Simulating Non-Kinetic Aspects of Warfare

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ABSTRACT

The United States Joint Forces Command (JFCOM) has the requirement to conduct joint experimentation for the Department of Defense. Joint experiments are conducted for many purposes: examine new warfighting concepts, determine the impact of new technology, assist in the development of new procedures, and study a specific type of joint combat or stability operation. A major shortcoming in previous experiments conducted by JFCOM has been the inability to model the political, economic, diplomatic, cultural, social, religious, psychological, informational, and infrastructure issues associated with modern warfare. For several years, JFCOM has been searching for a tool with the potential to model these critical areas of Effects-Based Operations, and also be used to bring members of the inter-agency groups into JFCOM experiments in a realistic, timely and cost effective manner. A recent prototype event demonstrated modeling at an unprecedented level of a granularity. The Krannert Graduate School of Business at Purdue University developed and modified for use the SEAS (Synthetic Environment for Analysis Simulation) simulation engine. SEAS is an agent-based simulation that models populations at varying levels of abstraction by portraying: environments, artificial agents, and the interactions among environments and agents. Human players dynamically try to influence the behaviors of the simulated agents, in keeping with their player defined strategy, as both players and agents respond to the confrontational dilemmas that the simulation facilitates. This paper will outline the reasons why a simulation like SEAS is so important to joint experimentation today. It will discuss how SEAS was used in a recent prototype demonstration conducted by JFCOM and address the potential for future use at JFCOM and the military services. The academic theoretical underpinnings of SEAS will be described, as will the composition and functioning of the intelligent agents used to represent the groups and organizations modeled in SEAS.

ABOUT THE AUTHORS

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INTRODUCTION

The United States Joint Forces Command (JFCOM) has among its major missions the requirement to conduct experimentation for the Department of Defense. This experimentation has many potential purposes to include: development of new warfighting concepts; analysis of potential contributions of new technology; development of new tactics, techniques and staff procedures; and, the study of specific types of joint combat operations. JFCOM conducts its experimentation under the auspices of the J9, Director of Joint Experimentation. Experimentation may take many forms to include workshops, war games and simulation supported events. Some simulation supported experiments are driven by closed-form constructive simulations that are able to run faster-than-real time and provide aggregated results of large military operations. Others feature Humans-in-the-Loop, interacting with the simulations through various input devices and working in real time in a virtual environment. The Distributed Continuous Experimentation Environment (Ceranowicz and Dehncke, 2003) at J9 is the venue for most of the experiments led by J9 personnel and supported by the military services from distributed sites around the country. The DCEE staff currently operates a wide variety of models and simulations of every level of resolution to support the requirements of the experiment designers.

State of the Art Today

The US military services have been conducting war fighting experiments for many years. A wide variety of models and simulations have been developed that do an excellent job of simulating combat operations at every level, from the individual soldier to the joint task force. Models and simulations can faithfully replicate, if desired, the physical characteristics of weapons systems and platforms, unit behaviors and the tactics of almost any desired combat operation large or small. While some shortcomings still exist, simulations of urban combat for example, the synthetic environments within which the participants conduct their experiments provide the necessary levels of resolution to allow for the conduct of the experiments. Most simulation professionals would conclude that models and simulations today, either in stand alone mode or as part of a larger simulation federation, can do a very good job of providing information regarding the kinetic outcomes of battle. Details on combat actions, weapons firing, combat attrition, and even joint operations can be modeled in a variety of ways to satisfy the needs of the experiment participants. The notable exception to that conclusion is with regard to modeling the non-kinetic aspects of warfare.

