SYSTEM DYNAMICS SIMULATION OF SPATIAL CHARACTER

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System Dynamics modeling has been applied to regional, urban, and community problem solving where critical policies are concerned with land-use controls. Representation of change in the spatial distribution and physical appearances of various activities have traditionally been achieved by modeling these as transfers between relatively homogeneous sub-area sectors. Due to lack of capabilities for direct representation of physical space showing the distribution and appearances of activities over geographic space, System Dynamics modeling has received little attention in environmental and city planning practice. In this paper, we describe the main components of a methodology to make the System Dynamics modeling more integral in planning and design for community development, also including spatial representation.

OVERALL APPROACH

System Dynamics (SD) is proposed as an important part of an integrative approach to community development planning and design. The main objectives of the overall approach, (Sancar, 1985; Sancar and Cook, 1988), are (1) generation of creative planning and design options; (2) creation of an environment conducive to social learning through searching and interpretation of relevant information; and (3) documentation of the interactions among the various participants, including their negotiations on different interpretations of reality, and how these were modified.

The components of the integrative approach are the human actors or the participants (experts, decision makers, relevant public), the model or representation of the decision environment, the process by which the model is developed and used by the participants, and the appropriate measures of evaluation corresponding to the above objectives. The primary component of the approach is the representation of the planning situation as perceived by the participants and is referred to as the situational model. Since the model characteristics, its evolution, and evaluation by the participants provide the information for systemic understanding and procedural improvement, the design and use of the situational model is the essence of the integrative approach.

This above mentioned methodology is shown in Figure 1, where the modeling activities consist of (1) customizing a generic community development model using structural modeling techniques, (2) arriving at a situational SD model which is capable of representing the spatial distribution of activities, and (3) visual simulation to represent

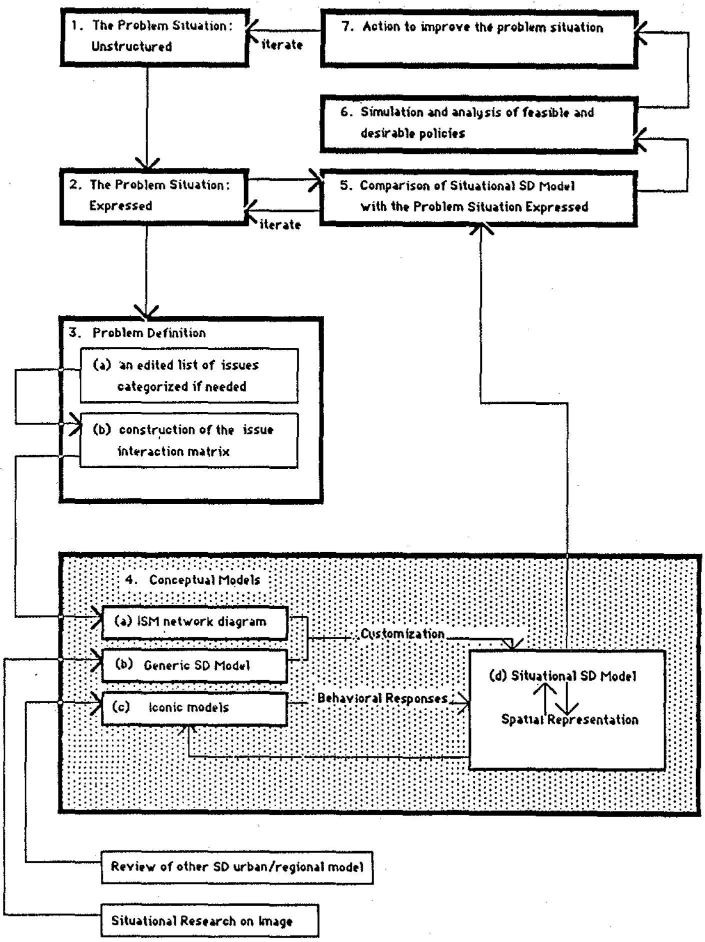


Figure 1. Overall Approach

changes in the spatial character, i.e., physical appearances of selected localities. The situational SD model and the iconic models are used to elicit behavioral responses to changes in spatial character. These in turn, become inputs to formulate and test the situational model to project changes in urban activity patterns, to provide referential context of socio-economic indicators for evaluation of design, planning and policy making proposals.

