Very High-Detail Depictions of Forests in Virtual Environments

Barry Bitters, Ph.D., GISP

Abstract

Current real-time simulation technology does not allow the efficient display of very detailed, wide-area vegetation in virtual environments. However, there has been significant research and development in the area of simulation and modeling leading to noteworthy advances in the rapid display of very dense vegetation. During the development of virtual environments, digital land cover data does not provide detailed discrimination of even a generalized specie mix within tree stands. We have devised a process to generate more detailed forest land cover information. To develop more detailed forest land cover information, it is essential to augment existing land cover data using authoritative ancillary sources. In digital form, we have captured the spatial extent of the native ranges of over 200 North American tree species. Augmented with an expanded set of realistic looking 3-D models of bare and in-foliage trees, this data provides significantly enhanced depictions of forest canopies in virtual space. Increased fidelity in the display of virtual environments is of concern to all individuals interested in the near photo-realistic portrayal of GIS data. We will discuss this development, display real-time simulations of forest environments, and discuss future directions of this line of research.

Introduction

Today's synthetic natural environments (SNE) can be characterized as simplistic representations of reality. A fundamental paradox for the real-time simulation community has always been how to economically evolve from simplistic representations of real-world environments to a more realistic depiction of natural and urban environments. This is exemplified by the current state-of-the-art in the display of natural and human induced vegetation. Current hardware and software limitations prevent the aesthetic display of wide expanses of realistic looking forests. As a consequence of the high feature counts that exists in typical forest stands (Table 1), and the complexity of even the simplest forms of vegetation, phenomenal feature counts occur in every-day, real-world forest stands.

Table 1. Representative real-world feature counts for vegetation (after Bitters, 2006).

Forest Class	*Feature Density*	*Total Features per sq. mi.*

Tree Nursery	440 trees/hectare (1087/acre)	695,680
Forests 100% Canopy Closure	6,500 trees/hectare (16,000/acre)	10,240,000
Forests 50% Canopy Closure	2,500 trees/hectare (6,178/acre)	3,953,920
Forests 10% Canopy Closure	1,000 trees/hectare (2471/acre)	1,581,440

Over the last 15 years, the fidelity, specificity, and level of detail of synthetic natural environments has continued to increase. These increases have kept pace with dramatic advances in hardware and software technology. Future advances in display and processing technology promise comparable increases in display fidelity. However, if database generation and resulting image generation is to keep abreast of these technological advances, the ways we approach visual database generation must also evolve.

Because feature detail, feature specificity, and feature variety are an important element of realism in SNEs, the database generation process focuses heavily on the capture of detailed feature data. For these reasons too, feature data capture is often the most expensive element of SNE database generation. If we wish to increase the fidelity of real-time displays, we have to analyze the ways in which feature data are collected, processed, and stored. In the future, to allow the rapid and relatively inexpensive development of more detailed SNE databases, more efficient means for the generation of these data structures must be found.

Forests and other types of vegetation, because of their complex nature and their potentially high polygon counts, are one of those broad class of features that have long been relatively ignored by SNE database builders. To attempt the creation of near photo-realistic virtual worlds and to economize in the display of vegetation results in synthetic environments that never truly approach near-photorealism. Until the real-time simulation technology reaches a point where it can display billions of polygons per scene at 60 Hertz's, the traditional polygonal tree model will have to remain the mainstay of real-time vegetation display.

The basic assumption of this paper is: when 3-D polygonal models of trees and other forms of vegetation are designed properly, artistically, and for computational efficiency; they can provide the required detail, specie specificity, and all those visual cues necessary for efficient and aesthetic real-time simulation displays. Further, if a wide variety of specie-specific 3-D vegetation models are available for use in real-time databases, the spatial feature content necessary for their ecologically correct display is readily available from both traditional sources of feature content and also from more non-traditional and disparate data sources. Combining land use/land cover data with other vegetation data sources, it then becomes possible to model natural and human induced vegetation in very realistic ways. This premise assumes the availability of a systematically designed and developed library of polygonal 3-D vegetation models – a collection of specie/genus specific 3-D models in various sizes and various foliage states.

Background

Regional forest diversity is strongly correlated with climate and human interaction with the environment. Many mechanisms have been hypothesized to explain these patterns; however, reliable predictions that would distinguish among them have rarely been derived. Specie diversity within individual forest stands is strongly correlated with a wide variety of environmental factors and not limited primarily to climate and human interaction. How a seed came to germinate at a particular location, has to do not only with climate and human interaction, but also topographic influences, ground water avalability, soil fertility, even animal interactions with the environment. At the individual tree level of detail, comprehending all of these factors, let alone modeling all of these factors, is beyond the current state of the art of real-time simulation technology.

