

*Lecture 5*

**Urban Development:  
Cellular Automata and ABM**

<http://www.casa.ucl.ac.uk/ASU/>

# Outline

- Types of Urban Models Again
- The Cellular Automata Approach: Urban Growth and Complexity Theory
- The Structure of CA: Representation and Rules
- Different Model Applications
- The DUEM Model: Software and Applications
- Links to Urban Morphology
- Links to Agent-Based Models
- The Last Lecture: References

## Types of Urban Models Again

**Land Use Transportation Models** – *LUTI/LUTM* dealing with location and interaction, transport and the urban economy, represented at a level of abstraction involving administrative rather than physical subdivisions of the city: generally cross sectional, comparative static. Top down.

**Cellular Automata Models (CA)** dealing with urban growth sprawl, land development and land cover, represented at finer spatial scales defined by or detecting physical morphology, do not deal with explicit transportation; dynamic in time. Bottom up.

**Microsimulation** – demographic and related rule based processes, individual-based, dynamic, non spatial. Bottom up in intent, Top down in conception

**Land Cover Models (LUCC)** which simulate vegetation cover, ecosystem properties, agriculture, as well as some urban.

**Agent-Based Models (ABM-MAS)** – a generic style of representation for individual-based dynamics processes, such as movement of individuals and objects

These classifications mix the substance of what is being modelled with methods for modelling: microsimulation, CA and ABM are methods, LUTI and LUCC are models of specific systems

# The Cellular Automata Approach: Urban Growth and Complexity Theory

Essentially CA models developed in the late 1980s early 1990s from at least three sources: bottom up thinking about systems in contrast to top down, concepts of emergence in particular related to morphology, GIS and raster based representation of activity layers

To an extent, CA represented a simple logic of building such models – first models built by geographers such as Waldo Tobler in the 1970s and 1980s but first urban models by myself, White and Engelen, and Clarke in the early 1990s.

These models have found favour in rapidly growing systems which are characterised by urban sprawl, like Phoenix. They have been quite inappropriately applied to non-rapid growth cities where the focus is on redistribution. They are clearly not as widely applicable to urban systems as LUTI models.

They have not been widely applied by municipalities as they do not contain explicit mechanisms for generating numerical forecasts that are demographically or economically based.

Where they have been applied, they have been nested within wider schemes which involve coupling to LUTI, demographic and other models.

# The Structure of CA: Representation and Rules

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

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 may be irregular and not necessarily spatially adjacent.

Neighbourhoods can be wider than 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

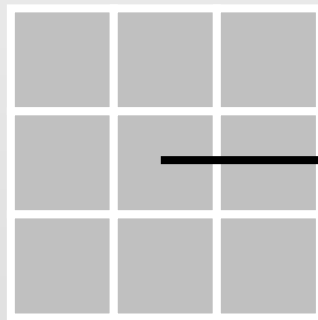
Cell-space models can relax some or all of these rules



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

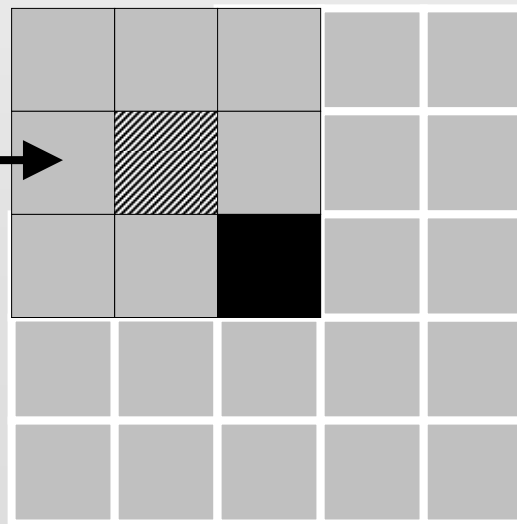
(a)

The neighbourhood is composed of 8 cells around the central cell



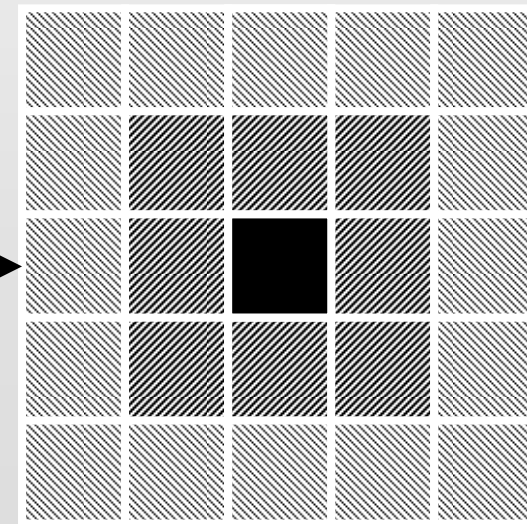
(b)

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.



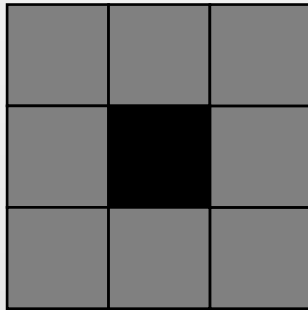
(c)

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

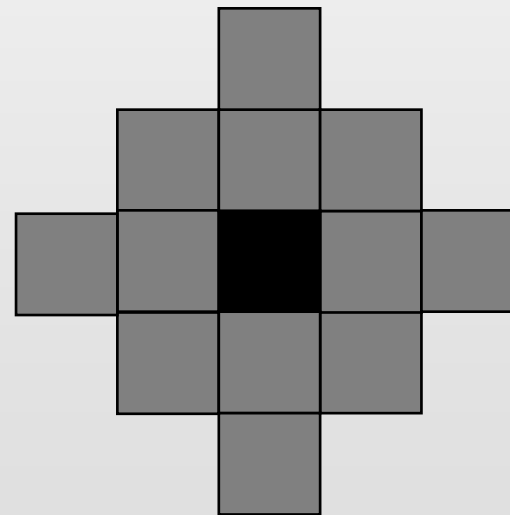


These are strictly deterministic CA models and we can have different shaped local neighbourhoods composed of different combinations of cells e.g.

