The Gods of Sugarscape

Digital sex, migration, trade, and war on the social science frontier

By IVARS PETERSON

In the ritualized warfare of the game of chess, the board is a miniature battlefield on which opposing commanders-in-chief marshal their forces.

Each playing piece has a particular pattern of allowed movements, and the game's rules shape the battle. The combatants can try out different strategies, directing bold attacks, mounting stubborn defenses, or waging wars of attrition across the grid.

At the Brookings Institution in Washington, D.C., social scientist Joshua M. Epstein and computer modeler Robert Axtell also have a playing field on which to audition their ideas. They play their game on a 50 by 50 square lattice on a computer screen, and the playing pieces, or agents, are colored dots occupying some fraction of the squares.

Epstein and Axtell are actually more like gods than commanders. They define the landscape, set the rules, and characterize the agents. Instead of participating in the action, they step back to observe what happens as the swarming agents, left on their own in these simulations, move about, gather sustenance, reproduce, and die off according to their programmed predilections.

From the patterns that emerge, the researchers can glean insights into human social and economic behavior. "We grow social structures—artificial societies—in the computer," Epstein says. "We can examine population growth and migration, famine, epidemics, economic development, trade, conflict, and other social issues."

"It's intellectually provocative work," comments economist Sidney G. Winter of the Wharton School of the University of Pennsylvania in Philadelphia. The resulting simulations "provide challenges to existing treatments of social and economic matters."

Epstein and Axtell describe their project in the newly published book *Growing Artificial Societies: Social Science from the Bottom Up* (Washington, D.C.: Brookings Institution/MIT Press).

"It's a magnificent achievement," says John L. Casti of the Santa Fe Institute in New Mexico. "What they've done in building a world inside a computer is a glimpse of how . . . science will be done in the 21st century."

The cyberworld in which Epstein and Axtell's agents dwell is known as Sugarscape. It's a two-dimensional landscape, represented as a square grid, containing two regions rich in a renewable resource arbitrarily called sugar. Every agent is born into this world with a metabolism demanding sugar, and each has a number of other attributes, such as visual range for food detection, that vary across the population.

They move from square to square according to a simple rule: Look around as far as your vision permits, find the unoccupied spot with the most sugar, go there, and eat the sugar. As it is consumed, the sugar grows back at a predetermined rate.

An agent's range is set by how far it can see. Every time an agent moves, it burns an amount of sugar determined by its given metabolic rate. Agents die when they fail to gather enough sugar to fuel their activities.

With hundreds of agents roaming the landscape, "interesting things begin to happen," Axtell says.

Initially distributed at random across the landscape, the agents quickly gravitate toward the two sugar mountains. A few individuals end up accumulating large stocks of sugar, building up a great deal of personal wealth. These happen to be agents that have superior vision and a low metabolic rate and have lived a long time.

A few others, combining short vision with a low metabolic rate, manage to subsist at the fringes, gathering just enough to survive in the sugar badlands but not looking far enough to see the much larger sugar stocks available just beyond the horizon.

At its simplest level, the Sugarscape model represents a kind of hunter-gatherer society, Axtell explains.

Yet even this rudimentary model reproduces the kind of strongly skewed distribution of wealth generally observed in human societies—where a few individuals hold most of the wealth and the bulk of the population lives in relative poverty.

Introducing sex and reproduction to Sugarscape is as simple as adding to the agent's string of numbers a few bits specifying gender.

A rule specifies the allowed behavior: An agent must select a neighboring agent at random. If the neighbor is of the opposite sex and of reproductive age, and if one of the two agents has an empty neighboring site (to hold offspring), a child is born. The child inherits a mixture of its parents' genetic attributes.

This new dimension enables the researchers to investigate the effect of cultural forces on biological evolution and vice versa. For example, in the absence of any cultural factor, agents with relatively low metabolism and high vision enjoy a selective advantage in Sugarscape.

Now, suppose that when an agent dies, it can pass on its accumulated holdings of sugar to its offspring. How does this cultural convention influence evolution?

The Sugarscape model suggests that agents who might otherwise have been "weeded out" are given an extra advantage through inheritance, Epstein says. The average vision of the population doesn't increase to the same high level eventually reached in a population where no wealth is passed on.

The researchers can also modify their model to observe the emergence of tribes (identified by numerical tags) and the process of assimilation (changing affiliation to join the local majority). Inevitably, there arises a primitive kind of combat, in which agents of two different tribes may plunder each other for sugar.

Various combat rules lead to patterns of movement that differ from those produced by the standard "eat all you can find" rule. For example, some combat rules lead quickly to strictly segregated colonies, each clinging to its own sugar peak. In other cases, one side wipes the other out.

The Sugarscape model also offers insights into other phenomena, such as the introduction of trade. In this case, the landscape contains heaps of two resources: sugar and spice. The agents are programmed with different metabolic rates, or preferences, for each of the two commodities. They die if either their sugar or their spice store falls to zero.

A mathematical formula called a welfare function allows each agent to compute how close it is to sugar or spice starvation. The agent then strives to gather more of the commodity it needs.

An additional system of rules specifies how agents bargain for and exchange sugar and spice according to their needs. These rules enable the researchers to document how much trade transpires and at what price exchanges occur.

When agents are allowed to live forever, so long as they never run out of food, the sugar-spice model shows that the average trade price converges to a stable level. Economic equilibrium emerges, Epstein says, just as textbook market economics predicts.

However, when Epstein and Axtell make the agents "more human" by giving them finite lives and permitting their preferences to evolve, the price no longer stabilizes and the market never reaches equilibrium.

