Affordable Creation, Modification, and Distribution of a Distributed Synthetic Environment

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ABSTRACT

The rapidly expanding use of low-cost, distributed, interactive, networked simulation is reshaping the requirements for terrain database creation, modification, and distribution. The terrain database no longer resides exclusively on the visual image generator, but is shared by the many components of the network simulator, including computer generated and semi-automated force simulations, electronic map displays, communication models, mobility models, and paper maps. Additionally, the substance of the terrain database can no longer be bound by the visual needs, but must contain correlated information essential to the various components of the networked simulation.

We must create and maintain a complete synthetic environment. The creation of the synthetic environment requires the integration of a broad assembly of structures and attributes needed by the various components of the network simulator. Modifications to the correlated synthetic environment database must be made both as a matter of database enhancement (adding a house, or road), and as a result of the run-time interaction (excavation of an anti-tank ditch or destroying a bridge). Common correlated sources for the distribution of the shared synthetic environment are fundamental to simulator interoperability. Database sharing for large networked simulations, with hundreds of individual simulators, requires efficient methods for both pre-distributions and run-time modification distributions. Standards should be considered to provide a common architecture and standard communication protocol to support cost-effective database creation, modification, and distribution in a distributed interactive simulation.

ABOUT THE AUTHOR

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INTRODUCTION

Historically, terrain database generation centered around the construction of the visual terrain database. The database was designed to provide the simulated world as viewed through the rendered scene of the computer image generator.

The goal of the early simulator builders was to provide the finest image generator and build the best terrain database that technology could support. The single most expensive component of the simulation system was the computer image generator.

With the high cost of the image generator hardware, it was only logical that the best performance was achieved by dedicating large amounts of time and money to create a database purpose-built for the target application. The database design needed to squeeze every possible cycle of compute power from the high-priced image generator. This approach to database generation was not unreasonable in light of the cost of the image generator hardware. The justification was simple: the computer generated image was the user's window into the simulated world. These images had to be the best technology could provide.

Over the past few years there has been a significant reduction in the cost of computer image generator hardware. Expectations are that the database costs should be decreasing at a similar rate. However, this expectation is ill founded. Consider the simplicity of the early flight simulation databases. The feature densities were very low, as low as one feature per square kilometer, and the terrain facet sizes were large, typically in the range of 500-1,000 meters on a side. Now consider the recent U. S. Army Close Combat Tactical Trainer (CCTT) Central United States database. The Central U.S. database contains a continuous density of approximately 2,000 features (e.g. trees, houses, barns, bushes) per square kilometer, and a nominal terrain facet size of 60 meters. In addition, roads, rivers, lakes, and tunnels are not merely draped over the terrain skin, but are formed into the skin to provide realistic three-dimensional feature characteristics.

The decreased cost of image generation hardware has increased the demand for larger, more complex, and more realistic visual databases. Consequently, it is unreasonable to expect database development costs to decrease equal to the reduction in hardware costs. In fact, it can be argued that the database development costs should increase by the factor of their complexity. Fortunately, this is not the case either.

Advancing technology to reduce database generation costs has been a continuous thrust of the simulation industry. A survey of database development over the last 20 years reveals that the problem of reducing database development costs is not new or easily solved [Cosman, 1989; McCarter, 1992; McKeoun, 1996]. Significant investment has been made by both government and industry to reduce database development costs.

Nonetheless, hardware vendors continue to develop faster and less costly image rendering systems [Clark, 1990; Cosman and Mathisen, 1990] and users continue to demand increased object density and improved scene realism. Users' expectations will always exceed the simulator's performance, forcing a continued increase in database complexity until we provide a simulated world that is indistinguishable from the real world.

Add to this increased visual scene complexity the inevitable evolution of network simulation. The database development task continues to expand. Database generation no longer focuses on only visual image generation, but must encompass the needs of all components of the network simulator. The database must now contain the correlated information essential to these various components. We must now create correlated shared synthetic environment databases.This paper reviews the current terrain database development process and outlines the fundamental shared requirements of the networked simulator from the perspective of the CCTT program. The concept of a single correlated shared synthetic environment database is presented and recommendations are given for improving database creation, modification and distribution in the context of a networked simulation.