Today's Simulation Requirements

Modern warfare has changed greatly since the fall of the Berlin War, the end of the Cold War, and September 11th, 2001. No longer do military leaders in operations centers at every level war-game great armies fighting across Europe. Today, in military colleges around the world, officers learn that combined operations with our allies are the norm, and that senior military leaders must be well versed in leading military operations that consider the non-kinetic aspects of warfare. Diplomatic, economic, and information operations must be coordinated with military operations to achieve the desired end state. Effects Based Operations, a currently popular concept for modern warfare, demands that the leadership consider the political and cultural underpinnings of an enemy, as well as the motivation of individual enemy leaders and fighters. The infrastructure and networks within the battlespace, and the commitment and involvement of the civilian population, take on new importance as military leaders seek to shape the battlefield before committing troops to actual combat operations. The so-called DIME (Diplomatic, Information, Military, Economic) and PMESII (Political, Military, Economic, Social Information, Infrastructure) factors are now as important in determining courses of action and analysis of an enemy by a four star Combatant Commander as terrain is to the individual combat infantryman. Unfortunately there were few, if any, models or simulations that could effectively and efficiently be merged into the architecture of the military experiment so as to allow human in the loop participation and/or produce quantifiable results that could actually alter the outcome of the experiment.

The Search for DIME and PMESII Tools

For several years, as JFCOM came to realize we were fighting and experimenting with a new kind of warfare, the planners of experiments sought to include the DIME and PMESII aspects of warfare into war games and experiments. The so-called Joint Inter Agency Coordination Group (JIACG) became a fixture in most JFCOM experiments and training at the Joint Task Force level and above. This group of experts, representing the various agencies of government, other than the military, was called upon to provide inputs to the military decision makers that should have influenced the outcome of the experiment or training event. For the most part the JIACG was represented by well meaning people who faithfully tried to represent their agencies viewpoints during the military planning cycle. Unfortunately, the advice from the JIACG tended to be stove-piped according to each agency's priorities, was not affected by any kind of 'zero sum' game calculations with the result being that each agency could recommend actions without a consequence on their resources or other participants. Since there were no simulations available that allowed for free play inputs by the players that caused an action-reaction result that actually affected the game's outcome, the end result at most war games tended to be input by BOGSAT—a bunch of guys sitting around the table.

Enter SEAS (Synthetic Environments for Analysis and Simulation)

As the pressure built on J9's Experimentation Engineering Support Department (EESD) to locate and operate a simulation that would play DIME and PMESII aspects of modern warfare in a realistic manner, the search moved to Purdue University and a simulation developed to support Fortune 500 companies, for nonmilitary purposes, by the Krannert Graduate School of Management. Dr Alok Chaturvedi, and his team, had been working on SEAS for over seven years and was adapting the model to support the Army's Recruiting Command (modeling the population of potential recruits), the US Department of Justice (Bio-Terrorism War games), and the state of Indiana's Homeland Security and Emergency Preparedness training. When J9 EESD representatives participated in one of the exercises at Purdue, the potential of SEAS to support and complement the J9's experimentation effort was immediately recognized.

Proof of Principal at JFCOM

Members of the EESD staff at JFCOM J9 were enthusiastic about the potential of SEAS to support the DCEE and upcoming experimentation events at J9. However, to prove the viability of the SEAS simulation, SIMULEX Incorporated (Purdue University spin off company) was given the challenge of developing a pilot model, in a short period of time, and with relatively little money, which would demonstrate how PMESII considerations could be played in a 'zero sum game' to illustrate the potential to contribute to a larger Effects Based Operations experiment. The geographical target area was Jakarta, and SEAS was asked to develop a prototype, based on prior work for the Department of Justice, and adapt it to a political-military setting. Simulex, using its intelligent agents to represent the population of Jakarta and surrounding areas, quickly developed a scenario, populated the database, and hosted the demonstration. The players for this capabilities demonstration were primarily members of the USJFCOM staff. These players represented officials from the US Departments of State and Defense, and representatives of the World Health Organization. Other players served as representatives of the governments of Indonesia (President) and Jakarta (Mayor) and members of their staffs in the ministries of Health and Transportation. Side affiliations were grouped in terms of colors: Blue related to United States friendly countries, Red related to a fictional Terrorist faction, and White represented experiment control. Players also represented members of the media, both favorable to Blue and favorable to Red, as well as an unbiased Associated Press (AP)-like reporter who actually was a member of the White Cell for the event. The intelligent agents within SEAS represented the population and responded to inputs from the players. Outcomes were measurable and affected other aspects of the game. Players provided input to the game via input devices in which they made choices on using available resources or implementing actions, which impacted on the population and caused a reaction. Input from the players included such actions as opening or closing ports and airports; increasing diplomatic activities; increasing media interaction; humanitarian aid through nongovernmental agencies; economic sanctions or aid; transportation and energy assistance. The Red team was able to influence the agents via acts of terrorism such as bombing or threats of weapons of mass destruction. And the media was able to 'spin' actual events and decisions of the players to influence the agents thereby causing reactions in public opinion, support for the various governments, and support for Red and so forth. Key to this game was the fact that decisions were 'zero sum' based, so that adding resources in one geographical area meant taking them away from another, and action by one arm of government could have a significant impact on another player such as closing the ports and seeing the resulting effect on the economy. The prototype clearly demonstrated the value and usability of SEAS for JFCOM experimentation events. Future plans for SEAS use will be discussed below.

