Lipari School on Computational Complex Systems

Jacob T. Schwartz International School for Scientific Research

Università di Catania

FACOLTÀ DI SCIENZE

MATEMATICHE · FISICHE · NATURALI

July 27-
August 2, 2014

A Science of Cities

Models of Urban Form and Function

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Key Themes

- A Little History and a Puzzle
- Multiple Perspectives on Cities Across the Sciences
- The Fascination with Form
- Attempting to Explain Location, Place and Space

  Social Physics, Economics and Transportation
- Systems Models, the Transition to Complexity and Urban Networks
- Enter Time: Generic Models, Agents, Cells, and Cities
- More General Theory: Scale, Size & Shape
- Attempting a Synthesis

A Little History and a Puzzle

Cities have been talked about since classical times, since the written record began but only in the last 150 years since the industrial revolution has there been a widespread and sustained effort to intervene in their functioning.

This has largely been through planning which began in the west in the late 19th century.

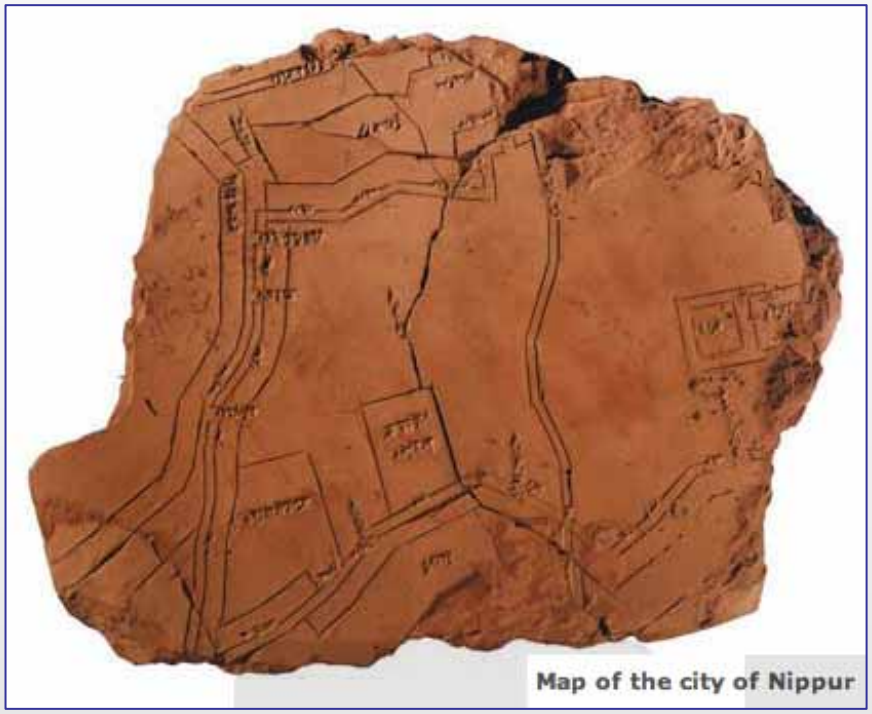
It now seems strange but there was enormous certainty that the evils of the industrial city were supposedly to be resolved by producing cleaner, greener versions of the same thing, but smaller, and away from the industrial city. A return to the countryside.

The puzzle now is that people thought they could do this with little understanding of the city. In fact they thought it did not need understanding and that all it needed was reorganisation. How can you have prediction or prescription before explanation? I guess in human affairs, it happens all the time.

Cities were physical as was their planning and the prevailing view was based on producing better cities through better physical plans.

The city was seen as a work of art more than a social mechanism or rather its planning was a work of art embodied in a strong physical order that assumed it would function a little better.

Here are some early – very early – examples



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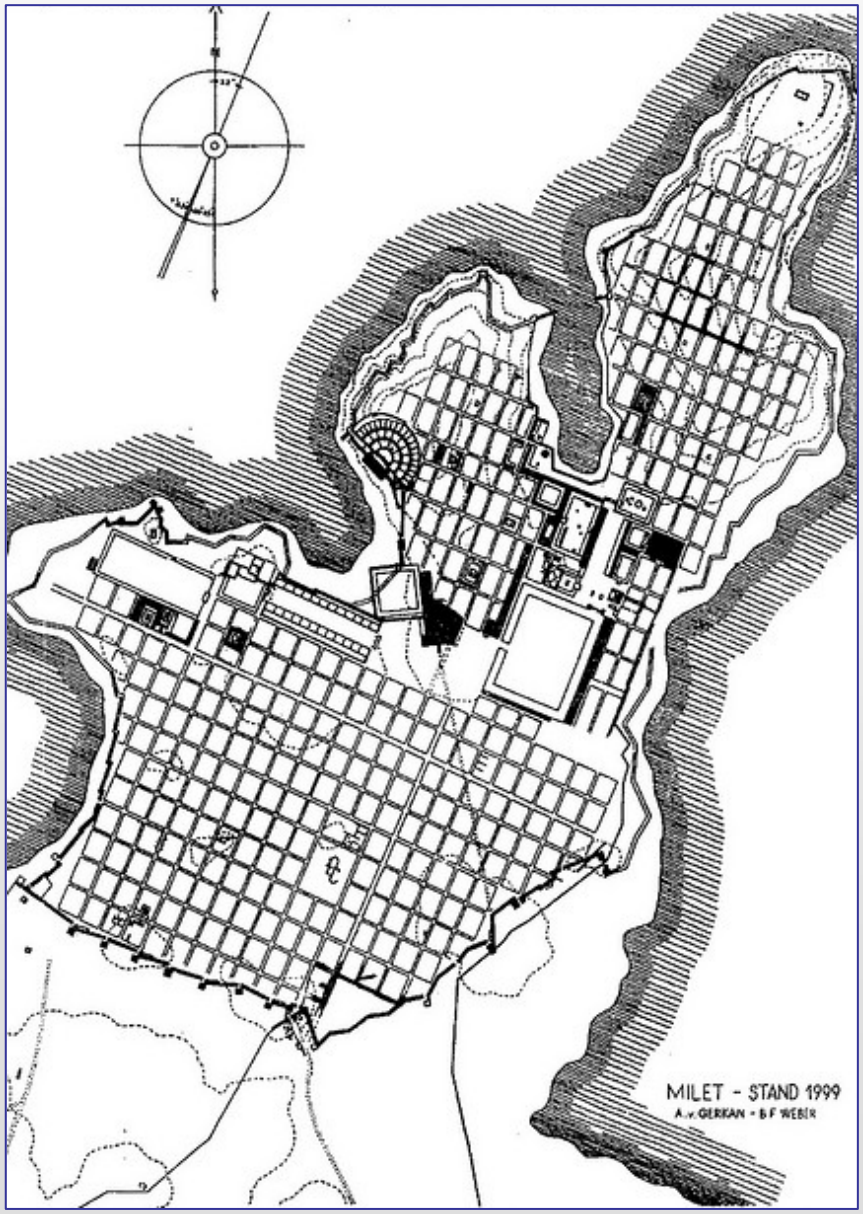

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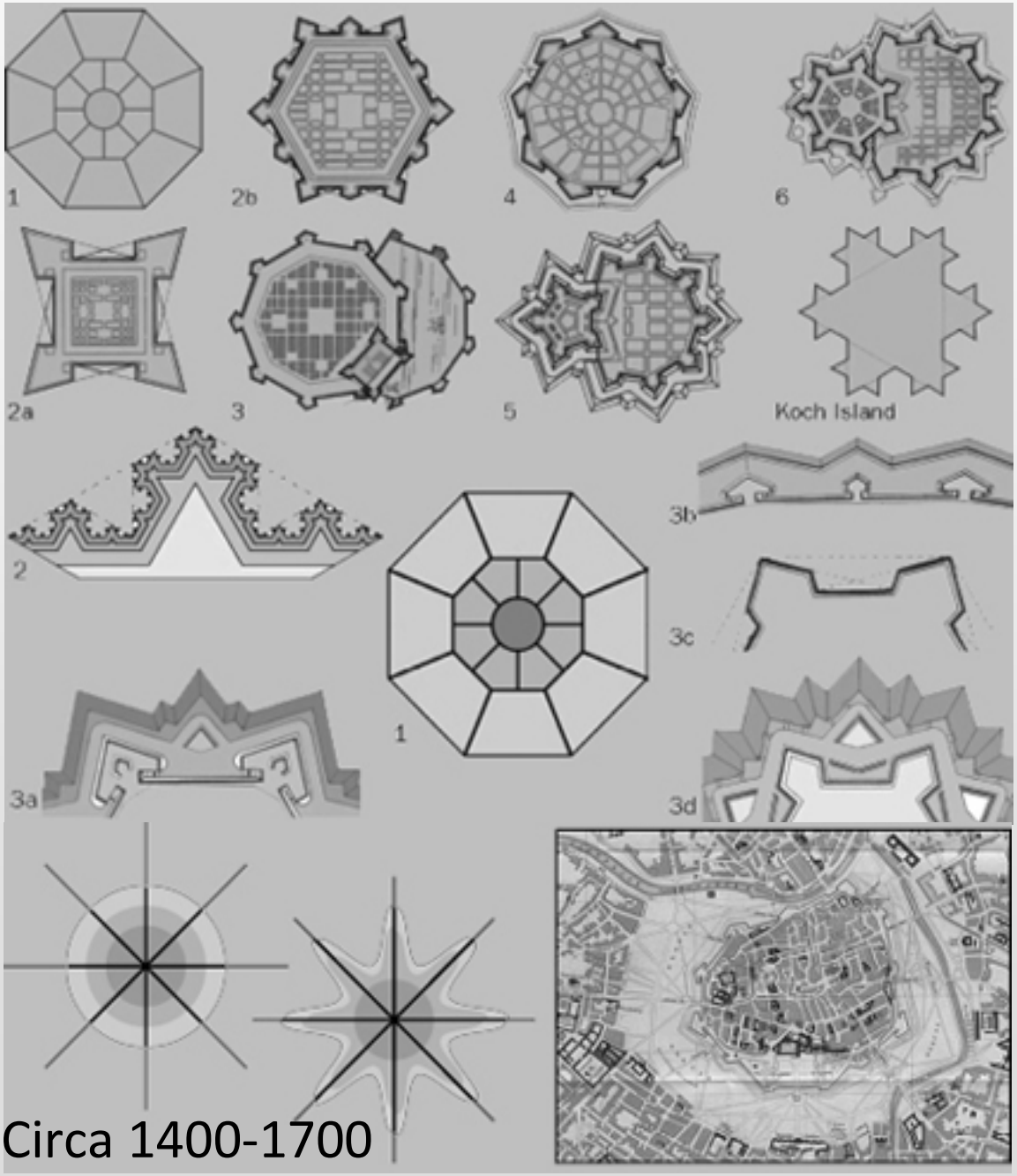
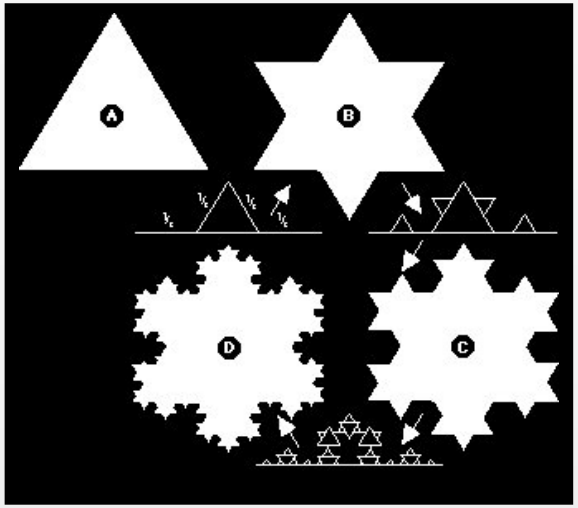
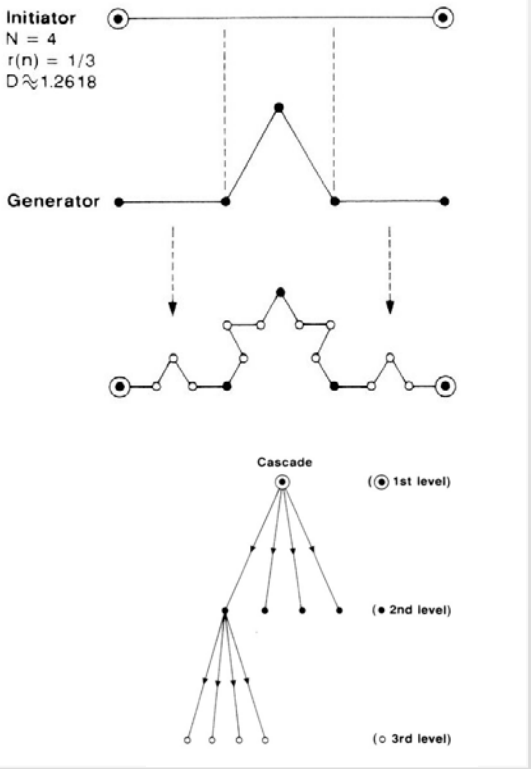
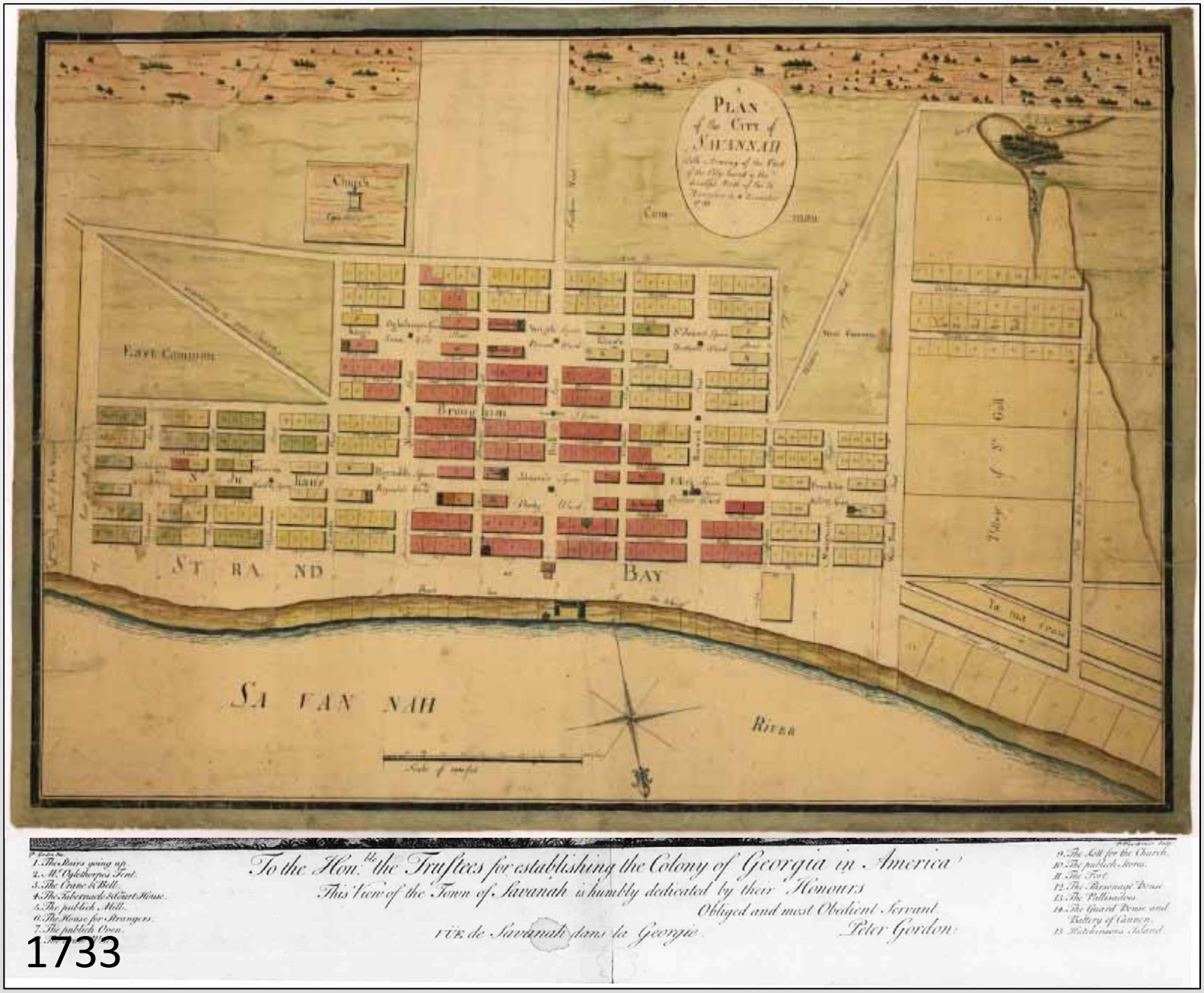


