ReVISIONS

Regional Visions of Integrated Sustainable Infrastructure Optimised for Neighbourhoods

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University of Surrey at Guildford

How Complexity Theory …

Can Be Used to Understand the Evolution and Design of Better Cities

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Outline

- What is Complexity? What is a City?
- Organic versus Planned Growth: Evolving Cities
- What are Fractals? Definitions and Properties
- Fractal Geometries: Patterns and Processes
- City Shapes at Different Scales: Modular Growth
- Fractal Growth Models: DLA
- Applications through Cellular Automata
- Moving to Agents in the Cellular Landscape
- How Do We Use this in Designing Better Cities?

What is Complexity? What is a City?

Over the last twenty years, in science and social science, and in policy analysis, indeed in general, we have realised that the world is an infinitely complex place, not quite as understandable as we once thought it was through science

Hence the rise of the complexity sciences. Key to this is the notion that systems and societies build and evolve from the bottom up, and are not planned from the top down

This has happened because of many different forces coming together:

- the demise of centralised economies/societies
- the miniaturisation and individualisation of technologies such as the computer, the car, even mass housing
- the growth of globalisation, the network economy
- The idea that all of us acting individually make a difference
- the fact that systems grow from their elements

Cities are excellent exemplars of such complexity, no one really plans them. Look at cities across the world – the nightlights data show cities are more like organisms that evolves than a planned form

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What is a city? We can illustrate the rudiments of complexity theory wrt to cities ….

- Systems of diverse, interacting elements, manifesting structure on all scales often organised in modular self similar ways
- Systems that are continually changing their size and scope through the behaviour of their elements, which often combine together to produce emergent structures and patterns
- Systems that are far from equilibrium and display novelty, surprise and innovation

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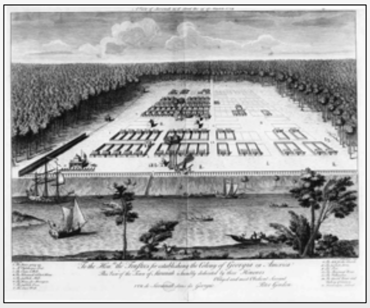
Organic versus Planned Growth: Evolving Cities

Cities that grow from the bottom up are essentially unplanned and we refer to these as organically growing. Of course no city is completely unplanned but there is a spectrum of cities across the continuum from planned to organic

To fix ideas, we will examine both ends of the spectrum in building our metaphor that cities are the example of complex systems *par excellence*



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Here are some idealised forms, which imply different degrees of planning – from Abercrombie's book **Town and Country Planning** (1935)

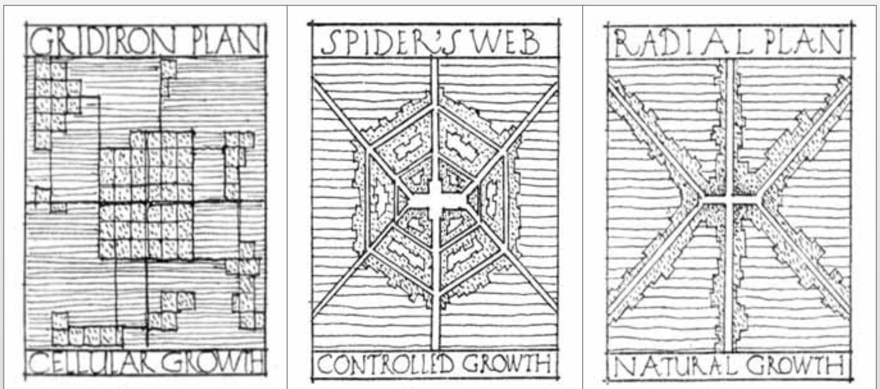

FIG. 1. FIG. 3. FIG. 2.

What are Fractals? Definitions and Properties

Fractals are objects that scale – they show the same shape at different scales in space and/or time

This property of scaling is sometimes called self-similarity or self-affinity

In our world of cities, we think of this scaling as being a replication of the same shapes in 2 or 3D Euclidean space

This suggests modularity in growth and evolution and processes that are uniform over many scales

The signature of a fractal is called its dimension and usually this suggests how the fractal fills space

If we think of 0-d as a point, 1-d as a line, 2-d as a plane and 3-d as volume, then a fractal also has *fractional dimension*.

This means that the Euclidean world is the exception not the rule as the integral dimensions are simplifications.

The best example of a fractal is a crumpled piece of paper

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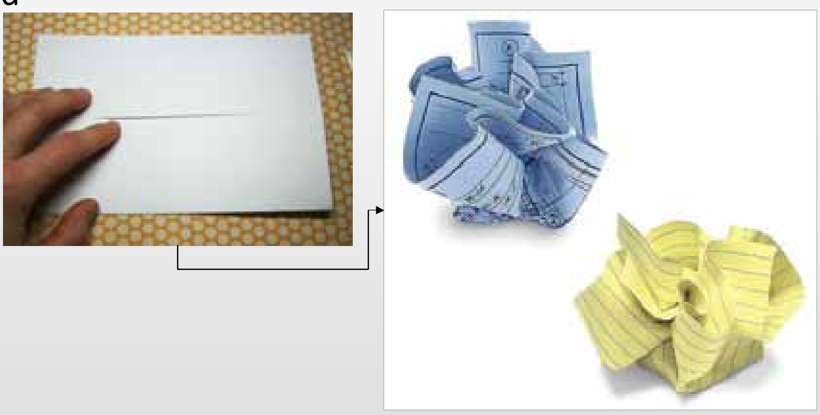
It is 2-d but when we crumple it we make it more than 2-d



Other great examples are tree structures ….

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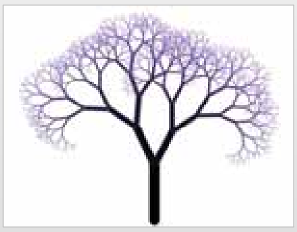

In fact in mathematics, a function is scaling if it can be shown to be scalable under a simple transformation – i.e. if we can scale a distance by multiplying it by 2 say and the function does not change qualitatively, then this is scaling – so power laws – functions like $f(y)=x^{-1}$ scale because if we multiply x by 2, say, we get $f(2y)= (2x)^{-1}=2^{-1}x^{-1}\sim f(y)$

We will not take this further but just point out that rank-size, even exponential functions imply fractality

In other words, if we take away space from our models, then what is often left in fractal phenomena is the idea that the aggregate scales in fractal terms.

Good examples of this are in terms of what human and economic geographers have called central place theory – in the order between big centres and small centres where the size distribution of centres usually follows a power law.

