3D Visualization for the Analysis of Forest Cover Change

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Abstract

Visualization techniques have been developed to recreate natural landscapes, but little has been done to investigate their potential for illustrating land cover change using spatio-temporal data. In this work, remote sensing, geographic information systems (GIS) and visualization techniques were applied to generate realistic computer visualizations depicting the dynamic nature of forested environments. High resolution digital imagery and aerial photography were classified using object-oriented methods. The resulting classifications, along with pre-existing land cover datasets, were used to drive the correct placement of vegetation in the visualized landscape, providing an accurate representation of reality at various points in time. 3D Nature's Visual Nature Studio was used to construct a variety of realistic images and animations depicting forest cover change in two distinct ecological settings. Visualizations from Yellowstone National Park focused on the dramatic impact of the 1988 fire upon the lodgepole pine forest. For a study area in Kansas, visualization techniques were used to explore the continuous human-land interactions impacting the eastern deciduous forest and tallgrass prairie ecotone between 1941 and 2002. The resulting products demonstrate the flexibility and effectiveness of visualizations for representing spatio-temporal patterns such as changing forest cover. These geographic visualizations allow users to communicate findings and explore new hypotheses in a clear, concise and effective manner.

Introduction

While it has been difficult for geographers to place a firm definition on the inherently ambiguous concept of visualization, its implementation shows promise for geographical data representation and exploration. In statistics, the premise that visualizing data is a necessary part of analysis is well established. Graphics are usually the simplest and most powerful means for communicating statistical results (Anscombe, 1973; Tufte, 1983). The term 'visualization' was first formally used by McCormick and colleagues in a special issue of *Computer Graphics* (1987) referring to the concept of scientific data visualization. The goal of these techniques is to provide insight through visual methods for a wide range of scientific problems such as medical imaging, earthquake simulation and displaying molecular structures. Within the field of geography, cartographers have been familiar with the idea since at least the 1950's (MacEachren and Taylor, 1994). The vagueness of the concept of visualization in geography is evident in recent attempts to define the term. Visualizations have been broadly characterized as the use of any concrete visual representation (MacEachren *et al*., 1992) and narrowly described as a private activity in which unknowns are revealed in a highly interactive environment (MacEachren, 1994).

Rather than attempting to (re)define visualization for this work, it is more useful to indicate the spectrum of what could be called geographic visualization. The following list suggests a hierarchy of visualization products based on interactivity and 3D realism: 1) Traditional two-dimensional maps, 2) Perspective view or 2.5D representation using either traditional cartographic methods or realistic visualization techniques, 3) Packaged sequence of 2.5D representations forming an animated movie, 4) A 2.5D/3D

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interactive environment presented on a flat display where the user controls how the data is displayed and the viewpoint, and 5) A fully immersive 3D environment using head mounted displays or projection systems like a CAVE (CAVE Automatic Virtual Environment) (Haklay, 2002). The field of remote sensing, which works with large amounts of data and produces results requiring display at multiple spatial and temporal scales, is ideal for exploring the application of visualization techniques.

One aspect of remote sensing research that presents a clear need for visualization is landscape pattern analysis. It has been shown that the analysis of changing landscape patterns is an important means for understanding ecological dynamics such as natural and human disturbances, ecological succession and recovery from previous disturbances (Turner, 1990). Satellite imagery and aerial photography that have been classified by vegetation or cover type provide an excellent source of data for performing structural studies of a landscape (Sachs *et al*., 1998; Fu *et al*., 1994). Simple measurements of pattern, such as the number, size and shape of patches (contiguous groups of pixels classified as the same cover type), can indicate more about the functionality of land cover than the total area of cover alone (Forman, 1995). When fragmentation statistics are compared across time, they are useful in describing the type of landscape change and the resulting impact on the surrounding habitat (Brandt *et al*., 2000). High resolution aerial imagery has also been shown to be effective for extracting individual image objects. This level of classification detail presents opportunities for analyzing landscape change patterns at a structural scale (Gerylo *et al*., 2000).

A difficulty with quantitative analysis of changing landscape patterns is the present method for analyzing and displaying the results of these studies. Traditionally, summary tables of patch measurements are presented along with raster classification maps, which may be overlaid on one another in a transparent fashion to illustrate change. For example, work by Franklin *et al*. (2000), focused on showing harvesting activities in the Fundy Model Forest, New Brunswick, Canada, over the period of a decade. Initially, the products of the project consisted of change maps based on two Landsat Thematic Mapper (TM) satellite images and textual tables quantifying the change. While these characterizations concisely relay a large amount of information, they are often difficult to interpret even by individuals intimately familiar with the study area. Further work on the Fundy Model Forest project produced annual change harvest maps, and simple methods were used to visualize the change with slide show animations (Franklin *et al*. 2002). While the animations enhanced the interpretability of the statistical change results, more sophisticated geographic visualization tools and techniques are now available.