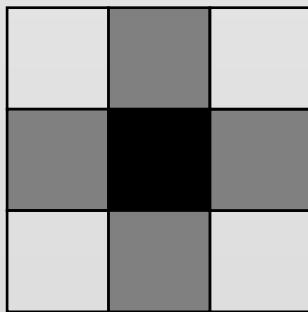
(a) Moore



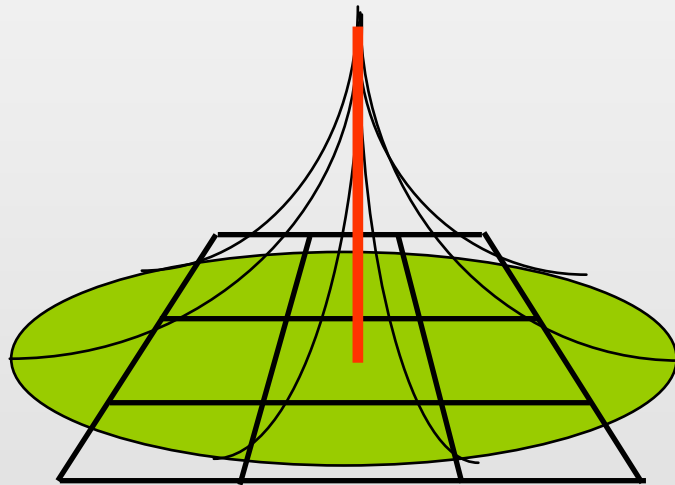
(c) Extended Moore  
von Neumann



(b) von Neumann



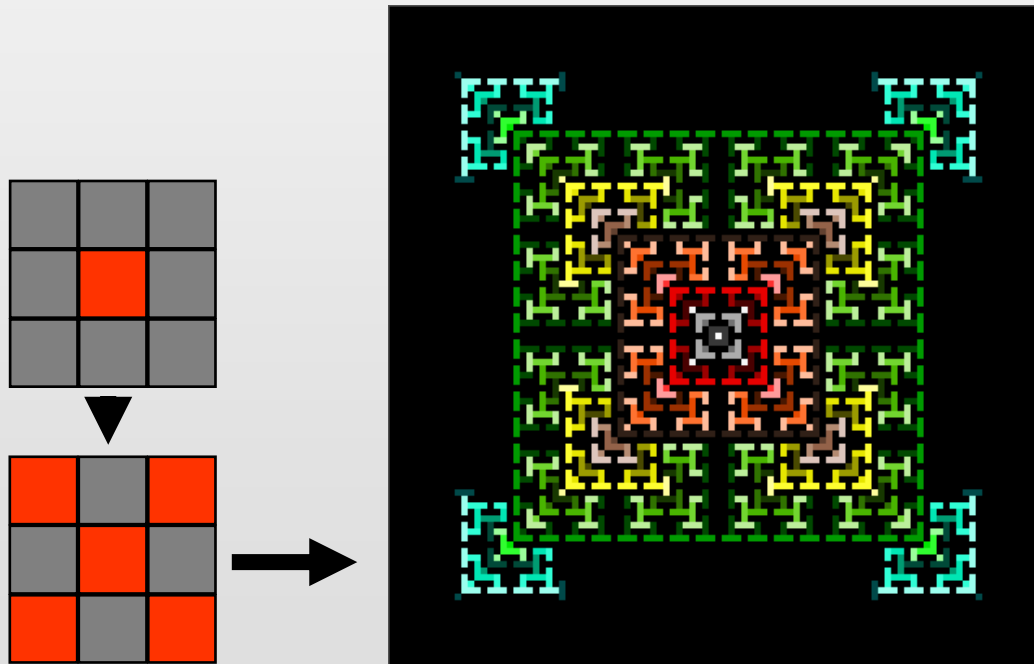
And we can have probabilistic fields defining neighbourhoods where there is a probability that a cell changes state – where the probabilities might vary regularly reflecting say action-at-a-distance principles e.g.



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

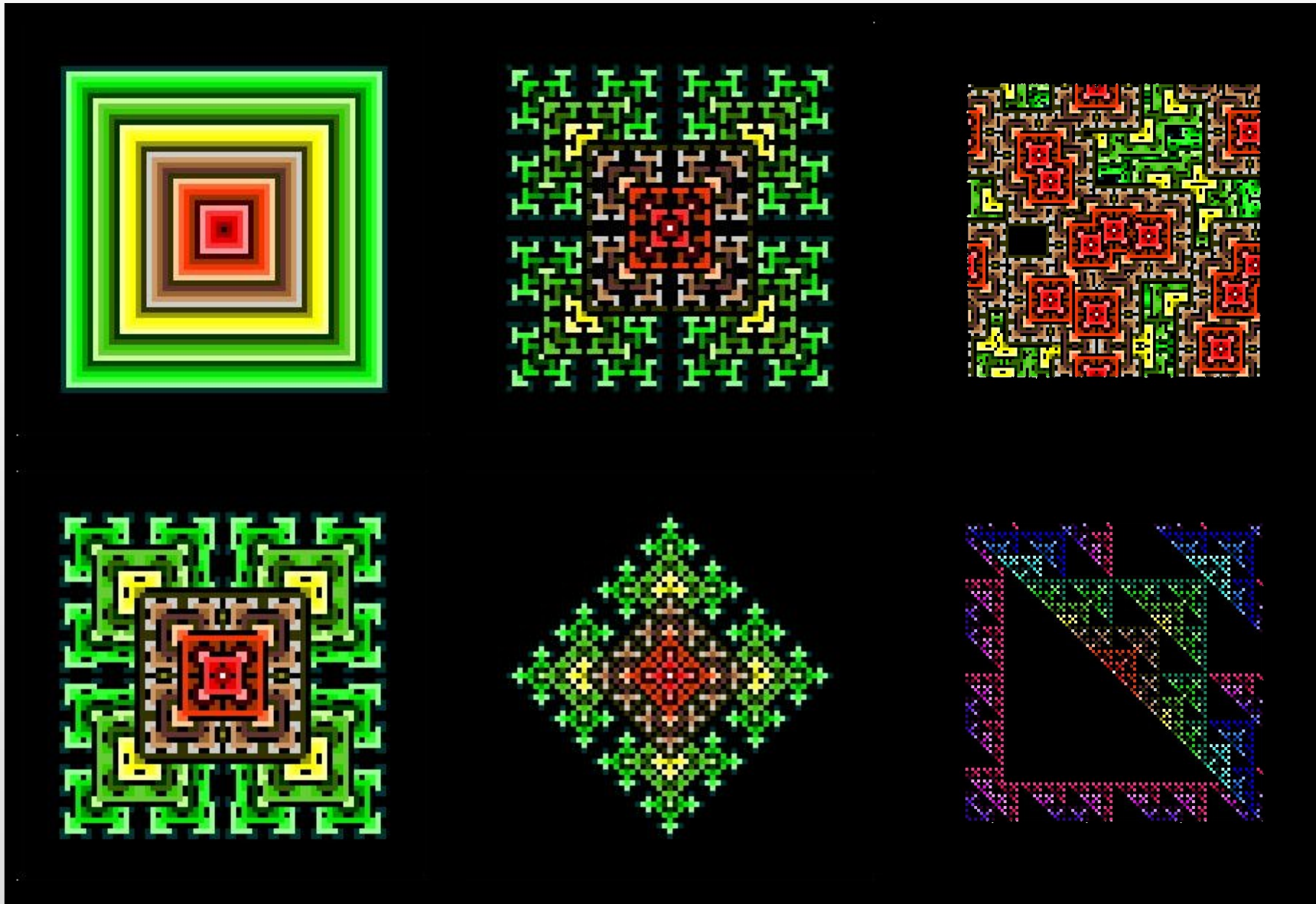
For example, for any cell  $\{x,y\}$  in the neighborhood,

