Sentient World Simulation (SWS):
A Continuously Running Model of the Real World

A Concept Paper for Comments

Government POC

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Version 2.0

August 22, 2006

Introduction

Modeling and simulation quickly becomes out of sync with new events, the emergence of new forces, and newly proposed theories. The goal of the Sentient World Simulation (SWS) is to build a synthetic mirror of the real world with automated continuous calibration with respect to current real-world information, such as major events, opinion polls, demographic statistics, economic reports, and shifts in trends. The ability of a synthetic model of the real world to sense, adapt, and react to real events distinguishes SWS from the traditional approach of constructing a simulation to illustrate a phenomena. Behaviors emerge in the SWS mirror world and are observed much as they are observed in the real world. Basing the synthetic world in theory in a manner that is unbiased to specific outcomes offers a unique environment in which to develop, test, and prove new perspectives.

SWS consists of components capable of capturing new events as they occur anywhere in the world, focus on any local area of the synthetic world offers sufficient detail. In other words, the set of models that make up the synthetic environment encompass the behavior of individuals, organizations, institutions, infrastructures and geographies while simultaneously capturing the trends emerging from the interaction among entities as well as between entities and the environment. The multi-granularity detail provides a means for inserting new models of any temporal and spatial scales, or for incorporating user-supplied data at any level of granularity. Therefore, SWS can be continuously enriched and refined as new information becomes available.

SWS consists of the following components:

- A synthetic environment that supports Effects Based Approach and a comprehensive representation of the real world at all levels of granularity in terms of a Political, Military, Economic, Social, Informational, and Infrastructure (PMESII) framework.

- A scalable means of integrating heterogeneous components across time and space granularities.

- Mechanisms that discover, gather, and incorporate new knowledge into the continuously running synthetic environment.

- A single façade of user interfaces enabling information from all sources (simulation generated data, parameters for models, and data gathered from the real world) to be searched, viewed and modified in an ontology-aware manner.

- Integrated Development Environments (IDE)s for constructing and configuring new models or modifying existing models and then incorporating these changes into the continuously running synthetic world.

- A means to take excursions from any point in time in the synthetic world to focus on select regions of the world, leverage private user data, or to research specific theories by simplifying the types of models to employ in the excursion.

SWS Components

The Core Synthetic Environment That Supports Pluralism of Thought

The core component of SWS is an agent-based environment named the Synthetic Environment for Analysis and Simulation (SEAS), designed to be agnostic to the type of simulations and choice of models in order to allow experimentation in the context of multiple and potentially conflicting theories. No single theory can adequately explain complex behavior, such as the rise or splitting of terrorist organizations. Each theory brings another perspective to the same phenomena. Only by combining these theories within the same environment can we gain a comprehensive perspective.
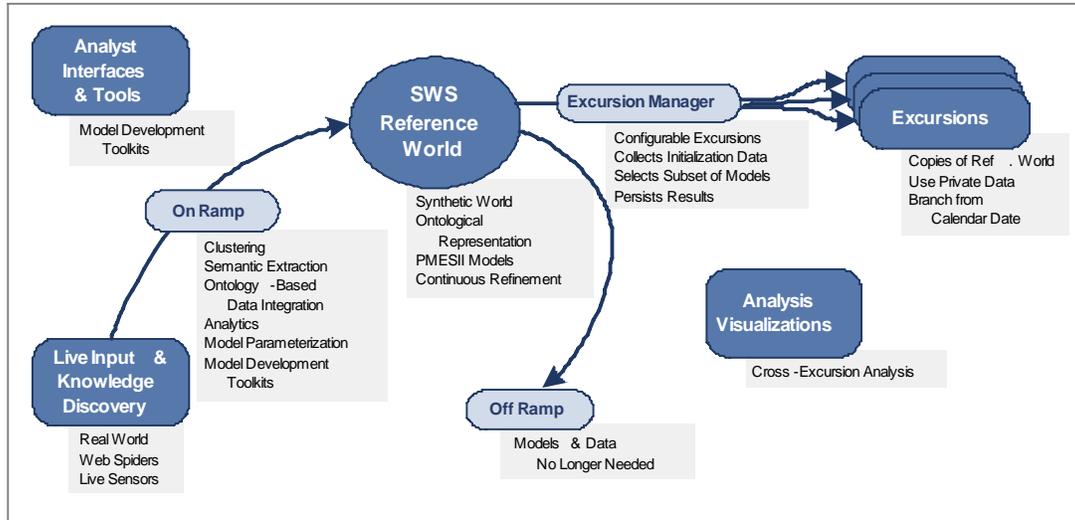
Figure 1: A conceptual view of the Sentient World Simulation

