Moving Toward a Distributed Continuous Experimentation Environment

Andy Ceranowicz
Alion Science and Technology
Alexandria, VA
aceranowicz@alionscience.com

Rae W. Dehncke
Institute for Defense Analyses
Alexandria, VA
rdehncke@ida.org

Tony Cerri
USJFCOM J9
Suffolk, VA
Anthony.Cerri @je.jfcom.mil

ABSTRACT

The U. S. Joint Forces Command (JFCOM) has the requirement to conduct joint experimentation for the Department of Defense (DoD). The JFCOM staff agency responsible to lead joint experiments is the J9. Joint experimentation is used to develop transformational warfighting concepts, technology, and processes through a series of wargaming and simulation activities, typically culminating with a large human-in-the-loop event. Thus far these events have been independent, each with its own setup, integration, execution, and teardown. To accelerate experimentation, include the Services and Allies, and reduce per event costs, J9 is transforming the way it executes experiments by creating the Distributed Continuous Experimentation Environment (DCEE). Initially, the DCEE will simply reduce overhead by creating a standing simulation infrastructure, including the Joint Experimental Federation (JEF) built for Millennium Challenge 2002 (MC02) and Service facilities. The DCEE will be a continuously evolving capability incorporating the latest simulation developments from the Services and other sources. DCEE expansion will be accomplished by linking additional simulations into the JEF, embedding new models in the existing federates, and linking with other federations. Preliminary DCEE development efforts have included: integrating scaleable computing power via the inclusion of DoD High Performance Computing assets; the development of a worldwide terrain database with high resolution inserts, including urban environments; developing a real time data collection and analysis capability; and developing simulation monitoring and control functions. A network of J9 and Service sites is being established to provide USJFCOM with a highly flexible, evolving, and distributed experimentation capability based on interlinked federations of simulations.

ABOUT THE AUTHORS

Andy Ceranowicz is the technical lead for federation and Joint Semi-Automated Forces (JSAF) development at J9. He led the development of the MC02 federation, JSAF and its predecessors, ModSAF and SIMNET SAF. Andy is a Senior Science Advisor at Alion and holds a Ph.D. in Electrical Engineering from The Ohio State University.

Rae W Dehncke, Colonel, United States Army (Retired), has been a member of the professional staff at the Institute for Defense Analyses (IDA) in Alexandria, Virginia since January 1995. He is currently leading the JSAF Federation Simulation Team and supporting Joint Experimentation for the USJFCOM J9. He earned a BA from Michigan State University, MA from the University of Arizona and was a Fellow at the Kennedy School of Government, Harvard University.

Tony Cerri is Director of the Experiment Engineering Division of the Joint Futures Lab, J9. He is responsible for ensuring that the M&S environment supports future joint experimentation concepts. He was the M&S Federation Manager for the MC02 experiment. He is a retired U.S. Army, Infantry, Lieutenant Colonel. He was awarded a Bachelor of Science from West Point in 1975, a Master of Science in Administration from Central Michigan University in 1990 and a Master of Science in Management from Florida Institute of Technology in 1995.

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DCEE

The Distributed Continuous Experimentation Environment (DCEE) is being developed by the US Joint Forces Command J9 Directorate to support joint experimentation. The Department of Defense (DoD) has embarked on a process of "continual transformation, so that our armed forces are always several steps ahead of any potential adversaries." (DoD 2003) "The Commander, Joint Forces Command (JFCOM), and other Combatant Commanders are responsible for developing joint warfighting requirements, conducting joint concept development and experimentation, and developing specific joint concepts assigned by CJCS [Chairman of the Joint Chiefs of Staff]. Commander JFCOM is responsible for coordinating concept development and experimentation efforts of the Combatant Commanders." (DoD 2003).

Experimentation Environment

Transformation is not simply the addition of new technology; rather it is the synergistic effect of new concepts and processes used in conjunction with new technology. The challenge is to develop these concepts and processes in the most effective and efficient manner. Simulation can be used to test, observe, and gain understanding of new concepts, processes, and technologies under current and future scenarios. The DCEE is envisioned as a place and process for rapidly and efficiently creating simulation environments for concept experimentation. The Experiment Engineering Department at J9 is responsible for creating and providing these environments and developing the DCEE.