Zipf's Law 1949

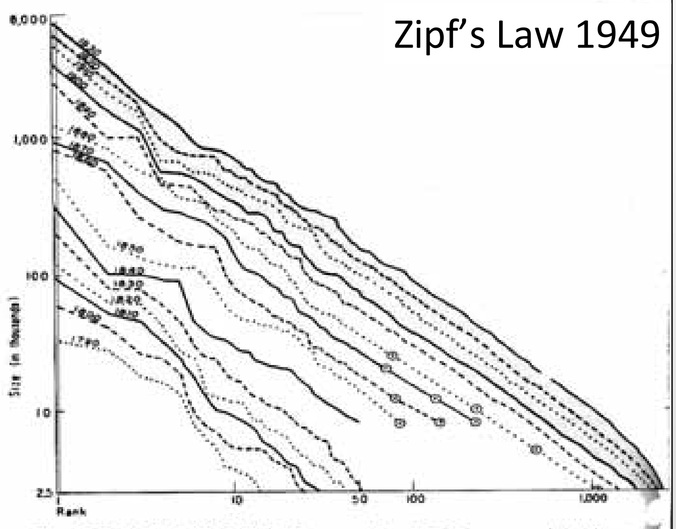

Fig. 10–2. U. S. A. 1790–1930. Communities of 2500 or more inhabitants ranked in the decreasing order of population size.

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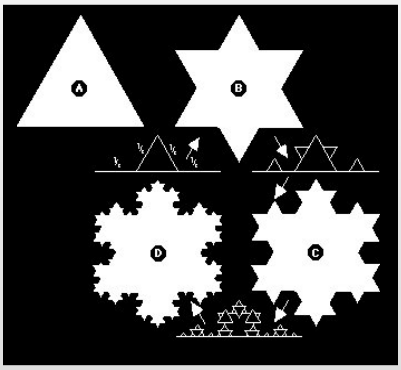
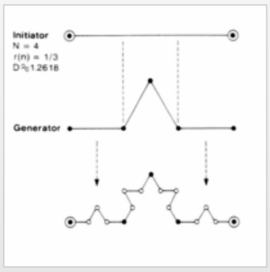
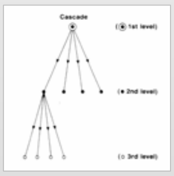
Fractal Geometries: Patterns and Processes

There are some basic conundrums and paradoxes with fractal geometry – the clearest one is the length of a fractal line – if a line is truly fractal, it fills space more than the line and less than the plane with a fractal dimension between 1 and 2. As it also scales – any bit of it has the same shape as an enlarged or reduced bit but the length is infinite. Note the famous paper in Science in 1967 by Mandelbrot – *How long is the coastline of Britain?*

We can shows this for the Koch curve. Note how we construct the irregularity by adding a scaled down piece of the curve

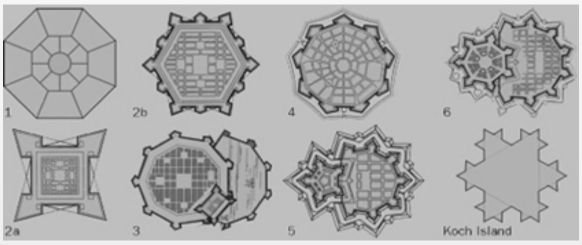


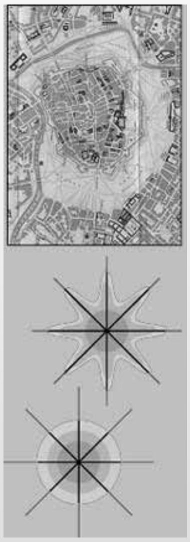


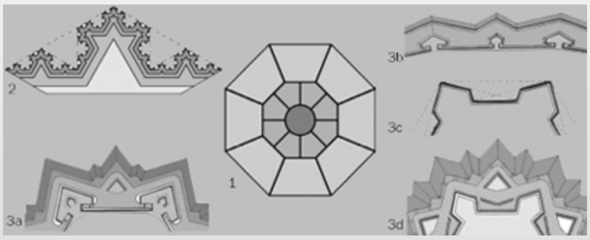


Note how hierarchy is a feature of the construction

And note how the line is infinite but the area is finite





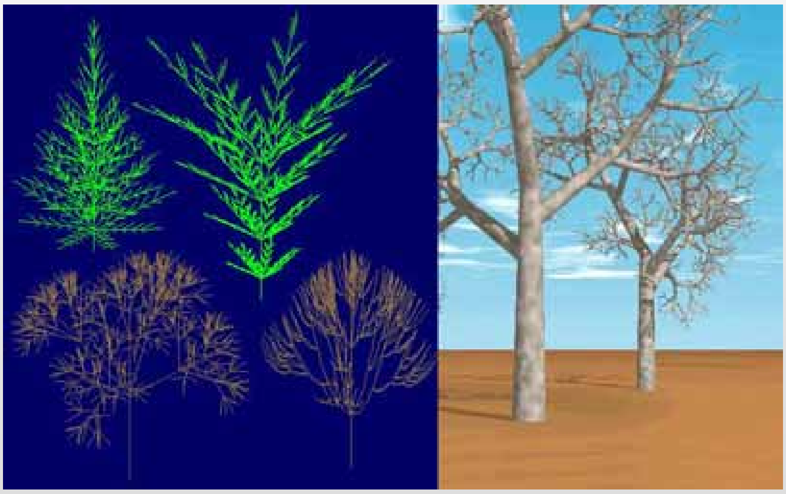


This is resonant in ideal towns and

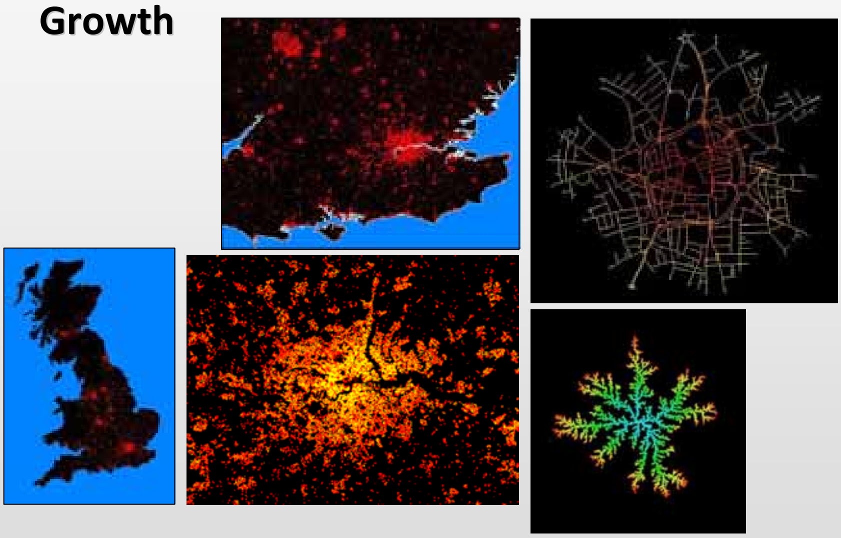
In many shapes in nature as we show …

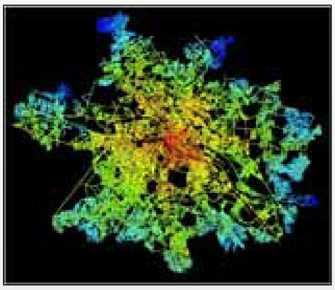
Barnsley’s fern, from his book Fractals Everywhere which is generated by a rather sophisticated mathematical systems of routine and repetitive transformations called the Iterated Function System

