Psuedo-Specific High-Resolution Data Boundary Techniques

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ABSTRACT

Training requirements for a variety of platforms are quickly expanding to include larger and larger gaming areas in response to customer demand and the availability of data. However, there still remain several drawbacks to using worldwide high-resolution photo-specific data: size of the data, the ability to correlate data with sensor and SAF versions, the time required to validate and correct data. Instead using auto-generated simulation models coupled with real-world data to quickly and economically create training environments remains an attractive option.

This paper describes two techniques recently developed to build realistic terrain texture that is pseudo-specific data (from low resolution data, i.e., Feature Identification Codes, or FICs). When using low resolution theme data resulting textures can appear "blocky" and unnatural. One way to improve this is to super-sample the boundaries between themes to a higher resolution in such a way that they appear more natural and less blocky when viewed up close. Stencils are defined for blending two or more theme types to create natural looking edges. Multiple stencils applied in specific ways are used to vary edges thereby avoiding repeating image patterns. Next, the super-sampled theme data is used with correlated templates of three-dimensional features to generate 3D content on-the-fly without the need of "pre-compiling" or "publishing" the database. The end result is the appearance of higher resolution terrain texture with accurately correlated 3D features.

ABOUT THE AUTHORS

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INTRODUCTION

Training requirements for a variety of platforms are quickly expanding to include larger and larger gaming areas in response to customer demand and the availability of data. Having sufficient resolution for a realistic whole Earth database provides flexibility for a simulator to be flown anywhere the user finds useful without having to build a new database. Simulators with whole Earth databases can be used for worldwide mission preparation. Fast Jet or fixed wing simulators need to provide coverage for a wide area of Earth as these aircraft can cover a large gaming area in a single training mission. How can we build a database that supports the ground surface resolution needed by a dismounted soldier and the wide expanse of geographic coverage needed by a fast jet such that the databases are correlated with each user and on sensor channels?

In a virtual environment simulation, the distant (or high-altitude) visual scene is largely characterized by the texture that is applied to the terrain skin. In the near scene, however, the terrain texture must be accompanied by a suitably dense overlay of 3D decoration that is appropriately correlated with the texture. The texture source, then, becomes a significant factor in how easily and effectively we can provide this correlation. We can assume two things, given the state of the technology: we cannot afford high-resolution photo texture everywhere; and we cannot afford the 3D feature density of the real world. Our approach must, of necessity, be a compromise, and likely based on the particular requirements of each system.

Broadly speaking, there are two options: start with photo-specific terrain texture and correlate an overlay of 3D features, or start with theme based terrain texture which can intrinsically include the 3D feature overlay. Photo-specific texture provides excellent, realistic looking databases but takes a considerable amount of data to populate a database, and the correlated 3D overlay involves a lot of manual labor. Theme based databases are easier to build and much more compact, but do not look as good. The theme-based approach could also be called a photo-derived geo-typical strategy, where the texture derives from photos of various types, melded together intelligently to correlate with the geo-specific FIC data. In other words, it is a photo-typical approach.

This paper will describe the differences between photo-specific and theme based databases. Advantages and drawbacks to each type of database will be presented as well as a recommendation presented for training applications that would benefit from a theme based approach. Finally, the paper will describe a technique that has improved the ability to make readily available theme based data more realistic.

Some Definitions

Photo-specific refers to the use of aerial or satellite photographs which have been mosaicked together to provide a continuous texture overlay that is geographically specific and unique. Significant off-line processing is needed to remove artifacts such as perspective layover, cloud cover, shadows, discrepancies in exposure/saturation/time-of-day/season, and (potentially) the presence of dynamic things like vehicles. Depending on the required highest resolution, photo-specific terrain texture can be a huge amount of data. The photo-specific approach creates the most realistic imagery, and the best correlation with the real world.

Global Land Cover Characteristic Data (GLCC) is a geographic raster data structure where the elements of the raster denote the type of land cover at each place. There are a variety of types of this data, at various resolutions.

Generally, 1KM data is available for the entire planet, and higher-resolution data is available for many areas of interest. The elements of the raster consist of individual FIC codes.

Feature Identification Codes, or FICs, denote the surface coverage in a somewhat abstract and macroscopic way. For example, FIC 24 may identify an urban area whereas FIC 82 would identify cool irrigated cropland.

