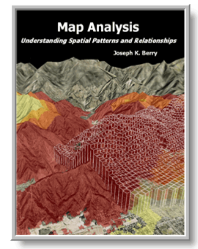
GeoWorld Articles ***Visualize Realistic Landscapes:** 3-D Modeling Helps GIS Users Envision Natural Resources*	 ***Further Reading for*** ***Map Analysis*** ***Understanding Spatial Patterns and Relationships*** ***(Berry, 2007 GeoTec Media)***

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Visualize Realistic Landscapes: *3-D Modeling Helps GIS Users Envision Natural Resources*

By Joseph K. Berry, David J. Buckley and Craig Ulbricht

Introduction

Maps are abstractions of reality. They use long-established techniques, patterns and symbols to summarize the real world as visual references. The distinction between reality and cartographic rendering, however, changes with a digital map.

A GIS' data management and modeling capabilities provide powerful tools to track landscape conditions and conceptualize spatial relationships. In natural resources, for example, map analysis is used to develop harvesting plans that consider a complex set of environmental and economic concerns. Various scenarios reflecting different management objectives can be rapidly generated. But an effective means to visualize the results and communicate aesthetic concerns had to wait for another generation of computer technology.

From movie-making to the scientific community, dramatic advances in 3-D visualization are taking hold. Within the next few years "rendering pallets" composed of realistic trees and rocks will become as common as color pallets in commercial GIS. More realistic 3-D renderings of landscape elements will form snapshots of analysis results, providing a glimpse of aesthetic as well as environmental and economic concerns. Sequencing a series of snapshots will animate movement through a landscape, or through time when coupled with a simulation model (e.g., vegetation growth). Today's 3-D visualization techniques are on the verge of constructing virtual realities that are difficult to differentiate from photographs.

The Need for 3-D Visualization

In most areas, the requirement to consider visual aesthetics of proposed resource development has been mandatory. To date, most organizations satisfy this requirement by presenting relatively simple 3-D perspectives showing proposed developments from key viewpoints. Such representations often are submitted as part of a public review presentation supplemented by photographs manually altered to provide a "best guess" of the development's impact.

Two primary factors have spurred the requirement for more realistic visualization tools. First, there's a general trend in natural resource management toward more detailed designs that use small treatment areas scattered across a large landscape. Second, public scrutiny and tighter guidelines are dictating better and more accurate planning, often at the watershed scale. Such factors have fueled a demand for visualization capabilities. As a result, visual impact assessments--and their "before and after" simulations— have become key elements of the submission and approval process.

The term "visualization" has become a hot topic in the GIS industry during the last several years, and capabilities to represent and animate 3-D images of the landscape are coming online. For example, the recent release of ArcView 3-D Analyst from Redlands, Calif.-based ESRI Inc. provides visualization capabilities in a PC environment that once were reserved for UNIX-based GIS products. In addition, features such as dynamic rotate, pan and zoom by using the mouse, and polygon feature extrusion (typically used with buildings) provide a Virtual Reality Modeling Language (VRML) 3-D-like capability that's effective for visualizing many GIS datasets. Even with such developments, however, today's conventional GIS 3-D capabilities still don't satisfy the explicit requirements for realistic representations in natural resource applications.

Existing Technologies

Computer visualization methods range from simple 3-D perspective diagrams to complete virtual realities. Four distinct categories of visualization techniques can be identified (McGaughey 1997): geometric modeling, video imaging, geometric video imaging and image draping.

Geometric modeling techniques build 3-D geometric models of individual features (or components) such as trees, buildings and roads. The individual objects are assembled to create a forest stand or landscape view depicting the perspective from a given viewpoint. The most common use of the approach uses simple 3-D cones for tree symbols.

Video imaging is a computer technique that "cuts and pastes" digital photographic images to represent landscape changes. The approach produces high-quality visualization output, but it's manually intensive, contains no direct geo-referencing to a GIS database and often suffers from the artistic/subjective nature of the creation process. In many instances graphics software, such as San Jose, Calif.-based Adobe Systems Inc.'s Adobe Photoshop, is used to manipulate images.

