AGGREGATION OF ENTITIES FOR ENTITY-AGGREGATE SIMULATION INTEROPERABILITY

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Abstract

The continual evolution of military simulations has provided much of the technology for the exchange of entity data between the environments. In particular, the extensive development in the resolution and granularity of aggregate simulations, combined with the entity data and ownership transfer capabilities of the High Level Architecture (HLA), has broken much of the virtual to constructive barriers for meaningful and productive data exchanges. So much so that in simulations, the real division has changed to be between the entity and aggregate simulations environments. The real challenge is no longer moving entity data between the live, virtual and constructive environments, but rather the movement of entity data between the entity and aggregate environments. This paper discusses eliminating the artificiality of aggregate state casualty resolution and assessment tables and the aggregation and de-aggregation of entities when passing ownership between entity and aggregate simulations.

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Introduction

Training simulations are traditionally conducted within three stovepiped environments, Live, Virtual and Constructive. Advances in both computing capabilities and simulation technologies have made possible technical interactions between the environments, which lead to training interoperability issues, particularly between simulations that separately maintain their players in aggregate and in entity level representations. This paper raises and examines the simulation interoperability issues between entity and aggregate levels of representation, and discusses potential solutions to them. In particular, the issues relating to "fair fight" interoperability between aggregate and entity level simulations are examined from a training management perspective. This paper reflects the personal opinions of the authors, and does not represent the official position of the government.

Definitions

Before we can begin any discussion of simulation management, first we must agree on the definition of the terms to be used. For this discussion of training simulations, the following definitions are provided. The authors stipulate these definitions are not authoritative across all military simulation, and are bounded solely for the purpose of this discussion of training simulations.

Traditionally, constructive simulations are semi-automated models using computer generated forces, which are grouped into various levels of aggregation. Such simulations may have human interaction or control at any echelon of leadership, often through a two dimensional "plan view" display, and may directly stimulate operational C4I. For this paper, constructive simulations are assumed to be aggregate level. Although some more modern constructive simulations do provide entity level representation, their behavior representations remain at the aggregate level. A virtual simulation is an entity level model using computer generated forces where each entity has its own individual behavior, while human interaction is usually provided at some higher echelon of command. For this paper, virtual simulations are assumed to be entity simulations.

One must also consider the basic differences between an entity-based simulation and an entity level simulation. In an entity-based simulation, the underlying computer system is aware of the existence of individual entities, but they exist and behave only as part of a larger grouping of forces. An entity level simulation recognizes each individual entity as a separate existence, not as a component of a whole, with its own identification, and more importantly, its own attributes and behaviors. Aggregate and entity level simulations also traditionally manage simulation time differently. Entity level simulations normally operate in real time, while aggregate level simulations normally operate in time steps, often at some level of acceleration from real world time.

The authors recognize that these definitions are arbitrary, since ModSAF, an entity level simulation, has traditionally existed in the constructive environment, and CCTT SAF, also an entity level simulation, were developed and exist within the virtual environment.

Representation of Forces

In aggregate level, entity-based simulations, groups of entities are instantiated and exist with group behaviors. Although entities are represented, generally, only units have behaviors. These units move, maneuver, react and engage as units or echelons. The granularity, or detail, of the simulation depends on its focus and purpose. The common representation of forces is either an area, for more traditional constructive behaviors, or as formation templates, for modern, entity-based simulations. Entity level simulations, on the other hand, provide each entity with its own instantiation and behaviors. Entities may maneuver as part of a higher unit, but these are formations instead of templates. A more basic example is that, in an aggregate simulation, 1st Platoon Company A is instantiated, and consists of vehicles A16, A11, A12, and A13. The platoon maneuvers and acts as a single echelon, and the platoon action is the primitive behavior. In an entity level simulation, entities (vehicles) A16, A11, A12 and A13 are instantiated, and together represent 1st Platoon, Company A. A16, in addition to its individual primitive behaviors, may be provided with command force reasoning or other form of command behavior, and thus directs the behavior of the other entities within the platoon.

Casualty Assessment Processes

Aggregate and entity level simulations conduct combat resolution, or casualty assessment, in fundamentally different manners. Both require that the engaging units achieve Line of Sight (LOS) between themselves, and then conduct combat resolution, but the similarity ends at that point.

When aggregate simulations conduct casualty assessments between groups (aggregates of entities), the line of sight is determined between the center of mass of the engaging formations. This center of mass is determined by the size and formation of the units, for example, a battalion moving in a diamond formation with support trains in the middle may have its center of mass roughly between and to the rear of the two center companies. The LOS computation thus may have two opposing battalion sized forces out of sight of each other, when their leading companies are in clear line of sight. The entity simulation, on the other hand, conducts LOS computations between all entities on the battlefield. Therefore, when any two opposing entities have achieved mutual LOS, are within weapons range, and rules of engagement allow, a combat resolution occurs.