Circa 1400-1700



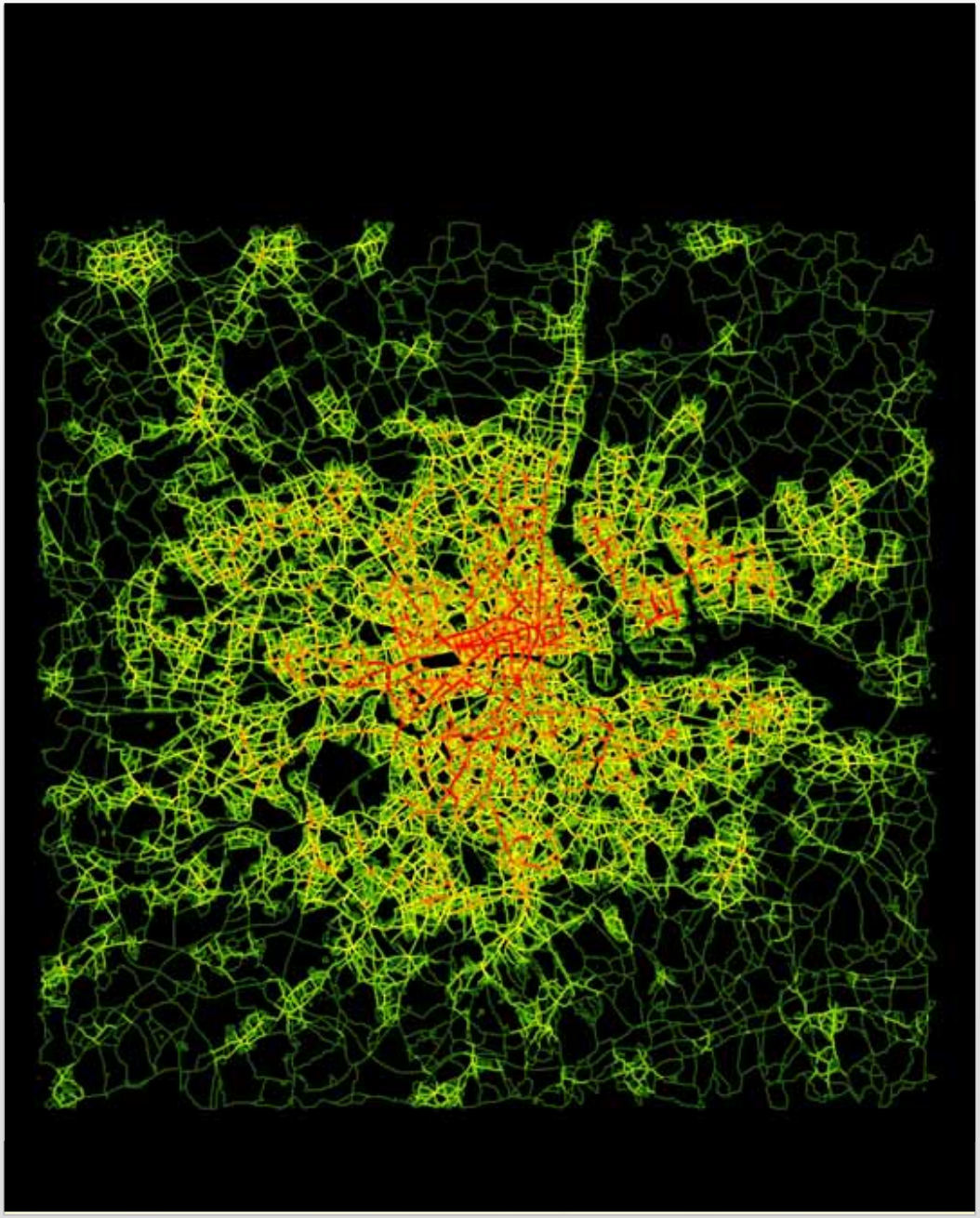



PLAN
of the CITY of
SAVANNAH
Church
Common
EAST COMMON
BROUGHTON
ST BA ND
BAY
SA VAN NAH
RIVER
To the Hon.ble the Trustees for establishing the Colony of Georgia in America
This View of the Town of Savanah is humbly dedicated by their Honours
Obliged and most Obedient Servant
Peter Gordon
VUE de Savanah dans la Georgie
1. The Stairs going up.
2. Mr Oglethorpes Tent.
3. The Crane & Bell.
4. The Tabernacle & Court House.
5. The publick Mill.
6. The House for Strangers.
7. The publick Oven.
9. The Lott for the Church.
10. The publick Stores.
11. The Fort.
12. The Parsonage House.
13. The Pallesadoes.
14. The Guard House and Battery of Cannon.
15. Hutchinsons Island.

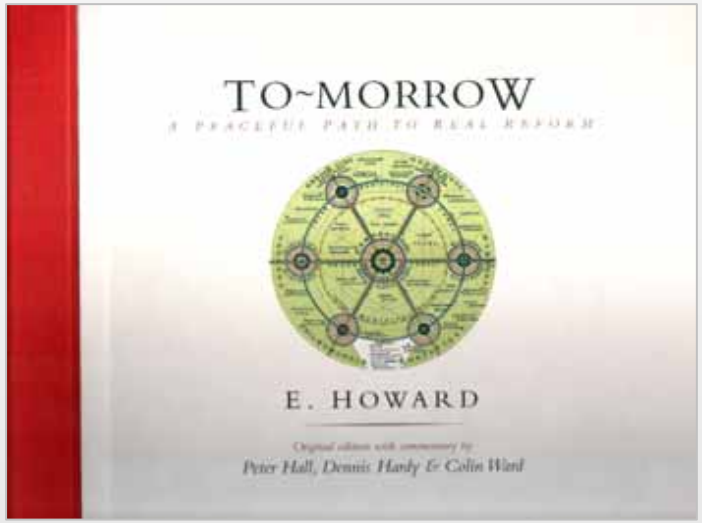
1733

By the middle of the 19th century, the idea that the cities could be improved through top down physical planning gained momentum and by the early 20th century various institutional apparatus had been put in place to do something about it. The key issues were:

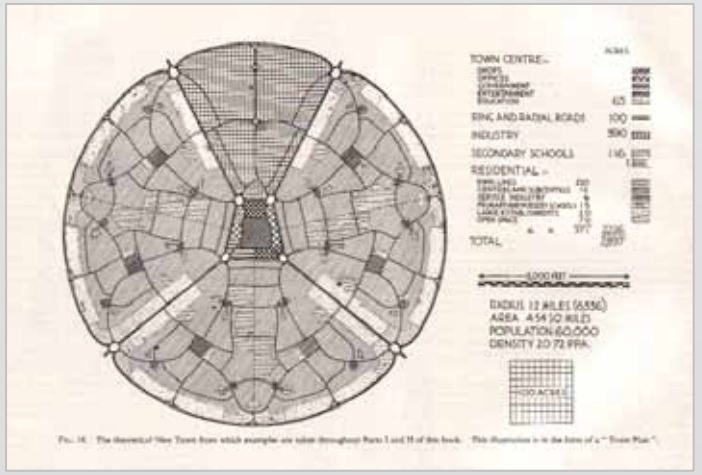
- Cities were regarded as something ‘evil’ to be managed
- The idea that the country should be moved back into the town was important
- Decentralisation, suburbanisation, counter-urbanisation was key to policy
- Managed ‘sprawl’ implicitly regarded as acceptable



A System of Cities: The Inter-Urban



A City: The Intra-Urban



Multiple Perspectives on Cities Across the Sciences

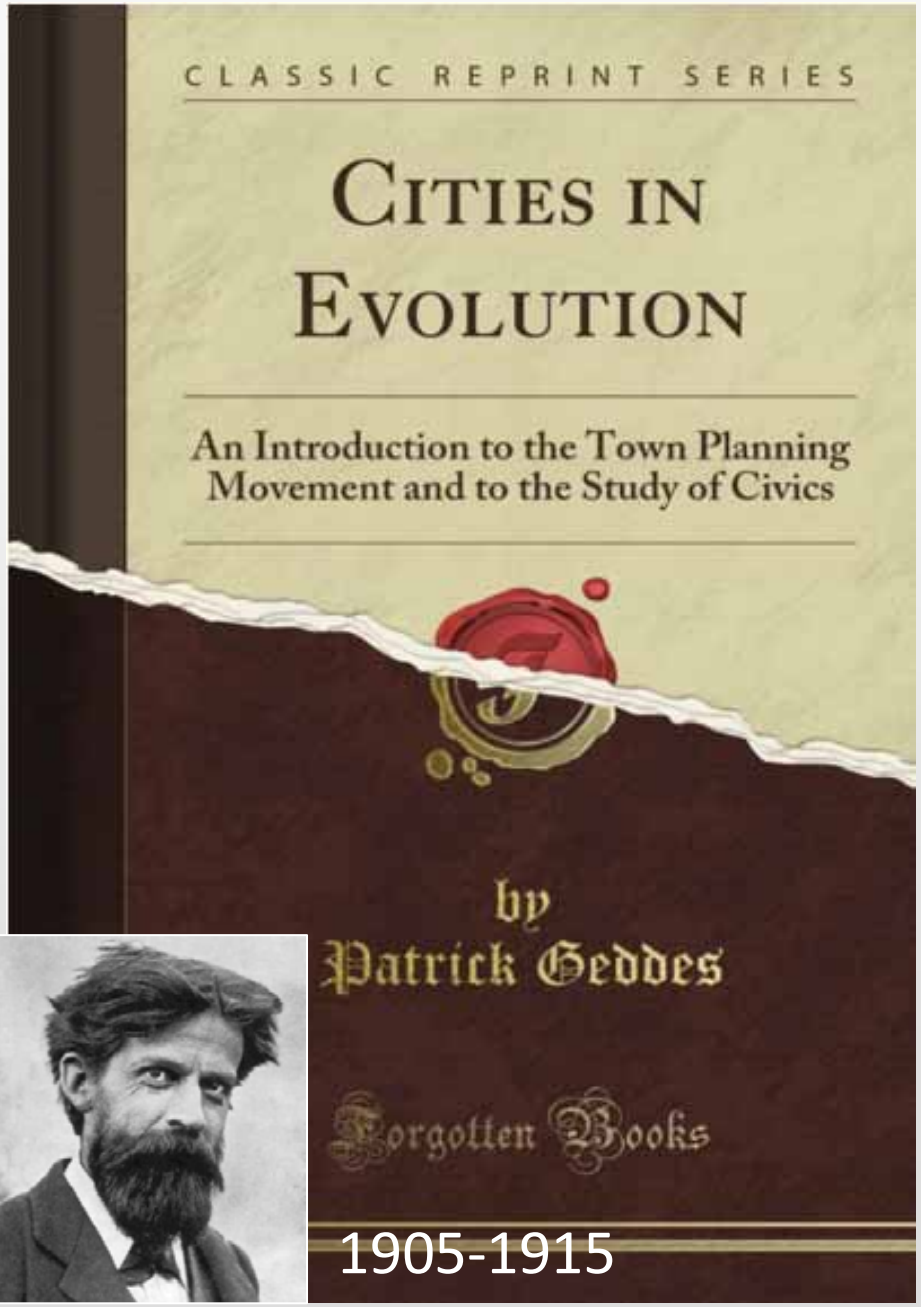
The 20th century saw the proliferation of ideas about the city in many intellectual domains

In the arts and humanities and the social sciences but also in engineering and more recently in physics

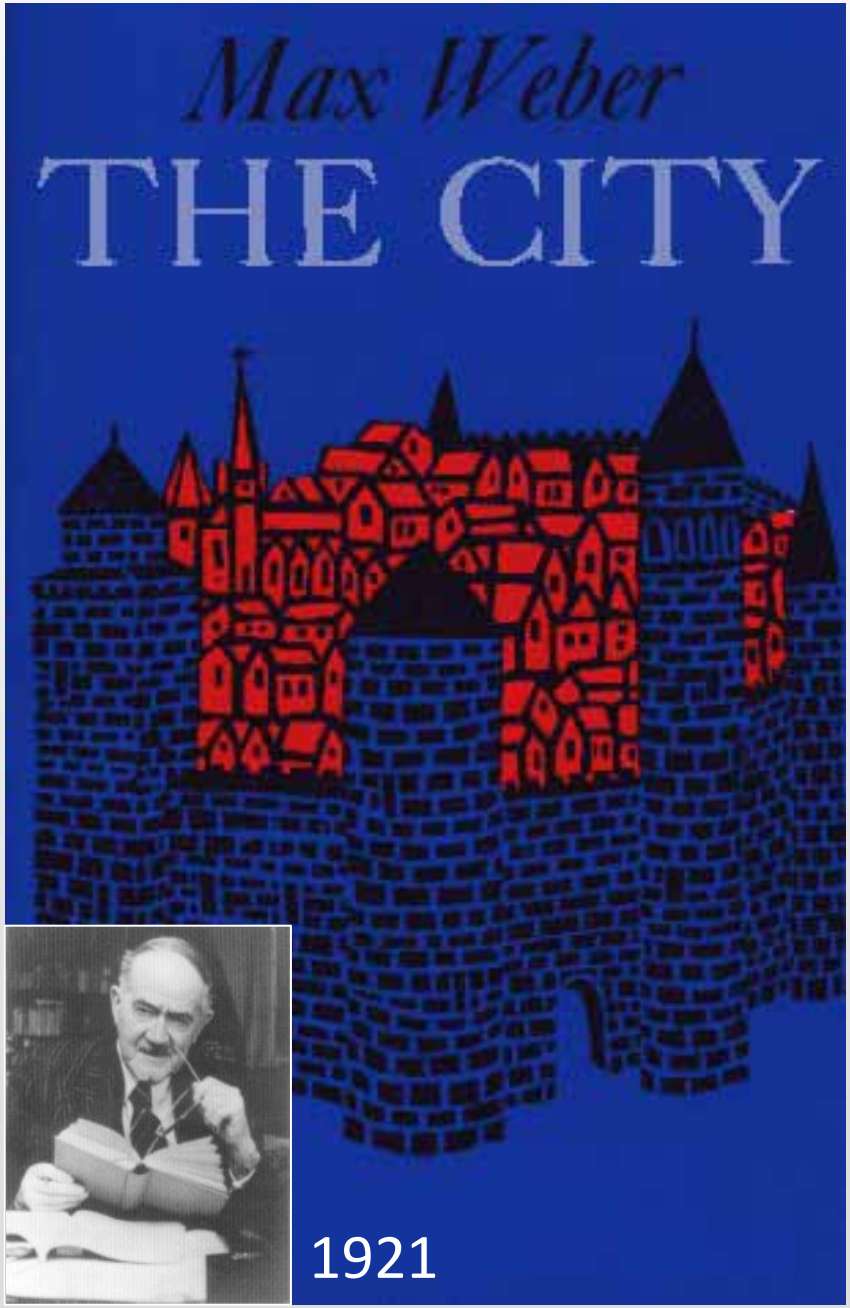
Each professing that they have the kernel of knowledge that will explain the key forces at work in the city

There is an enormous domain of 'urban studies' focusing on cities; and the professional and semi-academic domain of city planning and architecture

Two early books that focus on different perspectives imply a sense that there might be a science of cities



1905-1915



1921

I could show you a 100 books, perhaps a 1000, more,, which profess to explain the city but these two reflect an early concern with science – Geddes – and with politics – Weber.

Although a science of cities was largely not discussed, there were the seeds of a dawning recognition that cities could be understood more systematically

It is one purpose of this talk to try and build a bridge between those currents and what we are thinking about today.

The currents were primarily economic in focus – to explain the city as an economic mechanism although the dominant focus has been physical, and to a lesser extent social

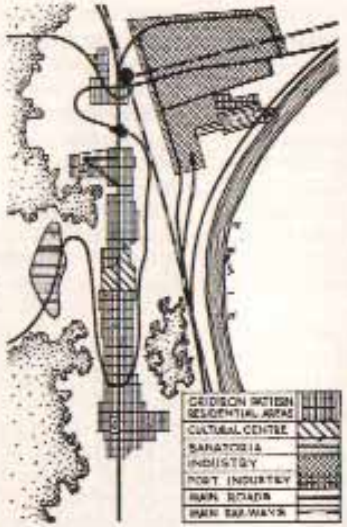
The Fascination with Form

As we have already seen, the city is always articulated in terms of its physical form. I call the quest to explain how cities function through the lens of form *physicalism*

In fact planning cities was almost invariably physical in its manner during most of the 20th century for it was always believed that the efficient and equitable functioning of cities would manifest in urban form

You could see pollution, slums, deprivation, traffic congestion, green space, and so on and a lot was considered to be only surface deep, hence easily solvable.