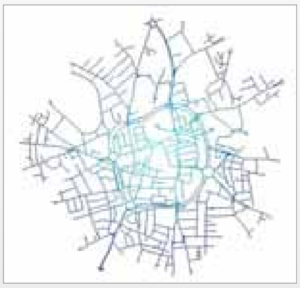
Computer graphics depends upon fractals ! At least for natural forms such as trees

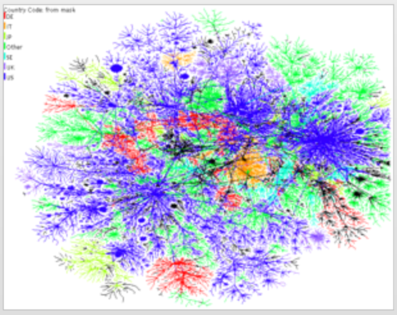


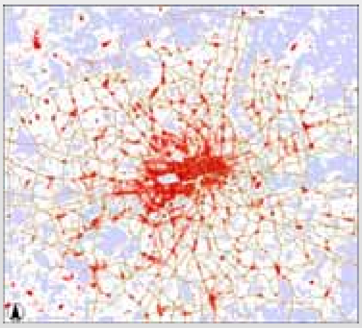
City Shapes at Different Scales: Modular Growth



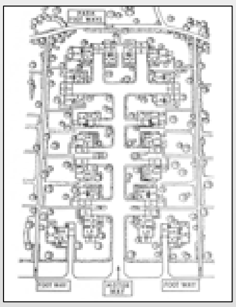


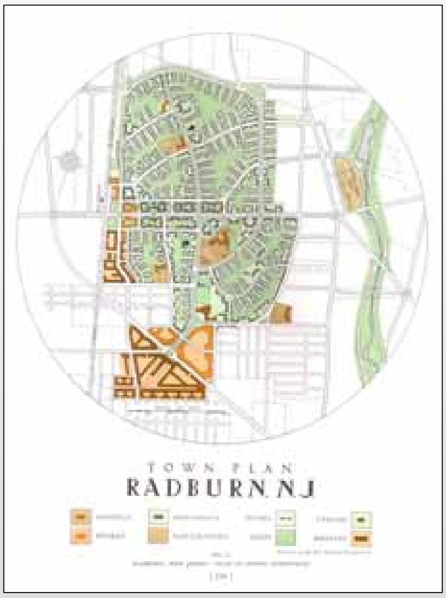


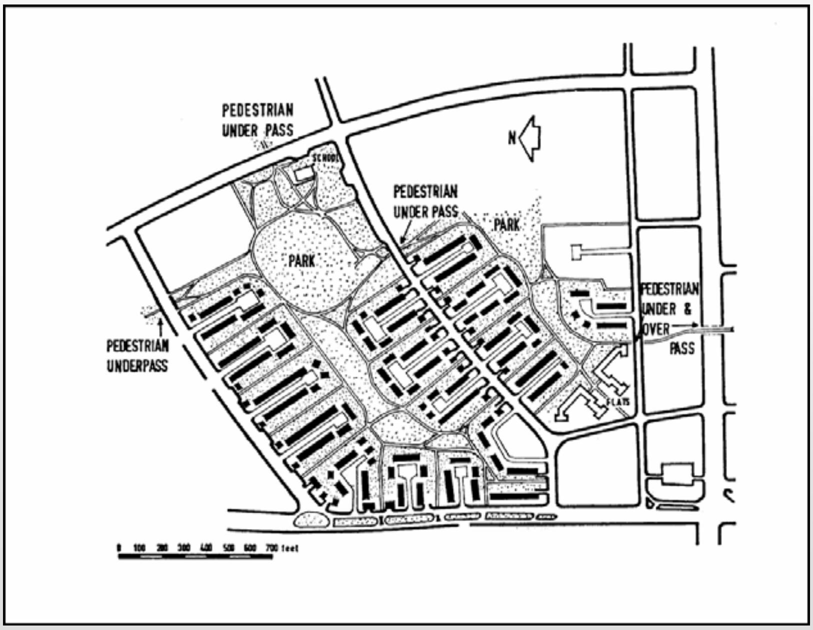


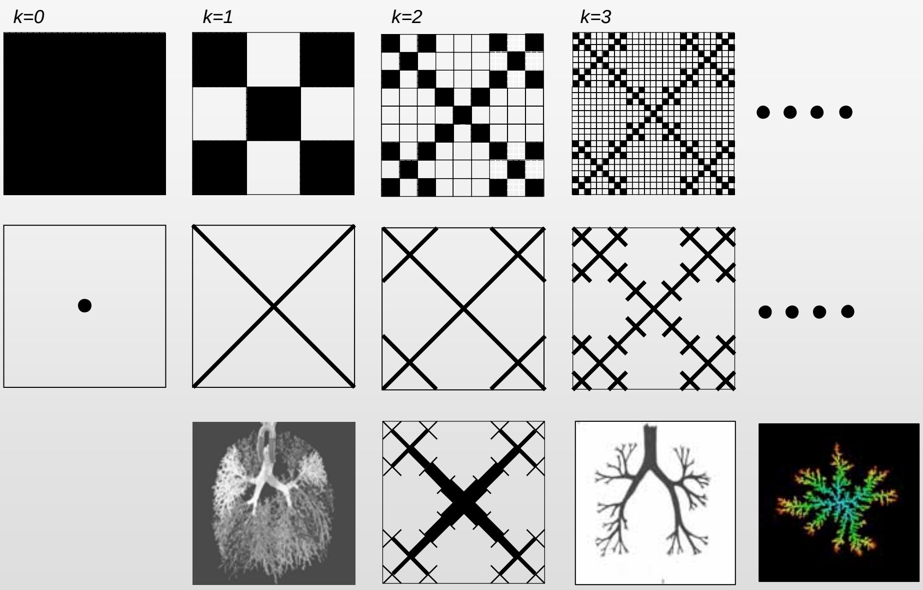


An early 'new town'
RADBURN, NJ
1920s









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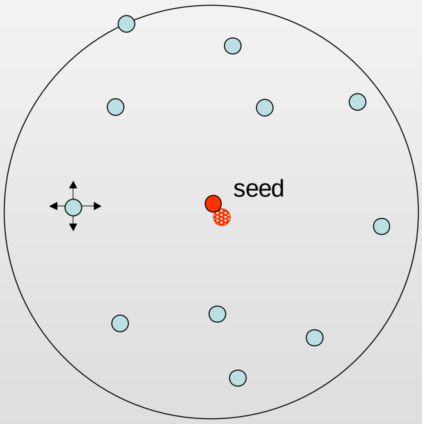
Fractal Growth Models: DLA

Ok, let me show you the simplest possible model of an organically growing city – based on two simple principles

- *A city is connected in that its units of development are physically adjacent*
- *Each unit of development wants as much space around it as it needs for its function.*

We start with a seed at the centre of a space and simply let actors or agents randomly walk in search of others who have settled. When they find someone, they stick. That is all.