WHAT MAKES SEAS DIFFERENT

SEAS allows the creation of fully functioning synthetic infrastructure and their relationships, economies, societies, nations, and organizations that mirror the "real world" counterparts in all their key aspects by combining large numbers of artificial agents with a relatively smaller number of human agents to capture both detail intensive and strategy intensive interactions. Major components of SEAS are described below.

The Environment

The environment describes the background, and the contextual structure of the domain for which the synthetic environment is developed. It models the entities, their behaviors, and describes the relationships among them that constitute the simulation's backdrop. The environment contains the geography and the physical details of the space such as the road networks, the structures, traffic patterns and pedestrian dispersion. It also implements the rule sets that guide the interaction of the agents between each other and also with the Environment. Hundreds of thousands of software agents, whose emergent behavior defines the environment, is used as a platform with which human players can engage in strategic decision-making simulations. The environment in this context is a hybrid of microeconomic analysis combined with models from the fields of operations research and management science, epidemiology, and psychology (although a much different, bottom up kind of simulation than the typical top down discrete event simulation). This approach wherein human players can participate concurrently with an agent-based environment offers the following benefits. First, it facilitates the seamless and interchangeable integration of human and software agents. This allows significantly more complex experiments and simulations to be conducted than are usually possible in the fields of experimental Economics (Kagel and Roth 1995), Psychology (Yantis et. al 2002), and Epidemiology (e.g. Kaplan, Craft and Wein 2002). These experiments can combine depth of decision-making (using humans) and breadth (combining artificial agents). Second, it allows a place where the consequences of decisions can be measured and analyzed. This extends the purview of traditional decision support from building models that support human decision making to actually being able to gauge the impacts of decisions as well. Finally, it is a laboratory for testing the efficacy of decisions, strategies and tools. Experiments can be devised that measure the effects of various decisions against the support tools used to arrive at those decisions.

