URBAN DYNAMICS INSTITUTE
OAK RIDGE NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY
March 27th 2018

Cities, AI, Design, & the Future

Can Artificial Intelligence Improve Design Intelligence?

Michael Batty

m.batty@ucl.ac.uk
@jmichaelbatty

http://www.spatialcomplexcity.info/
http://www.casa.ucl.ac.uk/

An Outline of the Talk

- Artificial Intelligence and Design Intelligence
- Basic Concepts about Complexity Theory
- Making Sense of Urban Development: Key Factors
- Related Concepts: Geodesign, Networks, ABM
- Design Solutions as Weighted Averaging
- Actual Development using Neural Networks
- A Simple Example: Averaging by Overlay
- Generalisation: Modelling at the Very Local Scale

Artificial Intelligence and Design Intelligence

Budhu asked me to speak on AI and Cities. I am in way an expert but let me throw out some ideas

I will not talk about how we get hold of massive data sets and search for underlying pattern but about design intelligence and how this differs from artificial intelligence

The problem we have in cities is what we see is not necessarily what we want. In short if we explain how things emerge and evolve – actual development – this is usually different from optimal, ideal development

So in a way, AI as it is developing to make sense of what we see is not something we see very much of so far – we do see a lot of modelling which in a way is a kind of AI

Basic Concepts about Complexity Theory

This will be my theme then – how we generate design intelligence and then how we can think of this as artificial intelligence. First let me describe some basic assumptions

- Cities develop, grow & change from the bottom up
- Countless 'comparatively uncoordinated' decisions (rational within their own frame) generate coordination across many scales – Adam Smith's Invisible Hand
- This manifests itself spatially as order and pattern which is said to 'emerge' at higher scales from that which the forces that determine them originate.
- For many years we have accepted that we might be able to simulate this kind of emergence

- The simplest examples are fractals – the dendritic pattern of streets in cities that determine optimal spatial patterns of how cities are resourced, how the hierarchy of central places is ordered and so on
- There has been plenty of thinking about cities in these terms. My own work on **Fractal Cities** which dates from the mid 1980s is one stream
- In this sense, our models embody a degree of intelligence – artificial to an extent although the assumption is that such intelligence should mirror how the system actually develops.
- In short our models should not be about artificial processes but real. This talk is about the tension between ***real*** and ***artificial*** but also between ***organic*** and ***designed***.

- But there has been very little thinking in terms of how plans are made. We tend to think of these as being somehow imposed on the city as top down, yet plans usually emerge from the bottom up
- The clearest theories of design reflect this notion that a plan is successively developed from a simple seed by a designer who works away at it recursively.
- In this sense then design is about a kind of artificial intelligence but more important about intelligence that leads to better systems, solutions
- In fact, design often conflicts with AI in that AI does not necessarily produce better results in any sense – for to replicate what we do, does not mean that what we do is best. So in this talk I will question AI in helping us to design.

Making Sense of Urban Development: Key Factors

- Let me return to urban development. The complexity model of emergence suggests that many factors determine the pattern of urban development that occurs, and we need to know these
- There is thus some sense that we might be able to produce models that combine a series of independent variables – factors – that can be used to predict such patterns. Indeed our urban models tend to attempt this such as CA models
- Recently developments in AI suggest that we might be able to find the patterns that lead to actual development but this is not necessarily the best plan

- So I am going to begin with showing you how we can generate a plan which is best but what I will do here is generate the plan as a process of group decision-making – again from the bottom up in such a way that the plan emerges from different and often conflicting individual plans. In a sense, my model will be based on a kind of intelligence but not one which necessarily leads to one actually happens
- The model is based on an old idea of pooling opinions but it has surfaced over the last 60 years in many contexts
- I will develop it here for a very simple example and then point the way to more information about it
- It has a quite well defined formal representation but here I will develop the idea here visually

Related Concepts: Geodesign, Networks, ABM

- Geodesign: group decision-making: … designing for change cannot be a solitary activity. Rather, it inevitably is a team endeavor with many participants (from the design professions and geographic sciences) …

