Standards for Procedural Terrain Generation

Abstract — This paper proposes art assets, construction scripts, data representation, data streaming and data transport standards designed to improve correlation of procedurally-generated geospatial terrain databases. The introduction of procedural-generation techniques for run-time creation of terrain data into the modeling, simulation and training (MS&T) industry requires new standards such that both simulation system interoperability and terrain data correlation can be ensured. Additionally, procedural-generation standards are required to reduce database production costs, to shorten development schedules, to enable content sharing, and to help minimize the risk of data content being rendered obsolete by innovations in technology.

1 Introduction

The purpose of this paper is to recommend art assets, construction scripts, painting rules, transportation representation, data model and dictionary, data streaming and data transport standards for procedural geospatial terrain database generation in run-time systems. The paper begins with a review of existing procedural technologies - which are the impetus for recommending standardization. Next, the paper introduces a conceptual geospatial data system architecture, that identifies the subsystem components and functional allocation around which these standards are framed. The subsequent sections of the paper details the recommended standards for procedural terrain database generation. The paper ends with a call to action to support procedural content generation standards.

The goal of these recommended standards is to reduce the costs and creation timelines associated with terrain data preparation while maximizing data sharing and improving terrain correlation.

2 Background

The U.S. Army's Synthetic Environment (SE) Core program [1] generates terrain databases for the U.S. Army's Integrated Training Environment (ITE) live, virtual, constructive, and gaming training systems. The objective of the SE Core program is to reduce ITE terrain database production costs by consolidating geospatial production efforts into a single activity. This consolidation eliminates duplicate efforts, and improves both geospatial database correlation and training systems interoperability.

Reducing terrain database production costs has always been a key focus of SE Core. SE Core has made significant progress toward cost reduction as can be seen in the nearly 10X reduction in cost per square kilometer of terrain database production over the life of the program. Much of this cost reduction was achieved through the use of technologies concentrated around procedural content generation. Procedural content generation tools are used in the creation of vegetation models and 3D building models, as well as, the painting of synthetic aerial imagery and the sculpting of elevation data. In the next few paragraphs, each of these areas of procedural terrain generation is introduced.

2.1 Create Vegetation

The commercial tools used in the hand construction of vegetation models are Creator [2], Maya and 3D Studio Max [3]. These vegetation models are used in traditional image generation systems like the EPX-50 [4] and Night Vision Image Generator (NVIG) [5], both of which are part of the ITE training systems. Each of these modeling tools have some procedural methods to accelerate vegetation model creation.

The commercial tool Silvador is used to procedurally create tree models for the U.S. Army Games-For-Training (GFT) Virtual Battle Space 3 (VBS3) databases [6], which is also part of the ITE training systems.

Lastly, Speed Tree [7] and Houdini [8], also commercial tools, are used to procedurally create vegetation models for the visual rendering systems of the ITE training systems.

Additionally, in the game-based runtime systems, grass and bush models are generated using game engine unique material systems. These small vegetation models are automatically generated and are randomly placed in real-time. These models are considered too small to affect correlation between the ITE systems.

Figure 1 provides an example, rendered in VBS3, of tree models that are placed before runtime based on feature data. Figure 1 also provides examples, in VBS3, of grass and shrub models that are generated and placed at runtime based on both a raster material mask and random scatter rules.

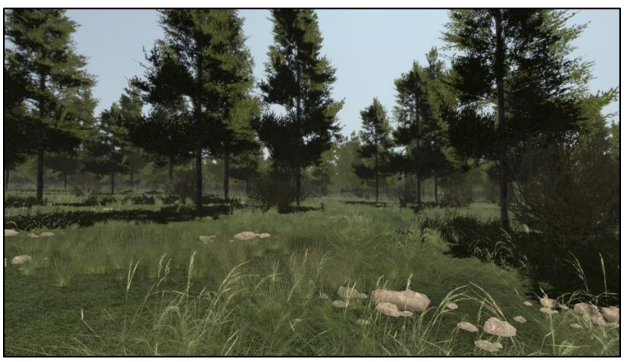

Fig. 1. Procedural Vegetation Example

2.2 Build 3D Models

During terrain database production, landmark features and training site buildings are typically created by hand using skilled 3D modelers. Training site building models are required in a training database to support soldiers during preparation for live training events. The reproduction accuracy of the live training site buildings in the training database is essential to support live training preparation. Also, the accurate representations of these buildings in the training database enables the comparison of live verses virtual training system effectiveness. Creating buildings by hand is costly and time consuming, and is only chosen when no reuse, open source or purchase options are available.

To minimize costs, the majority of the 3D building models in an ITE database are now procedurally created using the automated Procedural Model Generation (PMG) software [9]. The process, known as automated feature modelization, ingests vector feature footprint data, automatically cleans malformed footprint geometry, identifies “like” footprint features, procedurally generates 3D building models from the feature attributes, creates new point features with references to the newly created models and the angle of orientation (direction the front of the building is facing), and updates the feature data with these new point features.