Geometric video imaging is a hybrid approach that combines video-imaging techniques with geometric modeling, typically undertaken within GIS. Berris (1990) illustrated the possibilities for using such an approach in forestry applications, yet it's rarely used on a production basis. The primary difficulty arises in accurately georeferencing the photographic video images with the 3-D perspective framework (i.e., wireframes) generated by the GIS.

Image draping is a well-established technique in GIS. It involves draping an image, such as a digital orthophoto or classified satellite imagery, onto a 3-D perspective view. Image draping results in good texture and can produce visualizations suitable for depicting landscape-scale vegetation patterns. But image draping isn't effective for representing key viewpoint visualizations. The forefront of the image often suffers from coarse pixelization, resulting in an abstract impression.

Determining the best way to generate visualizations involves several factors: the representation scale required, the detail level needed and the availability of source data. McGaughey (1997) compares the four visualization techniques and offers general strategies for employing visualization in forestry-related projects.

Visualization Software

Two different, and to date unconnected, software sources are available for visualizing forests: commercial GIS/computer-aided design (CAD) software and scientific/research programs.

Commercial GIS/CAD software is characterized by traditional 3-D mapping techniques, such as wireframe terrain characterization with light-source-shaded perspectives as well as vector and image draping. These 3-D views can be generated from specific x,y viewpoints, supporting a wide range of surface-definition parameters.

Full-featured GIS software also supports image-rendering enhancements (e.g., atmospheric effects such as sky, fog and haze). Recent additions support the generation of map animations using standard MPEG encoding formats. However, GIS and CAD software typically don't have 3-D object rendering capabilities. Some users have integrated GIS capabilities with photo imaging, but these are usually project-based efforts and typically don't reflect a readily available functionality.

A host of specialized visualization tools have been developed within the scientific and research community (see "Software Packages for Forest Visualization," page 44), especially for natural resource-based visualization. Many of these programs reside in the public domain and are readily available via the Internet. Such software tends to be project-based and includes specific capabilities required for natural resource applications.

Typical characteristics of scientific visualization software include 3-D object rendering (geometric modeling), 3-D "fly-bys" (map animation), image morphing capabilities, VRML and a distinction regarding stand vs. landscape project scales.

Project Scales for Visualization

Visualizations can be characterized at three different project scales for natural resources: individual plot, stand (forest parcel) and landscape levels. Each scale represents a specific detail level and unique requirements for generating realistic visualizations. However, many projects require visualization at different scales. Landscape-level visualizations often are used to show altered vegetation patterns and visual effects within a valley or watershed. Stand- or plot-scale visualizations typically are used to show harvest unit layouts or specific stand treatments. Stand and plot scales tend to be used more for engineering purposes, whereas landscape-level visualization is used for planning and public presentation.

Plot-level visualization usually covers just a few acres, with the objective of depicting forest structure, habitat quality and silviculture prescriptions. Tree detail includes species, height, diameter and crown/foliage characteristics. Typical data requirements are individual tree characteristics, understory conditions and spatial arrangement of individual scene elements. Most plot-level programs don't include terrain variations.

Stand-level scales occur across much larger areas (up to 500 acres), with the goal of projecting area layout, such as harvesting parcels. Tree detail encompasses species as well as generalized height, color, density and crown characteristics. Data requirements include topography, ground surface characteristics, stand polygons, tree size, species distribution and general understory conditions.

Landscape scales involve areas greater than 500 acres, tracking vegetation texture, spatial arrangement of stand types, project area location, visual quality and insect or other stand damage effects. Tree detail is as high as stand scale in the foreground, but diminishes to texture mapping at greater distances. The data requirements are similar to those of stand-level visualizations.

As a general rule, the larger the project area the less detail required in the input data and final visualizations. Due to significantly larger interest areas, greater data volumes often are needed to generate landscape-level visualizations. At stand and plot scales, more detailed individual tree characteristics typically are required. In most cases, landscape representations depend on users sampling GIS-based polygon vegetation inventories for tree characteristics and then generating tree lists for placing trees on a 3-D landscape view. This is a critical requirement for using GIS-based polygon inventories, rather than field data, as the primary data input.

