

# CITIES, COMPLEXITY, AND EMERGENT ORDER

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*Summary: Most cities are not planned but grow organically from the bottom up as the product of individual and group decisions about how and where to develop. Here we introduce models from the complexity sciences which illustrate how the familiar patterns that we see in the morphology of cities emerge from this urban soup.*

Throughout the 20<sup>th</sup> century, most cities have been treated as somewhat dysfunctional stereotypes, where the quality of life is poor, their density too high, and their aesthetic form lacking in taste. Combined with congestion in their cores and sprawl around their peripheries, urban planning has sought to impose an evident order on their size and shape primarily using top-down control (Batty, 2008). By the middle of the last century, cities were widely regarded as systems whose form and structure could be redesigned using centralized planning akin to the way a physically engineered system could be controlled using cybernetic principles.

Yet the experiences of city planning over the last fifty years are now generally regarded as disastrous, with the plans that have been implemented often leading to more serious problems than those that they were designed to alleviate and solve. In short, the systems model of the city as indeed the planning systems that developed in tandem, were built around a conception of cities and their management that is far from the reality of the way cities actually develop as a multitude of individual as well as collective decisions generated from the bottom up. Cities grow organically as the product of millions of decisions and in the face of this complexity, it is not surprising that top-down controls have little effect on their structure. Cities reveal examples of what Horst Rittel (1969) called, over 40 years ago, ‘wicked problems’: problems that tend to be resistant to direct attack and obvious solution because of massive but indirect repercussions and impacts that occur in systems composed of multiple networks and relations.

During this time, a new model of how cities function has gradually emerged. The analogy of a city with a physical system has been replaced by that of a biological system (Simon, 1999) and as we know from our own experience, biological systems grow from the bottom up. They function because of their diversity with considerable redundancy in their parts which enable them to remain resilient in the face of turbulence in their environments. This change in perception has paralleled the development of new approaches to many systems that are now being explored under

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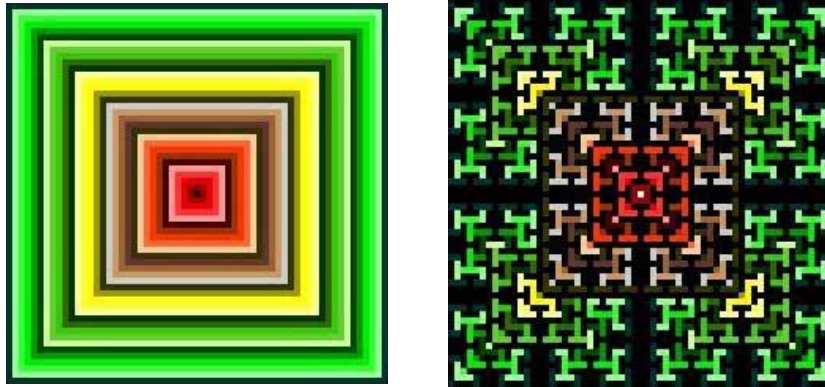
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the banner of the complexity sciences (Batty, 2005). No longer do we think of cities as being in equilibrium, in fact they are far-from-equilibrium, in a state of perpetual disequilibrium which is a consequence of their vibrancy and diversity. The notion of an equilibrium which is very central to the idea of a plan is increasingly irrelevant to the way we need to approach the problems of cities, and new approaches based on identifying key points of leverage are beginning to influence the way we might plan them. Rather than developing the kinds of blunt instrument that have dominated city planning for a century, the focus is increasingly on developing tools that enable us to intervene less but with much greater effect.

