URBAN AI

The New Urban Science, Complexity & Big Data

Michael Batty
Centre for Advanced Spatial Analysis
CASA-UCL

17 June, 2022

m.batty@ucl.ac.uk
@jmichaelbatty

An Outline of the Talk

- Not One Science but Many Sciences
- What Is a City? Mumford's Challenge
- A Kind of Science
  - *Regional Science, Location Theory, and Urban Economics*
  - *The Systems Approach*
  - *Operational Models for Urban Planning*
- Complexity and Morphology: Size, Scale and Shape
- The New Science: Statistical Physics
- Smart Cities: The High Frequency City and Big Data
- Using Urban Science to Invent and Plan Better Cities

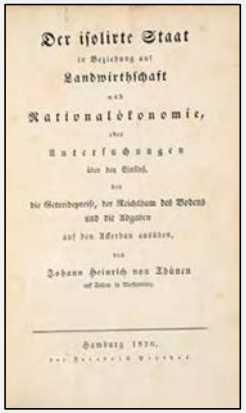
Not One Science but Many Sciences

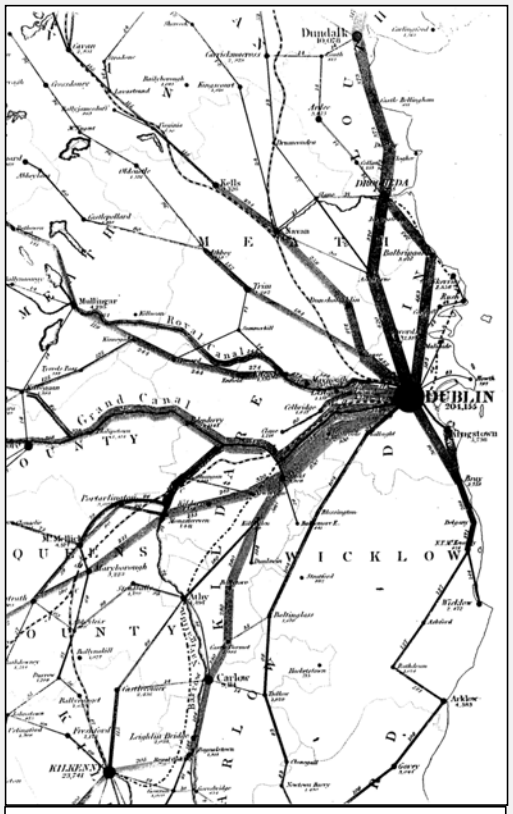
- In this lecture I will develop a picture of how we might begin to transform our knowledge of cities and how we might plan them using what I call the ***New Science of Cities***
- In fact, there is not one but there are ***many sciences*** of the city and the perspective I will outline is only one. ***complexity*** is key to this and so is ***big data***
- But to an extent this new science is being developed in analogy to the development of the physical sciences with a slight nod to the social sciences
- These are changing too from a world of firm predictions to a world where the only thing predictable is 'unpredictability'

- Let me take you back 500 or more years to the Renaissance and then to the Enlightenment which was the prelude to the Industrial Revolution based on mechanical technologies.
- The earliest glimmers of a science of cities can be seen back then – in analogies between mechanics, gravitation, how people move … in the work of Leonardo da Vinci, actually we could go back to the Greeks
- But in terms of cities, other viewpoints prevailed based on less abstract conceptions. In most of the last century, our world was based on the planning cities by rearranging physical form. Before I discuss the transition to new ways of thinking, let me illustrate some of these glimmers from the 19th century

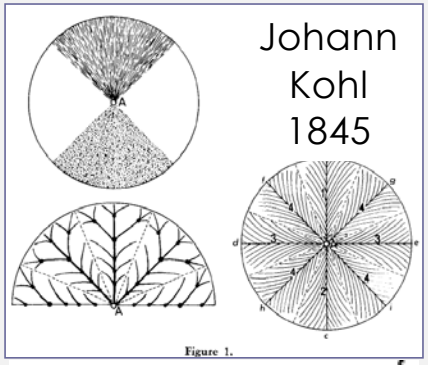


Von Thunen 1826



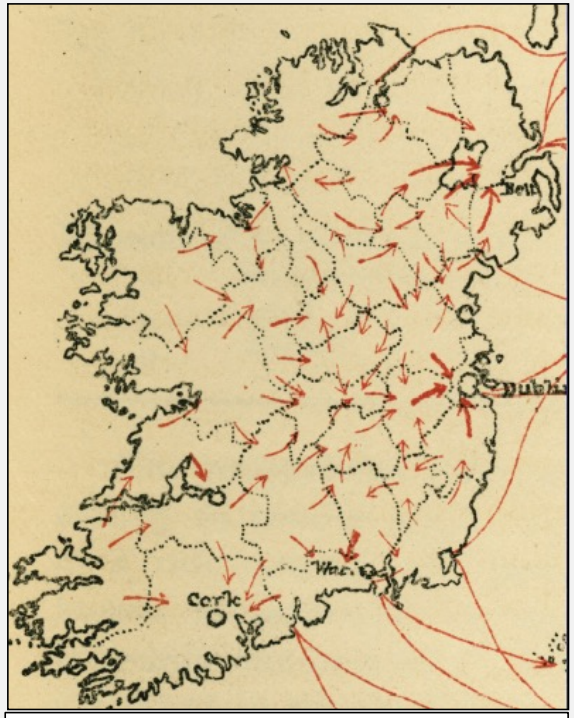


Harness, and the British Army in Ireland in 1837



Johann Kohl 1845





Migration: Ravenstein,1888
He plotted the desire lines using vectors to summarise the main direction of flow

What Is a City? Mumford's Challenge

- I will now fast forward to the first half of the last century. The social sciences were rapidly taking on the mantel of the physical sciences Ideas about how cities were organised were much influenced by the idea that we could treat human systems systematically and rationally.
- Moreover the notion that cities might be treated in simple physical terms was fast eroded by the notion that one could not understand cities without looking at their social structure.
- Lewis Mumford said it all in 1937 in a paper entitled "What is a City?" I have just written an editorial about this in the journal I edit ***Environment and Planning B***

Editorial

B Urban Analytics and City Science

EPB: Urban Analytics and City Science
2022, Vol. 0(0) 1–4
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/23998083221078077
journals.sagepub.com/home/epb
SAGE

Mumford's recurring challenge: What is a city?

In 1937, Lewis Mumford, one of the greatest historians of cities in the 20th century, wrote an influential essay entitled "What Is a City?" in which he argued that cities should primarily be considered as social institutions rather than physical artefacts. Everything about a city, he argued, such as its size and the organisation of its economic activities could only be understood as part its social functioning. In hindsight, this now appears to be an obvious and widely agreed perspective on cities but back then, it was quite a radical view. Throughout history, cities had been considered first

he argued that cities should primarily be considered as social institutions rather than physical artefacts. Everything about a city, he argued, such as its size and the organisation of its economic activities could only be understood as part its social functioning. In hindsight, this now appears to be an obvious and widely agreed perspective on cities but back then, it was quite a radical view.'