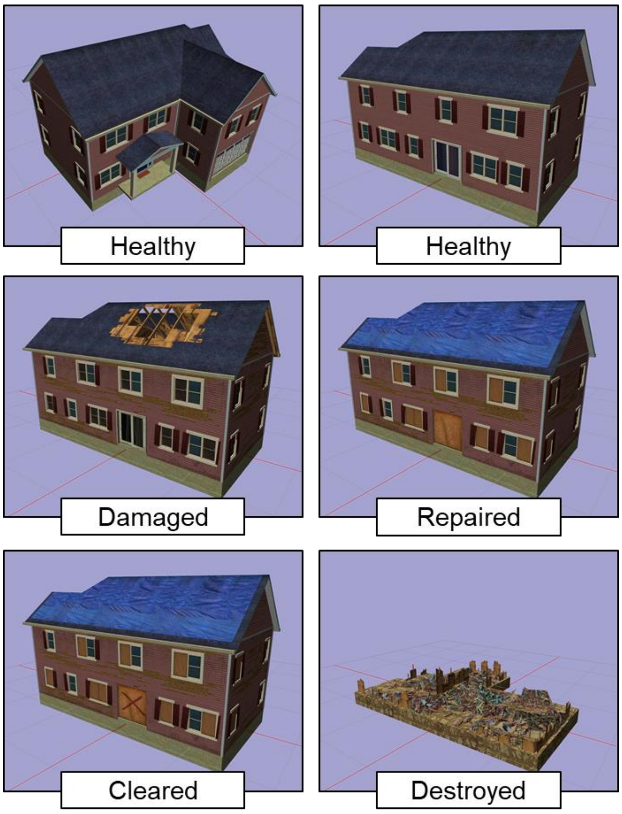

Fig. 2. Procedural Multiple Health States Example

Each training site building model must be produced with multiple levels-of-detail (LODs), multiple health-states, cleared states, and temporally repaired states. To reduce modeling time and cost, the procedural model generation tools must create models with the same complexity and functionality as hand built models. Figure 2 provides examples of the multi-state 3D models that are produced using the PMG software.

The geometric complexity and the range of functional capability of the 3D models created for game-based simulation systems are more costly to produce than models built for traditional image generators. For VBS, Unreal [10], Unity [11], and Vanguard [12] systems, high polygon count models are created with complex geometry including building interiors with functioning windows and doors. Examples of these models can be found in Figure 3 for both VBS3 and Unreal.

Fig. 3. Procedural Building Interior Examples

In addition to creating interior walls with functioning window and doors, procedural methods are also available to populate the interior rooms with cabinets, furniture and other accompanying items.

For each 3D model, special geometry is also created for the target rendering and reasoning system. For example, the VBS3 3D models require a shadow volume, a collision volume, artificial intelligence (AI) pathing, action points associated with the functioning windows and doors, and “roadway” waking/driving surface identification. These geometries can either be built manually, by the 3D modeler, or automatically, using the PMG software. Figure 4 shows a 3D visual model with examples of some of VBS3 LODs that are automatically created.

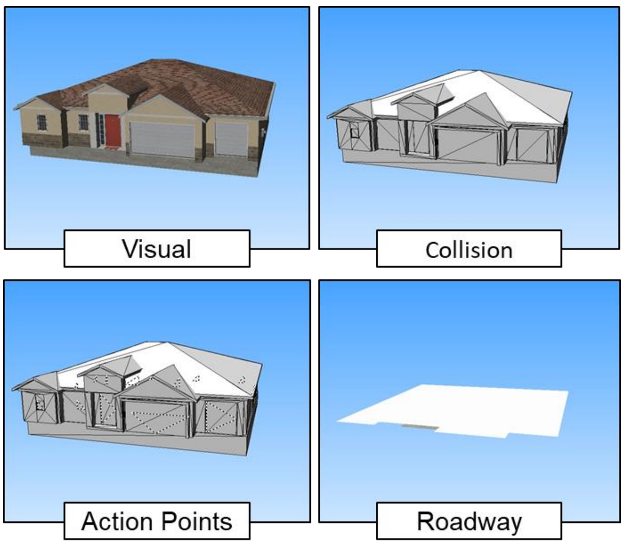

Fig. 4. Rendering System Special Geometry Examples

2.3 Render Aerial Imagery

A procedural imagery generation tool [13] was created to avoid the limitations and eliminate the preparation costs associated with using real aerial imagery. The limitations associated with using real aerial imagery starts in the collection activities where artifacts like cloud cover, snow cover, and seasonal variation, effect imagery quality. These collection artifacts are not easily removed, and are often accepted as limitations of using real imagery.

Nevertheless, once imagery is obtained, unwanted artifacts like cast shadows, cars on roads or in parking lots, tree tops, and unwanted transitory cultural clutter need to be removed. Aerial imagery artifacts, as illustrated in figure 5 and figure 6, are not easily overlooked when, in the visual system, the trainee sees artifacts like “simulated cars driving on tops of cars on the road”.

When real aerial imagery is used in a ground-based training system, specific features must be removed from the real imagery (e.g., tree tops, vehicles, and movable cultural clutter).

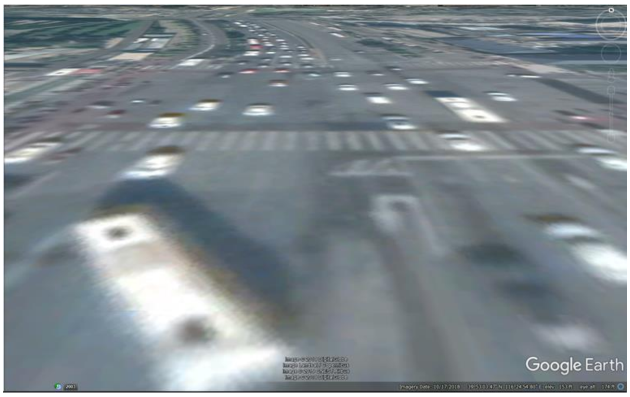

Fig. 5. Google Earth Real Aerial Imagery

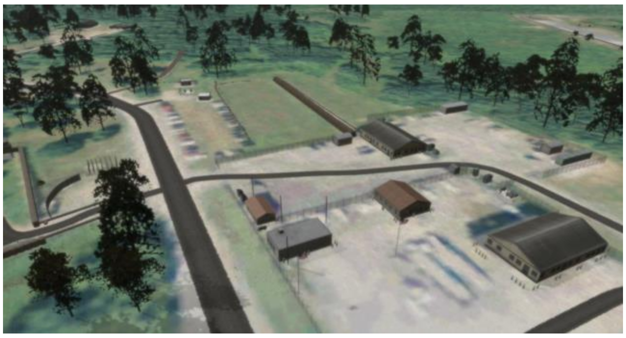

Fig. 6. VBS IG Real Imagery Example

Fig. 7. VBS IG Synthetic Ground Surface Imagery Example

Procedural aerial imagery is used to avoid all of the collection limitations, unwanted visual artifacts and usage constraints associated with real imagery. Figure 7 provides an example of procedural ground surface imagery. In figure 6 the unwanted artifacts such as disparate shadows (two conflicting shadows), cars in the parking lots, and tree tops on the ground can be seen. In figure 7 only the desired 2D surface features appear in the imagery.

