SURFACING URBANISMS

Recent Approaches to Metropolitan Design

2006 Association of Collegiate Schools of Architecture (ACSA) West Conference
Host: Woodbury University
October 12-15, 2006
Pasadena, California

Urban Complexity + Emergence: Procedural Modeling of City Activity and Form

Martin Felsen, Ben Watson, Uri Wilensky

In Conference Proceedings: pgs. 261-266
Conference Panel: Complex Systems

Urban Complexity + Emergence:
Procedural Modeling of City Activity and Form

Martin Felsen, *College of Architecture, Illinois Institute of Technology*

Ben Watson, *Dept. Computer Science, North Carolina State University*

Uri Wilensky, *Director of the Center for Connected Learning and Computer-Based Modeling, Northwestern University*

Cities are immense and extremely difficult to conceptualize, let alone model, and previous digitally based efforts have often failed to capture the complexity and indeterminacy of urban organizations. Architects and designers have had trouble conceiving of techniques for examining these systems due to their large number of interacting micro-parts that evolve over time. We've also had difficulty finding workable planning strategies that operate in a more decentralized manner to accommodate the multiplicity of (often autonomous) urban decision makers. To this end, an interdisciplinary team composed of an architect and urban designer, a computer scientist, and a mathematician, educator and learning technologist are researching and formulating methods of examining cities using the agent-based digital modeling program NetLogo.[1]

Using NetLogo we are studying city planning principles related to urban land use and metropolitan growth. NetLogo is a programmable modeling environment for simulating natural and social phenomena. It is particularly well suited for modeling complex systems developing over time, such as cities. With NetLogo, instructions are given to hundreds or thousands of independent "agents" (autonomous, or semi-autonomous proactive and reactive, individual software entities) all operating concurrently in a simulated urban environment. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals. The high-level nature of the software language enables rapid development and aids low-cost experimentation with different solutions; and, with its "open box" design, facilitates collaborations between architects, urban planners, software developers, computer scientists and other cross disciplinary partners.

Thinking about Complexity and Cities

If a city, any city, increases in complexity without being guided, managed or designed by one singular authority, we say the city "self-organizes." And no great city has been single-handedly master-planned by one person (or group of people). All great cities self-organize because their growth is based upon a variety of dynamic, open and non-linear processes. These processes are often based upon relatively simple parameters even though these parameters may at times look very complicated and opaque. Additionally, a city is composed of clusters and agglomerations of "parts" (such as buildings, institutions, infrastructures, governments, etc.) built over time. In short, a city is a complex self-organizing system composed of many different parts dynamically interacting in many competing and complimentary ways; the parts follow relatively simple rules, and are fairly oblivious to higher-level ambitions (or master-plans).

The Investigation of Complex Systems

The study of complex systems involves the examination of large numbers of interacting agents, which make decentralized decisions rather than follow centralized rules issued by a "leader" (someone or something issuing orders or directives from the top). And over time, from these decentralized or distributed *local* interactions, unexpected *global* behavioral patterns oftentimes emerge. For a dynamic system to evolve, each of the units self-follows a relatively simple set of rules, and under the right circumstances, this autonomous behavior has the power to manifest complex interrelationships. For example, if one is interested to study the non-linear dynamics of rain forest formation using a digital simulation model, "instead of studying a rain forest top down, starting from the forest as a whole and dividing it into species, we unleash within the computer a population of interacting virtual 'animals' and 'plants' and attempt to generate from their interactions whatever systematic properties we ascribe to the ecosystem as a whole."[2] Well known examples of complex systems that have recently been digitally simulated include ecosystems, weather systems, molecular systems, democratic governments, and many education systems. Cross disciplinary researchers of complex systems strive to understand the numerous behavioral, formal and structural characteristics that each system has in common.