- Mumford made the very telling point that you could not understand anything physical about the city unless you examined is social organisation. You couldn't understand how it had grown, how big its was, its shape and so on unless you knew how it worked – in abstract terms
- His point has become every more telling as cities have become ever more complex
- He also made the point that how do we define the boundaries of city – how do we draw boundaries in a world that is getting ever more global
- In fact Mumford even anticipated ideas about electronic communications that change the role of distance

A Kind of Science

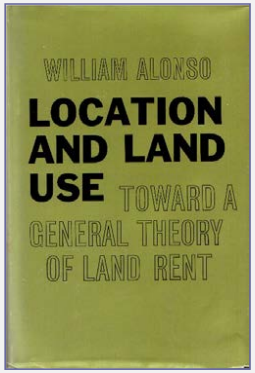
- So out of the middle of the 20th century came the notion that cities could be studied systematically – picking up on notions that cities were highly ordered affairs with the consequence that making them better, resolving the problems was one of getting this order to work better.
- From this came the systems approach – more of this in a minute – but also the movement identified the bits and pieces of location theory from the 19th and earl 20th century which was called 'social physics' or 'regional science'
- Regional science provided a powerful momentum for this new science

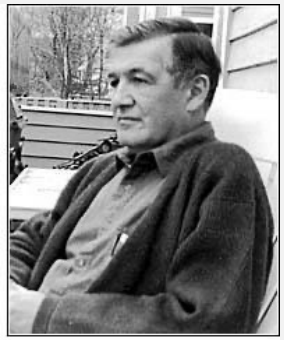
A Kind of Science:

Regional Science, Location Theory, & Urban Economics

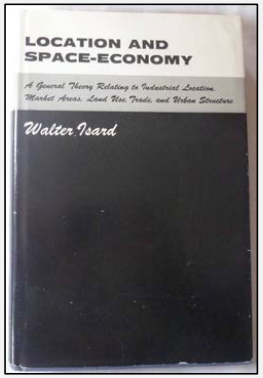
- There was great momentum to articulate the city as flows, potentials, linkages and all kinds of relationships that stitched the many subsystems of the urban system together. Input output model, population densities, spatial interaction and housing market models tied together in theories of urban economics dominated the 1960s and 1970s

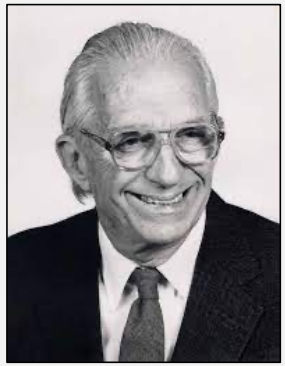




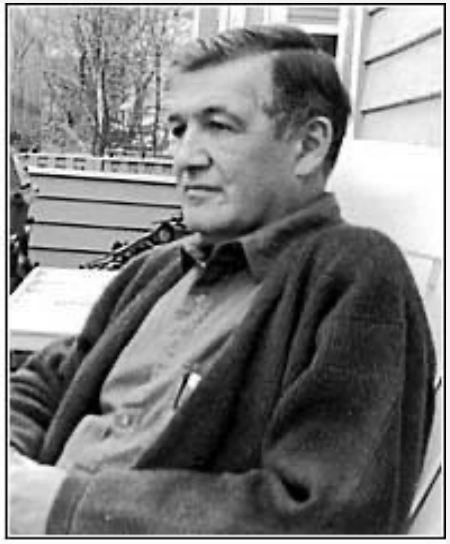


William Alonso, 1933-1999

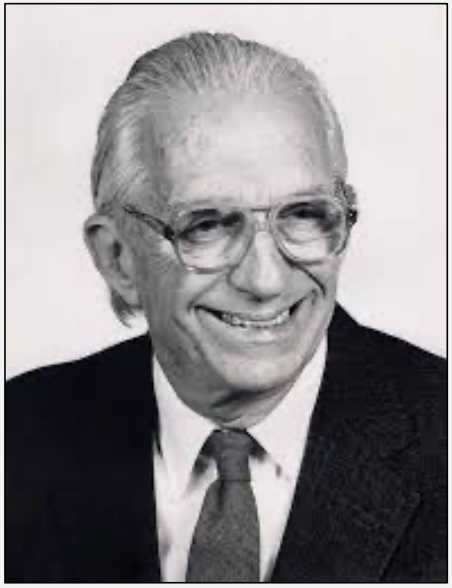


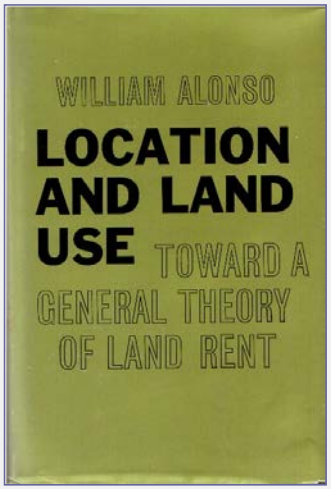


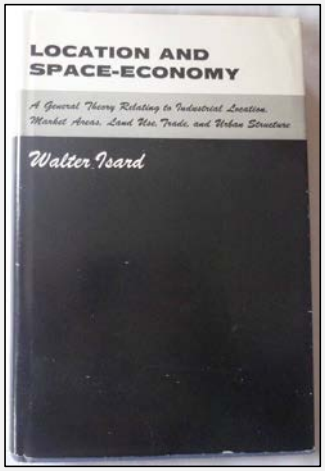




William Alonso, 1933-1999





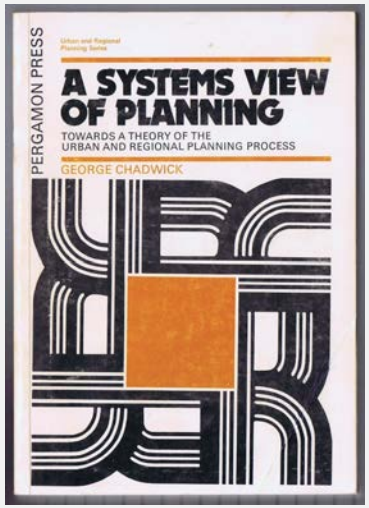


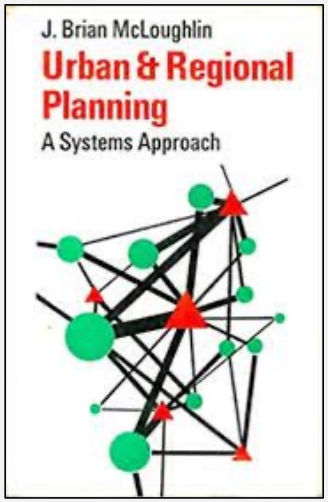
- Much of this analysis of the city was based on systems and this led to a related movement called ‘the systems approach’

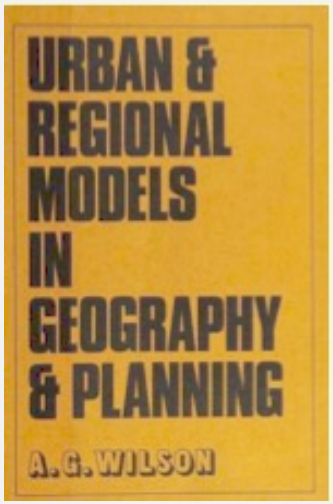
A Kind of Science

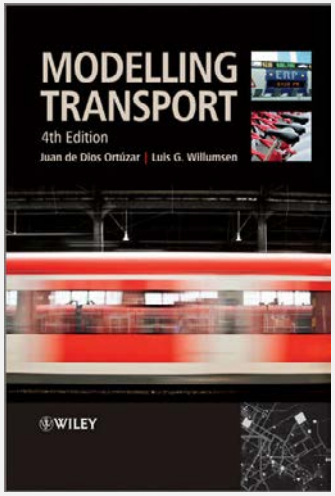
The Systems Approach

- The idea that many different systems had a common structure, built of hierarchies of subsystems organized from the top down led to ideas that one might control such systems in the same way – they could be conceived of as machines
- The control was based on what came to be called cybernetics defined mainly for physical systems but generalised as "the science of control in man and machine" (Norbert Weiner, 1948)
- Regional science and social physics fitted this model rather well