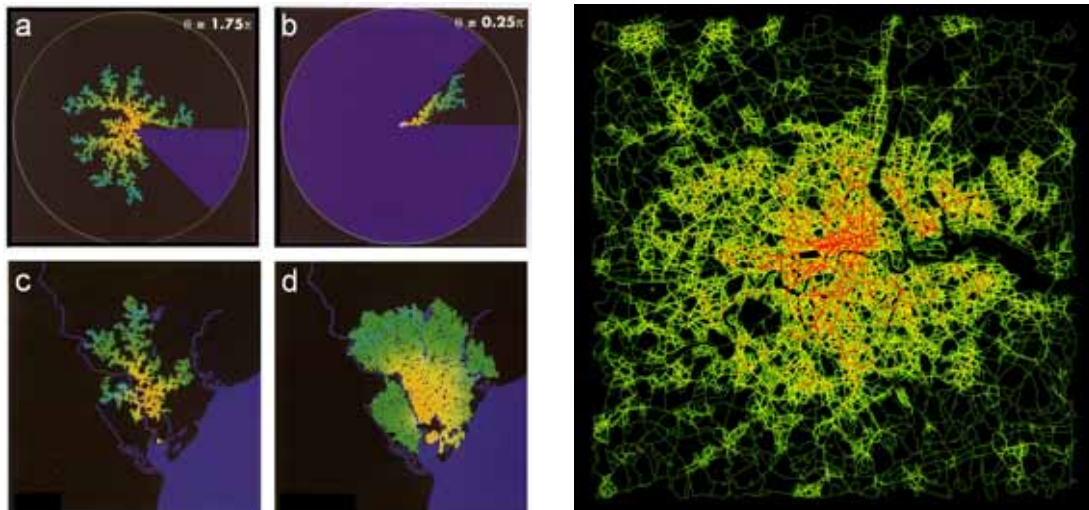
Since the 1960s, computer models of cities have been developed where one can test the impacts of planned (and any other kind of) development on their structure, first for cities in equilibrium where aggregate economic and demographic activities are simulated in terms of their locations, and then slowly and somewhat painfully for the dynamically changing urban structures where the focus has gradually become more disaggregate and detailed. From complexity theory have come models that instead of generating city structures at a cross section in time from the top down, simulate changes in urban structure through time, enabling both smooth and discontinuous change to be represented. Cities however do not usually change smoothly. There is an inevitable lag between how the built environment changes and how activities respond. Activities change at ever faster rates in comparison with the built infrastructure that contains them but has much longer life spans. To address this challenge of simulation, simple models that grow cities from the bottom up have been built around dividing the urban landscape up into small cells from which development is generated with respect to the influence of any one cell on any other. Cellular automata (CA) models articulate these development processes through uniform rules that act homogeneously on all cells with a cell changing its state from one land use to another dependent on the state of the cells in its immediate neighbourhood. These kinds of transition can be specified in as much detail as possible, thus mirroring the development process of acquisition, development, sale and purchase of land and the construction of the built form and its eventual occupation by various economic and demographic activities. Simple bidding processes mirroring how land and related markets operate can be simulated in this way as we imply by the following example.

In Figure 1, we illustrate a city organized around a gridded cellular landscape in which the development in each cell is a function of what happens in adjacent cells, the so-called neighbourhood. Neighbourhoods can be of different sizes and the actual composition of what features of a neighbourhood influence cellular development depends upon the processes being modelled. We will first build a model of cellular development which is based on a cell being ‘switched on’ if and when it is developed and ‘switched off’ if it has never been developed or loses its development, reverting to its virgin state. Then if *any cell* in the 8 cell neighbourhood around a particular cell is already developed, the particular cell at the centre of the neighbourhood is then developed. If we develop a central site, this model leads to a regular diffusion around this central site. If we then harden these rules saying that a cell is developed if and only if there is only *one cell* already developed in one of the furthest corners of its neighbourhood, the process generates a much sparser structure from the bottom up which has fractal similarity as it grows. We show this for both the *any cell* and *single cell* rules in Figures 1(a) and (b) respectively.



*Figure 1: Cellular Diffusion from a Central Seed – The Central Business District – Using Different Neighbourhood Rules*  
 a) based on any cell being developed, and  
 b) based on only one corner neighbourhood cell being developed

We can relax the rules slightly by simply developing a cell if it meets the ‘any cell’ rule and if the probability of its development, chosen randomly, is greater than 50 percent. This essentially produces a circular pattern which is gradually filled in as the simulation proceeds. This is still a diffusion but it is no longer regular, the ultimate patterning being random. What is quite clear is that many different kinds of morphology with different degrees of sparseness or density and different configurations or geometries can be generated in this way by changing the rules. By developing a space of rules in which say, cellular densities in the typical neighbourhood and the probability of development are varied systematically, we can generate a veritable ‘zoo’ of forms that provides a range of possible city-like developments under very different conditions of density.

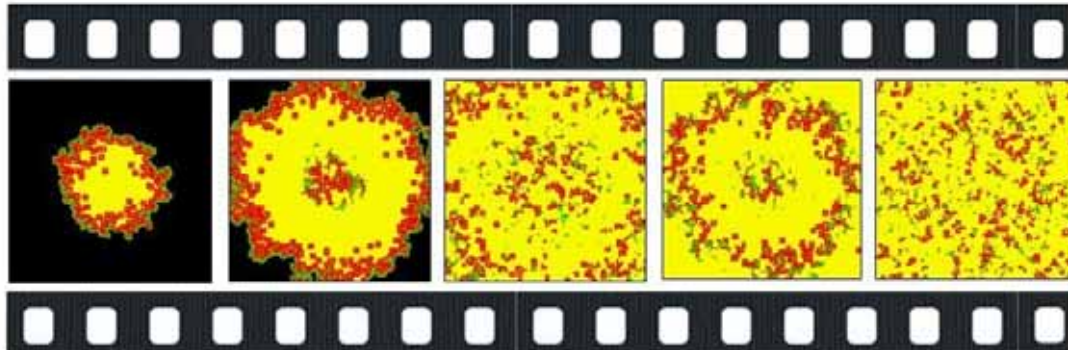


*Figure 2: Models of Cellular Growth and Emergent Morphologies Compared to Real Urban Form*  
 a) CA models in the Cardiff region, compared to b) the development of the transport network in Greater London