(i)



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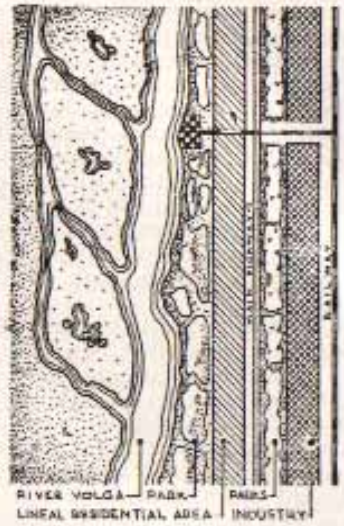

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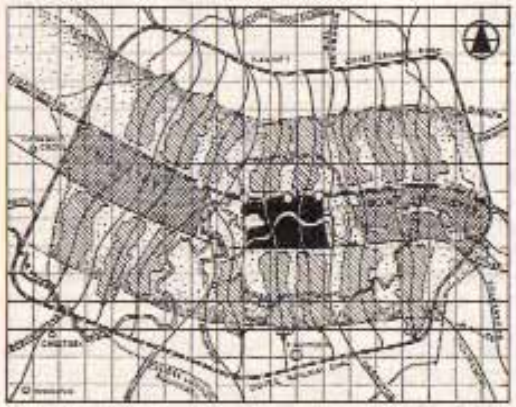
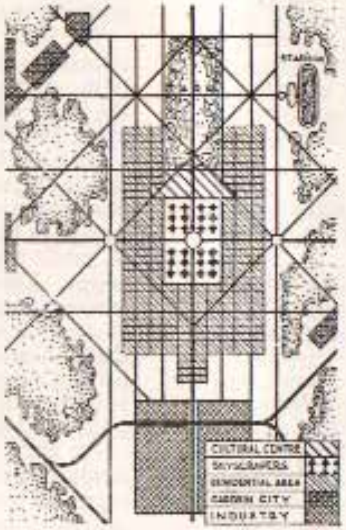
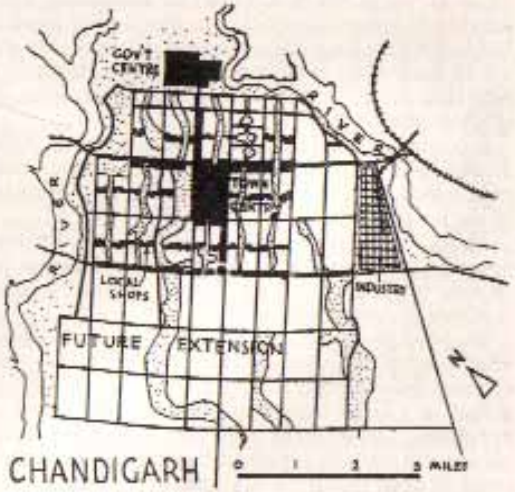


(iv)



(v)

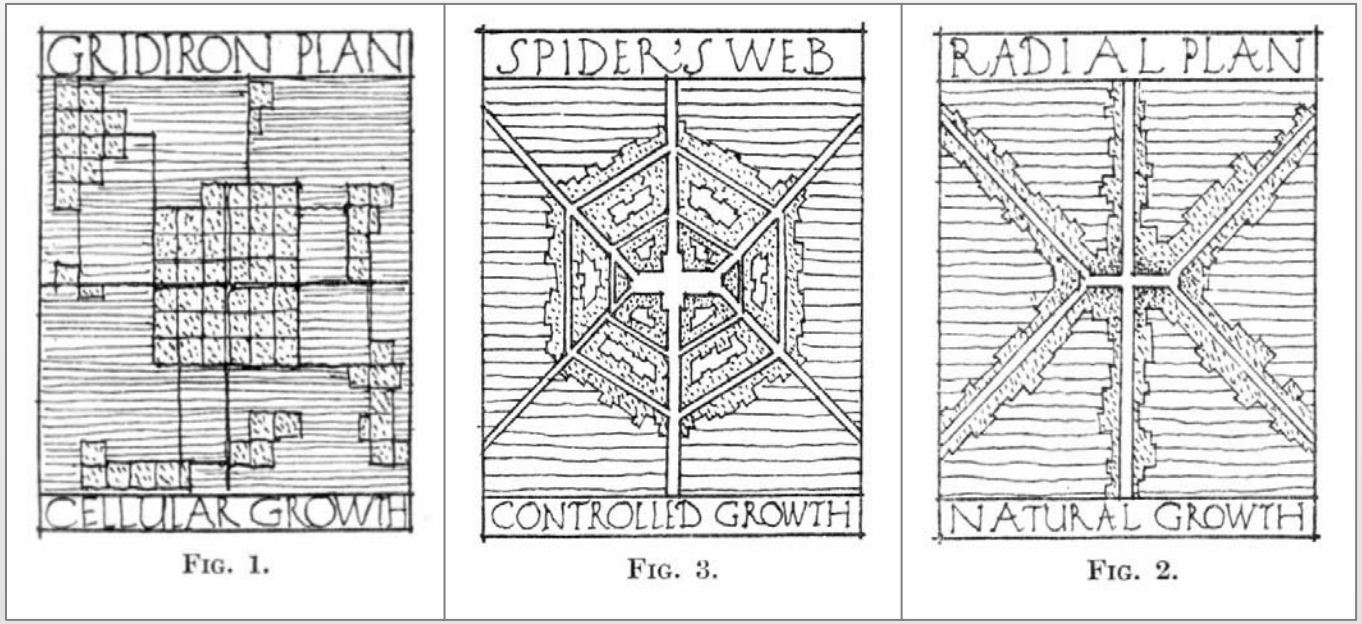


(vi)

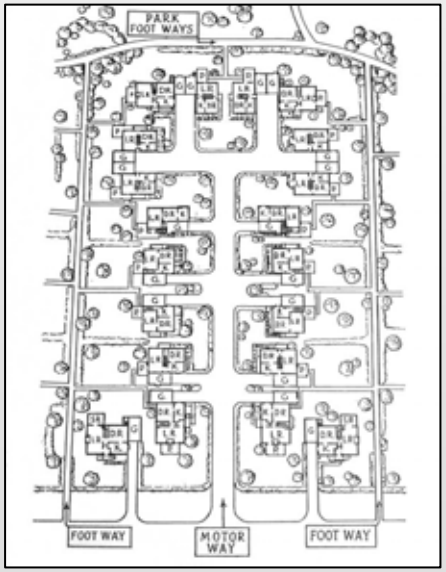
FIG. 17 PLANNING THEORIES

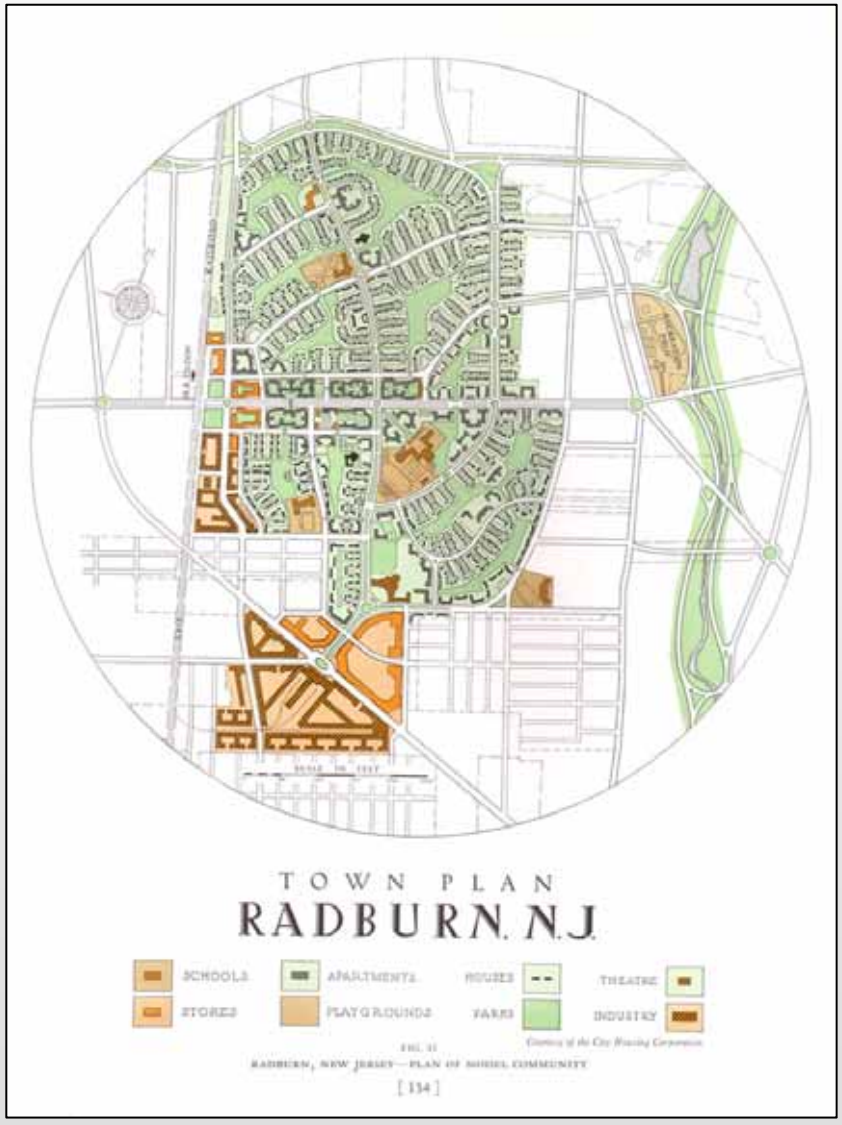
(i) The original Ciudad Lineal.
(ii) Garnier's " Cité industrielle ".
(iii) Part of a lineal plan for Stalingrad.
(iv) M.A.R.S. group Plan for a lineal London.
(v) Le Corbusier's " City of Tomorrow ".
(vi) Chandigarh.

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



Note that these forms are highly suggestive of generative models but let me digress briefly about the word 'city' and 'town' for one minute. I should perhaps digress about 'science' but that can wait.





Modular design: an early ‘new town’ RADBURN, NJ, 1920s

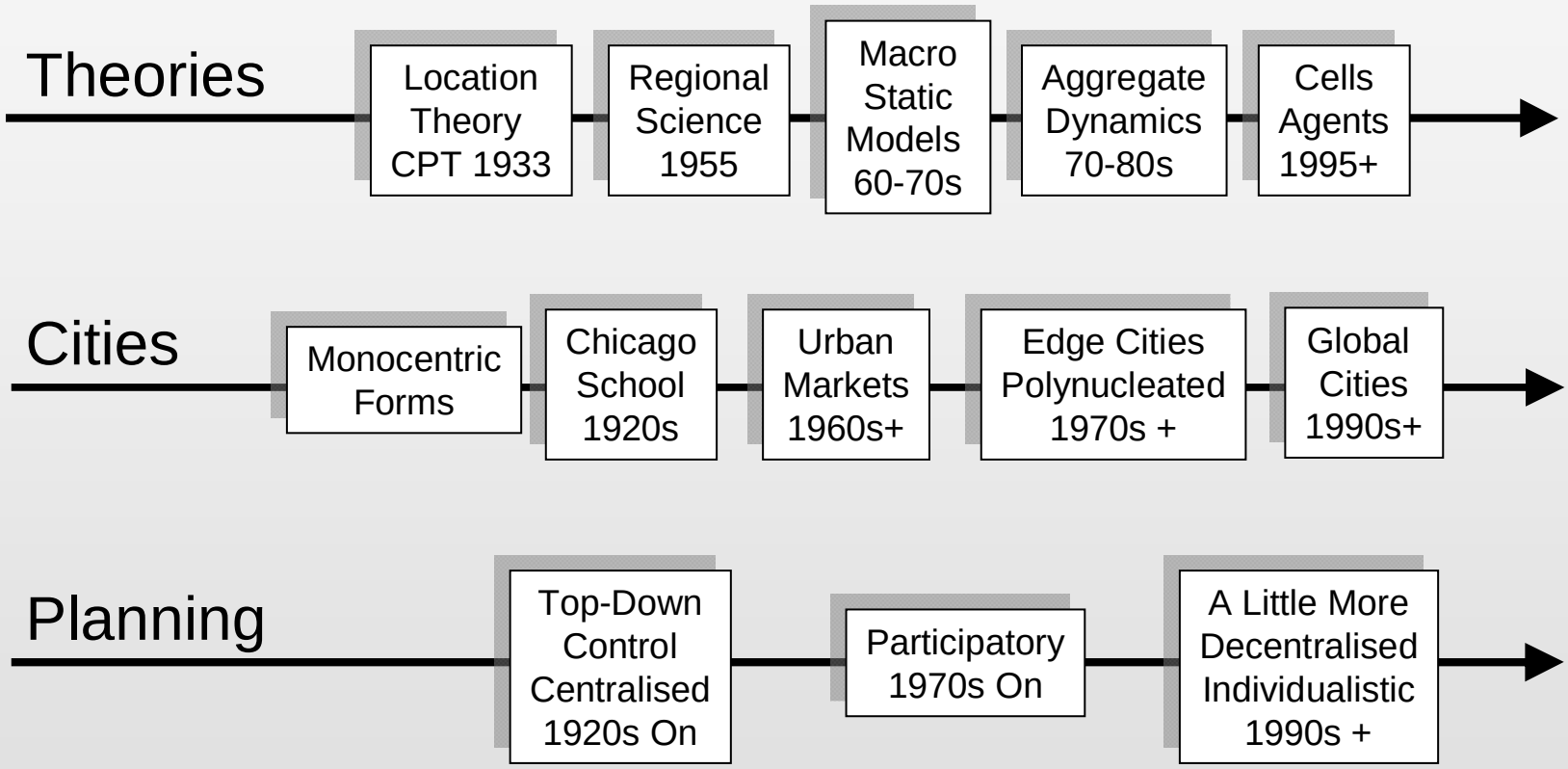
We are still fascinated by form today, as witnessed in more recent examples such as the planned developments in places like Dubai, arguably even more extreme than these more modest layouts of the early and mid 20th century

Attempting to Explain Location, Place and Space: *as Social Physics, Economics and Transportation*

Ok let me try to begin by sketching the various currents that began to fashion an understanding of cities as a science during the 20th century

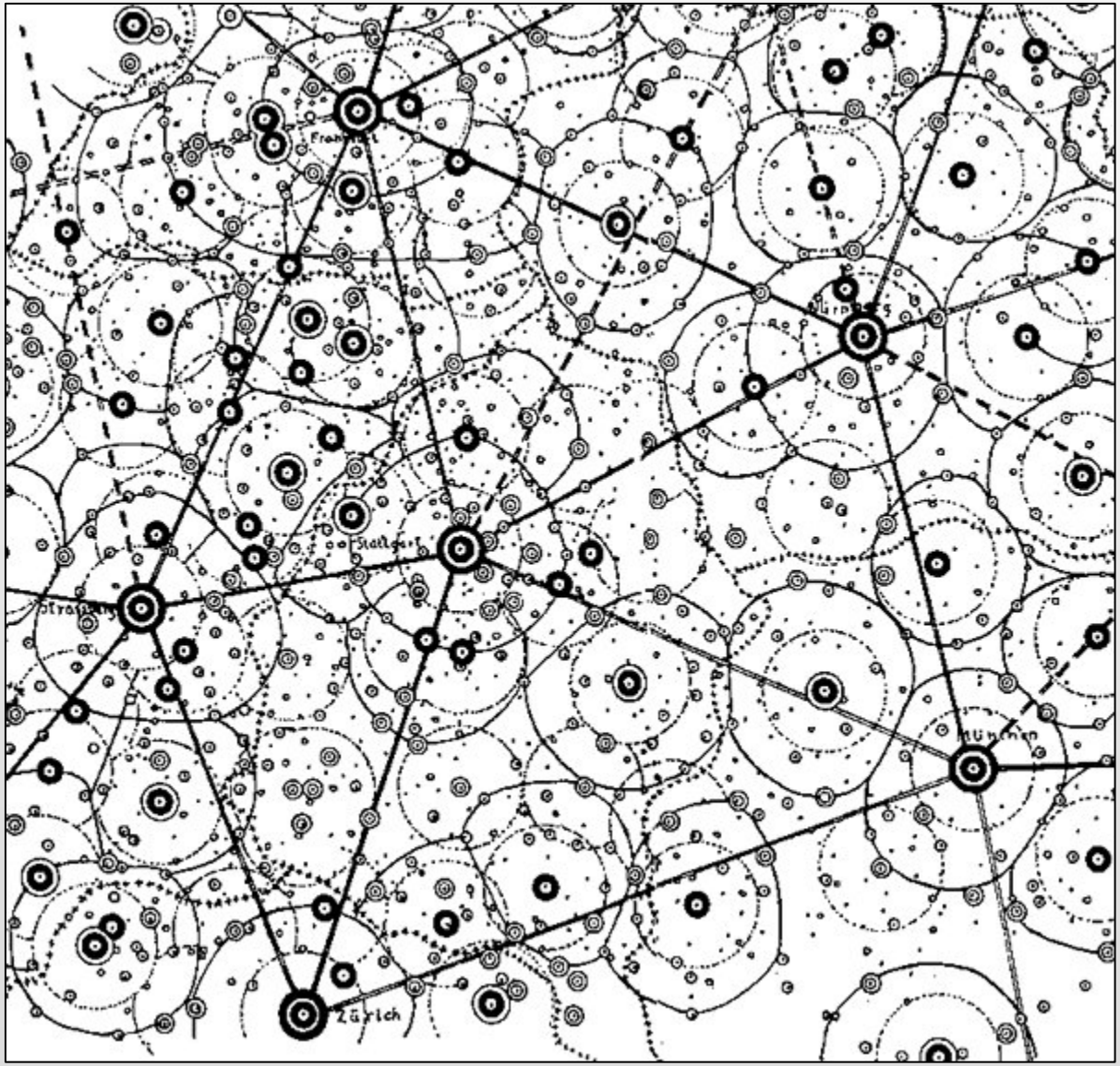
First I will sketch a chronology of ideas and then begin to sample them. It is a tall order to give you anything but a sample on such a wide canvas but I will try.

