Bridging Kinetic and Non-Kinetic Interactions over Time and Space Continua

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ABSTRACT

As non-kinetic warfare evolves, simulations are taking revolutionary steps forward to keep pace. Currently, a vast majority of attrition simulations synchronize on causal effects associated with tactical interactions. Truly revolutionary approaches bridge kinetic actions with their correlations outside of the tactical realm to provide a holistic view.

Modeling these interactions pose significant challenges for simulation developers. This paper describes a bridging technology explored by J9, the Experimentation Directorate of USJFCOM, to interface aspects of an attrition simulation, JSAF, with a behavior simulation, the Synthetic Environment for Analysis and Simulation (SEAS). Enabled by this shared virtual environment, geographies and events from the real-world are generated based on published scholarly research and open source data. This research provides the means to develop a realistic model of population behavior consisting of population density, demographics, culture, and beliefs.

Virtual agents are programmed with characteristics that replicate the behavior of individuals in given communities. Curious or volatile crowds emerge through micro-macro linkages of individual and group behaviors. In turn, group behaviors trigger macro-micro linkages that affect individual behaviors.

JSAF is used to provide the kinetic aspects of activities at the entity level within a city. SEAS generates the Political, Military, Economic, Social, Information and Infrastructure (PMESII) impacts of such activities at local, national, and global levels. A SEAS-JSAF bridge facilitates the military decision-making process in complex urban environments, providing situational awareness of urban warfare and the effects of crowds on military operations. Various paths to outcome can result from a planner's inputs and the emergent behavior of agents. Additionally, decision superiority is enabled through rapid and enlightened experimentation involving military and civilian operations. By allowing planners to conduct a virtual rehearsal, innovative courses of action can be developed to influence crowd behavior and implement effective countermeasures.

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BACKGROUND

A nation can potentially achieve its political goals by influencing the behavior of the civilian population, as opposed to relying solely on conventional combat operations. The Effects Based Operations concept (EBO) defines four factors of a Nation's influence, referred to as DIME: Diplomatic, Information, Military and Economic. The DIME factors can be directed against an adversary's political and cultural underpinnings, as well as used to leverage the perceived behaviors of key leaders and fighters in an effort to align such individuals with a nation's political aims.

The pressure points where DIME factors can be applied under the EBO paradigm are categorized as Political, Military, Economic, Social, Information and Infrastructure nodes (PMESII). The infrastructure and networks used by the civilian populations, which are also leveraged by the adversaries, can be directly impacted by applying DIME to specific pressure points.

Stability Operations (SO) are often required even after achieving a nation's political goals. SO are defined as the process of providing security, initial humanitarian assistance, limited governance, restoration of essential public services and any other reconstruction assistance needed to facilitate a transition to a legitimate, local civil governance (DoD 2004).

In order for a nation to have a stronger influence within a foreign community, and to allow unobstructed SO to occur, the population's support for the adversaries must be diminished. Without population support, adversaries cannot easily hide or disguise their actions, and may become more readily targetable in a preventive manner by a nation using the EBO construct. For example, if a population decides to reduce its support of an adversary hiding within its borders, then that population may increase the frequency of timely and relevant information reports to security forces. Armed with current information, the opportunity exists for the security forces to better anticipate future actions that an adversary may wish to execute. This ability to better anticipate future possibilities falls into the realm of predictive analysis and course of action (COA) tools.

There is a compelling need for a model that encompasses both the kinetic and non-kinetic EBO impacts on the PMESII nodes. The model must take into account the fact that these nodes may also be simultaneously leveraged by the population centers and the adversaries operating within these centers. It then becomes the focus of SO to help separate the adversary from legitimate local governance and population centers. Such a comprehensive model is missing among the state-of-the-art simulations.

The State of the Art Modeling Environment

A vast majority of attrition simulations synchronize on causal effects associated with kinetic interactions to model conventional combat operations. The Joint Semi-Automated Forces (JSAF) is the primary modeling and simulation component used by the United States Joint Forces Command (USJFCOM) to conduct experimentation of conventional combatant operations for the Department of Defense (DoD). JSAF can be used to evaluate different combat systems within a virtual battlespace. JSAF represents components of military organizations at a granularity where fundamental processes of target identification and kinetic actions associated with inflicting damage against targets can be measured. Individual sensors and munitions can be represented as distinct entities. Additionally, the processes of acquiring and engaging entities in the virtual environment are modeled as independent and explicit occurrences, enabling a quantified comparison of engagement protocols.

The virtual, urban terrain used by JSAF is constructed using real-world data acquired via satellite imagery. The terrain database is capable of representing potentially millions of buildings in detail (Ceranowicz, 2004). Each building is uniquely identified within the three dimensional environment so that emulated pedestrians and combat platforms can be associated or paired with particular buildings at particular locations, consistent with actual locations.

Buildings are modeled as Multiple State Objects (MSO), each with a Building Function Category (BFC) assigned automatically according to characteristics differentiated by the actual data or by hand (Prager et. al., 2004). Up to a thousand different types of buildings can be represented. The buildings are then used to help differentiate places to perform activities such as work, worship, entertainment, and rest.

