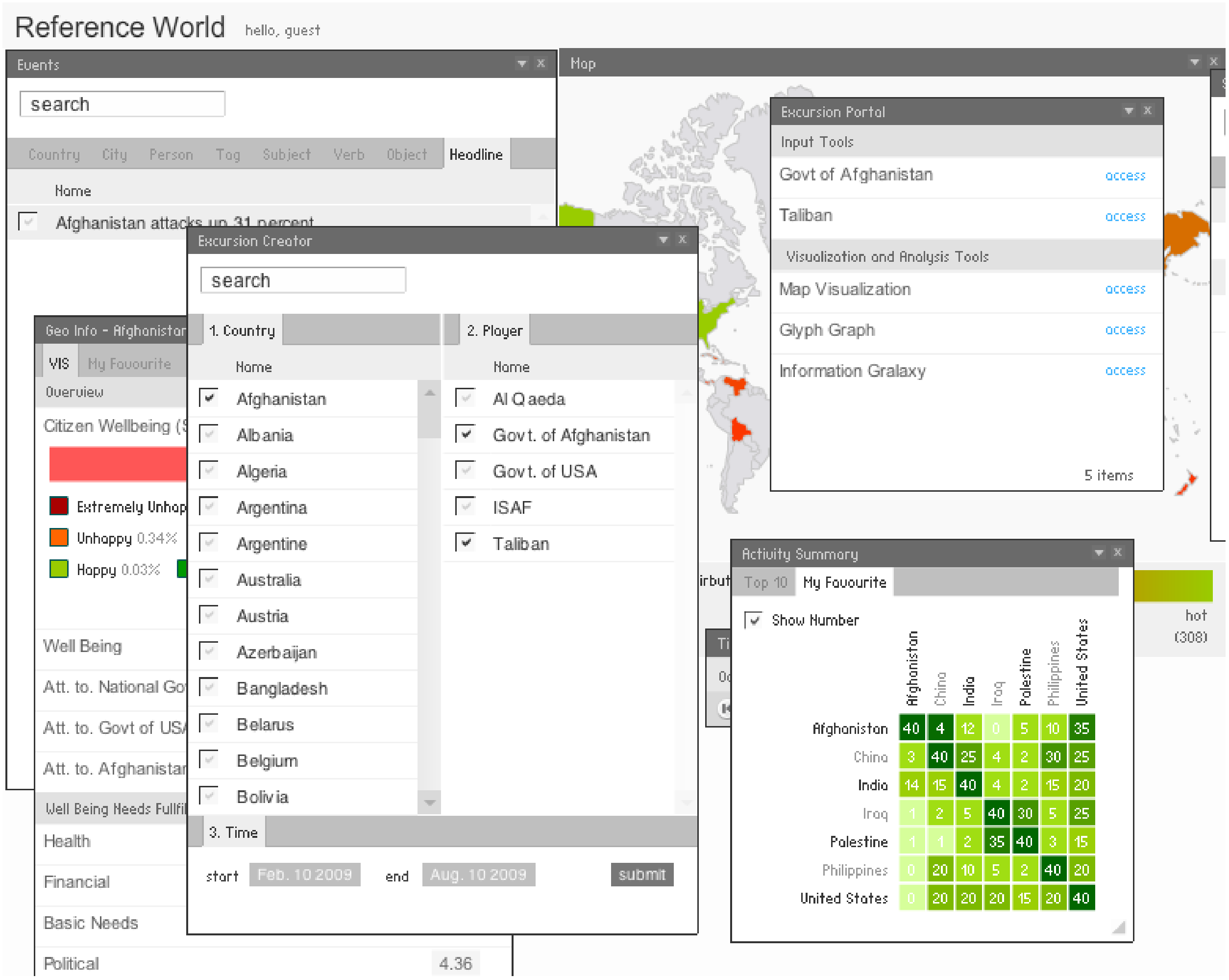


Figure 5. Reference World display containing Excursion Creator, Excursion Portal, Activity Summary panes in the foreground and GeoInformation Panel, Event Pane, and Map Visualization display in the background