Continuous

Until recently, J9 only executed a few simulation experiments a year. Each experiment was a standalone event complete with setup, integration, test, execution, and teardown stages. As the pace of transformation accelerates, more experiments with narrower focus are required; however, the work required to setup each experiment has remained the same. To get ahead of the accelerating requirement for more experiments, the DCEE has been established as a dedicated facility where networks, simulations, and hardware remain continuously setup and ready to support experimentation. Simulation environments will be available at practically the flip of a switch. Thus, time previously spent on setup, integration, and teardown will now be available for experimentation.

Distributed

Since J9 is developing joint concepts, it follows that they be developed and integrated in collaboration with the Services, government agencies, and coalition partners. The DCEE has attracted a wide community of interest, including the Services, Defense Agencies, Joint Activities, allied nations, and even industry as experimentation partners. They are fertile sources of models and simulations for experimentation, as well as fonts of expertise on many concepts and conduits for concept dissemination. However, DCEE partners are located around the globe and continuous experimentation based on continuous travel is unsustainable. Thus, the DCEE is envisioned as a fundamentally distributed facility with long-term network connections between J9 sites and those of its experimentation partners. This connectivity enables remote simulations from partner sites to join with DCEE simulations to create extended simulation environments.

Evolutionary

While 'evolutionary' is not part of its name, the DCEE must provide a continuously evolving and expanding capability. Transformation is a continuous process not a one-time event. Success will be measured by how fast DoD can adapt to new challenges and opportunities. We cannot support such an endeavor with a static simulation environment; the capabilities of DCEE must be continuously evolving. The DCEE must support both real experimentation and federation development simultaneously, thus providing both useful dividends and growth in capability. Fortunately, experimentation and simulation development are synergistic processes, with each process driving the other. Significantly better results can be obtained by combining the two processes than by trying to segregate them.

Human In The Loop Simulation

J9 uses a variety of different resolution environments for concept development ranging from computer assisted collaboration sessions, to wargames, to closed form constructive simulations, to Human-In-The-Loop simulations (HITL), to live exercises. It is very important that the right tools be utilized at the most effective time in the process. Although the DCEE will host all these simulations and tools, this paper focuses primarily on developments in the HITL component. Building on the success of its Millennium Challenge 2002 Experiment, JFCOM is using the MC02 federation (Ceranowicz 2003) as the starting point for the HITL component of the DCEE.

M&S FOR CONCEPT DEVELOPMENT

There is wide agreement that, in principle, modeling and simulation (M&S) should be a fundamental tool for concept development; yet in practice, most simulations are too slow, cumbersome, and expensive to impact much of the concept development process. In comparison to field exercises they are a bargain, but seminars and collaborative wargames move at light speed compared to M&S based events. A fundamental challenge for the DCEE is to make M&S efficient enough to extend its utilization to all phases of concept evolution, i.e., make M&S a tool that no concept developer can work without. M&S could make substantial contributions to the stimulation, visualization, exercise, and dissemination of concepts.

Stimulation

The seeds for new concepts come from past experience. Based on their experiences, forward looking theorists can imagine new systems and processes that can revolutionize the way we currently fight and do business. The challenge for M&S is to stimulate the imagination of new concepts by providing concept developers with virtual experiences through interaction with simulations of potential future scenarios. This is probably the hardest area for simulation to support – it requires a world model complete enough to produce accurate emergent phenomena and interfaces friendly enough to make concept developers want to use simulation to explore the future.

Visualization

Collaboration is vital to concept development in today's 'joint' world. Concepts are abstractions, which can easily have multiple interpretations. The efficiency of collaboration increases if people have a shared vision of the concept. M&S can express concepts as prototypes that can be shared to improve collaboration (Schrage 2000). One of the tools used in the DCEE to help concept developers is "G2", a process-modeling tool that can be used by an operator to capture concepts as they are expressed and then show them to the conference participants in a visual format. This capability to capture concepts in prototypes must become sufficiently user friendly to be used routinely by the concept developers themselves, just as they now use word processors instead of dictating to a typist. The resulting prototypes must be viewable, sharable, and executable, i.e., capable of being directly plugged into simulation environments and exercised.