JSAF includes a ClutterSim federate to emulate civilian vehicle and pedestrian entities (referred to as clutter) by modeling three classes of movement: static, dynamic and commuter (Haskell, 2004). Commuter clutter can be automatically assigned appropriate places to perform a multitude of activities and homes to commute between based on the buildings' BFCs. For example, commuter clutter provides the perception that pedestrian entities get hungry as they move between their places of work and one of many nearby restaurants.

As a result, JSAF can now provide a virtual, dense, urban environment in which to experiment. Within this environment, users can set the stage for events such as a car bomb detonation and can direct the movement of clutter entities accordingly. However, all changes to the daily routine of clutter commuters require manual input from JSAF operators. The behavior of the civilian population and the reactions of the population to kinetic actions of a foreign nation or by adversaries are subject to the JSAF operators' discretion.

Time and Space Challenge

Despite the need to incorporate non-kinetic models when simulating the outcome of operations, the detailed modeling required inhibits a computationally feasible simulation. A computationally light weight simulation is required in order to model a high density of people moving through urban road networks and interacting with millions of buildings. Extending the model of an individual to include a person's intentions and persistent behavior causes the simulation to become computationally infeasible. The only reasonable approach is to simultaneously handle multiple types of models, achieving the goals of each model appropriately while meeting the higher goal of accurately capturing population behavior in an urban setting.

Often, diverse models are implemented with different temporal and spatial granularities. With respect to modeling EBO, DIME actions can take place within minutes, but resulting second and third order effects on the population's demeanor may take days to surface. For example, a first order action to close a bridge can lead to second order effects of riots and cause third order effects of unemployment to emerge.

The Unsolved Challenge of Bridging Kinetic and Non-Kinetic

Modeling the influence of military decisions in urban environments poses new challenges, the most significant of which is the correlation between tactical combat actions and non-kinetic behavior. Simulations exist to model the kinetic aspects or the behavioral dimensions in isolation. The work described in this paper has the goals of modeling the influence military decisions have on civilian mood, and the effect of civilian behavior on subsequent military operations. In order to meet these goals, the model must accurately describe micro-macro dependences between local actions occurring within minutes, in contrast to macro behavior that potentially requires days to manifest.

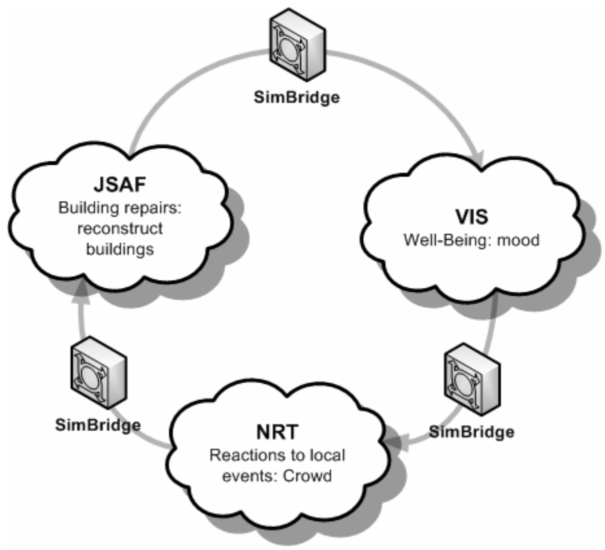
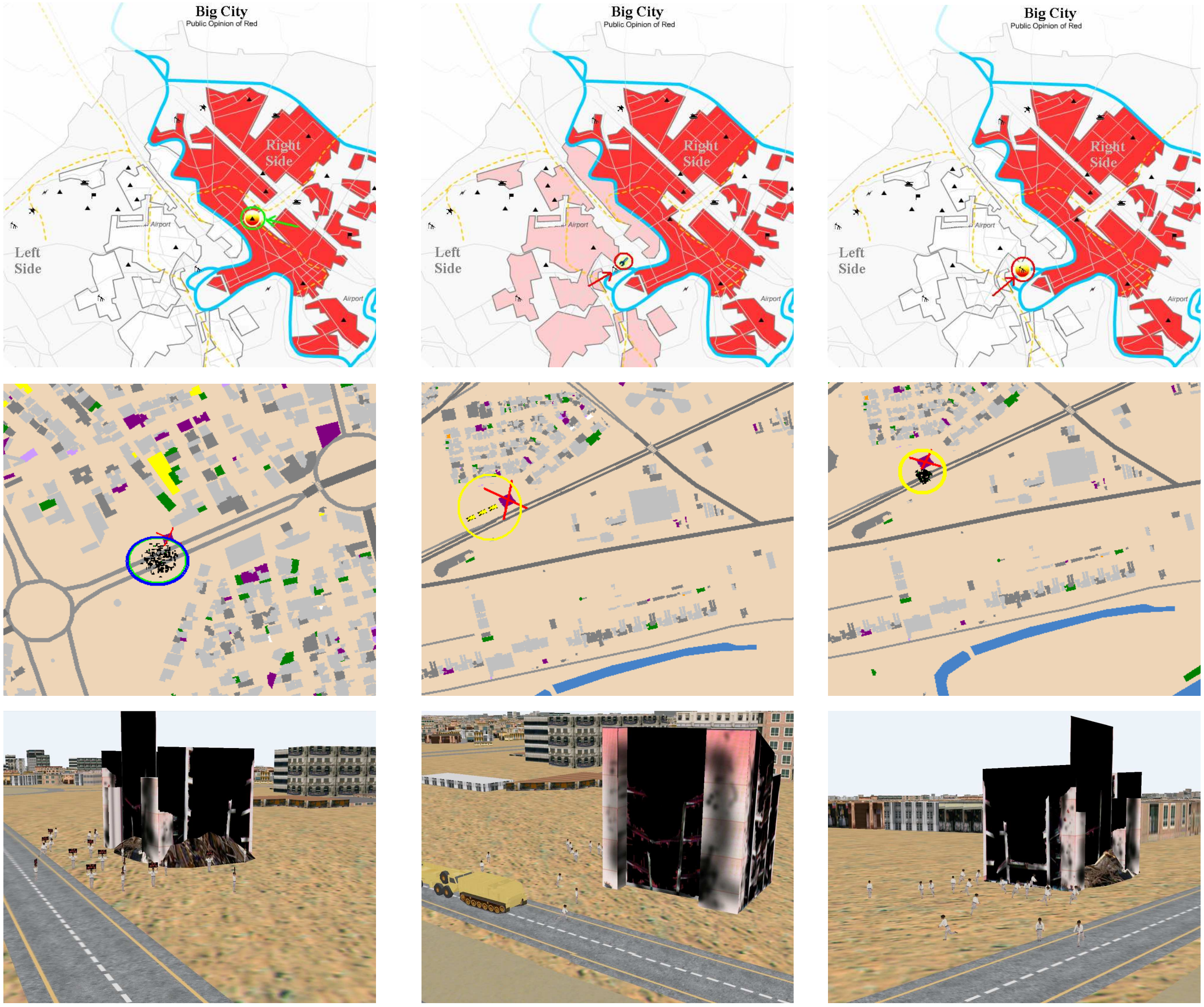


