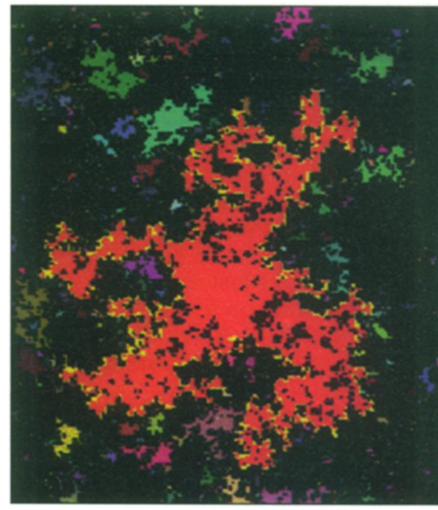
The Shapes of Cities
Author(s): Ivars Peterson
Source: *Science News*, Vol. 149, No. 1 (Jan. 6, 1996), pp. 8-9
Published by: Society for Science & the Public
Stable URL: http://www.jstor.org/stable/3979640
Accessed: 07/12/2010 12:09

The Shapes of Cities

Mapping out fractal models of urban growth

By IVARS PETERSON



Illustrations: Makse *et al.*/NATURE

An urban growth model based on correlated percolation shows a large central cluster surrounded by a number of smaller clusters.

Sprawled across a cluster of islands and adjacent territory where the Hudson River empties into the Atlantic Ocean, New York City and its satellite towns represent a huge agglomeration of more than 20 million people.

Two centuries ago, the city was already the largest in the United States, with a population of about 50,000 spread haphazardly across the southern tip of Manhattan. In 1811, to channel and organize future growth, city officials prepared a grid of numbered streets and avenues covering the entire island.

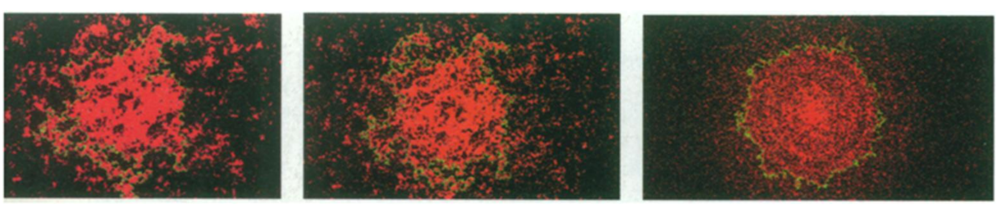
Even so, they didn't foresee the tremendous growth to come. Indeed, their report acknowledged that it might be a "subject of merriment" that they had provided a space for "a greater population than is collected on any spot on this side of China."

By the end of the 19th century, the island was filled to overflowing, and the city had extended its tentacles deep into the surrounding area.

Similar patterns of urban growth, mediated by topography and historical accident, have created other cities throughout the world. Over millennia, people have insisted on crowding together; they jostle for space and move about to create intricate, splotchy patterns of development.

Geographers and planners have long sought to understand this characteristic clumping of humans into towns and cities. They continue to study these growth patterns in the hope of uncovering simple laws that govern the number, size, and distribution of urban population centers. Such insights could yield a theory that relates the physical form of a city to the behavior of its inhabitants and to the multitude of social and economic processes that such actions encompass.

During the last decade, researchers have begun to examine the possibility of using mathematical forms called fractals to capture the irregular shapes of developing cities. Such efforts may eventually lead to models that would enable urban architects to improve the reliability of their predictions about the impact of planning decisions and the general course of a city's development.



In correlated percolation models of urban development, the probability of growth decreases as the distance from the central unit increases. In such simulations, a high correlation (left) produces a more ragged pattern than a low correlation (center). In contrast, positioning units randomly generates a compact cluster (right). In each case, red indicates urban areas and light green shows the boundary of the largest cluster surrounding the central unit.