In addition, multivariate sampling techniques usually are required. However, modeling and sampling algorithms can be complex, depending on the specifications and the source inventory data's detail level. Robust inventory sampling techniques remain the foundation for generating realistic treed visualizations. To date, such functionality has been lacking with most GIS and 3-D visualization software, and little integration has occurred.

Numerous visualization tools are available for generating views at plot or stand level. Most notable is the Stand Visualization System (SVS) (McGaughey 1997) used within the U.S. Forest Service (USFS) and other government agencies (Figure 1). SVS has been linked to the USFS Forest Vegetation Simulator (FVS) program, which simulates at the stand level tree birth, growth and mortality levels.

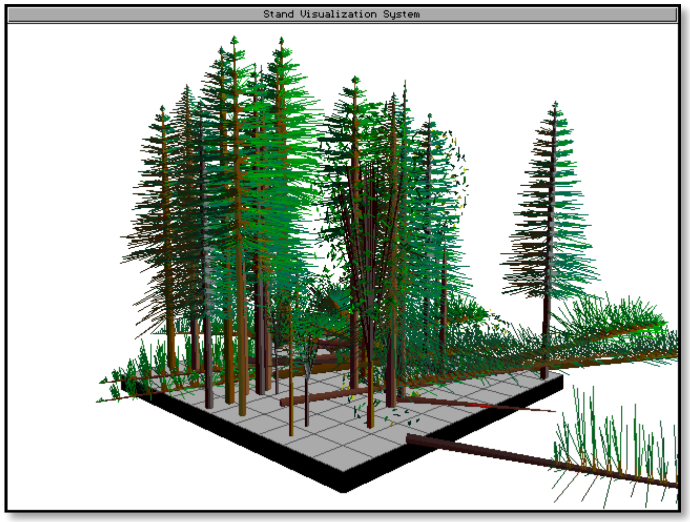

Figure 1. A typical SVS visualization using stand-level input.

SVS helps visualize and interpret FVS output as it generates 3-D graphic images that depict stand conditions represented by individual stand components, such as trees, shrubs and down material. Images produced by SVS, although abstract, provide a readily understood representation of stand conditions and help communicate silvicultural treatments and forest management alternatives to a variety of audiences.

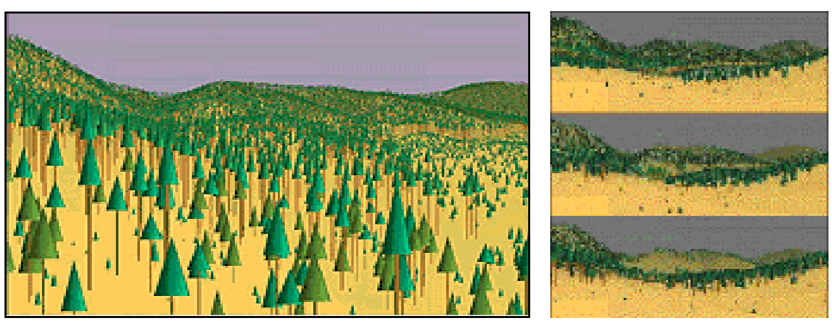

Figure 2. A SmartForest visualization representing forest growth model output for 1994 (top), 1996 (middle) and 1998 (bottom). Note increased forest cover, particularly in the distance.

SmartForest, developed at the University of Illinois Spatial Imaging Laboratory with funding from the U.S. Forest Service, is one of a few visualization programs that focus on the landscape level. SmartForest has capabilities to incorporate large forest databases and represent them at the landscape level. Figure 2 shows SmartForest visualizations that use output from a growth simulation model. Note the geometric modeling approach used to represent individual trees. The approach effectively represents much of a landscape scene's area, particularly if trees are dense, but loses its effectiveness for areas close to the observation point.

A New Era in 3-D Visualization

The primary requirement of operational natural resource applications is the need for realistic tree rendering, particularly for key viewpoint visualizations in which terrain and tree screening are essential. As previously mentioned, the geometric modeling technique is the primary method to satisfy this requirement.