- if any neighborhood cell other than  $\{x,y\}$  is already developed,
- then cell  $\{x,y\}$  is developed according to the following neighborhood switching rule



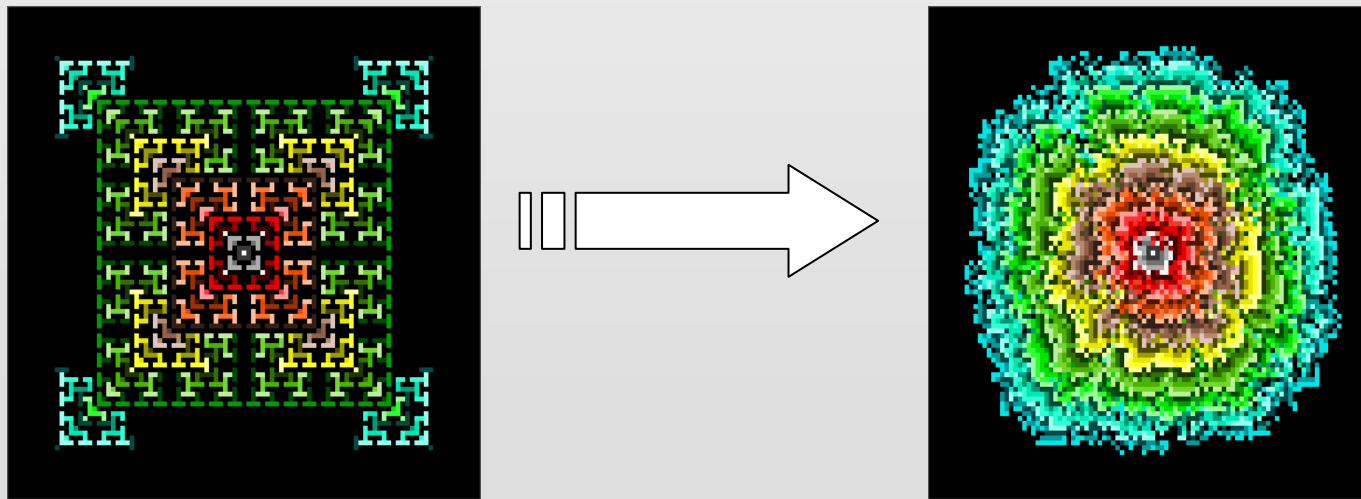
And 

This leads to

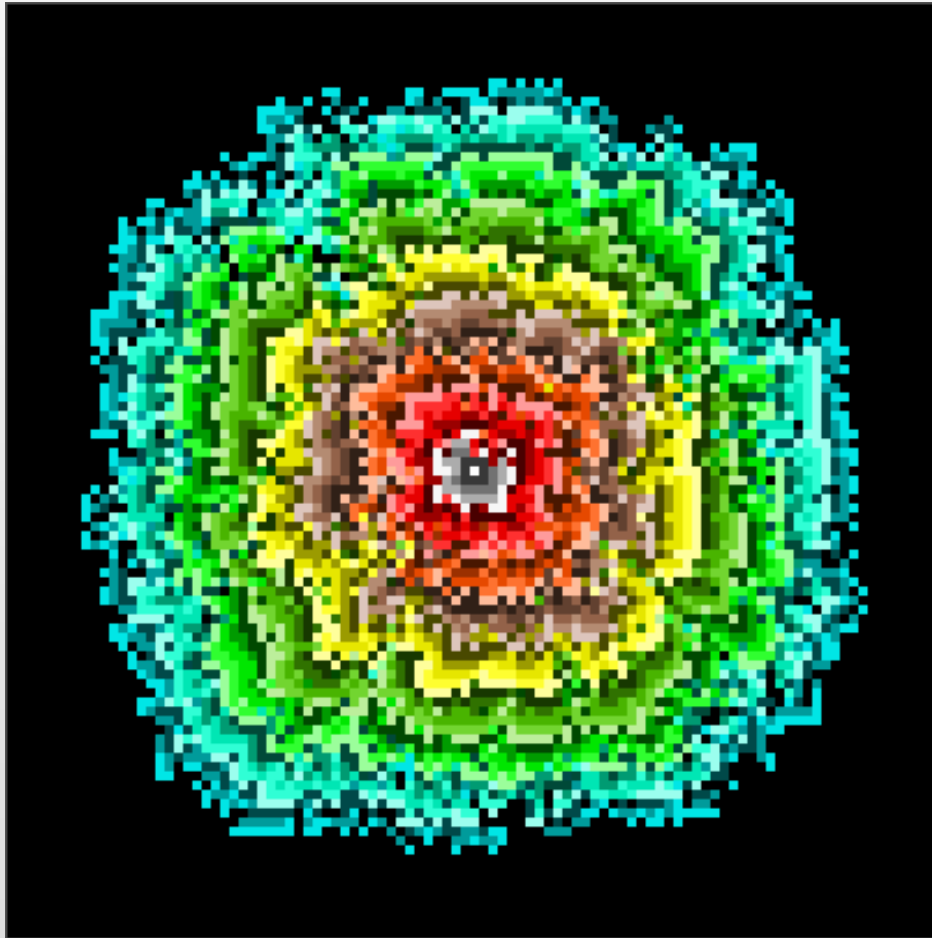


For probabilistic rules, we can generate statistically self-similar structures which look more like real city morphologies. For example,

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 overlaid so you can see how neighbourhood rules make a distinct difference