TODAY'S TERRAIN DATABASE

To lay the foundation for recommendations regarding synthetic environment database creation, modification, and distribution, an understanding of current database development process is essential. The CCTT program is a reasonable point of reference to describe the general practices in use today.

Terrain Database Creation

The traditional database creation process consists of a number of familiar tasks. A sound understanding of the user's requirements, and a firm grasp of the capabilities and limitations of the simulation system components are a prerequisite to begin this process. The first step in the database development process is to establish a performance budget for critical system resources. Although the primary system performance limitations are imposed by the computer image generator and the computer generated forces, all critical resources of the networked system are evaluated. The paragraphs below present notionally the flow and transformation of data through the process of database creation on the CCTT program.

Various forms of source data are used, either as direct digital input or as technical references. Typical digital sources include elevation data (e.g. DTED), feature data (e.g. DFAD and ITD), and imagery (e.g. SPOT, LANDSAT, and aerial photographs).

Digital Elevation Data. The terrain skin is developed from the digital elevation data. Digital elevation data is frequently down sampled to meet the performance limitations of the simulation system.

Digital Feature Data. Digital feature data describes the natural and cultural features that populate the terrain skin. Digital feature data usually contains point, linear, and areal feature references. Point feature data defines the location, length, width, height, and material composition of an object in the data. Linear feature data describes the roads, rivers, waterways, tunnels, and other lines of communications. Areal feature data defines the boundaries of bodies of water or outlines of a city. Areal feature data also describes the visible vegetation or surface representation of the land and the characteristics of the underlying soil. The feature data is thinned to meet the performance limitations of the simulation system.

Other Source Data. Digital imagery can be used as texture patterns draped over the terrain skin, or as a source to create digital elevation and feature data [Lukes, 1995]. Drawings, text descriptions, sketches, illustrations, photographs, and video tapes are useful in the creation of the reference models, feature models and vehicle models.

This source data is used in the creation of the terrain skin, the terrain features, feature models, reference models, and vehicle models.

Terrain Skin. The terrain skin is created by projecting the elevation data into a Cartesian coordinate system and re-sampling to a regular grid. The grid is transformed into right triangles, optimized for the surface slope and adapted to provide a best fit [Pope, 1995; Rodriguez, 1996].

Prepared Feature Data. Feature data, once thinned and filtered, is carefully reviewed to assure no ambiguities exist. Conflicts are resolved. The remaining data is enhanced with the placement of bridges, intesections, and overpasses. Data for roads and rivers to be cut and filled into the terrain skin are produced.

Feature Models. Feature models are structures placed at the locations identified by the digital point feature data. Typically, only a limited set of buildings and foliage models are created. These three-dimensional models are constructed of geometry and texture, typically by hand from photographs, drawings, and sketches.

Reference Models. Areal and linear features define the visual presentation of the terrain surface. Reference models are constructed to provide visual definition to these features. This includes defining the visual presentation of such features as grass fields and lake surfaces. Also, three-dimensional reference models are developed and used to populate vegetation and cultural areas. For example, a forest areal feature is populated by a three-dimensional reference model defining standing trees, and a city areal feature is populated by three-dimensional buildings.

Vehicle Models. Vehicle models are constructed in a manner similar to the three-dimensional feature models. Vehicle models are not considered part of the terrain, but are simply objects that can be placed within the terrain database.

The integration of the terrain skin with the feature and reference models (terrain and feature merge process) results in the creation of a three-dimensional model of a specific area in the real world. It is, indeed, only a simplified representation of the world. The result of the merge process is a polygonal representation of the terrain database. This polygonal database forms the definition of the correlated shared synthetic environment.

The polygonal data is formatted for the image generator. The data is also exported, extracted and formatted for the other components of the networked simulator. Hard copy maps are also produced.