Exercise

New concepts need to be evaluated across a wide variety of scenarios to ensure robustness and efficacy. Alternative concepts must be competed to determine which is the better approach. While seminars and wargames often provide the initial forum for exercising concepts, it is difficult for people to consistently impose accurate real world constraints during these types of experiments. Nor can they simultaneously apply the effects of the large numbers of constraints found in the real world and track their results manually. Computer-based M&S can provide these constraints and track results in an unbiased and mechanical fashion. The DCEE is currently developing a process for concept experimentation that allows for the early introduction of simulations in a Model-Experiment-Model paradigm.

Dissemination

Once a concept has been developed sufficiently, we need to disseminate it and spread awareness and understanding of the concept throughout DoD. Participation in a distributed, joint HITL experiment provides a powerful immersion into a concept for a great many personnel across DoD. Participants, ranging from junior officers to senior mentors, leave the experiment with a much deeper understanding of the concept than they could get from reading a document or discussing it at a briefing. Often great insights are provided by the players themselves; they take ownership and become the best spokesmen for the concept.

Return On Investment

The bottom line is that simulations must provide a significant value for the time and effort concept developers invest in using them. Otherwise, concept developers will focus their resources on more profitable approaches. To be effective, simulations must represent all of the domains addressed by the concepts being developed and support the expression of new concepts.

Simulations must be easy to use, understand, and validate. The easier and cheaper a simulation is to use, the more likely it will be to help effect transformation.

SCOPE

The first problem that DCEE must overcome is the rather narrow scope of available military simulations. Clearly simulations can't illuminate concepts outside of the domains they represent and today's simulations fall woefully short of representing the full range of potential conflicts. Military simulations have typically focused on the geometry and accounting of war. Range, line of sight, movement routes, force concentrations, supply consumption, and casualties are the types of things they understand. Transformation has changed the focus from the destruction of enemy forces to defeating their will to resist. Non-kinetic factors are of great importance and must be adequately modeled. This is a violent expansion of the domain of military simulation. Experimenters are no longer satisfied with knowing how many enemy vehicles have been destroyed and how many casualties were inflicted; they now want to know whether the enemy will continue to fight, surrender, or simply fade away. There are no accepted models that can predict when this will happen for even a single individual, much less for a unit. This change in simulation requirements is not a one-time event. Transformation dictates continuous and hopefully accelerating improvement in our ability to simulate new concepts to a degree of fidelity that is acceptable to the war fighter and concept developer.

How can the J9 continuously expand its simulations to include civil, social, psychological, economic, political, and unforeseen future factors? Large-scale, start-from-scratch projects to develop new simulations are too slow to keep up with rapidly changing concepts and the evolving world. Before they produce an operational system, requirements advance and leave the project behind. The DCEE solution is to concentrate on evolutionary development of its simulations, using integrative architectures to incorporate new models and simulations to meet new requirements while simultaneously using them for experimentation.

Expanding Scope by Federating

For its integrative architecture, J9 is relying on the Defense Modeling and Simulation's (DMSO) High Level Architecture (HLA) (Dahmann 1997, Kuhl 1999). This allows existing and future simulations to be linked together to expand the domain of representation. The terms 'model' and 'simulation' are often interchanged. In this paper, the term 'model' is used to denote a set of relationships that capture some aspects of an object or process. A set of equations, a decision table, a rule set, a function, or a C++ object class can all fit this definition of model. Models are integrated into simulations, which can be executed via computers to generate an allowable time evolution of the state of the represented system. The models in the simulation determine which evolutions are allowable. The simulation's integrative architecture controls the execution of its component models and enables interactions between them to produce coherent results. A federation is a collection of simulations that – although they can execute independently – execute together, effectively operating as a single simulation. As is the case with simulations, federations use integrative architectures to combine simulations.

