Lecture 7:
Cellular Automata Modelling:
Principles of Cell Space Simulation

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 Next Lecture
- If we have time, an example from West London

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 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 <u>two</u> states – not developed and developed

(a)

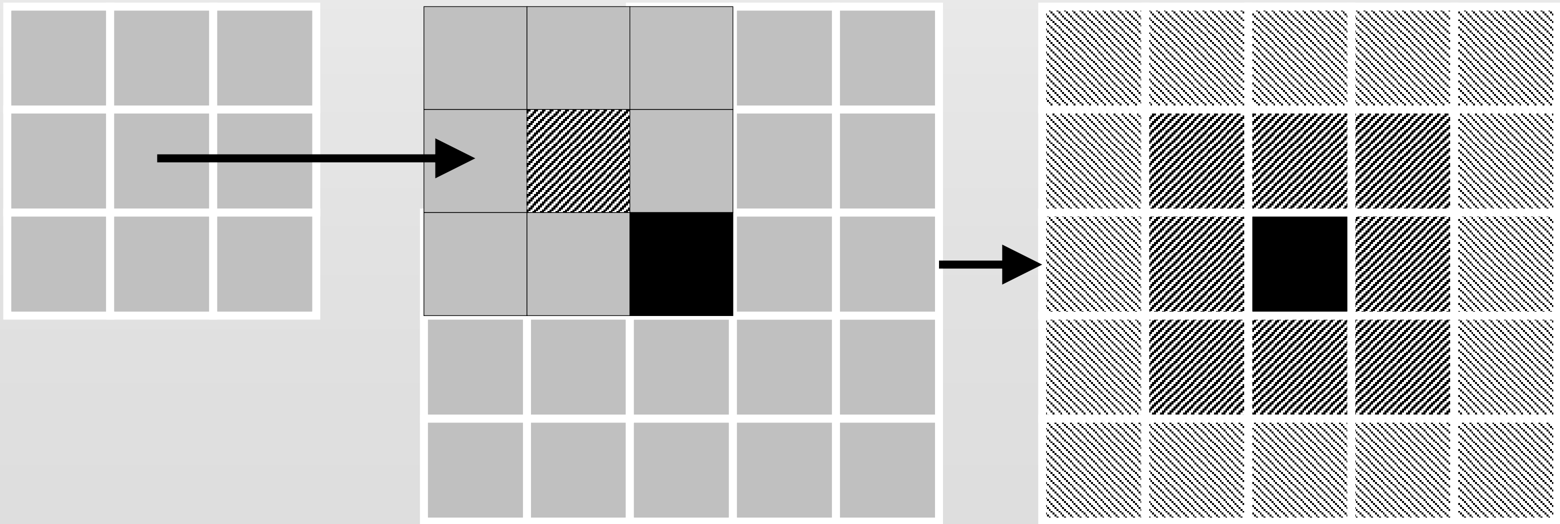
The neighbourhood is composed of 8 cells around the central cell

(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.

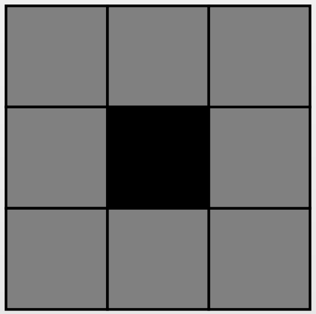
(c)

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

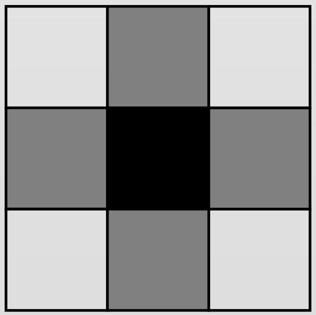


These are strictly deterministic CA models and we can have different shaped local neighbourhoods composed of different combinations of cells e.g.