A Theme is a block of texture, derived from an aerial photograph, which correlates with a particular FIC code. Where the FIC resolution is 1KM, the block of texture would cover a square kilometer; higher-resolution FIC data would cover smaller areas. The photo is processed to remove, as far as possible, artifacts that are naturally encoded into photographs but which are troublesome in this application, as previously described. Figure 1 illustrates some typical themes.

City Ground | Irregular Rice Fields | Cropland 1 | Cropland 2

Figure 1 – Various Theme Textures

The Theme Library consists of a number of themes that have been processed so they can be juxtaposed with reasonable boundary matching. It may include multiple themes associated with any particular FIC, since we want to avoid distracting repetition in the composited texture result. Note that we will sometimes use Theme and FIC interchangeably to refer to the underlying land cover characteristic.

The following sections describe the advantages and drawbacks of using both photo-specific database as well as theme-based designs. Note that in a robust system, one can combine both theme-based and photo-specific approaches so that areas of particular importance can be photographic, while the large expanses of "background" earth can be created with the efficiencies of the theme approach.

Photo-Specific Databases

Photo-specific databases have several compelling properties. They are extremely realistic, instantaneously recognizable, easily correlated with their real-world counterparts, and convey operational cues in a powerful and natural way. In the absence of practical constraints, this would be the way to make every database. However, the very things that make a photo so compelling are at the same time stumbling blocks relative to other aspects of the simulation.

In discussing the issues that attend the use of photo-specific texture, we should note that image compression algorithms are limited in their power, and that even mild compression ratios introduce visual artifacts that may have operational significance. Defects that may be subtle on organic texture motifs like forest and meadow may be particularly noticeable on cultural motifs that include buildings, roads and hard edges. Assuming the real-time system can use compressed texture and decompress it as it is paged from disk to texture memory, useable compression ratios may still be as low as 8:1 (JPEG).

The amount of texture needed is a function of resolution and geographic area. For example, an RGB texture at ¼-meter resolution with 8:1 compression uses six megabytes per square kilometer; a geo-unit of gaming area (one square degree) would be about 75 gigabytes, and a typical fast-jet database might be 100 geo-units. Seasonal and time-of-day requirements may significantly increase this. For these reasons, the photo-specific approach is usually used for insets into a more generic background.

An additional consideration is that the 3D feature decoration that overlays the texture must be specifically developed from the photos themselves, in a process that is still largely manual. For example, each building whose footprint appears in a photo must be correlated with an appropriate type from a feature model library, with a specific instance vector that includes position, rotation and scale. The same process is necessary for trees. For dense 3D environments this can be a significant amount of effort.

The file size of a worldwide photo-specific database can be prohibitively large. Photo data cannot be compressed to the same level theme data can. Depending upon the application multiple photos may be needed over the same area. The application will require higher level of detail for low level flight versus the detail needed for high level flight. As the eye gets closer to the terrain more detailed texture is needed to keep the texture from appearing blocky. The level of detail required from the chin window of a helicopter would need to be in “centimeters” not “meters”.

Photo-specific data does not support sensor simulation well. For sensor simulation, the red green blue (RGB) of photo only defines the color of the visibly reflected light; it does not tell anything about the material itself. Sensor simulation requires a material in order to simulate heat signatures and thermal fade. While there are some tools available commercially to help automate the process, identifying and tagging the objects in the photo is still a manual process that can be very time consuming. Infrared and ultraviolet must be recorded as additional photos which need to correlate with the RGB photo for accuracy when viewing the same scene through a visual and a sensor channel. The time required to validate and correct the sensor data can also be prohibitive as well as the ability to correlate photo-specific data with sensor and SAF versions.

Photo-specific texture captures a specific time of day and season. The real world varies relative to the time of day and the seasons. Multiple versions of photo-specific images may need to be captured to represent the scene acceptably. For example, a winter season in an area with significant snow coverage would require a post process or second set of satellite images for a ‘whiter’ scene. This requires twice the storage space and multiple recording of the same area; preferably all taken at about the same time to limit the chance the scene has changed in the real world. Ideally photographs are all taken at a consistent time of day and season. Photo-specific images can also require a post process to remove cloud coverage conditions and to make the illumination uniform.