The combat resolution, or casualty assessment, is also different. Aggregate simulation, once LOS, has been achieved, will use a lookup table, commonly based on Lanchester equations. These tables are based on the relative combat power of the opposing units en masse, and do not reflect the number of actual entities having true line of sight. While the basic Lanchester equations have been improved and updated over the years, particularly through the work of Bonder and Farrell, they do not provide significant variations to allow for the skill of the various participants. A particular weakness of this approach is that it does not allow for combat resolution based on the actual number of entities which have line of sight on opposing force entities, but rather is on the aggregate of the engaged units. Although most aggregate state simulations, which maintain entity level resolution, provide some level of terrain reasoning for LOS calculations, this is only at the formation center of mass focus. In other than relatively level terrain, it is not unusual for a normal template formation, whose center of mass has line of sight on the opposing force, to have a significant portion of its combat systems masked by terrain, or protected by terrain. Yet the combat resolution will assume all entities have firing line of sight, and are available to be engaged by the firing side. For example, Task Force 1st, 44th Armor, with three tank and one mechanized companies, conducts a meeting engagement with the 71st Grenadier Tank Regiment in broken but open terrain. Regardless of how many vehicles have actual line of sight on the opposing force, the first volley is nominally 64 vehicles against 170. After each volley, “kills” are assessed, and volleys continue with the new strengths until either one side is eliminated or withdraws, depending on the simulation’s rules of engagement.

An entity simulation, using a different approach, will calculate the light of sight for all entities in relationship to each other. Only individual entities having line of sight on a particular opposing entity will be capable of engaging that particular entity. Additionally, each entity engagement is conducted as a one on one equation of two sequences. First, given a line of sight, the firing entity shoots and the computer system determines a hit based on a random number resolution, given *X* probability. Assuming a hit occurs, the probability of a kill is also calculated on a random number basis, given *X* probability. This is known as the PhPk probability of an engagement. Typically, a more modern simulation with higher fidelity includes not only the PhPk adjusted for target exposure and attitude (frontal, side, defilade, etc), but may include a Ph for various conditions, such as firepower, mobility, or communications "kill." In the example above, TF 1-44 would actually engage with 42 tanks, those having line of sight from their defilade positions against the 80 vehicles of the two opposing force battalions caught in the open. Individual targets are engaged with PhPk resolution as rapidly as the individual firing tanks acquire targets with line of sight.

These differing approaches are taken for the basic reason that line of sight calculations are the single largest computational task within any simulation. Aggregate level simulations have large numbers of playing units, representing an even larger number of physical entities. When large scale engagements occur, most simulation host computers lack the ability to perform line of sight calculations for all possible entity pairings, and still maintain reasonable simulation time advances.

Essential Differences

The essential differences to the aggregate versus entity level simulations, in casualty assessment, is the aggregate grouping center of mass compared with actual entity location for line of sight calculations. Modern aggregate level simulations, which have fine detail aggregation and entity representation, have greatly reduced level of differences, but they still remain. Aggregated units conduct their combat resolutions at a differing, and lower, level of fidelity than do entity simulations. Even WARSIM, which promises the highest level of fidelity, and lowest echelon of resolution, will use a platoon sized equipment group center of mass for line of sight, and selects to appropriate weapon for the equipment group, instead of each vehicle selecting the appropriate weapon for the target and range. The other essential difference, applicable to most currently fielded simulations, is the difference between casualty assessment by aggregate look up table and the entity simulation use of individual PhPk.

Effects on "Fair Play"

When we discuss "fair play," we mean that in the interaction of entities hosted in different simulations, the differences in the simulation host are overtaken by the differences in the hosted entities. Another way of saying this is that the differences between the simulations are less than the differences in the players' skill levels. Fair play interaction is an inherent requirement for federations of training simulations, else soldiers will not learn from the simulations, believing their losses or defeats were the machine, not their mistakes or skill level.

When aggregate simulations are federated with entity simulations, fair play in combat resolution, shooting and hitting, requires that there be mutual line of site between the entities being engaged. Additionally, the possible outcomes of each exchange of fires must be relatively equal. If a platoon of four M1 tanks in simulation A engage a platoon of four T-80 tanks in simulation B, the outcome should be the same if the same four M1 tanks were hosted in simulation B and engaged four T-80 tanks hosted in simulation A. This is where the differences between aggregate and entity level simulations cause a training federation to break down.