Figure 1. A Full Cycle of Data Exchange between Kinetic and Non-Kinetic Models.

Linking JSAF with a behavior simulation, Synthetic Environment for Analysis and Simulation (SEAS), it is possible to represent a full cycle of military decisions (repairs of buildings under the auspices of the security force) leading to improved relations between friendly forces and a foreign culture, which in turn influences the reactions people have to local events (see Figure 1).

SEAS consists of two types of simulations, Near Real-Time (SEAS-NRT), and Virtual International System (SEAS-VIS). SEAS-NRT advances time at a fine granularity to address the interactions between civilian individuals and military/security force entities. SEAS-VIS simultaneously captures the perceived behavior of the population on a larger scale.

The following case study illustrates aspects of the correlation between military decisions and civilian behavior. The underlying technology for bridging simulations described below will be grown to include a full variety of military and civilian actions, to rely on a more complex behavior model, and used to represent realistic situations that warfighters in urban environments on foreign soil face. Realism is achieved



(a) Angry Crowd **(b) Repair Team** **(c) Curious Crowd**

Figure 2. Three Subsequent Scenes from the Urban Scenario

by closely attuning the simulations to the culture differences displayed by the populations, the geo-specific nature of the environment, and accurate modeling of the military/security forces' behavior.

For this case study, JSAF and SEAS were taken out of their preferred SPP (Scalable Parallel Processor) environment for information assurance issues associated with running the components in a DoD facility. In turn, any performance issues that may be associated with latency were not measured as it was not a variable of interest due to the artificialities related to this trial.

AN ILLUSTRATIVE URBAN SCENARIO

Specific kinetic actions and non-kinetic reactions were included in this case study with the goal of modeling the influence of other than direct combat actions on local civilian behavior.

- Building repairs was chosen to represent actions taken by military decision makers in support of SO.
- Bombs were included to cause building damage and provide local events that influence the population.
- The possible reactions of civilian behavior included the formation of curious or volatile crowds.

This is a reduced model of only certain types of actions and reactions. This first step represents a full cycle of interactions between kinetic and non-kinetic while spanning the time differentials between the micro and macro worlds. Future work describes how to include all major actions and issues in the model following the same fashion used for this case study.

The scenario for the simulation takes place in a fictitious area called Big City, representing a complex urban environment. The urban environment is constructed from high detail terrain data, consisting of building structures, building types, streets, and road networks for a specific area of the world. Detailed models of key buildings are also included to model the damage and repair of buildings.

