An Architecture for Integrated Modeling and Simulation for Emergency Response

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Abstract

A number of modeling and simulation applications exist for studying individual aspects of emergency response scenarios. The value of these applications can be significantly increased if they can be used in an integrated manner to study all aspects of a scenario. This paper presents an architecture for integration and distributed execution of such applications for analyzing an emergency response scenario. The proposed architecture is designed for integrating geographically dispersed modeling and simulation applications and repositories of data. It is designed to accommodate advanced visualization and human interaction together with data access and management capabilities.
Keywords: Modeling, Simulation, Architecture, Emergency Response, Integration.

1. Introduction

There is a growing need for preparedness for emergency response both for man-made and natural disaster events. The man-made disaster risk has increased due to a rise in possibility of terrorist attacks against the United States. Effective emergency response presents a number of challenges to the responsible agencies.

Modeling, simulation[1] and visualization techniques can help address many of the challenges brought forth by the need for emergency response preparedness. A recent survey [1] indicates that a number of modeling and simulation applications for analyzing various disaster events exist. These need to be brought together for studying the impact of disaster events as a whole. Not only do we need to understand how will a radioactive plume released by terrorists disperse, we also need to plan what traffic routes will people use to evacuate the affected areas, what demands will be placed on the hospital resources in the area, etc. The individual simulation models such as those for studying the radiological release need to be integrated with those analyzing the traffic movement through the highways and arteries of the affected area, and with those analyzing the resource constraints of hospital systems among others.

The integration of simulation models developed independently presents a daunting challenge in itself. Interoperability standards need to be defined that will allow the conforming models and data sources to be integrated. A framework and an architecture for integration needs to be agreed upon by the modeling and simulation community involved in developing applications in the area of emergency response. Infrastructure for development and deployment of the integrated solutions needs to be established.

This paper proposes an architecture for modeling and simulation for emergency response. Relevant reported frameworks and architectures for modeling and simulation are reviewed. The proposed overall approach for integrated modeling and simulation tools for emergency response is described. The proposed architecture itself is presented and its major components discussed. The paper concludes with discussion of further research for achieving the vision of the integrated emergency response framework.

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[1] Modeling and simulation in this paper refer to the use of computer-based models and simulations. It is recognized that physical simulation such as mock exercises play an important role in emergency preparedness, but such activities are not the focus of the discussion in this paper.

2. Related Research

A number of simulation tools have to be integrated to address multiple aspects of a single disaster event as described in section 1. The need for such integration in the emergency response context has been recognized as evident by the urban security project at Los Alamos National Laboratory that integrates plume simulation and traffic simulation to compute exposures to the cars traveling through the plume [2]. The Simulation Object Framework for Infrastructure Analysis (SOFIA) project is developing a high-quality, flexible, and extensible actor-based software framework for the modeling, simulation, and analysis of interdependent infrastructures [3].

A number of research efforts have been targeted at integration of simulation models outside the context of emergency response. In particular, Department of Defense (DoD) has spent a large effort in developing war gaming capabilities that integrate a number of simulation models and humans-in-the-loop. The DoD-sponsored research in this area started in the late 1980s with the development of SIMNET for real-time battlefield simulations of tanks in a virtual training environment. Most recently one thread of the work is evolving into the Standard Simulation Architecture, designed as a combination of the High Level Architecture (HLA) and the Synchronous Parallel Environment for Emulation and Discrete-Event Simulation (SPEEDES) developed in mid to late 1990s [4]. Another group of researchers is proposing bringing HLA together with the Model Driven Architecture (MDA), a concept developed by the Object Management Group (OMG). The model driven architecture uses a language, vendor and platform-independent metamodel as the core representation, with facilities defined to translate the representation for implementation. The combination of HLA and MDA offers benefits to both the developments and is recommended [5]. Any proposed architecture based on HLA should weigh the alternate approaches and their support in the industry and accordingly plan the implementation. Overall, the focus of the DoD developments has been on war gaming involving a number of human decision-makers and actors. The associated research should prove to be very useful for integrated simulations for emergency response, particularly for training applications.