This methodology presents two challenges from a modeling perspective. One is to develop a formalism to represent the spatial changes resulting from locational behavior of urban actors and to incorporate this into the SD model. The other is to develop a procedure which systematically elicits behavioral responses of the relevant public to visual simulations that show change, including those which cannot be formulated symbolically. This paper addresses the issue of representing spatial distribution of activities in SD models by using concepts and techniques borrowed from cartographic modeling and geographic information processing. The research is aimed at implementing a variable resolution spatial representation and graphic interface to display maps as well as graphs and other numerical output.

SPATIAL SIMULATION IN LANDSCAPE DESIGN: POTENTIALS

The use of iconic and symbolic models corresponds to the divisions between the professional domains of design and planning. Mathematical models are used to study spatial phenomena, particularly by theoretical geographers for testing theories of spatial behavior, and by planners for addressing land use and transportation problems. Spatial models (Lee,1973) or spatial interaction models (Wilson,1987) are mathematical models which represent the functional dependencies between system elements at different locations in space. These specify the relative location of system attributes or entities in terms of planar geometry and topology (Burrough,1986). The basic premise underlying a spatial model is that the spatial behavior of human actors is influenced by the distribution of urban activity and that this behavior in turn affects activity distributions through the modified behavior of other actors.

In the absence of robust theories concerning human behavior, modeling urban systems has largely relied upon empirical regularities observed in spatial distribution of activities (Bertuglia, et al.,1987). These approaches have been rationalized from the point-of-view of empirical testing of theory (Harris,1965; Lowry,1965) and the pragmatism of efficient computation and model performance (Lee,1973). But they have been criticised with regards to generating planning theory and solving problems in that they fail to capture the richness of observed behaviors (Lee,1973; Sancar,1985).

In response to the above criticism, behavioral geographers have adopted a behavioral approach to explain spatial behavior in terms of individual decision making as driven by perceptions of space (Cadwallader,1985). Expressions of function and activity in architecture appears to afford an appropriate "sign" for the observer (Purcell,1984). Expanding on this line of thinking, spatial decision-making can be operationalized as a "multi-attribute model" of perceived affordances to determine the overall utility of an entity, i.e., the "attractiveness" of a given localewhich is the weighted sum (or product) of that entity's perceived attribute levels. The relevant attributes include activity mix as well as form or appearances. Such models have been used in investigations of consumer spatial decision making (eg., Cadwallader, 1975; Sancar, 1977), and environmental perception (Purcell,1984; Nijkamp, 1987), where the emphasis has been on either activity mix or the issue of appearances.

Simulation models representing the qualities of urban space in terms of the local activity mix are compatible with spatial perception concepts of "sense-of-place" or "image" since it has been shown that the nature and level of activity and social interaction play a major role in formulating perceptions of the environment (Purcell,1987; Genereux et al.,1983; Tuan,1974; Clay,1973; Sancar and Macari, 1988). In addition to activity mix, their spatial organization and observable form also aid in organizing our experience of the environment. For example, way-finding studies attest to the effect of shape and organization of movement networks on spatial decision making (Passini,1984). In the normative literature, relationships between activities are the basis of Alexander's pattern language (1979,1977) as well as Lynch's theories of city form (1960,1981). Urban image is further influenced by particular places and settings which have assumed historic significance, personal meaning and/or physical character (Sancar and Macari,1988). These dimensions assume importance in the spatial behavior of urban actors which a symbolic model cannot fully represent. Visual simulation then provides the linkage for the use of spatial simulation models in the design process.

In conclusion, implementing a behavioral approach to modeling for landscape planning and design implies being able to represent the attractiveness of meaningful locales in terms of activity mix and their appearances, and the dynamics of the distribution of activities in space as a function of perceived attractiveness. The integration of iconic and symbolic modeling would allow one to represent behavioral responses to urban space quality which cannot be formulated symbolically. The use of such models can contribute to the accountability and ultimate defensibility of planning and design proposals and would ultimately create the essential continuum between planning and design activities.