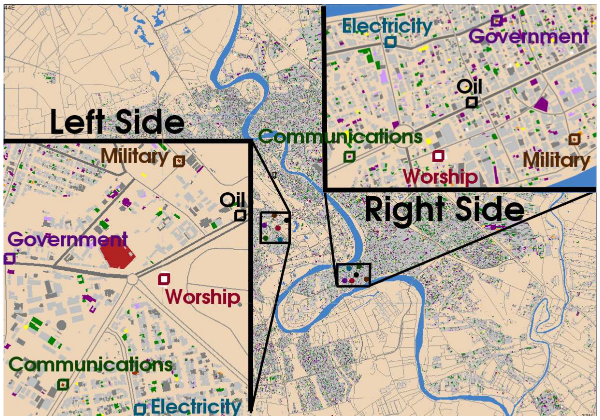


Figure 3. The Big City.

For the purposes of illustration, Big City was divided into two regions separated by a large river: referred to as Left Side and Right Side (see Figure 3). Initially, all the people are neutral with regard to the foreign security forces and any opposing forces seeking to destabilize the local government. The foreign security forces are referred to as Blue Forces. Opposing forces are referred to as Red Forces.

Bomb detonations that cause collateral damage to building structures result in reactions by nearby civilians. The moods of people are influenced by the state of the economy and the perception of the cause for the detonations. In this case study, the civilians assume all bomb blasts to be caused by the presence of Blue.

How a person (represented in the virtual environment) reacts to the destruction of a building depends on the relationship the person has to the function of the building. For example, the destruction of a bank influences the overall economy which can impact people's mood over a period of time; whereas, an act perceived as violence against a house of worship can ignite an immediate emotional response.

Further, an explosion can cause people to crowd, depending on their curiosity and mood. People that have become angry crowd at the location of an event to protest or riot. Other people may crowd out of curiosity. Still others will not approach the event out of fear or apathy.

Every detonation is assumed by the population on the Right Side to be the result of deliberate Blue Force action against their people.

One building of each PMESII type on the Right Side is damaged. Since Blue gets negative credit for the destruction, the Right Side becomes generally anti-Blue and pro-Red. Any new explosion on the Right Side elicits an angry response. Figure 2(a) shows the overall mood across the city (SEAS-VIS), the location of the bomb in the Right Side (JSAF-PVD), and a close up view of an angry crowd that formed due to the bombing of a bank (JSAF-ModStealth). JSAF reflects the agitated state of the population by clutter entities displaying or not displaying protest signs. The terms used above will be defined in the next section of this paper.

Since all of the explosions up to this point occurred on the Right Side, the Left Side has remained neutral. When an explosion occurs on the Left Side, most people who choose to crowd are doing so out of curiosity.

As more detonations occur on the Left Side, the mood of the people on the Left Side becomes more favorable to the Red Forces and less favorable to the Blue Forces.

Repair teams are sent to the destroyed infrastructures on the Left Side and they rebuild the buildings. Just as bomb detonations are credited to the presence of Blue, the people assume all building repairs to be caused by Blue's presence. As the buildings are restored, the mood of the Left Side becomes less agitated and more cooperative towards Blue. Figure 2(b) shows the mood of the Left Side being influenced by the actions of the repair teams. An additional explosion on the Left Side draws only a crowd of curious onlookers, as is shown in Figure 2(c).

THE SIMULATION ENVIRONMENT

The above scenario resulted from bridging a JSAF federation of simulations with a SEAS society of simulations. The JSAF simulations modeled commuter and pedestrian movement, collateral damage, and the process of repairing a building at the granularity of human and building entities. JSAF also provided the user interface to set off explosions at key buildings and to allocate non-combatant repair teams to rebuild specified buildings. The SEAS simulations modeled population behavior at multiple levels of granularity: city block, city region, national and international levels. The behavior and emergent social networks are captured within the SEAS model, while simulating people at the fine granularity of a city block enables crowding to be modeled within select areas.

A bridging technology was developed to enable the SEAS simulations to operate within the same virtual environment and to allow other simulations to interact with the SEAS behavior models while preserving causality in an efficient manner.

The only human involvement required to generate the above scenario was in deciding where explosions occurred and what buildings to repair. All other events and social behavior emerged as the various simulations interacted with and reacted to a shared virtual environment.

Joint Semi-Automated Forces (JSAF)

JSAF is a collection of simulations, linked together in a High Level Architecture (HLA) federation. The JSAF simulations used in this scenario were ClutterSim, DTSim, and ModStealth. The Plan View Display (PVD) is the JSAF graphical user interface used in this scenario for human-in-the-loop (HITL) input. The federates were connected using an implementation of a Run-Time Infrastructure (RTI) developed by USJFCOM J9, named RTI-s.

RTI-s does not include the overhead required to ensure that interactions are received by each federate in timestamp order. Rather, all federates are required to synchronize by their simulation times with the wall-clock time, and occasionally with a federate designated as the time master. Synchronization issues become critically important when bridging JSAF federates with other simulations that require timestamp ordering of events, as will be described below.

JSAF-ClutterSim

ClutterSim has been effectively used to incorporate crowds and background pedestrian and vehicle traffic into virtual urban environments (Speicher, 2004). The clutter entities move in accordance to road networks and buildings that are recorded in the terrain database. Using SPP resources affords JSAF federations the necessary scalability to potentially model millions of entities in virtual environments with millions of MSO buildings (Davis, 2004).