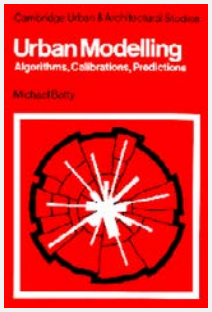
- The big question was could the city be conceived of as a machine, could it thence be modelled?
- Lots of issues – cities like machines were in equilibrium – of course they weren't; cities were considered aggregates of individuals but of course a multitude of problems in the city are based in individuals, not aggregates

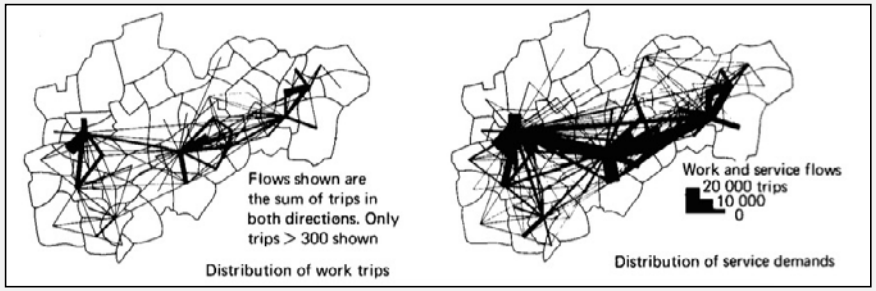
A Kind of Science

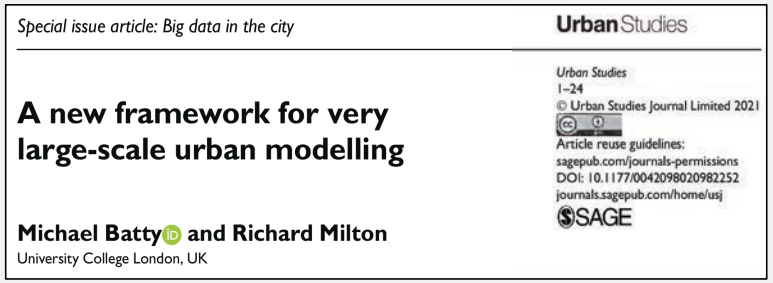
Operational Models for Urban Planning

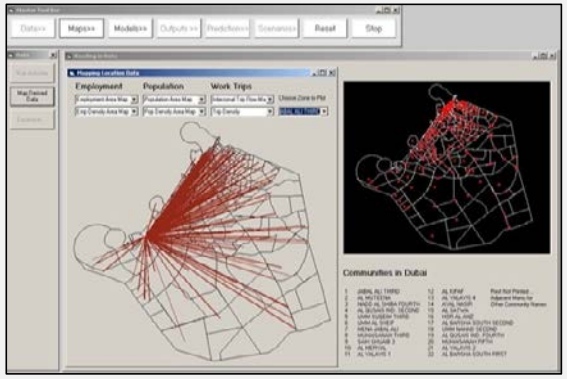
- Of course computers came into the scene in the 1950s and 1960s and largely computer models were highly simplified, aggregate, conceived of cities as being in equilibrium, no dynamics
- This was a timeless wonderland – and it was a very poor articulation of what cities were like
- They were changing before our very eyes and in this sense, the fact that they were so simplistic and simply defined away dynamics was highly problematic
- There was a strong reaction against them but what we achieved back then was not unimpressive given the limits

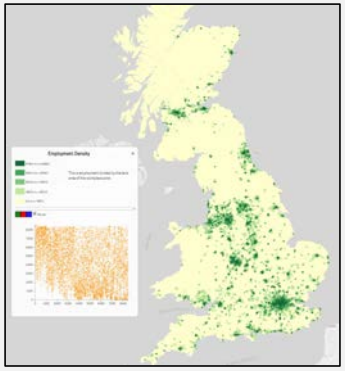
- We are still building these models – as sketch planning tools and they are useful – to echo George Box's famous phrase – "*all models are wrong but some are useful*" - examples

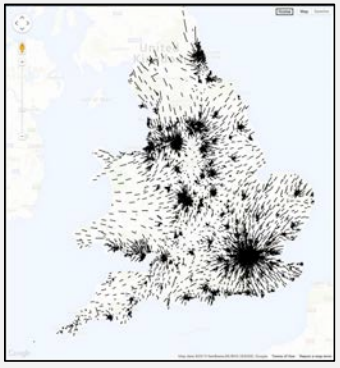


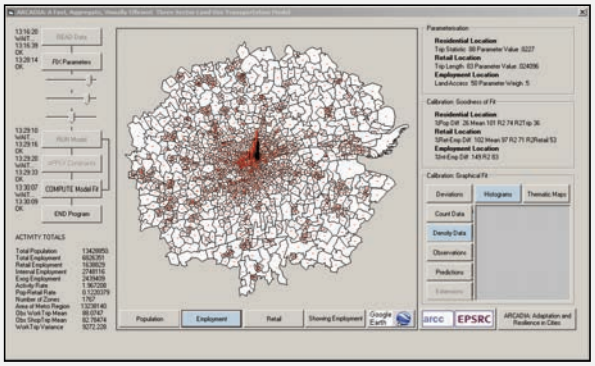










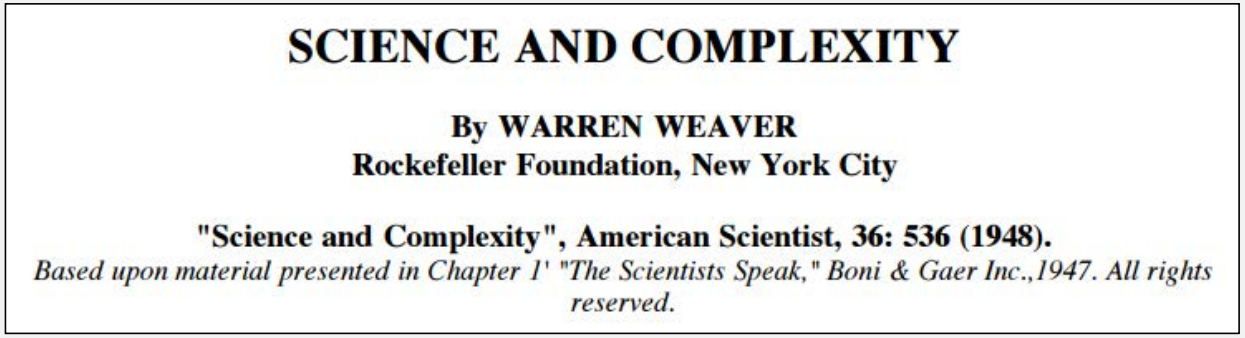


Complexity and Morphology: Size, Scale and Shape

- There was little doubt that the systems approach with its focus order, machine and top-down centralised control was not how the world worked
- We sort of all knew this but one had to start somewhere and that somewhere was with the simplest of systems.
- In fact city systems were not in equilibrium, they evolve and mutate and are full of surprising diverse happenings –
- If we control them as if they are machines, then it is no wonder that we get the kind of modernism that has plagued the world since machine thinking came onto the scene with the industrial revolution.