By basing the designing of the synthetic environment on a fractal representation, SWS avoids the most common pitfall faced by simulation environments: designing and optimizing an infrastructure for a parochial purpose and thereby limiting its application to a small range of problems. The fractal approach provides a consistent representation of the environment's building blocks to models with all granularities of access. The basic building blocks consist of individuals, organizations, institutions, information, and geographies. From these building blocks, communities are built, constructed into societies, nations, and ultimately providing a synthetic world. Coarse-grained models use a small sample of the population and localized fine-grained models use a full sample of the population in an area. The same individual who experiences events from a fine-grained model can be influenced by a coarse-grained model. This approach to enabling heterogeneous models to interact is a Society of Models approach, described below.

SEAS provides all aspects of behavior within the PMESII categorization and enables the application of Effects Based Thinking to the reference world of SWS.

A Society Approach to Integration

The cross-disciplinary nature of SWS fosters collaboration among diverse modeling and simulation developers. This diversity necessitates an approach to integration that does not limit developers of SWS components to adopt a uniform design, especially in terms of the temporal and spatial granularities with which the components interact with the synthetic environment. The Society Approach implemented in the SimBridge technology addresses the need to integrate components in a scalable manner while preserving heterogeneity.

The Society Approach is applied to three areas in SWS to integrate models, simulations, and components. A Society of Models enables models to operate at diverse temporal and spatial granularities within the same synthetic environment. A Society of Models is employed by the Synthetic Environment for Analysis and Simulation (SEAS) to integrate models ranging from global, regional, and national PMESII behaviors to near real-time emotional arousal.

A Society of Simulations captures the necessary data exchange among interacting simulations without requiring unscalable and difficult to maintain, centralized management. A Society of Simulations has been used to integrate SEAS with a tactical, kinetics federation of simulations, Joint Semi-Automated Forces (JSAF). This integration is described more fully in Figure 1.

A Society of Systems extends the Society of Simulations to include non-simulation components, such as third party visualizations, enterprise system databases, analysis tools, and live sensor feeds.

A Society Approach fulfills the need of integrating with the goals of:

- independent and concurrent development of components,

- heterogeneous and reusable components,

- and high fidelity of detail in a scalable system.

Sensitivity to Current Information Through Real-Time Knowledge Discovery

Continuously incorporating current information in SWS provides three key benefits that distinguish SWS from other initiatives at constructing a simulated environment:

- SWS remains up to date with respect to events and emerging trends.

- SWS leverages the prodigious amounts of data from all publicly available data sources, something that is infeasible for a small number of analysts to gather in a timely manner.

- Models used by SWS are continuously refined, parameterized, and validated, keeping the underlying model base of SWS relevant across time.

Burgeoning technology in the area of knowledge discovery has matured so that Web crawlers and spiders are now used in research and industry. Applying this technology to news portals, blogs, and other internet sources enables large amounts of data to be gathered and processed in a short amount of time.

By considering all available data, automated data mining provides an unbiased means of incorporating data originating from multiple sources, and therefore, data from multiple perspectives. Additionally, interesting outliers are discovered through text, video, and transaction analytics.

Believability and reliability metrics are applied to weight the influence of data from different sources depending on the type of source, experience with data from the source, and the type of data. The believability and reliability are then taken into account when incorporating the data into the SWS synthetic world.