With respect to this scenario, ClutterSim was enhanced to receive messages indicating where a crowd is forming, how large the crowd is, and the average anger level of the people in the crowd. Changes in a crowd's size or mood can be given in subsequent messages.

JSAF-DTSim (Dynamic Terrain Simulation)

The DTSim federate uses building models for detailed simulation of collateral damage to specific buildings. When a building is being rebuilt by a repair team, DTSim will generate messages to inform the other federates of the change to the building's damage level.

JSAF-PVD (Plan View Display)

The PVD is a two-dimensional, interactive visualization of the detailed terrain data merged with iconic visualizations of battlespace entities. Through the PVD, a user sets up the environment, detonates bombs, and chooses to send repair teams to rebuild certain damaged buildings.

JSAF-ModStealth

The ModStealth federate is a three-dimensional visualization capable of showing an indication of the anger of a pedestrian. This federate visualizes the state of the other federations.

Synthetic Environment for Analysis and Simulation (SEAS)

SEAS provides a behavior-based simulation system, modeling behavior at multiple granularities from international to individual persons in an integrated manner. SEAS consists of two types of simulations: SEAS-VIS models human behavior and SEAS-NRT model fine-grained human movement to simulate crowd formation. These simulations are described in detail below.

Virtual International System (SEAS-VIS)

SEAS-VIS is used to examine interrelated effects of intra and inter-nation dynamics, geopolitical situations, predispositions of leaders, and citizens' expectations, goals, and desires for well-being. The SEAS-VIS environment is composed of geographic entities (nations, provinces, cities) and their infrastructures (electricity, telecommunications, transportation, etc.), political systems (type of government, political parties/factions), social systems (institutions, organizations, groups), economic systems (formal and informal sectors), and information systems (print, broadcast, internet).

Each nation within the SEAS-VIS consists of five types of synthetic agents or entities: citizens (civilians, soldiers), non-citizens (rebels, terrorists), leaders, organizations, and institutions. To represent a synthetic nation each entity type is constructed as a proportional representation of the societal makeup of a real nation and encoded with static and dynamic traits. For example, a citizen agent is encoded with static traits such as race, ethnicity, income, education, religion, gender, and nationalism; and dynamic traits such as religious, political, societal, and violence orientations. The behavior pattern of each of these entities is derived from various theoretical paradigms covering a wide range of disciplines (Chaturvedi et. al. 2004).

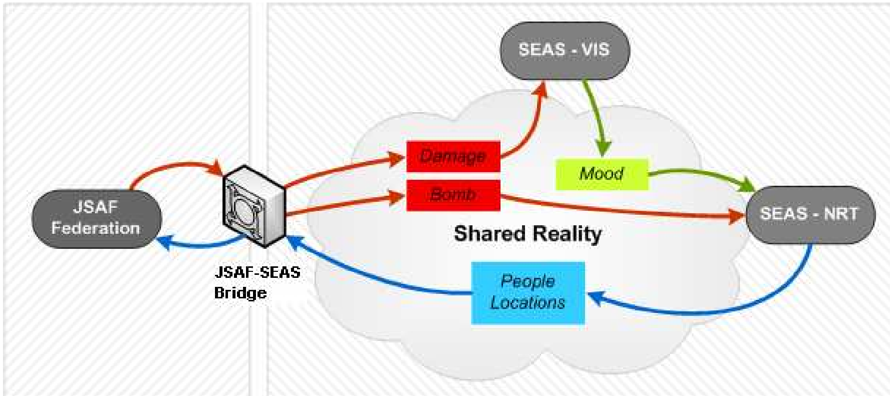


Figure 4. An Illustration of Shared Reality in a Society of Simulations.

SEAS-VIS uses information regarding the collateral damage to critical structures to produce the mood of individuals across the city, nation, region, and the world at large. The damage is classified under the PMESII categories.

SEAS Near Real-Time (SEAS-NRT)

While SEAS-VIS runs at faster than real-time clock speeds, certain significant events are modeled at a finer granularity using SEAS-NRT in order to grasp possible crowds, mobs, demonstrations, and riots that may emerge. Such micro events influence the behavior of the synthetic agents modeled within the SEAS-VIS. In turn, the reaction of the SEAS-VIS agents can trigger macro-micro linkages that affect other individual behaviors at a fine granularity, such as recruitment into a terrorist network, or an offensive event in one area of a city may allow a militant leader in another location to gain immediate support. SEAS-NRT is used to model select numbers of individuals at a time, adding movement and awareness of immediate surroundings to these individuals (Foong et. at 2005, Chaturvedi et. al. 2005).

When an explosion occurs, nearby individuals that sense the explosion are modeled using SEAS-NRT. Once an individual senses a bomb explosion, the individual can choose to approach the bomb location. The attraction of crowding around the bomb location for each individual is dependent on the person's mood, modeled by the SEAS-VIS simulation. The techniques used to link SEAS-NRT with SEAS-VIS and to link SEAS with JSAF are described next.