Factors that restrict most visualization software in rendering treed surfaces effectively include their limited ability to create realistic 3-D tree objects, resulting in stylized 3-D cones to represent trees. This can be marginally effective for extensive coniferous landscapes, but doesn't accommodate mixed-wood or deciduous forest landscapes. Also, such an approach creates an unnatural impression in the foreground.

Performance times for rendering geometric modeled surfaces can be long enough to prohibit interactive processing. But perhaps the most limiting factor to date has been that selecting objects for rendering is rarely tied to GIS-based vegetation/timber inventories. This usually results in unrealistic representations of tree density, height and species composition, thereby restricting the applicability of most visualization tools in operational GIS environments.

The next generation of realistic visualization software share several key capabilities that go beyond the requirements for vastly improved performance. Such capabilities include:

- 3-D object design tools to build custom symbols based on characteristics such as tree type, color, percent maturity, size at various maturity stages, hierarchy level of branching, degree of randomness for branching, density and distribution of leaves, and internal and external shadowing
- 3-D object rendering of symbols such as trees, buildings and other manmade features
- Simulation of atmospheric effects such as fog, haze and clouds
- Texture mapping to support realistic rendering of polygonal features such as roads, meadows, open water and background sky
- GIS-based polygon sampling to generate explicit tree lists (x,y tree locations) based on common vegetation inventory attributes such as species, average tree height, crown closure and/or stand exams
- Multimedia capabilities, including map animation for generating flexible, 3-D "walk-throughs" and "fly-bys" using tree and object rendered images
- Interactive geo-query tools for querying 3-D visualizations enabled by seamless links to GIS-based attributes, providing a framework for a suite of 3-D landscape design capabilities

To date, few visualization programs incorporate these extended capabilities. Although several programs provide basic 3-D rendering capabilities, most aren't tightly integrated with commercial GIS software in production or operational forestry settings. This integration level should be considered a priority for visualization software developers, because the ability to create 3-D visualizations based on GIS data inventories created by natural resource agencies is paramount.

A Virtual Forest

Virtual Forest, a development project under way at Fort Collins, Colo.-based Innovative GIS Solutions Inc., demonstrates a tight integration between the advanced capabilities of scientific visualization software and production forestry data housed within a GIS. Landscape views are depicted as separate themes that define the specific visualization events. Theme types include 3-D terrain surface representation, sun illumination, visual exposure, atmospheric effects, polygon rendering and texture mapping, and tree plantings and removals. The ability to define different themes allows users to represent multiple landscape visualizations, such as different timber harvesting proposals or alternative ski area developments. The methodology also supports temporal events that can reflect management actions and vegetation changes.

A "tree designer" is a key component to realistic 3-D rendering because it enables users to interactively design custom sets of 3-D trees. Changes in tree object parameters allow definition of species variations, seasonal impacts, stage of maturity and object type (e.g., no leaves, stumps, snags, etc.). Completed designs are identified as specific tree codes and saved as rendered bitmaps with different light-source shadings. The bitmaps then can be used for subsequent 3-D rendering using texture-mapping techniques. With this approach, surfaces can be rendered quickly because object shading is undertaken at the tree design stage, not during rendering. Texture mapping is ideal for representing background treed areas, whereas geometric modeling is often more appropriate for foreground areas.

Texture mapping with predefined symbols provides significant performance improvements over traditional methods of rendering treed surfaces, resulting in truly interactive visualization. The orientation of the visualization view allows users to dynamically rotate, pan and zoom ("fly") the rendered landscape. Viewing parameters also can be preset to a defined set of viewpoint parameters, such as those defined in the GIS environment.

The following factors will help make the next generation of rendered views more realistic than traditional visual techniques:

- *Atmospheric Effects*. Atmospheric effects can be added as visualization events through several different techniques, including sky, haze and fog representation.
- *Polygon Texture Mapping*. Polygons can be rendered using bitmap-based texture mapping, which allows the pseudo-realistic rendering of roads, harvest blocks, silvicultural treatments (scarified, early treatment, plantation, etc.), water and other landscape features. Figure 3 illustrates simple polygon texture mapping for harvest blocks and logging roads applied to a typical mixed forest rendering.