The visualization of natural landscapes has been increasingly used to deliver the results of environmental change studies and management plans, especially concerning forested environments (Tang and Bishop, 2002). Geographic visualizations have also been used to form hypotheses and explore data more effectively than traditional graphic representations (Hearnshaw and Unwin, 1994). Until recently, forest visualization efforts have focused primarily upon illustrating static concepts or the possible outcomes of management actions (Bishop and Karadaglis, 1997; McGaughey, 1997; Buckley, 1998). This form of time series visualization compares two or more individual images, generated to represent specific points in time. By animating these static visualizations to move the viewpoint through a 3D landscape, the visualizations would more clearly communicate spatial relationships based on the fact that human vision is "hardwired" with special sensors to detect motion (Gregory 1988). Along with animation through space, visualizations can also use animation to move the viewer through time to provide a dynamic representation of changing land cover. With recent increases in computer speed and software availability, forest visualization techniques are beginning to include the communication of change analysis studies using animation (Stoltman *et al*., 2002). The application of visualization to remote sensing is still at an early stage of development, requiring the investigation of topics such as the links between remotely sensed data products and visualization software, the appropriate use of animation through space and time and the amount of information that should be presented for various projects and audiences.

Goals and Objectives

The goal of this work is to demonstrate the potential of computer visualization as a tool for analyzing and communicating the results of remotely sensed landscape change studies. The visualizations in this discussion fall in the middle of the continuum of visualization types, focusing on photo-realistic perspective static images and animations depicting forested landscapes through time. These non-interactive visualization styles were chosen due to both the availability of existing visualization software and the desire to investigate the most effective methods of spatial and temporal animation and data representation prior to implementing the techniques in an interactive or immersive system. To meet our primary goal, two objectives were outlined:

- Demonstrate the utility of visualization techniques in the field of remote sensing using two examples of forest cover landscape change studies in different environments
- Investigate a variety of visualization methods in each environment, describe how the visualizations were created and discuss the benefits of each type of visualization

Methods

Study Areas

This investigation of visualization applications in remote sensing based land cover change studies deals with two ongoing projects working in different forested environments. Research in Yellowstone National Park is focused around the characterization of forest biophysical variables over time, while work in eastern Kansas is investigating the changing structure of forest cover in the region over the past 60 years. These two studies were selected for visualization work because they offered a wide variety of data sources, demonstrated both natural and human induced change, and the two projects are investigating distinctly different forest environments.

Over 80% of the United States' first National Park, Yellowstone, is covered by mountainous forest composed primarily of lodgepole pine (*Pinus contorta var. latifolia*) (Figure 1). Fire is an important natural agent of change in this ecosystem. The large fires of 1988 in Yellowstone National Park demonstrated how dramatically and rapidly the vegetation and consequently the condition of an ecosystem can change. The 250,000 ha of burnt forest created a striking mosaic of burn severities on the landscape of the park. Both the ecological and economic impacts of these fires have been significant (YNP, 1993; Polzin *et al*., 1993). As the burns have begun to naturally regenerate with lodgepole pine seedlings (Reed *et al*., 1999), the patchwork left upon the landscape has inspired numerous efforts to document and analyze the impacts of this natural disturbance (Stevens, 1990; Renkin and Despain, 1992; Turner *et al*., 1994; Hardy-Short and Short, 1995).

The Midland, Kansas United States Geological Survey (USGS) 1:24,000 Quadrangle, falls within the tallgrass prairie and eastern deciduous forest ecotone (Figure 1). The prairie biome, which once covered a vast expanse of the American Midwest, is now greatly diminished (Whitney, 1994). Prior to European settlement, habitats within the prairie's eastern ecotone were an interlocking pattern of forest and prairie, determined largely by the interaction of fire, topography, moisture, soil type, and biotic factors (Anderson, 1990). Human interaction with the landscape has since modified several of these controlling variables. Along the prairie-forest ecotone it is now well documented that woody species can invade grassland habitats that are not burned, grazed, cultivated or mowed (Holt *et al*., 1995) and it has been suggested that forest expansion into the grasslands of this region has occurred within the last 100 years (Abrams, 1986).

Data Collection and Classification

A wide variety of remotely sensed data was used to construct the visualizations of Yellowstone at three spatial scales. At the landscape scale, encompassing all of Yellowstone, six different sources of remotely sensed imagery were displayed simultaneously in the same band/display color combinations (mimicking Landsat band 4 = red, 3 = green, 2 = blue) (Table 1). For the stand scale of visualizations, 30 m resolution raster coverages of land cover within the Central Plateau region from before and after the 1988 fire were acquired from the United States National Park Service. The land cover classification used in these coverages was based on Despain's forest cover type classifications (Despain, 1990). At the plot level, feature extraction methods were applied to high-resolution DuncanTech imagery to identify the exact point location of individual trees, snags and deadfall (Figure 2) (Moskal *et al*., 2002). Due to rendering time for such a large area, a coarse 80 m Digital Elevation Model (DEM) of both Yellowstone and the adjacent Grand Teton National Park was used as the base terrain layer for all three visualization scales.

Table 1 Data sets used to construct the Yellowstone and Kansas visualizations.