Linking Simulations by Joining a Society of Simulations

Using the metaphor of a *society*, a comprehensive simulation is composed of the specialized JSAF and SEAS simulations. Each specialized simulation is regarded as a *member* of the society. A member simulation operates independently on its own understanding of reality. Members cooperate with each other to achieve the goals of the society while satisfying their own local goal.

The goal of the society in this case study is to model the influence of combat operations on civilian behavior and the impact of civilian behavior has on military decisions. The goal of the SEAS-VIS member is to model the impact that actions against and for the PMESII nodes have on a population's behavior. By interacting with the shared virtual environment, SEAS-VIS achieves its goal and also provides what other members need to complete their goals.

In order to link the various JSAF and SEAS simulations in the above scenario, the JSAF federation is included as a member of a society of simulations including SEAS-VIS and SEAS-NRT members. From the perspective of the JSAF federation, the society appears as a single federate that publishes and subscribes to HLA-compliant interactions.

Interactions between members occur when portions of their models of reality coincide. The portions or aspects that coincide are placed within a space accessible by all relevant members called *shared reality*.

The shared reality mechanism enables the necessary synchronization among members to emerge as a characteristic of the data access requirements of the members. Each member executes asynchronously until data external to the member is required. A member senses shared reality for data it depends on. If the data is not yet present, the member can conservatively wait for the data or optimistically continue, depending on the execution characteristics of the member.

The features shared among the JSAF and SEAS members are explosions, building damage levels, crowds, the mood of people, and the simulation time, as is illustrated in Figure 4. JSAF-PVD produces bomb explosions as messages on the JSAF federation network. A JSAF-SEAS bridge that is subscribed to bomb explosion interactions will receive a notification of the explosion and will store a bomb event in an internal queue. Since JSAF federates implicitly synchronize by wallclock time, the bomb event does not include a time value. The JSAF-SEAS Bridge queries the JSAF federation time master for the local simulation time. Once the time is received, the Bridge places the bomb entry in the shared reality accessible by the SEAS-NRT members.

SEAS-NRT members will sense any significant events that influence their movement by accessing shared reality for their local proximity. In this case, the significant events are explosions. Once an explosion is sensed by an individual, it queries shared reality for the public arousal level of the locality.

The arousal values for individuals are provided by the SEAS-VIS member. The events indicating damage to and restoration of infrastructure entities are modeled as DIME actions on PMESII nodes which are then sensed by individuals through media, social networks and the environment. The arousal of an individual is determined by behavior models that comprise demographics, information sensors, perception of such information based on the individual's perspectives, memory and the individual's goals.

The damage of buildings is produced as a message on the JSAF federation network and is received by the JSAF-SEAS Bridge just as the bomb detonations are. A corresponding building damage entry is placed within the shared reality accessible by SEAS-VIS. SEAS-VIS can sense these entries and categorize the damage or repair action under the PMESII classification using the BFC provided by JSAF.

Table 1. Diversity of Reporting Granularities among Simulation Members.

	JSAF Fed.	SEAS-NRT	SEAS-VIS
spatial	0.1 meters	< 1 meter	2 regions
temporal	< 3 seconds	< 1 second	14 seconds
population	crowds	individuals	individuals

SEAS-NRT individuals decide to approach a nearby explosion, flee the area, or ignore the bomb, depending on their mood. The SEAS-JSAF Bridge senses when SEAS-NRT individuals approach a significant event and will gather the specifications of the developing crowd. These specifications are provided to the JSAF federation as a message consisting of the location, size, and average anger level of the individuals in the crowd. As the crowd grows or shrinks, the SEAS-JSAF Bridge will generate an update to the crowd.

The spatial granularity at which a member executes is a characteristic of the member. The internal granularities of the members that share data do not have to match. Each member produces data in a form consistent with its internal representation of the data without the burden of transforming the data for use by specific other members. A member that uses data in shared reality may have to transform the data into a form consistent with its own internal representation. Table 1 shows an approximation of the finest granularity of interaction with each of the members. SEAS-VIS was designed to model only two regions for simplicity of this case study—the Left Side and Right Side of Big City.

Shared reality allows information to be exchanged between the three types of members without forcing all simulations to operate at the finest granularity of interaction. Allowing data to be exchanged across diverse granularities enables both complex behavior models and models involving the fine detail of movement to be applied to individuals in areas of high population density.

Constructing a Society of Simulations

In order to construct a society from a number of simulations, the following tasks must be completed:

1. Analyze a simulation member's input dependences and potential outputs.
2. Design the shared reality constructs that will be shared by multiple members.
3. Build a bridge for each member to connect the member to the shared reality.

Analyze the Member

A member's inputs are any way an external action can influence the application, such as dynamic inputs, initialization files, and data. Also take into consideration the time requirements for each data input.

Design the Types of Shared Reality Entries

Data produced by members will be placed in shared reality objects, according to the granularity of the producer.