Historically, it was felt that the integrative architecture was the most important part of the simulation – if the architecture was right, then all the other pieces would fall together. This assumption is incorrect; it is generally easier to build architectures to link models and simulations together than to develop models which can stand up to public review and validation. Architectures cannot produce good results from bad models. If the available models are incompatible, no architecture can resolve the problem; the models themselves need to be changed to make them compatible. If the models are compatible, it is easy to develop an architecture to link them together; many different approaches will work. The advantage of the HLA is that since it was designed to link arbitrary simulations together, it leaves many architectural decisions to be made after the individual simulations are selected. The objects involved, the messages to be sent, and the transfer modes can all be designed after the models are known. Thus it is easier to modify the architecture as needed to add new models. So the DCEE strategy is to solicit as many models as possible from other organizations and figure out how to integrate them into the Joint Experimental Federation (JEF). Using models from acknowledged subject matter experts increases confidence in the federation. JFCOM has asked its DCEE partners to nominate and integrate their best simulation into the Joint Experimentation Federation, further contributing to the acceptability of the results and the efficiency of joint federation development.

Model integration can be divided into a federate component, the changes required to introduce the new model as a federate, and an embedded component, the changes required to make the remainder of the federation use the new model. In some cases, it is possible to accomplish the integration of a new model entirely with one component. However, most often changes to existing models will be required to make them interact with a new model. These changes are minimized for a new entity model, such as a new aircraft, where all the objects and interactions required to express entity state and behavior are already available in the federation. The effort is primarily in the federate component. The new entity model has to be inserted into a single federate, either an existing federate or as part of a simulation that has to be federated. While this is one of the cleanest examples of the insertion of model via federating, there is typically still some embedding required. The other federates will need to have some information about the new entity such as: what are its detection properties, what weapons are best to use against it, what sort of emissions does it create, and how much damage will its weapons inflict. Federates that utilize sophisticated reasoning to decide how to interact with the new entity will require more information to be embedded then those that don't. An example from the other end of the integration spectrum is a camouflage model, where no new federate is required. Instead, each simulation in the federation needs to change its existing models to set, maintain, and publish the camouflage states of its entities, and take account of camouflage state in its detection models. Thus the new model is entirely embedded into the existing federates. The integration of most models lies somewhere in between, adding a new federate and embedding the models required to interact with that federate. There is usually considerable technical flexibility in the implementation of an integration and economic and schedule factors often end up driving the design.

Connecting Federations

Although the HLA provides a flexible architecture that can be adapted to new simulations, even the HLA is not as flexible as joint experimentation requires. To achieve their ambitious interoperability goals, the HLA designers generated requirements that inadvertently make it difficult to build scalable and fault tolerant federations. But, one size cannot fit all – no matter how stretchy the fabric, it will tear eventually. As a federation grows, the constituent simulations and models impose more constraints on the integration of new simulations and increase the cost of adding them. To bypass this limitation, the DCEE will use federation gateways for linking federations together instead of continuing to grow a single federation. This may lead to an "internet" of federations, hooked together by gateways in a manner analogous to the way IP routers connect different LANS together. Simulations in each federation are coupled together more tightly than simulations in different federations. Some of the potential benefits of inter-federations include: reduced integration effort, different RTIs and RTI configurations can be used together, each federation can be used standalone for different purposes, and the complexity of each federation can be reduced by partitioning problems into different federations. On the other hand, gateways become bottlenecks and single points of failure and looser coupling can produce lower interoperability.

The DCEE currently possesses one gateway and is in the process of developing a federation gateway. The existing gateway is the HLA/DIS (Distributed Interactive Simulation) Gateway. Although not strictly an RTI gateway, since DIS (IEEE 1998) does not use an RTI, it performs an equivalent function, which is to exchange simulation traffic between two different integrative architectures: the DIS architecture and JEF architecture based on RTI-1.3NG (Bashinsky 1999, Hyett 2003). Its success in many different events has shown that it is unnecessary to port DIS simulations to HLA solely for interoperability, since they can be integrated into RTI architectures quite well using gateways. This gateway can support multiple RTIs conforming to the RTI-1.3 Specification and multiple FOMs, using a technology called the Agile FOM Interface developed by DMSO and the Lockheed Martin Advanced Simulation Center.