The discovery technology is coupled with a semantic engine that extracts semantics from the data. The semantics are used to prepare the gathered data for use by the simulations and to relate the data to knowledge already in the synthetic world.

Other sources of data besides the internet are incorporated using the same knowledge discover and semantic extraction, such as proprietary, enterprise system, and classified data sources (classified and proprietary data would only be incorporated in select excursions.)

The Ontological Representation of Knowledge

Using an ontological repository of knowledge, SWS augments analyst knowledge with simulation semantics. The SWS ontological representation differs from traditional database approaches in that it stores ontology as well as data. Ontology is a methodology for categorizing and annotating data based on logical, human conceptualizations of what the data means. Interactions with the ontological annotations of data in the repository are fundamentally different from the interactions allowed by the prevailing RDMS and OODBMS approaches to database management. Traditional approaches coordinate tools with data by identifying the physical data in queries whereas SWS enables coordination based on the semantic meaning of data. A piece of data can be annotated with different keywords from diverse disciplines. Analysts as well as automated processes can describe data needs using keywords from their own domains, enabling cross-disciplinary integration and a unified view of both real and synthetic information. A non-ambiguous data categorization and annotation process is also needed to support the distributed and incremental process.

Data is also tagged with its informational sources and temporal lifetime. Consequently, multiple experiments can be performed utilizing the same models combined with different points of views by sourcing data from different informational sources or conducting an experiment in the context of a specific calendar date.

A seminal integration of a knowledge repository with an active simulation environment was successfully deployed in Urban Resolve 2015 (UR 2015). The implementation of an ontological representation of knowledge, called eXtensible Net Assessment (xNA), was used to augment analyst knowledge with

simulation semantics. Including xNA as a component of the prototype SWS deployed in UR2015 extends the Service Orientated Architecture (SOA) approach to provide a semantics-based integration of analyst knowledge, stored in a repository named Operational Net Assessment (ONA), with emergent simulation data. xNA supports multi-granularity and multi-disciplinary data to facilitate integration in the context of a diversity of models and data sources. xNA can also receive incremental data updates from analysts and automated data collection tools. More details on the prototype SWS are given in "*JFCOM J9 Deployment of SWS 0.5*" below.

Model Development IDEs

SWS provides a set of tools based on the ontological repository for use by experts from various domains to develop and experiment with models in the synthetic environment. A researcher begins with a set of theories to test. Using algorithms of how the theories interact with the rest of the synthetic world, the researcher creates models. The researcher designs a complete experiment environment using the new models and leveraging existing models by creating a profile consisting of a selection of parameters from the ontological data repository that fulfill the input requirements and support the experiment's scenario.

SEAS Integrated Development Environment (SIDE) provides the tools to create and retrofit the artificial agents in SEAS. Researchers will first design new types of agents along with the DNA and memory these types of agents will have using the design interfaces of SIDE. The design interfaces also allow the DNA and memory of existing agent types to be modified. After creating new agent types, SIDE is used to configure the population makeup of the new agents in the synthetic environment.

After the creation of new agents, researchers use Just-in-time Modeling Environment (JIME) to create and modify the behaviors of agents. Agent behaviors can be mathematical models based on variables that the agents sense from the environment or can be described procedurally using a workflow engine, a customizable system composed of states, transitions, and messages. The behaviors describe how agents interact with their environment and other fellow agents.

Before incorporating the new agents into the reference world of SWS, agents are prudently tested in the Bullpen tool. Using Bullpen, the behavior of agents is observed in a limited and controlled environment. Researchers create profiles of environment variables for Bullpen experiments to observe the range of decisions an agent makes and agent's resulting actions.

Additionally, the modeling environment of SWS is extensible using ModelNet. ModelNet is a collection of web-services that provides the functionalities of the aforementioned tools. Using the web-services, external modeling tools can be integrated into the SWS to enable researchers to use modeling tools that are best for their domain.