Such models produce different kinds of fractal (systematically regular and self-similar) shapes and we can begin to use these kinds of automata to infer the

conditions under which certain city shapes with different densities of occupation and accessibility of location are generated. This of course is relevant to thinking about what future city shapes might be more optimal than those we observe in reality and also the mechanisms needed to realise particular (optimal) shapes. This is hardly planning or optimisation but it is critical to exploring the future. In Figure 2(b), we show how such cellular automata generation can be used to generate city-like forms (for the physical structure in which the town of Cardiff sits) and in Figure 2(b) we show the development of the transport network in Greater London which mirrors similar cellular growth around the centre. Many cities have this shape as a resultant of bottom up actions that lead to filling space so that everyone is connected to the city in such a way that they seek the greatest space around themselves as possible.

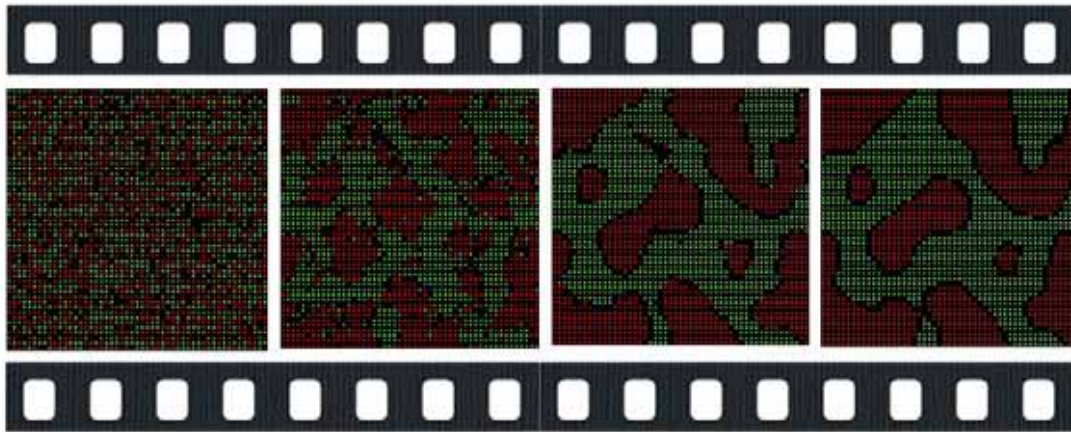
Cities of course cannot be understood purely as growth mechanisms, They regenerate themselves by mixing what already exists in different ways. Such processes can lead to segregation which is also an emergent phenomena, just as the dendritic structures pictured in Figure 2 are emergent. First if we simply assume that cities grow from their core to their periphery somewhat unevenly and that we simulate this by adding a little bit of noise to our CA models in Figure 1 above, then after a certain time has elapsed, the activity regenerates itself. If it is replaced with a similar amount of noise, eventually the structure that emerges is one that is completely mixed with respect to the date or year at which any cell of development takes place. We show this in Figure 3 where the film strip shows the way development takes place. This is in relatively regular rings as the city first grows, all the way to waves of successive regeneration that mix the development up.



*Figure 3: Successive Diffusive Growth Around a Central Seed and Continual Remixing Due to Differential Regeneration*

This is the opposite to what occurs if the pattern is mixed to begin with and then individual cells begin to change their location according to their preferences of having certain other individuals living around them, in their neighbourhood. Imagine a set of residents divided into red and green cells. The red cells have a mild preference for living close to other red cells and the same for green. We define this mild preference as follows. If a red cell finds itself surrounded by say 5 cells which are green and only three which are red, it tries to move or rather then individual moves if it can to a cell where its neighbours are more red then green. A symmetric decision making process occurs for green cells. Individuals in this model, originally specified by Thomas Schelling in 1969, are quite happy to live with an equal number of unlike neighbours but once this reaches a majority, then they seek to move. What happens in this model

is that even though there is only a mild preference for moving if the unlike neighbours outweigh the like neighbours, the ultimate pattern becomes highly segregated. This is a classic example of emergence occurring from the bottom up where there is nothing in the rules of movement at this micro level that implies the kind of emergence that occurs at the macro level. We show this in Figure 4.



*Figure 3: Segregation Using Schelling's (1969) Model where Agents Move to Find Locations Surrounded by at Least the Same Number of Their Own Group as Other Groups.*

What we have demonstrated here is the notion that complex morphologies such as cities emerge from the bottom up. The patterns we have shown are not imposed from the top down; in short, city forms such as these are not planned but are the product of a multitude of decisions that accumulate and stream through time, subject to continual regeneration and renewal as conditions for development continually change. Cities are examples of complex systems, par excellence, and the development of complexity theory in this domain serves to underscore the need to think about their planning in very different ways from what has gone before.

### References

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