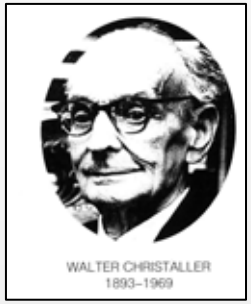
I will also attempt to see these in terms of ***size, scale, shape of location (actions) and interactions*** - watchwords for what a new science might be about



19th century industrial city …… 21st century global city

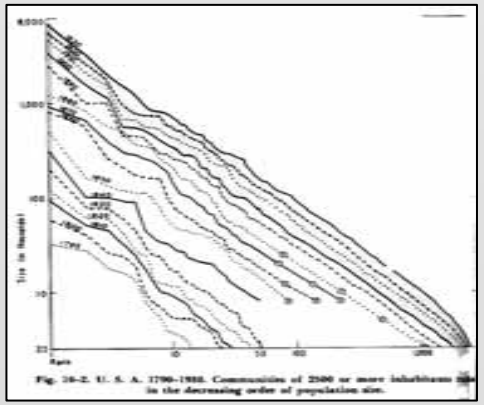
Economics between cities: Hierarchy, Size, Shape & Scale



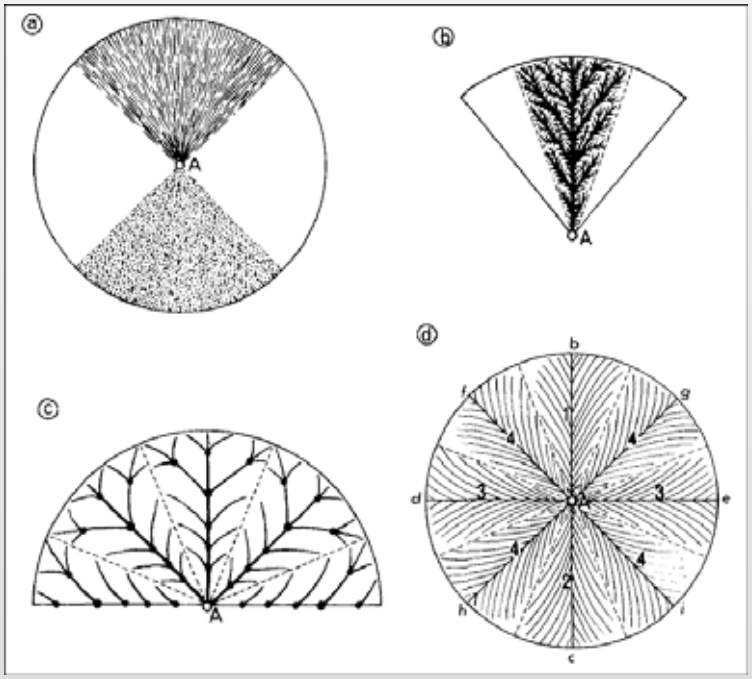


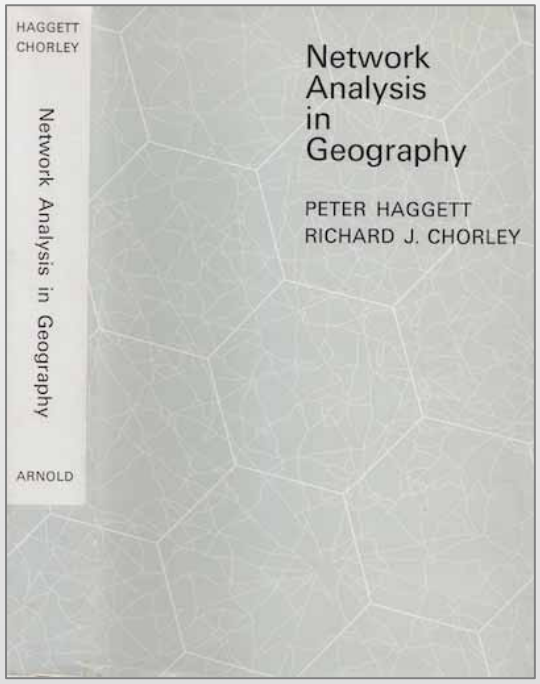
Losch

Zipf



There were several much earlier statements in fact: Kohl (1841) *Traffic and Settlements of People with Regard to their Dependence on the Morphology of the Earth's Surface*

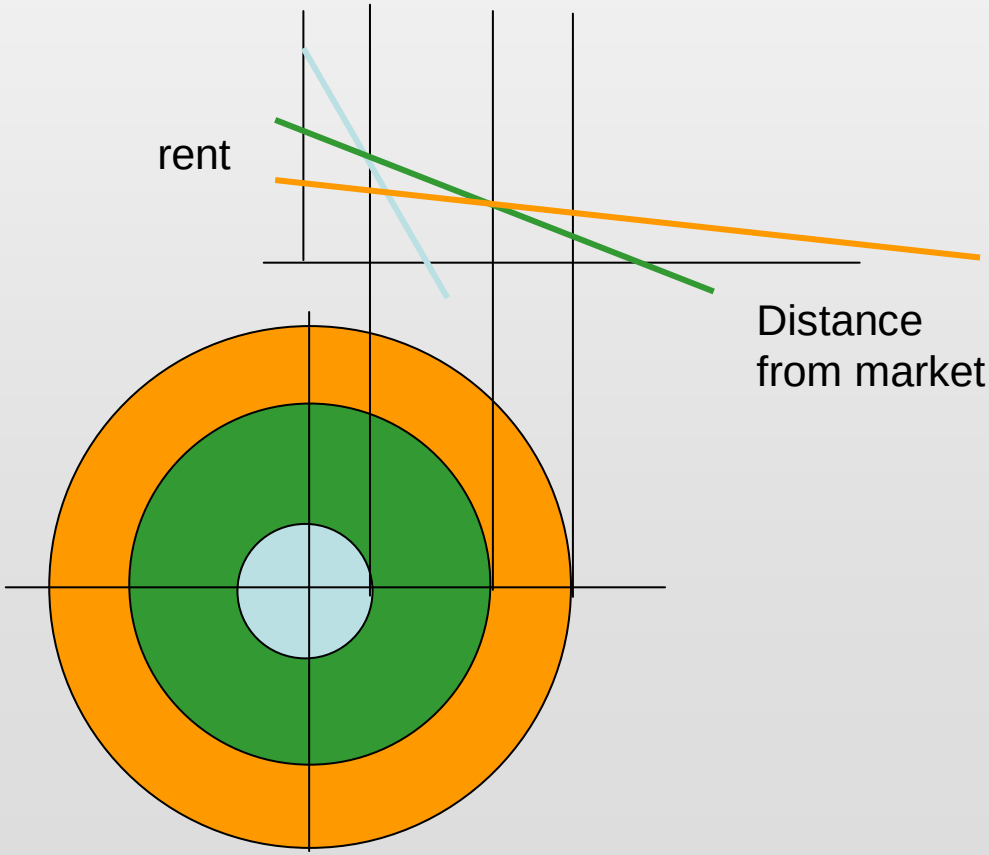




And in 1842 Jean Reynaud produced a version of Central Place Theory; latterly Haggett & Chorley 1969

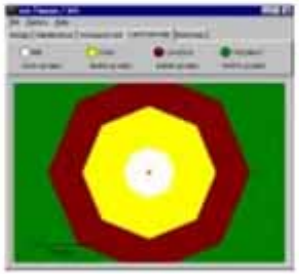
Economics within the cities: Price – Intra-urban, scale and size with shape implicit

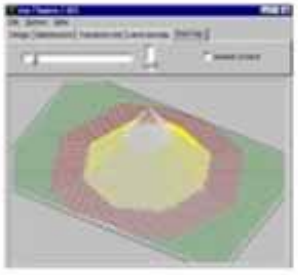
The best model I can show of urban economics in the mid to late 20th century is von Thunen's – of 1826



I have a little model to demonstrate this and it really contains everything we know about how accessibility shapes land use and how rent is determined. It relates a little to shape as well

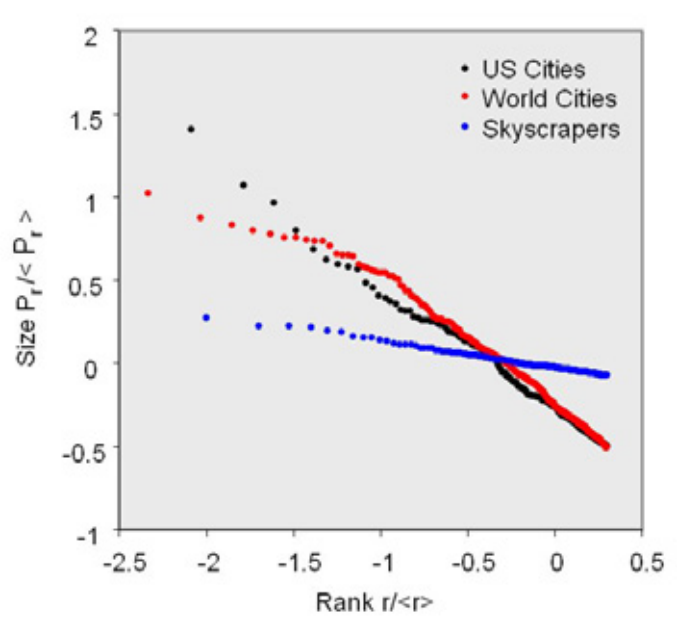
Von Thunen

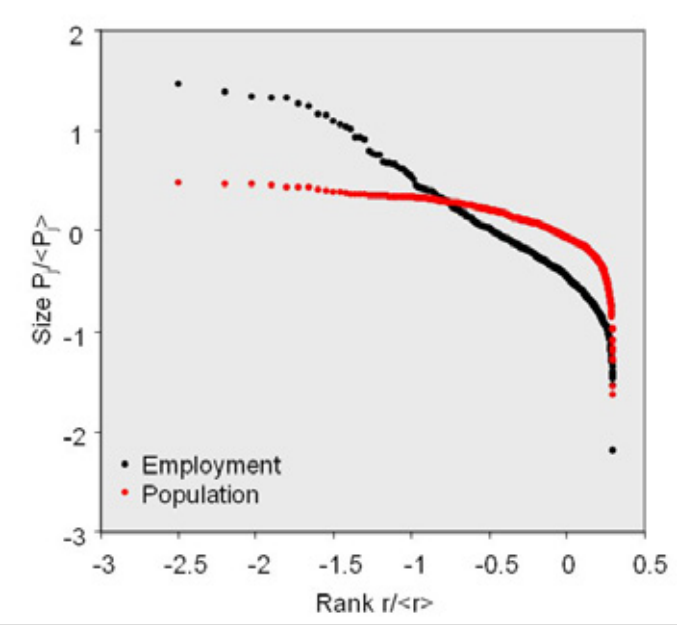


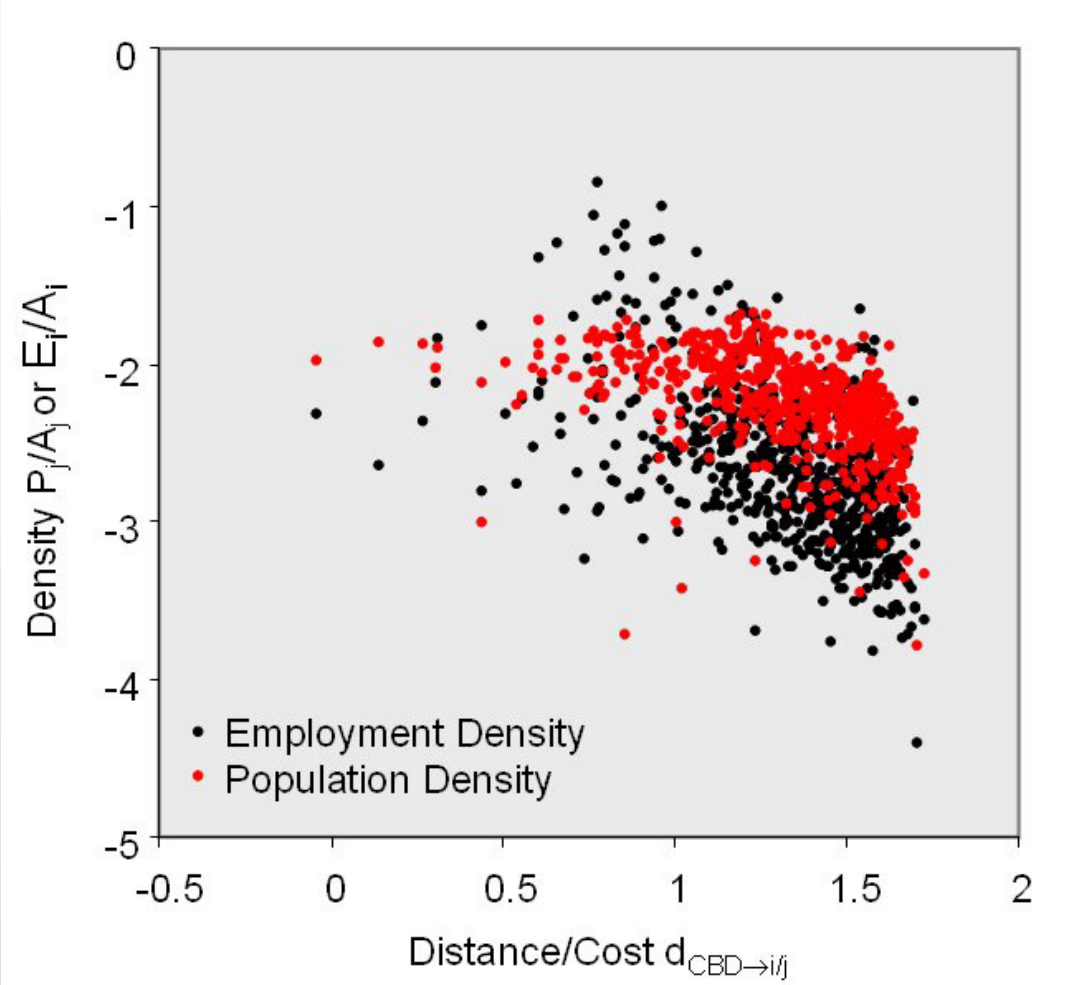


Spatial Interaction: A long history of application of the gravity model which treats distance as a scaling phenomena. I don't have time to go into this in detail but worth noting that the von Thunen monocentric city rent model is really a one dimensional spatial interaction model

Worth noting too that as yet a complete set of ideas about ***scale, size, shape, hierarchy*** for ***locations and interactions*** defining ***systems of cities*** (inter-urban) and the ***city system*** (intra-urban) has not been assembled but could be. Let me finish this brief section by pointing to the difficulties of fitting these kinds of idea to data and show some of these for London.


US Cities
World Cities
Skyscrapers
Size $P_r/< P_r >$
Rank r/<r>


Employment
Population
Size $P_j/<P_j>$
Rank r/<r>


Employment Density
Population Density
Density P_j/A_j or E_i/A_i
Distance/Cost $d_{CBD \rightarrow i/j}$

Systems Models, the Transition to Complexity, and Urban Networks

In the 1960s, there was some sense that we needed to underpin cities with comprehensive theory and the systems approach became popular. Systems conceived as being in equilibrium – another massive limitation of the emerging theories but fitting them rather well.

And top down in terms of their organisation – and control – fitting rather well the predominant model of planning that had become widely established since the end of the 19th century.

Onto this scene came aggregate, equilibrium, operational meaning empirically grounded in data and applicable for practical prediction, transport then land use-transport models.