Terrain Database Modification

In modifying a database, there is the potential to repeat many of the processing steps. Modifying the terrain skin requires changing the imported digital elevation data and recreating the terrain skin. Altering a road network requires changing the prepared feature data. Modifying the texture on a building requires changing the feature model. All of these up-stream changes require repeating the terrain and feature merge process, re-formatting for the image generator and, of course, exporting, extracting and formatting the data for the other components of the networked simulator.

It would be simpler to modify the polygonal representation of the data, without making modifications to the source, thus avoiding the time-consuming re-processing of the data. However, because portions of the abstract data exported and extracted for the computer generated forces database come from the prepared source form of the data, this is not possible. For example, the road in vector format is extracted from the prepared feature data, not from the polygonal representation. There are many other reasons, but this single reason is, by itself, reason enough to require re-compilation.

In CCTT, run-time modifications to the database are limited to planned dynamic features, such as multi-state objects, and by the placement of pre-built obstacle models, such as engineering craters and anti-tank ditches. These pre-built obstacles are distributed as part of the terrain database [Crowley, 1995].

Terrain Database Distribution

For a standalone simulator the database distribution process is a relatively simple task. The database is transferred to the image generator via tape or local area network.

In the case of a networked trainer, the distribution tasks balloon in complexity. The visual database and the extracted databases must be distributed across many systems in a number of formats. This distribution process can take days in large networked simulation systems.

The CCTT program uses a combination of local area network and hand-carried tapes to distribute the data.

CORRELATED TERRAIN DATABASE COMPONENTS

The terrain database must be shared by the components of the network simulator, including computer generated and semi-automated force simulations, electronic map displays, communication models, mobility models, sensor models, and paper maps. Each of the simulation components has unique data requirements.

Visual Image Generator Terrain Database. The visual image generator database contains geometry, color, and texture information organized in a hierarchical structure that provides rapid selection and rendering of the three-dimensional visual world

Sensor Terrain Database. The sensor database is often organized in a similar hierarchical structure to the visual database with the unique addition of sensor properties. In CCTT, the infrared and image intensifier properties are contained in the same database as the visual properties.

CGF/SAF Terrain Database. The Computer Generated Forces and Semi-Automated Forces database is perhaps the most demanding. The CGF/SAF database must contain all of the information necessary for the computer to “see and reason” about the world. This requires the geometry, color, and texture information (perhaps simplified), as well as the thermal characteristics of the infrared data and the reflectance properties of the image intensifier data. In addition, the CGF/SAF database requires abstract data relating to and about the terrain and features, abstract data that humans know by looking at an object. For example, by looking at the rendered image of geometry, color, and texture we can identify a building or a bridge. The format and organization of the CGF/SAF data is organized and represented in a form designed for efficient processing by the computer.

Electronic Maps. Electronic maps require contour line representations of the terrain skin, and source data-like representations of the point, linear, and areal features. In addition, feature labels and symbols provide the necessary mapping information.

Communication Terrain Database. Occasionally, radio or communication propagation models are required. The communication terrain database must be correlated to the visual and CGF/SAF database. A communication terrain database can be as simple as a gridded height masking table or as complex as a full geometric representation of the terrain database.

Mobility Terrain Database. CCTT uses a mobility model database for the Manned Module interaction with the terrain and features. This database is integrated with the CGF/SAF database. The key information required in the mobility database is the geometry of the terrain surface, the collision volumes of the three-dimensional features, and the surface and subsurface material characteristics (strength, type, moisture content, depth, etc.).

Paper Maps. Hard copy maps need almost the same data content as electronic maps. However, once printed, paper maps are not as easy to update as electronic maps if modifications to the database occur.

Each component of the network simulator must also support the common representation of the atmospheric and oceanographic environment; however, this data is acknowledged, but not addressed in this paper.

CORRELATED SHARED SYNTHETIC ENVIRONMENT

A correlated shared synthetic environment database is a collection of integrated and associated features and attributes defining a three-dimensional model of a world, distributed to all of the components in a networked simulation.

The critical factor in building and sharing a synthetic environment database is good tools [Mamaghani, 1995]. More specifically, good tools designed to facilitate rapid, affordable, purpose-built, synthetic environment database creation, modification, and distribution in the context of a distributed network simulation system.