Build a Bridge to Link Each Member to Shared Reality

Finally, design a member's bridge based on the member's inputs and the available data in shared reality. If the output data is in a format that the member cannot digest, a translator must be encoded within the member's bridge. Possible translations include transformations such as scaling, interpolating, sampling, and aggregating.

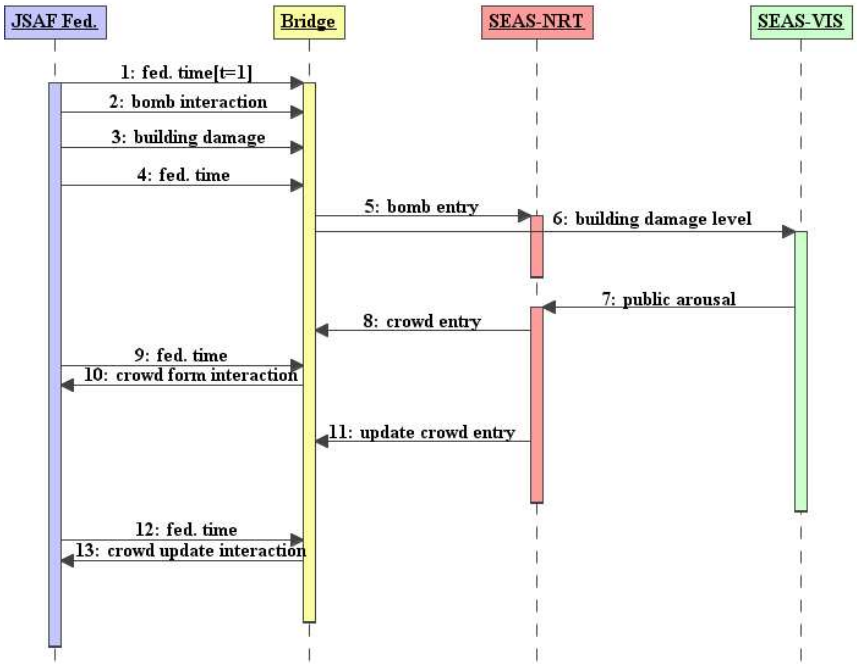


Figure 5. Time-Line of Interactions Between JSAF and SEAS Simulations.

The time synchronization among members must be set up carefully to avoid deadlocks, cascading rollbacks, and serialization. One of the simplest cases is to have each member driven by another member. A member waits for the time advance from a driving member by waiting on shared data generated by the driving member If a member has no driving member, it is free to advance its time indefinitely. There must be one member that will drive the society without being hindered to ensure that time will progress.

In the scenario described in this paper, the JSAF member drives the society. SEAS-VIS follows JSAF since it depends on building damage values. SEAS-NRT depends on SEAS-VIS to determine the mood of people in a crowd and therefore follows SEAS-VIS. The synchronization that emerges from making SEAS-NRT wait on JSAF is illustrated in Figure 5.

COMPARISON WITH RTI

Another common approach to linking simulations together is to construct a federation according to the High Level Architecture (HLA) standard. For the urban scenario described above, SEAS-VIS and SEAS-NRT simulations would become federates in a federation that includes the JSAF federates. SEAS-VIS would become a subscriber to building damage interactions and a producer of public arousal interactions. SEAS-NRT crowds would subscribe to bomb detonations and the public arousal levels of individuals.

For optimization, the spatial representation of Big City could be decomposed into regions so that one SEAS-NRT crowd federate would only receive interactions that represent bomb events and public arousal values of individuals in its spatial locality.

The map of producers to consumers and any decompositions of the interactions into regions would be explicitly described when the federation is designed. Additionally, the synchronization of SEAS-NRT with SEAS-VIS on public arousal interactions would be implemented as an added constraint within SEAS-NRT to enable a proper ordering of the public arousal value with the decision of an individual to approach an event.

The society of simulations approach is in contrast to the typical method used by HLA of keeping a mapping of publishers to subscribers and controlling the data interactions by a centralized management mechanism. Though the resulting patterns of interaction among federates are equivalent to the patterns of interaction among members in a society, a society approach does not dictate that all members use a specified time management mechanism.

In a society, the publishers and subscribers are managed autonomously. The interconnections between publishers and subscribers emerge as subscribers sense data the publishers produce. A subscriber can change its requirements to sense other data without coordinating with a centralized data management mechanism that owns the map of linkages.

The society of simulations approach was designed to enable heterogeneous simulations to interact in an efficient manner while allowing each simulation to operate autonomously. A society of simulations approach implicitly enables diverse data access frequencies among simulation members by allowing the members to manage their own data access requirements.

To add the new members to an existing society requires development of a bridge for each, but does not place new constraints on the existing members. The following section describes possible future applications of a simulation society.