Additionally, correlated material maps are required to support sensor simulations. When using real imagery, the imagery must be material classified – that is, each pixel must be assigned a material value that corresponds to the content captured in the color. This process can be time consuming, both in touch labor to train the material classifier and in computer processing time to process the imagery. The time-intensive artifact removal process is necessary, and failure to remove the unwanted features from the real imagery before material classification will cause the material maps to include incorrect materials, like “metal spots on road” where the cars are in the imagery.

Procedurally generated imagery supports the automated creation of material maps, eliminating the need for image material classification. Figure 8 provides an example of procedurally generated aerial imagery with the out-the-window and perfectly correlated material map.

The synthetic imagery is procedurally created using feature data, art assets and painting rules. The art assets are contained in Photoshop documents and include layers for the out-the-window and material textures.

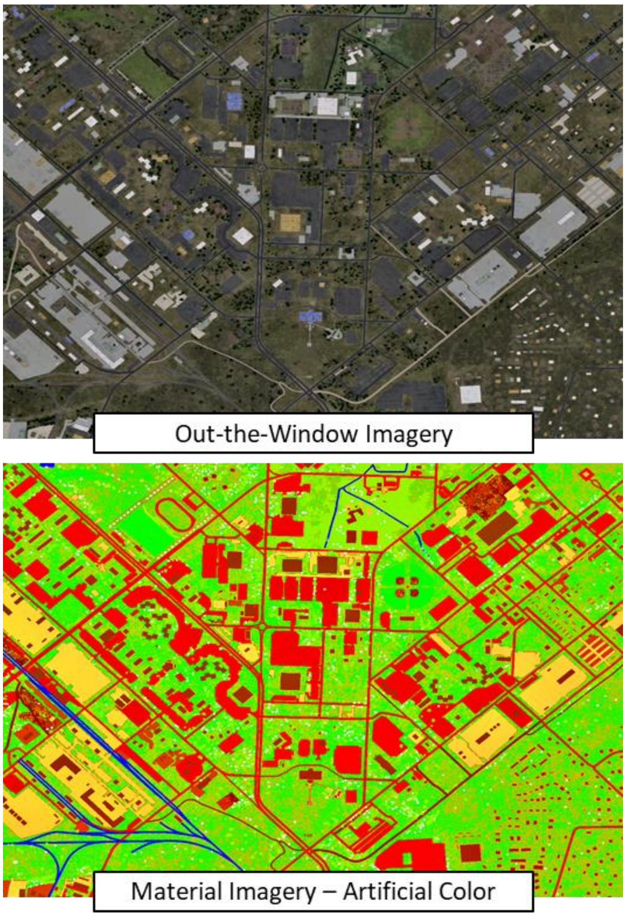

Fig. 8. Procedural Imagery Generation w/ Material Map

When real aerial imagery is used, it is limited to the current season present during image capture. Conversely, when procedural imagery is used, the desired season can be selected as part of the procedural image generation process.

The use of real aerial imagery also limits the training location to a place in the real world and at a specific time in history. Alternatively, procedural imagery supports the affordable creation of imagery for fictitious locations – such as Mission Land [14], for any time, past or future. This enables the simulation of locations like the dense urban terrain of the future, or a location after a natural disaster.

2.4 Sculpt Elevation

Tools to harmonize the spatial relationship between feature data and elevation data are used to procedurally create correlated high resolution terrain. Figure 9 shows a screen capture of a road and overpass with earthen ramps created from a low-resolution elevation data and road and bridge linear features. In figure 9, the top image is before elevation sculpting and the bottom image is after elevation sculpting. The synthetically-generated, high-resolution elevation inset describes the complex surface required to ensure vehicle traversal from road to bridge to road. No touch labor was used to modify the elevation data.

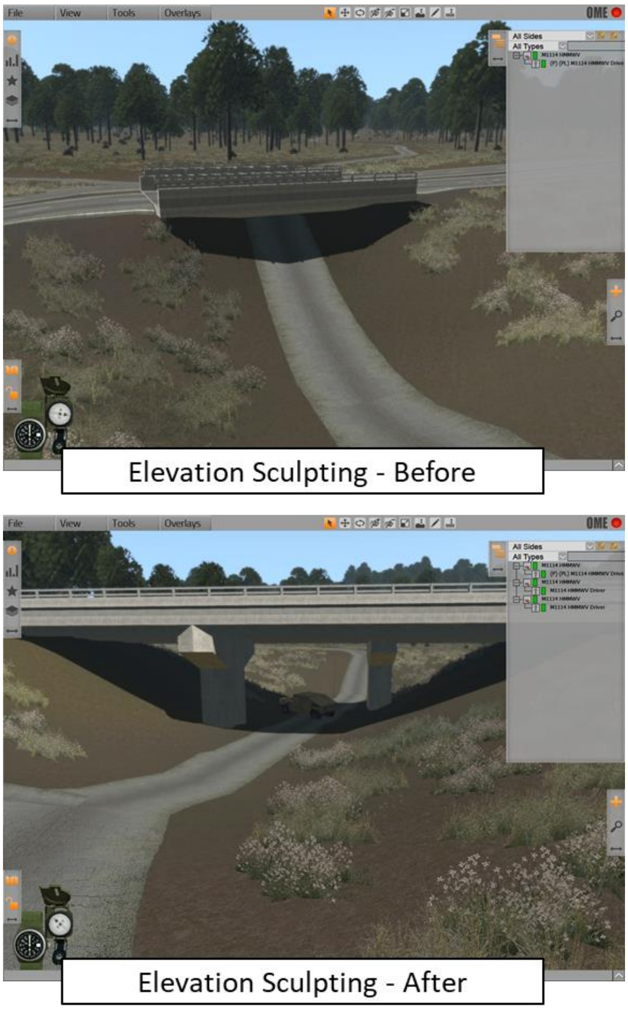

Fig. 9 Procedural High Resolution Terrain Data

The U.S. Army's SE Core program uses procedural terrain generation tools for vegetation, buildings, aerial imagery and elevation data to reduce database production costs, shorten production schedules, increase content density, and improve database quality while providing improved system-to-system correlation.