The Agents

Situated in the environment are agents. An agent represents typically one or more people in a simulation. An agent can interact with other agents and with the environment. A distinction is made between artificial agents and human agents. The roles of these agents can be interchanged based on the requirements of the problem domain. The behavior of the human players are not pre-determined and they are free to act as they wish under existing conditions (which might include various capabilities and constraints) which are very clearly described and presented to them in an intuitive and informative way. For example, a human agent playing the role of Health and Human Services at the local level may have a certain budgetary allocation, a certain stockpile of supplies, a certain number of hospital beds and a certain authority to screen, isolate, quarantine, and vaccinate. It is up to the person to make decisions in each of these areas. By contrast the behavior of artificial agents is rule based, though the rules may involve randomness and may evolve over time. To encode these rules, SEAS agent architecture uses a double helix DNA-like structure. In this model, one strand contains agent attributes and traits, while the other contains agent intelligence. The behavior strand of the helix contains the various "genes", which are particular for each class of agent. These genes are relevant attributes such as age, gender, race, education level, culture, geographical location, and other attributes that are programmable in order to motivate the behavior each agent will manifest. Each agent's behavior pattern is one of action – reaction – counteraction, elicited in response to the environment, other agents and stimuli such as response to a bio-terror attack. The intelligence strand contains the rules of engagement by which that agent abides during the course of the simulation. The rules of engagement are a mapping between the portfolio of gene values that a specific agent possesses and the exogenous variables that the artificial crowd supports. A typical rule might be of the form: agent is 41 years old, female, mother, educated, professional, from a large metropolitan area whose initial behavioral response to Bio-terror may be to flee; whereas a 21-year-old single male with a high school level education may be motivated to incite a crowd reaction or committed to fight for his cause. Exogenous variables may be decision parameters specified by human players in the environment (e.g., to target reaction to rumor or government mandate), or general crowd conditions such as the number of people involved, level of stress, fatigue, time pressures, weather, type of attack or time of day or night. Another aspect of the model formulation process is input data analysis and modeling. This involves the preparation of a large dataset upon which the model depends for its interaction. This step is often the most time-consuming task in the model life cycle but is required for relevance and validation to support the development of measures of accreditation. Simulation data analysis can be self-driven or trace-driven by which is meant respectively, deriving input values by sampling randomly from probability distributions, or deriving data from the measurement of the real system. In the SEAS, agent rules of engagement within crowds will be trace-driven in that they are generated from various data mining procedures that SEAS incorporates in the simulation. SEAS's intelligent agents contain autonomous processes that are adaptive and behave like human agents in a narrow domain. In their respective domains, communicate and collaborate in the environment. Since emergent behavior culminates from the nonlinear interactions of agents within the environment and with each other, there must be primitives supplied for facilitation. Especially critical are the functions of communication and collaboration. The conceptual model for this aspect of agent structure is based upon conceptual ports and channels. A port is a place where an entity submits its outgoing messages to the environment. A port allows its owner to configure its own communication rules. A channel on the other hand is a place where an owner can query messages from the environment discriminately. Entities that are "interested" in messages will create channels to query the ports for messages. This allows the system to define communication rules prior to runtime. Using the example above, if a human player desires to target children for vaccination, then this would be done by sending a message on his/her port; the children agents in turn would poll messages on this port to see what, if any, messages currently exist that they should be aware of. Each agent will have a set of eight behavior primitives that will enable them to perform their actions autonomously (see Figure 1). These primitives are Initiate, Search, Evaluate, Decide, Execute, Update, Communicate, and Terminate. Different algorithms are used to differentiate between the agents. For example,