The heritage of these models largely built around spatial interaction and discrete choice theory in terms of travel demand are still with us today. These models are policy-orientated, large-scale, fit rather badly, and tend to be one-offs. And they persist …

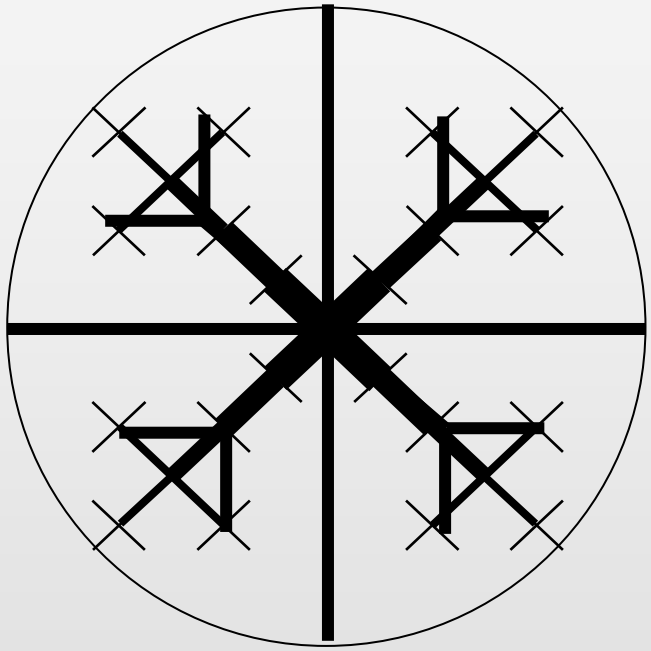
I talked about them yesterday in detail but they have evolved and new kinds of models have emerged, particularly those focussed on temporal dynamics and disaggregation to the level of individuals – **agent based models** and **microsimulation**

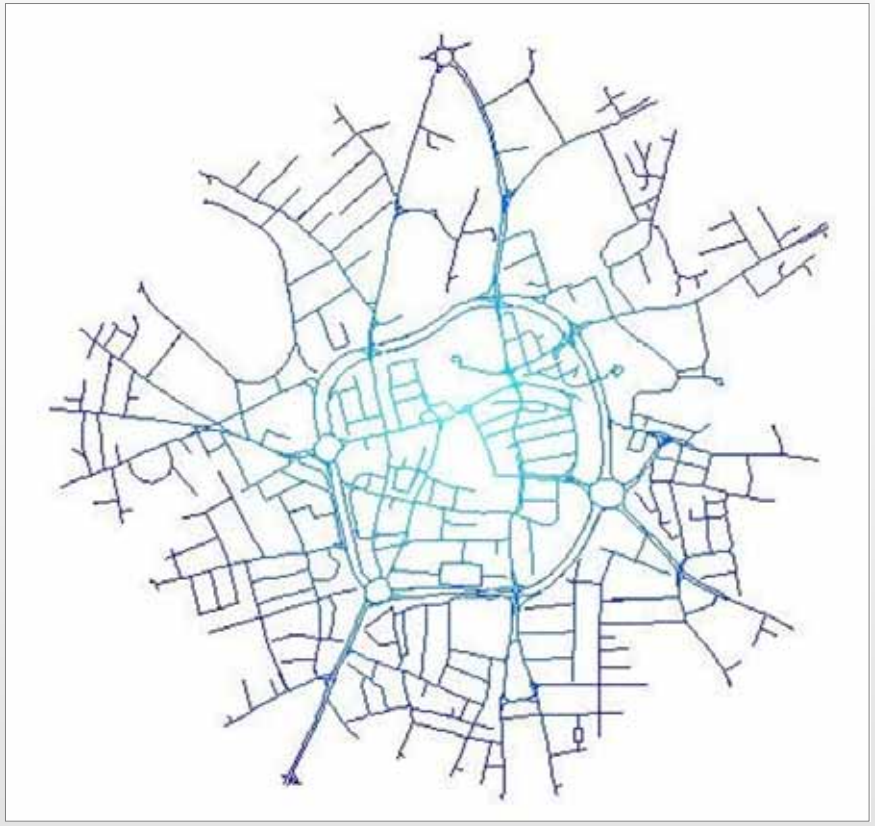
The models I talked about yesterday are much more disaggregate and some quite interesting developments from the TRANSIMs work at Los Alamos – in particular MATSIM, UrbanSim and so on.

Notions about modelling individual behaviours are key to these developments but this raises the problem of validation which is much more problematic for these types of model which are intrinsically dynamic and focus much more on multiple processes than the aggregate models that came first.

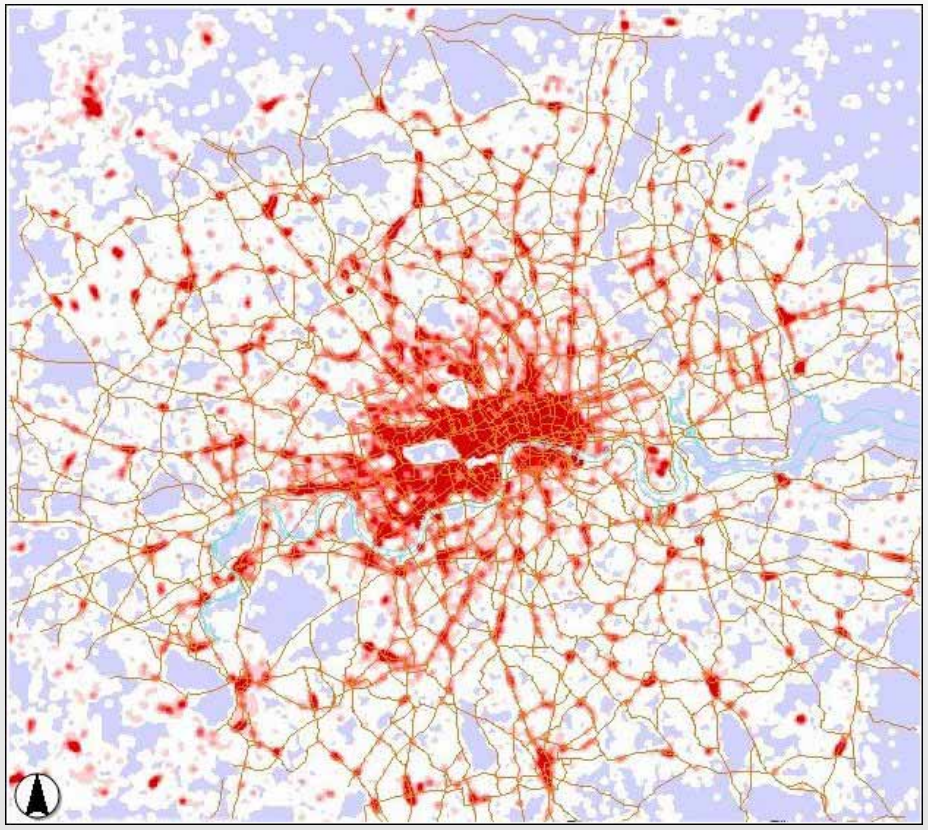
I will say a little about these later but before I do, I need to raise one key issue that we have been talking about throughout this school and that is networks

Systems of course are often defined in terms of networks, usually defined in fact and generically a system is as set of elements that interact in some way to some purpose. In this sense, the interactions are networks and flows. We have spent a bit of time on flow yesterday and Vito talked a lot about networks. Luis also talked so here I will simply fill in a little background focussing on how space is filled –



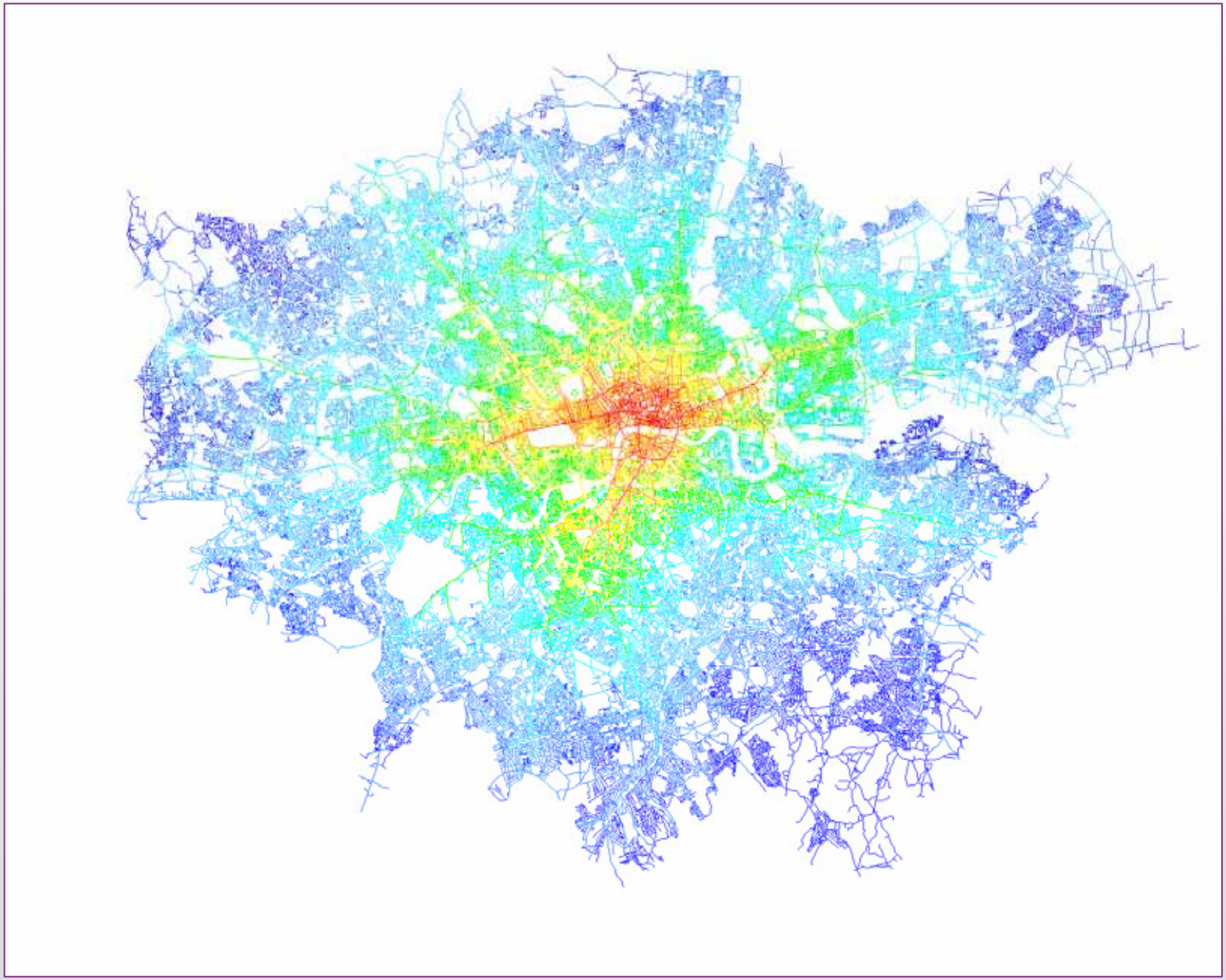


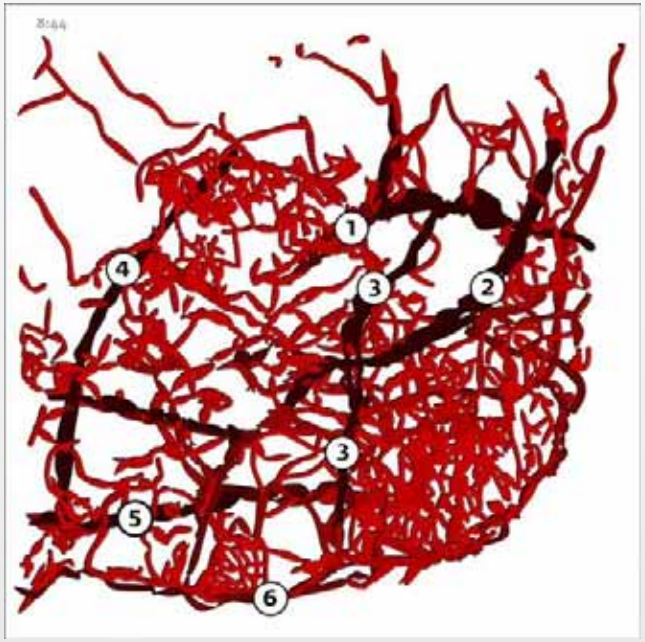
This is a small English town Wolverhampton population about 400,000



This is a large city: Greater London population about 8 million

Some examples of networks in cities, mainly London

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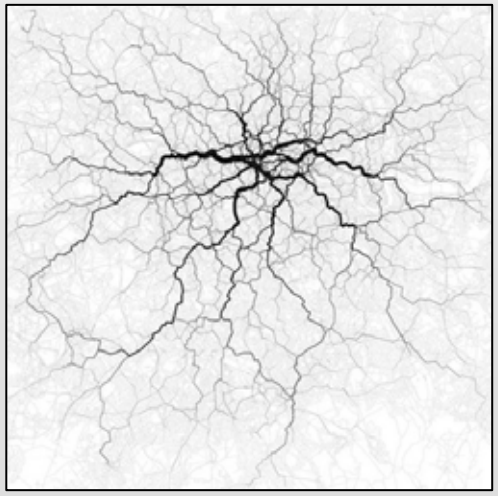


Enter Time: Generic Models, Agents, Cells, and Cities

So far most of this science has been a timeless science, a world in equilibrium for obvious reasons. Cities look like they are in equilibrium physically because of the inertia of the built environment, temporal data is inordinately hard to get and so on.

In the 1970s, there were many flirtations with chaos and catastrophe theory, with bifurcation theory and some models were developed theoretically

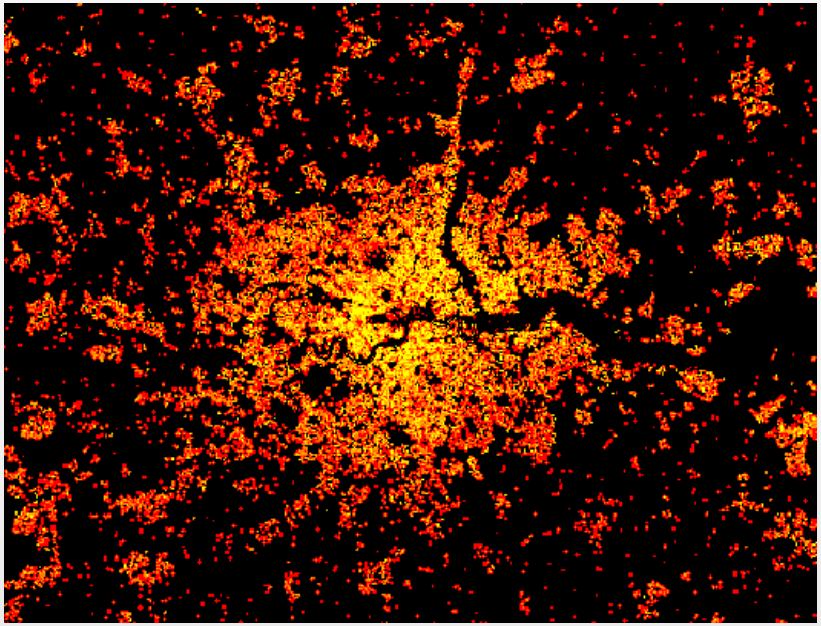
Progress was slow and probably the most significant is the embedding of interaction theory into predator prey models to simulate rapid growth

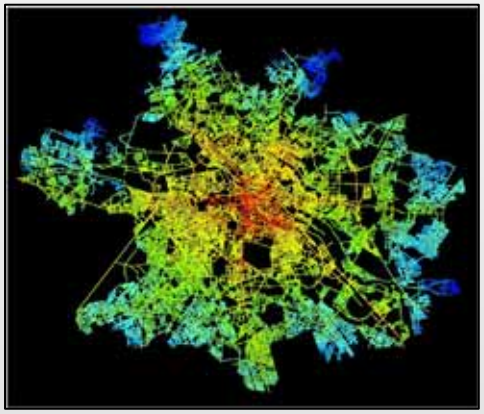
But by far the most significant were notions about how urban structures might be generated akin to the way fractal structures grow and this meant that the mantle of physicalism continued. Let me show some more pictures of what the focus was – explaining urban growth using **fractal models**

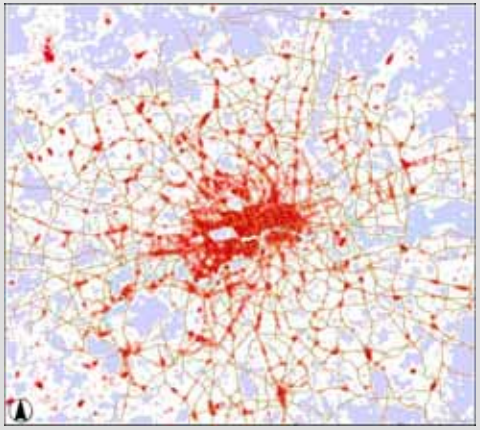
In fact a good deal of this was anticipated in the early quantitative geography movement beginning in the late 1950s where there was a concern for morphology.