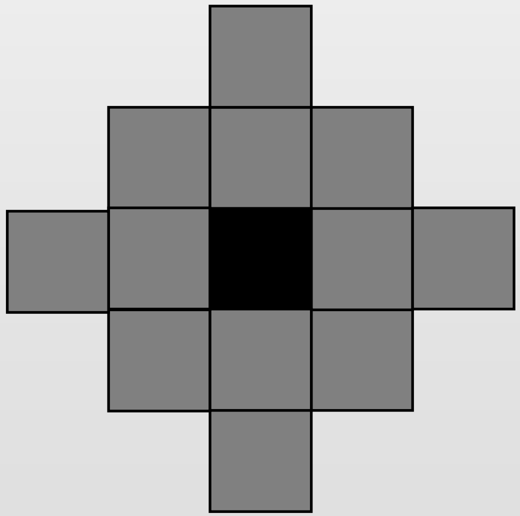
(a) Moore



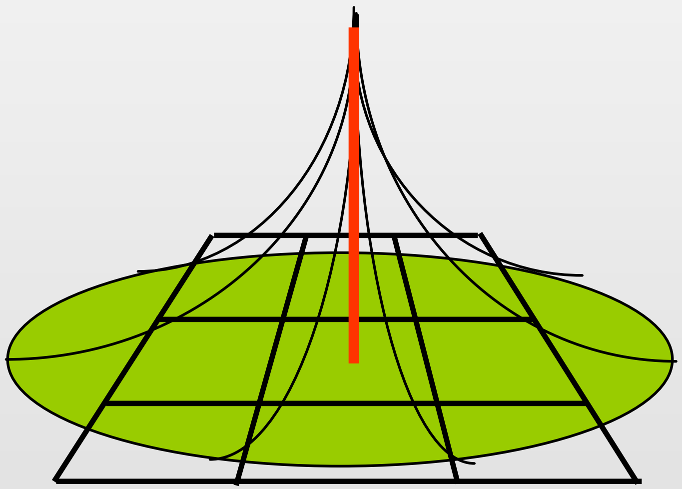
(b) von Neumann



(c) Extended Moore von Neumann



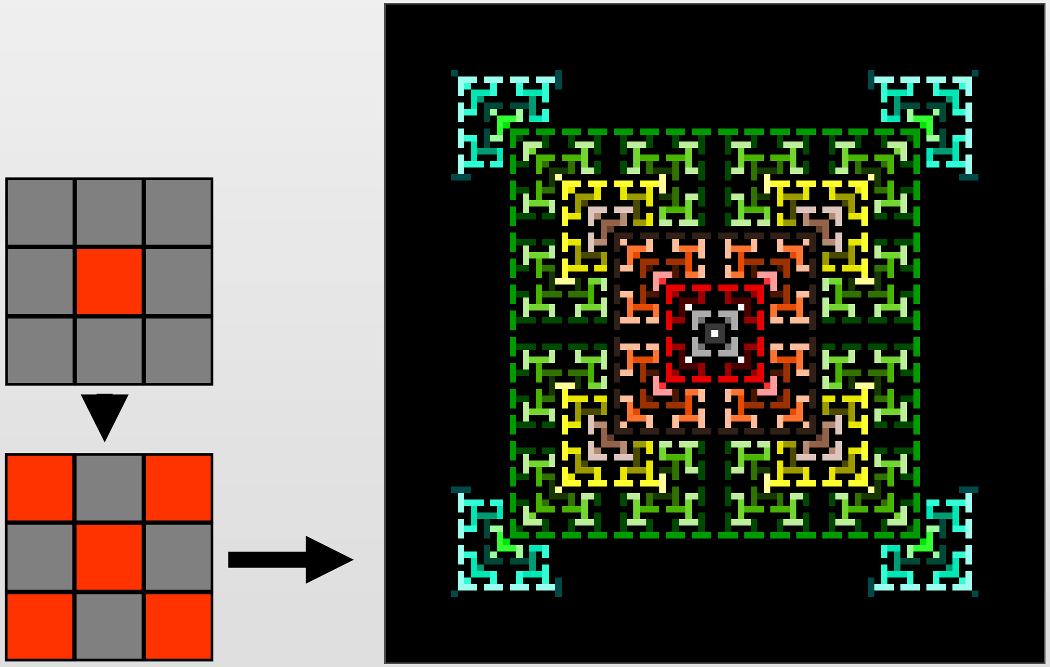
And we can have probabilistic fields defining neighbourhoods where there is a probability that a cells changes state – where the probabilities might vary regularly reflecting say action-at-a-distance principles e.g.



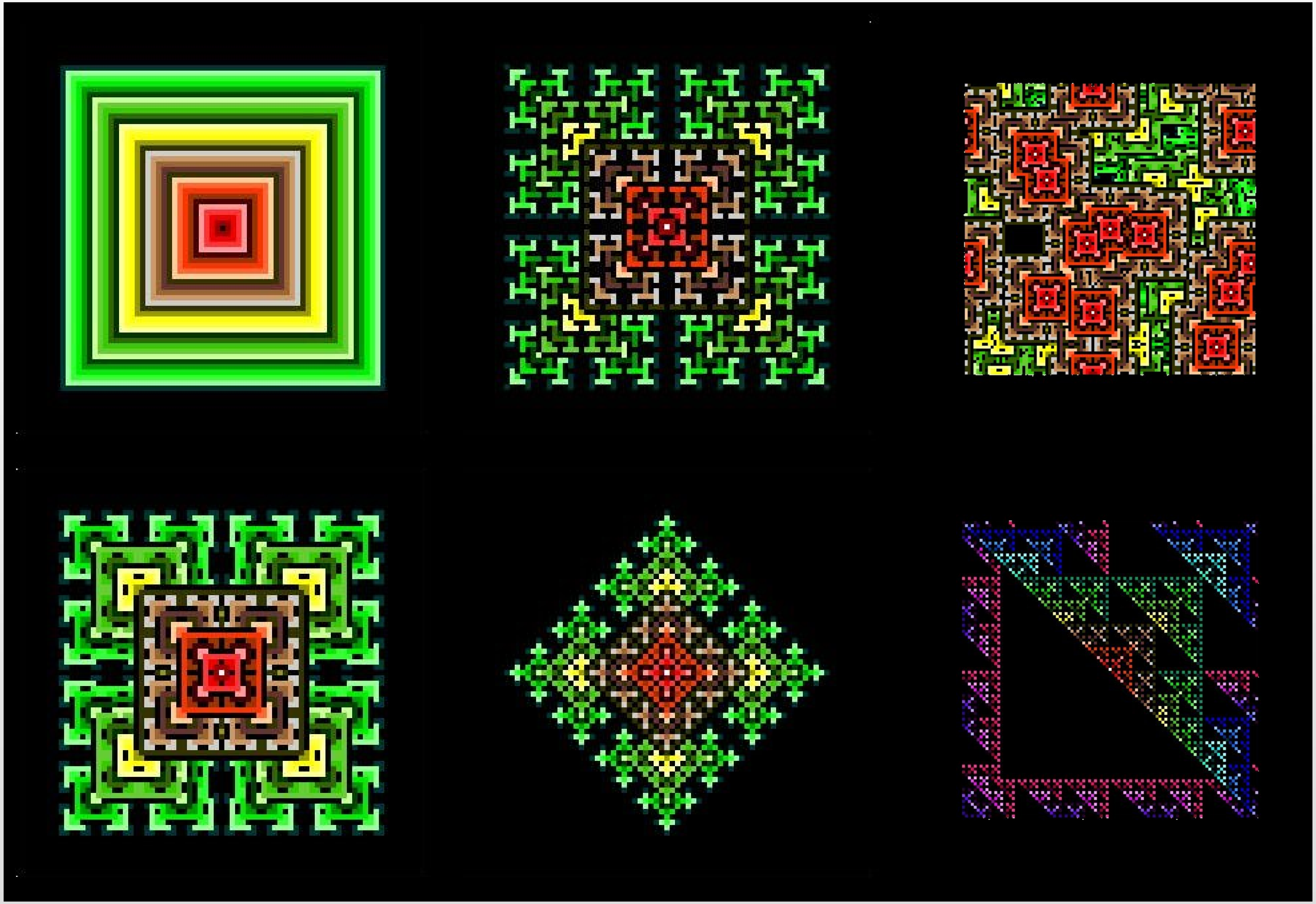
We will now show some examples of how one can generate idealised patterns that illustrate emergence

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



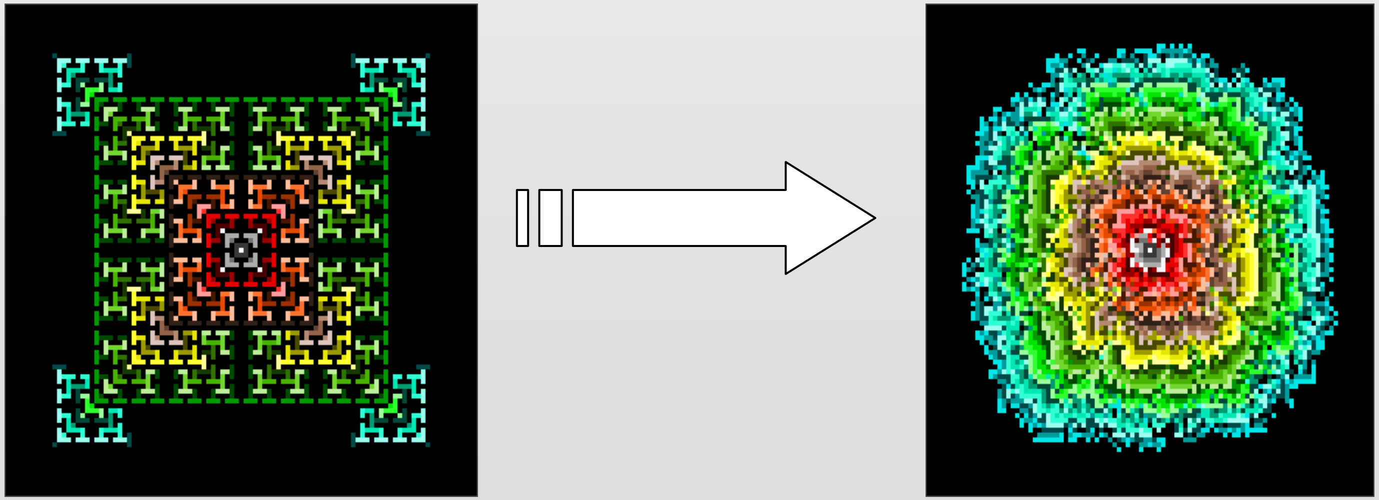
And changing There rules in various ways lead to many different patterns