In essence, this is random walk in space which is can be likened to the diffusion of particles ○ around a source ● but limited to remain within the influence of the source – the city



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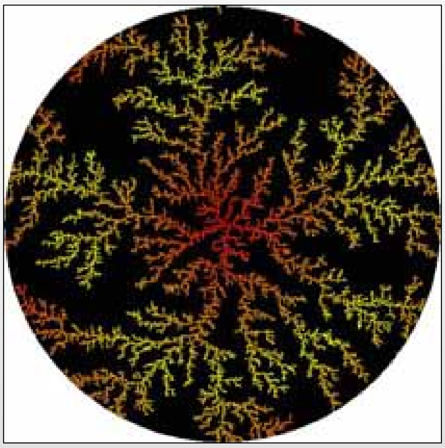

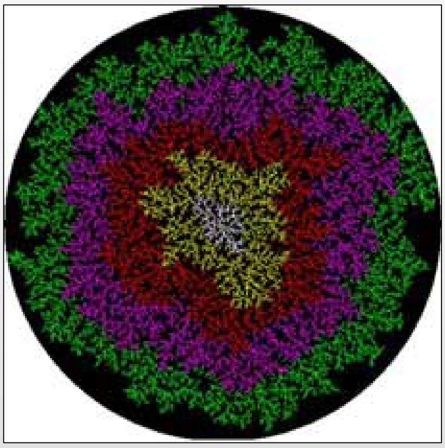

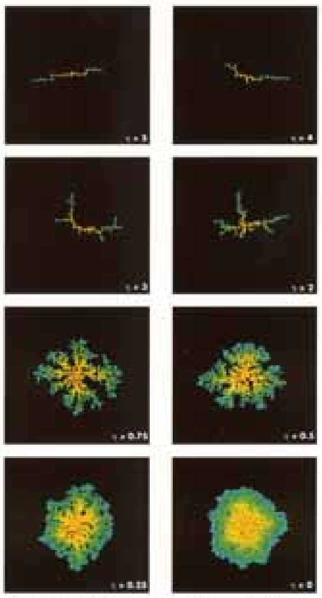

Plate 8.4 Urban Forms Generated by Systematic Distortions to the DBM Field

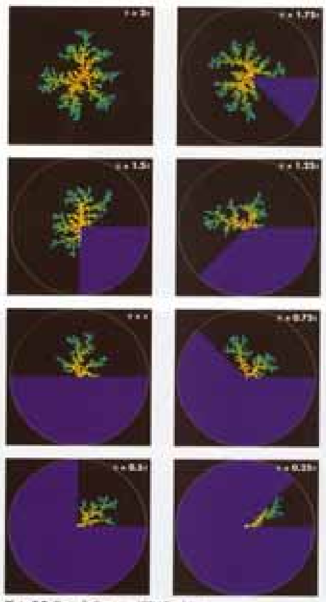

Plate 8.5 Physically Constrained DBM Simulations

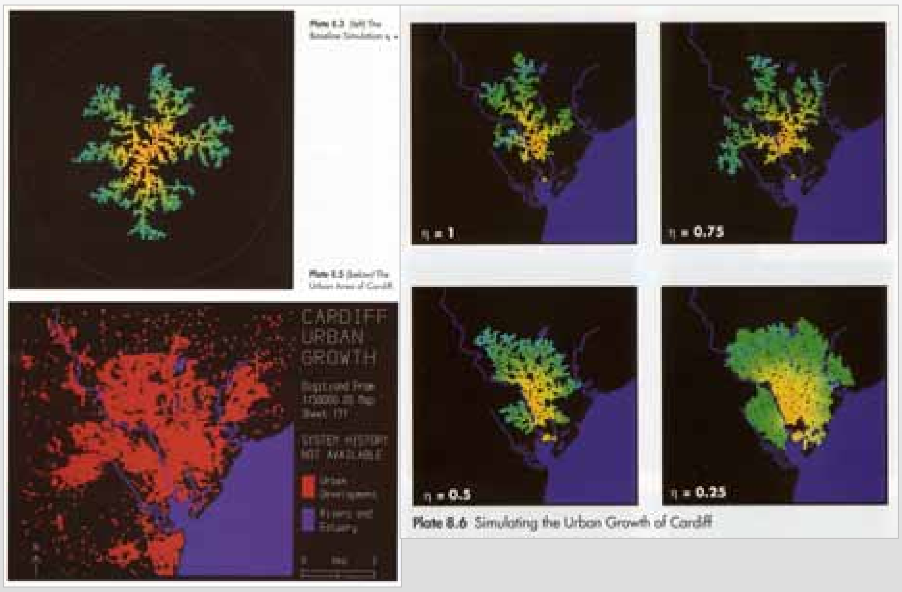

Plate 8.6 Simulating the Urban Growth of Cardiff

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Applications through Cellular Automata

To illustrate how CA works, we first define

- a grid of cells, (or it could be irregular but to simplify we will assume a square grid)
- a neighbourhood around each cell which is composed of the nearest cells,
- a set of rules as to how what happens in the neighbourhood affects the development of the cell in question
- a set of states that each cell can take on – i.e. developed or not developed
- an assumption of universality that all these features operate uniformly and universally

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This defines a (cellular) automata machine that can be applied to all cells that define the system: i.e. each cell is an automata

Some things to note: cells are irregular and not necessarily spatially adjacent.

Neighbourhoods can be wider then those which are formed from nearest neighbours- they could be formed as fields – like interaction fields around a cell

Strict CA are models whose rules work on neighbourhoods defined by nearest neighbours and exhibit emergence – i.e. their operation is local giving rise to global pattern

Cell-space models can relax some or all of these rules

This is how a CA works defined on a square grid of cells with two states – not developed and developed

(a)

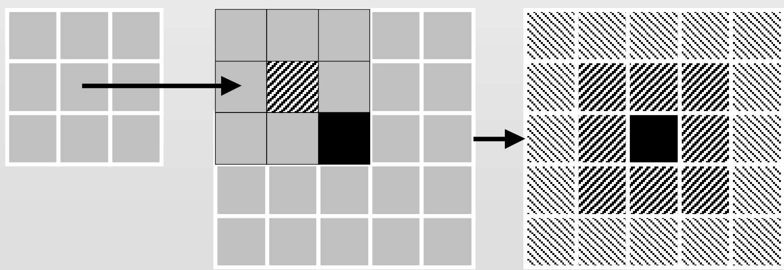
The neighbourhood is composed of 8 cells around the central cell

(b)

Place the neighbourhood over each cell on the grid. The ***rule*** says that if there is one or more cells developed (black) in the neighbourhood, then the cell is developed.

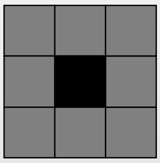
(c)

If you keep on doing this for every cell, you get the diffusion from the central cell shown below.