  Carl Steinitz (2012) A Framework for Geodesign, ESRI Press, p. ix

- Agents and Actors: a model of how agents combine their conflicting views of a design solution to a consensus; an agent based model (ABM)
- Graphs and Networks but non-spatial networks – social networks: a social power structure
- Building Models involves many forms of intelligence

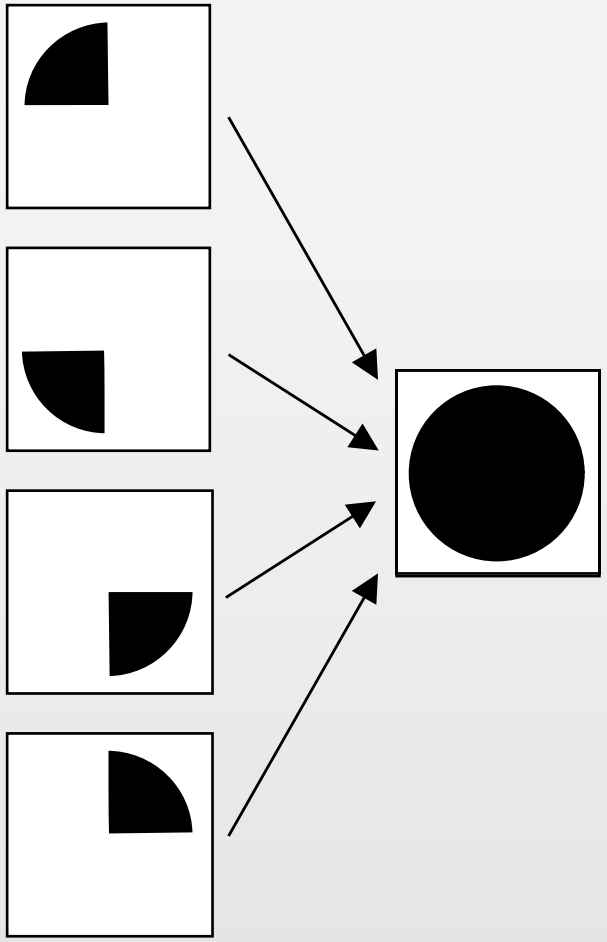
Design Solutions as Weighted Averaging

Factor 1
Access to Housing

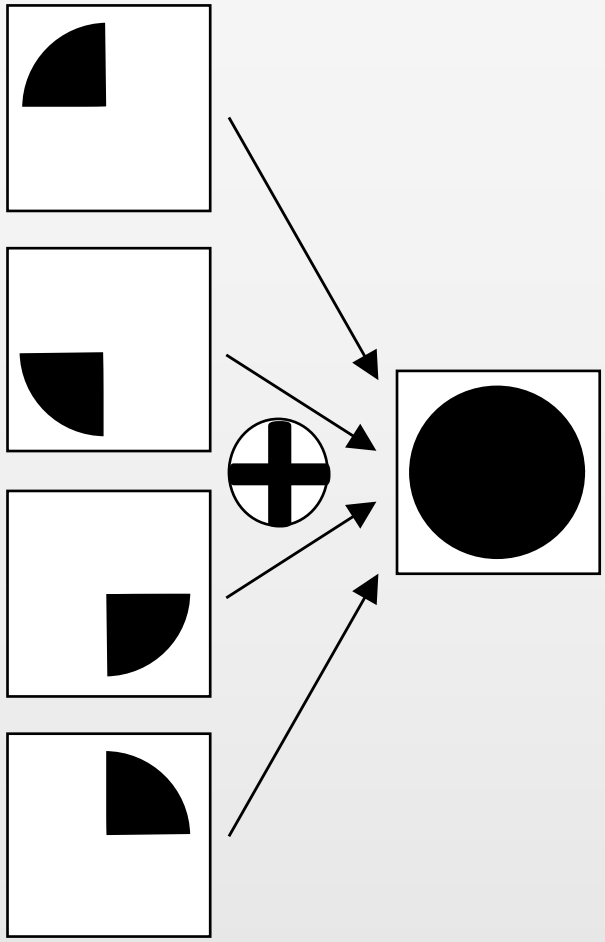
Factor 2