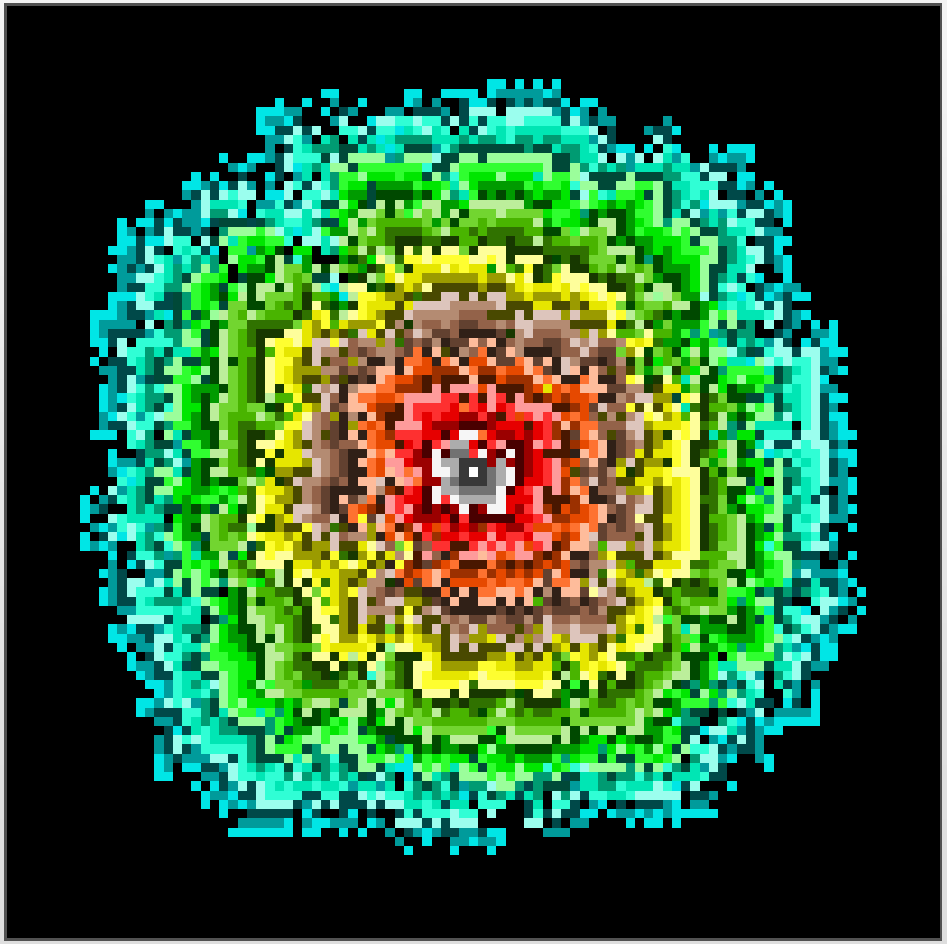
For probabilistic rules, we can generate statistically self-similar structures which look more like real city morphologies. For example,

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



Different Model Applications

At least 12 groups around the world, probably more now 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*

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

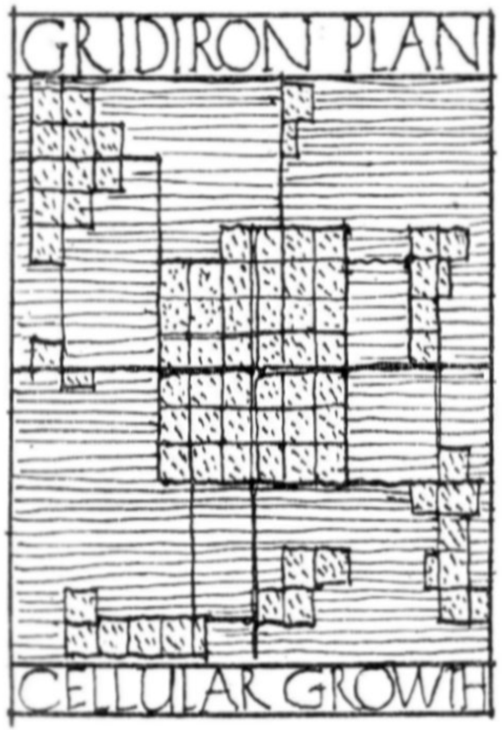


Fig. 1.

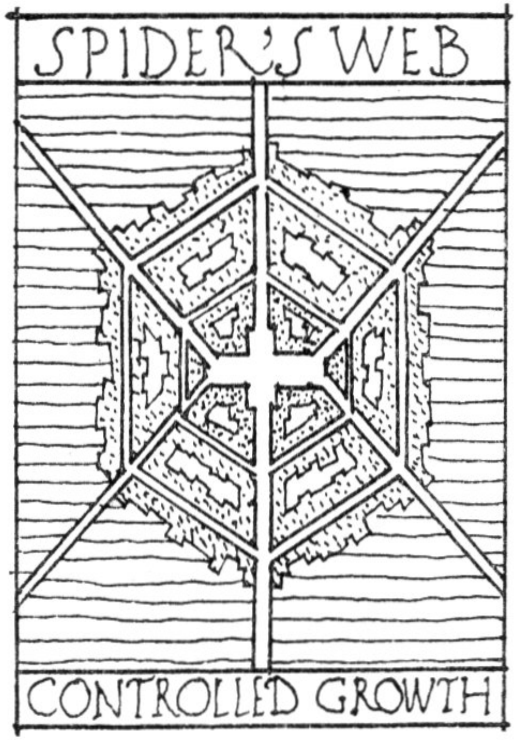


Fig. 3.