The integration of simulation models requires that the data is translated from one model to another model in the right context. Typically, human analysts have to spend some time ensuring that the translation of data is consistent based on the semantic understanding. Translation using syntactic grammar can be more efficient but not always possible. An agent based architecture has been developed that uses object-oriented modeling techniques to encapsulate and organize the syntactic information while the semantic information of the objects is examined for data integration purposes [6]. The proposed architecture can provide value for interoperability of emergency response simulations.

The Dynamic Information Architecture System (DIAS) has been developed at Argonne National Laboratory as an object oriented simulation system that provides an integrating framework for new and legacy applications and can adapt to different contexts [7]. The system has been used both for U.S. Department of Defense applications and civilian applications. It is frame-based and uses the concept of entity objects as analogs to the real world entities being studied. It uses an extensive library of entity objects that can be used in modeling environmental, transportation, and command and control applications. The requirements for building the library of objects may require a large effort for implementation of the system in an emergency response context.

HLA has been used for integrating distributed simulation models in the manufacturing domain. A neutral reference architecture was developed for integrating distributed manufacturing simulation systems with each other, with other manufacturing software applications, and with manufacturing data repositories [8]. The need for standardization of interfaces was highlighted. Experience from this past research will be used in the development proposed here.

This brief review of related research indicates the feasibility of developing an architecture for modeling and simulation of emergency response and at the same time indicates a need for standardization of interfaces and semantic and syntactic representations.

3. Proposed Overall Solution

The types of simulations envisioned for emergency response will be multi-facetted, real-time, and synchronized, i.e., no single simulation model or software system will be capable of representing all aspects of the emergency response problem. Furthermore, these simulations will need to be rapidly configured to respond to changing threats. The key technical elements of the proposed solution to be developed successively are:

- Emergency Response Framework – A framework is needed to bring together the individual efforts in the emergency response domain. The framework will allow mapping of individual efforts in a common structure and identify the gaps that need to be addressed. It will also identify the need for integration among different tools and will serve as a basis for defining the interoperability standards for the purpose. Jain and McLean [9] describe such a framework.
- Architecture for distributed simulation – Standards are needed to provide an infrastructure to enable the interconnection of different types of simulation systems into distributed environments. This architecture needs to provide mechanisms to coordinate the initiation, execution, and shutdown of distributed simulations, enable data transfers from dispersed data sources, and provide time synchronization. A basic scheme for such an architecture is described in the next section.
- Simulation transactions –These transactions are needed to transfer information and simulated objects among distributed simulations while they are executing. Standard formats for transaction data would allow independently developed simulations to be integrated more quickly and effectively. NIST is currently using the Extensible Markup Language (XML) as an integration mechanism on several projects and it is believed that this could be used to integrate emergency response data.
- Simulation templates and model formats – Simulation model libraries can significantly reduce simulation development costs for users. Neutral model formats will enable the development of simulation reference model libraries, generic templates, and application-specific models, independent of the user's simulation environment. Neutral data formats will be defined for library models and templates to enable sharing among different vendor systems. XML will be considered as a possible encoding system for storing these models.
- Reference data sets – Test data sets will be needed to allow developers to test their software and perform integration tests. Standard formats for reference data and sharable reference libraries for these types of data would help to accelerate the modeling process and lead to the development of more realistic models. The test data sets should include information to help in model validation, which is difficult to achieve otherwise. For this role, the test data sets will have to be based on real occurrences or developed carefully with expert input.

The implementation of an integrated framework and interoperability standards for modeling and simulation for emergency response will significantly improve the emergency preparedness of the nation. Independently developed tools can then be quickly integrated together for end-to-end modeling capability for an emergency scenario. The integrated capability can then be used for applications ranging from planning and training to actual response, should the imagined scenario occur in real life.

4. Proposed Architecture

The intent of the architecture is to provide a common backplane that allows plug and play with tools from various sources for modeling, simulation, visualization, data access and management for emergency response. The architecture for the emergency response simulation is shown in figure 1. It is divided into the following component elements:

- Simulators
- Scenario Emulator
- Data access and management
- Human interface modules
- Tools for identification, detection and learning

Each of the major components of the architecture is briefly described below.