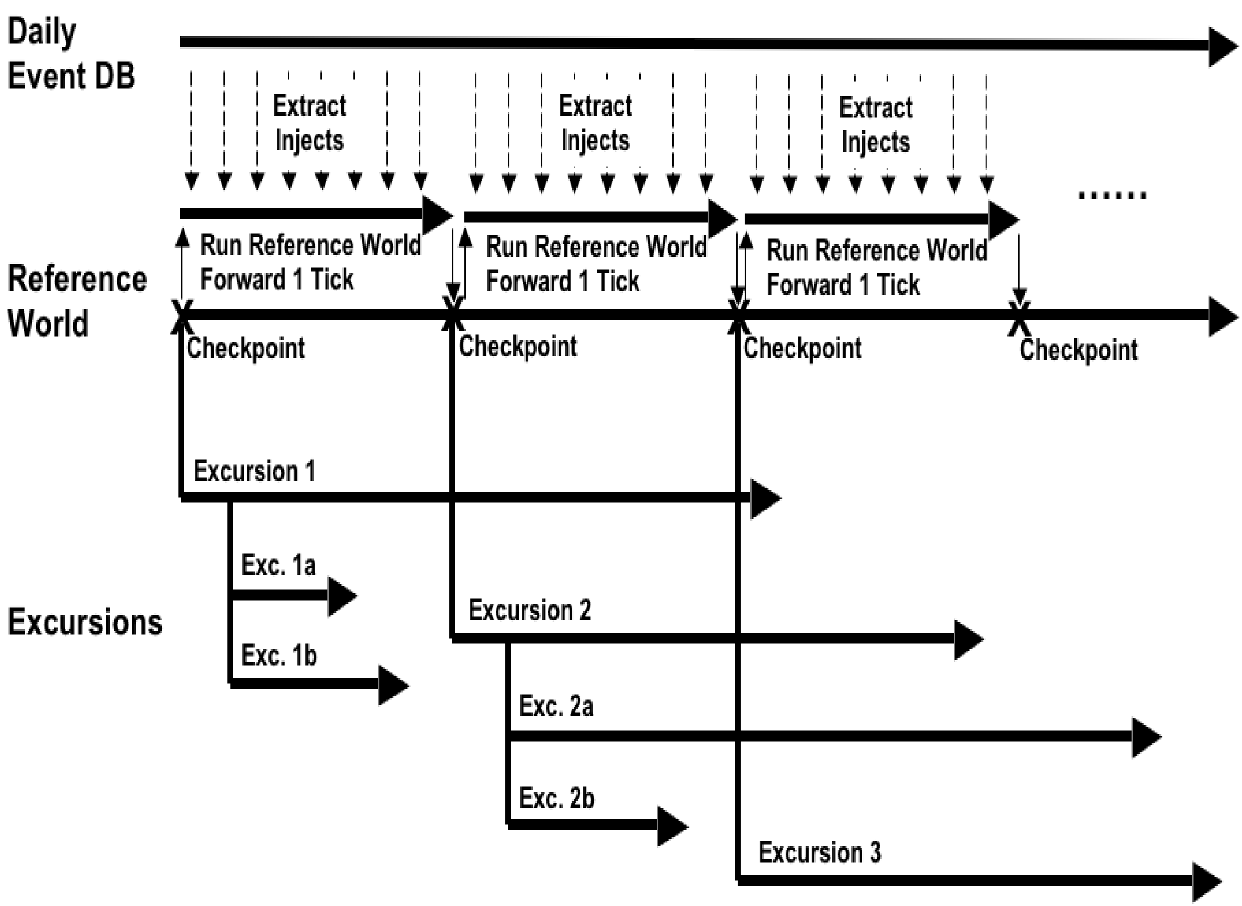
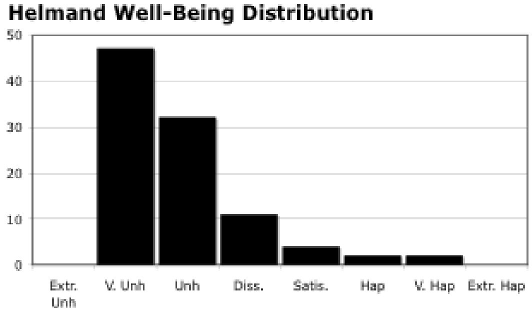