Training Federations

As military operations, and training, move into the 21st century, we are continually faced with new challenges, in technology, in military operations, and in the way we train and prepare for military operations. Virtually all fielded training simulations were developed in the cold war period, or are based on simulation concepts from that period. The threat was monolithic, combat was mid and high intensity, and aggregate state simulations were the only means of training upper level command echelons. Our operational threat and environment has changed. While we still continue to organize and train to fight the mid level threat, most of our operations are conducted in low intensity conflict and operations other than war. Typically, American military deployments are joint service, if not coalition, and are focused on preventing or stopping armed struggle, rather than conquering it. The world political struggle is in the fragmented or fragmenting countries riven by ethnical and cultural conflict. Our forces, a mix of mid-intensity equipped warfighters and civil affairs and support troops, face a training dilemma of insufficient operational spectrum in their training simulations. We have, to date, been unable to provide them with a single simulation that can provide entity level representation within a deployment theater, and provide them with all the threats and operational training requirements needed.

We turn to confederations of training simulations to resolve this deficiency. Aggregate level command and staff simulations are linked with entity level combat simulations, and possibly also virtual reality or live instrumentation simulation systems. While this solution provides the simulation capabilities our forces need, it brings it own list of problems. As a community, we have solved the problems of how to exchange data between various simulations, and how to manage and coordinate time between the simulations. Now we have to solve the fair fight interoperability, how can aggregate and entity level forces interact with each other in such a way that the soldiers win not by the host simulation technology, but instead by their own skills and abilities.

When an aggregate simulation force engages an entity simulation force in a training confederation, there are three ways for the combat resolution to be a "fair fight." The aggregate simulation may expend sufficient computational resources to determine each engagement entities' location and line of sight to all other entities within a high fidelity portion of the simulation data base, and engage using entity level PhPk. The entity level simulation may conduct pseudo-aggregate units using center of mass line of sights equivalent to the aggregate simulation, and use equivalent casualty look up tables. Or, given the capabilities of the HLA Run Time Infrastructure (RTI) ownership of the engaging groups may be passed from one simulation to the other so that all the combat resolutions occur on the same machine with the same set of processes and algorithms. This third approach offers highest level of equality in the simulations, and is also the least expensive in terms of simulation management.

While it is equally feasible for the entity level simulation to pass ownership of engaging forces to the aggregate simulation, it seems most likely in the training arena that the aggregate simulation would pass ownership to the entity simulation. There are several reasons for this assumption, both from a training management viewpoint as well as from a simulation management viewpoint. Training federation would normally mix aggregate and entity level simulations because, while a large force array is needed, the entity level resolution is important to the training exercise, else the exercise would involve only the aggregate simulation. From a simulation management viewpoint, the entity level simulation places everything at the individual entity level, and so can receive from the aggregate simulation the locations and identifications of all aggregated entities. The same could not necessarily be said for an aggregate simulation. The necessary unit tactical formation templates, aggregate behaviors, and command entities may not be present at the platoon and company level. They are not in currently available aggregate simulations. While there are always other circumstances, we believe the most efficient and practical means of fair play interaction between heterogeneous simulations is to pass ownership of aggregate entities to the entity simulation for combat resolution. Doing this, however, raises a series of issues that must be addressed both in simulation management and in training exercise management.

Simulation interaction issues

When creating a training federation of aggregate and entity level simulations, technical issues regarding terrain data base correlation, object models, entity identification and attributes, and location/behavior correlation must be considered to ensure appropriate interactions between the federates. Current technology and fielded simulations make these very difficult challenges, but emerging standards and simulations offer significant promise. We believe that, by examining the concept of entity ownership transfer between the simulations, that much of the problems can be resolved, and emerging standards can complete the solutions.

Terrain data base correlation has always been a major issue between heterogeneous simulations. The correlation is mostly manual, resulting in simulation-significant seams and artificiality's. This has been a particular problem where the terrain databases have not shared vegetation and human artifacts, but only terrain features. The advent of the SEDRIS standard for TDB description allows simulations to exchange data about vegetation and artifacts, and ensures a high degree of correlation. With such a high correlation, and with terrain data bases using common NIMA data sources, entities can be correctly positioned for ownership transfer, without the risk of improper transition.

