INTEGRATION OF AN URBAN SIMULATION MODEL AND AN URBAN ECOSYSTEM MODEL

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This paper explores the development of an integrated urban-ecological simulation framework by linking two lines of urban and ecological simulation modeling. We propose a framework for linking the UrbanSim Model and the Urban Ecosystem Model, and describe the structure of the proposed approach. The model is object-oriented and links urban actors to ecological processes through a disaggregate spatial structure.

OVERVIEW AND OBJECTIVES

Concern about the health of the natural environment, and about increasing pressure placed on the environment by human activities, has manifested itself in various ways in public policy and academic research. Within the United States, the Clean Air Act and the Intermodal Surface Transportation Efficiency Act have focused legislative pressure on the metropolitan planning of transportation infrastructure to minimize effects on air quality. Internationally, scholarly and political interest in broad environmental issues such as global warming, acid rain, deforestation and tropospheric ozone depletion capture the public imagination, focus the energies of international bodies such as the United Nations and motivate academic research.

Two separate streams of research have focused on the interactions between human activities and uses of land with the natural environment. One stream deals with metropolitan scale modeling of land use, transportation, and environmental effects, focusing in particular on air quality impacts. The second treats a broader geographic and environmental context of human induced stress on natural ecosystems, most often within the context of global change. We refer to these two respective research areas as urban simulation models and ecosystems models. While both of these research areas deal with human-environmental interactions, they do so with significantly different emphasis, scale, methodology and objectives.

The purpose of this paper is to seek common ground between these two research directions. We examine the reach and limitations of each approach, and attempt to synthesize the strengths of both into a framework for developing an integrated urban ecosystem model at the scale of an extended metropolitan area that encompasses its ecological domain. The research builds on the respective modeling efforts of the authors in these two areas, and provides a foundation for a modeling effort now underway at the University of Washington to develop an integrated ecosystem model for the Puget Sound ecosystem.

In the next two sections, we briefly describe the two contributing models that we seek to integrate. We conclude with a section that describes our framework for synthesizing them, and discusses difficulties that must be resolved in order to complete the integration of the modeling approaches at an extended metropolitan scale. We do not attempt to address a literature review within the space constraints of this paper, though a more thorough description of antecedent research in the two respective literatures is available in other papers (Waddell, 1998; Alberti, 1998);

URBAN SIMULATION MODELING

Much of the focus of recent urban simulation modeling efforts has been channeled into developing approaches that are more behavioral, disaggregate, understandable, and useful for policy analysis and strategic planning (Wegener, 1995) than were earlier models aimed at facilitating transportation planning (Putman, 1983). One of the most recent innovations in urban simulation modeling is the development of UrbanSim, a land use simulation model being developed and applied to growth management and regional land use and transportation planning in the states of Hawaii, Oregon, and Utah (Waddell, 1998). It is this modeling approach that we propose to integrate with the ecosystem modeling approach described in the following section.

The UrbanSim model is based on an object-oriented framework that models the key market behaviors of households, businesses, land developers, within the context of infrastructure and policy choices made by governments. The theoretical basis of the model draws on random utility theory and the urban economics of location behavior of businesses and households. Choice processes are linked through logit models that model the selection of an alternative from a finite set of discrete alternatives, such as a location choice from a set of zones. The model currently represents space using zones that correspond to metropolitan travel demand models, with which it is designed to integrate. The spatial framework is currently being revised to use a grid representation of land, in order to gain resolution and allow the model more flexibility in describing spatial context.

The UrbanSim model predicts land use, physical development and redevelopment, the movement and location of businesses and households by type, and land market prices. Since accessibility is a key influence on location choices, the model is interfaced with travel demand models to account for the feedback relationships between land use and transportation.

The UrbanSim model manages environmental constraints on development at the level of individual land ownership parcels. GIS overlay techniques are used to assign environmental features such as floodplains, wetlands, slopes, fault zones, slide-prone areas, as well as policy constraints such as urban growth boundaries, to individual land parcels. With this GIS integration, the user interface allows analysts to develop policy scenarios consisting of development policy and transportation infrastructure, to simulate urban dynamics in annual increments over time horizons of twenty or more years. The model is implemented as an object-oriented design using the Java programming language.

Issues that UrbanSim and other urban simulation models do not currently address, and that constitute the motivation for this paper, is the interaction between urban activities and the natural environment. These interactions include emissions from point and non-point sources, the use of resources such as water and energy, the conversion of land from agricultural and forest uses to urban uses, and other human-induced stress on the environment.

URBAN ECOLOGICAL MODELING

Environmental simulation models have been developed for several decades to replicate atmospheric, hydrological, and ecosystem dynamic processes and assess the effects of various natural and human-induced disturbances. It is only during the last few decades that increasing environmental impacts associated with rapid growth in human activities have generated an increased interest in modeling the interactions between human and ecological systems in an integrated way. Natural scientists have been challenged with two major tasks: coupling atmospheric, terrestrial, and ecosystem dynamics and incorporating a more realistic representation of human activities.