Representing Forest Diversity in Simulation Space. For its entire history, the real-time simulation community has been faced with a distinct dilemma when attempting to represent vegetation in 3-space. Generally, the representation of vegetation has not been considered a critical factor in the development of visual databases. Early in the history of real-time simulation the fence and roof method of modeling forests was the typical means of portraying forest stands as objects standing above the terrain. Although visually disturbing, this method provided a means to generalize forests as objects standing above the terrain surface.

As computing power increased, more of the polygon budget could be allocated to the depiction of vegetation. This allowed the modeling of individual trees using billboards. In the billboard technique, a digital image of a real-world object is applied, usually to a single, flat polygon – a single polygon that, in 3-space always faces the viewpoint; thereby always allowing for a full front view of the polygon face. However, because there is no visible depth to 3-D billboard model, the resulting lack of parallax makes this technique effective only for vegetation objects in the background of a scene. This technique is still used today in a broad range of 3-D models particularly to portray lower levels of detail.

As display systems became even more powerful, billboard modeling of vegetation was gradually replaced by multi-polygonal modeling techniques. In this approach to modeling individual trees, 3-D models composed of multiple levels of detail were used; where each higher level of detail within a 3-D model would employ more polygons to portray both added detail and depth to the model.

In recent years, numerous researches have advocated the use of procedural and fractal approaches to the generation of very detailed renditions of vegetation features. This approach to 3-D representation has its origin in Lindenmayer system modeling, or L-systems for short. The L-systems concept was first described by Aristid Lindenmayer in the late 1960's, as a means to describe and compute repeating patterns in biological growth. An L-system is a formal set of recursive rules and symbology based on Chomsky strings. The resulting objects are fractal-like and are based on the common complexity concept that simple rules when recursively applied can create complex structures.

In the seminal work of Przemyslaw Prusinkiewicz and Aristid Lindenmayer – The Algorithmic Beauty of Plants (Prusinkiewicz, 1990) the concept of L-Systems is applied to the detailed modeling of vegetation. As a direct result of this expansion of the L-Systems concept to vegetation modeling, there are several producers of procedural 3D plants modeling software: Bionatics (Bionatics, 2007), Interactive Data Visualization's

SpeedTree (IDV, Inc, 2007), Onyx Computing's OnyxGarden (Onyx Computing, Inc. 2007) just to name a few. These software packages specialize in very detailed, and very realistic 3-D modeling capabilities for vegetation. Many of these systems allow the creation of very detailed procedural 3-D models and then the conversion of these detailed models into traditional multi-level of detail polygonal form.

If the level of detail available from true procedural 3-D modeling capabilites is desired in simulation space, most of the available procedural 3-D vegetation modeling systems are heavily dependent on run-time development of feature content and exploit graphics card processors to a significant extent. However, many available run-time systems are not capable of processing procedural feature content. Therefore, in the case of vegetation displays, it is inevitable in a distributed simulation environment, that disparate display systems with differing runtime capabilities will display different renditions of vegetation; some using lower detail polygonal vegetation models, and some using much higher detail procedural renditions of vegetation. Until all display systems within a distributed simulation environment can process procedural 3-D vegetation feature content in real-time, correlation between distributed federate displays will be problematic.

Methodology

The combined effects of numerous physical and biotic factors result in the formation of environmental gradients that dictate the native range of plant species. Environmental gradients are specie specific and are the defining factor of the optimum range in which species can exist. Outside these optimum ranges, in bordering areas of less optimum conditions, plant species may exist in significantly less abundance. Beyond these bordering areas, because individual species can not function efficiently, there will be limited or no presences of the particular specie. Effectively modeling this gradient in real-time simulation databases, and modeling this gradient for multiple species within the same area, is the key to more realistic displays in simulation space.

Forest Diversity

In most simulation databases, forest diversity is discriminated based on three general categories of forest vegetation: coniferous/evergreen, deciduous, or mixed coniferous-deciduous vegetation. Even when randomly scattering several different 3-D tree models over an area, this three-class differentiation does not provide the required specificity to allow the creation of a detailed and realistic looking visual display. To enhance the quality of visual cues in forested areas, more information is necessary to generate realistic forest settings in simulation space.