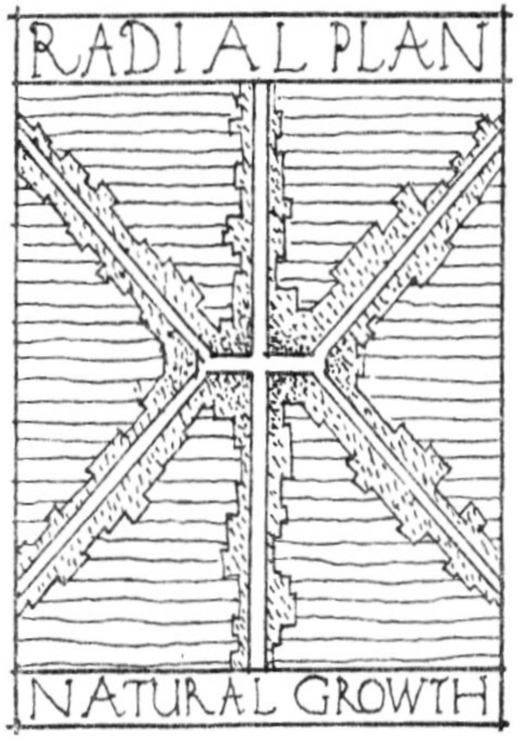
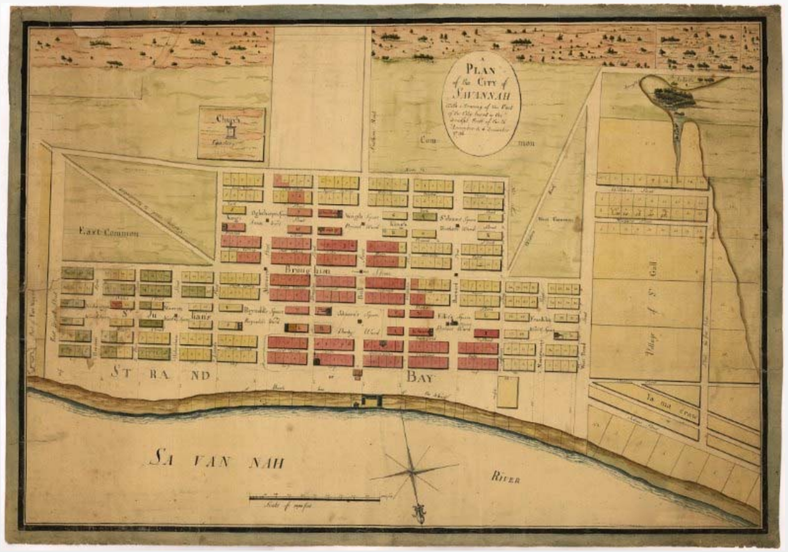


Fig. 2.


East Common
ST RA ND
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