4.1. Simulators

A number of simulator modules will be integrated to allow analysis of a disaster event and its aftermath. A number of types of simulators are envisaged at this time as discussed below. It is expected that this list will grow in the future. Hence, the architecture presented in the figure uses generic blocks to represent simulators that will be brought together.

- *Disaster Event Simulator* – This module simulates the disaster event itself. It models the original occurrence of the event that triggers the disaster and its primary impact. For modeling of a conventional bomb explosion in a commercial building, this module will model the occurrence of the explosion and determine the forces generated and fires started due to the explosion. Depending on the tool, it may continue modeling the spread of fire in the building in this module or that may be simulated using the impact simulators discussed next.

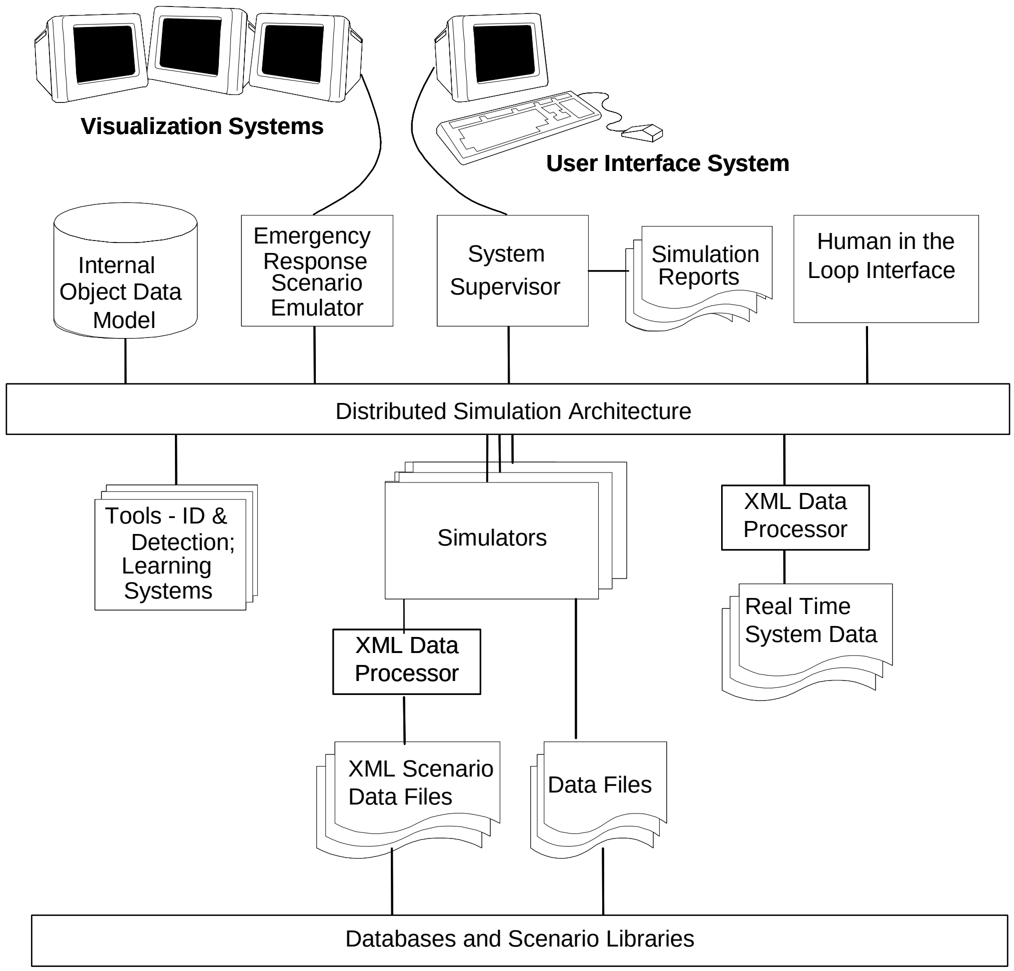

Figure 1. Schematic of architecture for integrated modeling and simulation of emergency response.