Another disadvantage to photo-specific images is that the shadows are baked in. Dynamic shadows are an emerging technology that enhances the scene greatly to deliver realism and convey a time of day. Baked-in shadows provided by photo-specific images are taken at a snapshot in time and need to be minimized or removed so as not to confuse the viewer, provide a false representation of time of day, or show a duplicate shadow image if dynamic shadows are also provided by the image generator. Ideally photographs all are taken at high noon to minimize the shadow effect. Photo-specific images should also be taken from directly overhead to minimize perspective issues. Inevitably, it is not possible for all satellite imagery photos to be taken under the same ideal conditions and removing baked-in shadows from the photos is a difficult (if not impossible) and time consuming process.

Lastly, photo-specific images contain moving objects that are not moving; cars on roads being the primary culprit. As image generator technology improves, the ability to add three dimensional objects to simulate moving traffic becomes more common. Again, to avoid duplication of features, a manual process to remove traffic from roads would be needed. In general, the problem with photo-specific data is that it captures “what it looks like” not “what it is.” To simulate the scene we need to know “what it is”. Theme-based data tells us “what it is” and therefore does not have the “what it looks like” problems. The following section describes the advantages and draw backs of theme-based data as well as two ways to improve a scene that uses this data.

Theme-Based Database

Now let us talk about the problems and limitations of a theme-based database then we will present the advantages. First we need to understand that a theme cell is still a photograph and thus the problems mentioned above still apply. However theme-based data introduces new problems that also need to be addressed.

Because each theme is a patch of photo, it does not inherently tessellate with itself or naturally join with other theme cells. These problems must be solved off-line or at run time. Completely generic and homogeneous themes like forest, dirt or grass can be made to tessellate rather easily, but one needs to be careful to remove low-frequency stuff that creates a “glen plaid” visual effect in the distance. More complex themes that contain a mixture of fields, roads, structures etc. are very difficult to tessellate or combine with unlike neighbors. Unfortunately, these are the themes of highest visual significance.

Since the theme cells are geographically small (typically 1 km), we will need a number of variations, and a scheme to randomly mix them together. Theme cells are small but the fidelity of the theme source is low (i.e. large areas of homogeneous areas), so there is a huge visual repetition problem which is only slightly solved by having lots of variations of each theme. Since theme cells need to fit together, all the theme cells in the library need to be acquired at or resampled to the common theme resolution (e.g. 4 meters.)

Many regions only have 1km Global Land Cover Characteristic Data (GLCC); this resolution is too low to be practically useful. Figure 2 shows an example of land-use data that is commonly available at various resolutions around the world. High resolution theme data is not available everywhere. Typically 1km GLCC data is available for the whole Earth and this is insufficient resolution even for outlying terrain areas.

There are, however, some powerful advantages to the theme-based approach. By using theme data the scope of the photo collection problem is greatly reduced. For example, we only need to gather one pine forest theme under near-ideal conditions instead of photographing all pine forests under near-ideal conditions. It is much easier to collect the photographs desired for a theme based database since the amount of data is greatly reduced. The resolution of the theme texture is decoupled from the resolution of the controlling FIC matrix, so you can introduce higher resolution theme texture by simply modifying the theme library, and changes made to the library automatically appear in the rendered image. The work to provide correlated 3D features is related to the size of the theme library, not the geographic extent of the database. Each block of theme texture can have an associated set of correlated 3D features that are also rendered along with the terrain texture. It is easier to provide alternate themes for each particular FIC to provide day/night and seasonal variations, and the sensor correlation problem is greatly simplified. Because the terrain texture is assembled from the theme library using the information in the FIC matrix, the amount of data that needs to be stored and read from disk is orders of magnitude smaller.

The most significant problem, already alluded to, is that FIC data is not available at the desired resolution for all the areas we wish to simulate. This paper introduces a technique for synthetically improving on the available low resolution FIC data. By intelligently synthesizing higher-resolution information, we improve scene realism and greatly relax this limitation.