Synthetic Environment Database Creation

Everyone wants their synthetic environment database built faster, cheaper and better. But, they also want their database built to their specification for their application. This requires ever-changing tools and methods. Additionally, digital source data continues to change in format and improve in content, and different geographic areas demand different database content (rice patties, rock outcrops). The creation of a synthetic environment database is still not a “turn-the-crank” process.

Synthetic environment database creation is essentially the process of sampling the real world, and then reconstructing a three-dimensional, geo-spatial model from the sampled data. Hence, it follows that if the correct sampling is performed, and the right information is retained, then the reconstruction of the simulated world will be faster and cheaper. If the data is collected with the target application in mind, the user can get a better database built to their specification for their application.

Efforts are underway to automate the extraction of digital source data from aerial imagery [Lukes, 1995], and to improve the format, content, and correlation of the digital source data [PAR, 1996]. These front-end tools and standards activities focus on improving the digital source data collection and representation. This will make the digital source data collection process more affordable, and will allow the collection process to emphasize the target application in the collection process [Lenczowski, 1996].

We also need to focus on tools that make the reconstruction of the three-dimensional model faster, cheaper, and better in the context of a networked simulation. This can be accomplished by building good tools that are focused on creation of the synthetic environments to meet today’s needs and plan for the needs of the future. A number of fundamental capabilities must be available in future modeling tools to meet this goal:

- Automated processing. The creation tools must focus on automating the simple repetitive tasks.

- Accelerated editing. Provide the modeler with power tools designed to provide effective interactive editing of the database for the modeling tasks that are not automated. This feature is fundamental in dealing quickly with new and changing source data content.

- Robust import and export. The tools must support a robust suite of import and export funtions. This will be key in dealing with ever-changing source data formats and in exchanging databases among heterogeneous simulation systems.

- Integrated content. Provide tools that support the multiple, integrated representation of the data for the various components of the network simulator.

- Associated content. The tools must provide forward-links and back-links from source feature to polygon and polygon to source feature. It is critical for interactive editing that when a polygon is modified, the source is modified at the same time so that consistency is maintained.

- Incremental construction. Incremental area construction of the synthetic environment database is critical for cost-effective development. The tool must correctly manage geographic boundaries. More important, incremental construction is the key to rapid prototyping and incremental system development.

- Performance Planning. Tools which provide networked system level performance planning are crucial. Databases become easier to build when the system capability is understood.
- Standard Library support. Standard libraries of models and texture must be developed for industry use [Latham, 1996]. Databases are cheaper when libraries of textures, feature models, and vehicle models are available for rapid reuse.
- Unlimited size. The tools must support both large geographic extents and extremely dense databases.
- Extensible content. If the tool is to support current and future needs, it must provide a data model that is easily and quickly extended. This will support the addition of new attributes to the database such as behavior and sound.

The synthetic environment database must be built to operate under the performance constraints of the target simulation system. That is, when the synthetic environment is constructed from the source data, the specific system performance must be understood, thus assuring that no component of the network simulation will be overloaded, and no correlation compromising oversimplification will be required in the distribution process.

Synthetic Environment Database Modification

The synthetic environment modification process must be affordable, both for database maintenance and run-time modifications.

Database maintenance entails the typical changes that follow the initial database release. This can include changing a texture or a color to meet a user's need, adding foliage to provide concealment along a corridor of approach, or decreasing the inclination of a ramp on a road leading to a bridge. There always seems to be one more small change that the user and modeler must make. Database development is never finished, it is simply declared complete when time or money is exhausted. In fact, no matter how comprehensively a database is tested, small problems are inevitably found, sometimes years after the database is built. Furthermore, some problems are not observed until the database is distributed to the other networked components, such as SAF/CGF and manned modules.

The run-time modifications of the database have been generally referred to as dynamic terrain or dynamic database. These modifications are typically the result of simulated actions such as artillery cratering or engineer excavating.