SYMBOLIC REPRESENTATION OF SPACE AND SYSTEM DYNAMICS MODELING

There have been relatively few applications of SD in urban and regional planning. Regional models by Hamilton, et al. (1969), urban growth models for developing economies (Qin et. al., 1987; Wang and Xinnong, 1987) and applications for community development planning (Sancar and Cook, 1988; Wallace and Sancar, 1988) are some examples. Even fewer applications contain disaggregation of space and spatial variables necessary to study spatial phenomena.

At the urban scale, Forrester (1969) has demonstrated how systems concepts could be applied to explain the dynamics of urban growth, maturation, decline and the effects of urban policy making with the Urban Dynamics Model (UDM). Using a 'generic city' which lacked a specific planning context, the model can not be considered a planning model, but rather a theoretical study in generic urban structure. UDM was widely studied and criticised for a variety of reasons. In response to a criticism regarding the lack of spatial disaggregation necessary to study spatial phenomena, such as suburbanization, the model was enhanced and tested by simulating the historical growth of actual cities (Graham,1974; Schroeder,1975). The nature of space represented with these models can best be described as "conceptual", consisting of two zones, the center city and suburb, lacking formal spatial representation. Each zone consisted of a homogeneous distribution of activities. The model essentially consisted of two models, one for each zone, with an interface which modeled flows of residences, transportation and employment between zones.

In modeling urban/regional systems, symbolic representation of space can be achieved in several ways. One approach represents spatial relations indirectly by embedding phenomena as attributes at locations in space (Burrough,1986; Peuquet,1984). Once an entity is located, contextual relationships in space must be inferred using geometric properties of planar topology. In other approaches used in graphs, networks (Haggett,1968; Peucker and Chrisman,1975), and spatial "grammars" (March and Stiny,1985; Lloyd Jones,1984), the spatial relationships are explicitly represented and space is encoded as an attribute to the relation. In either case, the representation must include a spatial matrix and functions used to describe relative location in terms of proximity, adjacency, distribution, etc. (Burrough,1986; Preparata and Shamos,1985).

The primary intent of this study is to explore an approach to spatial representation generally known as the bucket or cell technique (Burrough,1986) in conjunction with SD modeling. This technique uses spatial zones, or grid cells, as discussed earlier in context of other modeling efforts. The advantage of the bucket representation is its simplicity. It is also compatible with the development and growing use of data bases in geographic information processing. Variable resolution can be obtained by implementing a hierarchic data structure, such as the "quad-tree" method (Samet,1984). Control over the variation of cell size is useful in response to the inevitable incompleteness of spatial data. From a standpoint of landscape design and planning, this variable resolution would also allow investigation of fine and smaller-scale activity patterns, potentially down to "site-level" activity.

Ultimately a spatial model needs to be evaluated in terms of the following capabilities:

1. Replication of agglomeration phenomena and landuse patterns associated with central places and urban commercial hierarchies; the use of data from and comparison of model performance with published results of other models,
2. Replication of selected general city forms and landuse patterns described in the normative literature (Lynch,1981,1960; Alexander, et al.,1987,1979,1977),
3. Assessment of the effects of variable resolution on the spatial pattern generation, including establishment of pattern hierarchy of commercial activity as related to vehicular circulation and other open spaces,
4. Geometric analysis of pattern stability, model sensitivity and their dependence on the behavioral multipliers which represent spatial perception (Aracil et al.,1985; Aracil,1981).

IMPLEMENTATION AND DISCUSSION

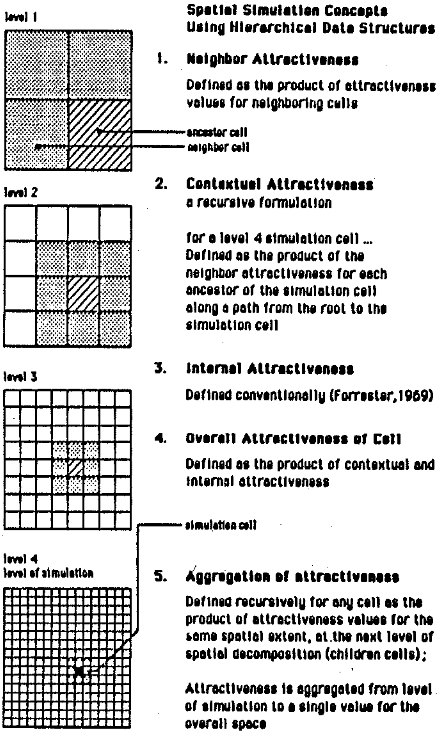
Since current commercially available SD software are not capable of implementing variable resolution spatial representations, the model had to be written in a general programming language. In this first version, the main goals were to provide a graphic interface for map display, graph, and numeric table output "on-the-fly" as well as to provide the ability to interrupt the simulation to change model and output parameters.