Excursion Management

SWS provides a configurable interface for configuring an excursion from the continuously running SWS reference world to meet the individual needs of a user. User needs addressed by the Excursion Manager include:

- Exploring multiple courses of action by taking different sets of actions in identical copies of the reference world.

- Using proprietary or classified data in a controlled experiment without interfering with the publicly accessible SWS.

- Constructing a synthetic environment for only a portion of the world or including only certain models, simulations, tools, visualizations, or data sources.

- Conducting simultaneous excursions in different areas of the world and merging the nonproprietary and unclassified results together.

Once an excursion is configured, the Excursion Manager fulfills the following:

- Designs a Society of Simulations, consisting of the user-configured choice of simulations and components and any other components that the simulations depend on (referred to as members.)

- Sets up shared reality, the space shared among all members that are active in the excursion.

- For each excursion, pulls appropriate information for a specified calendar date from the ontological repository to meet the members' input requirements.

- Persists significant simulation results in the ontological repository, tagged with this excursion's identifier, for later analysis and cross-excursion analysis.

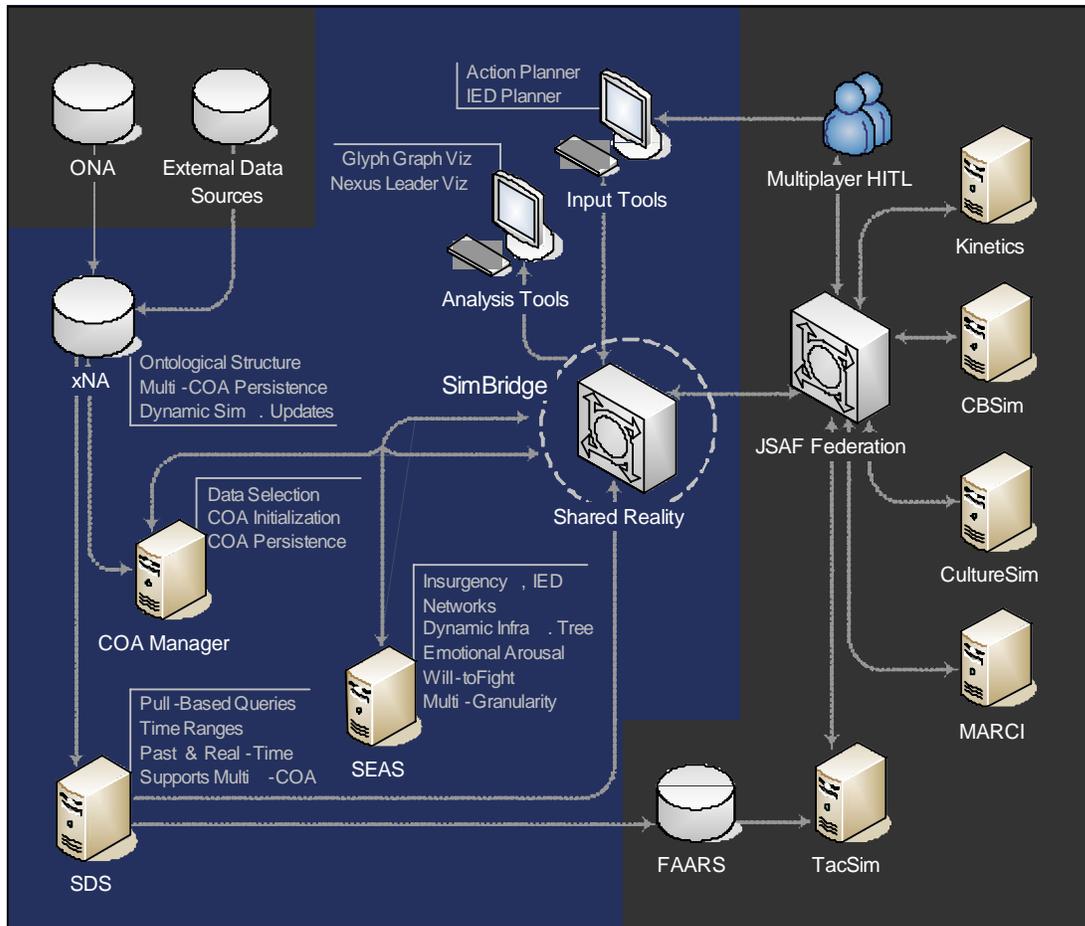## JFCOM J9 Deployment of SWS 0.5 for UR 2015