Data Type / Sensor	Resolution	Acquisition Date(s)
Yellowstone		
Landsat TM	30m	June 15, 1997
SPOT	25 m	June 7, 1999
ASTER	5 m	July 2, 2001
IKONOS	1 m	July 21, 2000
Digital Orthophotos	1 m	July 1994
Kansas Applied Remote Sensing Program DuncanTech Digital Camera Imagery	~40 cm	July 2000
US National ParkService Classification of Yellowstone's Central Plateau	30 m	Pre and Post 1988
Digital Elevation Model	80 m	
Kansas		
Black and White Air Photos	1 m	1941, 1954, 1966, 1976, 1991
Color Infrared Air Photos	1 m	2002
Digital Elevation Model	30 m	

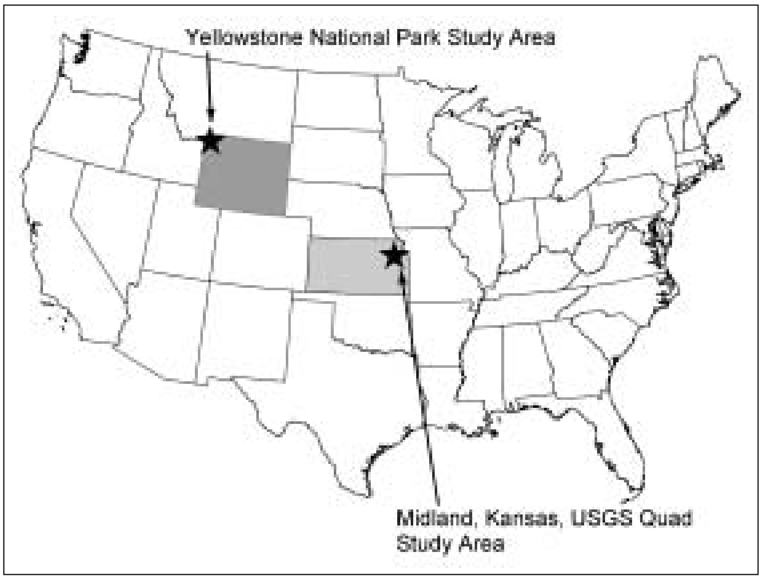

Figure 1 Yellowstone and Kansas study area locations.

The data sets used for the study of Northeastern Kansas forest cover change were more limited in spectral depth than the Yellowstone study, but more dense in temporal coverage. Therefore, the Kansas data were used to create multi-date static and animated visualizations. Black and white aerial photography from 1941, 1954, 1966, 1976 and 1991, as well as color infrared photography from 2002 were collected for complete coverage of the Midland, Kansas USGS Quadrangle for six specific dates spanning over 60 years. After georectifying all dates of the imagery, Definies' eCognition was used to classify the photography using an object-oriented approach. The object based classification used by eCognition allowed the panchromatic black and white imagery, as well as the color infrared imagery, to be classified into forest/tree cover, non-forest, roads/building structure and water classes. Prior to using the classified data for the creation of visualizations, the classification was simplified into only two classes: forest and non-forest cover. The still visualizations used in this project were driven by these classified forest cover data sets, while the animations used were based on change detection between dates using post-classification comparison. For the Kansas forest visualizations, a more detailed 30 m DEM was used as the base terrain layer because the modeled area was substantially smaller than the Yellowstone region.

Visualization Development

Software: Visualization and animation tools are still quite rudimentary in commercially available remote sensing and GIS software packages. By combining the abilities of numerous pieces of software it is possible to demonstrate what a single geospatial package may someday be capable of producing. This project relied on five different types of software: remote sensing image analysis, GIS, image editing, video editing, and landscape visualization. After an exhaustive search, 3D Nature's Visual Nature Studio (VNS) was chosen as the most appropriate photo-realistic visualization software package for exploring forest rendering techniques at a variety of scales. Along with its lifelike rendering ability, VNS was selected for a number of other specific qualities:

- Integration with georeferenced GIS datasets
- Flexibility of land cover type development using "ecosystems" and "ecotypes"
- Use of raster or vector formats to drive rendered vegetation components
- Both motion and time-series animation ability

As McGaughey (1997) suggested, before starting any visualization project it is important to consider the available data, the size of the study area and the intended use of the resulting products. In Yellowstone, the visualizations created for this work attempted to accurately recreate the landscape and vegetation communities at scales ranging from the entire landscape down to individual plots of trees. In contrast, the Kansas project had a longer running data set to work from. These visualizations were made in an attempt to capture the process of forest cover change within a much smaller study area by focusing more on animation techniques than accurate tree type representations. Taken individually, each static or animated visualization product provides a unique display method for relaying many aspects of remotely sensed forest cover change studies.

Yellowstone Visualizations: Visualizations covering the largest possible area, the landscape level, are used primarily to provide an overview of a study region and show the general spatial arrangement of landscape elements. The landscape level visualizations for Yellowstone used VNS to demonstrate the image-based visualization approach of draping imagery data over a digital terrain model. Six remotely sensed image data sets at a variety of spatial resolutions, from 30 m Landsat TM to sub-meter digital camera imagery, were draped upon the 80 m DEM terrain data using texture-mapping techniques. Finally, GIS vector layers, such as the Yellowstone park boundary and text labels, were inserted to aid in interpretability. Still renders were generated from this project and animations were created using a pre-defined camera flight path in the form of a vector GIS layer. This was the simplest visualization modeling technique, which can be implemented within numerous software packages.

Projects designed to relay the overall structure of a functional unit of land cover are termed "stand level" visualizations. The next stage of visualization for Yellowstone was a mixed-scale approach, using vegetation objects to visualize forest structure between a landscape and stand level of detail. The visualizations highlight landscape characteristics such as the spatial arrangement of stand types and stand structure. The focus of the landscape/stand level visualizations was three successional stages of the lodgepole pine forest: the seedling/regenerating stage, the even height mid-successional stage and the mature forest stage. VNS represents trees, snags, deadfall, ground cover and other vegetation types using image objects taken from the real world. Objects are either placed individually on the landscape or grouped together in associations called "ecotypes." Each ecotype consists of groups of image objects, each with their own height range and density specifications. At the landscape/stand level, where only general land cover classes were known, raster coverages were used to drive the placement of ecotypes upon the landscape. Two separate visualization projects were created using the raster land cover classifications from before and after the 1988 fire. Pre- and post-fire stills and animated visualizations were developed to demonstrate the usefulness of these visual tools in landscape/stand level spatial metrics analysis.