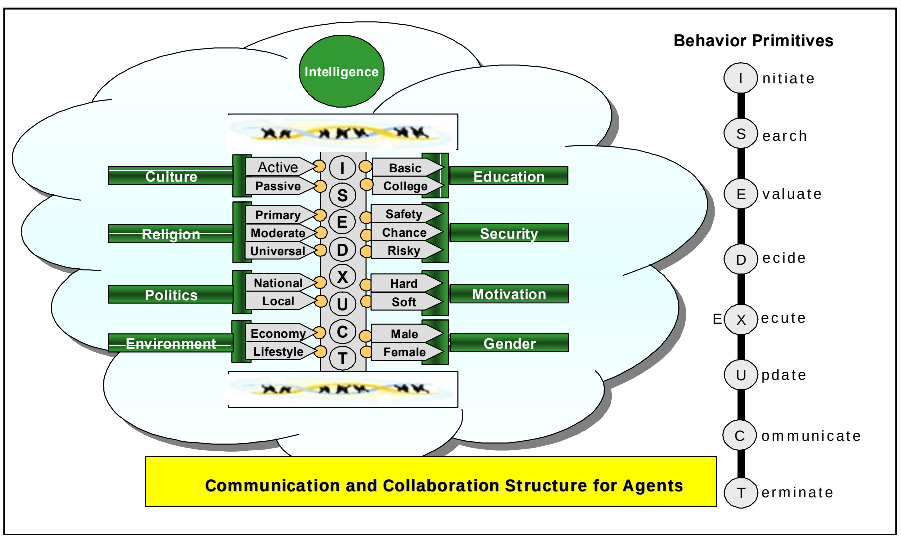

Figure 1. Agent Architecture and eight basic behavior primitives

each agent has a well-defined set of responsibilities and authorities so that it can execute its tasks effectively. The agents will be programmed to maneuver within their domain from the perspective of micro-macro linkages displayed in their collective behavior model. In addition to the elemental agent structure, it is necessary to provide a conceptual model for agents to an agent representing a smart individual will have more sophisticated search and evaluation algorithm than that of a not so smart agent SEAS agents display the following five decision-making characteristics. First, adaptation by relating effects (desired and un-desired) to actionable events through cause-effect relationships. Second, course of action (COA) selection, sequencing, and timing actions that will achieve the desired effects and suppress the undesired effects in a timely manner. Third, sensing to determine the indicators of effects and what and when to look for those indicators. Fourth, evaluation by determining metrics by which Measures of Performance and Measures of Effectiveness can be formulated so that COAs can be compared. Finally, self-regulation as plans that implement selected COAs unfold and sensors provide the status of indicators, calculate the degree of success and determine if changes should be made to COAs.

The Implementation Architecture

SEAS is designed for ease of use and provides researchers the ability to plug in their own data to run simulations and experiments. Each individual researcher is able to design and conduct their own experiments, collect the data and analyze the results in a secure and private manner. The Technical Architecture of SEAS is depicted below (see Figure 2).

– at varying levels of resolution, data, and inter-model coupling relationships. These essential elements can be selected, sustained, and appropriately combined to build any desired simulation through conformance to model and XML standards. Each component is validated before committing it to SVMR to ensure an accurate representation of the behavior of its real-world counterparts, and for a specific level of simulation detail. The amount and validity of data relevant to social and crowd behavior is currently not extensive in any repository, as most of the data reflects individual behavior, which therefore entails subjective per-individual inputs. SEAS has a software zoom capability, called Dynamic Resolution Manager (DRM). Simulations can be presented at varying levels of fidelity. With a user-friendly graphics interface, different data sets can also be selected and the information presented enhanced via DRM. Supported by the ability to accept live inputs, such as real-time transaction data from an Enterprise Resource Planning (ERP) or other databases, allows simulated