A second gateway is now being developed to connect federations that are semantically similar but use different RTIs, FOMs, and Data Distribution Management (DDM) schemes. The initial motivation for building this gateway was to link JSAF federations running on Scalable Parallel Processors (SPP), using RTI-s (Calvin 1997, Helfinstine 2001) and the JSAF Standard FOM, into the existing DCEE federation, which uses RTI-1.3NG and the JFOM (Joint FOM). However, once the possibility of multiple FOMs is accepted, other benefits become apparent. It is possible to optimize each FOM and DDM scheme for the set of simulations using it. This insight comes from MC02, where many of the server based federates were actually non-RTI "federations" of multiple processors with gateways (or bridges) to translate between their internal representations and the external RTI-1.3NG/MC02 FOM representations. All the translations from the internal representations to the external FOM were isolated in the gateways taking that burden off the primary simulation processor. Gateways also provide FOM isolation; you can make changes to one FOM or RTI without requiring changes to the other federations. Even the simple process of propagating a new FOM or RID (RTI Initialization Data) file takes quite a while on large federation. Connecting to a different federation only requires changing the gateway in use. Finally it can help to simplify the main FOM by eliminating many of the private FOM elements required. As usual this flexibility comes at a price; some scalability may be lost, as running multiple FOMs causes information to be duplicated for each FOM, thus increasing bandwidth requirements. However, for Local Area Network (LAN) traffic this is not usually an issue and for Wide Area Networks (WAN), the problem can be limited by restricting the number of federations with traffic on each WAN connection. Furthermore, as will be discussed below, the use of multiple federations can also aid scalability.

Deep Interoperability

The major price of using federations and especially inter-federations is deep interoperability. Models designed for a single simulation architecture usually have a single set of semantics, a fairly consistent level of resolution, and each phenomenon is represented by a single model. (Note, in composable simulations, multiple models of the same phenomenon may be encouraged; as usual exceptions are the rule). This provides deep interoperability where each model reacts consistently to events in the simulation. With a federation of simulations, a single model for one phenomenon is very unlikely. Thus, fair fight issues arise where different models react differently to the same situation. Since inter-federations will be more loosely coupled, even more interoperability issues will arise requiring careful crafting of what is represented where. One of the goals of the DCEE is to gradually move toward deeper interoperability between the simulations involved. This can be accomplished by three mechanisms. First, a model from one simulation can be selected and made into a server that provides the same model function for all the simulations. Second, a common model can be selected and embedded in all the simulations to make them all use the same model. Finally, the same data and algorithms can be used to implement compatible models in each simulation. As simulations are used together over time to address the requirements of different experiments, their modifications will naturally tend to bring about deeper interoperability.

Beyond Existing Models and Simulations

Even if a federation contained every model in existence, it would still be far from a complete simulation of the world. The underlying data and corresponding models simply do not exist. Even for simple phenomena that we understand well, it is difficult to obtain all the data necessary. For example, getting accurate and consistent high-resolution terrain data for many areas of the world, even after the Shuttle mapping missions, is still difficult. Weapons interactions are far too numerous to ever be fully characterized in field experiments. There are many other phenomena, such as the trait of honesty, where the available data is insufficient to formulate models. The more we expand our simulation domain, the more often it will be necessary to rely on subject matter experts to guess at how to interpolate between scarce and possibly conflicting data points to produce the data required for simulation. While established with good intentions, validation and verification requirements encourage developers to ignore phenomenon with significant effect because validated data is not available or accessible. Even in such cases, it may be necessary to work with best guesses to provide the best insights possible for concept developers. We also have to resist a perception that often drives us to always seek more data; it is a myth that data rich models are always more accurate and produce more valid answers than lower resolution models. In many cases, accuracy and resolution can be negatively correlated because higher resolution models require more data, which has to be derived from questionable sources, producing less accurate results than the lower resolution models. The experimenter must strike a balance depending on the goals of the experiment. The DCEE is attempting to increase its capability to support the full range of scenarios required for concept development by working with its partners to develop new models of phenomena that are not supported by current models.