3 Identified Procedural Processes

Evaluating the procedural technologies used in the current modeling, simulation, and training (MS&T) domains, studying the procedural generation technologies used in the game industry, and reviewing the emerging research in procedural content generation has provided insightful into future technology investments. We have identified seven distinct procedural processes:

1) Procedural creation and intensification of the **terrain surface geometry**. This is done by procedurally creating the terrain surface geometry from raster data. Intensification is done by procedurally fracturing the surface into a more intricate surface. Traditional database generation systems create polygon surfaces in a terrain mesh, smart mesh, an integrated triangular irregular network, or another similar polygon form.
2) Procedural creation of **terrain surface appearance**. This is realized by using feature data, art assets, and painting rules to decorate a realistic looking surface appearance. Some systems call this simulated or synthetic imagery.
3) Procedural creation of **2D surface transportation models**. This is made by creating roads and railroads and modifying the surface geometry by using feature data, art assets, and transportation feature rules. This procedural process also includes creating bridge and tunnel models when required. Some systems place these features on top of the terrain surface and others integrate them into the terrain surface geometry.
4) Procedural creation of **2D surface hydrology models**. This is done by procedurally creating flowing water and water bodies and modifying the surface geometry by using feature data, art assets, and hydrology flow rules (rivers with gravity flow and gravity levels water bodies). Some systems deform the terrain surface to represent the hydrological features and other integrate them in to the terrain surface geometry.
5) Procedural scatter of **3D surface model intensification.** This is accomplished by procedurally scattering point features along linear features or within areal features. Additionally, procedural based intensification is done to add small features associated with other features.
6) Procedural creation of **3D surface vegetation models**. This is achieved by procedurally creating 3D tree and bush models using features with attributes, art assets, and creation rules.
7) Procedural creation of **3D surface buildings models**. This is done by procedurally creating 3D building models using feature footprint geometry with feature attributes, art assets, and creation rules.

The proposed standards cover these procedural processes. Nevertheless, after reviewing the usage of these procedural methods it became clear the standards must be addressed in the context of a geospatial data architecture that defines collection, processing, distribution and usage.

4 Geospatial Data Architecture

Our conceptual training system geospatial data architecture is based on the goal of severing all geospatial data from a central location with the data in the most abstract form as possible. Figure 10 presents our proposed geospatial architecture for the future training systems. The geospatial data is not reposed at a central location, only cached. It is assumed that a low resolution worldwide map representation is always available at every location for situational awareness and location selection.

The data at the central location is pulled from approved source providers, processed to provide a single, unambiguous representation of the requested geospatial location, augmented to support the desired training, and then delivered to the point-of-need, on-demand.

The approved source data includes world-wide map data based on, national and international authoritative repositories, local and regional resources, and collections specific to a mission or location (drone collected, hand modeled, etc.). The Real-Time Consumption Machine automatically mines data from a defined set of approved source collection sites.

The source data is collected as sites are updated and the demand is established.

The Real-Time Consumption Machine, requests and receives the source data on a pre-determined schedule; automatically cleans and conflates these sources; and tailors the data to the requesting system's needs. This includes extracting features and attributes from imagery, LiDAR, photographs, and videos to support procedural creation. It also adapts the data to support the requestor's bandwidth, computational resources, and system constraints. The tailoring accommodates the compromises required for the runtime systems and what is required to support the training objectives.

The On-Demand Streaming Machine presents the data to the runtime systems. On-demand the data is either:

1) Stream Layers: stream in the most abstract form possible from the central location to the point-of-need, then instantiated into a concrete form and visualize on the edge device;

2) Stream Mesh: instantiated in real-time, at the central location, to a concrete form (e.g. terrain polygon mesh) and then stream to the point-of-need and visualize on the edge device; or

3) Stream Video: instantiated in real-time at the central location, to a concrete form and visualize, and then stream as video to the edge device.

At the central location, in a Real-Time Consumption Machine and On-Demand Streaming Machine, the data is cached in an abstract form:

- **Terrain surface geometry** data is reposed as high resolution point data and derived in real-time at the desired fidelity and in the desired form.
- **Terrain surface appearance** data is reposed as art assets and representation rules, combined with the feature data and rendered in real-time at the desired resolution. Compressed full color imagery along with classified imagery provides an alternative storage of the terrain surface appearance.
- **2D surface features (transportation and hydrology)** data are reposed as art assets and representation rules, combined with the surface