The most detailed stage of visualization is the plot level, where specific changes in stand structure can be illustrated. In contrast to the 30 m resolution raster land cover classification at the stand level, exact locations for trees, snags and deadfall were known at the plot level. For these visualizations, GIS point coverages derived from sub-meter digital camera imagery were used to place individual image objects, such as trees and standing dead snags, of various heights upon the terrain. Two 30 x 30 m study sites were selected for the plot level visualizations. The first site was located in a regenerating forest while the second was selected within a mature forest (Figure 2).

In an effort to improve upon the plot and stand level visualizations, the park was revisited in the fall of 2002 to collect image objects specific to Yellowstone and photograph various land cover classes. These datasets allowed the refinement of the ecotypes developed for the various land cover types created to more exactly match the living and non-living vegetation objects specific to Yellowstone (Figure 3).

Kansas Visualizations: The non-animated visualization of multi-temporal land cover data results in individual stills representing a single date of forest cover derived from remotely sensed imagery. Multiple dates of still renderings can be viewed side by side allowing comparisons of forest structure through time. The 30 m DEM of the area was used to generate a terrain as a foundation for the visualizations. As the Kansas forest cover classification was simplified to forest and non-forest cover types, only two ecotypes were created in VNS. Appropriate ground cover and vegetation image objects were combined to mimic a generic forest and grassland vegetation cover for this region. To complete the models, the classified forest cover data sets for all six study years were brought into VNS, where the appropriate vegetation classes were linked to the VNS ecotypes. After selecting an appropriate view angle, still visualizations of the forest cover through time were rendered by cycling through the classification dates.

Visualizations using animation provide a greater sense of the process of land cover change recorded by multi-temporal imagery. By representing real world time in years with animation time in seconds, this display method represents change in the same way that we are familiar with viewing it in the real world. The animated visualizations were created using a different approach than the static renderings. This was done because the resulting product needs to describe the change between years, rather than the before and after snapshots produced by the still frames. Within a GIS, classification comparisons were produced between each consecutive date pair of forest cover data. This process reduced the six dates of forest/non-forest classified imagery to five change comparison images with classes defined as unchanged non-forest, forest addition, forest removal or unchanged forest cover. In VNS, instead of using static ecotypes, as with the still visualizations, the forest and non-forest ecotypes were replaced with four different animated ecotypes to match the classification comparison results. The animated ecotypes represented the unchanged classes with grassland or tree cover, the forest addition cover class with growing trees and the forest removal class with trees shrinking

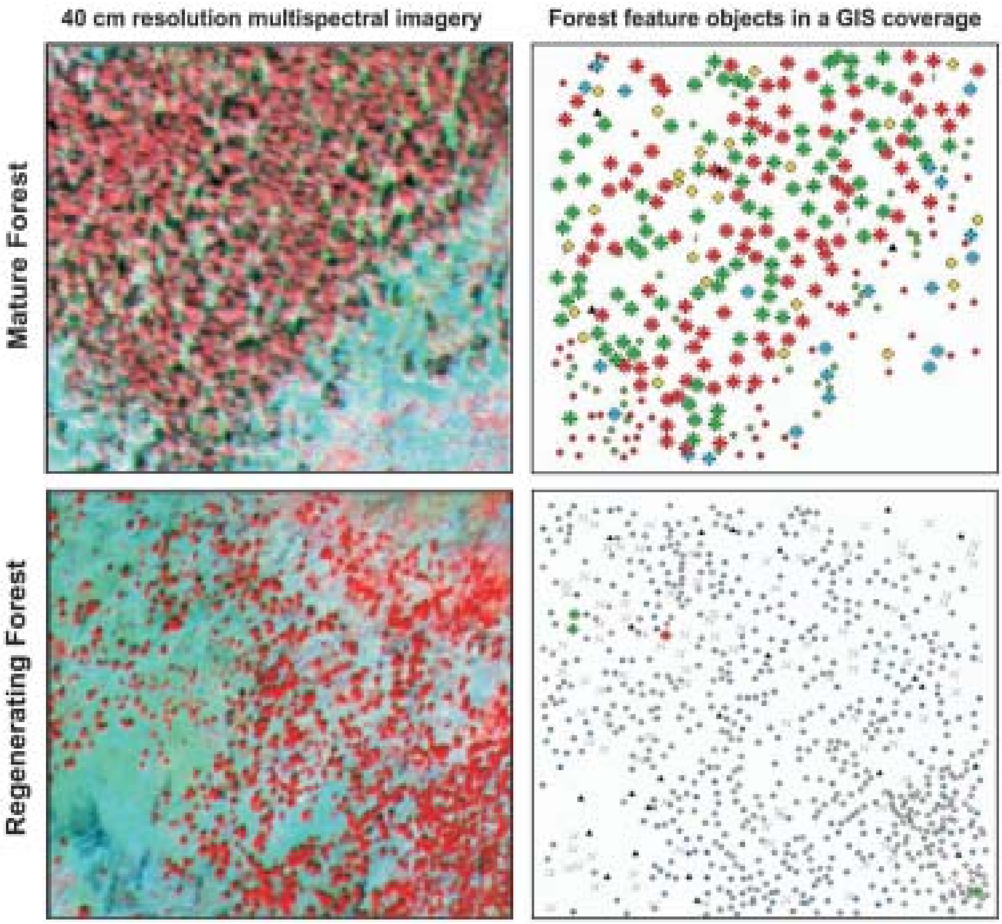

Figure 2 KARS sub-meter DuncanTech camera imagery and derived GIS point coverages for vegetation objects.

and disappearing from the landscape. Once the classified comparison data and animated ecotypes were brought together in VNS, animations were created by selecting a camera location and defining the time interval to be rendered.