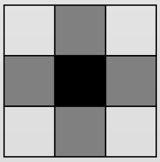


These are strictly deterministic CA models and we can have different shaped local neighbourhoods composed of different combinations of cells e.g.

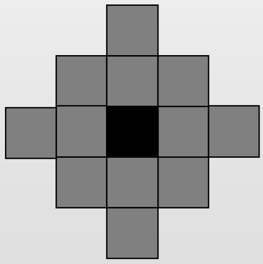
(a) Moore



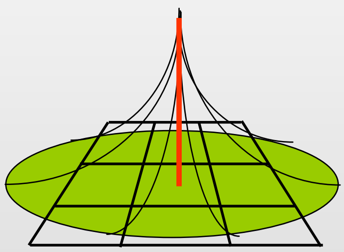
(b) von Neumann



(c) Extended Moore von Neumann



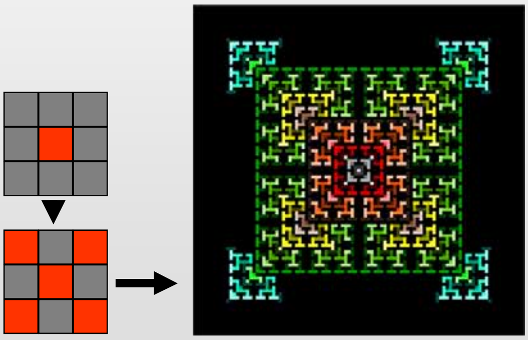
And we can have probabilistic fields defining neighbourhoods where there is a probability that a cells changes state – where the probabilities might vary regularly reflecting say action-at-a-distance principles e.g.



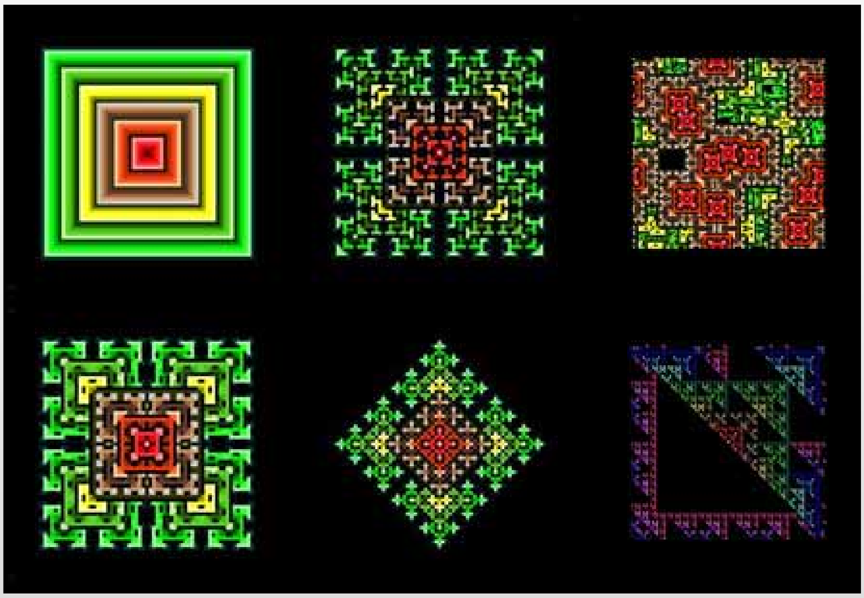
We will now show some examples of how one can generate idealised patterns that illustrate emergence

For example, for any cell {x,y},

- if only one neighborhood cell either NW, SE, NE, or SW other than {x,y} is already developed,
- then cell {x,y} is developed according to the following neighborhood switching rule

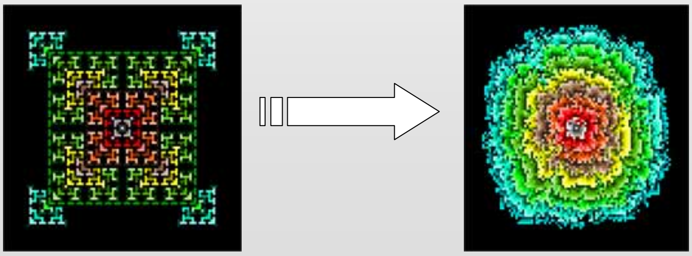


And changing There rules in various ways lead to many different patterns

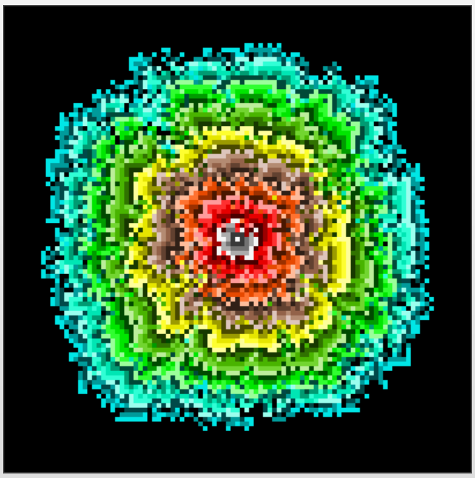


For probabilistic rules, we can generate statistically self-similar structures which look more like real city morphologies. For example,

if any neighborhood cell other than {x,y} is already developed, **then** the field value p {x,y} is set **&**
if p {x,y} > some threshold value, **then** the cell {x,y} is developed



Here are the constructions we have seen overlayed so you can see how neighbourhood rules make a distinct difference



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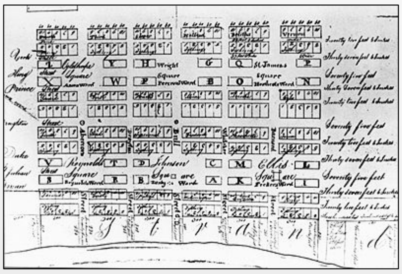
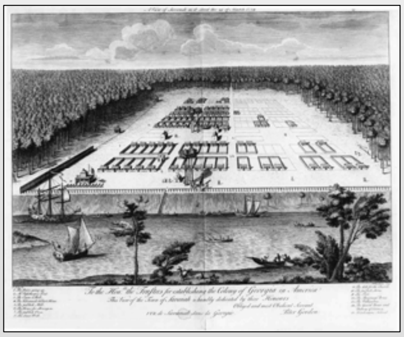
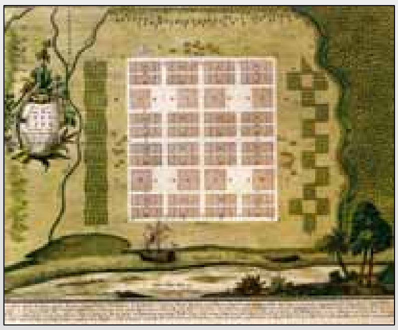
Different Model Applications

At least 12 groups around the world, probably more developing these kinds of model