In the context of a network simulator, the ideal solution is to treat the maintenance modifications similar to the run-time modifications. Once the database is distributed to the components of the networked simulation, it is very costly to reprocess and redistribute the shared synthetic environment. The desired solution is to provide modeling tools that support both pre-distribution and run-time distribution of database modifications. Once the databases have been distributed, it is desirable for database maintenance activities, to distribute the modifications as only incremental updates to the shared environment. Obviously, dynamic terrain modifications are distributed at run-time over the network. Demonstrations of dynamic terrain modifications transmitted over a Distributed Interactive Simulation (DIS) network have shown this approach to be practical.

In order to provide a generalized method for database maintenance and run-time modification, the modeling tools require the following features:

- Modeler and User Editing. The tools should support both modeler and user modification to the synthetic environment. The tools should be friendly, with no distinction between fixing a road cut and digging an anti-tank ditch.
- Incremental Modification. Once a modification has been made to the synthetic environment database, the changes must be communicated to all components of the simulation. To provide effective modification to the database the concept of on-line source data will be required. Also, all of the components of the network simulator will need to listen to the changes.
- Associated Modification. The tools must provide updates to all associations contained in the database. If a road polygon is modified to the degree that the vector feature is changed, the vector feature must be modified.
- Configuration Management. The tools must provide identifiable, historical event recording of all changes to the synthetic environment, for both maintenance and run-time modifications.

It is not mandatory that the maintenance and run-time modifications use the same approach. To assure real-time run-time modifications of the environment, only limited changes may be possible. It is imperative that database modifications be supported in a cost-effective manner.

Synthetic Environment Database Distribution

The goal is to build a correlated shared synthetic environment database which defines the simulated world for all of the components of the networked simulator. This requires that the definition of the correlated environment be from a single common reference. The definition of the correlated environment can be defined as the real world, aerial photographs, sampled digital source data, or the polygonal database. Of course, the only true reference is the real world, everything else is a simplified model. However, to propose that each component of the network simulator start by sampling the real world as a common reference for building a shared environment is neither logical nor affordable, and certainly interoperability and correlation would be questionable.

The logical point of distribution of the correlated shared synthetic environment occurs after the reconstruction of the three-dimensional, geo-spatial world model. That is, after the polygonal representation is established. This provides a common concrete definition of the three-dimensional world.

The distribution can be divided into pre-distribution and run-time distribution:

Pre-distribution. The initial database distribution and maintenance update distribution of the correlated shared synthetic environment must be supported. SEDRIS is designed to tackle the initial database distribution of a synthetic environment. SEDRIS can also be used for maintenance updates by reprocessing an updated SEDRIS database transmittal. However, on-line methods for maintenance update distribution are desirable. It is reasonable to consider the future development of SEDRIS as a standard for on-line maintenance update distribution, and potential on-line initial database distribution.

Run-time distribution. The run-time distribution must remain focused on real-time performance. The current protocol development for the dynamic database modification distribution will provide a near-term solution for the requirements. However, elements of the SEDRIS exchange process should be considered as potential methods of data representation for the real-time data distribution.

All of the network simulation components that require a representation of the synthetic environment must receive and maintain a local copy of the shared environment.

Paper maps appear to be the only network component that will not be able to move to this on-line architecture. However, paper maps of the real world are often out-of-date. Similarly, a simulation map may be out-of-date, therefore, tools for effective selective map sheet update need to be developed.

CONCLUSION

It is clear that to reduce the cost of the correlated shared synthetic environment database development in the distributed interactive simulation environment better tools and standards are required.

As a simulation community we must consider the development of standards focused on defining the communication for not only the run-time modification to the shared database, but also for the pre-distribution (initialization and maintenance modifications) of the database. SEDRIS is focused on the exchange of the large volume initial distribution, but we should plan now to make this the standard for pre-distribution maintenance modification and, potentially, run-time database distribution.

The simulation infrastructure must be defined such that each component of the distributed simulation can accept and support this active distribution architecture.

REFERENCES

Cosman, M., "A system approach for marrying featuress to terrain," in *Proceedings of the 11th I/ITSC Conference*, November 1989.