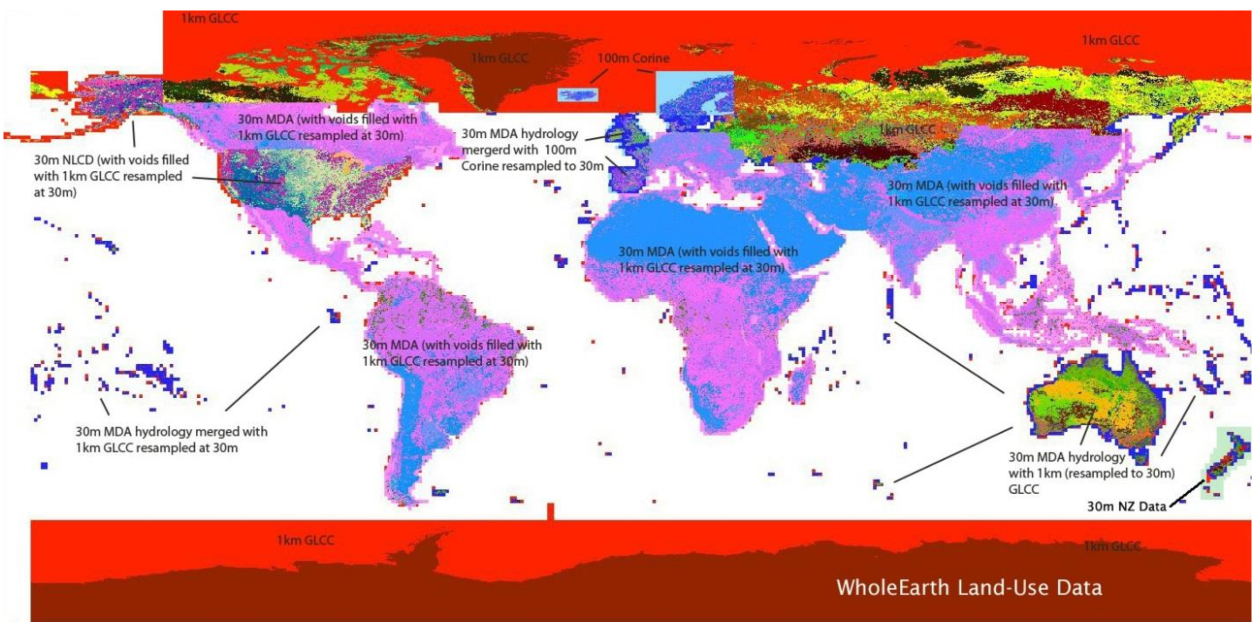

Figure 2 - Whole Earth Land-Use Data

Theme-based data is typically available as a raster image, which means the source data has been sampled and quantized to the raster grid. Each element of the grid gets only one theme type, even if the original source data included a mixture of types. Additionally, the choice of type can be as arbitrary as the preference of the human doing the original work, or the nuances of the software that is attempting an auto-classification. The problem is attempting to recreate an approximation view of the world from limited data that is believable. Using themed data introduces potential edges along the theme edges wherever different themes border each other as seen in Figure 3. The nature of low resolution raster data is to cause the terrain to draw with artificially straight boundaries. The bordering edge must be blended to avoid the appearance of an artificial edge; but blending edges is not a sufficient solution. Some edges like water boundaries do not make sense for blending. For example, water boundaries tend to be defined by a hard edge.

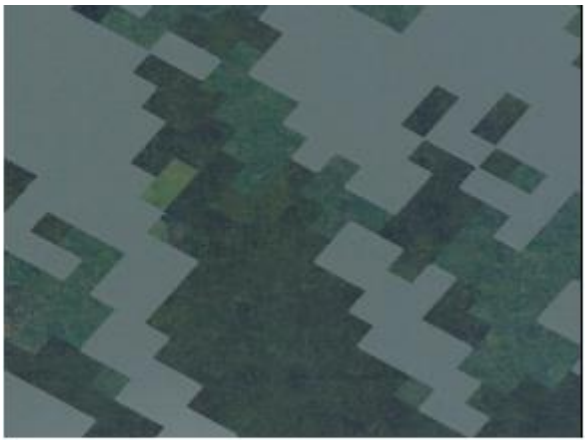

Figure 3 – Original Theme Data

Figure 4 – Pseudo-Specific Boundary Enhanced

Using the pseudo-specific enhanced boundary technique and the same source data as used in Figure 3, the scene is greatly improved as seen in Figure 4.

Having a theme based database with acceptable resolution become useful as a simulation database for many uses. Because the whole Earth can be represented, views can be generated around the entire Earth from high altitudes down to the surface using a fraction of the space needed by a similar photo based database. Out-the-window visuals are always correlated with various sensor visualizations. Using 3D models makes for a more realistic view of the world as opposed to the “flat” view that is typical of a photo database; especially when viewed up close. The 3D models also allow for proper interaction with the Earth. Bombs can properly and realistically alter the landscape in a 3D themed database. Moving model vehicles do not drive over the baked-in vehicles. The terrain is more flexible and can be more realistically adapted to different simulation scenarios. This makes for a more useful simulation database.