- Into this debate came ***complexity theory***. Systems were not built from the top down but evolved from the bottom up. They were full of diversity and innovation and hence unpredictable.
- They are dominated by feedback but no negative feedback that damps things down but positive feedback that generates innovations
- The roots go back a long way: One of the earliest and best statements of why complexity is key to all explanation in science and beyond was made by Warren Weaver in his valedictory address to the Rockefeller Foundation of which he was Director in 1948.

- In a paper entitled 'Science and Complexity', he said there were three approaches based on problems of **simplicity** – physics prior to 1900; problems of **disorganised complexity** – physics from 1900 on– and finally problems of **organised complexity** – biological and human systems - the problems of the things that we are interested in – cities, societies …
- Weaver's address was popularised by Jane Jacobs in her famous 1961 book which I read in a beach in Crete in 1965 and didn't understand a word of. But it has also been resonant in several other early discussions of complexity
- Here are some of the key papers that were being written just as the systems approach reached its zenith.

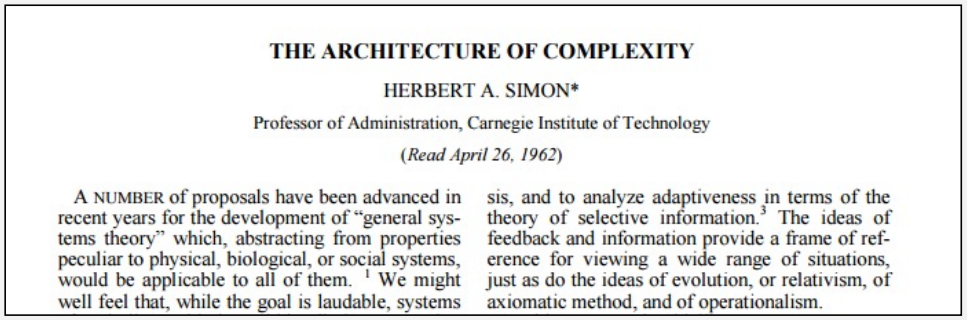


SCIENCE AND COMPLEXITY

By WARREN WEAVER
Rockefeller Foundation, New York City

"Science and Complexity", American Scientist, 36: 536 (1948).

Based upon material presented in Chapter 1' "The Scientists Speak," Boni & Gaer Inc.,1947. All rights reserved.



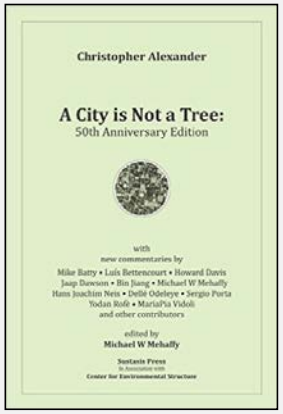
THE ARCHITECTURE OF COMPLEXITY

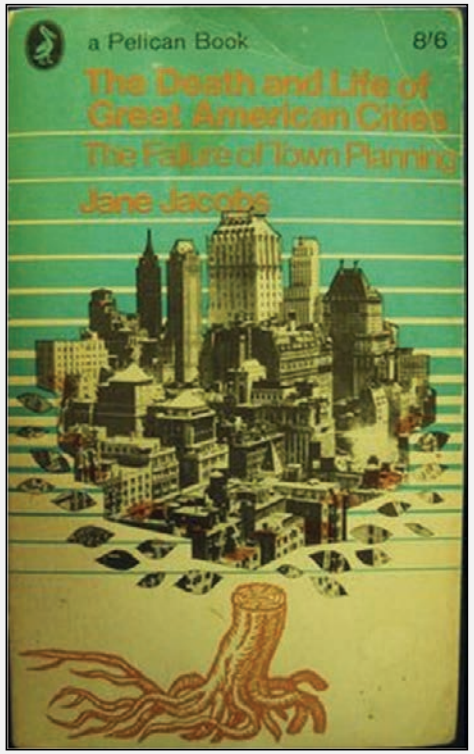
HERBERT A. SIMON*

Professor of Administration, Carnegie Institute of Technology

(*Read April 26, 1962*)

A NUMBER of proposals have been advanced in recent years for the development of "general systems theory" which, abstracting from properties peculiar to physical, biological, or social systems, would be applicable to all of them. [1] We might well feel that, while the goal is laudable, systems sis, and to analyze adaptiveness in terms of the theory of selective information.[3] The ideas of feedback and information provide a frame of reference for viewing a wide range of situations, just as do the ideas of evolution, or relativism, of axiomatic method, and of operationalism.





I could spend my whole talk on these questions but I want to push the argument here to more general conclusions about what we need to do with all this for cities and for planning

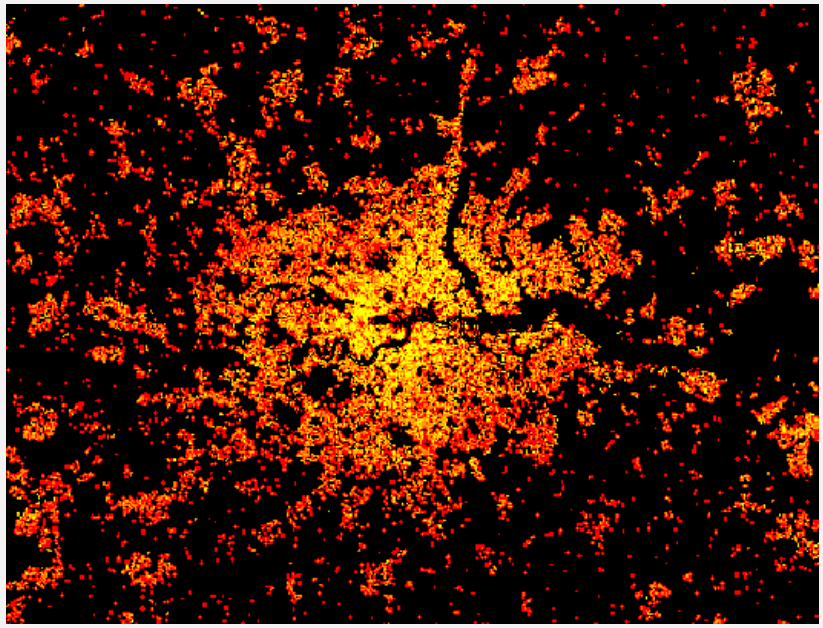
So Again, What is Complexity?

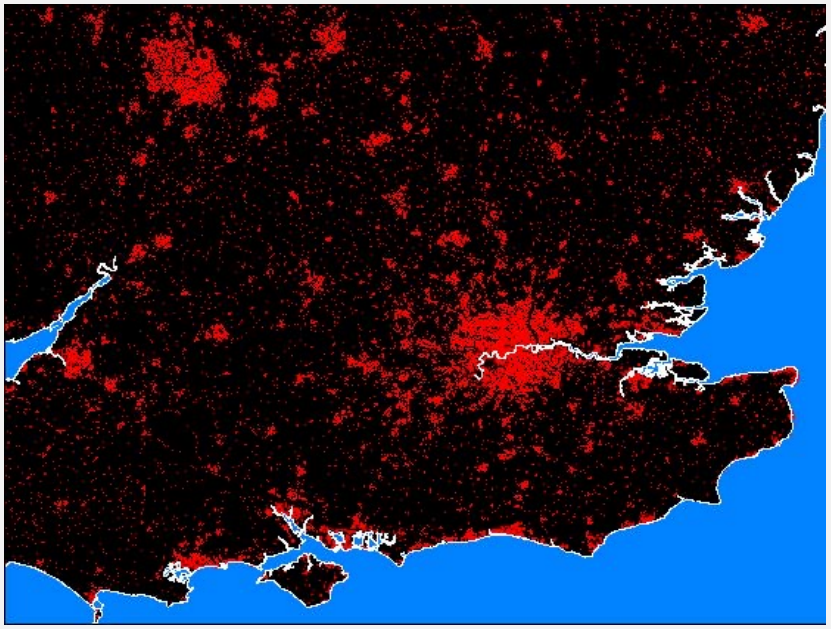
- There are at least three defining issues – first the notion that no longer in science is there an acceptance that there are watertight theories leading to **firm and definitive predictions**
- Classical physical theory was originally defined for **closed systems** either at a scale where 'we assume' that our actions do not matter – individually –as in the universe, or in a closed controlled context like a lab. We can no longer define the boundaries of a system in simple ways
- As soon as we move to the real world, this predictability can no longer be accepted and this is destroying classical theory