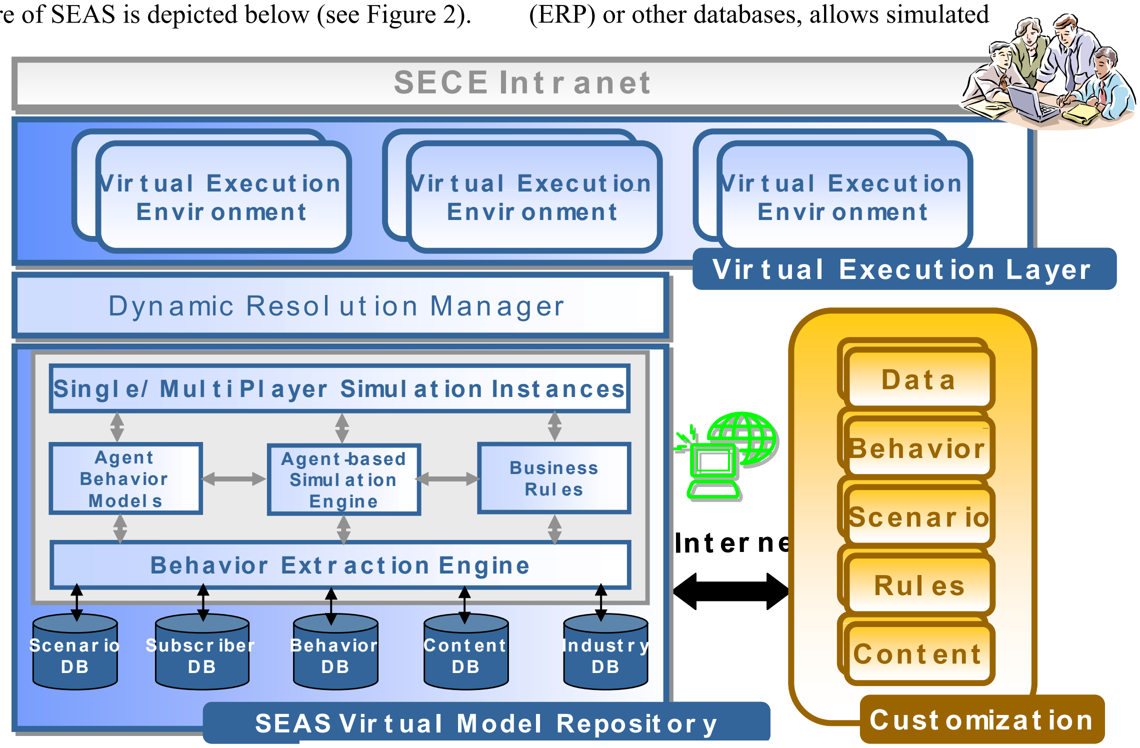

Figure 2. Technical Architecture of SEAS

The key distinguishing features of SEAS are virtual execution environment (VEE), SEAS virtual Model Repository (SVMR), and Dynamic Resolution Manager (DRM). VEE will enable researchers to configure a unique execution environment for their own requirements. Many such environments can run simultaneously. SVMR is a warehouse consisting of validated simulations, models, and model-components

environments to be organized hierarchically for various levels of access. Information can be easily displayed and readily transitioned from one focus to another using detailed modeling, such as engineering level modeling, to aggregated strategic-, theater-, or campaign-level modeling. SEAS is made up of User Interfaces, Agents, an Environment, Rule Sets, and database all realized in Java, JINI, JavaSpace, XML, and Flash. The researchers have extensive experience with this environment including execution on a single PC through 250,000 agents running over a Gigabit network between two supercomputers. JavaSpace is a descendant of the Linda system developed at Yale University (Gelernter, 1985). It also forms the connectivity between the user interfaces and the underlying databases. As a result of JavaSpace's flexibility (Freeman, et. al 1999), it is relatively easy to attach different user interfaces to a model. In an Army sponsored simulation event, hand-held, wireless personal digital assistants (PDAs) were used to capture decision maker responses in each step of the simulation. Synchronization of the agents' interactions is maintained through JavaSpaces. The state of the simulation, including the agent, is persisted in a database. Feedback to the decision makers was done via web sites projected on large screens that provided maps of the current conditions. Once the agents and interfaces have been implemented, the model must be solved and calibrated. Solving the model generally occurs in every time-slice cycle. Once human players have set decision parameter values for a particular slice of time, a solution cycle involves evaluating each agent to see whether it changes its state. An agent may perform many steps as part of this evaluation process; for example, an agent may communicate with its "friends" or agents with similar characteristics, before making a decision. This can be a time consuming task when large numbers of agents are involved. A technique for calibrating the model includes retrofitting the model with vast amounts of historical data. This is an integral part of the model and is beneficial for the validation process.

Immediate Plans to Support Experimentation

The first application of SEAS to JFCOM's experimentation program begins by working with event planners for Unified Vision (UV) 2004 and Sea Viking (SV) 2004. Basing on the scenarios for these events, JFCOM will investigate the usefulness of allowing SEAS to model the PMESII factors that could be used to influence populations in two different regions of the world. In the first case, SEAS will complement the attrition functionality associated with an evolving analytical tool called the Joint Warfare System (JWARS). Using JWARS to investigate aspects of major combat operations, SEAS will enable the investigation of factors of what was previously known as Stability Operations, but has been renamed to Security, Transition, and Reconstruction. Specific for UV04, the SEAS and JWARS interaction will be a manual adjustment of the soft factors that influence an adversary's will to fight. Starting the anticipated daily cycle, SEAS will model the potential perceptions of the regional populations, and the SEAS outputs will establish the initial conditions that would lead to crisis. Ideally, regional JIACGs would emphasize other than military means to avert conflict, but for UV04 the experimentation control group (also could be known as White Cell) will cause a conflict to occur regardless of the JIACG's actions. After JWARS conducts a series of model runs to determine the attrition of military forces, SEAS will then run to determine if a scenario adjustment is needed by the White Cell to keep the wargame's events moving toward a desired goal or end-state. The results of these JWARS and SEAS runs are then presented to the wargame participants (which involves the JIACG response cell) to stimulate decisions on what DIME actions should occur to generate a desire effect on the populations. Next the JIACG uses SEAS to determine potential COAs where the different aspects of DIME may be used to influence the populations. Once the JIACG selects a final COA, then the SEAS outputs, to include such areas as an adversary's will to fight, are then used to recalibrate JWARS's coefficients that relate to PMESII. After dozens of JWARS runs conducted over several hours, the entire cycle is started again, where each wargame move equates to several simulation days to allow for emerging effects from the applied actions on the populations (see figure 3).