- *Impact Simulators* – These modules simulate the secondary impact of the disaster event. For the building explosion example, these modules may include those for modeling the impact on the building structure due to explosion and fire, for modeling impact on the utility infrastructure in and around the building, for modeling casualties among occupants of the building, for modeling behavior of occupants in the building, and for modeling traffic jams around the building. Typically, these will be multiple simulators modeling complementary aspects of the scenario. The impact simulators will include the influence of environmental factors for modeling the impact. For example, prevalent wind speeds will impact the spread of fire in the building and potential spread of fire to other buildings.
- *Response Agent Simulators* – These modules simulate the actions of the response agents such as police, fire, utility crews, city, state and federal government agencies, etc. as called for by the scenario. In the building explosion scenario, these modules may include those for modeling the response by the police, by fire crews, by emergency medical personnel, by utility crews, by the city office and for modeling the treatment of injured at the hospital.
- *Information Flow Simulator* – This module simulates the flow of information on the disaster event. It will model the occurrence of 911 calls, relay of the event information by media, information read by sensors, information forwarded by agencies such as building security, police and other civil defense agencies. For the building explosion scenario, the simulator will model the placing and receipt of 911 calls, the communication to police, fire and emergency medical personnel, the flow of information in administrative agencies until they trigger actions by response agents.

4.2. Emergency Response Scenario Emulator

This module brings the results of all the different simulators together by emulating the status of all the objects in the scenario. The emulator also serves as the communication medium between the simulators and as the input for visualization systems. For an event involving a building explosion, one of the impact simulators will model the panic evacuation of occupants of the building and that will be emulated in the emulator. This information will be used by the traffic simulator to model a traffic jam and the scenario will be updated in the emulator. The traffic jam information will be used by the response agent simulators for planning the arrival routes of emergency response crews and for using some of the police crews for crowd control. The integrated scenario information will be used for the animated display of the scenario using the visualization systems.

4.3. Data Access and Management

- *Databases and Libraries* – A number of databases and libraries will be used to drive the integrated emergency response simulation. These will include terrain and city street maps, land and building use databases, commuting pattern databases, utility network databases, weather forecasts, etc. The libraries will include disaster event scenarios and the related files required by the multiple simulators described above.
- *Real time Systems Data* – The real time systems data may be generated by a number of automated sensors and from the inputs by various first responders at the scene. Such data will be imported for updating the simulators using the XML data processor described below. The real time data can be used for training exercises and response to actual events.
- *Data Files* - These interface files provide a mechanism for providing data that is not suited for XML format, for example, GIS data and other graphics data.
- *XML Scenario Data Files* - These interface files are key to understanding the entire concept of the integrated emergency response simulator. The files provide a mechanism for configuring the individual simulator modules and sharing data between them. XML is used to encode the data in the file. These files contain not only executable or computable data to be processed by the simulation, but also descriptive text that is intended only for human interpretation. They also contain a network of cross-reference links between the various types of data required for interaction between various simulation modules. They support references to other external computer files and/or paper documents that provide more appropriate mechanisms or standards for encoding or representing data, e.g., response agent's behavior. Subsets of individual data types, i.e., substructures, may be created, stored, and/or exchanged using the files.
- *XML Data Processor* – This module is a library of routines that handle the import and export of data in the prescribed XML format of the neutral scenario data files. The primary function of the module is to read the neutral scenario data file in XML and translate the data into and out of the internal object structure of the respective simulator modules. It is also responsible for creating XML output files.
- *Internal Object Data Model* – This data model is used to maintain the status of all the objects in the scenario. This model supports the scenario emulator and the communication amongst various simulator modules.

4.4. Human Interface Modules

- *Simulation Supervisor* – This module is responsible for synchronization of all the simulator modules. It configures the emergency response scenario through synchronized initialization of all the simulator modules from data contained within the *Neutral Scenario Data Files* and coordinating the execution of the various modules during a simulation run; and outputs simulation reports.
- *User Interface System* – This module provides capabilities for creating and modifying scenario data files, managing the display screens for configuring the system and observing simulation runs, debugging, and displaying results. It also is responsible for the generation of custom reports of simulation results. Many of the capabilities may be duplicated by the allowed interactions through the visualization systems discussed below. For example, a user can use the textual interface to send an additional medical unit to an identified area, or use the visual interface to point and drag a unit to the area on the graphical display. Such an action will then update appropriate multiple simulations including the response agent simulators and information flow simulators.
- *Visualization Systems* – This module provides the graphic representation of the scenario and the events. This may range from a single monitor viewed by naked eyes to advanced computer aided visualization environments (CAVEs) viewed using data helmets and interaction devices such as data gloves. The module reads the information from the scenario emulators and displays them using the configured hardware. The visualization systems should allow the capability of integrating layers of data and simulation outputs generated by different systems. The layers may be overlaid on geographic representations with user controllable degrees of transparency to aid in the understanding and analysis of the data and simulation results.