METHODOLOGY

Direct use of low resolution data causes the scene to be rendered with blocky boundaries between the themes. Figure 5 demonstrates two themes (green and purple). A simple nearest neighbor super-sampling of the theme data to a higher resolution will not improve the scene and will retain the jagged and pixelated appearance of the original source data. What is needed is a way to introduce a more realistic looking boundary.

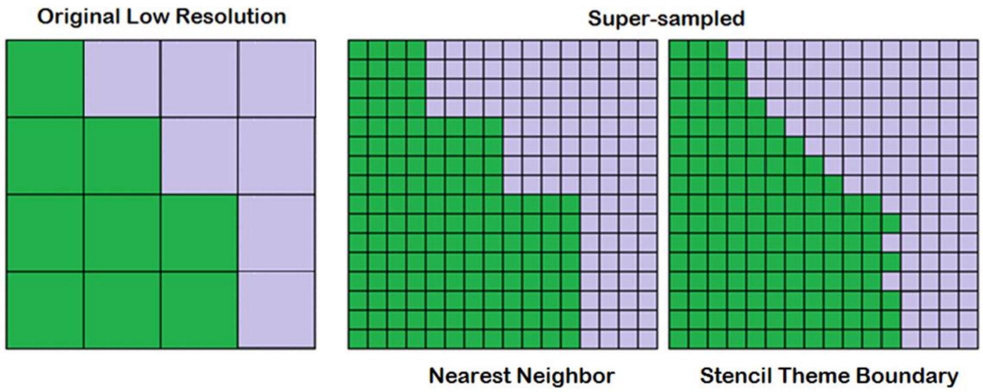

Figure 5 – Super Sampling

Theme Data

Theme data is stored in a two-dimensional array or grid that correlates with a location on the Earth (see Figure 6). In, Figure 6, the ‘20’ may represent a forest theme bounded by prairie land ‘33’ and farmland ‘45’. Three dimensional models can be placed based on the theme information. Dense trees can be added to the forest theme area; sparse trees can be added to the prairie land; and occasional farm buildings added to the farmland area.

20	20	20	20	20	20	33	33
20	20	20	20	20	33	33	33
20	20	20	20	20	33	33	33
20	20	20	20	33	33	33	33
20	20	20	20	45	45	45	45
20	20	20	20	45	45	45	45
20	20	20	45	45	45	45	45
20	20	45	45	45	45	45	45

Figure 6 – Boundaries of three themes.

Some boundaries in nature are contiguous like the edge of water next to land. Other boundaries are noncontiguous; think of a forest next to a grassy meadow. The algorithm needs to account for the type of geographic themes. Theme boundaries generally have a similar shape and can therefore be generically defined.

Stencils

Stencils are used to define higher resolution boundaries between themes. The stencils are used for blending two or more theme types to create natural looking transitions/boundaries. In Figure 7 and Figure 8 the black and white areas define the shape of the boundary for two different themes. These stencils define the boundary along a vertical edge.

Figure 7 - Non-contiguous Desert Theme

Figure 8 - Contiguous Water

Themes can be defined to have a contiguous or non-contiguous boundary. Contiguous boundaries like a water edge should have a well-defined edge. Non-contiguous boundaries like a forest edge can vary and tapper off in different ways. Noncontiguous boundary stencil themes will have a lower priority than contiguous theme stencils. It is important to maintain a contiguous border whereas the non-contiguous border has more flexibility on how it looks in the final definition. Each theme will have multiple variation stencils defined in order to remove unnatural repeating patterns as seen in Figure 9.

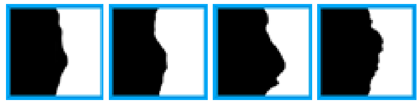

Figure 9 – Water Edge Theme with four variations

The stencil edges must line up so that the boundaries of adjacent stencils match. This means that the stencil must either occupy the entire, half, or none of the stencil's edge. This allows stencils to be placed next to any other theme's stencil.

Stencils are identified by a theme ID and corner code. For any theme, there are fifteen (15) possible stencils that may be used for "painting" the canvas. The black box represents the unique theme values out of the foursome (see Figure 10).

