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SYLVATICA: an integrated framework for forest landscape simulation

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ABSTRACT

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In this paper we present the proposed conceptual approach and essential subsystems of SYLVATICA, a landscape-based simulation model which will integrate several resource-management technologies in a visual interactive environment. We believe this approach incorporates several critical technologies which should be common to any integrated landscape-based simulation and visualization environment.

INTEGRATED SYSTEMS FOR FOREST MANAGEMENT

The development of integrated software systems to resolve environmental or resource-management issues has not kept pace with the emergence of new computer technologies or the complex, multifaceted problems associated with environmental management. A fundamental problem is that highly specialized analytical programs such as Geographic Information Systems (GIS) or detailed forest simulation models are used in isolation. While each program may be powerful in and of itself, realistic solutions to natural resource problems can only arise by integrating results from these packages at the appropriate spatial and temporal scales. In forestry, these scales generally involve forest growth across a regional landscape at a time scale measured in decades. In the systems cited above, GIS can represent the spatial distribution of forest stands and associated data only at a single point in time. Most forest growth models, on the other hand, use sophisticated algorithms to simulate temporal change, but consider only point estimates of the composition and growth of individual forest stands/ecosystems. This lack of spatial resolution in forest models makes it difficult to extrapolate temporal changes to the mosaic of forest stands nested within a landscape. It is this integration of space and time in the broader context of the regional landscape that must be the focus of environmental and natural resource management.

In addition to a lack of integration among the primary types of decision support software, the development of visualization techniques has lagged behind the science of simulation, GIS, and knowledge management systems. While a number of rule-based expert

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systems and simulation models are available to resource managers, they typically represent trees as arrays of numbers and statistics. These stand tables and stocking charts have been in the mainstream of forest management for many years, but do not readily convey information on stand structure, spatial pattern, or tree form in the way that a well-structured visualization system might. As sophisticated computer graphics become more readily available in the microcomputer environment, it becomes possible to deliver this technology to the forest manager, the natural resource specialist and the student.

OVERVIEW OF SYLVATICA

The SYLVATICA simulation will be a game-format visual interface around existing mathematical models of forest growth and ecosystem processes, with associated encyclopedic knowledge bases and rule-based decision support systems. To integrate forest stands within the landscape, this system must include two fairly separate levels of resolution.

Landscape level

A forest/landscape level will provide an overview of the regional topography and forest cover types. This could be a hypothetical (or typical) landscape, or it could be a digitized aerial view of real property. Landscape images may be rendered using triangular irregular networks based on topographic data or with fractal methods. The visualized landscape will consist of a mosaic of forest cover types, wetlands and riparian systems. The user will have the ability to view or access information on any of these landscape elements using a mouse or cursor-driven graphical user interface. The visual representation of an individual stand, for example, may be accessed by pointing and clicking on that stand.

Stand/site level

The geo-referenced data from the landscape level will provide a framework for the stand or site level of the system. The stand/site level will permit on-site visualization, dynamic change, and manipulation of particular stands and individual trees. The user may view the stand from several perspectives, from overhead to ground level. The overhead view would show the degree of canopy closure (and resulting competitive interactions) as a function of stand density and tree distribution. The ground-level view will show trees in perspective as viewed from a particular vantage point. Pointing and clicking on a particular tree will produce a dialog box containing typical mensurational data: species, diameter, merchantable height, crown ratio, crown class, and defect. Trees may be marked for cutting, allowing simulation of different silvicultural practices. Results of silvicultural treatments will be obtained by linking this information with forest growth models.

Forest growth models

The descriptive information contained in these two hierarchical levels will be used as input to models of forest growth and succession. Forest growth and yield models (e.g. TWIGS, Brand et al., 1987) provide a means to evaluate forest growth and the economic viability of different timber harvesting scenarios. Successional or ecosystem models such as LINKAGES (Pastor and Post, 1986) predict changes in stand composition overtime as functions of climate, site quality, nutrient cycling and other factors. These ecosystem models will be valuable for evaluating long-term impacts of factors such as climate change, increased ozone or other atmospheric pollutant levels, or acidified deposition. By linking these models with the spatial analysis capabilities of GIS and changes in ecosystem boundaries, the face of the landscape may be predicted.

Decision support systems

Finally, a variety of consultation systems will be available both at the landscape and stand levels to provide expert opinion and advice to the user. Hypertext systems will provide access to an organized and structured scientific knowledge-base. Expert system rulebases on silviculture, wildlife management, or old growth guidelines can be accessed to provide advice on different management scenarios (Rauscher and Hacker, 1989). Tutorial systems will help guide the user through this vast array of data, information and knowledge.

The completed model will allow the user to visualize the effects of silvicultural or other resource management strategies, natural or anthropogenic disturbance, or global climate change over long time horizons. In addition, it will provide a means to synthesize management and scientific information about forests, and identify research needs.

SUBSYSTEMS WITHIN SYLVATICA

Our strategy is to integrate a number of analytical subsystems into an overall operating environment. Each subsystem performs a specific role in managing or providing information on the forest environment. For natural resource management systems, we feel these are the fundamental components required to build comprehensive geographically based simulation and decision support models:

(1)A Geographic Information System (GIS) will be used to create, manipulate and analyze spatial data. Layers in the GIS database will include landform, soils, forest cover types and ecological patches, as well as management units such as forest stands and compartment maps.

(2)A Database Management System (DBMS) will manage numerical data associated with the forest stands (e.g. basal area, density and mean diameter) as well as individual tree data (location, diameter, height and defect).

(3)Forest simulation models will be used to change forest composition over time according to successional pathways, environmental conditions and management practices.

(4)A Hypertext System (HS) will be used to structure and provide access to existing knowledge about the system. An encyclopedic textual database of relevant knowledge will be maintained in a hypertext environment to help a user understand what they are doing and why (Rauscher and Host, 1990).

(5)Knowledge-based Management Systems (KBMS) will be used to provide opinions and advice through simulated consultations with experts in various fields.

(6)Tutorial systems will be used to watch over the user, much as a mentor might, and provide guidance and direction.

(7)A Graphical User Interface (GUI) will provide a common link between the user and the model's subsystems. The INFORMS demonstration program (STARR Lab, Texas A & M) and the IIASA Environmental Impact Analysis systems (Fedra et al., 1990) provide excellent examples of GUIs as interfaces to commercial or custom-programmed subsystems.

CONCLUSION

We have presented a conceptual strategy for developing a visualization environment which integrates the spatial analysis capabilities of GIS with the predictive capabilities of forest growth and yield and succession-oriented models. While a number of collaborative efforts are currently working in these directions, there is a wide gap between development and implementation of these technologies as management tools. The visualization environment and the creation of a unified interface between the user and relatively complex model subsystems will be the key toward moving these sys-

tems from the programmer's workspace to the manager's desktop.

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