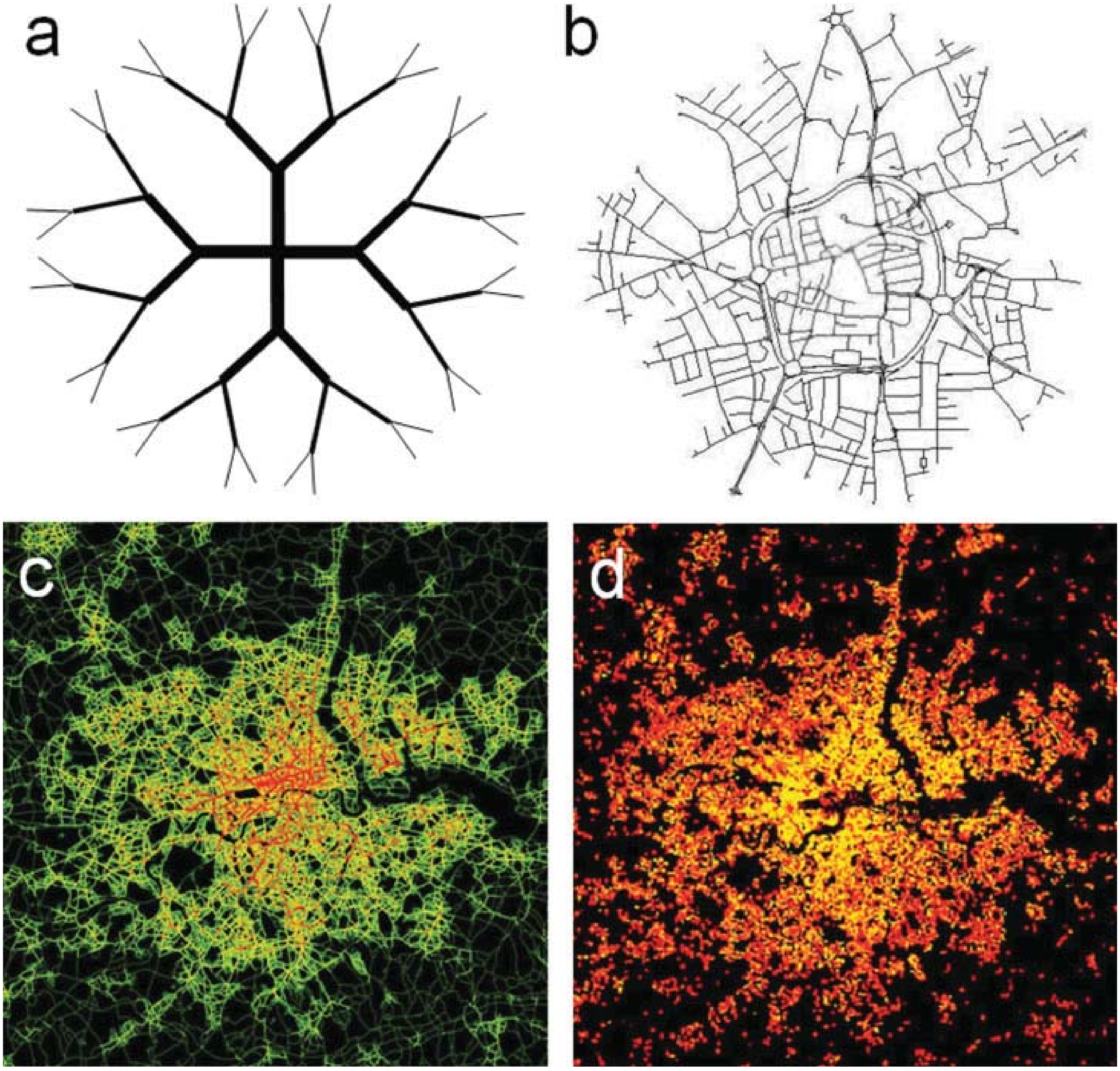

A Digital Breeder for Designing Cities

The idea that inspired designs mirror processes of biological evolution is fast gaining ground as we learn more about how complex systems such as cities function. **Michael Batty** illustrates how cities can now be grown in 'digital laboratories' and, by imposing realistic constraints on their form, begin to breed 'good designs' that emerge from continual feedbacks that reinforce the best and iron out the worst.