SCALABILITY

Expanding domain coverage alone is not sufficient to support joint experimentation. A simulation that can simulate a person with 100% accuracy with resolution to the cellular level, but can only simulate a single person would not be very useful for DCEE. Similarly, a simulation that can only represent a single building will have limited utility. Not only does DCEE need to be able to represent many different things, it must represent large populations spread out over large geographic areas.

The DCEE seeks to simulate both the larger areas and higher resolution areas in order to support joint operational level experiments. Large areas are necessary to reflect deployments from CONUS to multiple conflict sites and the operational level of Joint Task Force concerns. Furthermore, secondary and tertiary effects of military action in one part of the world are rarely isolated; they reflect interconnected systems operating around the globe. Higher resolution areas are required to represent precision attacks carried out by small groups of Special Forces, precision weapons, and additional means. Here tactical actions have operational or even strategic importance. Furthermore, joint transformation is now extending down into the tactical areas to deal with the “friction points” between Services cooperating in tactical engagements. There is a special interest in urban areas that the DCEE must address.

Large areas with urban centers are filled with large populations of people, civilian vehicles, and structures. Due to limitations in scalability, current simulations are often restricted to simulating tens of thousands of entities. This is insufficient to represent military support forces, let alone the civilian population and traffic in a major city area.

With the focus on asymmetric warfare, we increasingly have to represent the civilian population since it serves as the primary cover for opponents.

To support these requirements, DCEE needs simulations that can scale to represent large areas and populations. To do that, J9 is investigating the development of more efficient models as well as the ability to focus more computational resources on the problem areas. As models of differing scalability are linked together, those with lower capacities will either need to be upgraded or limited to deal with only a subset of the total environment – filtering out the remainder using gateways or interest management.

Terrain

To expand the play box, DCEE is investigating utilizing more efficient terrain representations and multiple resolution areas. A low-resolution terrain that encompasses the entire world in longitude and extending from 75 degrees North to 60 degrees South latitude has been built using the Global Terrain Reference System format. This format divides the world into roughly 100x100 km cells. JSAF was modified to allow it to dynamically map these cells into memory to allow JSAF entities to move throughout the entire database. The database allows the embedding of higher resolution terrain areas within the context of the low-resolution terrain box. Thus far, areas with Digital Terrain Elevation Data (DTED) resolutions of 0, 1, and 2 have been successfully embedded. Automated software has been developed to smooth the transition between areas of different resolutions, thus making it easier to embed new areas.

To model urban areas, CTDB (Compact Terrain DataBase) Format 7 is being modified to allow the representation of very large numbers of very dense buildings with penetrable interiors resulting in a Format 8 CTDB (Miller 2003). Test databases have included cities with up to 1,800,000 buildings. This has required considerable optimization of the CTDB building representations and the automated generation of building interiors. Multiple Elevation Structures (MES) are still used to represent interiors, but have been optimized for scalability. Representations for large numbers of individual trees are being added in the form of maskable rasters. A single raster is used to represent trees in multiple areas but each location can be customized to eliminate trees by masking off subsets of the raster. Currently, the primary use of CTDB terrain is to act as an obstacle to visibility and movement. Future terrain representations need to provide enough richness to drive the behavior of civilian population models as well as military operations. For this purpose, the structures in CTDB 8 databases will be annotated with tags specifying their purpose and other attributes that can be defined as part of scenario development. This will allow buildings to be identified as command posts or communication centers as well as supermarkets, schools, and hospitals.

Terrain representation has been a difficult area in which to achieve deep interoperability. Each simulation has a different representation of terrain with different schemes for locating elevation posts and different ways of interpolating between them. Some simulations use projections to eliminate Earth curvature while others represent it explicitly. All these differences lead to correlation errors. Unfortunately, terrain elevation is the simplest part of the problem. Even more disagreement exists in feature representations. Some simulations use abstract feature representations like low-density urban area, while others represent individual buildings. Some simulations represent buildings as published objects while others like JSAF build them into the terrain. As experience with more efficient and complete terrain representations grows, J9 hopes to share these terrain representations with its experimentation partners and develop common representations.