- Once we move to the real world all kinds of external and uncontrollable forces disrupt this classic predictability.
- Complexity theory has developed because of this, because the systems we deal with have inherent unpredictability. Key concepts such as emergence, surprise in prediction, and bottom up action are central to these ideas.
- Second, the idea that there are explicit interactions between many and multiple elements in the world defines a scale change in how we might deal with these elements. If there are P elements, then simply by defining possible interactions between each of these, there are P^2 connections and these are only for first order effects.

- Third, the notion is that the world is becoming more complex: in simple network terms as P gets bigger, then the number of interactions grows exponentially.
- Now we cannot define, by any measure, the possible number of interactions P^2 as a measure of complexity, life is much more subtle than this but this does give a sense of how absolute complexity can be 'approached'.
- In fact, there is a fourth notion: the very nature of these interactions is changing in time, that is that the nature of how P links to P is changing qualitatively in terms of what these interactions are – i.e. through new technologies – and also quantitatively in terms of the powers of .

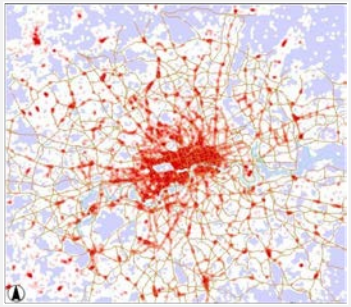
- So complexity theory embraces flows, interactions and relationships. In particular as the size of a system changes, it changes qualitatively
- Big cities are harder to travel in than small cities, they have different infrastructure and they provide more opportunities for diverse innovative thinking
- They generate economies of scale (agglomeration) as well as diseconomies.
- We see hierarchy everywhere: patterns are different at each scale. Let me show some pictures of morphologies that are fractal, self-similar, illustrating discontinuities as well as continuities



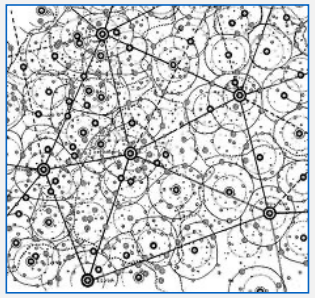












- These patterns show many features of the world of cities such as how forces repeat themselves at different scales. How complex patterns emerge from simple bottom-up decisions, and also how random mutations determine that one morphology is never exactly the same as another.
- How historical accidents condition evolution and development and how changes in size and scale. In fact the kind of world that Jane Jacobs described in her first book was one of order within chaos – order and diversity being different sides of the same coin. To an extent this characterisation defines unpredictability and we will come back to this towards the end when we figures out what we need from all this to think about cities and make them more sustainable.

The New Science: Statistical Physics

- The science is extensive – based on social physics, urban economics, on hierarchical self-similar process and on how all these features can be integrated to explore how cities change in terms of their size and shape.
- The new science is one of size and shape and how cities change as they evolve, so it still deals with physical form
- We can define three related kinds of scaling that we can develop with respect to the generic size of a system that we measure by P, say population.
- Now our key to size and scale is that measures of the size of the system all spin off from the number of elemental units

- We assume first that the number of interactions is P^2 but that sometimes were may be less than this number as the scale can be to any power of P . If the power is greater than 1, this is positive allometry and if less than 1 it is negative allometry and these are key relations in terms of size. If we are interested in, say, the wealth of a system, then we often find that the relation is something like $W \sim P^{1.1} = P^{\alpha}$

- This is our ***first scaling relation***, that of allometry. In fact our ***second relation*** can be derived from this and this is essentially the interaction between two populations. At a point, we might say this is P^2 but it is more likely to be something like

$$I = K\frac{PP}{d} = K\frac{P^{\alpha}}{d}$$

- Where I is the interaction and d is some measure of friction due to the fact that everyone cannot interact as if they are standing on the head of a pin – this is a distance effect. K is often some scaling factor – the gravitational constant in gravity models but it might be a ratio that scales the interaction to reasonable limits, like Dunbar's Number – the average number of acquaintances, about 250.
- Once we have the interaction in this form, then consider two different places i and j with a distance d_{ij} between them and we get our second scaling relation

$$I_{ij} = K \frac{P_i P_j}{d_{ij}^{\alpha}}$$

- Note that α is a power that often is between 1 and 2
- Our third relation is rather different and relates to the frequency of sizes. If we take a large number of cities say of different sizes and we measure their frequency f_i, we can array these as

$$f_i \sim \frac{1}{P_i^{\beta}} = P_i^{-\beta}$$

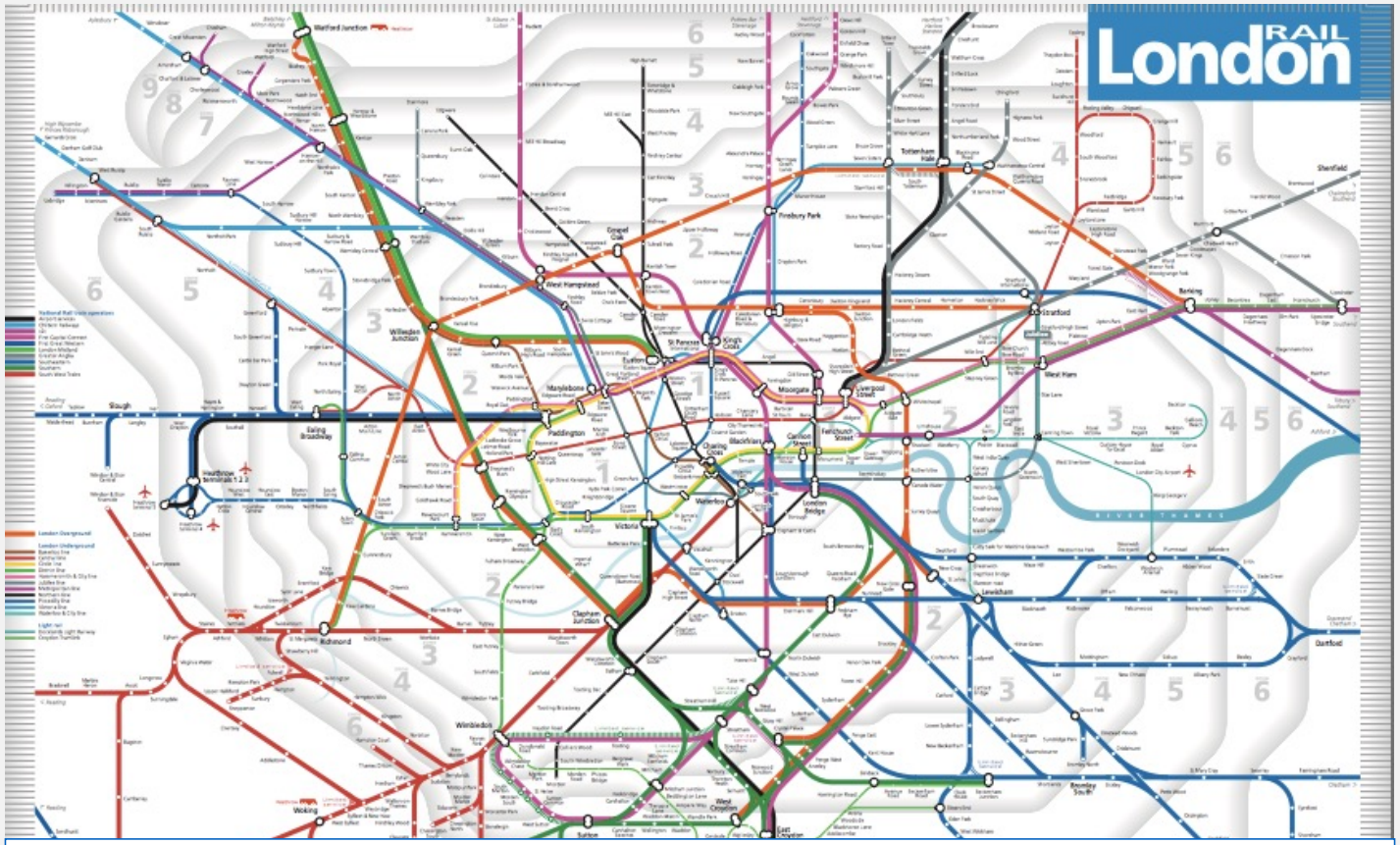
- This can be manipulated into our **third scaling relation**, the rank size rule which is key to the size distribution of objects in a spatial system. All of these are what we call power laws of various kinds.