M. Batty (2009) A Digital Breeder for Designing Cities, Architectural Design, 79 (3), 46-49
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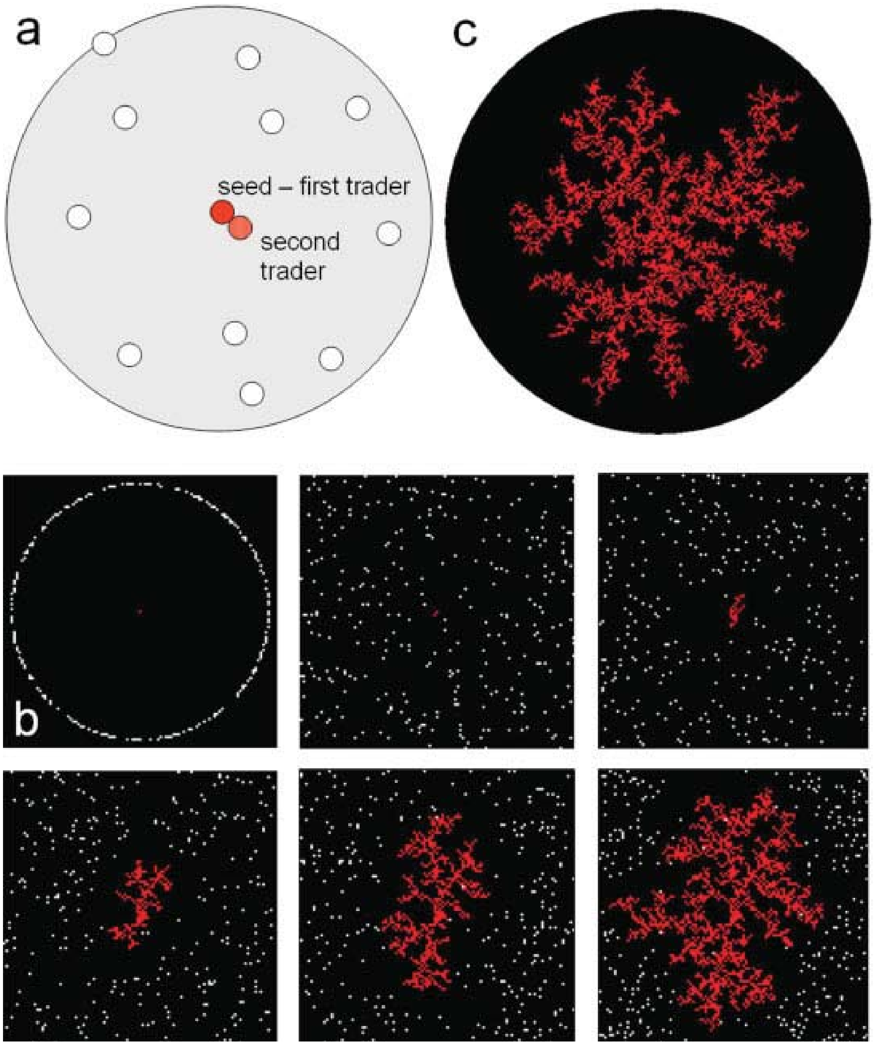