Scalable Parallel Processors (SPP)

To support the simulation of large populations of people and vehicles, J9 has been investigating the integration of scalable parallel processing clusters into the DCEE (Lucas 2003). JSAF and SLAMEM have been modified to run on these SPP clusters. This effort is essentially a continuation of the DARPA SAF-Express program from the late 90's (Brunett 1997a, 1997b). A 256 node Beowulf cluster at the University of Southern California was able to simulate over a million entities, which were interacting with entities simulated at the J9 Simulation Analysis Center in Suffolk, VA. A second test utilized three clusters located in Maui, USC, and Ohio. These tests demonstrated that significant computational resources could be applied to joint experimentation from remote sites.

The critical technique for dealing with very large populations of entities is interest management. This allows federates to limit their attention to those entities in their areas of interest. No simulation can keep up with updating hundreds of thousands of remotely generated entities if they are constantly changing state. To support interest management, RTI-s has been modified to use active interest management routing and source side filtering of entity publications (Helfinstine 2003). This "source squelching" prevents data from being sent unless another federate has requested it. One of the classic downfalls of source squelching has been loggers and other federates that indiscriminately subscribe to all entities. To eliminate the logger problem, local loggers are being developed, which use an RTI intercept to capture any information that the simulation passes to the RTI, even if the RTI does not forward that information to anyone else. Tools to support SQL-like queries of this locally logged information are also being built. Federates that do not support active interest management and subscribe to all entities will be isolated with federation gateways and restricted to operating in a limited region. That way they can only interact with a subset of the entities in the world. The size of that area will depend on the density of entities in that area. Another issue for source squelching is viewers that attempt to zoom out to see the “big picture”. They can destabilize the entire network. Solutions are being developed that will allow them to only see aggregated and/or lower update information when observing large areas.

Unlike the multicast addressing used by the MC02 federation to achieve interest management filtering, active interest management routing uses an internal application layer field to indicate which interest region each message is associated with. Thus active interest management filtering can be transported over any lower layer protocol: TCP, UDP-unicast, UDP-multicast, or MPI (Message Passing Interface). MPI is only available on SPPs, IP many not be available on SPPs, and TCP performance can be adversely impacted by network latencies. Fortunately, lower layer protocols can be mixed and matched using a different transport for each “connection”.

The number of active interest management regions available in a multicast implementation is limited by the number of multicast groups that the local switch can handle. The CISCO 6509 is rated around 7000 groups. While this may seem like a large number, if you take the surface of the earth and divide it into 7000 regions, you get approximately 71,000 sq. km. per region – an area big enough to swallow any city and far too big to effectively reduce the traffic a simulation needs to worry about. By employing active interest management routing techniques, we were able to utilize around 100,000 interest regions during our SPP tests. By mapping variable sized areas to these interest regions, we were able to effectively segregate the traffic from over a million entities scattered around the Pacific Rim. Interest management routers were developed, which can be connected in a tree topology to route messages between simulation federates. The simulation federates form the leaf nodes of the tree. Adding more routers to the tree decreases the number of simulations each router needs to support. We are also evaluating another router approach, which uses a mesh topology rather than a tree. The mesh topology requires only two router hops between any two simulations and avoids a central bottleneck like the root router node in the tree topology. However, the number of connections required to maintain a full mesh grows rapidly and external communications with an SPP are often limited to special nodes like the head node, restricting a mesh to a single SPP. All of the routers use source side filtering, so that only what is requested on each connection is sent. The biggest disadvantage to using point-to-point connections is that if multiple nodes are subscribed to the same information, it has to be duplicated for each interested node. This can be particularly bad in the case of WAN links where the available tail circuit bandwidth is usually limited. One of the issues that still needs to be resolved is how best to mix multicast and unicast data paths to optimize filtering for each node vs. total bandwidth requirement.