- *White and Engelen, RIKS, Holland – **GeoDynamica, METROnamica***
- *Clarke, UCSB/NCGIA, USA – **SLEUTH***
- *Yeh and Li, Hong Kong – Pearl River – RS bias*
- *Wu/Webster – Southampton/Cardiff – urban economics*
- *Xie/Batty – Ypsilanti/London, US/UK – **DUEM***
- *Cechinni/Viola – Venice, Italy – AUGH*
- *Rabino/Lombardi – Milan/Turin, Italy – NN Calibration*
- *Semboloni – Florence, Italy – links to traditional LU models*
- *Phin/Murray – Brisbane/Adelaide, Aus – visualization*
- *Portugali/Benenson – Tel-Aviv, Israel – **CITY** models*
- *Various applications in INPE (Brazil), China (Beijing), Japan, Portugal, Taiwan, Canada, Haifa (Technion), Ascona, France (Pumain's group), Louvain-la-Neuve, Netherlands (ITC), JRC (Ispra+Dublin+RIKS), even at CASA Kiril Stanilov's model*

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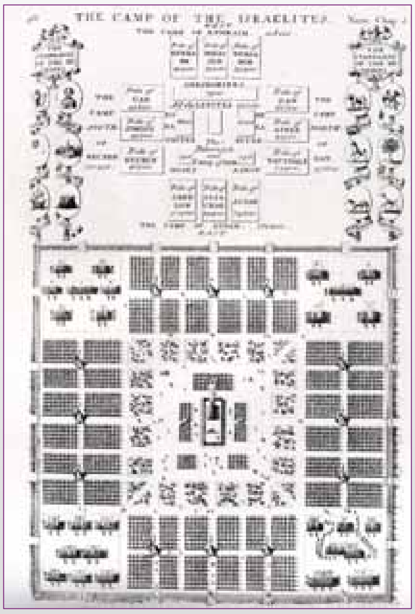

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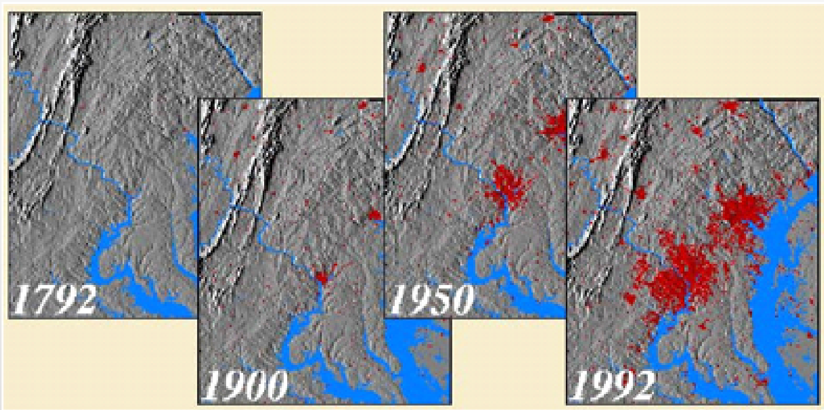
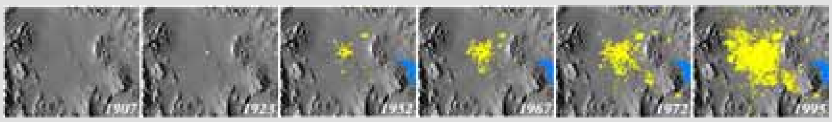
Applications through Cellular Automata





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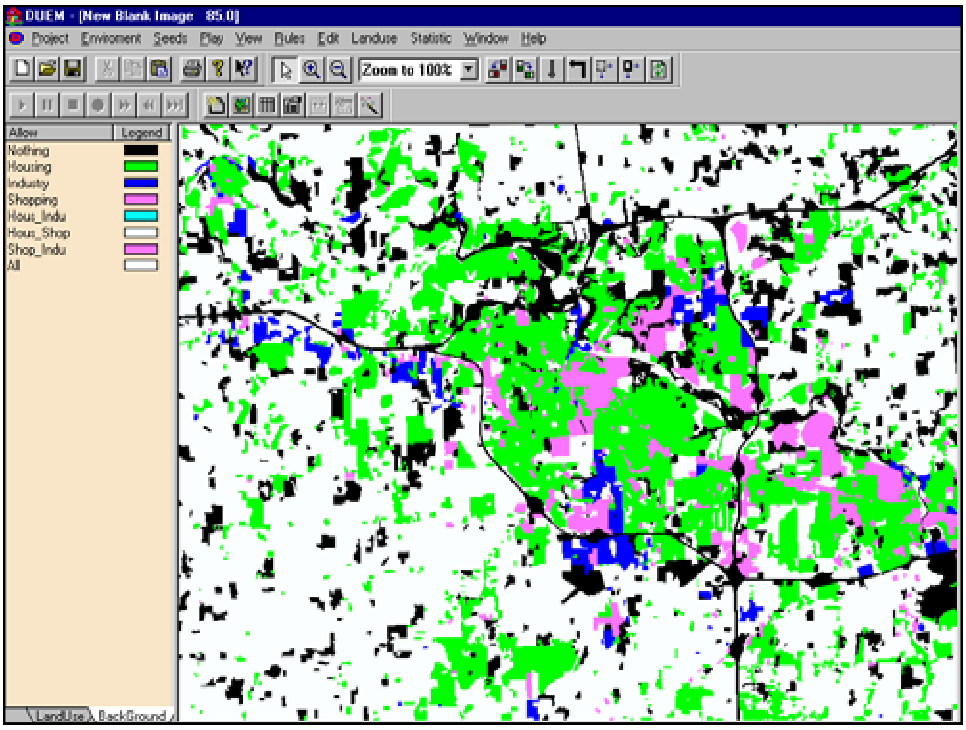
DUEM - [New Blank Image 85.0]
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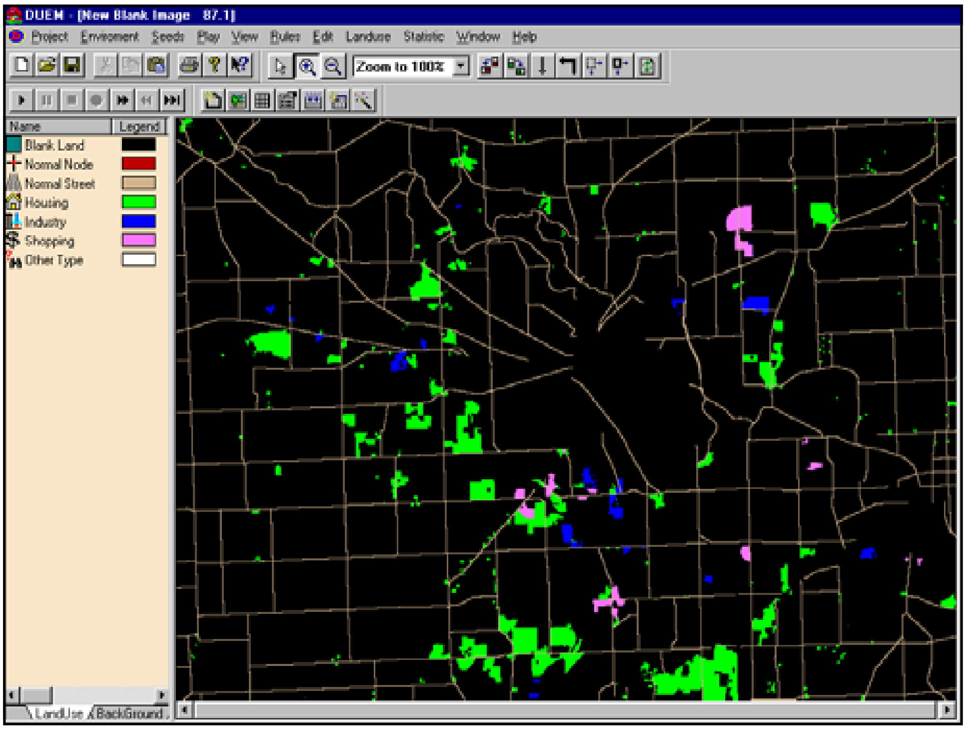
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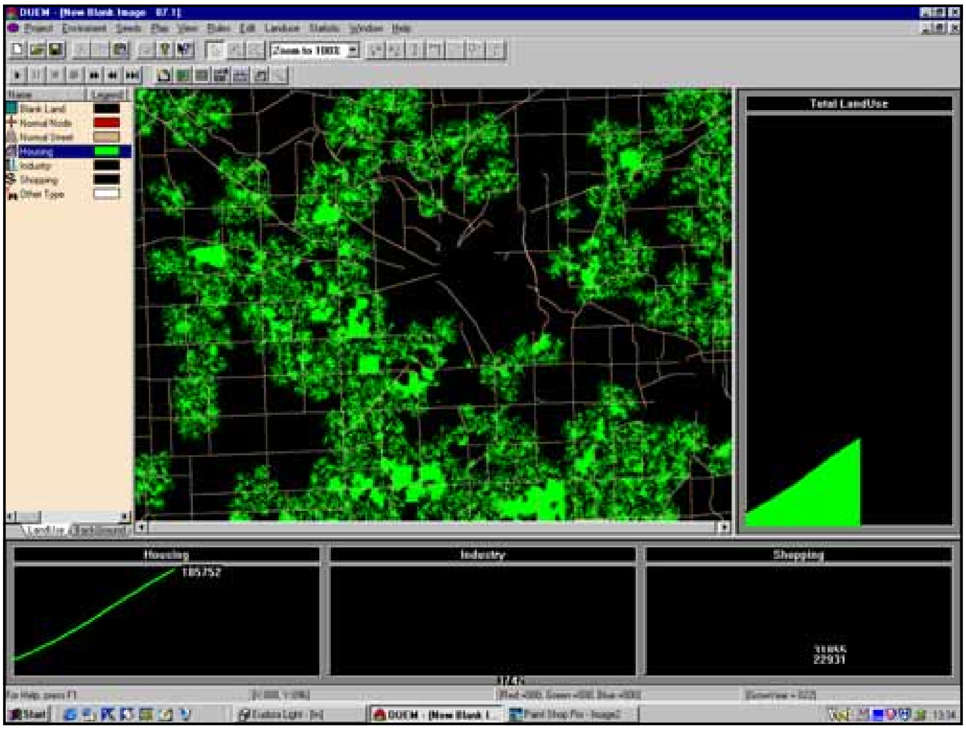