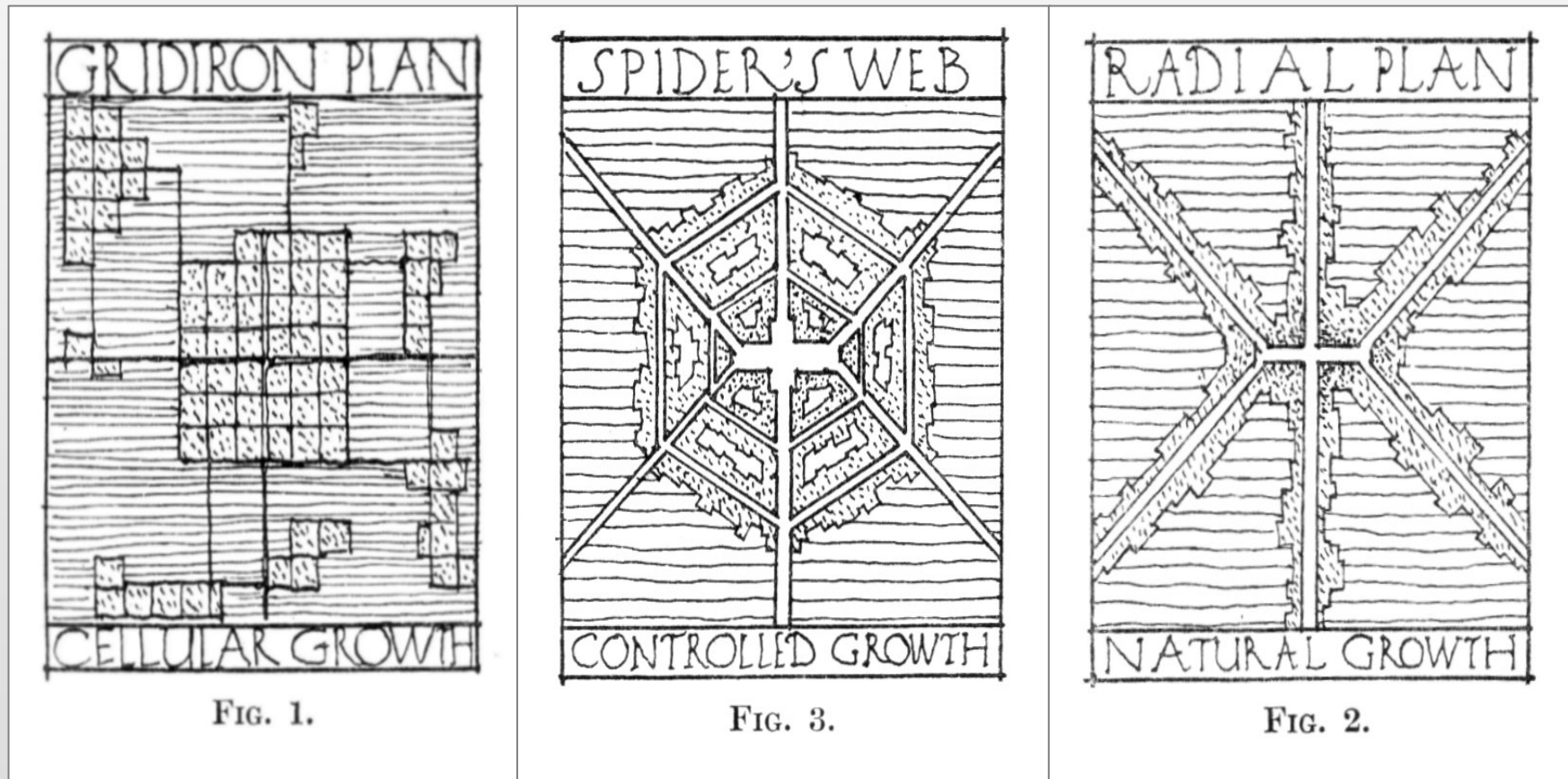
# Different Model Applications

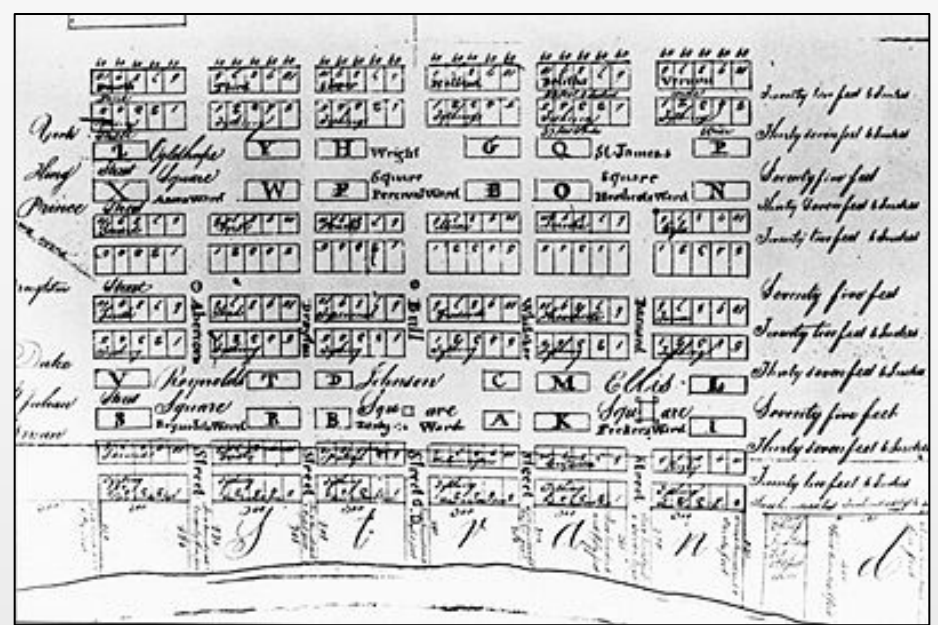
At least 12 groups around the world, probably more now  
developing these kinds of model

- *White and Engelen, RIKS, Holland – **GeoDynamica, METRODynamica***
- *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*

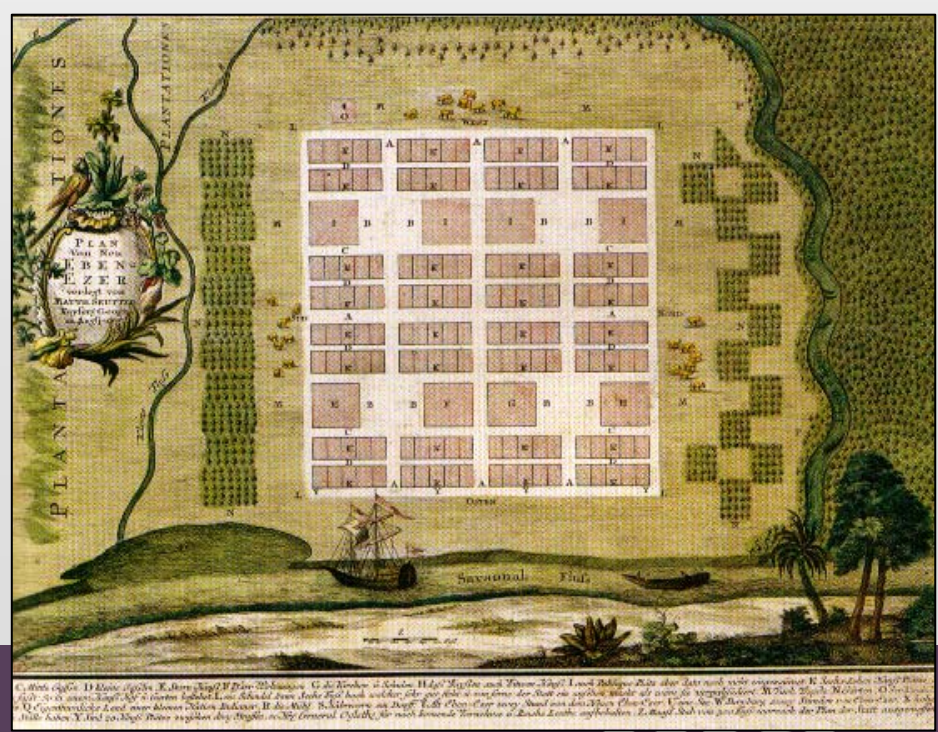
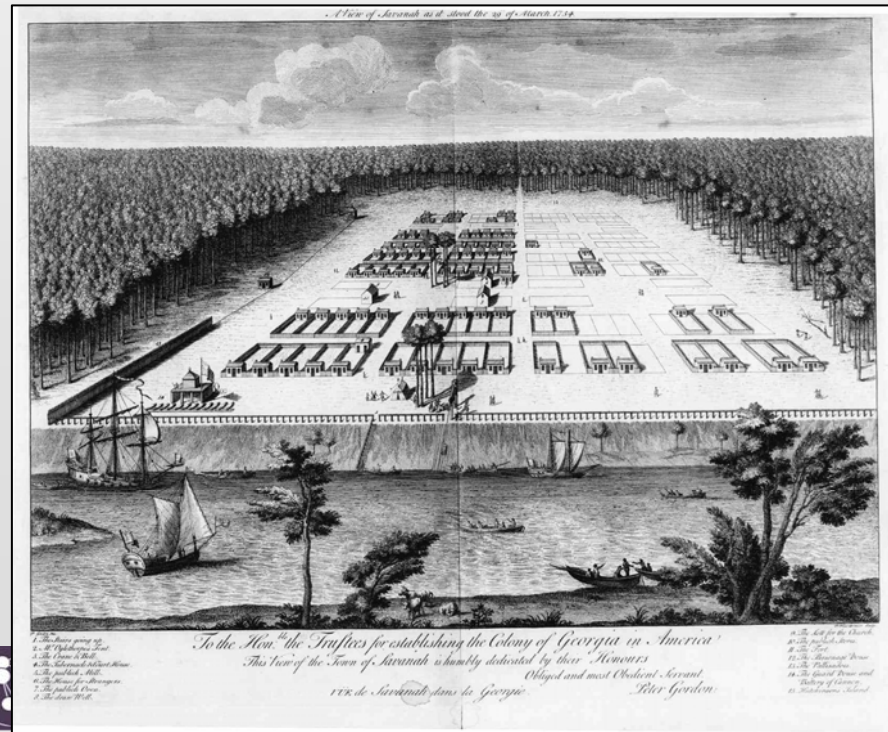