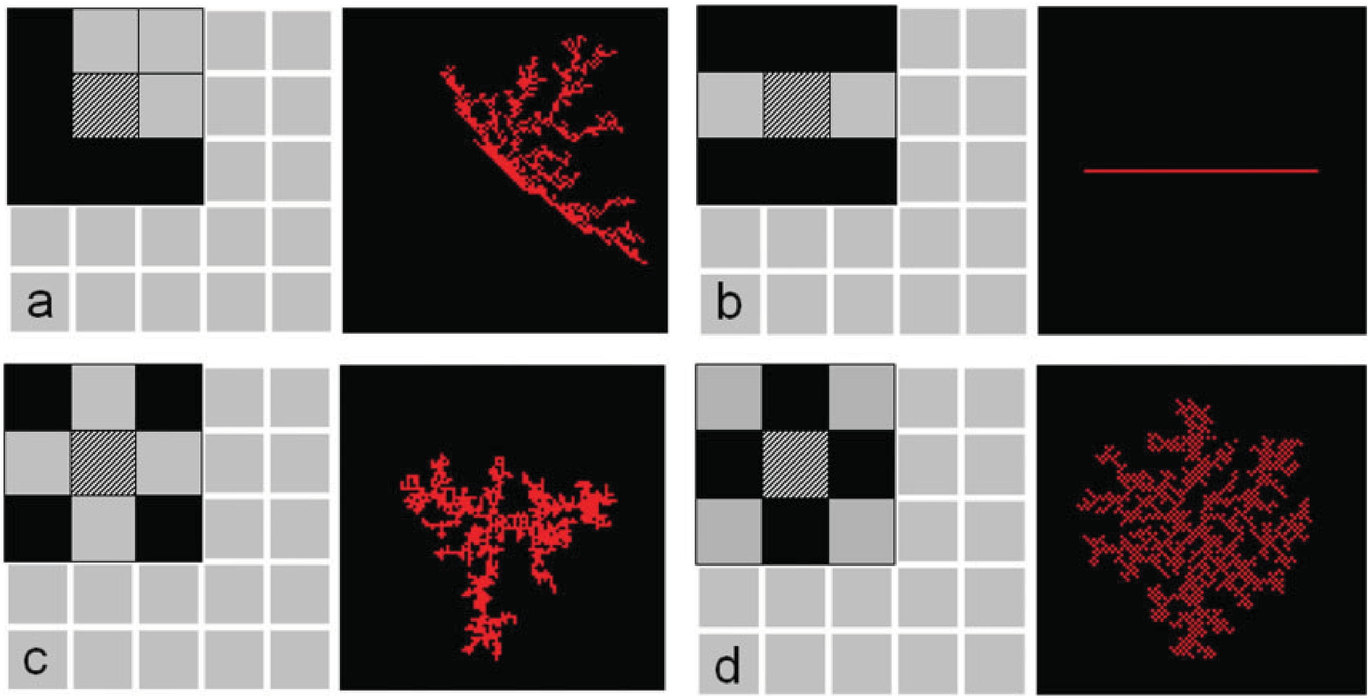
opposite:
Figure 1: Network growth and urban clusters
a. Idealised hierarchical radial network growth around the city core;
b. Road network growth around the centre of a small English town (Wolverhampton);
c. Road network coloured according to traffic flow in Greater London;
d. Clusters of urban population density in Greater London.

left:
Figure 2: Breeding urban forms
a. The simple logic of the model based on random exploration of the urban space;
b. Growth of the structure from the central seed;
c. The dendritic structure that results when the space is spanned.

This year marks the 200th anniversary of the birth of Charles Darwin and the 150th anniversary of his book On the *Origin of Species* that changed the world. In timely fashion, Darwin's fundamental message that life proceeds through a natural selection that slowly but surely preserves the fittest among the population and destroys the rest, appears increasingly attractive in explaining the growth dynamics of a variety of non-biological organisations such as cities. Such selection proceeds in very small steps that most now agree take place at the genetic level, with the result that those organisms that survive are very well adapted to their environment and to each other. In analogous fashion, cities are one of the best exemplars of how well-adapted designs emerge from what appear to be countless uncoordinated decisions generated from the bottom up that produce order on all scales. This emergence of order is the hallmark of complex systems and it is hardly surprising that with the growth of digital computation, it is now possible to simulate such evolutionary processes, thereby suggesting how 'good designs' might emerge among a universe of possible designs.

If good urban designs can be grown by manipulating this kind of complexity, then this promises to provide a much more sensitive, less intrusive way of managing our environments than the blunt instruments that have hitherto characterised planning. City design should thus ascribe to Darwin's message that it is small changes, intelligently identified in the city fabric, rather than massive, monumental plans that lead to more successful, liveable and certainly more sustainable environments. Christopher Alexander continues to preach this message, as did Jane Jacobs,[1] but it has been a long time in coming.