Results and Discussion

Yellowstone

The landscape level image-based visualization incorporates six different remotely sensed data types draped over a digital terrain model (Figure 4). The animation created from the landscape level visualization offers a flyby that places the spatial extent of Yellowstone National Park in context. The flight path was chosen to highlight each of the imagery types available for the park, demonstrating their coverage extent, spatial resolution and spectral characteristics. This geographic visualization helps to orient those unfamiliar with the study area, illustrate properties of remotely sensed data and provides a general sense of land cover structure. While draping images upon a 3D terrain is common, the use of a wide variety of sensor imagery provides a unique tool for introducing experts and the public to the Yellowstone study.

Visualizations at the landscape/stand level of detail are useful in communicating the overall structure of land cover patterns and land cover change. Landscape metrics and spatial analysis are becoming widely used in many aspects of ecological assessment and resource management. By quantifying the pre and post 1988 landscape using various spatial metrics, comparisons can be made between the temporal representations of the landscape. Summary tables can quantify differences representing change in the forested landscape, but indicating the specific variety of change is often difficult. Visualizations are used to support the content of landscape metrics analysis making the information more accessible to forest managers, ecologists and the public. Figure 5 provides a comparison between the traditional display method for representing landcover change and more realistic geographic visualizations. While the stills show a snapshot of a stand level view, animations created for this project further acquaint the viewer with the landscape structure by means of motion simulating flight and ground based movements. This style of animated visualization is the logical progression from the “before and after” still image visualizations which are often used in impact assessments.

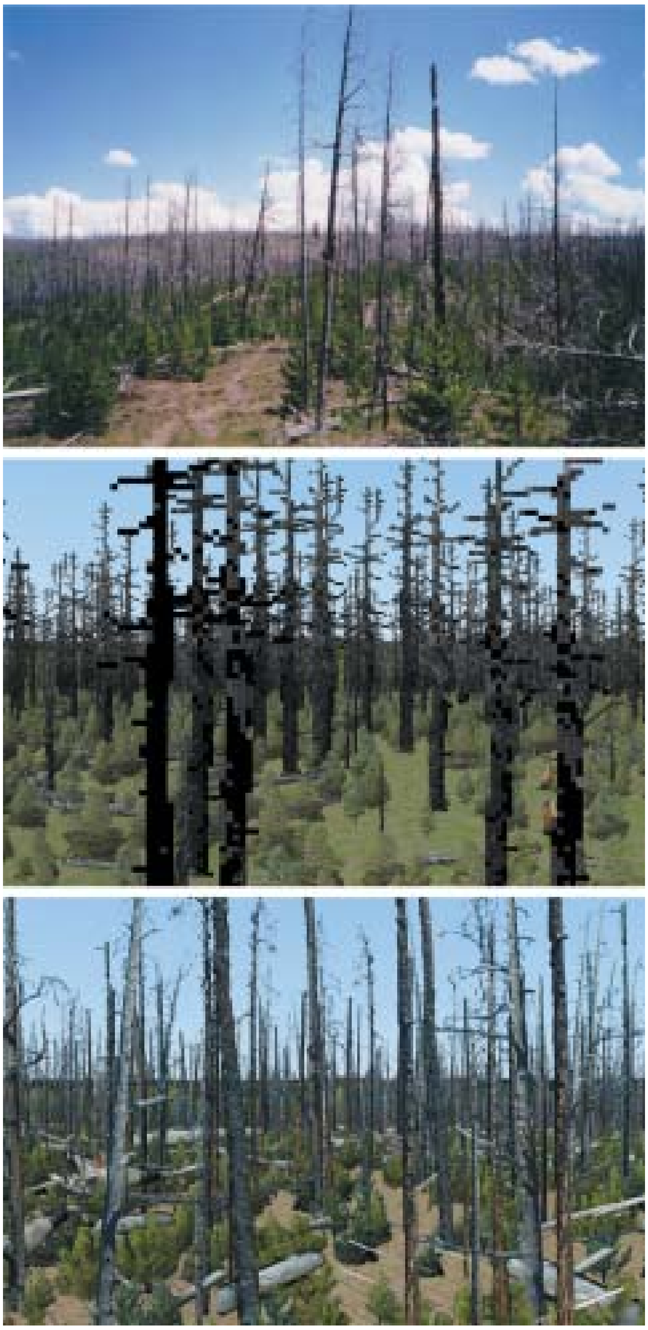

Figure 3 Ecosystem refinement for regenerating forest: (top) field photo, (middle) initial visualization using generic image objects, (bottom) final visualization using image objects acquired in Yellowstone.