- *Human-in-the-loop Interface System* – This module provides capabilities for human interaction with the simulation and will be primarily used for training applications. The interfaces may range from simple computer terminals allowing keyboard input to represent decisions by emergency response management officials to virtual reality interfaces used by individual emergency response workers to model individual actions.

4.5. Tools for identification, detection and learning

The emergency response simulator will allow access by various kinds of tools. It can serve as a test bed for identification and detection procedures through representations of real and dummy pre-disaster event histories. It can also be used for training learning systems particularly when integrated with human-in-the-loop simulations.

The proposed architecture above uses a number of components and a number of interfaces. Standards are needed for the architecture, data structures and interfaces, and formats for text and graphics files. A few standards have been developed to address some of the basic issues. The distributed simulation community led by Defense Modeling and Simulation Office (DMSO) has standardized the high level architecture (HLA). Some standards have also been established for virtual reality modeling that may be relevant for advanced visualization of simulation results. Standards relevant to this area have been identified [1].

5. Conclusion

This paper presented an architecture that provides for integration of modeling and simulation tools to allow a systems approach to study and analysis of emergency response. The architecture is intended to provide a generic platform that allows plugging in legacy and new applications on a common backplane provided by a distributed simulation architecture. The adequacy and validity of the architecture may be tested using a prototype. It is recognized that the area of modeling and simulation of emergency response is attracting a lot of attention and the expected rapid development may lead to enhancements in the architecture in the near future. It is also recognized that prior to implementation of such an architecture, the modeling and simulation community will have to come together to establish standards for terminology and representation to allow development of XML interfaces and processors. Efforts are being planned at NIST for such purposes.

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References

1. Jain, S. and C.R. McLean, 2003, "Modeling and Simulation of Emergency Response: Workshop Report, Relevant Standards and Tools," National Institute of Standards and Technology Internal Report, NISTIR-7071.
2. LANL, 2003a, "Urban Security Project," http://www.lanl.gov/orgs/d/d4/aquality/urban.html, last accessed on November 21, 2003.
3. LANL, 2003b, "Interdependent Infrastructure Modeling, Simulation, and Analysis Project (SOFIA)," http://www.lanl.gov/orgs/d/d4/infra/sofia.html, last accessed on November 21, 2003.
4. Steinman, J.S. and J.W. Wong, 2003, "The SPEEDES Persistence Framework and the Standard Simulation Architecture," Proceedings of the Seventeenth Workshop on Parallel and Distributed Simulation (PADS'03), June 10-13, San Diego, California, 11-20.
5. Tolk, A., 2002, "Avoiding Another Green Elephant – a Proposal for the Next Generation HLA based on the Model Driven Architecture," 2002 Fall Simulation Interoperability Workshop, September 8-13, Orlando, FL.
6. McDonald, J.T. and M.L. Talbert, "Agent-based Architecture for Modeling and Simulation Integration," Proceedings of the National Aerospace & Electronics Conference (NAECON 2000), Oct. 10-12, Dayton, Ohio.
7. Campbell, A.P. and J.R. Hummel, 1998, "The Dynamic Information Architecture System: An Advanced Simulation Framework For Military And Civilian Applications", http://www.dis.anl.gov/DIAS/papers/SCS/SCS.html, last accessed on January 20, 2004.
8. McLean, C.R., S. Leong and F. Riddick, 2000, "Integration of Manufacturing Simulations using High Level Architecture (HLA)," Proceedings of the 2000 Advanced Simulation Technologies Conference, April 16-20, Washington DC.
9. Jain, S. and C.R. McLean, 2003, "A Framework for Modeling and Simulation of Emergency Response," Proceedings of the 2003 Winter Simulation Conference, Dec. 7-10, New Orleans, Louisiana, 1068-1076.