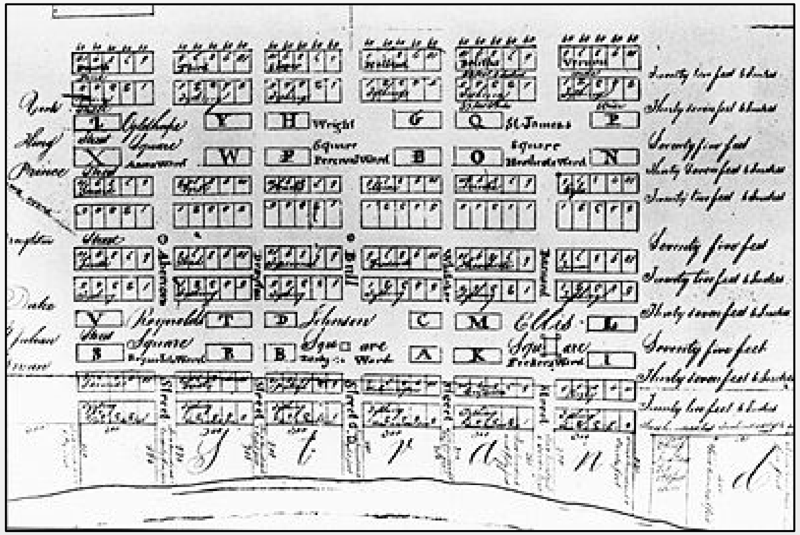
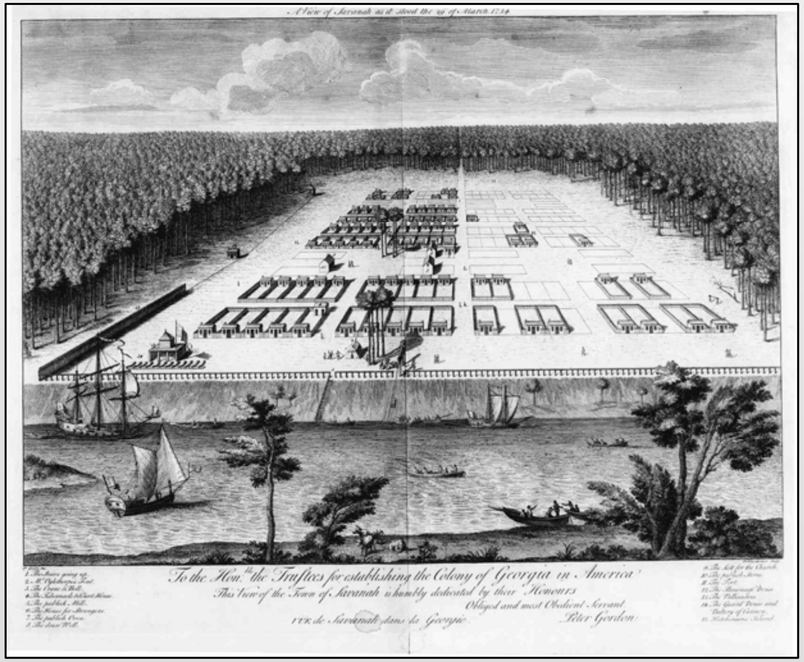
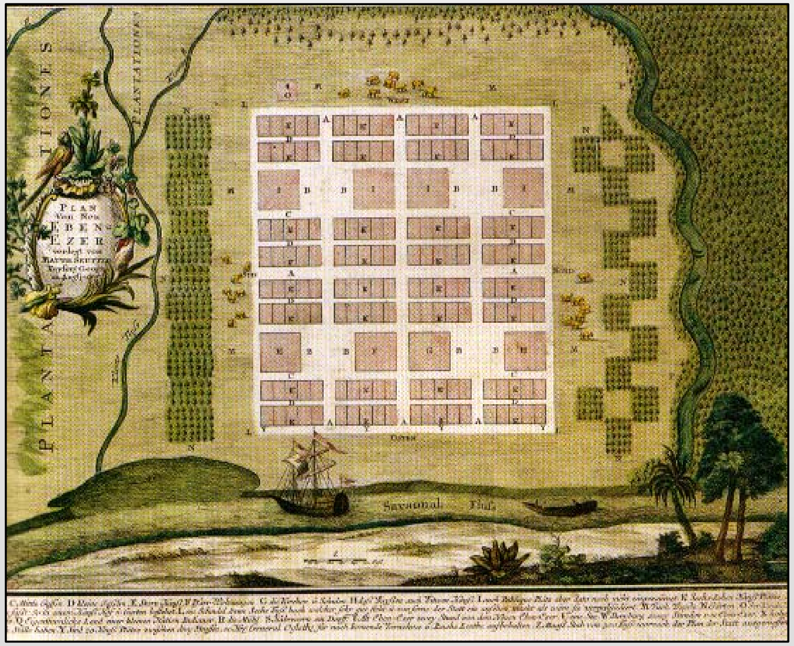
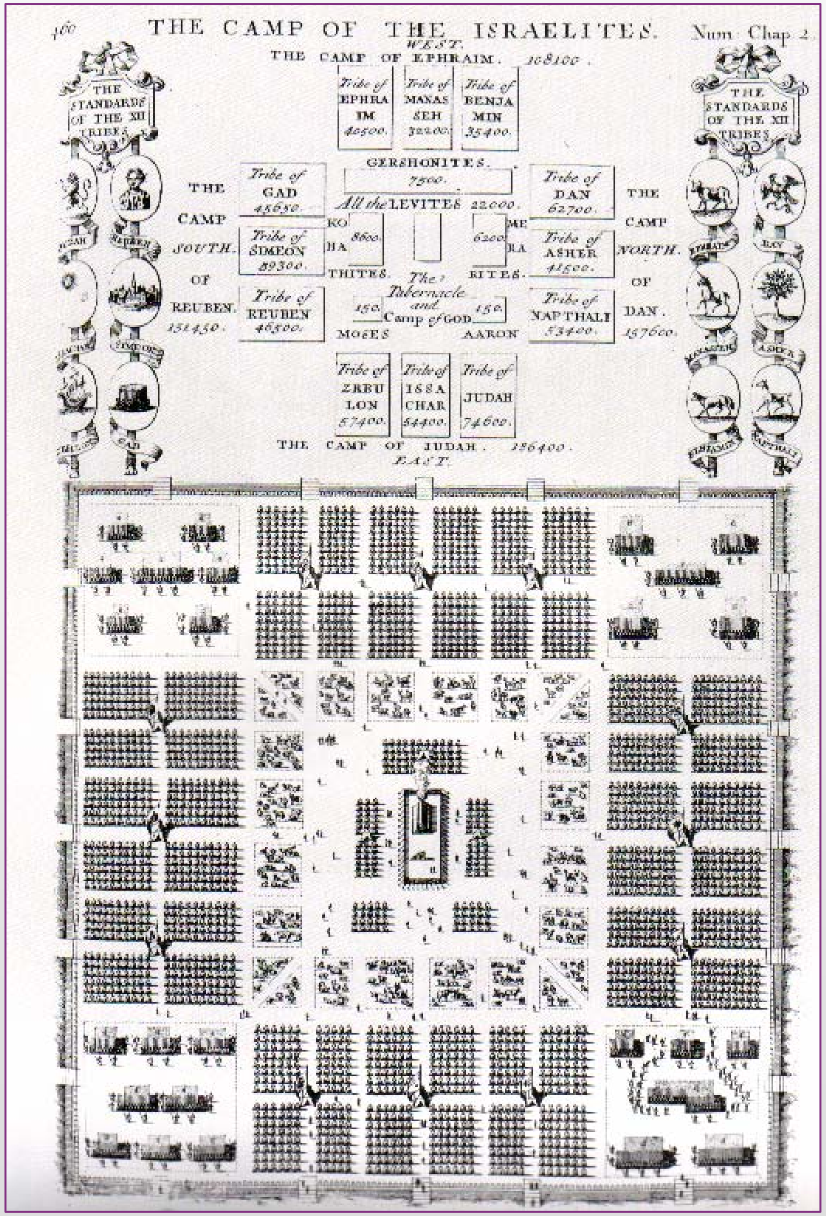