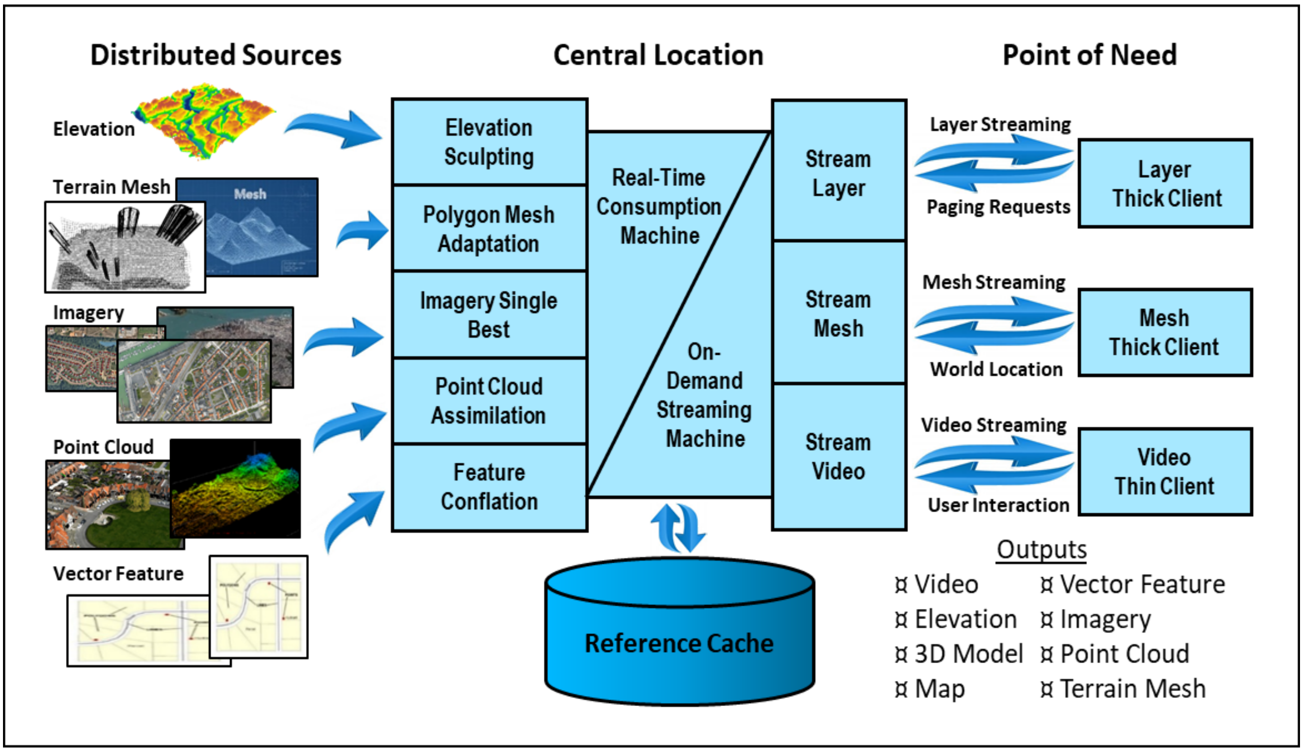

Fig. 10 Conceptual Geospatial Data Architecture

feature data, and rendered in real-time at the desired complexity. Transportation and hydrology may be represented in the segmented and classified imagery.

- Geo-typical **3D surface models (vegetation and buildings)** are reposed as art assets and construction rules and procedurally **intensified** and generated into 3D models using feature data, in real-time, at the target fidelity
- Geo-specific **3D surface models (vegetation and buildings)** are reposed as complete 3D models, and placed by the feature data in real-time. As an alternative to feature data placement, geo-specific models may contain location.

It is acknowledged that, at a central location, the terrain data could be precompiled (instantiated ahead of time). This is the general practice today, and is considered something that is no longer desired for future training systems.

6 Recommended Standards

Consistent with our Conceptual Geospatial Data Architecture, we recommend a number of interface and data standards that supports our procedural terrain generation vision. These standards promote both content reuse and improve interoperability when used in the creation of terrain data on the rendering and reasoning systems. The following sections outline our recommended standards.

6.1 Standards for Feature Attributes

Enhanced feature attributes are desired to improve the automated creation of geo-representative 3D building models using procedural generation techniques. A typical building feature from Vector Map (VMAP) or Open Street Map (OSM) contains only footprint geometry, building height and building function type attributes. From this information, a geo-typical building can be created.

However, to create a more geo-representative building requires additional feature data attributes. For example, if we are interested in a 3D model of a house that looks like the house pictured in figure 11, we need many additional feature attributes to accurately represent the residential model.

Fig. 11. Desired House Recreations

For example, building height or number of stories, exterior wall colors and materials, roof type, colors and materials, gable placement, and apertures (doors and windows), and appendages (chimneys, A/C units, utility boxes, stand pipes, etc.) can all be used to procedurally create a more representative 3D house model. Figure 12 shows a procedurally generated model based on enhanced feature attributes identified from the building photograph shown in figure 11.

Fig. 12. House Created from Enhanced Attributes

If building interiors are required and enhanced feature attributes are available, these enhanced feature attributes can be used to speculate the layout of the interior. Some speculations are relatively straightforward, for example, for the above house model, the garage doors open into the interior garages. Others speculations, are more heuristically derived — the large picture window in the front of the house is the living room, the small windows are associated with bathrooms, the medium sized windows are associated with bedrooms. Interior speculation rules are unique for each building type, supporting a wide variety of interiors.

To define features and attributes requires a well-defined data model. It is recommended that a **standard data model** be selected. It is very important to the tools used to procedurally generate terrain that the data model include explicit feature relationships. The inclusion of explicit feature relationships allows for the correct generation of related and adjacent features.

Of consideration is the U.S. Army's Geospatial Center's (AGC) Ground-Warfighter Geospatial Data Model (GGDM) [15], but this is not an international standard data model and does not contain all of the enhanced attributes required to support geo-representative 3D models. Also of consideration is the Open Geospatial Consortium (OGC) CDB [16]. Although it is an international standard, and has a good feature and attribute definitions, it lacks essential relationship and enhanced feature attribute definitions. The Simulation Interoperability Standards Organization (SISO) Reuse and Interoperation of Environmental Data and Processes (RIEDP) has the opportunity to address the data model needs [17]. Unfortunately, the RIEDP standard will compete with existing standards that are already complete and in-use today.

To create correlated procedural geometry, it is critical that all systems agree to the definitions and share an understanding of the features, which leads to the use of a **standard data dictionary**. Of consideration is the SEDRIS Environmental Data Coding Specification (EDCS). This dictionary would be ideal for this purpose, however it is not widely adopted [18]. The U.S. Army's most recent data dictionary is the National System for

Geospatial-Intelligence (NSG) Feature Data Dictionary (NFDD) [19]. The National System for Geospatial Intelligence (NSG) Core Vocabulary (NCV) Standard (2018-05-23) Edition 2.0 from National Geospatial-Intelligence Agency (NGA) [20], which is replacing NFDD, is of primary consideration. Unfortunately it is again not an international standard. Internationally, the Defence Geospatial Information Working Group (DGIWG) Feature Data Dictionary (DFDD), which NFDD is derived, could be a candidate. However, NFDD is already deprecated and replaced with the DGIWG Defence Geospatial Information Framework (DGIF) [21]. DGIWG is the multi-national body responsible to the defence organizations of member nations for coordinated advice and policy recommendations on geospatial standardization issues.