Hypercard medium on the Macintosh SE proved to be most flexible in this application for a variety of reasons. These included the multi-media capabilities of Hypercard anticipating a future integration with video imaging and other forms of visual simulation, hence Hypercard and Hypertalk were used along with external routines written in C, for all modeling purposes.

In computational terms, the current approach takes the SD model to be a collection of directed acyclic graphs (dags), with the root of each dag-tree comprising a rate variable. When the model is initialized, the attractiveness for the overall space is calculated and the "root process" i.e., the global SD model is run (for the given time interval), determining the net inflow of stocks into the system. Next, the net inflows are allocated to each of the spatial cells at the simulation level of the hierarchy as a function of their attractiveness values. Following this allocation, a diffusion process is modeled, based on interaction among cells at the simulation level. A new attractiveness value is obtained for each cell, which are then aggregated from the simulation level to a single value for the overall space. The process is repeated for each time interval.

The use of "hierarchical arrays" allows hierarchical aggregation and recursive decomposition of variables and parameters in space and is particularly suitable for formulating attractiveness. Presently, product formulation of attractiveness is being used as illustrated in Figure 2. Figure 3 shows the spatial distribution of a single stock (residences) as an output of a simple model, using density and distance between neighbouring cells as the main parameters to determine the attractiveness of locations for the initial allocations and the diffusion processes.

This initial application suggests that using the approach described here, it is feasible to incorporate spatial representation into SD modeling. However, the amount of programming effort to expand and refine the approach for comprehensive modeling with more sophisticated visual input/output is anticipated to be substantial.



Spatial Simulation Concepts
Using Hierarchical Data Structures

1. **Neighbor Attractiveness**

   Defined as the product of attractiveness values for neighboring cells

2. **Contextual Attractiveness**
   a recursive formulation

   for a level 4 simulation cell ...
   Defined as the product of the neighbor attractiveness for each ancestor of the simulation cell along a path from the root to the simulation cell

3. **Internal Attractiveness**

   Defined conventionally (Forrester,1969)

4. **Overall Attractiveness of Cell**

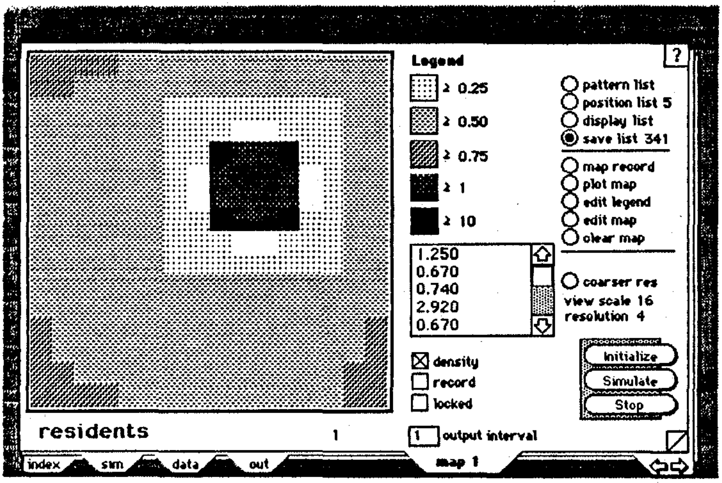
   Defined as the product of contextual and internal attractiveness

5. **Aggregation of attractiveness**

   Defined recursively for any cell as the product of attractiveness values for the same spatial extent, at the next level of spatial decomposition (children cells);

   Attractiveness is aggregated from level of simulation to a single value for the overall space

Figure 2. Attractiveness Formulation



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1.250
0.670
0.740
2.920
0.670

view scale 16
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1 output interval

Figure 3. Example of Spatial Distribution

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