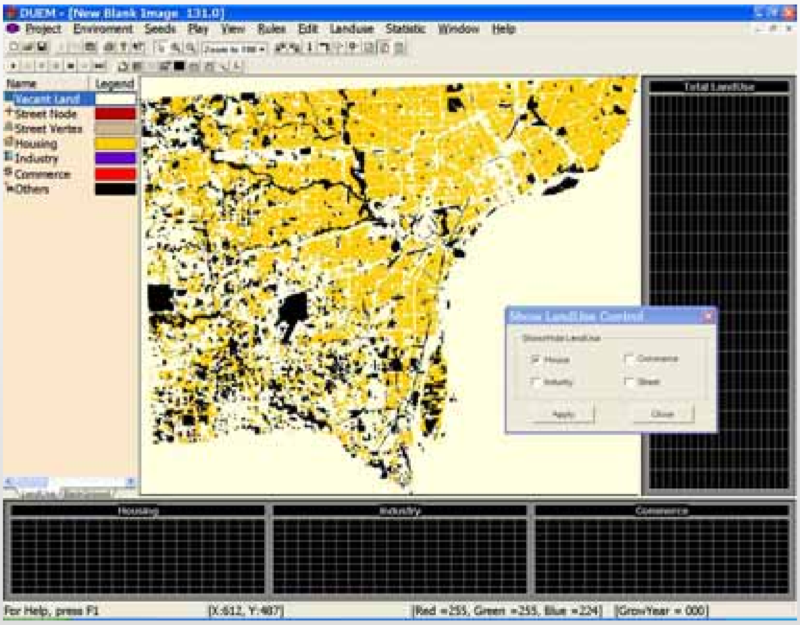

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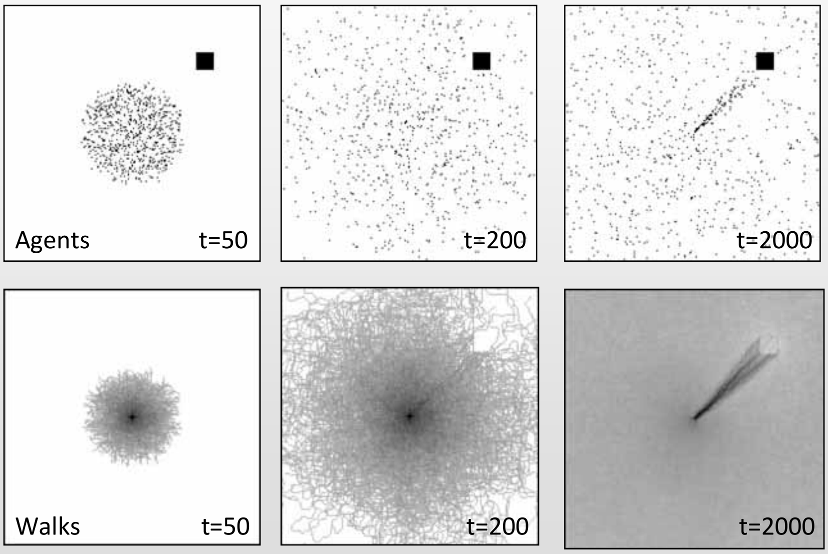
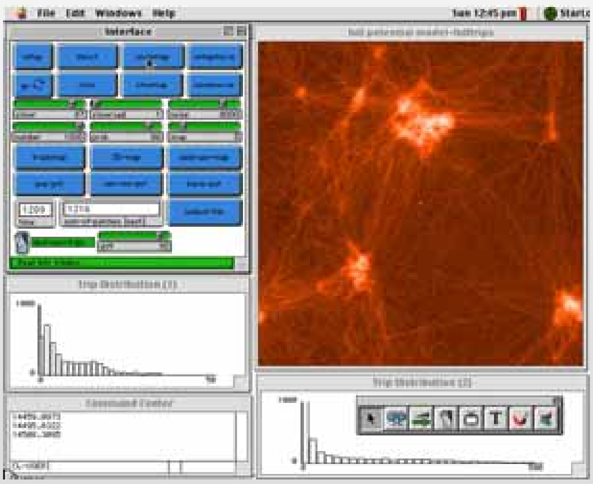
Moving to Agents in the Cellular Landscape



A Typical Visual Interface for simple Agent-Based Models



How Do We Use this in Designing Better Cities?