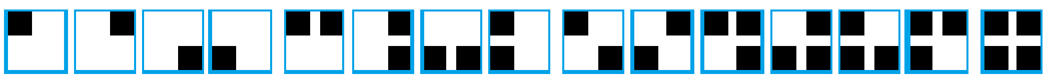

Figure 10 – 15 Stencils Per Theme ID

Stencils can be rotated or inverted to define other stencils. Figure 11 shows an example of eight (8) non-contiguous stencils that are used to create the fifteen (15) possible stencils

Figure 11 – 8 Contiguous Boundary Stencils

Stencils will be subsampled to the target multiplier. So a 256 x 256 stencil will allow the theme data to be super-sampled 255 times the original resolution. For example 1km texture can be super sampled with a 256 x 256 stencil to produce 4 meter texture. Multiple stencils applied in specific ways are used to vary boundaries thereby avoiding repeating image patterns (see Figure 12). The next section describes an example boundary algorithm.

Pseudo-Specific Boundary Algorithm Example

Step 1: A group of four theme IDs are identified. The appropriate stencils are chosen based on which quadrant the theme occupies. In this example, the 'green' theme occupies the upper right corner so the stencil is chosen that only occupies the upper right corner. This is repeated for each quadrant so we can have between two to four stencils being applied.

Step 2: In this example we have three stencils that need to be applied. The stencils are sorted by a predefined priority. The stencils are subsampled to the target super-sampling rate (in this case 4x4).

Step 3: Next the stencils are applied to the supper-sampled target using a painter's algorithm. The lowest priority 'orange' theme is used as a "basecoat". Notice that the stencil is not actually used in this case. Next the 'purple' theme is added using the stencil. Lastly, the 'green' theme is added using the stencil. Note that the undefined space (space that was not colored by any stencil) was painted with the lowest priority theme ID value. This makes sure the higher priority stencil boundaries are preserved so that contiguous boundaries are not broken.

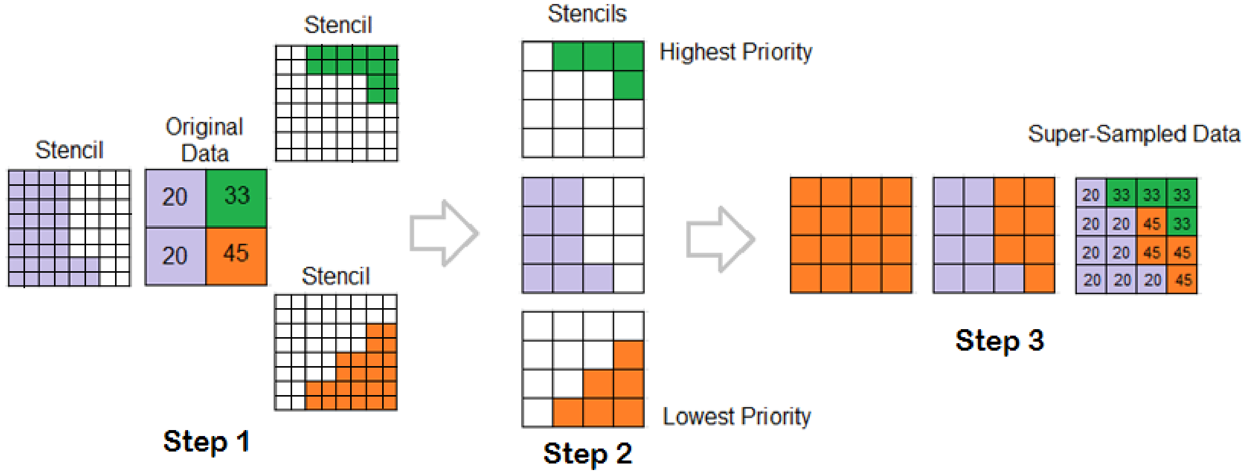

Figure 12 – Super-sampling with stencils

This process is repeated for all the theme cells. Actual results of the theme boundary super-sampling can be seen in Figure 13. Notice the blocky borders on the left. The right side shows how the borders have been improved with pseudo-specific theme based super-sampling.