Forest Community Data

Forest communities are broad generalizations of the specie makeup of forest canopies, understories, and undergrowth. Forest community data can be used to augment broad forest class data and add an additional dimension to the display of forest data. The natural distribution of tree species is dictated by a complex interaction of numerous natural conditions: primarily regional climate, soil, elevation, and soil moisture content. This information is often available in forest community databases.

Tree Specie Ranges

Identifying the exact ranges of individual species is the key element in the generation of more realistic looking forests in simulation space. However, because environmental gradients are the combined effects of multiple physical and biotic factors, identifying the spatial extent of the native range for an entity does not defines its density throughout that range. Such environmental factors as solar illumination, temperature, soil type, and soil moisture; just to name a few; will vary within a specie's native range and will have a significant impact on its abundance locally within the range.

Tree Representation

A fundamental element essential to the realistic portrayal of point feature forests is the existence of a set of specie specific tree models – tree models that provide those visual cues showing characteristic shapes, sizes, colors, and seasonal variations of tree species.

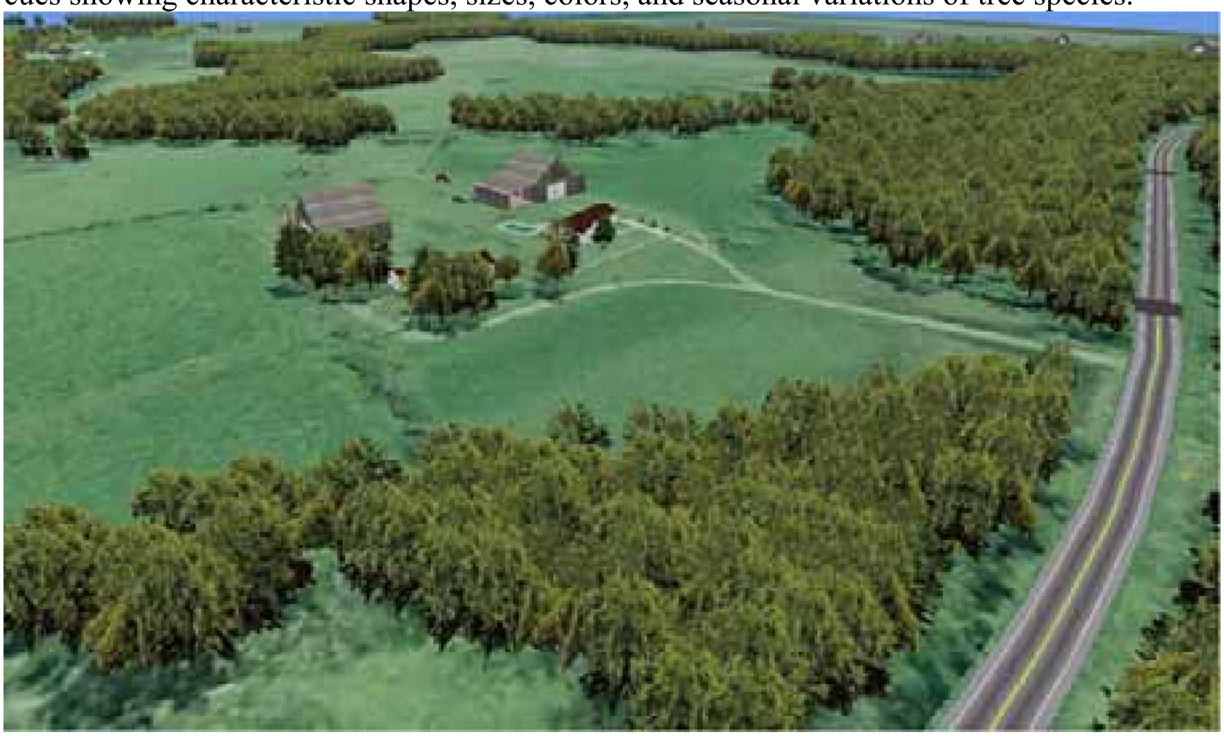

Figure 1. Forest stands represented by a randomly scattered, single, 3-D tree model. Notice the unnatural regular appearance, consistent height, and apparent "regimentation" of each forest stand.