Regardless of which data model and data dictionary reaches widespread adoption, both a well-defined and content-complete data dictionary and data model are required to support a comprehensive geospatial data representation. The model and dictionary must include both the manmade features, and the features representing abstract concepts like political and property boundaries, restricted air space, and name labels found on maps. The data model and dictionary must also contain, or allow addition of, the enhanced attributes necessary to describe geo-representative feature. The NSG Core Vocabulary is the recommendation at this time. A data model is still needed.

6.2 Standards for Transportation Features

Transportation features are the most important and prominent features for ground-based training systems. Defining how roads are represented in the surface geometry determines how well the systems will operate, correlate, and interoperate. It is necessary to have standards that describe complex transportation features. Rules for how roads are procedurally created will ensure correlation when these procedural techniques are applied. It is recommend the **road representation standard** include the level of fidelity defined in OpenDrive™ from Association for Standardization of Automation and Measuring Systems (ASAM) [22] or Intelligent transport systems (ITS) — Geographic Data Files (GDF) GDF5.1 — Part 2: Map data used in automated driving systems from International Organization for Standardization (ISO) [23]. Both include features such as: lane lines, turn lanes, stop lines, cross walk markers, signs, signals, etc. Like other types of features, transportation features require a good data model representation to procedurally generate consistent and correlated roads.

Critical in the procedural generation of traffic signals is the association of the signal lights to the control or behavior of the lights. Some signals are timed, some have traffic sensor logic, some include time-of-day and time-of-week logic, some are controlled as larger signal groups, and some even have centralized traffic controls. Connecting signal lights to the desired control must be done within the procedural generation.

GGDM and OGC CDB both have a road definition, unfortunately both lack a complete characterization of high fidelity transportation features. The SISO RIEDP has an opportunity to address these transportation data model needs, but this standard is years away from approval. OpenDrive can be a good data model for certain uses, but is narrowly focused on transportation features for modeling and simulation applications. OpenDrive has recently transitioned to a mature standards organization, so there is expectations for improvements and promotion of the standard. The ISO standard is near completion and is similar to the OpenDrive Standard. The ISO GDF5.1 — Part 2 Map Data Used in Automated Driving Systems standard is focused on the needs of the self-driving vehicle industry. The ISO standard is being adopted by big players in the automotive industry, and will likely become the standard of choice for transportation feature representation. The ISO standard is considered the most likely candidate.

6.3 Standards for Streaming Features

The OGC Web Feature Services (WFS) provides streaming of point, linear and areal features [24]. It is recommended that OGC WFS be adopted as the **standard for streaming feature data**. It is also recommended the definition of these streamed features, their geometry, and their attributes be more rigorously specified to support consistent usage. We recommend using OGC WFS and companion standards for streaming the layered data. This is an example of streaming in the most abstract form possible from a central location proposed in our Conceptual Geospatial Data Architecture.

6.4 Standards for Transporting Features

When streaming is not available and data must be **transported on media**, it is recommended that GeoPackage [25] be adopted as a transport container for features and other layered data. It is recommend the NSG Application Schema Profile [26] be adopted and matured.

6.5 Standards for Intensification (Scatter)

If content intensification methods are to be used, it is critical that standards are created and used. These standards must include scatter parameters created on the server or scatter rules used on the client side. Adherence to standards will ensure correlation of intensified features on disparate clients. This is an area that requires additional work, as no existing standards are currently identified.

6.6 Standards for Model Procedural Generation

Automatically generating 3D models for use at the point-of-need will minimize the throughput requirements for streaming content. Consequently, we recommend the adoption of three standards: 1) construction rules, 2) art asset content, and 3) model functionality for procedural models.

6.6.1 Construction Rules for Procedural Models

It is recommended that a standard for the rules to generate 3D models be created. Of consideration is the Esri® Computer Generated Architecture (CGA) specification [27]. CGA's are the construction grammar of Esri's CityEngine™, used to generate architectural 3D content. Figure 13 provides a snippet of a CGA.

It is noted that the current CGA specification does not have all of the required or desired functionality, and that once adopted by OGC, enhancements will be required.