Wright
St. James
Square


To the Hon.ble the Trustees for establishing the Colony of Georgia in America
This View of the Town of Savanah is humbly dedicated by their Honours
Obliged and most Obedient Servant
Peter Gordon


PLANTATIONES


THE CAMP OF THE ISRAELITES.
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Tribe of BENJAMIN 35400.
GERSHONITES.
7500.
All the LEVITES 22000.
Tribe of GAD 45650.
Tribe of DAN 62700.
THE CAMP SOUTH. OF REUBEN. 151450.
THE CAMP NORTH. OF DAN. 157600.
Tribe of SIMEON 59300.
Tribe of ASHER 41500.
Tribe of REUBEN 46500.
Tribe of NAPTHALI 53400.
The Tabernacle and Camp of GOD.
MOSES
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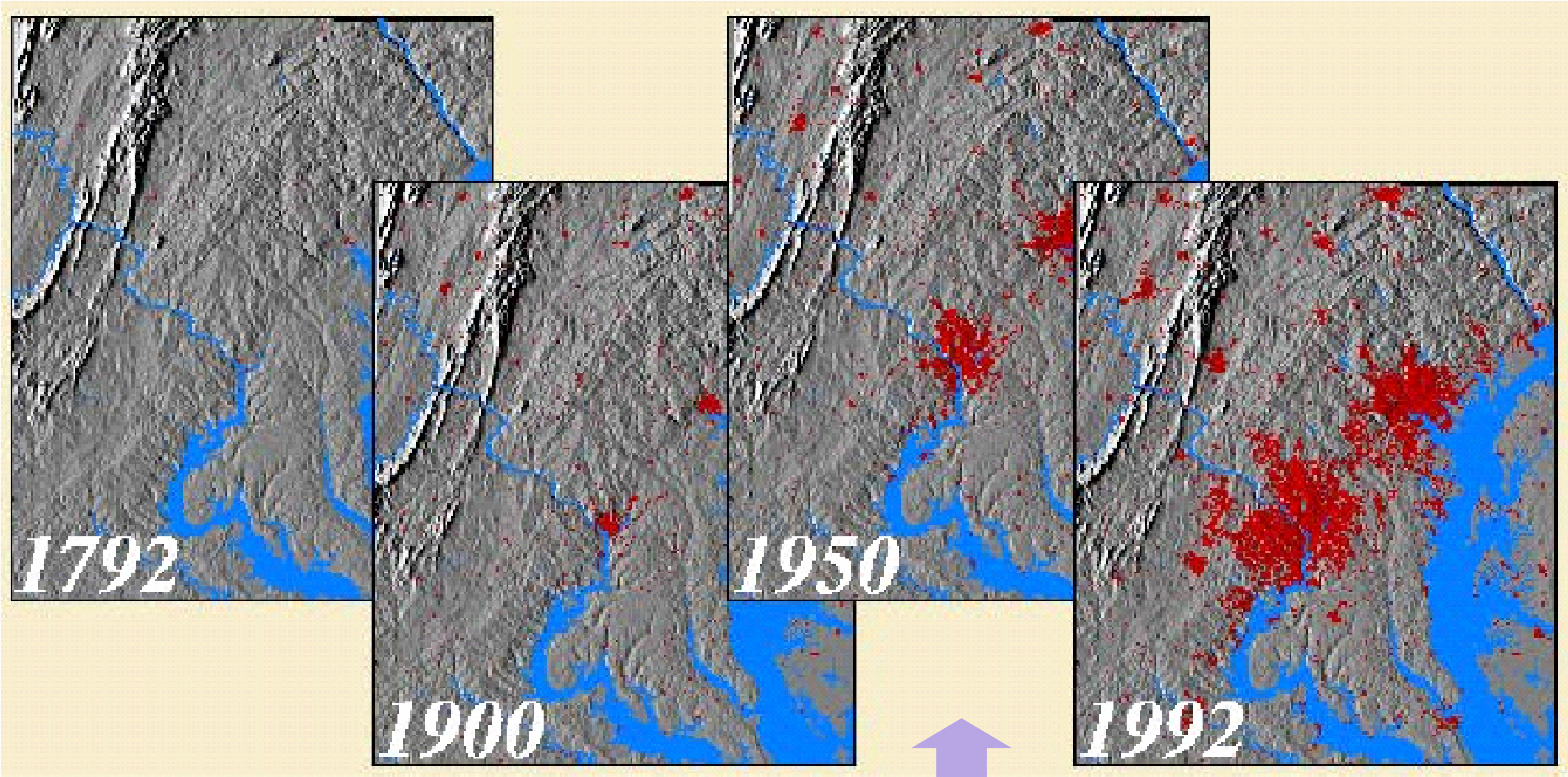
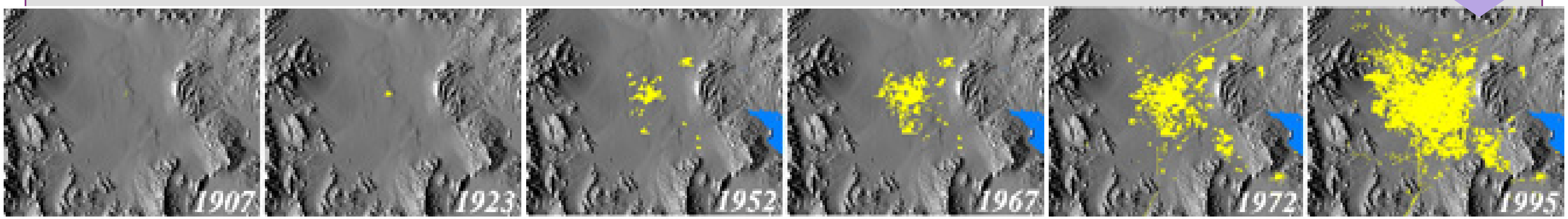
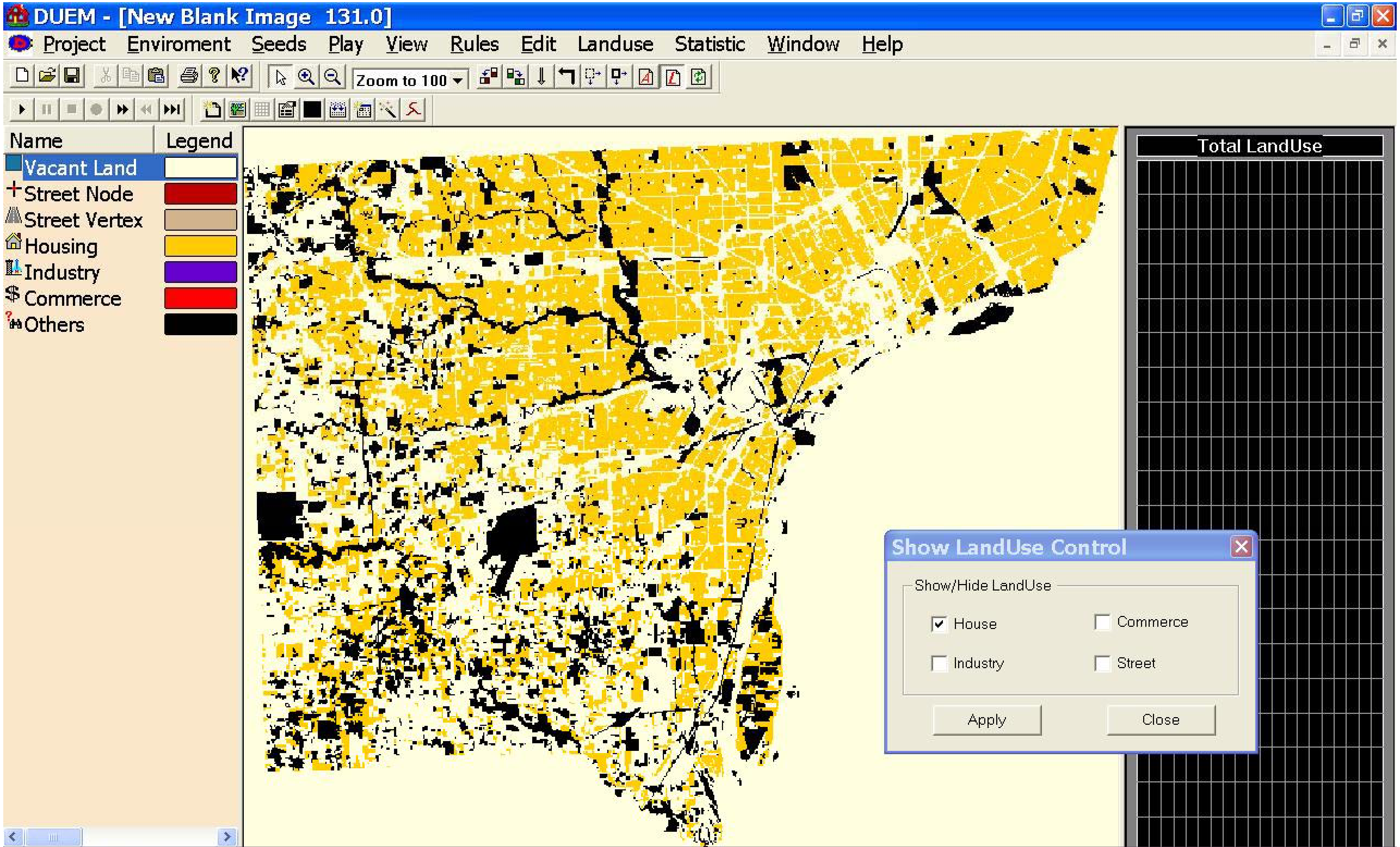