Generally, land use and land cover information is available for most areas of the world. This type of data provides generalized information on the broad types of forests in a

region. Land use and land cover data usually only defines four broad classes of vegetation: deciduous, coniferous, mixed deciduous/coniferous, and scrub.
In conjunction with other ancillary information about regional plant communities, it is possible to derive more detailed conclusions about the makeup of unique forest stands. For example, within the Southwest United States there exist several well defined warm desert plant communities (Table 2). Each of these is further divided into several series or subdivision.

Table 2. Plant Communities and Subordinate Series and Subdivisions of the Southwest U.S. Warm Deserts (after Barbour, 1999)

Mojave Warm Desert Community
- Creosote Bush Series
- Joshua Tree Series

Sonoran Warm Desert Community
- Viscaino Subdivision
- Arizona Upland Subdivision

Chihauhaun Warm Desert Community
- Agave lechuguilla Series
- Tarbush Series

Each series has a generally accepted boundary and detailed information is available describing the percentage of groundcover and the specie diversity within each association. Climatic factors, slope, aspect, and ground water data are also readily available; further defining the occurrences and spatial limits of these communities. This depth of detail on biodiversity and specie occurrence is available for all of North America and to varying extents, this same type of information is available the world over. By combining this depth of detail on the diversity of forest vegetation with regional land cover data, it then becomes possible to define not only a plant community for each forest stand, but also to determine a generalized mix of tree species that might occur in that topographic regime. The actual process used to augment land cover information for each forest stand is:

1. Determine land cover class for each forest stand.
2. Identify eco-region and corresponding tree communities.
   a. List evergreen species.
   b. List deciduous species.
   c. List under story species.
3. Identify all species that have a native range within the forest stand boundary.
   a. List final prioritized evergreen species.
   b. List final prioritized deciduous species.
4. Determine wetlands condition.
   a. If wetlands, remove upland species from list.
   b. If not wetlands, remove wetlands species from list.
5. Determine topographic regime.
   a. Evaluate specie elevation range.
   b. Evaluate specie slope preferences.
   c. Evaluate specie aspect preferences.
6. Based on steps 2-5 determine appropriate specie mix for each stand.

Executing this process for each individual forest polygon within a vegetation layer will result in a prioritized list of tree species; as an attribute for each polygonal vegetation feature. This prioritized list of tree species can then be used as the basis for random distribution of specie-specific, 3-D tree models within the spatial extent of each polygonal vegetation feature.

Computing Individual Tree Placement

At the individual tree level, three situations are essential to generate a "natural looking" forest environment: 1) random tree locations; 2) random specie distributions; 3) random tree rotations; and 4) variable tree heights. The following discussion addresses each of these topics and describes our approach to each situation.

Random Tree Location. Random placement in natural forest stands is characterized by; 1. true random placement, 2. irregular relative spacing, and 3. occasional grouping of multiple trees. The relative location of naturally occurring vegetation is always random in a natural state. For this reason, a random point scattering tool is necessary that will generate truly random point feature locations within each polygonal forest stand boundary. Many point feature scattering tools have a function that regulates the overall maximum and minimum spacing between individual points. We have found that these tools do not generate truly random positions. In a natural state, each vegetation feature is irregularly spaced relative to its neighboring features. If "randomly" scattered features appear to be evenly spaced relative to each other, then in 3-space there will often be a systematic appearance to scattered point features. This occurs when the point features are scattered based on an algorithm that uses minimum distances between features.

The exceptions to the standard random placement rule is cultivated vegetation; i.e. orchards and tree farms. Because of their systematic nature, a tool for the placement of point tree features in evenly spaced rows is essential to creating the characteristic, systematic placement of individual instances.

Random Specie Distribution. Except in the case of orchard and tree farm settings, forest stands do not contain homogeneity among species within a stand. For this reason, the distribution of specie specific 3-D models must be based on some form of non-systematic scattering. Diversity indices (Mouillot, 2004), 3/2 power law applications (Zeide, 1987), and scaling relationships based on fractal specie distribution (Green, 2003) have been explored by numerous researchers. However, these studies assume vegetation densities far in excess of those that can be displayed in current real-time display systems; and further, their efficacy in faithfully predicting spatial relationships and specie abundance are still under debate. For these reasons, our approach to the random specie distribution problem has been the use of a random sampling of the predicted random tree locations based on a computed, or published (when available) specie percentage within a stand.