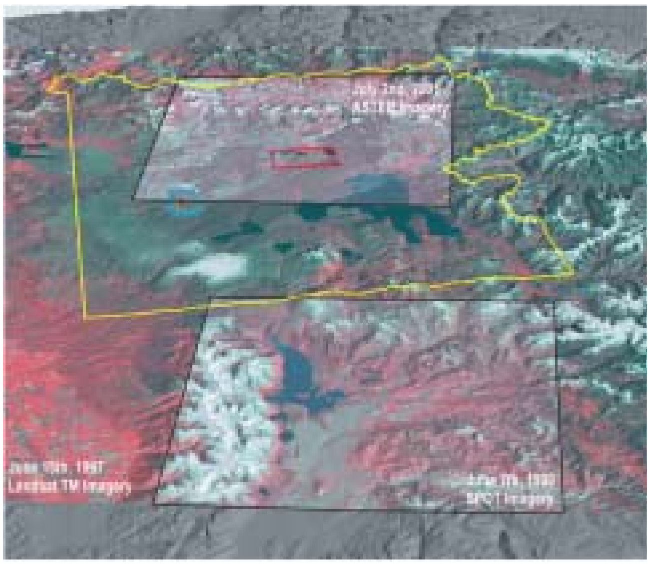

Figure 4 Landscape level visualization. The Yellowstone National Park boundary is delineated in yellow, the IKONOS imagery is shown in red and DOQQ image in light blue.

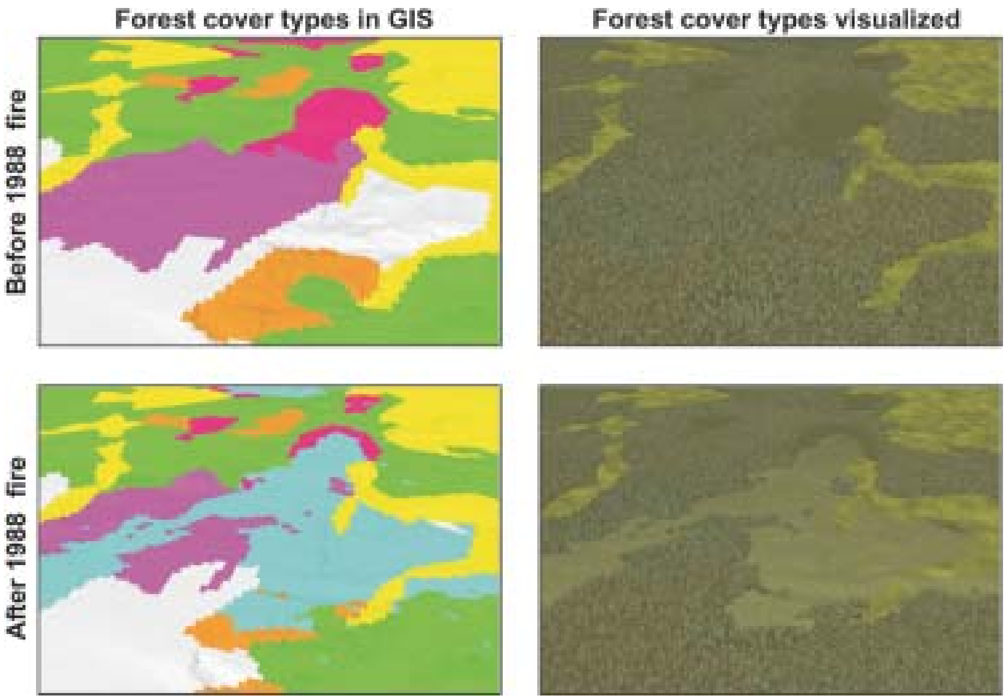

Figure 5 GIS polygon view of the landscape compared to a view using rendered forests.

By moving through the visualized landscape before and after the 1988 fire, the user can gain an understanding of the various ecological communities within the study area, the structural impacts of the fire upon the park's forests and, more generally, the ability of remotely sensed imagery to detect these changes.

The finest level of detail of a forested land cover type can be illustrated with plot level visualization, which highlights unique structural characteristics of a specific forest plot. More precise changes in forest composition and structure are presented at this scale. The plot level visualization in this study demonstrates the ability of object oriented feature extraction to describe the position and size of individual trees and other landscape components. While a GIS or paper map provides the means to catalog and display the spatial position of point features representing trees in the plot, only someone intimately familiar with both the forest ecology and display symbology can comprehend what is physically on the ground. In contrast, the visualized representation of these plots clearly communicates the forest structure, including species/object type, location and size, in a simple yet powerful manner (Figure 6). As well as suggesting the precision and detail level possible with modern remote sensing technology, this visualization application represents one of the key benefits to merging visualization and remote sensing: Remote sensing allows us to precisely locate objects on the earth's service without physically visiting the location, while visualization provides the means to realistically illustrate what this information actually represents.