- Look at Christaller's central place diagram earlier in this talk and count the frequency distribution of sizes and then rank these against size. You can do the same with any of the size distributions or clusters of urban development shown earlier.
- All these relations are power laws and they all display the characteristic of self-similarity. This means that when we scale the relation we find the same functional form – that is if we multiply population $W' = P^{1.1} = P^{\alpha}$ by a scaling factor Z then we get the same relation; that is
- $W' = (ZP)^{1.1} = Z^{1.1}\ P^{1.1} = Z^{1.1}W$

Smart Cities: The High Frequency City and Big Data

- So far I have talked about what we might call the low frequency city – how cities change over longer rather than shorter time period
- For most of the last century, our focus has been in how cities change over years and decades and our plans have been so focused - I am not talking about urban design but even urban design takes place over longish time periods
- Since computer scaled down to fine scale where they can be embedded into very small objects a new focus on the high frequency short term city has merged – over 24 hours or a lot less.

- We now have big data, from real time streaming and this is changing the sorts of models that we are able to build – much finer scale models – disaggregate based on agents or individuals that where the behavioural basis is much richer than anything in terms of the new science based on complexity.
- These models are much shorter term, nearer the data and insofar as they generate predictions these are in the very short term. Even then the new tools face the same problem – Box's dilemma
- The new computation also related strongly to new tools for visualization of complex systems and there are many examples that go back to the 'precomputer' age



Tube, Overground and National Rail Networks in London
where Oyster cards can be used



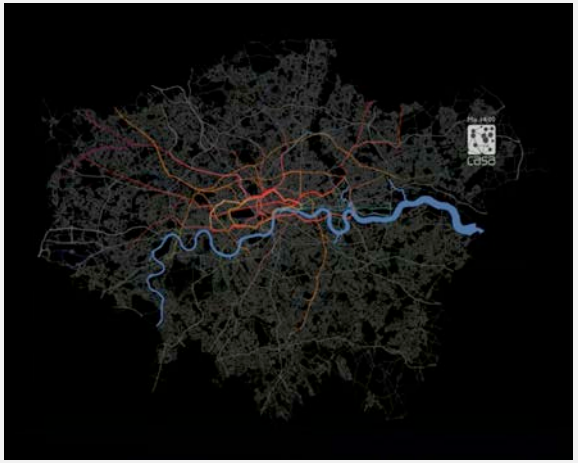
Passenger Demand for Travel: Flows From Tap-In to Tap-Out Data