Figure 6. Continuous Updating of SWS – Afghanistan

Helmand Profile

Statistics	
Population	1,099,160
Annual GDP (1990 US Dollars)	$149,614,400
Public Opinion of Govt of USA	3.06
Public Opinion of Govt of Afghanistan	3.01
Public Opinion of Afghanistan Taliban	3.64
Public Opinion of Afghanistan Al Qaeda	2.43
Public Opinion of ISAF	3.12
Well-Being	1.88
Political Needs Fulfilled	3.97
Security Needs Fulfilled	1.46
Basic Needs Fulfilled	1.68
Social Needs Fulfilled	3.70
Religious Needs Fulfilled	4.51
Education Needs Fulfilled	2.46
Finance Needs Fulfilled	1.47
Health Needs Fulfilled	2.07
FOM Needs Fulfilled	2.28

Helmand Well-Being Distribution



Helmand Population Distribution

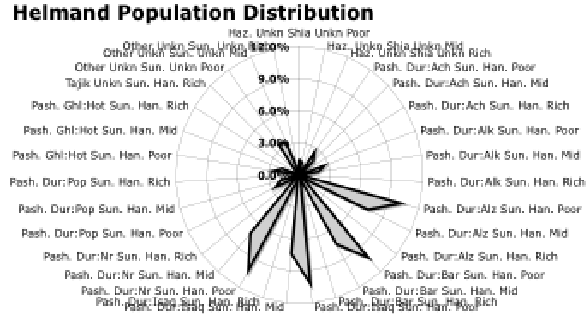


Figure 7. SEAS Provincial Profile for Helmand Province

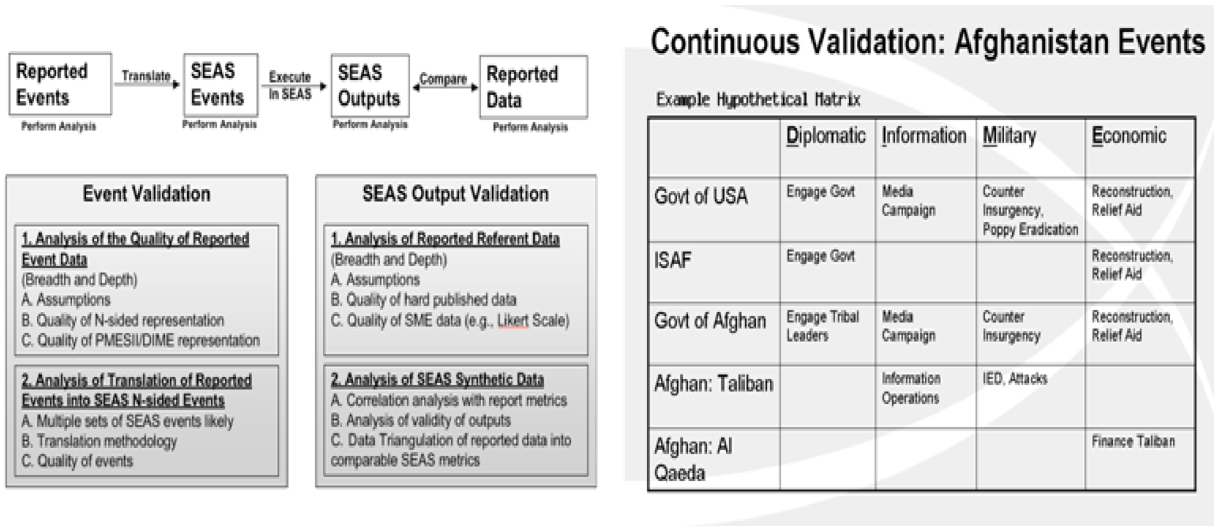


Figure 8. (a) Continuous validation and (b) Significant event validation

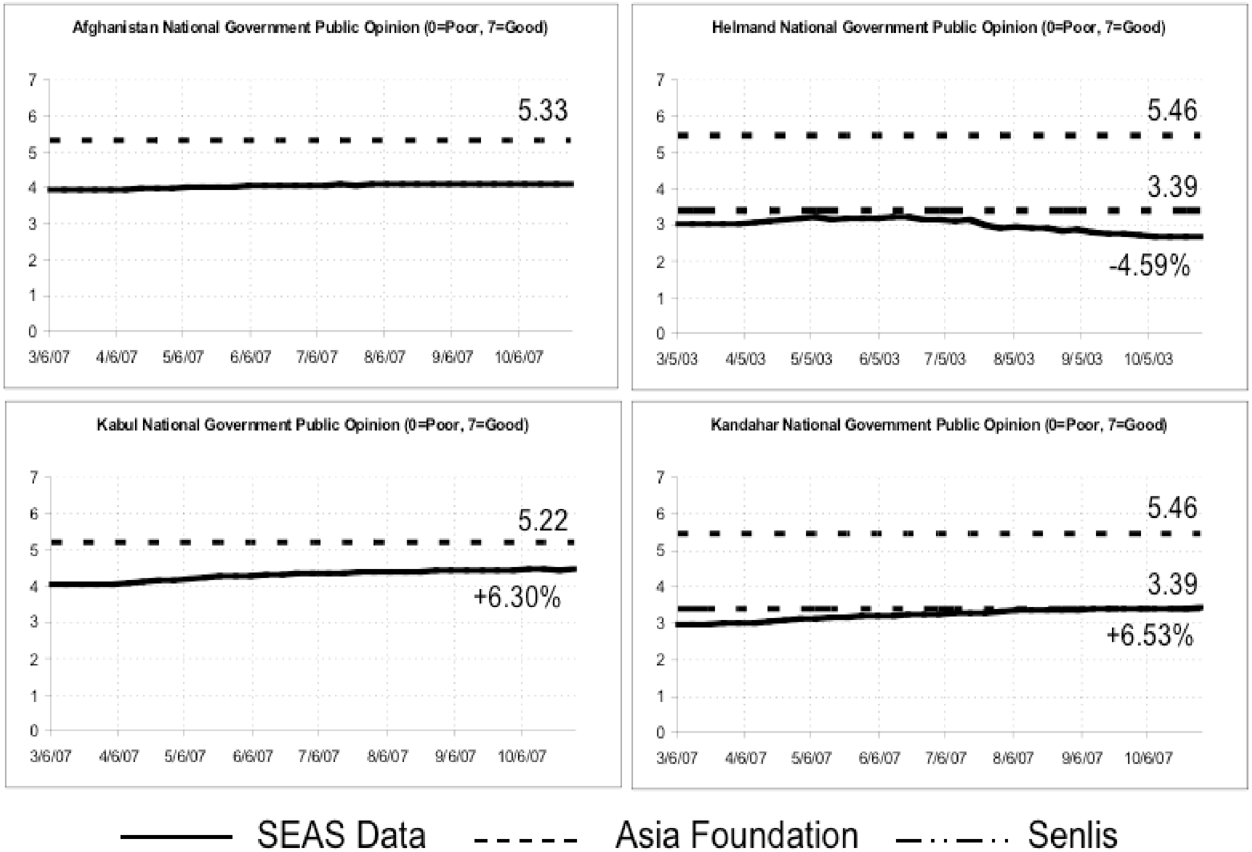


Figure 9. Comparison of Synthetic vs Actual Public Opinion Data