USABILITY

Even if we overcome the limitations of scope and scalability, ease of use will remain a roadblock to making M&S ubiquitous in the concept development process. Unfortunately, this area may be even more difficult than scope and scale. Ideally, a concept developer could start up the simulation, enter in his concept, pull up a few canned scenarios and watch the execution. He would then get a summary report comparing the performance of the concept to that of a baseline scenario. The current state-of-the-art is far from this ideal. While closed form simulations can be run without human intervention, they require considerable work to set up their scenarios, which are very specific and include all the decision criteria that will be required during the run. Going to HITL simulations allows humans to make those decisions during execution and the scenario is reduced to initial conditions plus a human-readable expression of the concept. The down side is that the concept developer has to coordinate with a multiple operators to utilize the simulation. It is interesting to note that HITL simulations are often better for concept evaluation precisely because it takes much longer to build behaviors incorporating new concepts than it does to have operators puck according to the new concepts. Operator time can be traded for programmer time. While the coordination with operators is invaluable for sanity checking and concept refinement, support of initial concept development will require that the concept developer be able to perform all the pucking and concept entry required to run the simulation by himself.

Distributed Control

While distributing DCEE makes it easier to include people from many sites in an experiment, it also makes it harder to locate, schedule, initialize, and start all the distributed resources available. DCEE is using a central control system called MARCI (Multisystem Automation Remote Control and Instrumentation) to find the available resources, start simulations on them, and monitor their health. MARCI has been used for starting JSAF federates for several years, so successfully that operators have almost forgotten how to start up JSAF manually. It has now been expanded to run applications on remote SPP clusters (Williams 2003). In the future, the goal is to expand it to allow a single operator to control software distribution and startup for most DCEE applications. This will be a tremendous increase in efficiency and will make it much easier to configure the federation consistently.

The Burden of Data

Another significant problem for utilizing simulations is the data required to initialize them. If a concept developer asks for simulation support, he is usually buried with requests for data. What is the force structure, what parameters should be used for the systems, what terrain resolution is required? To address this problem, the J9 Joint Experimentation Data Support System (JEDSS) project is collecting combat system parameter data for three different scenario timeframes – the present, about seven years out, and approximately twenty years in the future. The goal is to have common system representation data for multiple simulations so all the concept developer needs to do is to select a timeframe for testing his concept. In addition to force and system data, we also hope to create a set of baseline scenarios that can be stored for future use. Clearly these data and scenarios will need to be updated regularly, but to encourage continuous experimentation, it is necessary to remove the data burden from the concept developers. Another place where DCEE needs to alleviate data burdens is across different resolution simulation systems. If a concept is captured in a process model during a collaborative wargame, the concept developer should not have to express it again for a closed-form simulation, and yet again for a HITL event. DCEE needs to make it possible to carry results and concept definitions from one simulation venue to another.

Data Collection and Analysis

DCEE is also building data collection and analysis tools that can provide real time responses for a limited set of queries during the execution of an experiment and then support standard and custom queries after each experiment execution (Graebener 2003). These tools rely on standard components such as relational databases, Excel, PHP, and have web interfaces allowing analysts scattered across the federation network to access their results. They also make it easy to export results for reports and presentations. Fundamental to the success of these analysis tools is the flexibility to allow analysts to define their own queries and manipulate their results.

CONCLUSIONS

Building a simulation environment to support all phases of joint concept development is a difficult task. The DCEE simulation environment needs to be general, powerful, easy to use, and scalable. The range of domains that concern DoD is growing rapidly and only a continuous team effort can hope to keep up with it. DCEE will use a loosely organized long-term community of partners to develop new capabilities through the evolutionary development of existing simulations. New models and simulations will be integrated as they become available via embedding, federating, and federation gateways. Good models are more important than simulation architectures. No architecture can produce good results from bad models. DCEE will take advantage of as many existing simulations and models as possible but in many cases new models will be required. These models should be developed by domain subject matter experts as 'portable models' that are easily accessible throughout DoD and can be embedded into multiple simulations. Model integration is not a silver bullet; there will be many difficult problems in the details of most integrations. DCEE will be looking for linkage approaches that go beyond syntactic integration to achieve deeper semantic interoperability without falling into "one size fits all" traps, such as inflexible standards and fixed architectures, which make future advancements more difficult and thus impede transformation. Flexibility is not optional; it is the essence of transformation.

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