Geographer Michael Batty of the Centre for Advanced Spatial Analysis at University College London first became aware of fractal geometry more than a decade ago. Through his strong interest in computer graphics, he learned that computer programs based on fractal ideas could generate remarkably realistic renderings of mountainous landscapes, trees, foliage, clouds, and other types of branched or irregular structures.

In each of these examples, the geometry displays a hierarchy of similarity. A magnified portion of a fractal looks very similar, if not identical, to the overall structure. Further magnification reveals details that again resemble the full pattern. Hence, fractal objects look the same whatever the magnification. Zooming in for a closer view doesn't smooth out the irregularities or end the branching.

Batty soon recognized another example of that fractal self-similarity—that the concept fundamental patterns repeat themselves on different scales. "The basic technique gives you patterns that are reminiscent of the way cities grow," Batty says.

Fractal structures also lead to scaling rules that mathematically relate such variables as density and size. Batty noticed that urban models often incorporate comparable relationships, linking, for example, the sizes of cities and towns to their number within a given area.

"Thus, you have a few big settlements and a very large number of small settlements, such as villages," Batty says. More quantitatively, "you could say you have one big city, then two cities half the size, four towns that are half the size of those, and so on."

The same kind of scaling rule can apply to other urban hierarchies. For example, shopping center size can range from individual shops and small clusters of stores serving city neighborhoods to business districts, malls, and megamalls that draw customers from large areas. The bigger the shopping center, the fewer of that size serve a given area.

To develop fractal models that could be applied to urban development, Batty and his collaborators turned to techniques first used in statistical physics to describe the agglomeration of randomly wandering particles into two-dimensional clusters. In particular, they investigated the process called diffusion-limited aggregation.

In this growth model, a fractal form starts as a single tiny cluster embedded in a dilute sea of randomly moving particles. Every time a particle happens to bump into this seed, it sticks and stays put. The resulting two-dimensional pattern looks somewhat like a bare tree seen from above, with thin, irregular branches extending out in all directions.

This model predicts that only one fractal cluster forms from a single seed and that most of the growth takes place at the tips of a cluster's branches. After a while, the core is almost completely screened by its branches from further development.

Applied to cities, such a model emphasizes how uncoordinated local decision making can generate global patterns that give cities their particular sizes and shapes. It suggests that a city's overall structure can emerge naturally out of individual actions without any coordinating authority. Batty and Paul A. Longley of the University of Bristol in England describe these ideas in *Fractal Cities: A Geometry of Form and Function* (1994, Academic Press).

"Our view now about the shape and form of cities is that their irregularity and messiness [are] simply a superficial manifestation of a deeper order," the authors argue. By identifying this deeper order, it may be possible to develop theories that can aid urban planners.

There are many recipes for creating fractal forms, and these different approaches lead to alternative models of and perspectives on urban development.

When physicist Hernán A. Makse of Boston University looked at *Fractal Cities*, he wasn't impressed with the match between the patterns generated by models based on diffusion-limited aggregation and the actual patterns of urban sprawl illustrated in the book.

"DLA [diffusion-limited aggregation] didn't seem to be a good model for cities," he remarks.

Instead, he was struck by the resemblance between the shapes of real cities and the patterns resulting from a mathematical model that he and his coworkers were developing to represent the ability of liquids or gases to flow through sedimentary rock.

In general, the permeability of rocks such as sandstone can change tremendously over short distances; these fluctuations significantly affect fluid flow through the rock. In the past, researchers regarded the fluctuations as nearly random variations, with a little short-range order reflecting the influence of neighboring regions on each other.

Makse and his colleagues discovered that they could obtain a better mathematical representation of sandstone permeability by assuming the presence of long-range correlations, statistical patterns that apply across the entire object. Permeability is not the result of a simple random process, they noted. It is intimately tied to the way in which the sandstone was formed. Geologic processes, such as the deposition of sand grains by moving water, impose their own kind of order.