# Historical Examples – from Abercrombie's book **Town and Country Planning** (1935)





A View of Savannah as it stood the 20 of March 1734



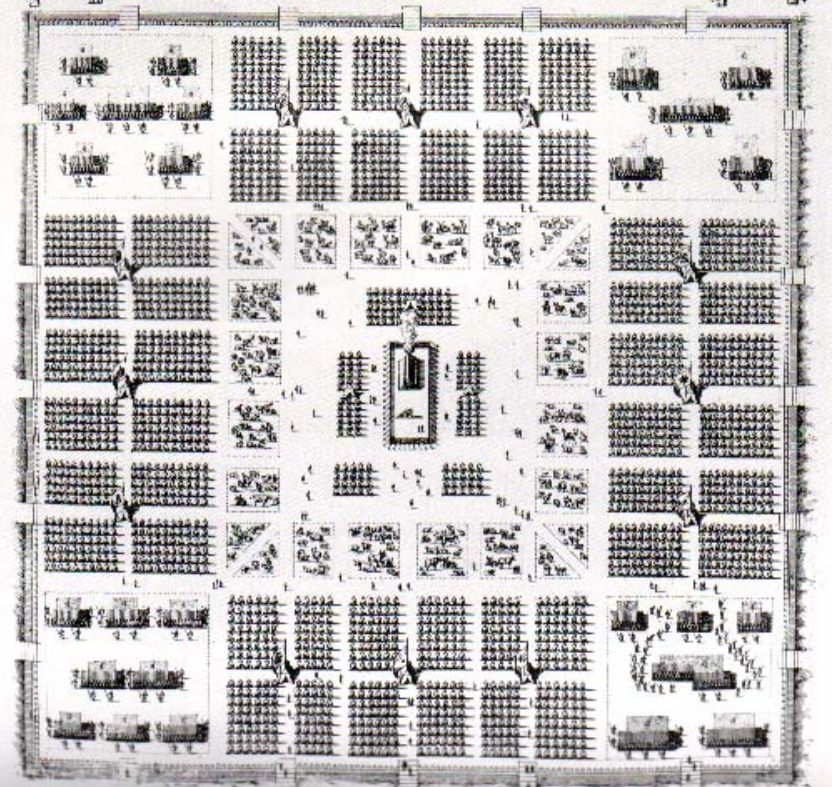
# THE CAMP OF THE ISRAELITES.

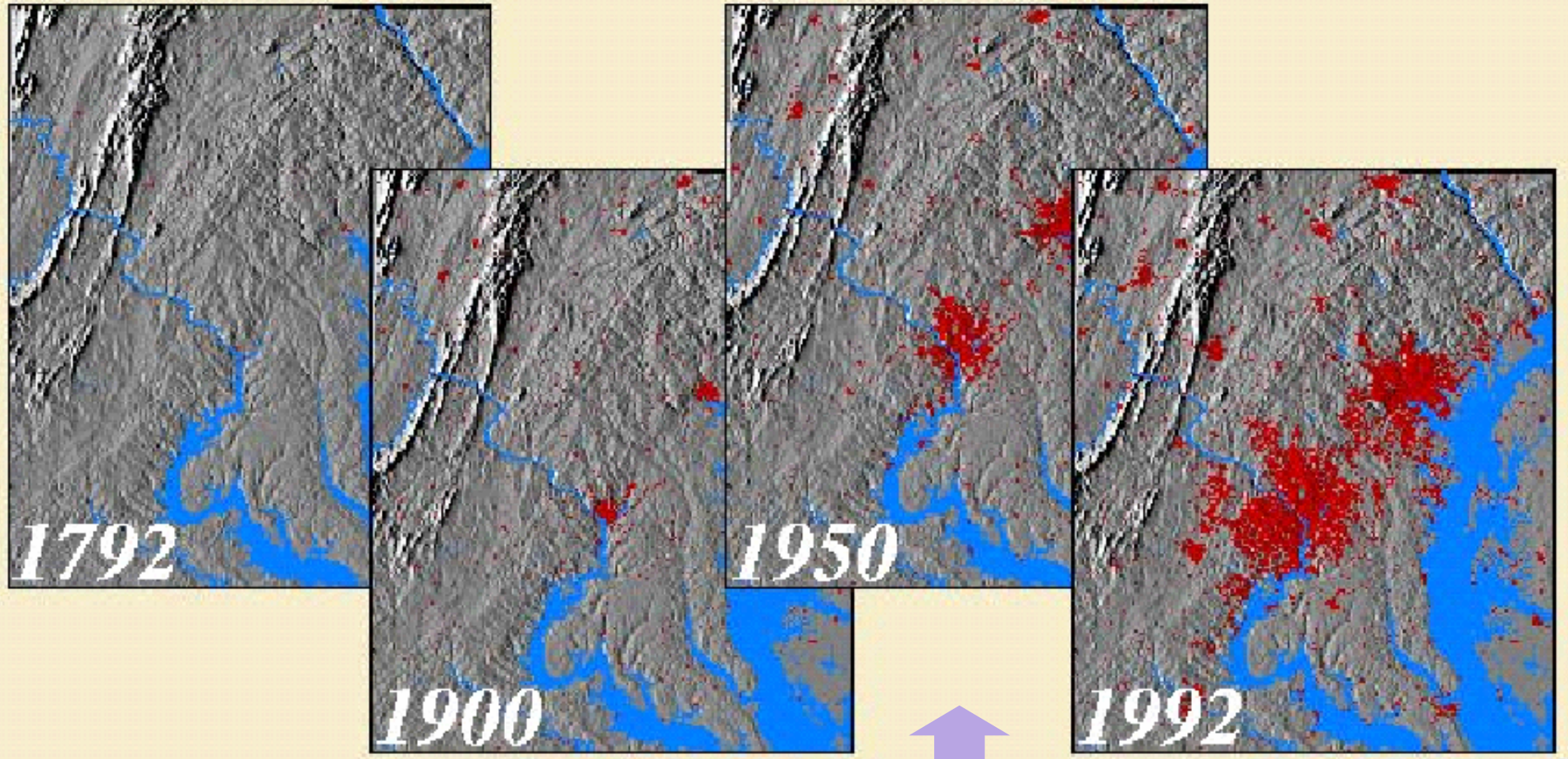
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WEST.