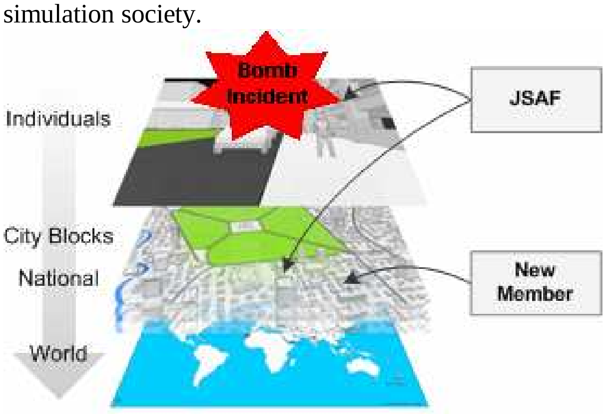


Figure 6. Enhancing the JSAF-SEAS Society with New Members.

FUTURE WORK

A virtual environment in which the same problem sets can be viewed from multiple perspectives provides a consistent platform across experimentation, analysis, and training. Experimenters develop and test new models within a simulated environment; analysts validate a model by testing it under diverse problem sets and comparing it with other established models; using Human-In-The-Loop (HITL) components, trainees can interact with the same virtual environment and leverage validated models in the training process.

A society of simulations consisting of JSAF and SEAS offers a consistent and extensible virtual environment in which simulations can incorporate the links between macro and micro behavior within a global context. A new member of the society can access shared reality at a level inherent to its model, whether it operates at the national or individual level. No matter what level the new member accesses, the member can cooperate with other members in an integrated manner across all levels, from individual to global, as is illustrated in Figure 6.

Simulations connected as new members of the society of simulations could access interactions published within the JSAF federation through the JSAF-SEAS Bridge. Similarly, simulations connected as federates to JSAF could influence the PMESII nodes through the Bridge.

The following examples describe ways in which the JSAF-SEAS society could be extended to leverage new application areas.

- Joint Warfare System (JWARS) provides a model of military strategy at the campaign level, taking into account certain "soft factors" that can be used to determine the will of a soldier to fight an adversary. While these soft factors are focused on the morale and readiness levels of military forces, the values of these factors could be influenced by the will of the soldier's people to continue to support their military. Soft factors could also be used to include the influence of a foreign population's continued support for an occupying force.
- Using a society of simulations approach allows simulation members developed according to diverse standards to interact. Joint Operations Army Navy Air Force (JOANA) is an operational level national simulation developed in Germany to model non-combatant influences on the stability of a region. The model incorporates actions such as illegal drug trafficking, relief efforts, and refugee migrations. The model involves convoys, supplies carried by the convoys, and the disposition of crowds at national and international levels. Actions can be triggered to occur automatically dependent on specified behavior and stress levels associated with the JOANA aggregates, such as when riots in refugee camps result from food shortages or terrorist attacks. Enabling interactions between simulations developed by the international community and the U. S. developed simulations, such as JSAF, fosters involvement from international partners.
- Process models and commercial multiplayer games could be added to extend JSAF's functionality with multiple models based on different underlying assumptions. Connecting these extensions within the JSAF-SEAS society allows the extensions to leverage both JSAF and SEAS. If such extensions or any of the proposed member simulations are connected directly to the JSAF federation, interaction with the population models of SEAS can occur through the two-way JSAF-SEAS Bridge.

- Additionally, streams of live sensor data could be integrated into a society, appearing to the other simulations as any other data source. Live sensor data can be used for continuous refinement of simulation data. Operational Net Assessment (ONA) utilizes a knowledge base consisting of PMESII nodes, possible DIME actions, and a corresponding list of probable PMESII effects. A simulated world incorporating these nodes and effects, verified by live data, provides insight into the dynamic aspects of ONA.
- By providing a user an immersive portal into the virtual world, a society of simulations could also be used to address training. The user's actions can produce realistic influences on the simulated environment, involving population behavior and tactical actions.

Further development of the JSAF-SEAS Bridge is also planned to enable more civilian actions to be represented in JSAF that are based on mood. For instance, a crowd may degrade into a riot in response to a convoy of foreign troops moving through a population center that has been agitated by the media.

CONCLUSIONS

The bridging technology described in this paper enabled simulations of tactical actions to cooperate with simulations of civilian behavior, with the goal of producing a comprehensive virtual environment for modeling urban operations. A full cycle of actions and reactions emerges, modeling the reaction of civilians to the actions of a military/security force. Manual input is required only to perform certain high-level decisions, such as which buildings to repair and the detonation of explosions. Such a virtual environment allows plans to be tested that incorporate the effects that DIME actions have on PMESII nodes.

The SEAS and JSAF simulations represent very different types of simulations in terms of time and data management, yet, they can interact efficiently and effectively through a shared reality. The Bridge between SEAS and JSAF demonstrates the potential benefits gained by bridging together simulations from diverse perspectives. The ability to extend a specialized simulation to include interactions from other simulations without constraining all connected simulations to a single time and data management technique fosters composability and reuse.

Using a society of simulations approach presents the necessary environment in which to test current models and develop new models for EBO. An existing society of simulations can be extended to include additional members representing new application areas or newly developed models with significantly different characteristics. Using the JSAF-SEAS, a consistent model of EBO is provided for experimentation, analysis, and training. No other system presents a seamless integration of multiple levels, from global to individual, necessary for developing comprehensive EBO models.

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