Growth through time: Washington DC-Baltimore   Las Vegas

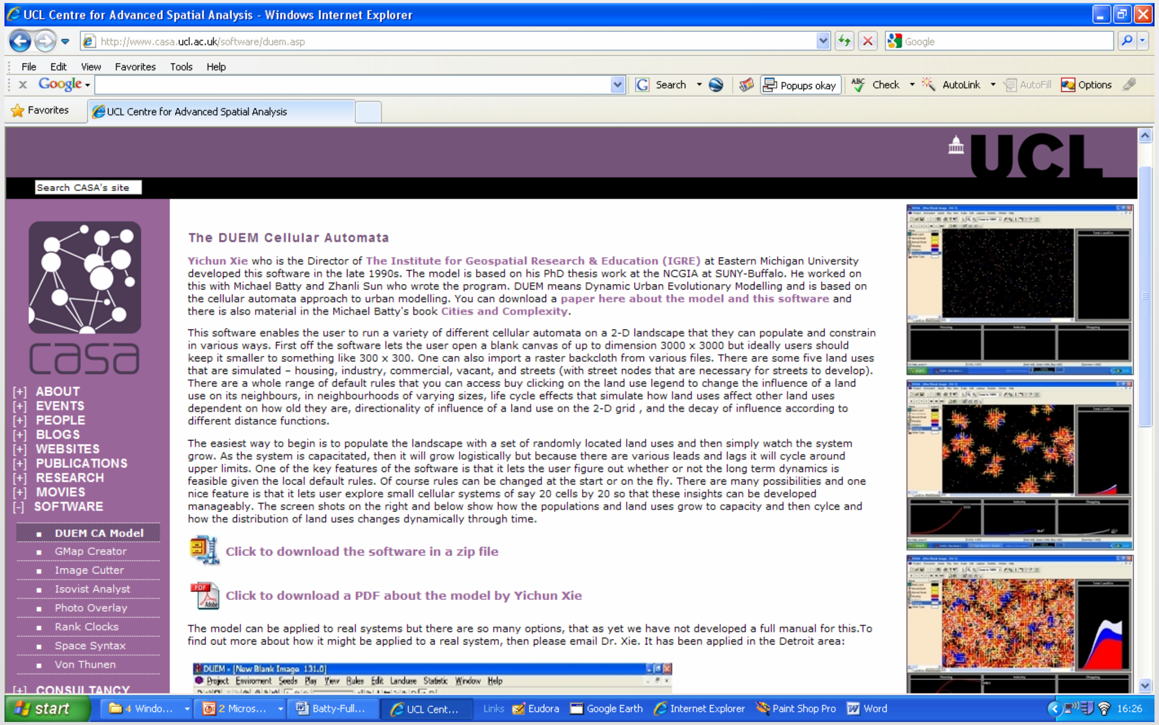




You can download this software from our web site at http://www.casa.ucl.ac.uk/

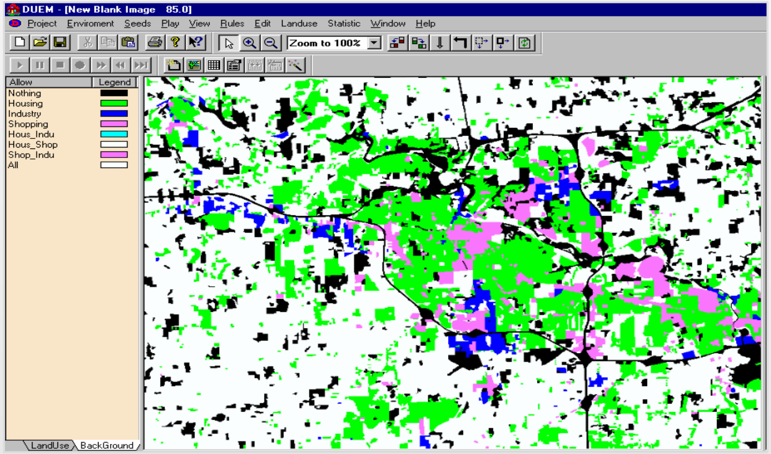
The DUEM Model: Software and Applications

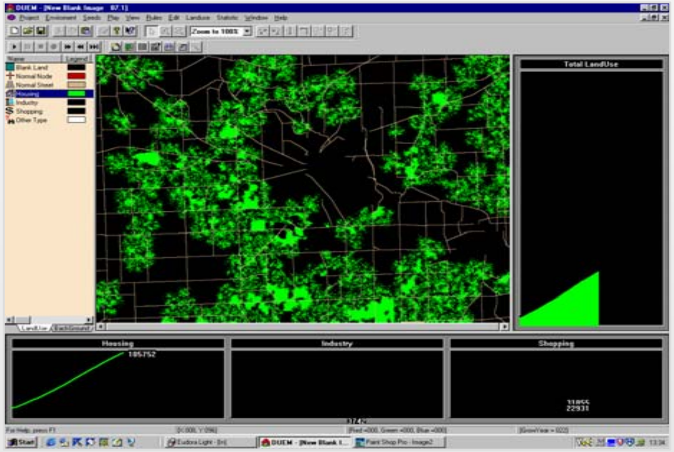
Now I can demonstrate this model which has been applied to the Detroit region. It is downloadable from our web site at http://www.casa.ucl.ac.uk/software/duem.asp

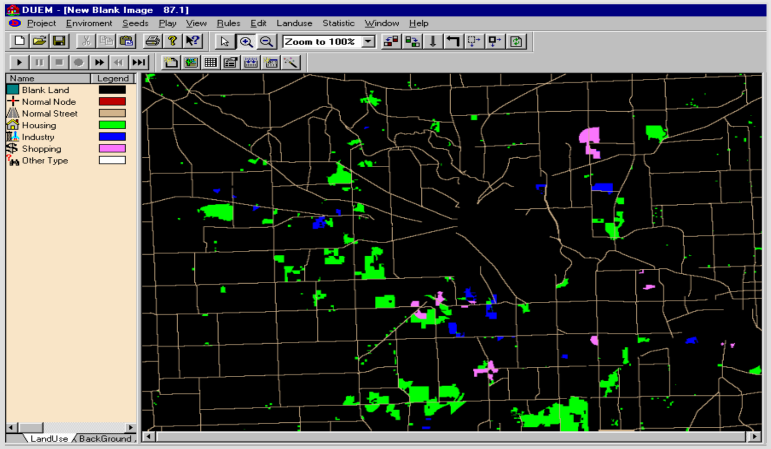


Before I do so, I will show some slides from some applications.