Random Tree Rotation. A common result of randomly placing 3-D tree models into a visual database is that often, all models are oriented at the same angle. When this occurs, at the edge of forest stands, the individual tree models create a tessellation effect that is often a visually disturbing anomaly. Because the location of each tree model was generated randomly, it is possible to use the point feature record number as the basis for assigning an arbitrary orientation value. The orientation of each model can be computed by subtracting 360 from each Record ID until the orientation value is less than 360. This technique eliminates the repetitive visuals effects on forest boundaries.

However, this technique of computing orientation values is not effective for 3-D models within orchards or tree farms. The point features used for orchards and tree farms are usually generated systematically and the Record IDs are usually sequential along either rows or columns. Using the above technique for computing the orientation value will potentially produce neighboring tree records with an orientation difference of one degree. This orientation difference is not enough of a change to eliminate the visual repetition effect. By merely dividing the orientation results computed above by 10 (and ensuring the orientation value is greater than 0), in effect assuring that neighboring tree models have orientation differences of at least 10 degrees, the visual repetition can be removed in orchards and tree farms.

Variable Tree Height. To add a bit of random vertical texture to the top of the canopy, instead of having all trees the same height, it is necessary to have the ability to vary the height of each tree in such a way as to give the appearance of an haphazard canopy surface. Rather than depend on software to vary the height of each model at runtime, we have depended on the use of multiple versions of each tree specie mode – each at a different height. Currently, we are creating three versions of each model: one at normal mature height; one at 0.75 percent of the normal mature height; and one at 0.5 percent of the normal mature height.

The decision of which height versions to use within an instance of forest is dependent upon the availability of detailed stand height information in source data. When stand height information is not available from ancillary source data, a representative stand height must be determined locally. In the realworld, stand height is based on a complex interaction of many variables; a complex function of forest community, forest height, stand age, slope, slope aspect, soil type, and climatic factors, just to name a few. Future research into the complexity of tree growth relative to other neighboring trees and the age of adjacent stands may provide more in site into this dilemma.

Tree Model Production

If an increased set of tree species are stored in a visual database, it naturally follows that there must be a wider variety of 3-D models available to display the increased specie diversity. We have embarked on an ambitious program to create multiple versions of 3-D models for a significant number of the more prevalent species of North American trees. Table 3 provides a broad outline of this modeling effort.

Table 3. The tree model production effort.

Tree Type	*Number of Species*	*Number of Models Being Produced*
Broad-leaf, Deciduous – w/out foliage	24	72
Broad-leaf, Deciduous – with foliage	24	72
Broad-leaf, Deciduous Undergrowth w/out foliage	7	21
Broad-leaf, Deciduous Undergrowth with foliage	7	21

Deciduous Needle-Leaf w/o foliage	2	6
Deciduous Needle-Leaf with foliage	2	6
Needle-Leaf	17	51
Succulents	2	6
TOTAL MODELS		255

Texture Production

Silhouettes of common North American trees (Petridge, 1958) have been used as a starting point for the development of a series of textures for the development of broadleaf and needle-leaf 3-D models. Figure is an example of the Beech tree silouette. These silhouettes provide detailed images of broadleaf species without foliage and needle-leaf species with foliage.

Average and maximum height values for each variety of trees have been used to scale representative height and canopy diameter values. From these dimensions, two additional sets of height and canopy diameter values were computed resulting in dimension for tall, medium, and small version of each tree model.

The 3-D Modeling Effort

Each evergreen-coniferous species is represented by a single “foliage-on” 3-D model. Although in arid climates, many evergreen-broadleaf species have a dormant brown variant during dry seasons, at this time no dormant evergreen-broadleaf 3-D models have been produced.

For each deciduous tree specie (to include needle-leafed deciduous species such as Larch and Bald Cypress), there is a 3-D model representative of a with-foliage (summer/wet season) and a without foliage (winter/dry season) situation.

If one were to be really fanatical about the realistic modeling of landscapes, for each deciduous tree species, there is also a need for 3-D models representing the colorful fall foliage and the brown foliage prior to shedding leaves, maybe even a version with spring foliage. However, these would require additional effort in the production of texture maps, a level of effort beyond current and projected funding.

In addition, each tree type should be represented by at least three versions. As a minimum, a short, medium, and tall version should be available. Determining the ultimate dimensions of each different model version will be based on the typical heights, trunk diameters, and tree profiles available from Petridge (1958) and other authors.