Let us look at some idealised city forms and see if we can figure out the modular rules that lead to their design

In fact it is surprisingly easy to figure out some of these rules as architects and planners – even the great one, especially the great ones – use pattern books to cast their designs. Let us look at Garden Cities which are the basis of the British new towns.

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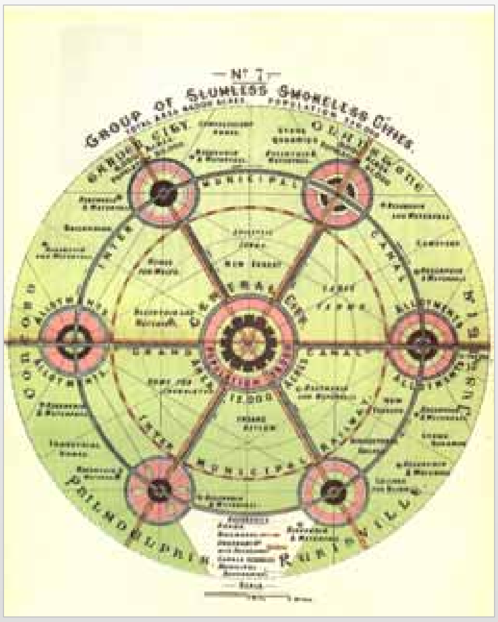

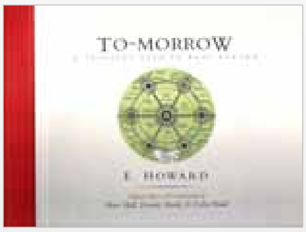

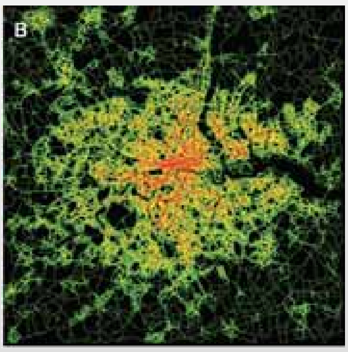

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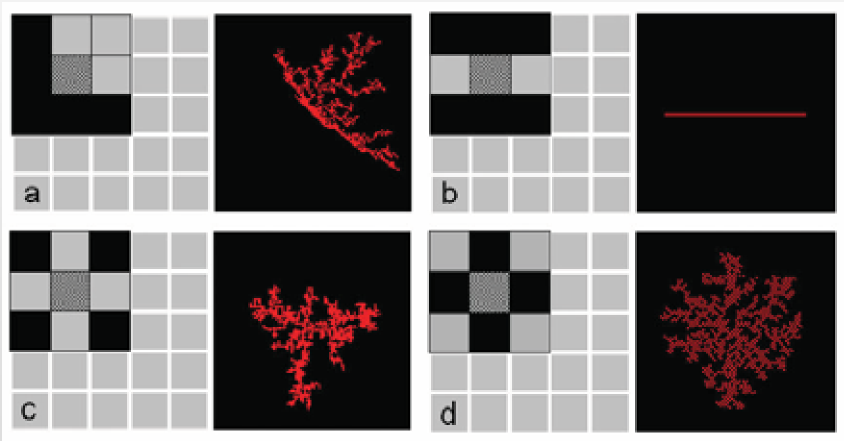
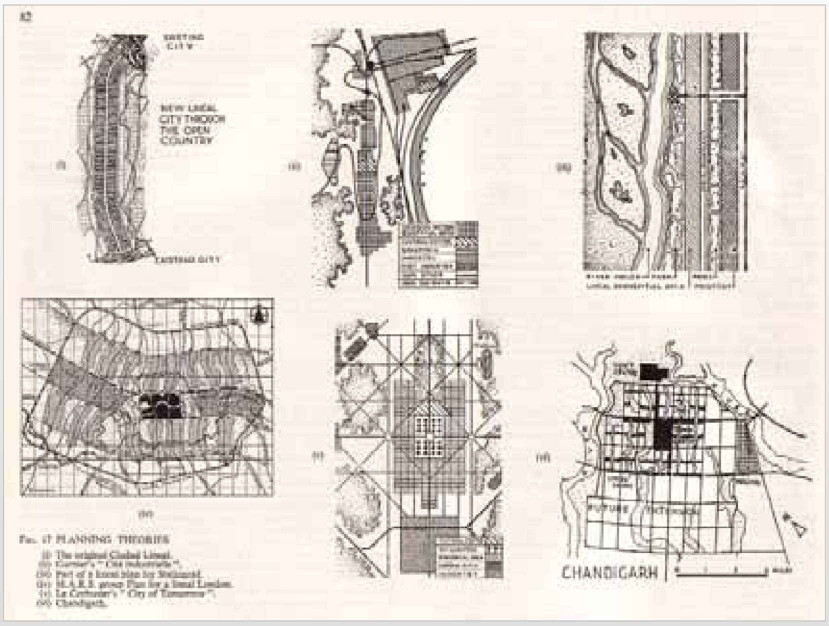
We can steer the development in different ways by constructing rules based on 'ruling' out or 'admitting' certain cells for development – embodying constraints





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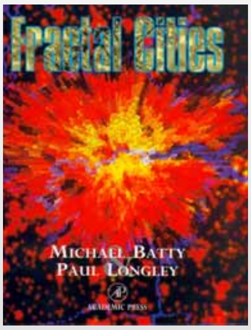
Broadacre City

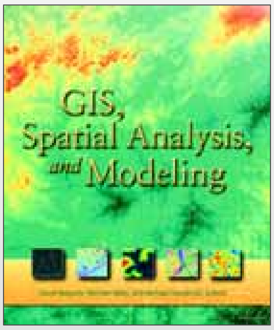
Frank Lloyd Wright, 1934

A square mile section of what was proposed to be a continuous fabric of inhabited landscape across the American continent

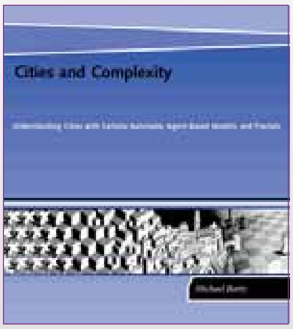
My book **Fractal Cities** with Paul Longley is online at www.fractalcities.org. And you can download it



Fractal Cities
(Academic Press, 1994)



GIS,Spatial Analysis & Modelling
(ESRI Press, 2005)



Cities & Complexity
(MIT Press, 2005)


Questions,
Discussion?
www.casa.ucl.ac.uk/WSA-fractals.ppt
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