Figure 2: Components of SWS v0.5

JFCOM showcased the first prototype of SWS, SWS v0.5, in the Urban Resolve 2015 (UR 2015) exercise. UR 2015 was set in a synthetic urban setting and consisted of both simulation and real-time HITL inputs. SWS 0.5 consisted of SEAS environment, a Society of Simulations and Systems implemented through SimBridge, a deployment of xNA with knowledge from a classified repository and data from research on public data, and an Excursion Manager.

Synthetic Environment for Analysis and Simulation (SEAS)

JFCOM has used SEAS to conduct a number of HITL experiments, providing the ability to evaluate the Effects Based Approach, in Sea Viking 05, Multinational Experiment 4, and UR 2015. Each deployment built on the previous, serving as stepping stones in the development of SWS.

Virtual International System (SEAS-VIS)

The SEAS-VIS model is a representation of the Institutions, Organizations, Leaders, Individuals, and Infrastructure that make up a society. The geography of a society is modeled at various levels including City, Province, Country, Region, and World in terms of Political, Military, Economic, Social, Information, and Infrastructure (PMESII) nodes. The virtual environment integrates multiple theories from various disciplines to program behaviorally accurate agents with dynamic rules that govern and guide their actions and interactions. SEAS-VIS facilitates a seamless and interchangeable integration of human and software agents and allows for testing the efficacy of theories, decisions, strategies, and tools.

SEAS-VIS offers the ability to do course of action (COA) analysis, test hypotheses, learn through experimentation, conduct effects-based operations and planning, and develop and refine Operational Net Assessment (ONA). The product allows the user to evaluate and manage the challenges of international crises.

Near Real Time (SEAS-NRT)

SEAS-NRT consists of human behavior models that are best suited to a short period of time (within hours), such as crowding and rioting, escalation of emotional arousal, and terrorist personnel collaborating in improvised explosive device attacks. Following the fractal approach to representing an environment, the SEAS-NRT models operate on the same entities that SEAS-VIS models operate on. In this way, SEAS-NRT and SEAS-VIS are coupled together in a Society of Models. Individuals respond to the media and world public opinion models in SEAS-VIS, placing the individual in a dynamic global context, while also enabling the individuals to sense and react to local events in real time.

SimBridge

Model integration within SEAS and application of SEAS to the tactical, kinetic realm, have been facilitated by SimBridge, an implementation of the Society Approach. Through SimBridge, SEAS has been integrated with Joint Semi-Automated Forces (JSAF) federations that implement the High Level Architecture (HLA) approach to simulation integration. SEAS connected to JSAF through a liaison that joined the JSAF federation as a single federate. In this way, SEAS was enabled to interact with CultureSim, CBSim, real-time HITL players, and many other components. SEAS interacts with CultureSim to represent real-time population movement and activity. SEAS with input from a Chemical Biological Simulation (CBSim) capture the influence of chemical and biological dispersions on population behavior.

Supporting the Society of Systems approach, the SimBridge Data Service (SDS) provides a query interface through which visualizations, analysis tools, and external data base systems can leverage data residing in shared reality. For UR 2015, SDS provided a selection of statistics representing the state of SEAS models at various granularities to an external data repository, Future After Action Review System (FAARS), and to Tactical Simulation (TACSIM), modeling human intelligence gathering. TACSIM used statistics such as public opinion of Blue (one side in the multiplayer war game) to determine the willingness of the population in a city sector to provide intelligence reports.

eXtensible Net Assessment (xNA)

Underlying SEAS is an ontological representation of SEAS knowledge within the eXtensible Net Assessment (xNA) component. A repository populated by analysts' understanding of Operational Net Assessment (ONA) is matched with corresponding entities in xNA, enabling SEAS to draw from classified ONA data to conduct certain classified excursions in UR2015. Also, selected types of changes that occur within the simulation run time are persisted back into xNA, creating a dynamic ONA.

xNA represents knowledge tagged with the perspective, source, and excursion where the knowledge originates from. This enables analysis tools to perform cross-COA analysis, such as tracking the emergent growth of an insurgent organization in multiple scenarios where different actions were taken against terror cells.