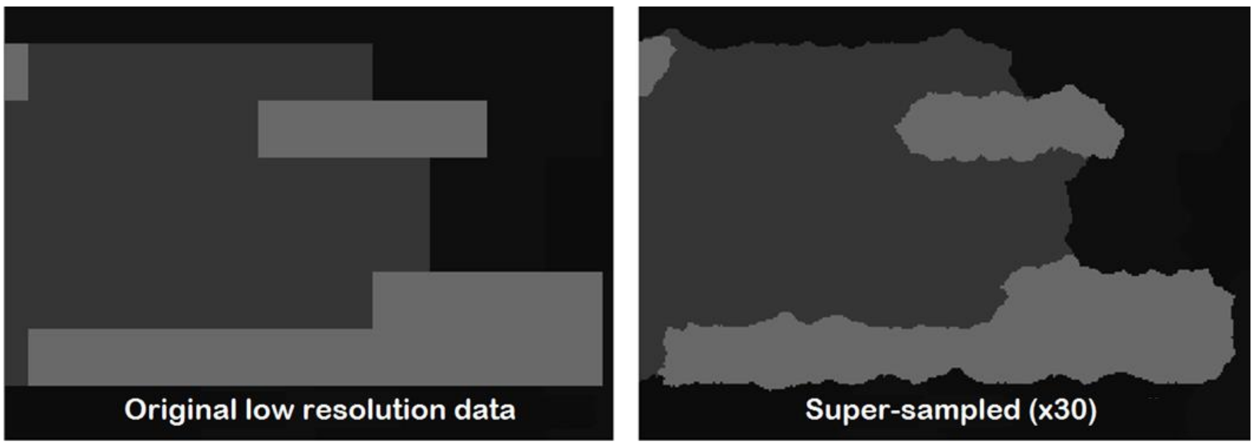

Figure 13 – Actual Results

3D POINT FEATURES

The super-sampled theme data is used with correlated templates of three-dimensional features to generate 3D content on-the-fly without the need of "pre-compiling" or "publishing" the database. The end result is the appearance of higher resolution terrain texture with accurately correlated 3D features. By giving the visual database vertical development the sense of realism is greatly increased. Figure 14 and Figure 15 only hint at the added realism. To really appreciate the improvement to the scene with regards to depth and perspective the database must be flown.

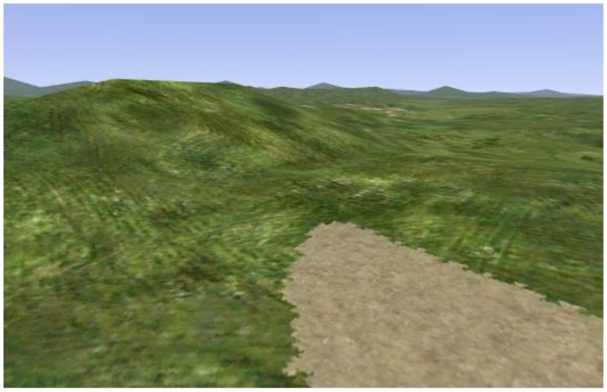

Figure 14 – Themes only

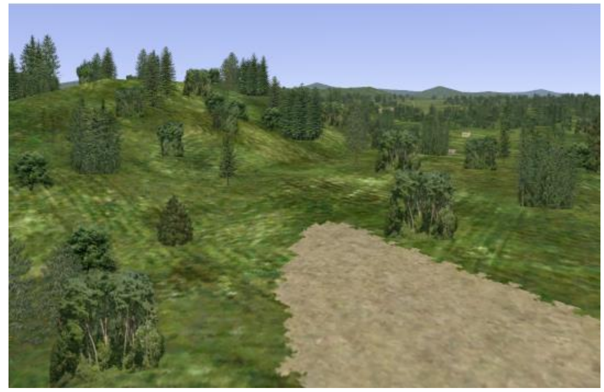

Figure 15 – Themes with 3D content

SUMMARY

The photo-specific strategy has compelling appeal and can be thought of as the “gold standard” for depicting terrain, texture and correlated 3D features. But like gold, it’s expensive, and the theme-based photo-typical approach can provide similar training effectiveness at reduced cost. The best system would employ both strategies in an inset/background approach. But theme-based approaches suffer from lack of a world-wide theme data source at appropriate resolution.

We have shown that intelligent processes can be used to upsample low-resolution theme data in ways that provide natural transitions between theme types, and that clever blending strategies can meld the theme texture patches into a continuous cover that makes visual sense. Additionally, a correlated 3D feature overlay that is part of the theme library can be cost-effectively developed to provide appropriate scene detail up close. The run-time construction of both the terrain texture and the feature overlay from theme building blocks allows greater flexibility to pursue continuous improvement of the database without committing wholesale changes.