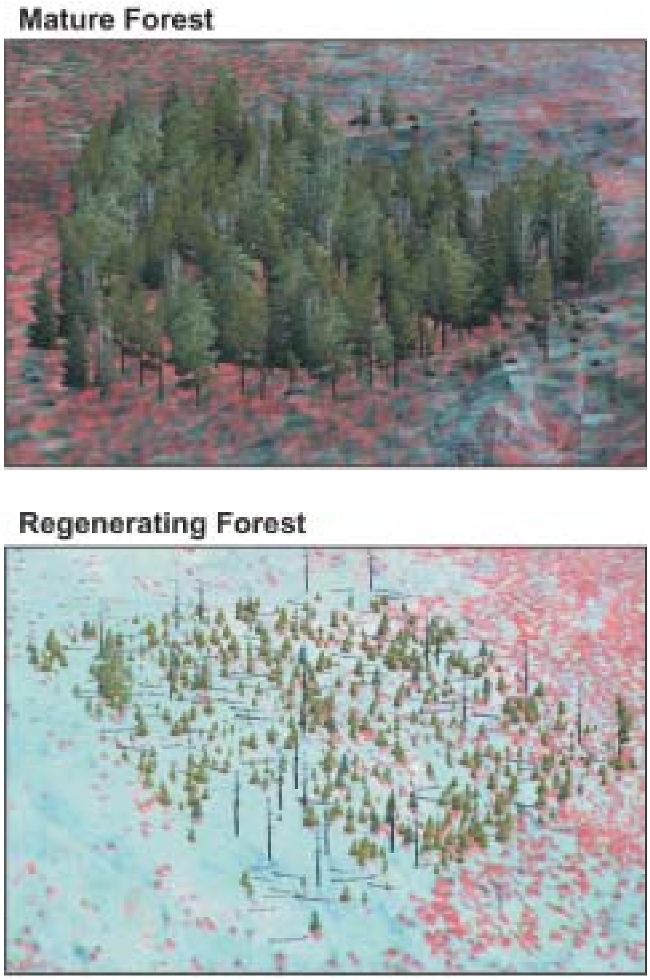

Figure 6 Plot level visualization based on uniquely identified image objects.

Kansas

The first visualizations developed from the Kansas forest dataset were static images displaying the extent of forest cover at specific dates corresponding to the aerial imagery. The stills are based on the idea that forest cover is more easily understood when it is displayed as a collection of 3D tree objects (Figure 7). The resulting products are similar in appearance and provide the same benefits as the landscape/stand scale visualizations from Yellowstone. This style of geographic visualization provides a more familiar and interpretable way of comparing multiple dates of land cover than a traditional GIS Polygon view. Static visualizations of a 2.5 km^2 subset of the study area were rendered from three different vantage points and compiled together to produce a mass-multiple display comparison (Figure 8). This non-animated style of visualization can effectively supplement quantitative patch structural measurements describing the same area.

The animated visualization used the same classified data sets as the static visualizations, but recreated the changing forest cover as a dynamic process rather than individual moments in time. By animating the appearance or removal of trees in much the same fashion that forest cover would change in the real world, viewers of these animations can experience the events of the landscape history of this area. Used in connection with quantitative patch structure measurements, the animations provide a visual reference in a qualitative format. To demonstrate this concept, the final Kansas animation was amended to include graphs of several landscape metrics (area, number of patches, average patch size and total edge), which are displayed in an animated fashion that progresses in time with the visualization (Figure 9).

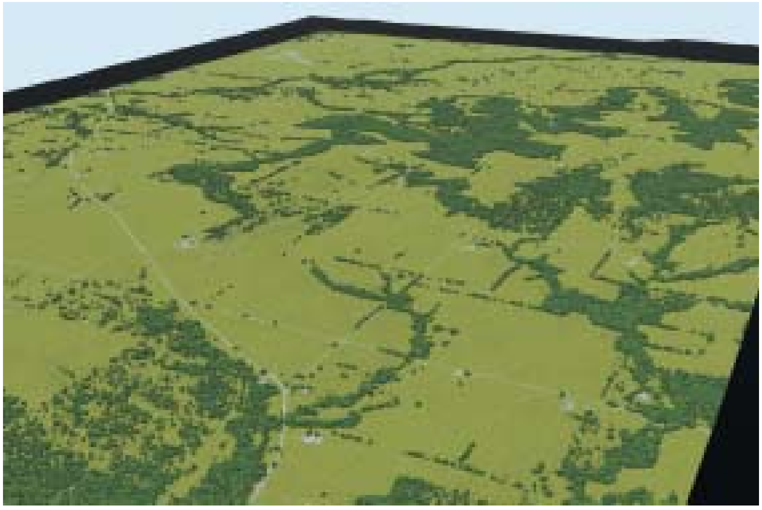

Figure 7 Visualization of the southern half of the Midland, Kansas USGS Quadrangle.