Early efforts in understanding the interactions between urban development and environmental change led to the conceptual model of cities as urban ecosystems (Odum 1963; Douglas 1983). However these efforts have not been translated into operational simulation models. Integrated simulation models have gained increasing interest during the last decade as a new approach to link biophysical and socio-economic systems in the assessment of global environmental change (Dowlatibadi 1995). At present more than 30 integrated assessment models have been developed as part of research programs on climate change (Alcamo 1994; Dowlatabi 1995; Rotmans et al. 1995). In addition, a new generation of spatially-explicit regional integrated models is now emerging (Maxwell and Costanza 1995).

Advancement in the study of ecosystem dynamics and in computer processing have made it possible a more explicit treatment of the human systems in ecological models. The development of Geographic Information Systems has provided with the capability to integrate spatial processes. However current integrated assessment models are still too primitive in representing human behavior and the heterogeneity of urban land uses. These models predict environmental disturbances from aggregated measures of economic growth and urbanization. This constitutes a major limitation in integrated modeling. Growing scientific evidence shows indeed that micro-scale phenomena and their spatial configuration is important in understanding the dynamics of such systems (Godron and Forman 1982).

To address this problem, Alberti (1998) has proposed an Urban Ecosystem Model (UEM) currently being developed at the University of Washington as part of the Puget Sound Regional Integrated Simulation Model (PRISM). UEM will predict human stressors under alternative urban land use, demographic, economic, policy, and environmental scenarios. Using a process-based landscape model developed by Costanza et al. (1990), UEM will simulate spatially-explicit processes that link socio-economic and environmental factors at a variety of scales. Specific objectives of UEM are to: a) quantify human stressors in the Puget Sound area (e.g. nutrient discharges); b) determine the spatial and temporal variability of these stressors in relation to changes in the biophysical structure; c) relate the biophysical impacts of these stressors to the spatial heterogeneity in human activities, land uses, and management practices; and d) predict the changes in stressors in relation to changes in human factors.

AN INTEGRATION STRATEGY

In this section we propose that the current urban and ecological simulation modeling efforts described above offer an important opportunity for developing an integrated urban-ecological modeling framework at the metropolitan scale. The changes in land uses and physical development predicted by UrbanSim are among the required inputs for the UEM model to predict the changes in land cover and their ecological stresses. Changes in land use in an urban region alter the biophysical structure and habitat and influence the flows of resources both directly by redistributing solar radiation and mineral nutrients and indirectly by determining the resources needed to support human activities. The consequences of urban growth will be very different depending on whether the land demand is satisfied by increasing urban density, converting agricultural land or by clearing forested land (Alberti 1998).

The structure of the model we propose is an object-oriented model that extends the object properties and methods now implemented in the UrbanSim model, to add production and consumption behavior to households and businesses, and to link these through a grid representation of land to infrastructure and natural systems. The structure of the integrated model identifies the principal objects as households, businesses, buildings, land, infrastructure, resources, emissions, ecosystems, and the biophysical components (climate, atmosphere, and hydrology). Figure 1 represents the urban ecological dynamics that the integrated model could address. Initially, not all of the elements depicted will be modeled. For example, we will focus initially on water resource use, and water-related rather than airborne emissions.

[Insert Figure 1 Approximately Here]

The principal urban actors, represented in the model as objects corresponding to businesses, households, developers, and governments, each make choices that alter the state of the urban activity database, which is linked explicitly to individual cells of appropriate resolution. Households, make choices about moving, location, housing type, travel, and consumption. Businesses make similar location choices, and production and consumption.

Production and consumption by businesses will be modeled using a combination of the aggregate economic Input-Output methodology developed initially by Leontieff (1951), and a microsimulation at the level of individual business establishments geocoded to a particular location. The Input-Output model reflects the structure of consumption and production within the economy, aggregated into sectors. These aggregate flows will be allocated using microsimulation to individual business establishments geocoded to a cell, according to the industry and size of the individual business.

Consumption by households will be handled through a microsimulation approach to forecast the demand of specified products and services. This technique is flexible enough to represent sensitivity to a variety of technological and policy factors that affect consumer behavior. It could, for example, be made to incorporate the lifecycle of products and services which would enable us to account for technological substitution.

The core location model in UrbanSim will be revised from its current aggregate structure to one based on microsimulation, and from a zone description of space to one based on a high resolution grid structure. The conversion of UrbanSim to a microsimulation implementation will require modification of several components of the model, including the procedures that now operate at an aggregate level to predict economic and demographic processes such as shifts in the economic structure, aging of the population, shifts in the income distribution, and other related changes. The current procedures that address land market clearing and price adjustment at an aggregate level of zones will need to be modified, using a microsimulation of the market search process. Since the model currently predicts bids made by businesses and households for alternative locations and building types, and uses these to assign sites to the highest bidder, this will be a change in implementation but not in theoretical structure.

The urban ecosystem model simulates four types of human-induced environmental stressors: land conversion; resource use, emissions, and habitat change. The land conversion model is currently a deterministic model based on the land use, socio-economic and ecological features of a given cell. We are now exploring the possibility of using an approach that estimates the transition probability that a given cell of given ecological and economic conditions will be converted from its current cover type to each alternative land cover type.