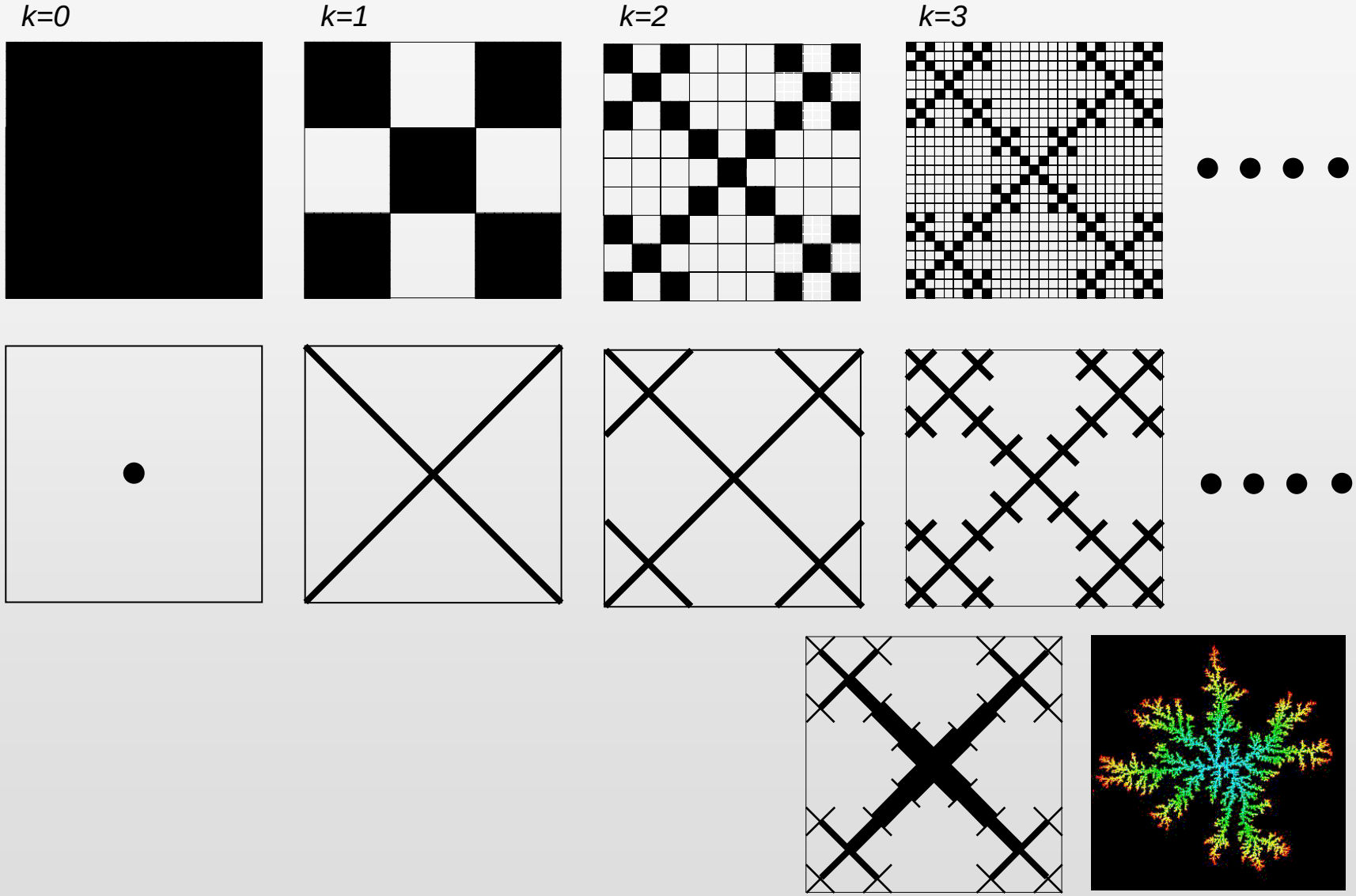
And the implementation of these ideas was generally based on cellular automata kinds of algorithm.

Let me show how these kinds of models might be built.







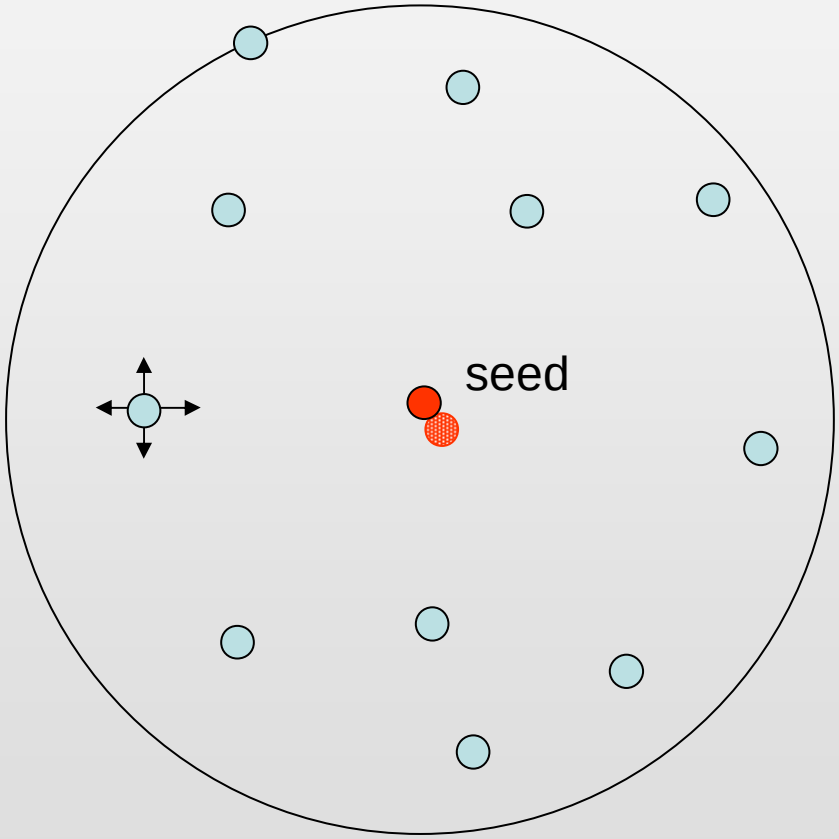

k=0
k=1
k=2
k=3

Ok, let me show you the simplest possible model of an organically growing city – this is the fractal growth model called Diffusion-Limited Aggregation – developed by Witten and Sander in the 1970s. For a city we can argue that it is based on two simple principles

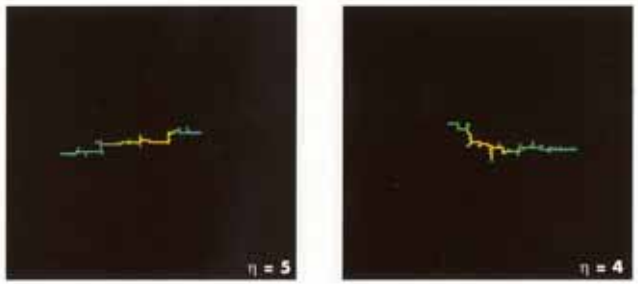
- *A city is connected in that its units of development are physically adjacent*
- *Each unit of development wants as much space around it as it needs for its function.*

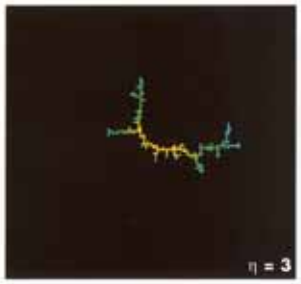
We start with a seed at the centre of a space and simply let actors or agents randomly walk in search of others who have settled. When they find someone, they stick. That is all.

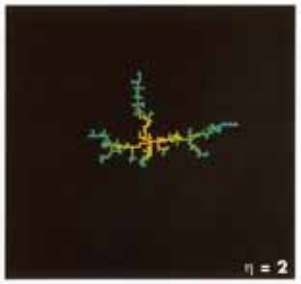
In essence, this is random walk in space which is can be likened to the diffusion of particles ○ around a source ● but limited to remain within the influence of the source – the city

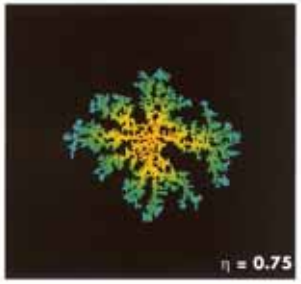


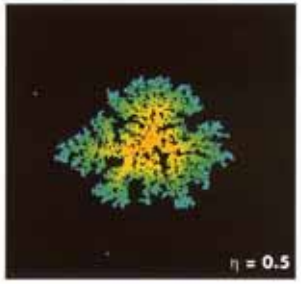
We can run a little program to show this. Let me try

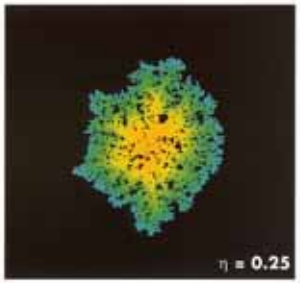












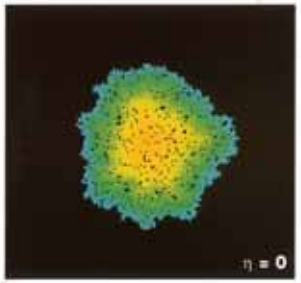
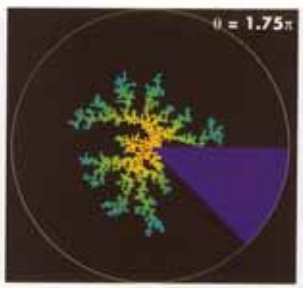
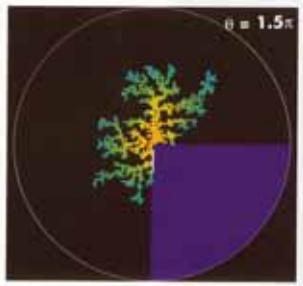


Plate 8.4 Urban Forms Generated by Systematic Distortions to the DBM Field





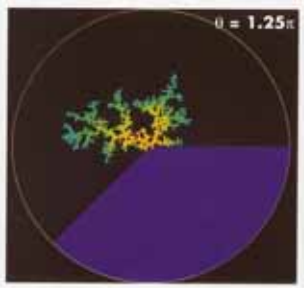


Plate 8.2 Physically Constrained DBM Simulations

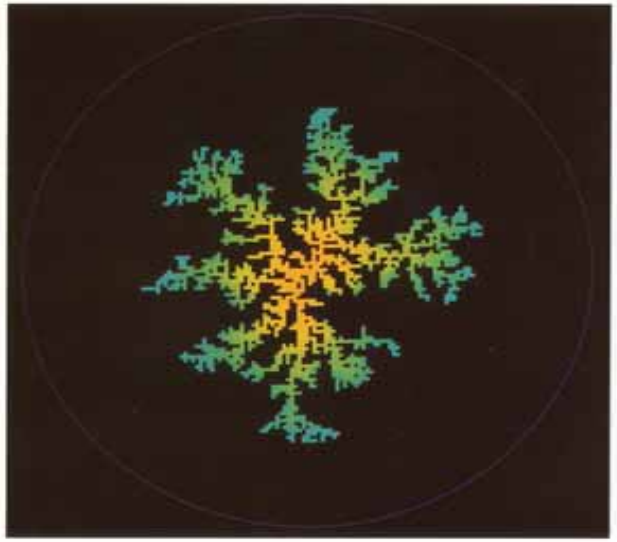
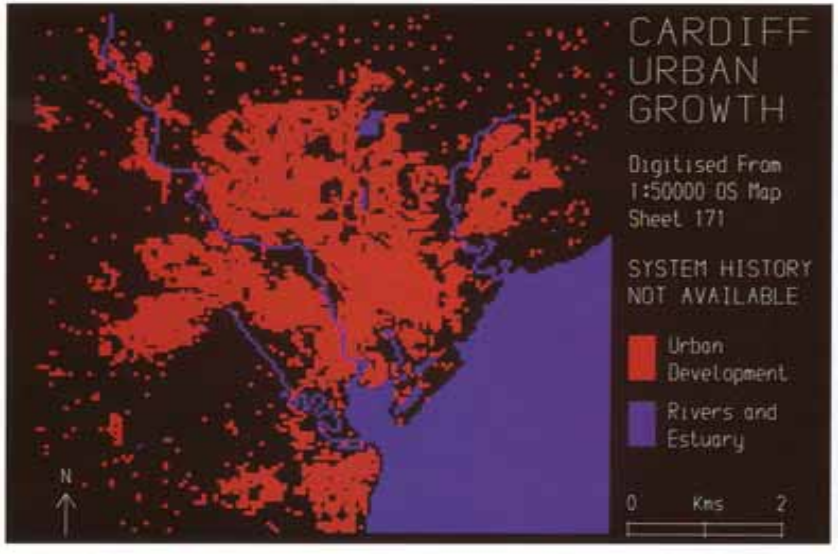


Plate 8.3 *(left)* The Baseline Simulation η =

Plate 8.5 *(below)* The Urban Area of Cardiff.



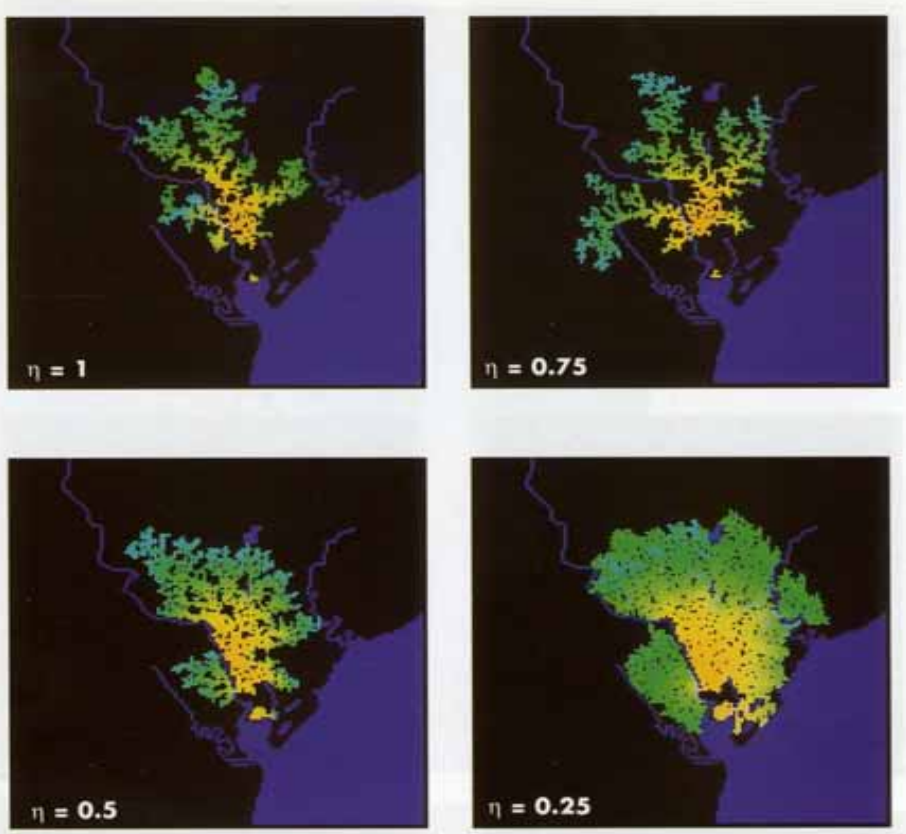
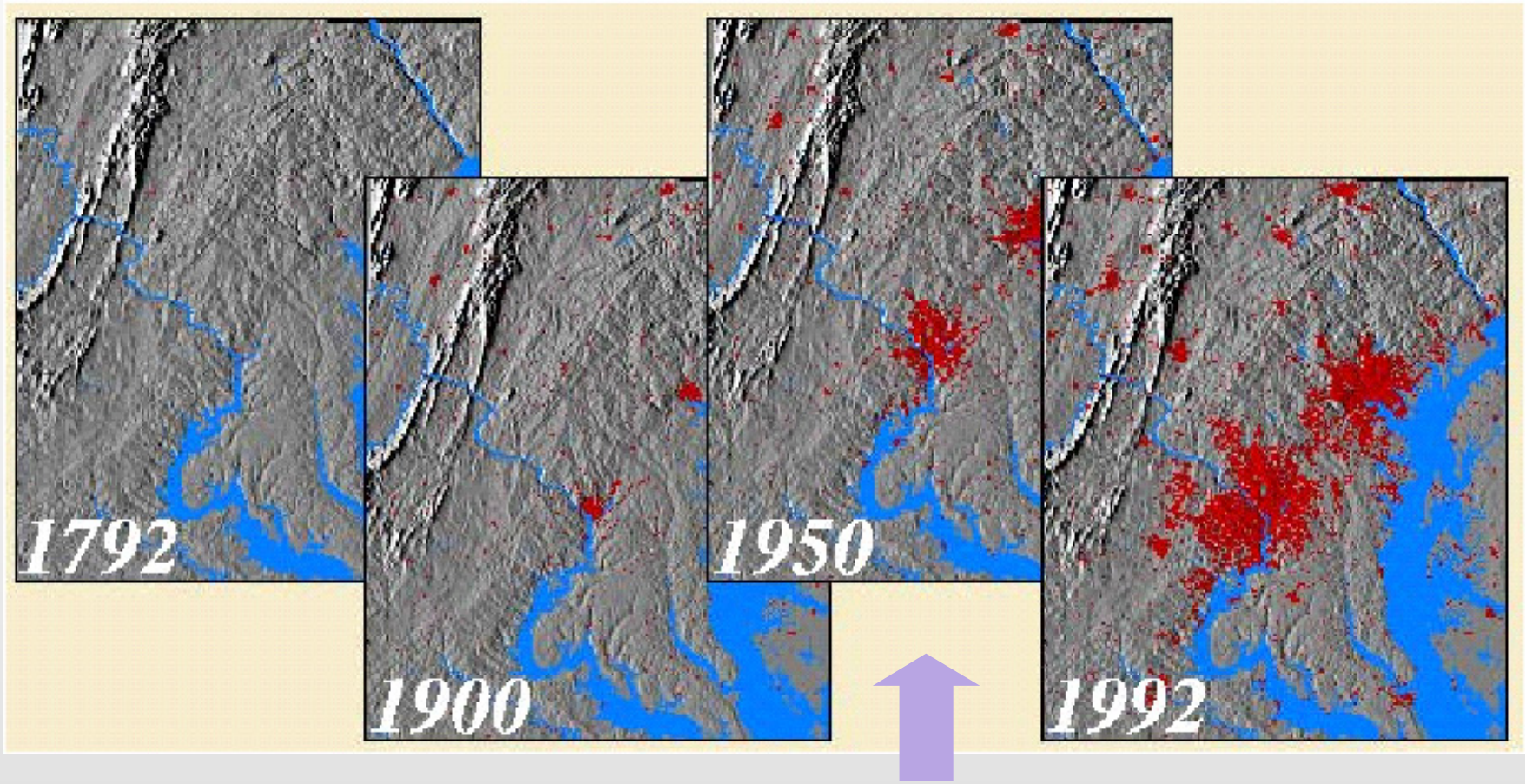