- *Polygon Boundary Extrusion*. Using 2-D polygon geometry, features can be extruded onto the surface as 3-D containers (polygon walls). User-definable parameters include wall height as well as symbology for display of nodes, arcs and vertices. Figure 4 shows GIS polygons as containers ready for filling with rendered trees. The rendering process is analogous to color fill (paint bucket) in a standard painting package, except a 3-D object rendering pallet is used instead of a conventional color pallet.
- 3-*D Digitizing and Query*. Full 3-D model capability for on-screen digitizing polygons on the surface and rendering or removing trees. Object (tree) removal can use either a "percent removal" (complete removal of objects) or "harvest" approach (partial removal of objects).

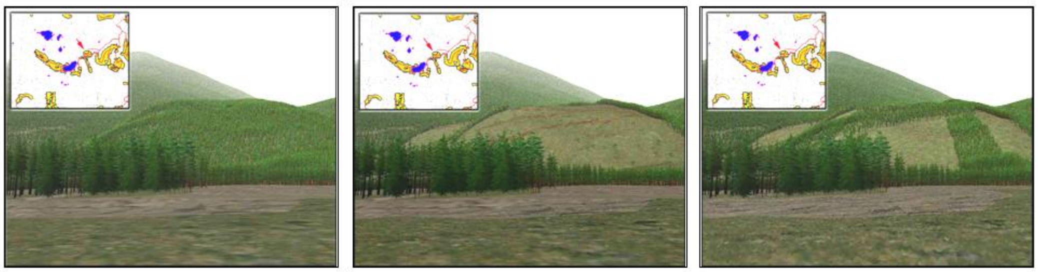

Figure 3. A figure illustrates the detail level of rendered trees and simple polygon texture mapping techniques applied to a proposed harvest area and logging roads. Note the different tree symbols intermixed to represent different species.

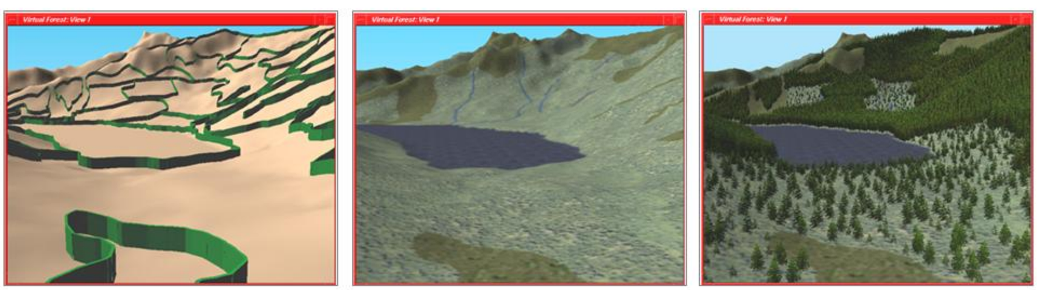

Figure 4. Polygons are represented as containers ready for rendering with trees. Multiple polygon layers can be represented, including inventory, lakes and proposed harvest blocks. Texture mapping also can be used to provide a more realistic look to the underlying surface.

Visualizing What Might Be

For thousands of years, traditional mapping has used a variety of abstract symbols, colors and patterns to characterize a landscape. Conventional GIS software extended these procedures to the digital map and linked map features to attribute data. Advanced analytical tools provide entirely new ways to address complex spatial relationships and model alternative management actions. Until recently, however, the rendering of GIS results primarily has been restricted to the same set of display techniques used in manual cartography.

The next generation of visualization techniques radically changes the image of mapping. As shown in Figure 5, users will be able to consider different visions of the future and see the results in renderings as realistic as a snapshot. Users will be able to apply 3-D rendering pallets in conjunction with conventional 2-D color pallets. The textured surface will complement the classic 2-D GIS thematic map. However, it's critical that these visualization capabilities be positioned to leverage the substantial investment already made by most companies and government agencies in GIS databases.

Figure 5. A treed surface uses the polygon containers identified in Figure 4. This view overlooks the lake and adjoining harvest blocks. The tree species (primarily Western Hemlock), height and density were derived directly from an ARC/INFO polygon inventory coverage.

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