The Starting Position of Systems

The investigation of complexity also involves looking very closely at the starting position of nascent systems. Systems such as cities typically start very modestly, with very view interrelated parts. Jane Jacobs wrote in 1961 that cities are more than the sum of their unrelated parts by saying, "great cities are not like towns only larger, they are not like suburbs only denser."[3] When a city begins it cycles of growth, if conditions are optimal, small events and minor interactions between its various parts have the potential to quickly propel it toward greater levels of complexity and self-organization. And continuous informational feedback loops are vital to potential success if a city is to become more than a suburban collection of buildings and infrastructures. John Gribbin explains that "what really matters for complexity is simply that some systems ("system" is just a jargon word for anything, like a swinging pendulum, or the Solar System, or water dripping from the tap) are very sensitive to their starting conditions, so that a tiny difference in the initial "push" you give them causes a big difference in where they end up, and there is feedback, so that what a system does affects its own behavior."[4]

Tipping Points

Importantly, when feedback is particularly intense it has the capability of propelling a system toward a critical threshold, or tipping point, and entering a different state of behavior. Instead of a system experiencing steady incremental change over time, tipping points cause changes to happen fast, and the results often create dramatic and unexpected effects. As Malcolm Gladwell has written, "the tipping point is that magic moment when an idea, trend or social behavior crosses a threshold, tips and spreads like wildfire."[5] Common examples of sudden physical transitions include water suddenly transforming between solid, liquid, and gaseous phases, due to changing levels of energy flow; and, the sudden explosions of urbanization and city making due to available energy and ingenuity. In this sense, this process is said to be "non-linear" because strong mutually interactive (feedback) behavioral features on one side of the pre-tipping-point timeline are not proportional to features on the other side of the timeline. That is, instead of progressive stages of development, a phase transition causes a system to leap forward. In his book *A Thousand Years of Nonlinear History*, Manuel De Landa documents a series of urban tipping points and explains that as a result of harnessing several technological innovations in the Middle Ages a sudden "acceleration in urban development that would not be matched for another five hundred years, when a new intensification of the flow of energy- this time arising from the exploitation of fossil fuels- propelled another great spurt of city birth and growth in the 1800s."[6]

Emergent Phenomena

Traffic jams, the organization of beehives, the fluctuations of populations in ecosystems, and land uses patterns in cities are all examples of self-organizing systems that display emergent behavior. Emergence occurs when rule-following agents within a system form more complex macro-patterns or behaviors as a collective population. The game SimCity is designed as an emergent system. SimCity is a digital simulation and city-building computer game first released in 1989 and designed by Will Wright. Like "real" great cities, SimCity has the potential of urban self-organization that display emergent behaviors. Stephen Johnson writing about the parallels between self-organizing real cities and emergent simulations of virtual cities writes that SimCity is "a meshwork of cells that are connected to other cells, and that alter their behavior in response to the behavior of other cells in the network. A given city block in SimCity possess a number of values- the price of land, say, or its pollution level. As in a real-world city, these values change in response to the values of neighboring blocks; if the block to the west drops in value, and the eastern neighbor develops a higher crime rate, then the current block may well grow a little less valuable. Because each cell is influencing the behaviors of other cells, changers appear to ripple through the entire system with a fluidity and definition that can only be described as lifelike."[7] Studying emergence is important because it provides a new lens and explanatory framework to describe processes of urban pattern formation and the mechanisms of pattern maintenance. In general, emergent patterns touch upon deep issues of interdisciplinary science such as evolution, order vs. chaos, randomness vs. determinacy, and analysis vs. synthesis.

Why Use NetLogo?

Agent-based modeling in NetLogo provides a learning tool to understand how individual decisions effect overall results. NetLogo is optimized for modeling emergent bottom-up systems: local interactions between large (or small) populations of agents, governed by simple rules of mutual feedback can be efficiently modeled allowing the mind to wrap itself around a complex idea. Importantly, NetLogo disproves the assumption that emergent collective behavior implies some kind of centralized authority. The elucidation of this concept makes the program important to the study (and teaching) of architecture and urban design.

New NetLogo Models

Each of the models that this collaborative team has so far created has provided insight into the key notion that city patterns in particular and urban organizations in general emerge from the bottom-up (vs. top-down, or hard-control planning). The scope of the models we have created differ based upon scales of interest; so for example, while one model simulates entire cities, other models simulate smaller systemic urban conditions such as population density, pollution patterns, and infrastructure distribution.

City Model

A new NetLogo model named the "City Model" simulates residential, commercial and industrial building development as well as road networks and open-space developments within cities. We associate each of these land usages with distinct *developer* agents, which act in a simulated environment we call the *world*. The world consists of a rectangular grid of atomic areas called *patches*. Patches compose the interactive landscape upon which agents aggregate and evolve—they are the ground upon which the agents move. Each patch is 40 ft (~12m) square, allowing the simulation to represent tertiary roads using a one-patch width. With a 200x200 patch world, our City Model simulates an environment approximately 1.5 miles square.