Plate 8.6 Simulating the Urban Growth of Cardiff

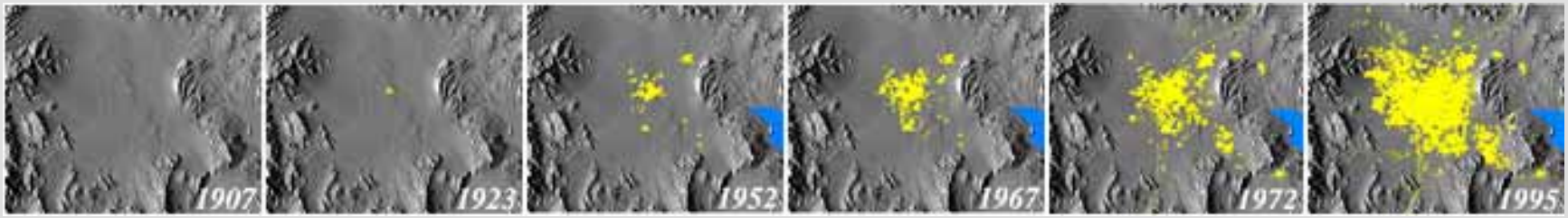
These kinds of idea have been implemented as cellular automata models and a flurry of such applications have been developed. One problem is that they lack a specific transportation dimension – in that although cells have fields around them that enable them to influence other cells – these tend to be simple links and do not incorporate any notions of flow

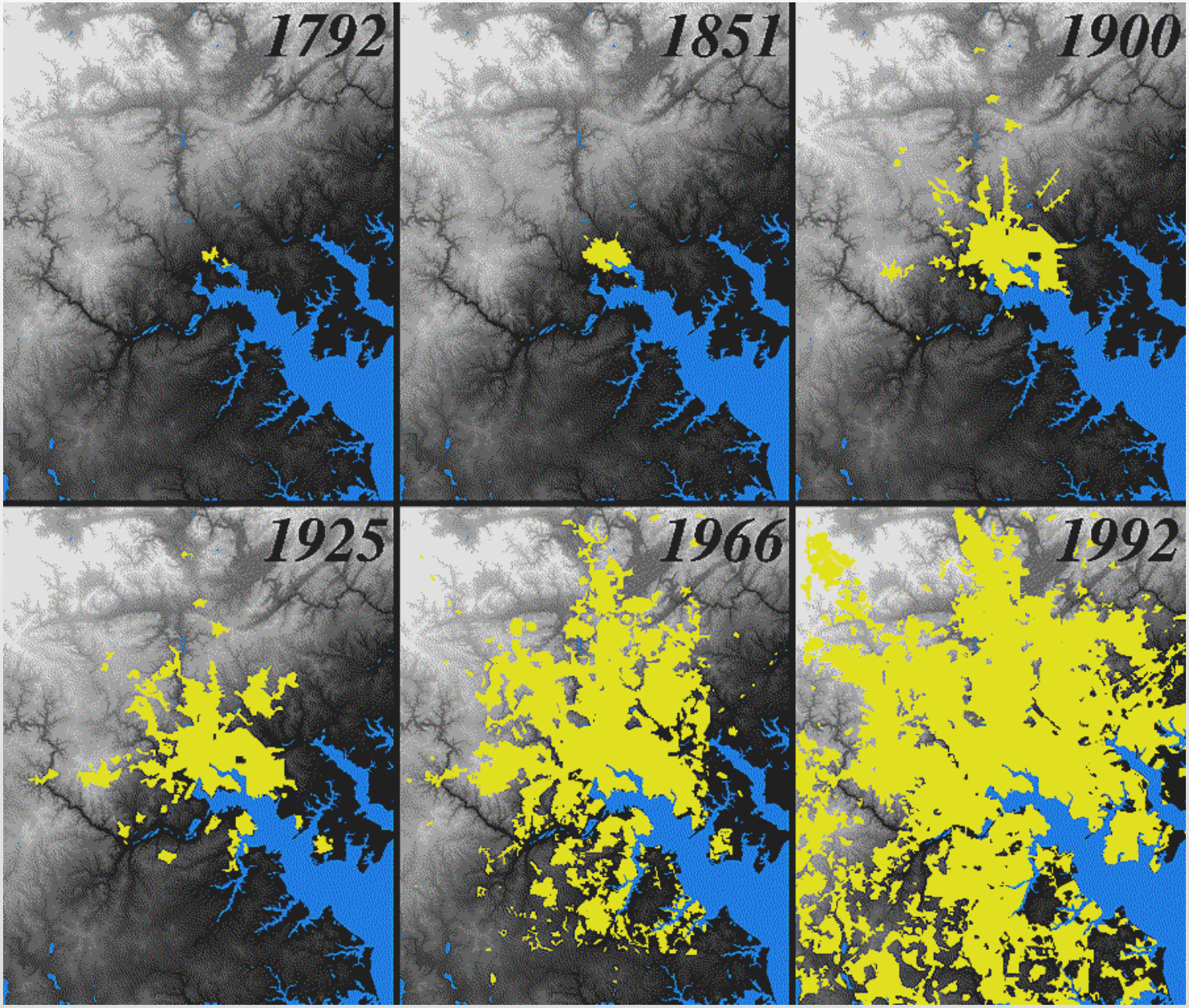
In that respect they are less operational than their forerunners that I talked about yesterday.

I show two variants here – the work of Clarke on his Gigalopolis project funded by USGS and some of our own work on west London.



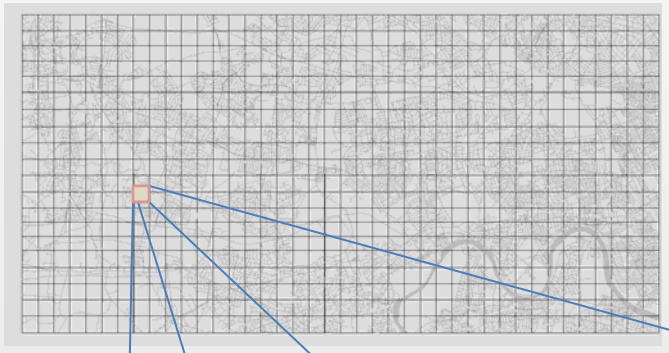
Growth through time: Washington DC-Baltimore Las Vegas




1792
1851
1900
1925
1966
1992


Greater
London
Canvey Island
Isles of Sheppey

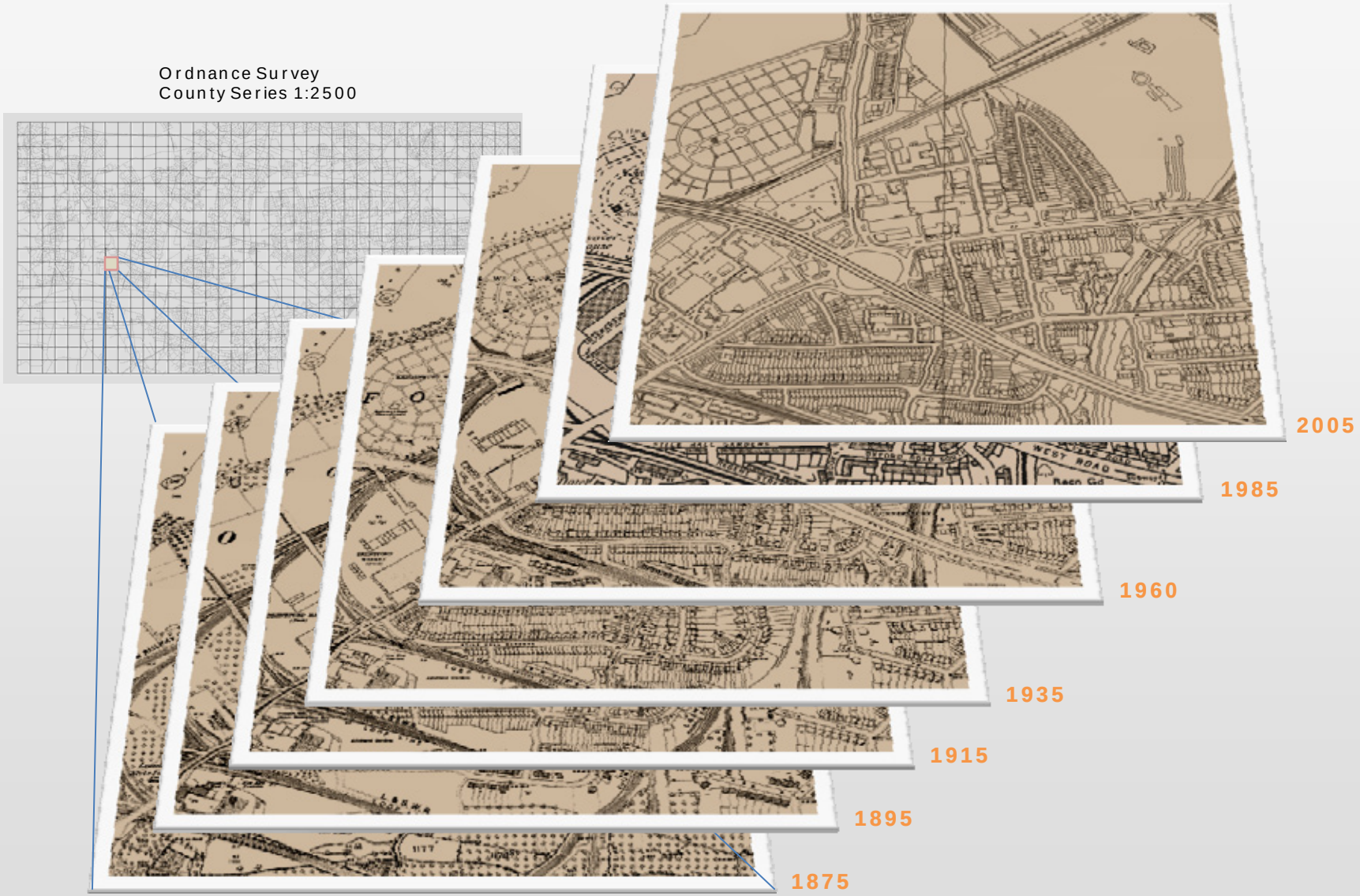
Ordnance Survey
County Series 1:2,500



1 : 2,500

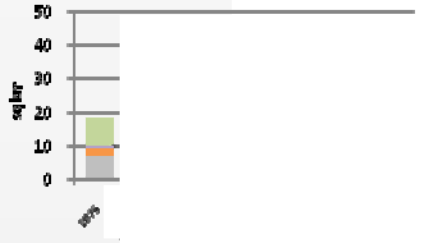
1 : 10,000

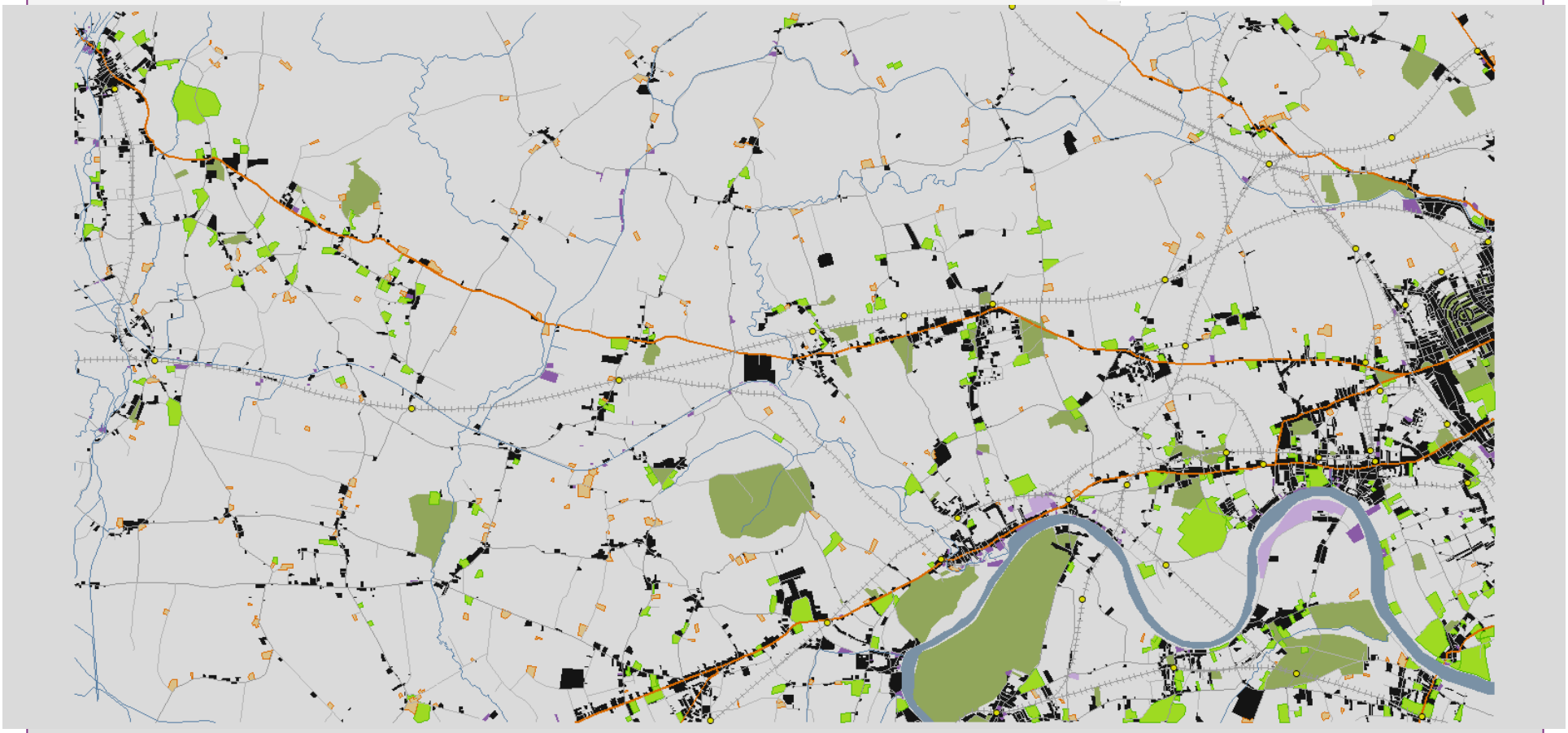
1875


Ordnance Survey
County Series 1:2500
2005
1985
1960
1935
1915
1895
1875

1875 spatial structure

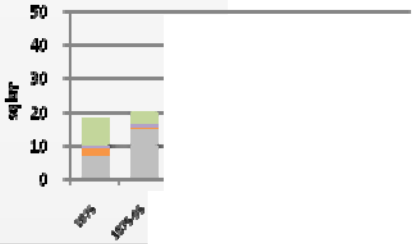
1875 development
industrial uses





1895 spatial structure

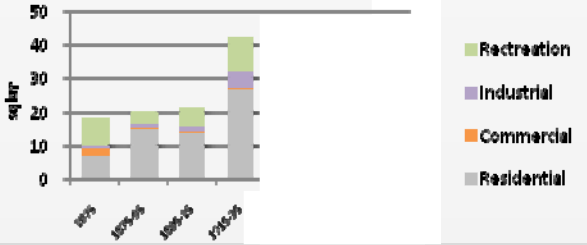
1875 development
1875-95 development
industrial uses