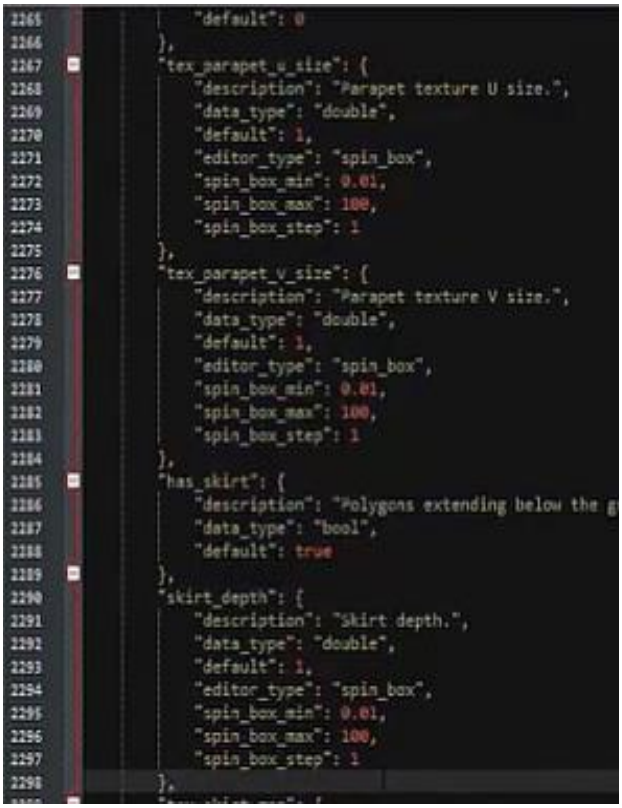

Fig. 13. Computer Generated Architecture Snippet

6.6.2 Art Asset Content for Procedural Models

To complement the construction rules, it is recommended that a specification define rules for the art asset content that supports the procedural model generation tools. These rules must define texture spatial resolution, wrapping and tiling schemes, map types, and any other attributes that ensure reusability. For modern game engines, this includes advanced texture techniques. It is recommended that an art asset standard provide the ability to separate the assets in layers and include labeling and metadata to enable long term maintenance. It is suggested that a file format similar to the Adobe Photoshop Document (PSD) [28] be used. To complement the PSD specification, a specification for the content within the PSD file is proposed. Figure 14 provides an example of the layer definition within a PSD. No PSD content specification is identified for consideration, nonetheless multiple organizations have indicated that they have documentation that could be a starting point for a standard.

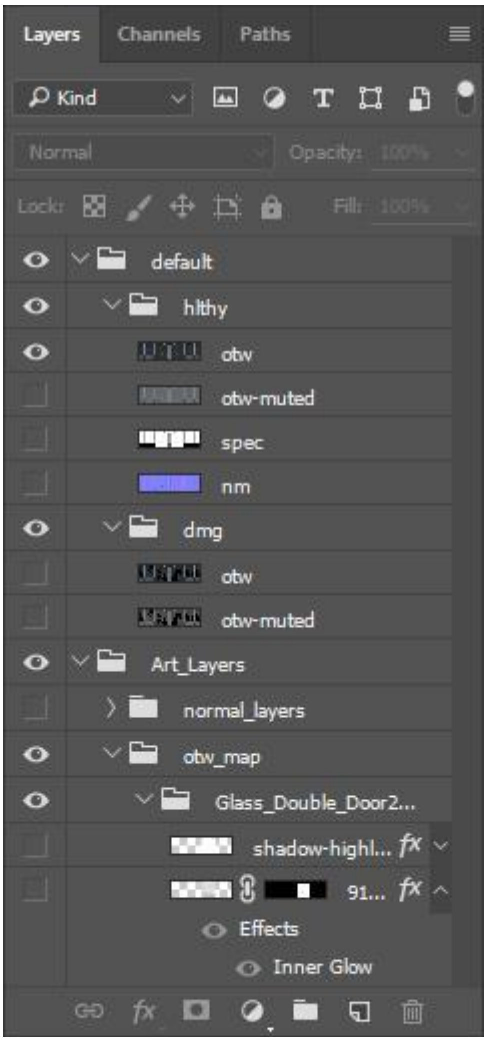

Fig. 14. PSD Layer Definition Example

6.6.3 Model Functionality for Procedural Models

To support the unique content required of runtime training systems, a method for defining these special characteristics is required. These include defining methods to describe the multiple health and repair states, encoded mission function data, behavior geometry and attributes, multiple levels-of-fidelity and multiple levels-of-detail. As noted in Section 2.2, these definitions are often unique to the rendering or reasoning systems. It is important that these system-unique special characteristics be generalized to provide support for current systems and help minimize the impact to support emerging future systems. No standards have by identified for consideration.

6.7 Standards for 3D Models and Terrain

Procedurally generating terrain at the point-of-need, reduces the network bandwidth usage. However, it also places a large computational burden on the edge devices. Even if the edge device can support the high computational load, it may be more desirable to stream the ready to visualize geometry. This includes streaming individual 3D models, as well as, streaming complete terrain surfaces.

6.7.1 Standards for 3D Models

Landmark 3D models are most likely created pre-runtime, reposed in a central location, and streamed to the point-of-need on-demand. These models may be generated with touch labor and represented in a 3D model formats like OpenFlight [29] or Filmbox [30]. Alternatively, these models may be LiDAR scanned or photograph and photogrammetry derived and represented in a polygon mesh in a file format like Wayfront's .obj [31]. Regardless of the method of creation, these models must be efficiently represented and streamed.

6.7.1.1 Standards for 3D Models Files

It is recommended that a common 3D model definition be agreed upon. This definition needs to include standards for organizing geometry hierarchy in a consistent and reliable component-labeling scheme. All apertures and appendages must be defined and able to be referenced. The standard must explicitly define the relationships of model components. The standard must define the rules for LOD creation and support the explicit definition of LODs. Standards for materials must be defined [32]. Past and current organizations have such model standards, like the (former) Advanced Project Research Agency (ARPA) War Breaker World Reference Model Entity Flight Specification [33] or the OGC CDB OpenFlight best practices [34]. A common standard must be identified or created. It is recommended, for consideration, that a modern format standard for models be selected and a content specification be developed.

6.7.1.2 Standards for 3D Models Streaming

Once created these models must be efficiently streamed. A standard is recommended to support 3D model geometry streaming. The Khronos Group, OGC and ISO have standards for steaming 3D model geometry, but none provides the functionality and content complexity required to stream complex 3D models use in M&S application. We recommend working to extend a standard for efficient 3D model geometry streaming. The Khronos Group promotes the GL Transmission Format (glTF™) for the efficient transmission and loading of 3D models [35]. glTF minimizes both the size of 3D assets, and the runtime processing. For consideration, glTF and a new content specification will provide the desired standard.

6.7.2 Standards for Terrain

In addition to individual models, terrain must also be created and streamed in an efficient format, when required. This is required when the terrain is created at a central location and streamed to the edge device.

6.7.2.1 Standards for 3D Terrain Files

OpenFlight terrain tile files and Wayfront's .obj files are the two common formats used today to store 3D terrain. OpenFlight is feature rich, and in wide-spread use within the MS&T industry. Wayfront .obj files are small, very efficient, and supported by most commercial graphic applications. However, both will require a content specification to provide guidance on how to represent specific MS&T data constructs. OGC CDB includes OpenFlight, but not for terrain. OGC CityGML is also a candidate [36]. Further requirements maturation is required. No formal recommendation is identified.