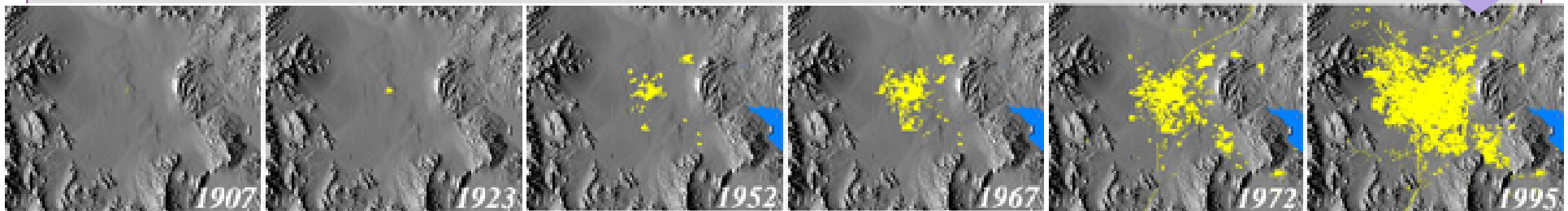
THE CAMP OF EPHRAIM. 108100.			
Tribe of EPHRAIM 40500.	Tribe of MANASSEH 32300.	Tribe of BENJAMIN 35400.	
GERSHONITES. 7500.			
All the LEVITES 22000.			
Tribe of GAD 45650.		Tribe of DAN 62700.	
Tribe of SIMON 59300.		Tribe of ASHER 41500.	
Tribe of REUBEN 151450.		Tribe of NAPHTALI 157600.	
THE CAMP OF JUDAH. 126400.			
Tribe of ZEBULON 57400.	Tribe of ISSACHAR 54400.	Tribe of JUDAH 74600.	

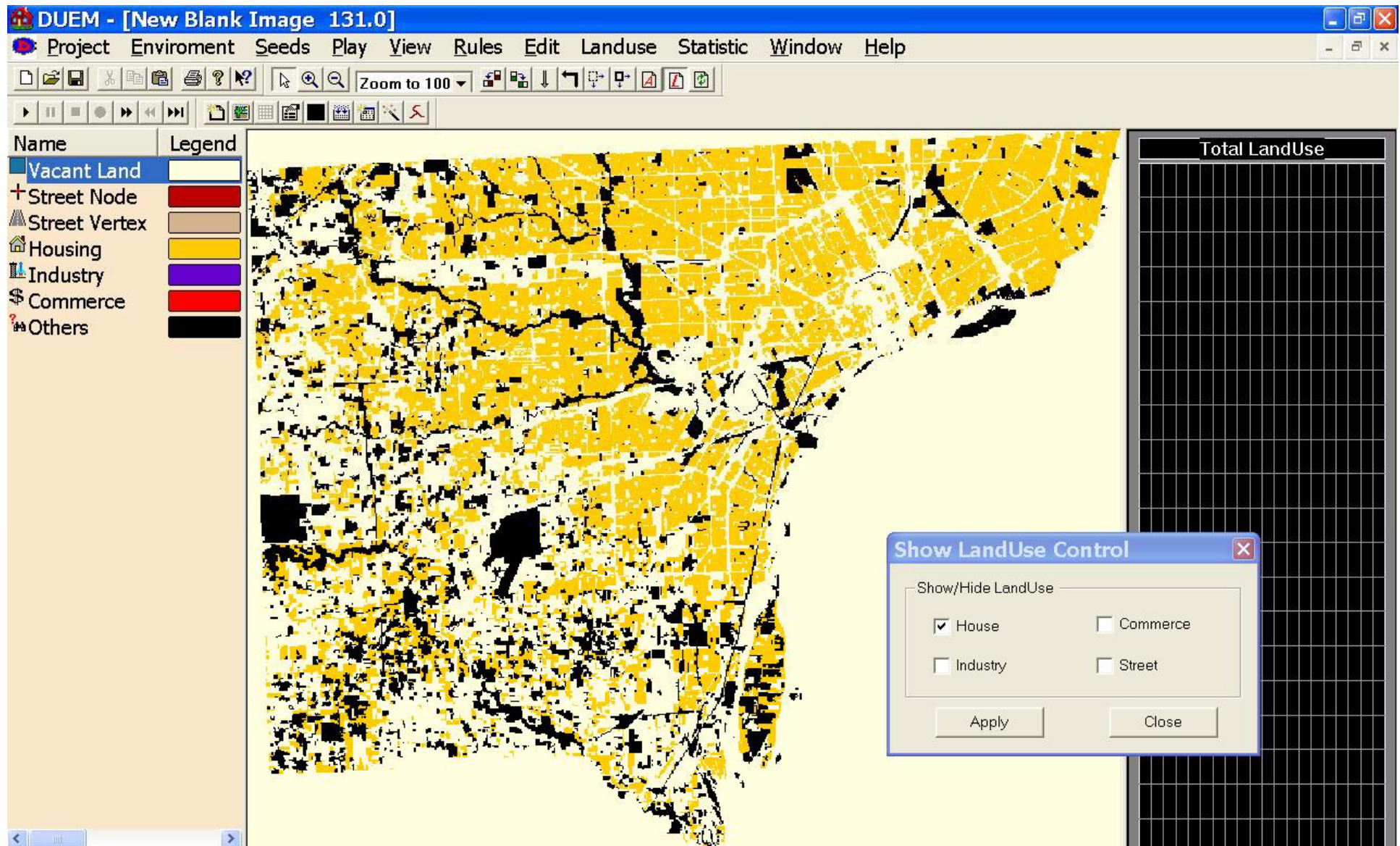
EAST.