Course of Action Manager (COA Manager)

Users interacted with SWS 0.5 in both real-time interactions as well as for faster-than-real-time analysis. Eight SEAS environments were used simultaneously to investigate the use of different sets of action plans and to provide an unclassified interface with a select subset of events. One of the environments was placed in a Society of Simulations with JSAF to capture events in real-time.

A COA Manager was implemented to enable each of the environments to be initialized and to enable simulation data to be persisted, tagged with a COA identifier. A specific environment could be restarted by accessing saved data for the desired COA.

The implementation of COA Manager is a step towards an Excursion Manager needed to facilitate SWS excursions.

Use Cases of SWS

Training

- SWS provides the context within which training excursions are done, presenting the training community with the unprecedented ability to train in a live and comprehensive synthetic environment that is validated by theory and up to date with the real world.

- For skill refinement, a trainee's skills can be directly compared with an experienced individual's skills by immersing the trainee into the synthetic environment in the real-world context where the event actually occurred and analyzing the ensuing reactions of the simulated environment.

- Skill acquisition is supported by the ability to illustrate the emergent effects achieved by certain doctrinal theories, and the proper contexts in which to apply them.

- The experimentation platform provides trainers with the ability to store and recall training experiments, start another training experiment where an earlier one left off, and compare results from multiple experiments.

Analysis

- Analysts' theories are continuously weighed against emergent phenomena in SWS. As SWS progresses with new real world events, the divergence between proposed theories or models indicates a need for a change in thinking. Likewise, the synthetic world may confirm the relevance of theories.

- Cross-excursion analysis reveals the influence of "what if" excursions from a comprehensive perspective.

- The synthetic reference world of SWS provides immediate access to a mix of details from both the real and synthetic worlds which remain up to date with respect to real world data and include details which are not easily obtainable in the real world, such as measurements of emotional arousal for a group of people.

- The analysis capabilities of SWS also reveal relationships between entities that emerge over time. Analysts can perform full strategic, operational, and tactical net assessment with access to a dynamic description of the links between nodes and across nodes and resources.

Planning

- SWS provides tools to develop, reuse, and compose action plans into playbooks. A playbook database enables planners to recall playbooks.

- Planning tools enable plans to be developed for temporally and spatially fine-grained actions as well as long-term actions and to place combined plans into a single playbook.

- Additionally, SWS facilitates the integration of Interagency participation in computer assisted events.

Operations

- The execution environment enables plans to be utilized in a scenario and decision making to be injected.

- Augmenting real-time information with near real-time and faster than real-time simulations allows RCC to develop and test multiple courses of action to anticipate and shape behaviors of adversaries, neutrals, and partners.

- SWS will provide the ability to develop and assess DIME campaigns.

Experimentation

- Users of SWS can take excursions that are configurable for the user's unique needs, such as selectively including or excluding models, interfaces, visualizations, and data sources.

- Users concerned with a localized region of the world can construct an experiment that uses only a subset of SWS.

- The results from multiple excursions can be merged into a single picture using SWS' Excursion Manager, providing cross-excursion analysis.

- A subsequent excursion can be instantiated using the results from a previous experiment.

- Researchers can construct experiments to evaluate new models or employ user-supplied data without interfering with the SWS reference world. The new models can be tested and refined in an experimentation environment.

Testing

- SWS provides an environment for testing Psychological Operations (PSYOP) and Civil Affairs activities, capable of illustrating the impact of these activities on populations.

- Commercial users can construct experiments to use proprietary data in a controlled environment.