Access to Retailing

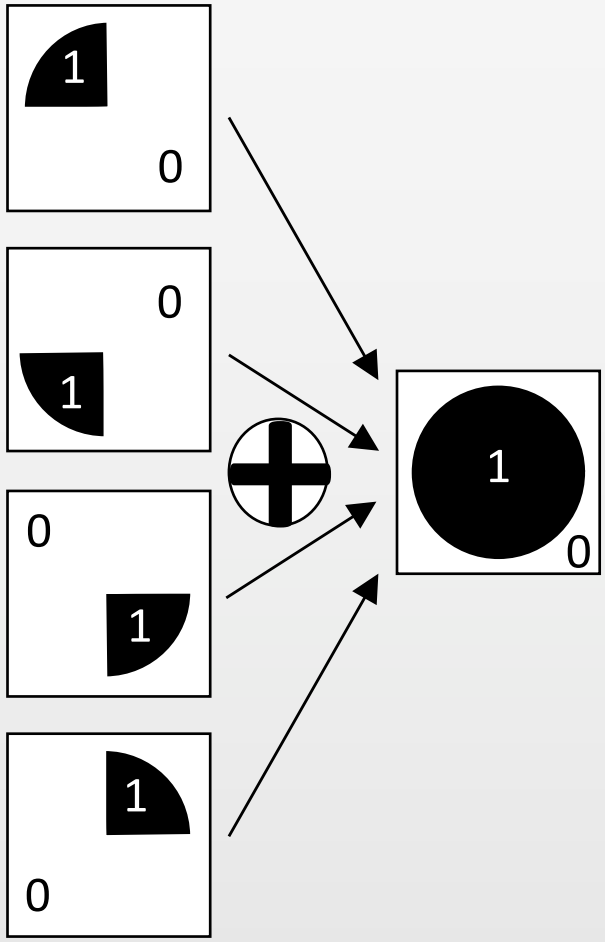
Factor 3
Access to Health Care

Factor 4
Access to Education

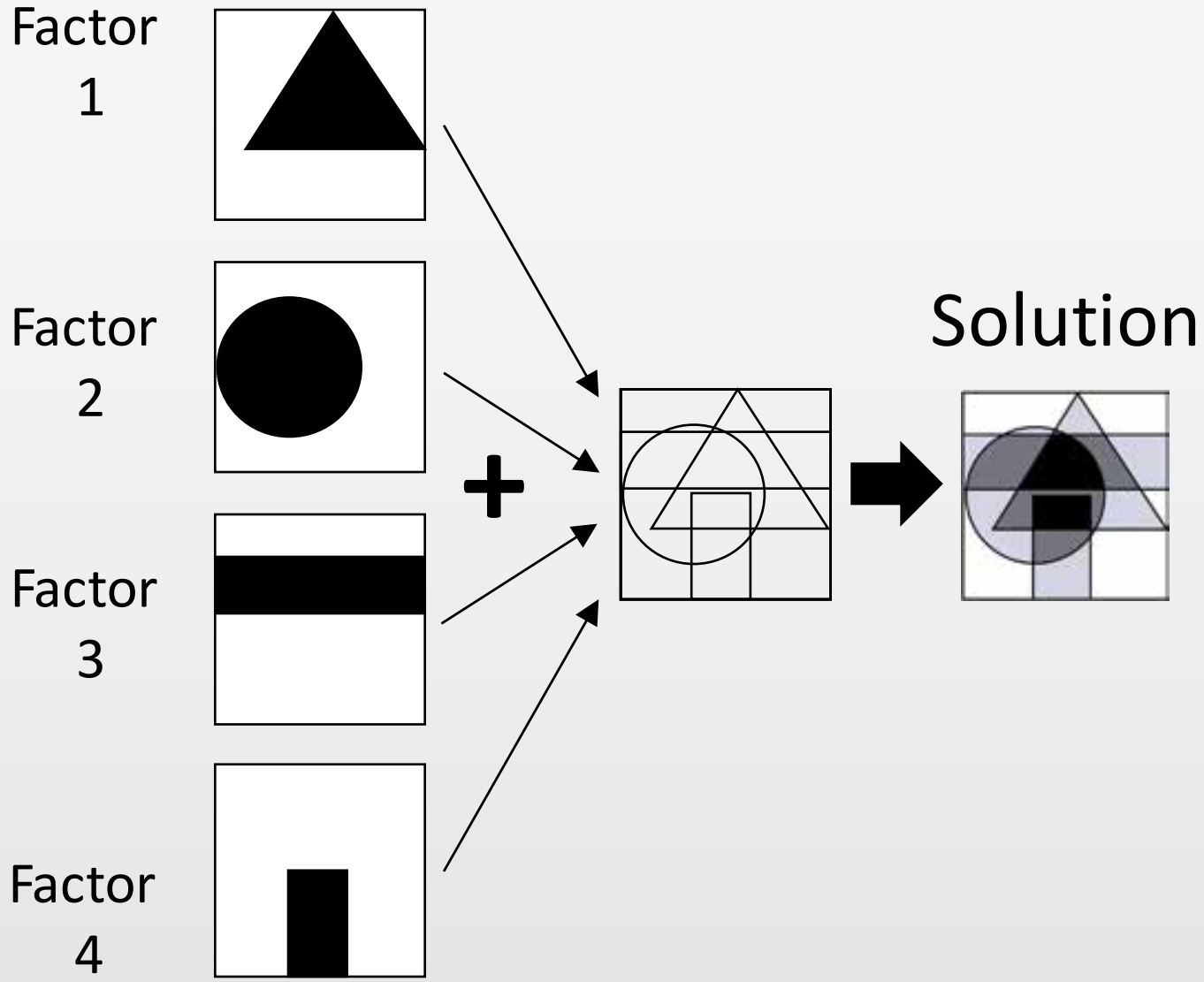


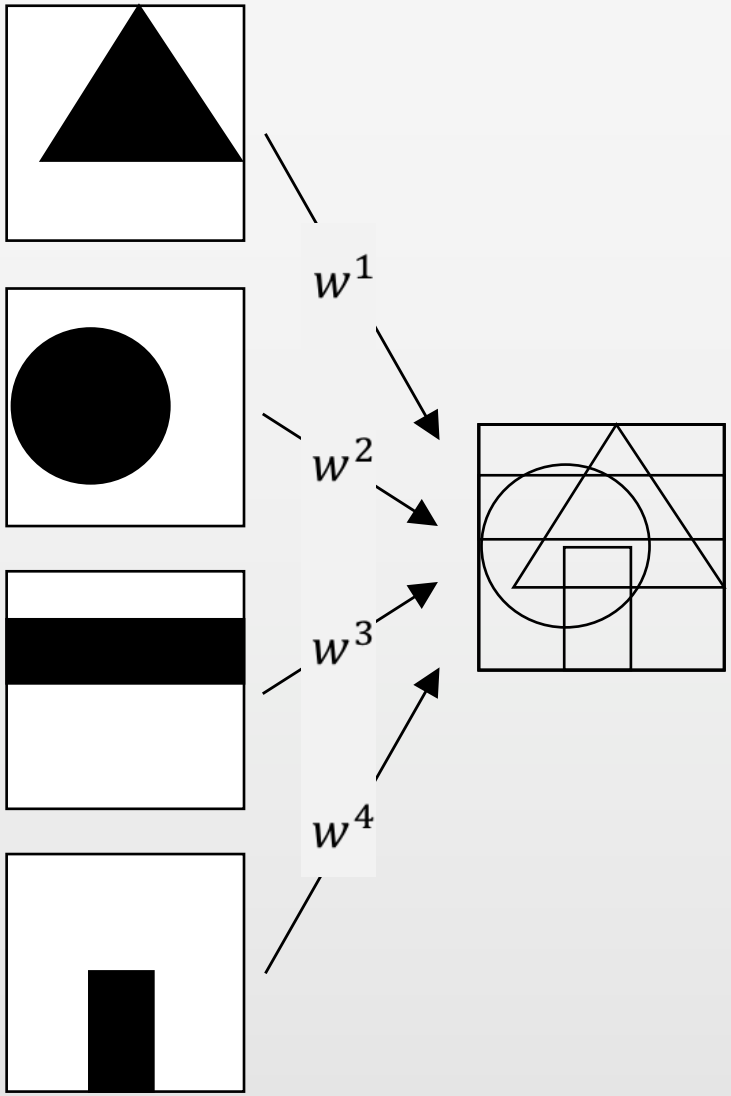
Adding or Synthesising Physical Influences