Growth through time: Washington DC-Baltimore Las Vegas





You can download this software from our web site at <http://www.casa.ucl.ac.uk/>

# The DUEM Model: Software and Applications

Now I can demonstrate this model which has been applied to the Detroit region. It is downloadable from our web site at <http://www.casa.ucl.ac.uk/software/duem.asp>

The screenshot shows a Windows Internet Explorer browser window displaying the UCL Centre for Advanced Spatial Analysis website. The page title is "The DUEM Cellular Automata". The main content area contains text describing the model, its development by Yichun Xie, and its application to the Detroit region. There are three screenshots of the DUEM software interface showing different stages of simulation. The left sidebar contains a navigation menu with categories like ABOUT, EVENTS, PEOPLE, BLOGS, WEBSITES, PUBLICATIONS, RESEARCH, MOVIES, and SOFTWARE. The bottom of the browser window shows the Windows taskbar with various open applications.

UCL Centre for Advanced Spatial Analysis - Windows Internet Explorer  
http://www.casa.ucl.ac.uk/software/duem.asp

Search CASA's site

## The DUEM Cellular Automata

Yichun Xie who is the Director of The Institute for Geospatial Research & Education (IGRE) at Eastern Michigan University developed this software in the late 1990s. The model is based on his PhD thesis work at the NCGIA at SUNY-Buffalo. He worked on this with Michael Batty and Zhanli Sun who wrote the program. DUEM means Dynamic Urban Evolutionary Modelling and is based on the cellular automata approach to urban modelling. You can download a paper here about the model and this software and there is also material in the Michael Batty's book *Cities and Complexity*.

This software enables the user to run a variety of different cellular automata on a 2-D landscape that they can populate and constrain in various ways. First off the software lets the user open a blank canvas of up to dimension 3000 x 3000 but ideally users should keep it smaller to something like 300 x 300. One can also import a raster backdrop from various files. There are some five land uses that are simulated - housing, industry, commercial, vacant, and streets (with street nodes that are necessary for streets to develop). There are a whole range of default rules that you can access by clicking on the land use legend to change the influence of a land use on its neighbours, in neighbourhoods of varying sizes, life cycle effects that simulate how land uses affect other land uses dependent on how old they are, directionality of influence of a land use on the 2-D grid, and the decay of influence according to different distance functions.

The easiest way to begin is to populate the landscape with a set of randomly located land uses and then simply watch the system grow. As the system is capacitated, then it will grow logistically but because there are various leads and lags it will cycle around upper limits. One of the key features of the software is that it lets the user figure out whether or not the long term dynamics is feasible given the local default rules. Of course rules can be changed at the start or on the fly. There are many possibilities and one nice feature is that it lets user explore small cellular systems of say 20 cells by 20 so that these insights can be developed manageably. The screen shots on the right and below show how the populations and land uses grow to capacity and then cycle and how the distribution of land uses changes dynamically through time.

Click to download the software in a zip file

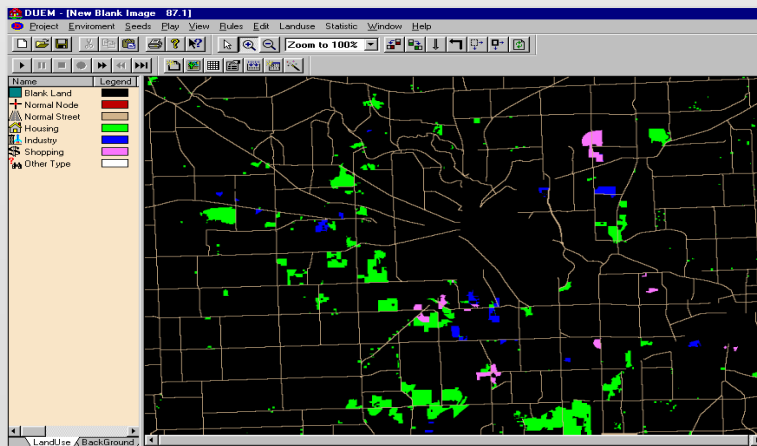
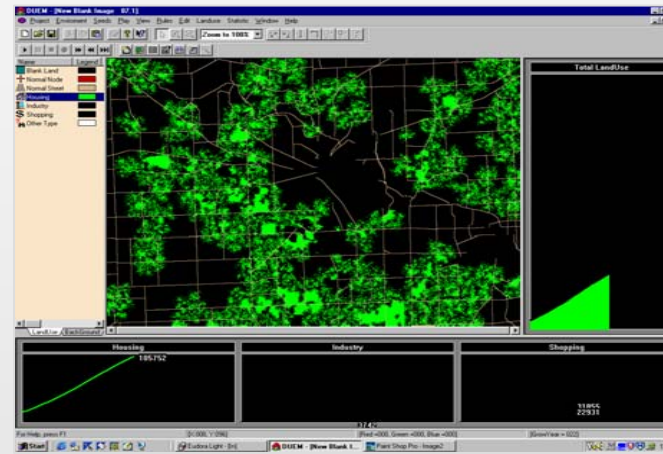
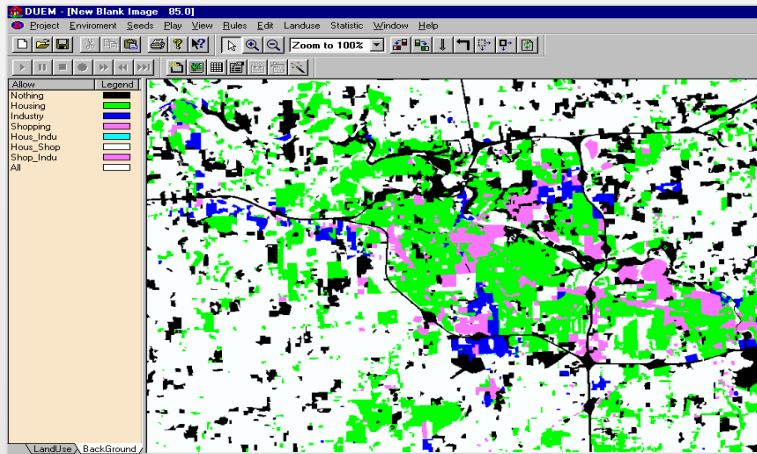
Click to download a PDF about the model by Yichun Xie

The model can be applied to real systems but there are so many options, that as yet we have not developed a full manual for this. To find out more about how it might be applied to a real system, then please email Dr. Xie. It has been applied in the Detroit area:

DUEM (New Blank Image 131-D)

Before I do so, I will show some slides from some applications.

There is a **CEUS** 1999 paper on this but the rudiments are included in my book referenced at the end.