In the real-time simulation community, past efforts at the development of 3-D tree models can be characterized as relatively haphazard. As a particular situation demanded a different type of 3-D tree model, a new model was developed independent of any systematic tree modeling effort. As a consequence, there exists no comprehensive, public-domain, collection of 3-D polygonal tree models – a systematic collection suitable for use in future simulation systems. Any attempt at the systematic display of a wide variety of different tree species therefore demands that a correlated set of 3-D models be available to portray the tree species in simulation space.

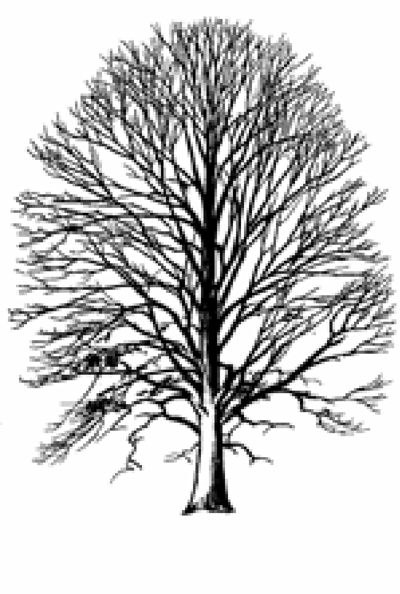

Figure 2. A silhouette of the "typical" field-grown Beech tree (Fagus grandifolia Ehrh.) without foliage (Petridge, 1958).

We have embarked on a production effort to create just such a systematic collection. Using published tree silhouettes as a basis for standard tree shapes and sizes as shown in Fig. 2, we are creating an extensive collection of specie-specific 3-D tree models that vary in size and foliage state – both bare and with leaves. This collection of 3-D, polygonal tree models can be used as scatterable objects in the forest vegetation algorithms discussed earlier. Table 3 outlines the planned product that is ongoing in this production effort. The final total of 255 tree models might be misconstrued as a daunting task. However, in reality only one unique model is required for each individual tree specie. For each individual specie, this unique model is used as a template for all other foliage and size variations. As an example: for the broad-leafed, deciduous tree – the common Beech tree (Fagus grandifolia Ehrh.), an original model of a full size, without-foliage tree was created. From this 3-D model, two additional versions were created at scales of 0.75 and 0.5. Foliage was then added to the original full size 3-D model and again two additional versions were created at scales of 0.75 and 0.5.
The initial representation must be a 3-D model with 3 levels of detail (LOD) similar to the leaves-off version of the Beech tree in the VOT 3-D Model Library (v14820001_beech-tree-winter.flt). Using this 3-D model as the template for all the other models in this project will greatly simplify the work effort. Then the work that is required on all other models is to rename, rescale, and replace the existing texture. There are a few other manual tasks like renaming the top-level group, that will have to be performed. However these are trivial compared to manual resizing of all polygons.

Results and Conclusions

In recent years, there has been extensive research into fractal and procedural techniques for the display of point vegetation features. As these techniques mature (and as real-time computational capabilities mature enough to allow their use), these techniques for the generation of computationally efficient, and very detailed point vegetation features should replace the traditional polygonal vegetation feature. However, in the interim, until use of these techniques become available over a broad range of real-time simulation display systems, polygonal tree models are the only viable option for the portrayal of realistic vegetation in current systems.

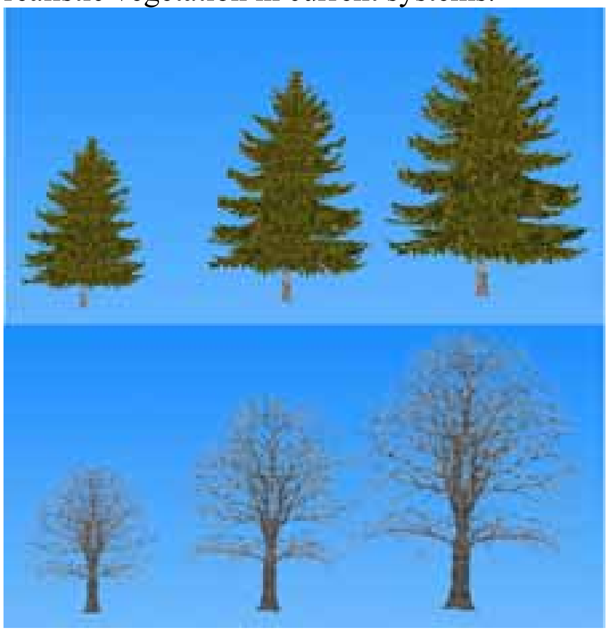

Figure 3. Representative examples of 3-D models generated during this research effort.