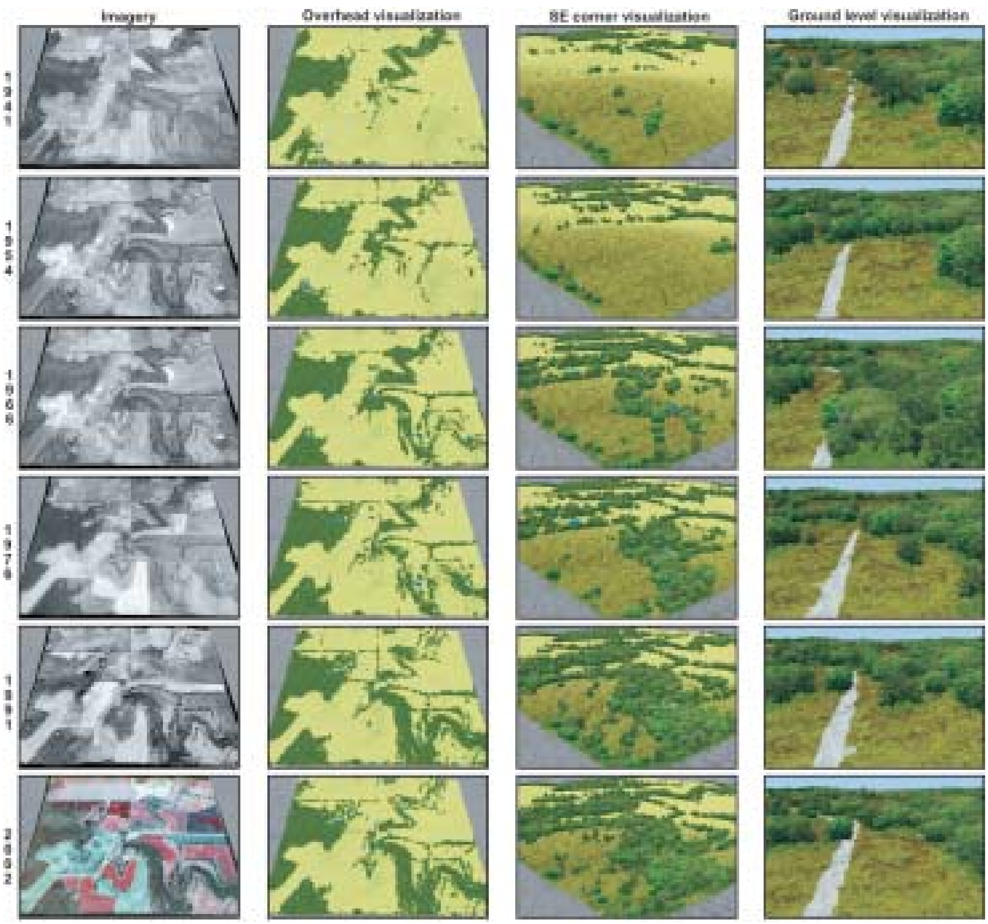

Figure 8 Time-series forest cover change visualization for a 2.5 square kilometer region of the study area.

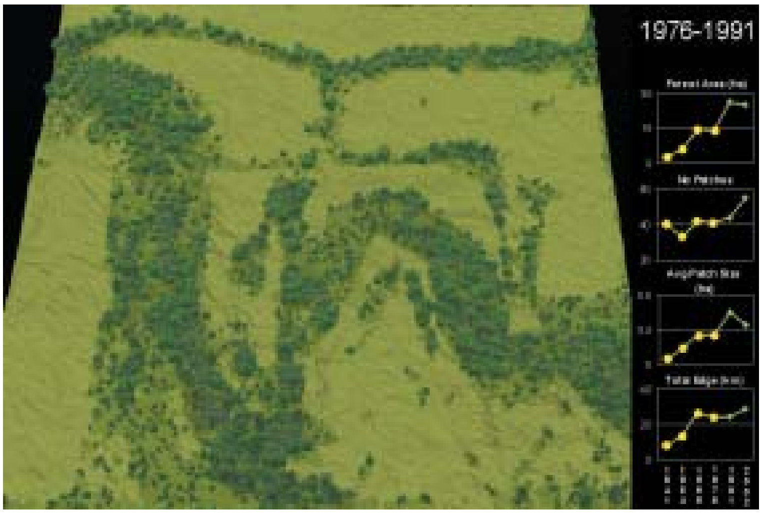

Figure 9 One frame of an animated visualization showing forest cover in a visual and quantitative form.

Animated visualizations can also be used as a stand-alone data exploration tool for investigating relationships and drawing conclusions regarding the nature of the changing forest cover. This final visualization represents another key benefit to merging visualization and remote sensing: Remote sensing permits the archival and classification of the landscape at various points in time, while visualization can tie each of these snapshots together by representing the detected change as a process using visually familiar objects.

Conclusions

These examples demonstrate the utility of 3D computer visualizations for illustrating various types of forest cover change in two distinctly different environments at several spatial scales. The purpose of examining two different types of forest cover change was to demonstrate the applicability of these visualization techniques to a wide array of forest research areas. Any remote sensing based research resulting in forest compositional or structural classification, forest modeling, or forest management plans could benefit from the ability to more clearly relay results to intended audiences. It is also reasonable to assume that the visualization methods demonstrated here are not limited to forestry research and could be effectively applied to any geospatial data set. Future efforts dealing with this style of geographic visualization should focus on refining the animation techniques used to relay forest cover change by investigating new methods for displaying landscape structure information as it evolves through time.

While this work provides an overview of the methods and significance of landscape visualizations, there are several specific benefits and drawbacks related to the approach taken with this project. With all of the visualizations created for this work, once a visualization project or model is setup, stills or animations can be rendered from any camera angle and motion path. Similarly, new data, such as a more recent date of imagery, a proposed landscape modification or the results of a landscape model can be quickly added to the project. Such flexibility suggests the ease at which new modified visualizations can be created once a specific project is finalized. In contrast, as all visualizations are in some ways an abstraction of reality, it is important to note their limitations. For example, with the animated display of the Kansas forests in this project, all trees grow to a set height range in the time period between two dates of remote sensing data, regardless of the amount of time the area has been classified as forest covered. This limitation, or those specific to other visualizations, should be clearly explained to the end user so that they understand what they should and should not try to infer from the display. In general, the major shortcoming with visualization tools available today is their complexity and the vast number of software packages that are needed to supplement the actual visualization software. It seems that we will not see these visualization techniques used effectively by the whole of geography until the tools needed to create them are combined into one coherent package.

Online Access to Visualizations

Images and animations discussed in this work are available online (http://www.kars.ku.edu/projects/visualization/).

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