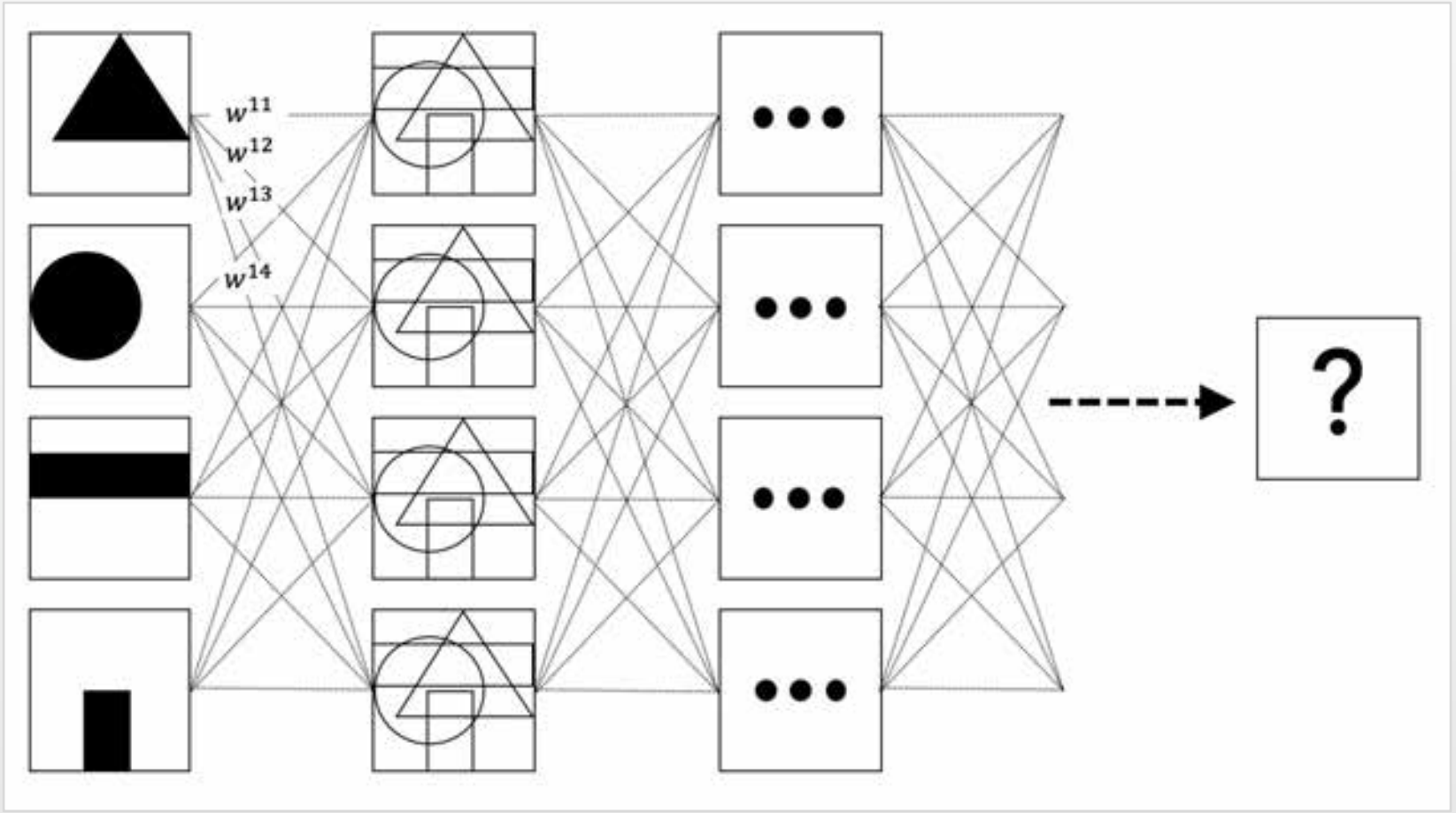