This mathematical approach is called correlated percolation.

After he noted a possible link to urban growth models, Makse started to investigate how he might apply correlated percolation to the shapes of cities. The key idea was that, in an urban setting, development units (representing people, businesses, capital, or resources) do not attach themselves randomly to an existing cluster. Their placement is strongly influenced by the presence of other units.

Working with Boston colleagues H. Eugene Stanley and Shlomo Havlin, Makse developed a model in which the probability that a unit occupies a given spot decreases gradually as the distance from a central, compact core increases. Moreover, when a unit occupies a certain location, the probability of additional development is highest in its vicinity, and this probability decreases at a certain rate as the distance from the unit increases.

Thus, the rules introduce long-range effects that influence how clusters form and grow. What happens at a given site depends on the state of all other sites in the model.

After they built their model, Makse notes, they realized that the correlations they had introduced into their rules reflect the obvious tendency of people to live next to other people.

Using computer simulations, the researchers experimented with different rates of falloff from the central core and with different degrees of correlation. They found that strongly correlated clusters develop fairly compact central regions with much looser agglomerations of units at the fringes.

The resulting patterns closely resemble maps of population data for such cities as Berlin and London (see illustrations). It's also possible to extract mathematical relationships that include powers (expressions with exponents) that relate the sizes of towns and other population centers surrounding a large city to their distances from the city's center.

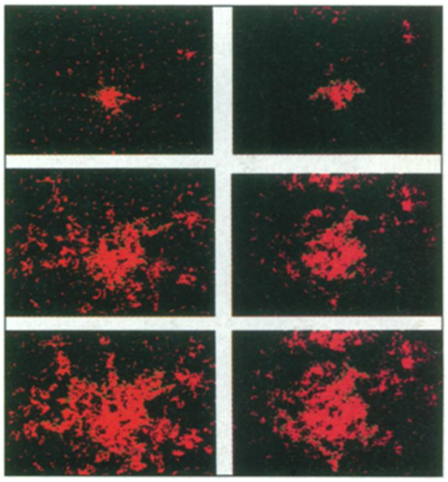
"Our model predicts that growth does follow some law," Stanley says. Makse, Stanley, and Havlin report their findings in the Oct. 19, 1995 NATURE.

"Their analysis generates forms consistent with power laws describing how population in real cities varies with radius and area, and with relations governing their size and spacing," Batty comments in the same issue of NATURE.

The recent focus on fractal models of urban development represents one aspect of a renewed interest in the importance of local actions, individual decisions, and self-organization in shaping cities.

"We've got to think about all kinds of systems as being highly decentralized and highly local," Batty contends. "If we build models at this level and enable them to produce ordered patterns, that's really the way forward in terms of explaining the shapes of cities."

Cities are complex, and current models are still quite crude. It's likely that no one model will fit all cities, past and present. Moreover, the urban landscape itself is changing, as seen in the emergence of huge edge cities with multiple centers of population and world cities linked together by sophisticated new communications technology. However, realistic models of how local activities lead to large-scale patterns and order may eventually serve as important tools for planning and predicting urban development.



The population distributions of Berlin and surrounding towns for the years 1875, 1920, and 1945 (left column, top to bottom) resemble those in an urban growth model based on correlated percolation (right column).

Makse and his colleagues have already noted that their correlated percolation version of city growth suggests that central planning often has only a limited effect on the shape of a metropolis. The modelers did not include, for instance, the efforts of planners to contain London several decades ago by putting rings of parkland around the city. Growth still occurred; communities expanded and arose on the far side of the parks. The resulting pattern, despite the planners' goals, resembled the physicists' prediction.

"You could say that the lawmakers do what they want to do, but people will live where they want to live," Stanley comments. "That's roughly what we found in our model."

"Theories like these are generating changes in our views of cities and how we might alleviate their problems," Batty says. "They are likely to be much more effective than those that have operated hitherto." □