6.7.2.1 Standards for 3D Terrain Streaming

The OGC 3D Tiles standard is designed for streaming of massive 3D geospatial content such as Photogrammetry, 3D Buildings, Building Information Modeling (BIM), computer-aided design (CAD), Instanced Features, and Point Clouds. The 3D Tiles standard defines a hierarchical data structure and a set of tile formats which deliver renderable content to the point of need. The OGC 3D Tiles standard does not define explicit rules for visualization of the content; a renderer may visualize the 3D Tiles data however it deems suitable. Consequently, the rendering of the 3D Tiles needs to be defined - similar to a 3D model definition. Because a 3D tile can include 3D models, it must include all of the functionality associated with a 3D model. This definition must include geometry hierarchy and labeling scheme that provides the necessary content capability.

For alternative consideration, the OGC Indexed 3D Scene Layer (I3S) and the Scene Layer Package Format (SLPK) Specification [37] offers a potential starting point.

Further requirements refinement is required. No formal recommendation is identified.

6.8 Standards for Transporting Models

Furthermore, when streaming content is not available and model and terrain data must be transported on media. It is recommended that a format be adopted for models and terrain. This is likely the format they were created, but alternatives should be considered.

Similarly, file formats should be selected for Photogrammetry data, 3D Buildings data, Building Information Modeling (BIM) data, computer-aided design (CAD) data, Instanced Features, and Point Clouds.

Further requirements refinement is required. No formal recommendation is identified.

6.9 Standards for Procedural Imagery

High-resolution imagery places a big demand on both server and client storage systems and burdens network throughput to deliver the imagery. Imagery resolution pyramids are very helpful to manage network throughput; however, visual simulation requires both unity and zoom sights simultaneously. When a magnified sight is required, imagery pyramids may not be adequate to render properly. With new sensor technology providing greater than100X magnified site, high-resolution imagery is needed at long ranges and for 360 degrees around the eye point. For ground-based training, very high resolution imagery is required. Procedurally generated imagery, at the point-of-need, can provide the ground surface appearance with minimal impact to the network. Accordingly, rules and art assets are recommended.

6.9.1 Rules for Procedural Imagery

It is recommended that a standard for the rules to paint synthetic imagery be defined. This will be similar to CGAs for 3D models, but for imagery. It should include the rules for multiple types of imagery, to include ground surface, aerial imagery, and associated material maps to facilitate sensor representation. Today, multiple vendors are offering commercial tools for procedural imagery, and there are a number of government owned procedural imagery tools available. nVidia is leveraging an generative adversarial networks (GANs) to convert simple drawings into beautiful landscapes [38], which could provide additional innovation to the synthetic imagery creation process. Regardless of the method used to create synthetic imagery, standards are desired to ensure reuse of art assets and to establish the required outputs, to include material maps.

6.9.2 Standards for Art Assets

It is recommend we define standards for art assets that support the synthetic imagery generation. This art asset standard should be common to the standard required for procedural 3D model generation. Again, the art asset should include the layers and include labeling and metadata to enable long term maintenance.

6.10 Standards for Materials

There are many commercial products that support material map based sensor simulation like JRM's SenSimRT [39] and Renaissance Sciences Corporation (RSC) SimHDR-IR [40]. However, there are limited standards for material definitions. The U.S. Navy has created NAVAIR Portable Source Initiative (NPSI) Standard for Material Properties Reference Database (MPRD) [41], but minimal adoption has been achieved. The OGC CDB standard has a material list, but it appears to be focused on the scope of its mission rehearsal origins. RIEDP is working on a material list that may evolve to address the needs of modern sensor simulation systems. It is proposed that an industry defined material list with attributes be created.

6.11 Standards for Building Interiors

After an extensive search, no standards were identified for the procedural generation of building interiors. Some research was found on the use of deep learning for the automated generation of floor layouts for residential homes. The approach used by the PMG software was identified as too-immature for public presentation. It is recommended that research be dedicated to this area of need.

6.12 Standards for Sculpting Terrain

Many Database Generation Systems (DBGS) implement software to perform some form of terrain sculpting. These software products represent decades of development and testing to achieve reasonable terrain output. Likewise, runtime rendering systems that have implemented procedural generation of terrain surfaces have significant investment in development and testing. None of these systems publish their methods and none promote standardization of their methods. It is recommended that research be dedicated to this area of need, if an industry sharable approach is to be made available.

7 Conclusion

Today, runtime formatted terrain databases are built in advance of the training event, using specialized DBGS software. Terrain correlation and system interoperability is accomplished by generating all of the runtime databases at the same time, with the same content, and then distributing these databases to the corresponding simulation systems prior to the training event. This traditional terrain database production approach requires significant lead-time.

Procedural generation techniques are used in DBGSs to make the runtime terrain databases production processes faster and more affordable. This helps to reduce the terrain database production lead-time, but does not eliminate it.

It has recently been portrayed that by using a single runtime rendering and reasoning system in a networked training environment the terrain database production process can be fully automated and interoperability issues be eliminate. But, using a single runtime system is very unlikely – because newer technology always emerges. It is suggested that employing data and interface standards that promote consistent use is a move sustainable solution.

The goal of these proposed procedural standards are to support the generation of terrain databases that ensures terrain correlation and system interoperability and meets the training need - regardless of whether it is fictitious countries with political unrest, a futuristic city with massive populations, extreme winter, or just a live training range.

The move to procedural generation of terrain on-demand at the point-of-need ensures that the network limitations and intermittent connectivity can be managed without loss of training capabilities.

It is recommended that the MS&T community support the efforts to develop standards for procedural terrain generation. Specifically, it is recommended that the MS&T community promote the CGA specification as an OGC standard, and support the development of complementary art asset and model functionality standards. It is recommended that the MS&T community support the development of painting rules and art asset standards for procedural imagery generation. Last it is recommended that the MS&T community support the SISO RIEDP effort in the development of a materials standard for use in the SISO RIEDP and OGC CDB standards.

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