The object model of an entity has traditionally been unique to the instantiating, or owning, simulation. This has caused differences in both their description and their rendering. It has also caused differences in the various attributes, and in some cases, capabilities, between simulations. HLA compliant simulations are required to describe their entities within the construct of the DMSO Object Model Template, ensuring some level of equivalency between the simulations. Appropriate attention in creating the Federation Object Model (FOM) allows for varying levels of fidelity between the object models, allowing each simulation to maintain the level of fidelity appropriate to its rendering. While an aggregate simulation may maintain a very different level of object resolution, ranging from whether a tank turret is articulated, or if there are antenna present, agreements in the FOM will permit each simulation to maintain the resolution required for it's application. The second major issue here is that the object model must be of sufficient detail that individual entities are recognizable within the aggregate simulation. This requires that the aggregate simulation be at least entity based and not constructive in detail. A platoon aggregation must have either a template or equivalent rendering so that the simulation can provide XYZ data for all entities to be transferred. This also raises the issue of being able to provide entity identification for the forces involved. Traditionally, constructive simulations maintain identities by units, rather than by entity. Entity-based aggregate simulations, such as WARSIM, can or do maintain individual entity identification, essential to a training simulation where ownership will be transferred for combat resolution. One of the issues related to both location and identification is not just the need to know not only who an entity is, and their XYZ, but also the role of position they play. When transferring entity ownership from an aggregate to an entity simulation, it is important to know which roles the individual entities represent. When ownership of Company A is transferred from aggregate to entity simulation, knowing that tank A66 is the company commander allows that entity to be provided with the appropriate individual command behaviors. And more importantly, allows the effectiveness of the command structure of the company to be reduced if that entity becomes a casualty.

The concept of entity identification as part of duty position is related to the issue of maintaining entity attributes, since duty position could be considered an attribute as well as an identifying function. In addition to duty position, training functionality may require that additional attributes have value, and need to be maintained even after a unit or grouping has completed entity interactions and is transferred back to the aggregate simulation. Among these attributes are warfighting logistics: ammunition quantity and type expended, fuel consumed, miles driven for maintenance failure, and potentially, time awake and engaged for personnel fatigue considerations.

Perhaps the most difficult issue of ownership transfer between aggregate and entity simulations are the actual mechanics of physical transfer. We break these into three portions; physical location, orientation and viewpoint, and behavior transfer. The physical location problem is perhaps the easiest to resolve. In an aggregate model, there is an existing formation template which may have, depending on the resolution of the model, identified XY locations for each entity within the formation. As part of the ownership transfer process, the simulations must agree on where each of the entities are, ensure that the XY location is converted into an acceptable XYZ location with velocity data, and then actually conduct the handoff. Attention must be paid to determining the appropriate XY location, since a template location when aggregated may include entities superimposed upon buildings, in rivers, or in inappropriate ground locations, to include tactically inappropriate attitudes. This same process must be followed when moving from entity to aggregate, with the entities being required to move to the appropriate template formations prior to handoff.

The problem of orientation and viewpoint is a significant issue, since aggregate simulations, even when entity-based, will probably not have vehicle orientation, turret/weapon orientation, or a crew viewpoint or search pattern. Yet these items are critical for vehicles instantiated within an entity simulation, particularly if combat is imminent. Related to the issue of orientation and viewpoints is the critical issue of behavior transfer. This, probably the single most difficult issue in transferring entities between simulations, is also arguably the most critical. The aggregate is existing in one simulation, and executing a collective behavior there. The entity simulation must instantiate the object models of the entities, assign appropriate behaviors, and do this within a space of time that allows the seamless transfer of the entities from one simulation to the other, without artificialities. This problem of behavior attribution to transferred entities is not one that has been faced before in training simulations. We don't yet know how to:

- transfer the ownership of a unit of entities,
- put them in the correct XYZ locations,
- ensure they are looking the right direction with turrets, sensors and crew eyes, performing appropriate search functions,
- and ensure they possess the correct individual behaviors and battlefield situational awareness.

While the simulation community has demonstrated essentially seamless transfer of entity ownership, and has also demonstrated movement between aggregate and entity states, the two functions have not been done simultaneously to date.

Summary

We have discussed the differences in representation and combat resolution between aggregate and entity simulations, as well as the inherent inability to have "fair fights" between these simulations. We have raised simulation management issues that must be addressed in transferring entity ownership between simulations. The problems are not simple, but they can be solved. The HLA and SEDRIS standards will continue their evolution to enhance interoperability. Simulation developers and managers will develop the tools and techniques necessary for transferring entity ownership concurrent with aggregation/de-aggregation. Training managers and scenario developers must understand the issues involved in these training federations and plan both for the complexities of the transfer, as well as ensuring that as few transfers as possible are required in the scenario. The future training environment with entity-based aggregate simulations federated with entity level manned and automated simulations offers unparalleled training opportunity. But achieving this opportunity requires more than compliance with interoperability standards. We still have much technical work to do, and we need to learn new processes in setting up training exercises.

Suggested Readings:.

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4. Taylor, James (1983), *Lanchester Models of Warfare*, Military Operations Research Society of America, Alexandria, VA.