User Input and Control Tools

In every NetLogo model, including the City Model, a user controlled interface allows users to adjust initial parameters of a simulation model. In the City Model, there are two primary sources of user input that control the starting conditions of the organization and pattern of a simulated city:

1. The interface allows a user to adjusting a series of "sliders" to control specific city parameters. Particularly important parameters controlled by sliders include water elevation, the development of roads and open-space, and the relative densities of residential, commercial and industrial development. Some parameters (e.g. water elevation) are global and affect the entire world, while others (e.g. road parameters) are local and can either be applied to the whole world or to a specific portion of it through the painting interface.

2. The interface allows a user to "paint" parameters. The painting process works in a similar fashion the *brush tool* in Photoshop. The painting process controls a terrain height map (or landscape topography) that can either be input directly using a painting interface, or

imported from an image file. The painting process also controls certain types of city development directly.

The City Model produces good results without any intervention, using a flat terrain and parameter defaults. The investigators recognize that a user desires flexibility in the creation of city design, so to meet these demands, a user may not only paint parameters than influence developer (agent) behavior in certain localities, but also remove unsatisfactory development and either further adjust these parameters, or directly input certain development themselves. These actions may be taken before the simulation begins, or at any point during the simulated development of a city. In short, the City Model offers a user complete automation while also providing as much interactive control as is necessary to generate a city that is both realistic and useful.

Our system generates a rasterized map of land uses, with residential, commercial, industrial and open-space uses occupying properties called *parcels* made up of several patches, and roads occupying series of patches connected to form a transportation network. Each parcel describes its population, population density, age, and value. Roads are identified as either primary or tertiary.

Building Developer Agents

Building developer agents have two states: prospecting and building (residential, commercial, industrial or open-space). Initially, building developers *prospect* the world, hill-climbing through a landscape of land values while remaining within a block length of existing development. As they prospect, building developers examine adjacent parcels or undeveloped patches to see if building is prohibited (i.e. residential sites cannot be immediately redeveloped into industrial sites according to City Model zoning, and vice versa) or if the site has already been marked “unprofitable”. To determine profitability, building developers first produce a cost model calculating potential land value.

Tertiary Road Developer Agents

Two types of developer agents build tertiary roads: *extenders*, which ensure that undeveloped land can be reached; and *connectors*, which ensure that the tertiary road network is adequately connected. Both types of developer agents are governed by a set of parametrically or paintable road constraints.

Primary Road Developer Agents

Primary road developer agents strive to connect high density regions far from primary roads to the primary network. While prospecting, primary road developers behave much like tertiary extenders: they hill-climb in a distance-to-primary-road landscape, and will only begin building if they are a calculated distance from primary roads. Primary road developers build in two modes: *geographic* and *urban*. Developers are in the urban mode whenever any development is present within their *view slice*. A view slice is a small group of patches that are a radius of 5 patches away from the current patch and less than 22.5 degrees of rotation off the developer agent’s current heading. Otherwise primary road developers are in the geographic mode.

Future Work

In the near term, we will model agents that populate other major land usage categories such as institutional and mixed-use buildings. And we will create agents to enrich our road hierarchy, including freeways and heavy/light railways. Because the dynamics that shape a city continually change, we will work toward the creation of higher-level parameter sets that describe more complex urban growth and change over time.

Acknowledgment

This paper and ongoing research at IIT, Northwestern University and NC State University is generously supported by the National Science Foundation (Grant CCR-0326364).

Notes

1. Uri Wilensky. (2006). *NetLogo*, <http://ccl.northwestern.edu/netlogo>, Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.
2. Manuel De Landa, A Thousand Years of Nonlinear History (New York: Zone Books, 1997), 18.
3. Jane Jacobs, *The Death and Life of Great American Cities* (New York: Vintage, 1961), 30.
4. John Gribbin, Deep Simplicity (New York: Random House, 2004), Introduction xx.
5. Malcolm Gladwell, The Tipping Point (New York: Little Brown and Company, 2000).
6. Manual De Landa as quoted via interview in Stephen Jonhson, *Emergence* (New York: Scribner, 2001),112-113.
7. Stephen Johnson, *Emergence* (New York: Scribner, 2001), 88.