In the last 20 years, it has become clear that cities, far from being messy, disorganised forms, have rather well-defined spatial structures. Order and pattern appear on all scales, with urban activities forming clusters of different sizes. These clusters are supported by networks which transport energy to sustain them and which fill space efficiently as tree-like hierarchies. These represent the most parsimonious ways of delivering energy to population clusters that diffuse to take the greatest advantage of the space around them. Figure 1 shows a sample of real

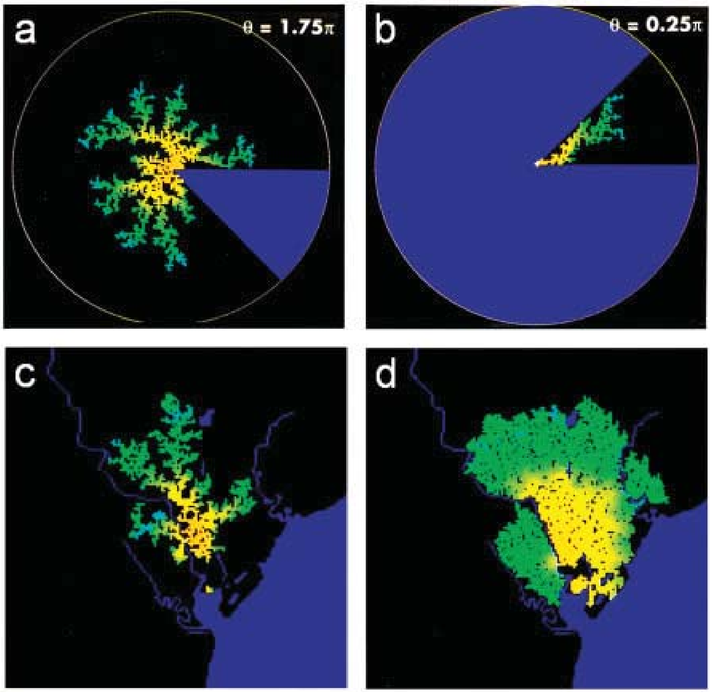


and idealised networks and clusters of urban development based on dendritic forms that fill space in such a way that the city remains connected. These structures are fractals, objects which are self-similar at successive scales, forming clusters whose distribution follows scaling or power laws according to a strict hierarchy and frequency of sizes. The most complete examples of organic order occur in cities with no central planning such as those developed in the medieval period in Europe[2] and, more recently, in the rapidly developing cities of the Third World.

Growing city shapes such as those in Figure 1 from the bottom up in digital laboratories requires clear rules to be specified that determine how agents locate with respect to one another. As a minimum, these rules must reflect two very basic forces: first that people aggregate in cities to realise scale economies of agglomeration, which means that people should always be connected to one another; and second, that people should be able to live with as much space around them as possible. These two forces compete and contradict each other: the first leads to centripetal growth, the second to centrifugal. Now imagine a uniform homogeneous plain and a trader who decides to settle at the intersection of a track and a river where the land is fertile and flat. If another trader happens, by chance, to find the trader who has settled, that trader also decides to settle there. In the wider hinterland, a certain proportion of traders will find the settlement with a certain probability. Given enough time and enough traders, the settlement will grow, but how?

A schematic of the location process is demonstrated in Figure 2a. The individuals who seek to settle are arranged around a circle well outside the location of the settlement, the centre of which is the red solid dot where the original trader locates. Each individual is a solid white dot who begins to search for the 'city' – the red dot – via a random walk. If they find a cell adjacent to the red dot, they settle, turn 'red' and no longer move. Another white dot is launched somewhere in the hinterland and the process continues with many white dots searching for the city of red dots. The city builds up, not as a compact mass, but as a dendritic structure, based on the way the two principles of proximity and space interact. The result is surprising in that order emerges from the bottom up, with the actual shape dependent on a sequence of incremental, randomly determined decisions. The structure that emerges is path dependent and thus 'history counts'. Figure 2b shows the growth path where the final structure in Figure 2c is not a compact mass with a dimension of 2 or a linear city with a dimension of 1, but a pure dendrite, a fractal, with a fractional dimension of about 1.7.