1875 development
1875-95 development
1895-15 development
industrial uses
50
40
30
20
10
0
sq km
Recreation
Industrial
Commercial
Residential

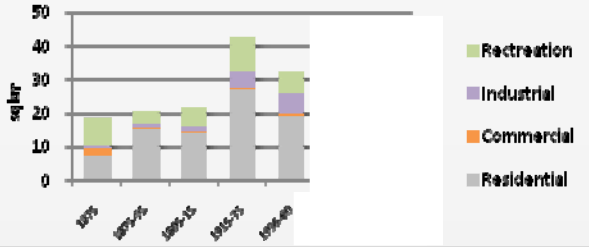
1935 spatial structure

1875 development
1875-95 development
1895-15 development
1915-35 development
industrial uses



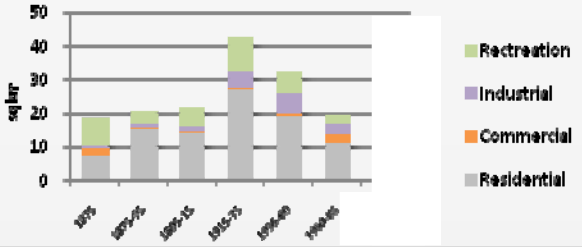
1960 spatial structure

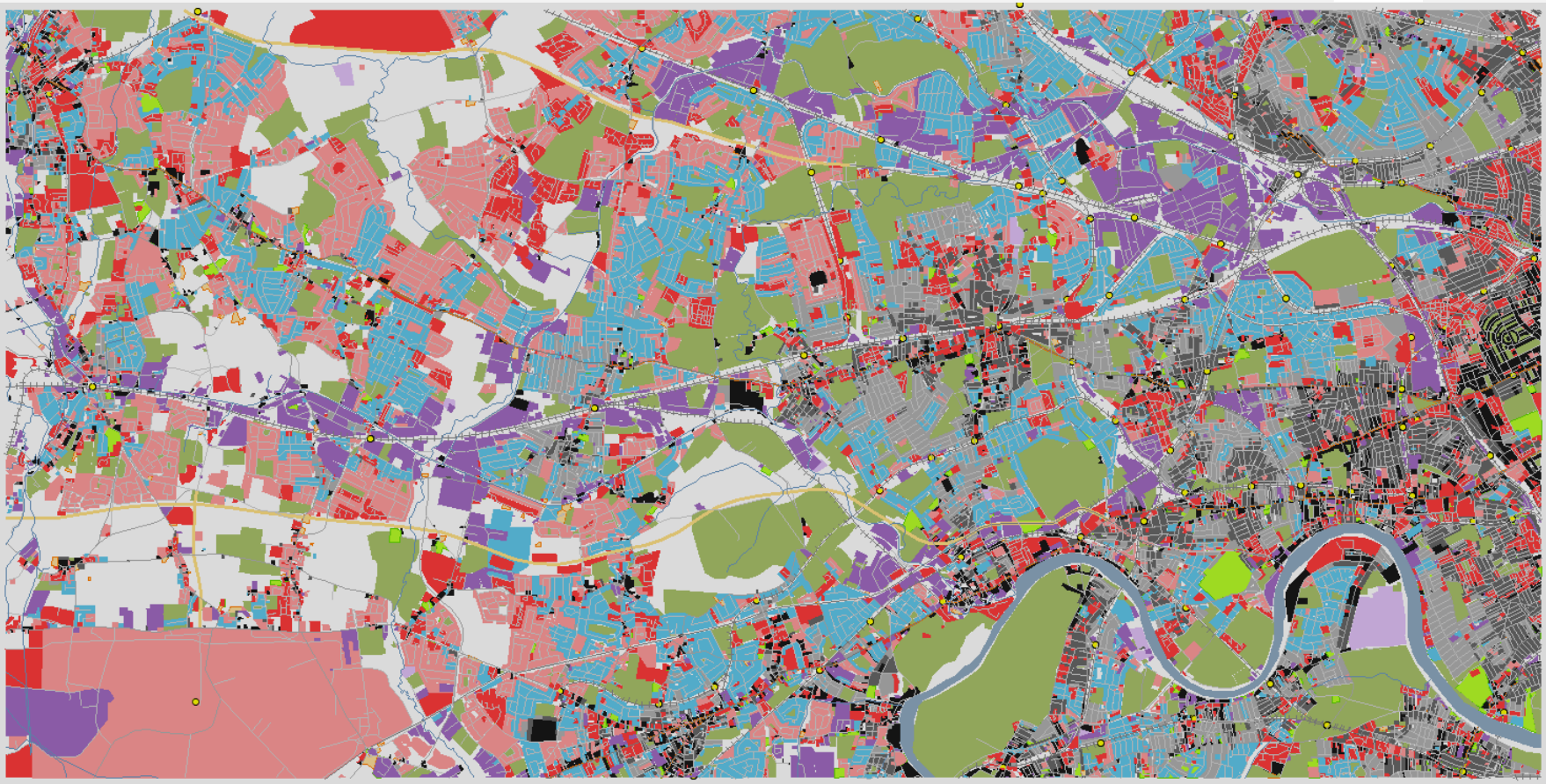
- 1875 development
- 1875-95 development
- 1895-15 development
- 1915-35 development
- 1935-60 development
- industrial uses



1985 spatial structure

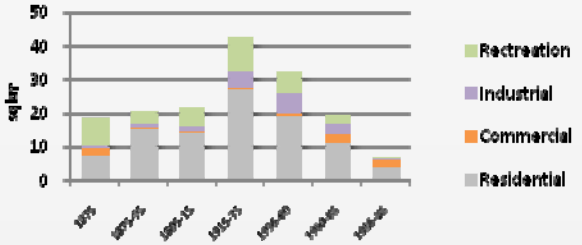
- 1875 development
- 1875-95 development
- 1895-15 development
- 1915-35 development
- 1935-60 development
- 1960-85 development
- industrial uses

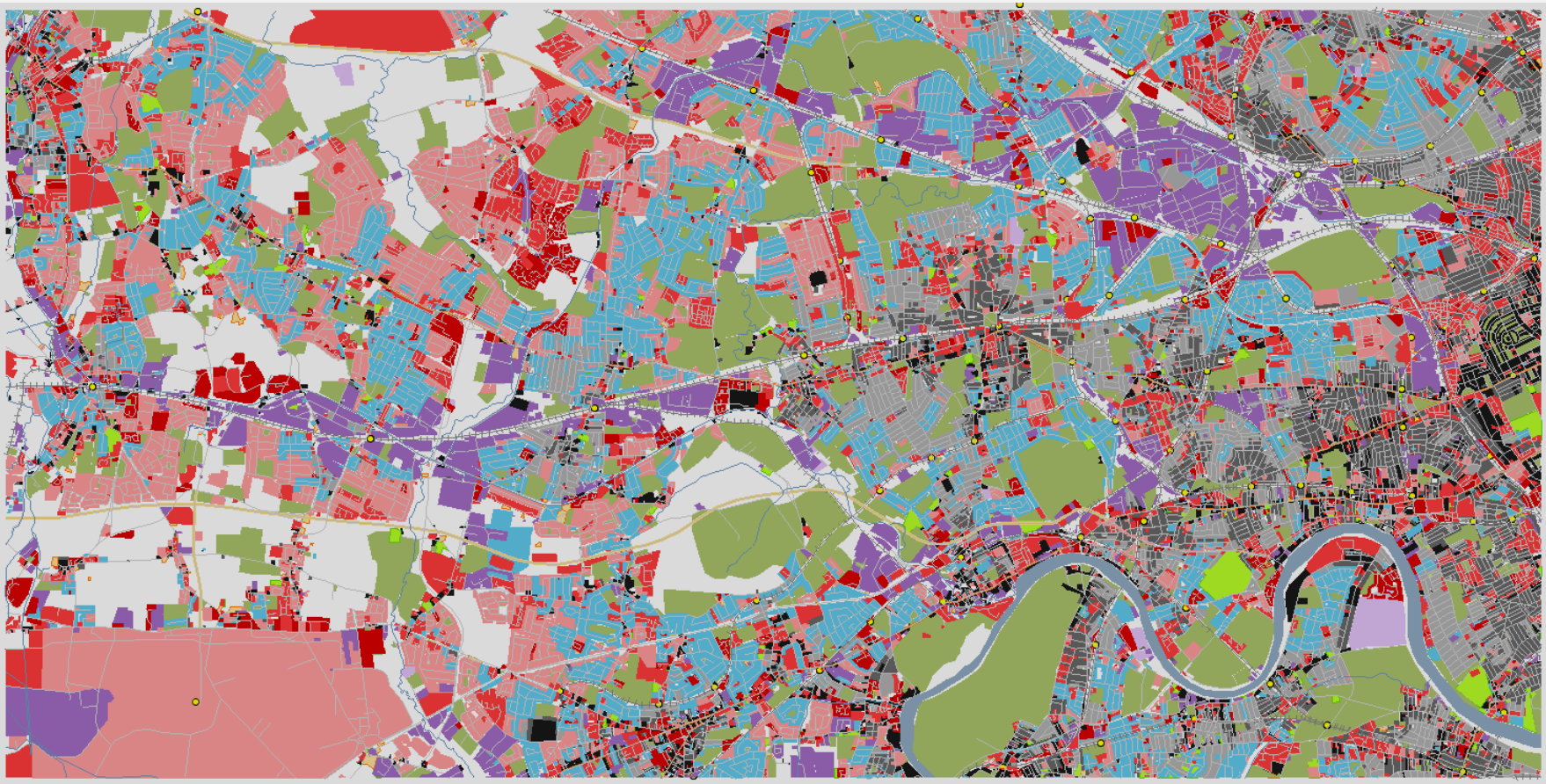




2005 spatial structure

1875 development
1875-95 development
1895-15 development
1915-35 development
1935-60 development
1960-85 development
1985-05 development
industrial uses





More General Theory: Scale, Size and Shape

There are some really key questions that dominate what we have said so far. To a large extent what Luis has said is the real meat of this sort of theory and I will simply make a few key points to finish that relate to this more generally

There are also lots of things that relate to cities and their analysis that I have not talked about – particularly at the fine scales and over short time periods

In so far as the kinds of things I have talked about are tested empirically and there is quite a lot of work on this, their goodness of fit – performance – is poor

In fact many of these models are not tested at all. These processes are rarely tested, their outcomes might be. But let me list some key problems:

- The level at which the system is considered – aggregation v. the individual – to what extent should we be searching for a theory that embraces both consistently. This has been impossible so far in economics ?
- Dynamics – the time horizons over which we need to observe cities functioning – the smart cities, big data focus is shortening these massively but with consequent changes in what we are interested in
- Equilibrium – do such models that we have seen have any place in a theory of cities?

- The extent to which our models should be tested and validated empirically? A place for models as thought experiments and as simulations of a range of outcomes – exploring the solution space.
- The role of prediction more generally in social systems is key, especially in the context of design and prescription
- To what extent should a science of cities embrace design? This raises the whole question of policy
- The age-old question of organically growing versus planned cities needs extensive scrutiny in the wider context of a science based on the evolution of cities
- I have talked about location but interaction is key

- The key focus to me is on ***scale***, ***size*** and ***shape*** applied to ***locations*** and ***interactions*** –which means on activities and actions in fixed places, and on interactions between places
- These can be accomplished at ***intra-*** or ***inter-urban*** scales and a good question is whether we should expect the same processes and structures and patterns to pertain to both
- I am conscious that my focus on morphology has played down interactions, networks, and although these have entered, all and more of what I have said here about locations apply to interactions that have their own morphology.

Attempting a Synthesis

The biggest question of all is should we attempt a synthesis? Even if not, I am sure we need a big picture in which to anchor our efforts.

I realise this has been a rather general talk but I know that some of my colleagues who study cities would consider it to be rather narrow. And that is a paradox

I would welcome comments and of course discussion because I think there are many aspects of this history that we should be cautious about and we need to identify unproductive lines of inquiry. These as we know do not necessarily die out and good ones do not necessarily prosper.

Questions, Comments …

My coordinates again

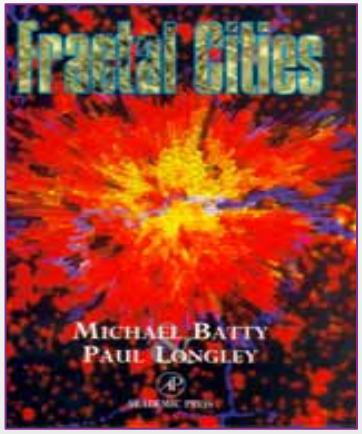
m.batty@ucl.ac.uk

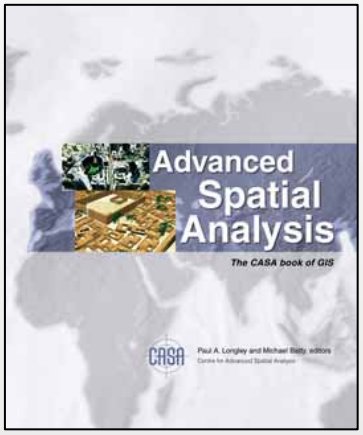
http://www.complexcity.info/

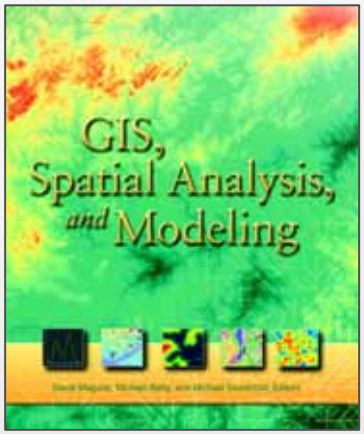
The web site where
you can find this material

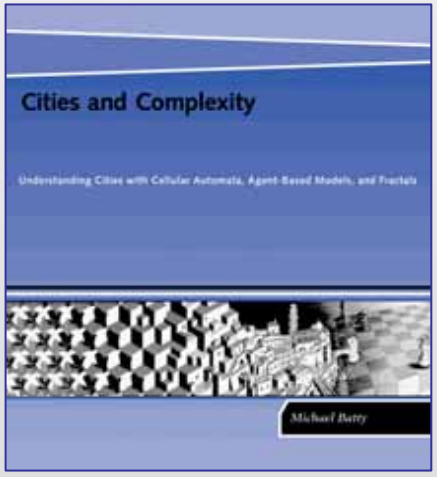
http://www.spatialcomplexity.info

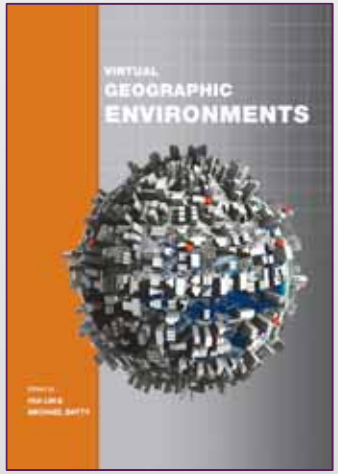
Some of our books which are about some of this

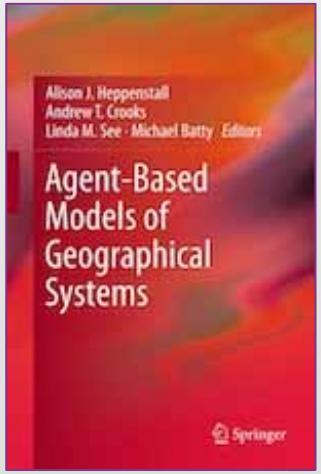


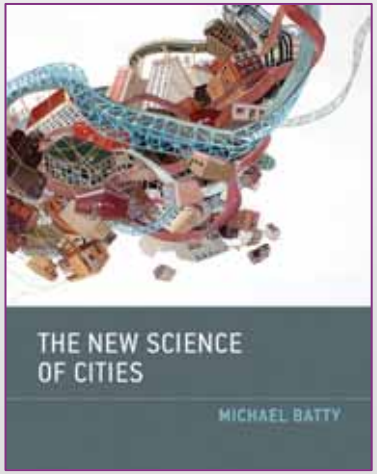












And you will find details of how to get them at

www.complexity.info