"The assumption that we can let markets produce efficient allocations [of capital or resources] on their own is deeply challenged by our work," Epstein claims. "We see how brittle traditional economic theory really is."

Epstein and Axtell's Sugarscape simulation is just one example of a wide variety of computer models now being developed on the basis of interactions between agents governed by given rules rather than on equations defining global behavior. The idea is to model from the bottom up—seeing behavior emerge out of interactions among individuals—instead of from the top down—deriving the behavior of individuals from overarching laws.

Researchers at the Santa Fe Institute, Los Alamos (N.M.) National Laboratory, and elsewhere have worked out agent-based models of urban transportation systems, insect colonies, business organizations, financial markets, and other situations. Such approaches are also useful in studies of artificial life—forms that exist only in the computer yet mimic certain aspects of the behavior of living organisms (SN: 8/10/91, p. 88).

What distinguishes the Sugarscape project is its emphasis on seeing what sorts of socially relevant behavior can emerge from the collective interaction of individuals following the simplest possible rules. "The surprise is that we can grow [complex, recognizable behavior] with incredibly simple rules and simple agents," Epstein says.

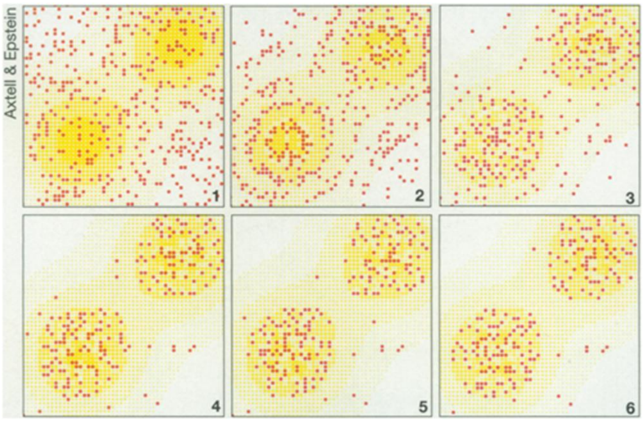
Such agent-based modeling shows that social norms can arise out of very primitive behavior, though it doesn't necessarily demonstrate how the norms actually came about, notes economist Thomas Schelling of the University of Maryland in College Park.

Epstein insists that although these bare-bones models can't really be used to make specific predictions, they can suggest explanations of some widely observed macroscopic phenomena, from distributions of wealth in typical societies to erratic price fluctuations in markets.

"We think of our model as a laboratory for social science," Epstein says. Researchers from a wide variety of disciplines, including economics, biology, demographics, and environmental studies, can use this approach as a research tool to tackle oft-neglected, cross-disciplinary issues like the effects of inheritance on the genetic evolution of a system.

"One can readily imagine hypotheses or mechanisms that no one has thought of before arising out of this kind of model," Winter adds.

Axtell & Epstein



This sequence (1-6) begins with agents (red dots) distributed at random across a landscape that features two concentrations of a resource arbitrarily called sugar (yellow dots). As time passes, the resource-seeking behavior of the agents tends to lead them to the sugar mountains. Only a few manage to survive on the fringes.

Like others working with agent-based models, Epstein and Axtell must interpret the patterns they observe on the computer screen. After all, their agents are no more than strings of digits and the observed behaviors no more than patterns in a computer's memory.

"It is the act of interpretation . . . that allows these electronic worlds to make contact with their real-world counterparts," Casti notes.

In the case of Sugarscape, the model is more a metaphor than a realistic depiction of society. No one literally spends a working day accumulating sugar. The landscape and agent characteristics are simple stand-ins for the more complicated things that occur in the real world.

In one application of their method, Epstein and Axtell are now working with archaeologist George J. Gumerman of Southern Illinois University in Carbondale and his colleagues to "grow" the Anasazi society, a Native American culture that flourished in the U.S. Southwest for hundreds of years, then suddenly disappeared. The archaeologists have data on weather patterns, crop yields, and other environmental conditions during that period, along with information about the Anasazi culture.

"This gives our modeling an empirical target," Epstein says. The researchers hope that agent-based simulations may shed light on whether environmental or cultural factors were primarily responsible for the society's abrupt decline.

Epstein and Axtell are also working with H. Peyton Young of Johns Hopkins University in Baltimore to study how caste systems, in which a small elite demands more than its fair share, arise in societies (SN: 5/4/96, p. 284). "We want to know whether or not equity comes about naturally in social systems," Young says.

The Sugarscape laboratory is still very much in the development stage. Researchers are just starting to examine ways of tailoring this approach to address specific needs and issues in the social sciences, economics, and elsewhere.

One key issue in the Sugarscape approach involves how to tweak the model to obtain such phenomena as the emergence of governments. "There may be some kind of threshold beyond which you can't take a step up in understanding . . . human organization without making the agents smarter," Winter says. "The problem is how to make the agents smarter in a way that remains true to the basic approach."

Sugarscape is already an immensely attractive playing field because the limited repertoire of the agents makes it easy to understand, measure, and depict what's going on and why the agents behave as they do. Moreover, typical Sugarscape experiments take only a few minutes on an ordinary personal computer.

"There are lots of opportunities to try things out," Epstein says. "Our artificial societies let you get your teeth into things that conventional theory can't handle."

The Sugarscape effort is part of Project 2050, a cooperative venture of the Santa Fe Institute, the Brookings Institution, and the World Resources Institute in Washington, D.C., to identify conditions for sustainable development on a global scale.

By providing insights into population growth, resource use, migration, economic development, conflict, and other global social processes, games played on the Sugarscape grid may help shape the policies needed to direct the future course of society. □