The resource model will include various modules each predicting the use of water, energy, and materials on the basis of consumption, infrastructure capacity, and efficiencies of technologies. The emission module is a mass-balance model which will simulate pollution loads into the atmosphere, water, and soil and relative contributions from the various media.

The habitat change model predicts human-induced disturbances to natural ecosystems. It will link the outputs from the previous three modules to an existing ecosystem dynamics model such as the General Ecosystem Model (GEM) developed by Fitz et al. (1994). The urban ecosystem spatial processes will be modeled using the spatial simulation approach developed by Costanza et al. (1995) in the Patuexent Landscape Model (PLM) to replicate ecosystem processes at the regional scale.

The urban ecological framework is designed to take into account the interactions between the ecological impacts and urban processes. These include feedback from the ecological changes on both households and business location choice, and land and resources availability. Although significant details remain unresolved, this framework appears to provide a solid foundation for integration of urban and ecological modeling approaches.

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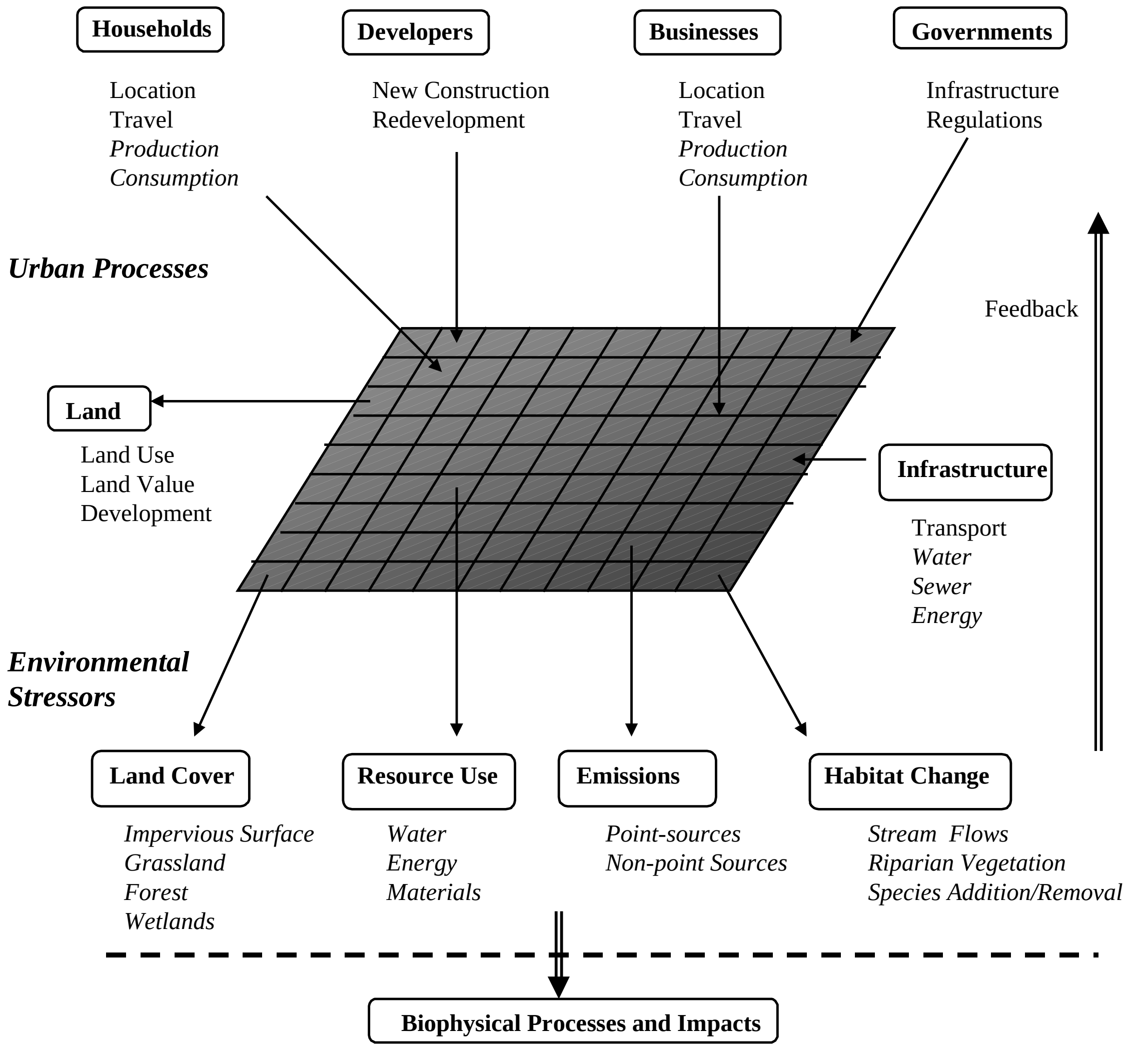
Figure 1:
Urban and Ecological Dynamics



Note: Processes in italics are new model components not presently modeled in UrbanSim