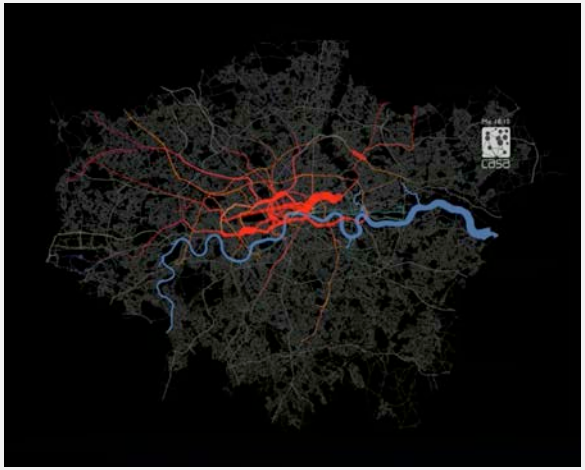

OYSTER GIVES UP PEARLS



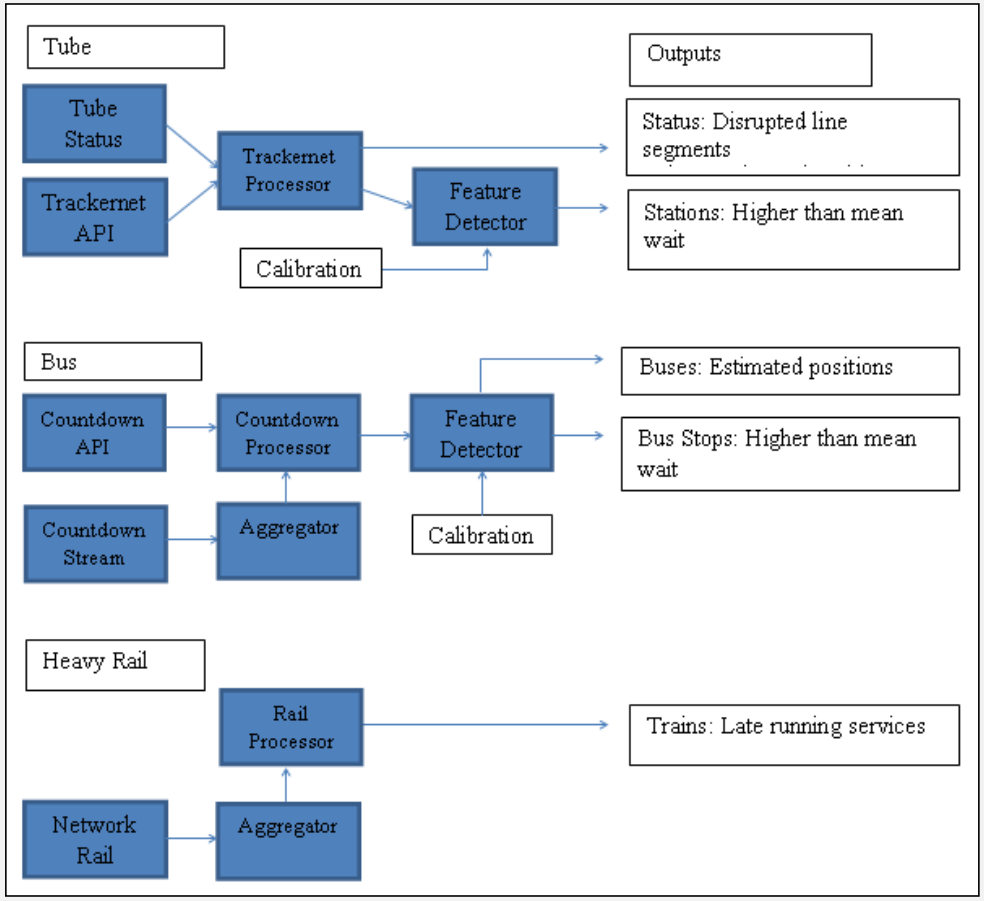


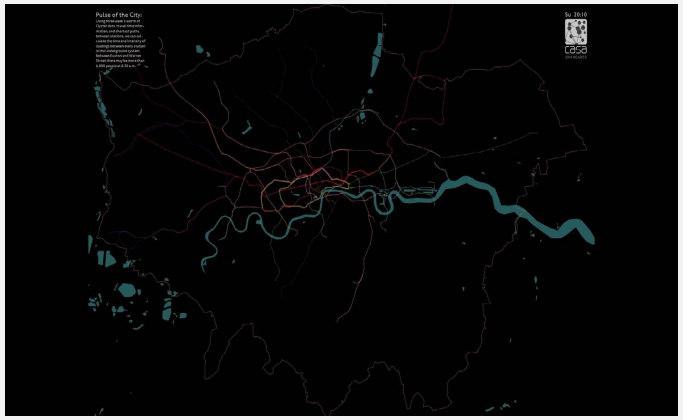




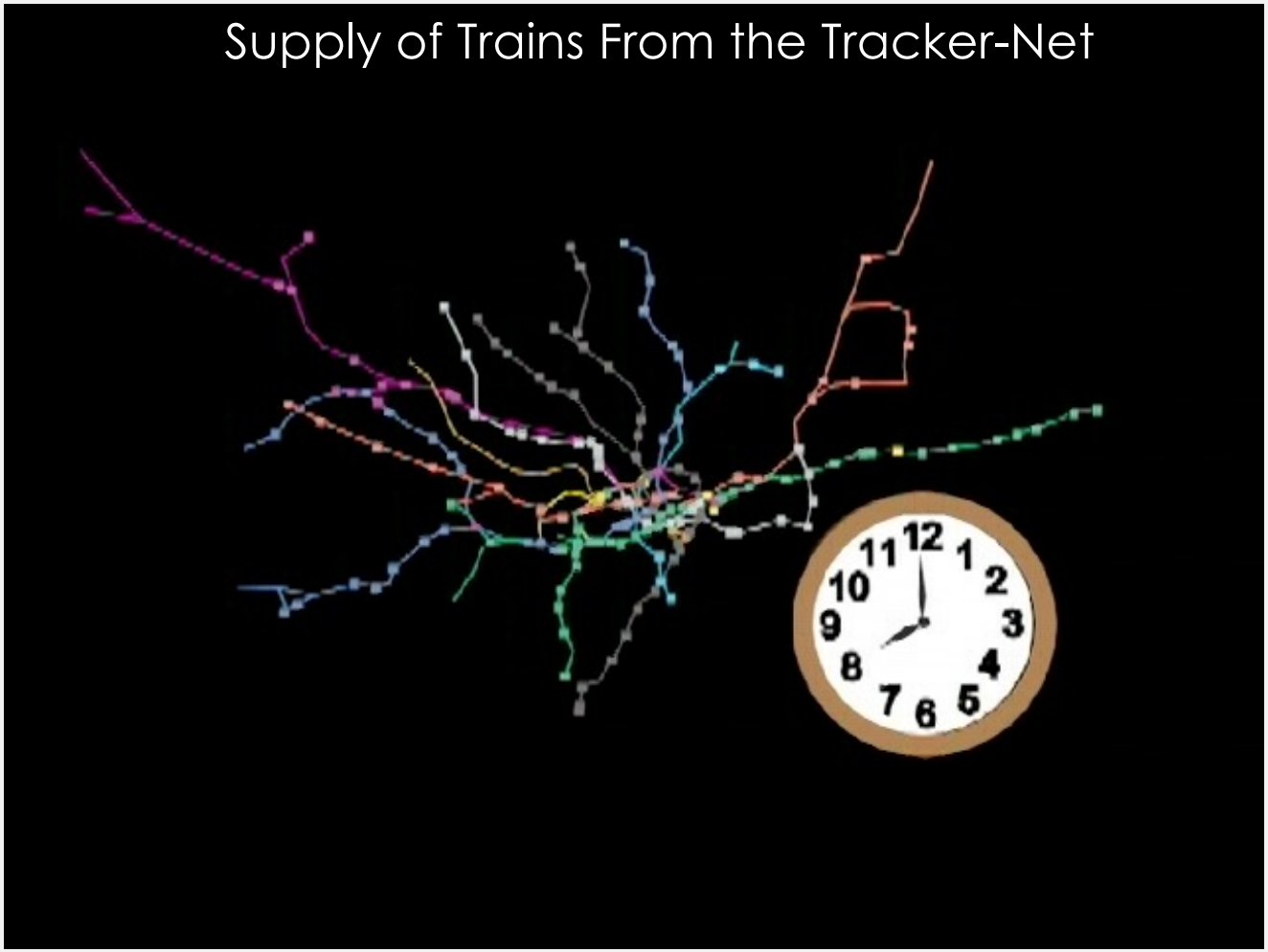


The Public Transport System in Terms of Vehicle Flows and also Passenger Flows from Oyster








Supply of Trains From the Tracker-Net





Using Urban Science to Invent and Plan Better Cities

- I could spend a lot more time on the smart city but I simply want to flag up the fact that it is data really that the smart city produces for the kinds of science that I have been talking about here
- So far the smart city is hardly related to this new science, few have fashioned good theory and ideas of how smart cities are linked to low frequency cities. This is a challenge
- Let me finish by pulling out some key issues that guide our search for the good city, for better cities which are more equitable and more efficient, more sustainable
- And the first is ***predictability***

- I said at the beginning of the talk we now live in an era of ‘predictable unpredictability’ or perhaps one of ‘unpredictable predictability’ – the first term if better
- If we can predict and in some senses we never have been able to for prediction is magic, then we need to think hard about how we can think of explaining an unpredictable world.
- To me, the answer lies in exploration. We need to explore the future and the way we can begin to do this is through the kinds of models I have alluded to here
- As well as many other techniques and tools from story telling all the way to highly formalized models that stretch our imagination

- To an extent we might think we can predict the near future for the most likely prediction is just a little but beyond the present but if you reflect we can't even do this very well. The future is unknowable.
- Another key theme is that we live in a world of multiple relationships – interactions; ***the new science is thus a science of flows*** and the great challenge is to think of cities as flow systems – again this is not new – indeed as old as the hills – as I showed at the start of the talk
- In fact it may be beyond simple flows between single entities – it may be a science of flows between flows and so on all the way down, as Alice said.