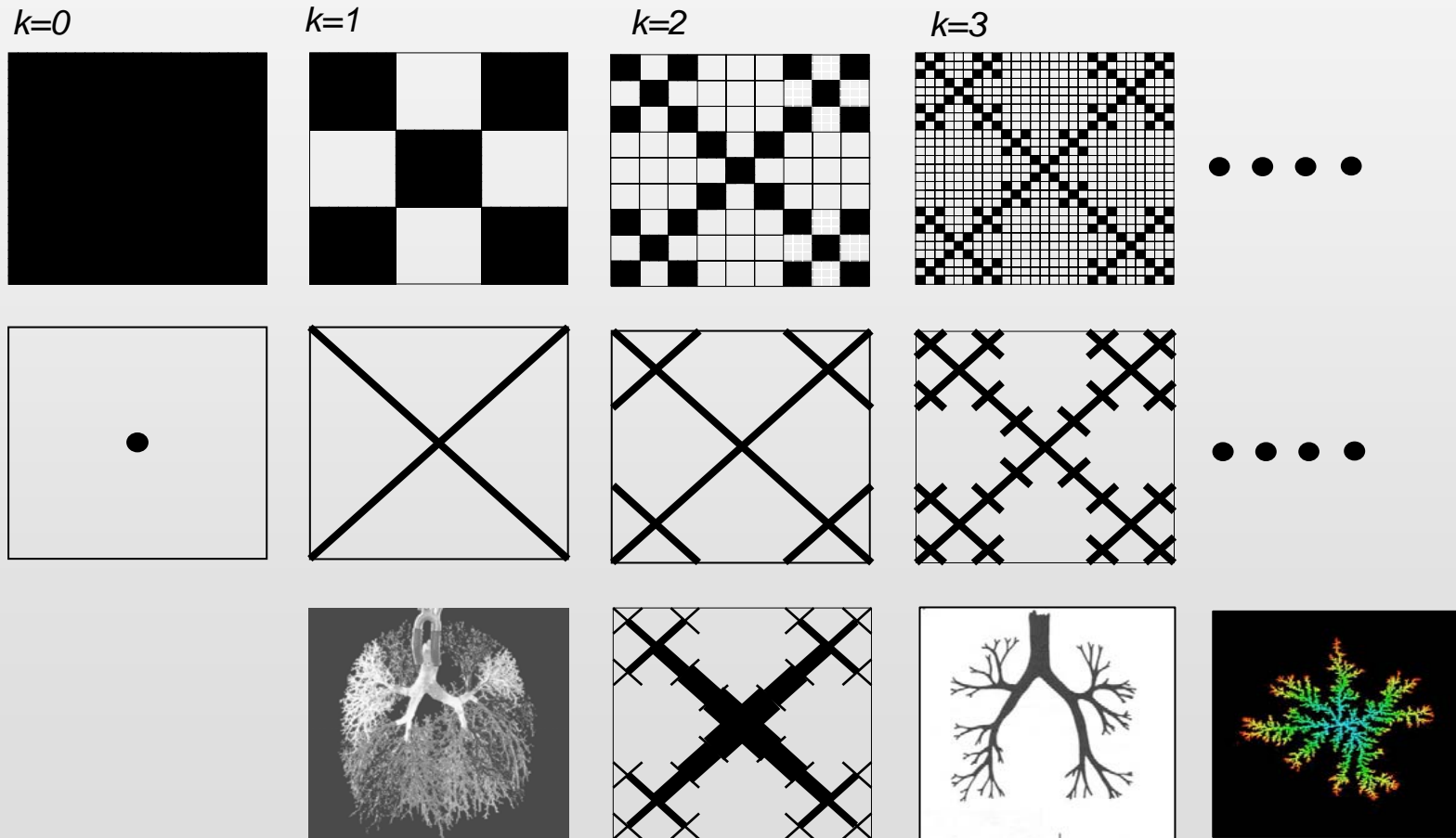
*Batty, M., Xie, Y., and Sun, Z. (1999)  
Modeling Urban Dynamics Through  
GIS-Based Cellular Automata,  
Computers, Environments and Urban  
Systems, 23, 205-233.*



Duem.exe

# Links to Urban Morphology

To anticipate how this relate to form and scaling and related issues, let us look at a hierarchical scheme





## Links to Agent-Based Models

Now often CA is conflated – merged – with ABM but ABM is a distinct style of modelling – it assumes many of the structures of CA but it poses active agents or objects who have a sense of purpose, who are autonomous in some senses, on the system.

There are very few ABM models as such although there are some in traffic modelling like TRANSIMS and MATSIM and some in residential segregation based on Schelling's model

A good summary is in Andrew Crook's blog:

<http://gisagents.blogspot.com/>

## The Last Lecture: References

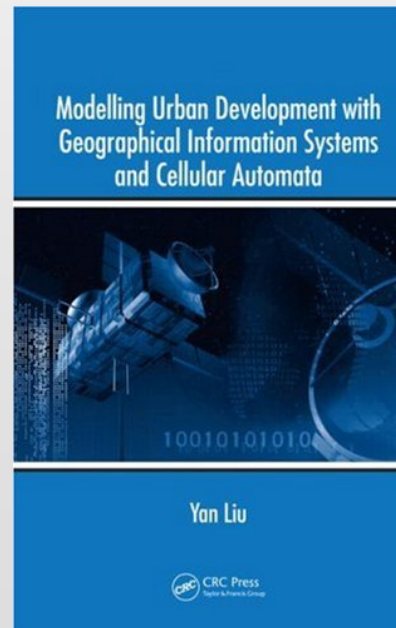
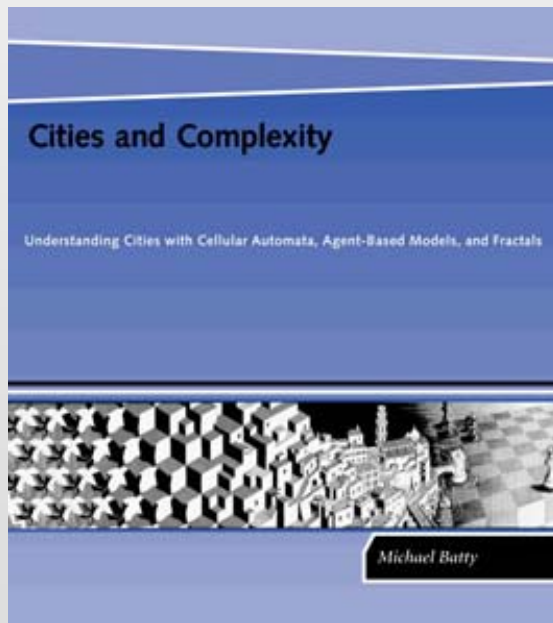
In the last lecture, I will talk about urban morphology and fractals and tie some of this back to spatial interaction. On CA modelling, there is a relatively simple and I hope intelligible article I wrote in 1997 in the Journal of the American Planning Association:

*Batty, M. (1997) Cellular Automata and Urban Form: A Primer, Journal of the American Planning Association, 63, 266-274.*

I will put this onto our web site

There is a lot to read on CA. More generally my book **Cities and Complexity** (MIT Press, Cambridge, MA, 2005) has a lot of general material and covers the DUEM model.

A more focussed book is Liu, Y. (2008) **Modelling Urban Development with Geographical Information Systems and Cellular Automata** (CRC Press, Boca Raton, FL).



# Reading

I will put material up on the web tomorrow

***Any Questions?***

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