In this paper we have discussed a technique for augmenting low-resolution land cover data with other sources bio-diversity data to increase the vegetation information content within a visual database. By merging spatial biodiversity data and the spatial extent of native ranges for specific species with any available land cover data, it is possible to generalize the tree-specie content of forest stands. To do this, detailed shapefiles showing the native ranges of over 270 native North American tree species are now available at the following web site: http://vissim.uwf.edu/ForestVeg/ForestVeg.html. At this website there are also several biodiversity and ecosystem studies of forest community data for North America and other areas of the world, all in shapefile format. This data is in the public domain, is available for free download, and may be used and distributed without any restrictions. In addition, to allow the display of this added vegetation detail, a preliminary set of specie-specific 3-D polygonal tree models is also available for free download and unlimited, unrestricted distribution. Using these 3-D models and the placement technique described above, it is possible to create simulation databases with detailed forest stands similar to that shown in Figure 4.

Figure 4. An example of the diversity of tree species possible in future virtual forest stands.

References

Barbour, M. G. and Billings, W.D. 1999. **North American Terrestrial Vegetation**. Cambridge University Press. New York.

Bejan, A. 2000. **Shape and Structure: From Engineering to Nature**, Cambridge University Press, Cambridge, UK, 2000.

Bionatics, Inc. 2007. **RealNat**. http://www.bionatics.com. Last visited: 05 April 2007.

Bitters, B. 2006. Geospatial Perpetual Motion: Finding Hidden Information within Existing Geospatial Databases. **Proceedings of the IMAGE 2006 Conference**, Scottsdale, AZ.

Burns, R.M. and Honkala, B. H. 1990. **Silvics of North America Agriculture Handbook 654**. US Department of Agriculture, Forest Service, Washington DC.

Crawley, M.J., Ross, G.J.S. 1990. The population dynamics of plants. **Philosophical Transactions: Biological Sciences**, 330(1257):125-140

Currie, D.J., Mittelbach, G.G., Cornell, H.V., Field, R., Guégan, J.F., Hawkins, B.A., Kaufman, D.M., Kerr, J.T., Oberdorff, T., O'Brien, E., and Turner, J. R. G. 2004. Predictions and tests of climate based hypotheses of broad-scale variation in taxonomic richness. **Ecology Letters**. 7(12):1121–1134.

Green, J. L., Hart, J. and Ostling, A. 2003. Species richness, endemism, and abundance patterns: tests of two fractal models in a serpentine grassland. **Ecological Letters**. 6(10):919.

IDV, Inc. 2007. **SpeedTree Version 4**. http://www.speedtree.com/. Last visited 05 April 2007.

Kuchler, A. W. 1988. The classification of vegetation: in **Vegetation Mapping**. (ed.) A W Kuchler and I S Zonneveld (London: Kluwer Academic Publishers) pp 67–80.

Mouillot, D., and Leprêtre, A. 2004. A comparison of species diversity estimators. **Research on Population Ecology**. 41(2):203-215.

O'Brien, E.M. 2006. Biological relativity to water energy dynamics. **Journal of Biogeography**. 3(11):1868–1888.
Onyx Computing, Inc. 2007. **OnyxGarden**. http://www.onyxtree.com. Last visited: 05 April 2007.
Ostling, A. 2000. Self-similarity and clustering in the spatial distribution of species. **Science**. 290:271a.
Petridge, G. A. 1958. **A Field Guide to Trees and Shrubs**. Houghton Mifflin, Boston.
Prusinkiewicz, P. And Lindenmayer, A. 1990. **Algorithmic Beauty of Plants**. Springer-Verlag, New York.
Roy, P. S., Singh, S. and Porwal, M. C. 1993. Characterization of ecological parameters in tropical forest communities—A remote sensing approach; J. **Indian Soc. Remote Sensing**. 21:127–148.
Scheuring, I. 1991. The fractal nature of vegetation and the species-area relation. **Theor. Popul. Biol.** 39(2):170-177.
Zeide, B. 1987. Analysis of the 3/2 power law of self-thinning. **Forest Science**. 33(2):517-537(21).
Barry Bitters, Ph.D., GISP MTC Technologies, Inc 7411 Alban Station Court, Suite A-104 Springfield, VA 22150 Phone: [703] 735-4857 bbitters@MTCtechnologies.com