Mamaghani, F., "Creation and usage of synthetic environments in realtime networked interactive simulations." *Conference on Integrating photogrammetric techniques with scene analysis and machine vision II, (SPIE Proceeding Volume 2486),* Orlando, FL, April 1995.

Lukes, G., "Cartographic support for advanced distributed simulation," *Conference on Integrating photogrammetric techniques with scene analysis and machine vision II, (SPIE Proceeding Volume 2486),* Orlando, FL, April 1995.

Pope, C.N., Vuong, M., Moore, R.G., and Cowser, S.S., "A whole new CCTT world," *Military Simulation and Training*, no.5, 1995.

McKeown, D., Bulwinkle, G., Cochran, S., Ford, S., Harvey, W., Hsieh, Y., McGlone, C., McMahill, J., Polis, M., Roux, M., and Shufelt, J., "Automating the construction of large-scale virtual worlds," *Proceeding of the DARPA Image Understanding Workshop,* pp. 215-245, February 1996.

McKeown, D.M., Gifford, S. J., Polis, M.F., McMahill, J., and Hoffman, C.D., "Progress in automated virtual world construction," *Proceeding in the DARPA Image Understanding Workshop,* pp. 325-335, Feburary 1996.

Crowley, J.L., and Moore, R.G., "Synthetic Environment Protocol." *Proceedings of the 11th DIS Workshop.* Institute for Simulation and Training (IST), Orlando FL.

Watkins, J., "Design of the CCTT Terrain Reasoning Database." *Proceedings of the 5th Conference on AI, Simulation, and Planning in High-Autonomy Systems.* University of Florida, Gainesville, FL.

McCarter, S., "An Approach to Designing Interoperabel Visual Data Bases for Networked Environments utilizing Computer Image Generators of varying fidelities," *Proceedings of the 14th I/ITSC Conference*, November 1992.

Zvolanek, B., "Common Database Attribution for Correlated Multi-Sensor Image Generation," *Proceeding of the IMAGE Conference, Scottsdale, AZ 23-28 June 1996.*

Rodriguez, A., Liddiard, H.T., Daniel, C., Pankow, W., Woolridge, R., "Design and Development of the Central U.S. Primary database for the Close Combat Tactical Trainer" *Proceedings of the 1996 IMAGE Conference, Scottsdale, AZ 23-28 June 1996.*

Lenczowski, J., "Minimizing the Producer to User Information Gap," *Proceeding of the 1996 IMAGE Conference, Scottsdale, AZ 23-28 June 1996.*

Latham, R., McKenna, G., Davis, G., "Building a texture database library," *Proceedings of the IMAGE Conference, Scottsdale, AZ 23-28 June 1996.*

Goettsche, C., Hallmark, S., Harlin, D., Phillips, D., "Visual Data Base Design and IG Emulation: A Graphical Approach," *Proceedings of the 7th I/ITSC Conference*, November 1985.

Widder, P.A., Stephens, C.W., "Data Base Generation: Improving the State-of-the-art," *Proceedings of the 5th I/ITSC Conference*, November 1983.

Clark, L.C., Cosman, M.A., "Terrain Independent Feature Modeling," *Proceedings of the 12th I/ITSC Conference*, November 1990.

Cosman, M.A., Mathisen, A.E., Robinson, J.A., "A New Visual System to Support Advanced Requirements," *Proceedings of the IMAGE V Conference, Phoenix, AZ, 19-22 June 1990*.

Cosman, M., Schmacker, R., "System Strageties to Optimmize CIG Image Content." *Proceedings of the IMAGE II Conference, June 1981.*

Wales, C.E., Cosman, M., "DMA and CIG: A Shotgun Wedding." *Proceeding of the 5th IITEC Conference, November 1983.*

PAR Goverment Systems Corp., "Enhancements to Digital Topographc Data (DTD) Standard Formats and Products for Synthetic Enviornement Terrain Database Generation," *U.S. Army Topographic Engineering Center, 29 Mar 1996.*