- And let me finish for I have been going on too long. A lot of the new science depends on data that we cannot easily observe. In a globally connected world where everything influences everything else either directly or indirectly, much of this is invisible
- We can no longer draw boundaries very clearly but we have to, so we need to think of our theories and models are pertaining to relativities – to questions of what happens as we relax the strictures we impose on theory
- We need to develop multiple theories and learn to live with them and learn to contract one with another.
- I could go on but let me stop here and throw the floor open

URBAN AI | URBAN AI

UCL University College London

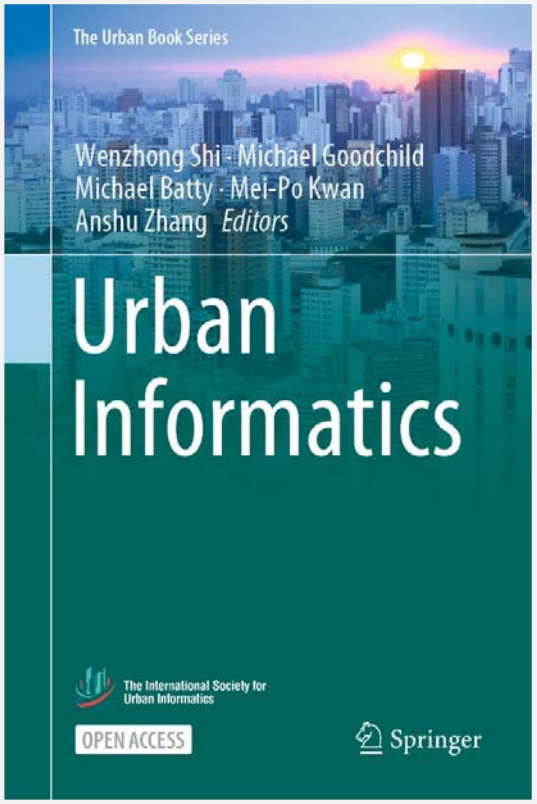
Thanks

Michael Batty
Centre for Advanced Spatial Analysis
CASA-UCL

17 June, 2022

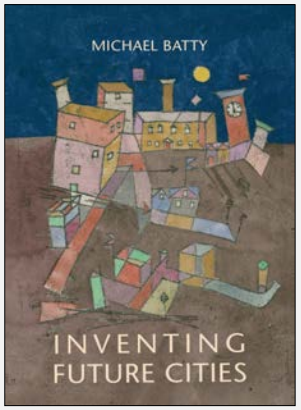
m.batty@ucl.ac.uk
@jmichaelbatty

Michael Batty, m.batty@ucl.ac.uk Chairman CASA, Bartlett Professor of Planning

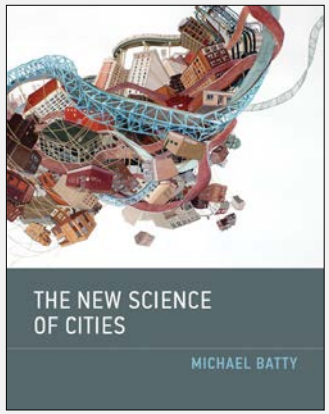


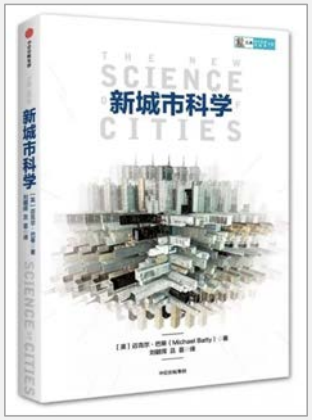
open access – download the book free from

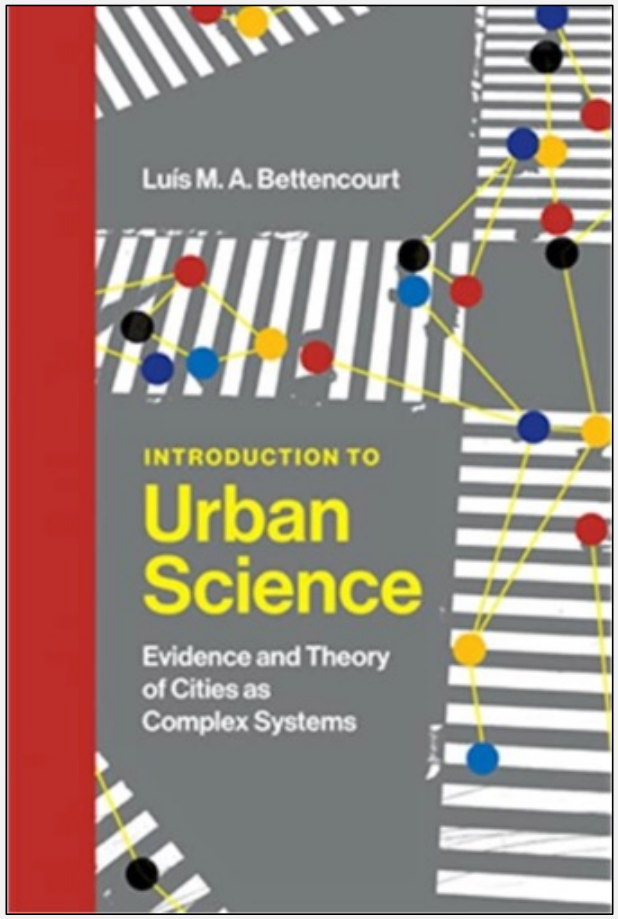
https://www.springer.com/gp/book/9789811589829

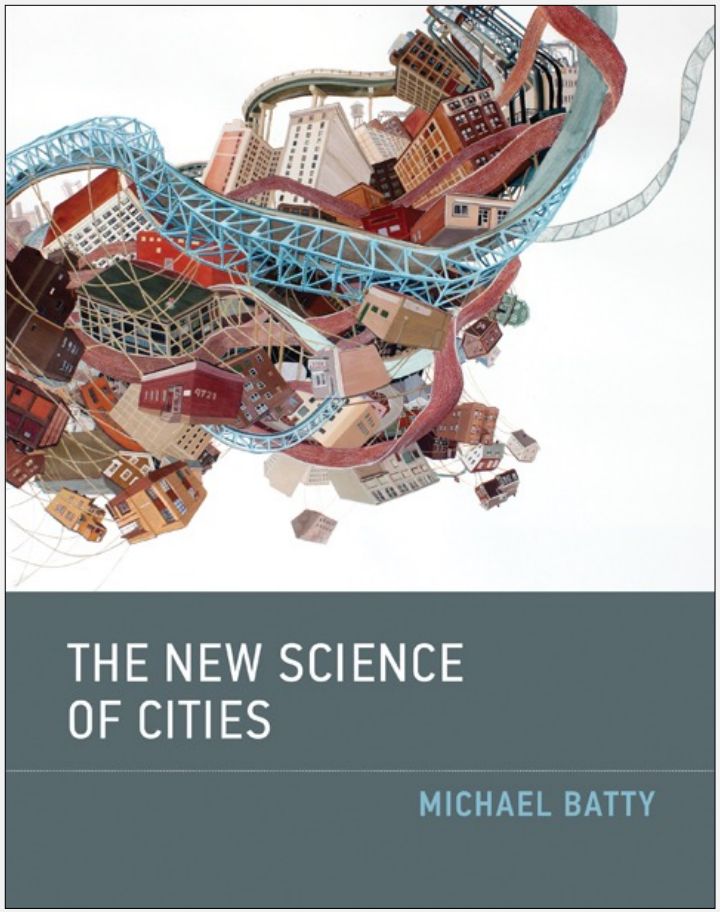









Luís M. A. Bettencourt
INTRODUCTION TO
Urban
Science
Evidence and Theory
of Cities as
Complex Systems


THE NEW SCIENCE
OF CITIES
MICHAEL BATTY