To breed new designs, these rules need to be manipulated to reflect the principles for growth. They reflect a genetic code in that they tell the location how to respond to the agent and vice versa, which is accomplished by forming rules that pertain to the vicinity or neighbourhood of each location in question. These rules encode any relevant information and, in the case of the species of 'agents' in Figure 2, they consist of simply telling the agent to fix its location if



opposite:
Figure 3: Configuring the rules that generate urban morphology by cellular automata
a. Rules that orientate the city to the northeast;
b. Rules that force the morphology into a linear city destroying the variety of form;
c. Rules that keep development compact and linear;
d. Rules that keep development compact and sparse.

left:
Figure 4: Growing cities in a physically restricted container
a. Around a river estuary;
b. On a spit of headland;
c. Cardiff under the standard diffusion-limited aggregation growth model;
d. Cardiff under a set of rules that reinforce compactness.

another agent has already settled in its neighbourhood. The model is a cellular automaton where the cells (locations) in the neighbourhood determine what happens to the cell in question. Figure 3 illustrates what happens when the rules are changed by excluding some cells from consideration (shown in black in each of the cellular templates with the resultant breed alongside).

Thus linear cities can be generated only where linearly adjacent cells can be developed or cities skewed in orientation due to climatic influences which restrict development to, for example, their windward side and so on. The general idea is to specify rules that are both realistic and optimal, that do not break the process of ordinary decision-making but mutate and interact to produce good designs. Figure 4 suggests 'containers' can be defined in which such breeding takes place and which mirror the topography of both ideal cities and real cities, such as Cardiff. Actual cities evolve towards designs that are at least sustainable and, to some degree, workable, and thus the starting point should always be the rules that generate real cities. The challenge lies in defining changes to these rules that improve the workings of real cities by meeting goals pertaining to flows, densities and economies of agglomeration.

The digital tools used to generate cities in this manner and which are central to the laboratories used to breed different urban forms are now widely available as packages that allow cellular systems (incorporating principles of cellular automata) and agent-based models to be constructed. Starlogo from MIT's Media Lab and its Web equivalent Netlogo are the most generic, but more specific packages such as RePast for agent-based models are also available, all as freeware or open source.[3] What is required now is further experimentation with these kinds of models by others who are able to fashion such systems to meet different constraints and objectives, thus generating as wide an array of possible city forms as can be imagined. AD

Notes

1. The organic analogy between design, buildings and cities was first formally presented by Jane Jacobs in her book *The Death and Life of Great American Cities*, Random House (New York), 1961, and at much the same time by Christopher Alexander in his *Notes of the Synthesis of Form*, Harvard University Press (Cambridge, MA), 1964. Alexander's recent magnum opus *The Nature of Order*, CES Publishing (Berkeley, CA), 2004 takes these ideas much further.
2. Excellent examples of cities in history that display the kind of organic order which is a consequence of growth from the bottom up are contained in Spiro Kostof's *The City Shaped: Urban Patterns and Meanings Through History*, WW Norton & Co Inc (New York), 1993. An outline of cities as fractals is included in Michael Batty and Paul Longley, 'The Fractal City', *Architectural Design*, 67 (9–10), 1977, pp 74–83, while the book by the same authors, *Fractal Cities*, Academic Press (San Diego, CA), 1994 deals with the mechanics of how to construct these models (see http://www.fractalcities.org/). Extensions to the models are illustrated in Michael Batty, *Cities and Complexity*, MIT Press (Cambridge, MA), 2005), and a more detailed discussion of the cellular automata methods used to breed cities in this way can be found online in *Cluster Magazine* at http://www.cluster.eu/v2/editions/batty/.
3. Starlogo software for any platform can be downloaded from http://education.mit.edu/starlogo/, and Netlogo from http://ccl.northwestern.edu/netlogo/. A good source for agent-based modelling software including RePast is Andrew Crooks's blog http://gisagents.blogspot.com/.