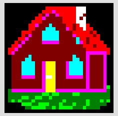
There is a ***CEUS*** 1999 paper on this but the rudiments are included in my book referenced at the end.







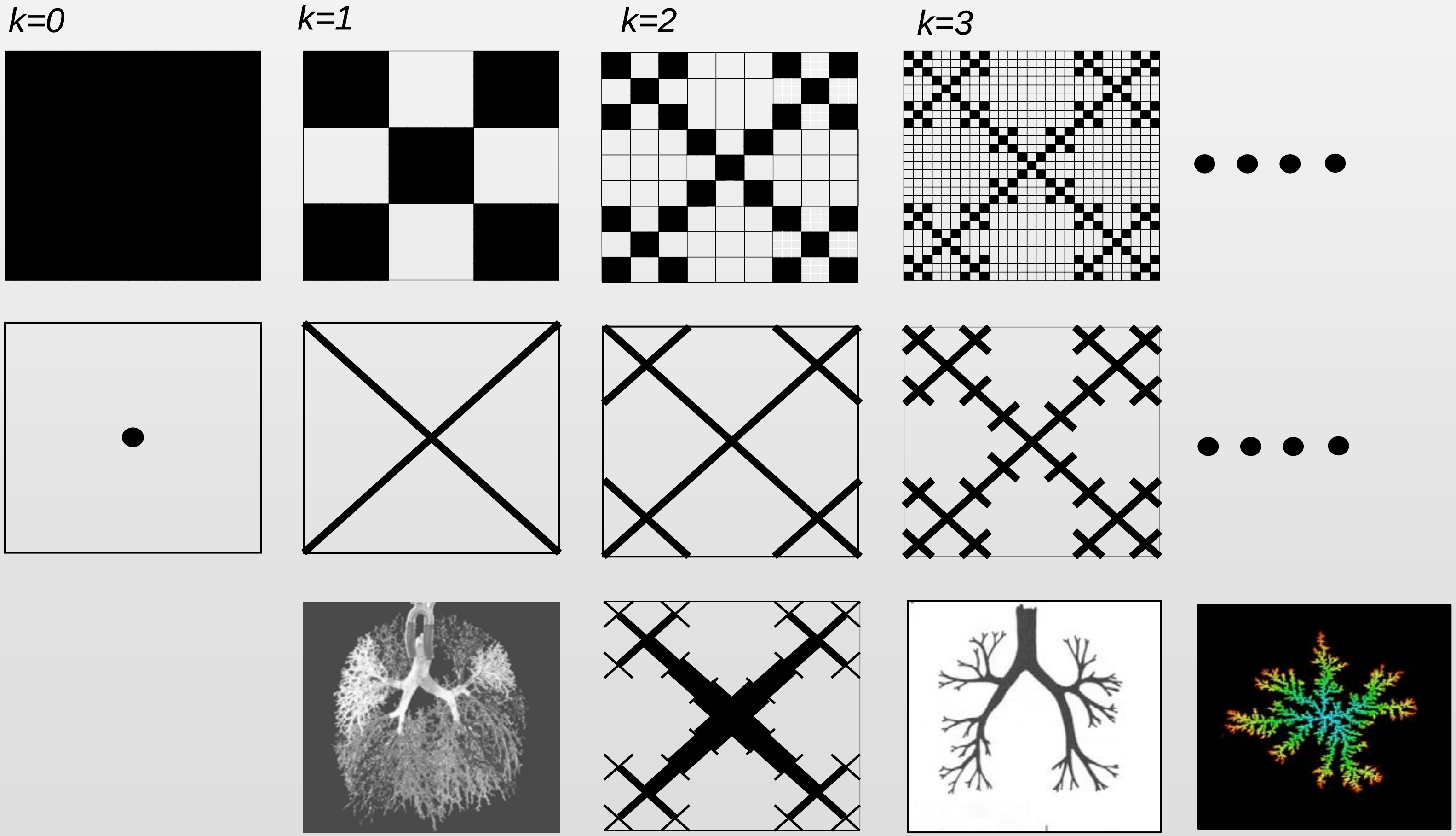
Batty, M., Xie, Y., and Sun, Z. (1999) Modeling Urban Dynamics Through GIS-Based Cellular Automata, ***Computers, Environments and Urban Systems, 23****, 205-233.*



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 Next Lecture: References

In the next lecture, I will talk about agent based models, specifically pedestrian models

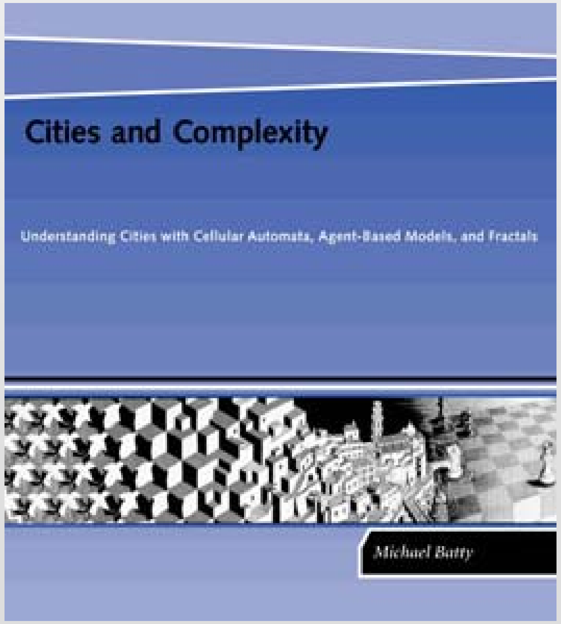
On CA modelling, there is a relatively simple and I hope intelligible article I wrote in 1997 in the Journal of the American Planning Association:

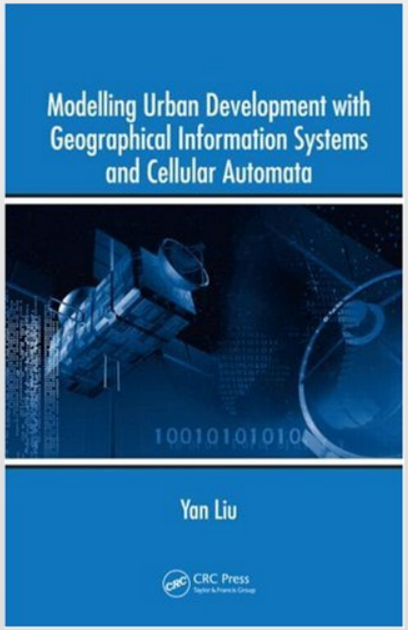
Batty, M. (1997) Cellular Automata and Urban Form: A Primer, ***Journal of the American Planning Association*****, *63****, 266-274.*

This is on 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).





Questions?