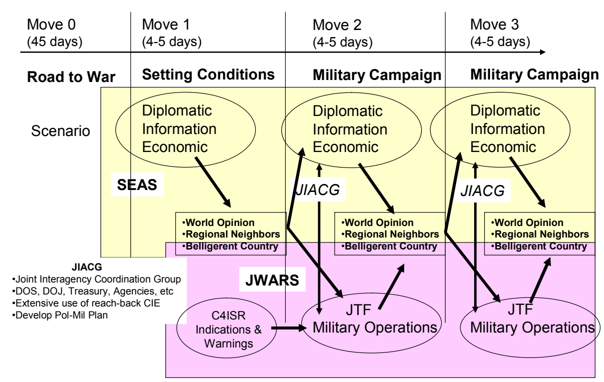

Figure 3. SEAS and JWARS Interaction

Future Plans to Support Experimentation

SEAS applications may spawn from an automated interface between SEAS and JWARS. Due to SEAS' realization of data in XML formats, the notation of SEAS as a common model framework between JWARS and Joint Semi-Automation Simulation (JSAF) is technically feasible and under investigation. With SAF as the base simulation for the Urban Resolve (UR) series of experiments to study Joint Urban Operations (JUO), a SEAS and JSAF interface may be used to add a more pronounced PMESII component for UR. Plus, SEAS may expand to the training realm as further automated interfaces are being discussed for the Joint Theater Level Simulation (JTLS) and the Joint Conflict and Tactical Simulation (JCATS) Federation. SEAS may become a component of the Joint National Training Capability (JNTC) by leveraging any of the potential ties previously mentioned. Additionally, SEAS's capability to model populations has many applications for Homeland Security, especially when state and local governments are preparing for the eventualities associated with the potential of national disasters such as hurricanes and wide-spread flooding.

CONCLUSION

Evolving a tool to allow for the investigation of more than just the military aspects of national power has been identified as a need by JFCOM. As the methods to conduct M&S supported experimentation evolves, then tools that get at the PMESII aspects of Effects-Based Operations become more important. This paper has started with a discussion of why we need a simulation like SEAS at JFCOM. After describing how JFCOM got involved with SEAS, the technical explanation of why it is different from other simulations was developed. Finally, a few words on where PMESII supported M&S may evolve will point the reader towards the future. In summary, SEAS-like tools may potentially be revolutionary as we transform the way we conduct experimentation.

REFERENCES

Ceranowicz, A., Dehncke, R., & Cerri, A. (2003). Moving toward a Distributed Continuous Experimentation Environment, *Proceedings of the 2003 Interservice/Industry Training, Simulation and Education Conference.*

Freeman M. & Capper J. (1999). Exploiting the web for education: An anonymous asynchronous role simulation, *Australian Journal of Educational Technology, Volume No. 15*, pp 95-116.

Gelernter, D (1985). ACM Transactions on Programming Languages and Systems, Volume No. 1, pp 80-112.

Kagel, H. & Roth, A. (1995). *Handbook of Experimental Economics*, Princeton University Press.

Kaplan, E , Craft D. & Wein L. (2002). Emergency Response to a Smallpox Attack: The case for Mass Vaccination, *Proceedings of the National Academy of Sciences, Volume No. 99 # 16*, pp 10935-10940.

Yantis, S, Medin, D, Gallistel, R. & Wixted, J. (2002). *Handbook of Experimental Psychology*, John Wiley and Sons. 3rd ed.