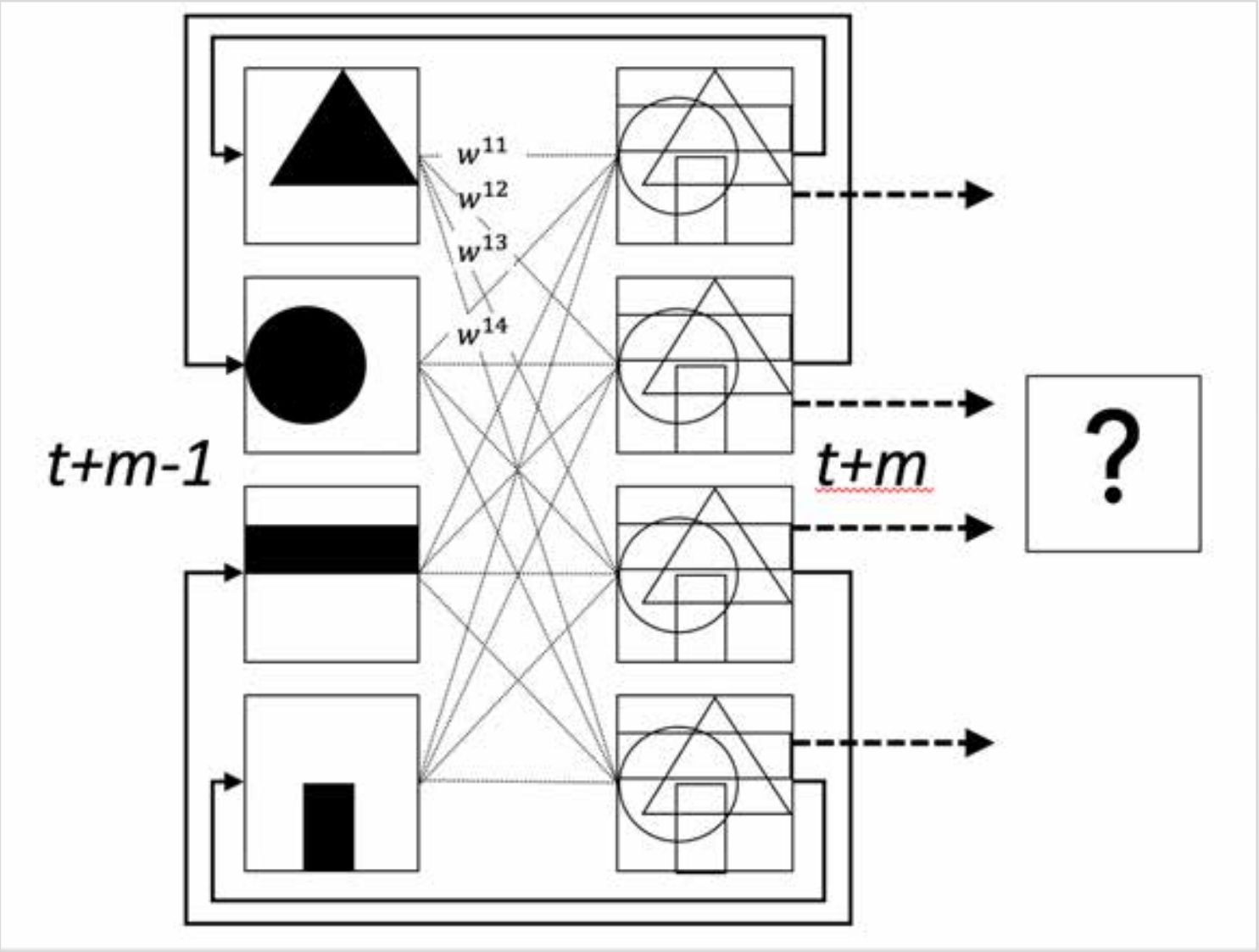


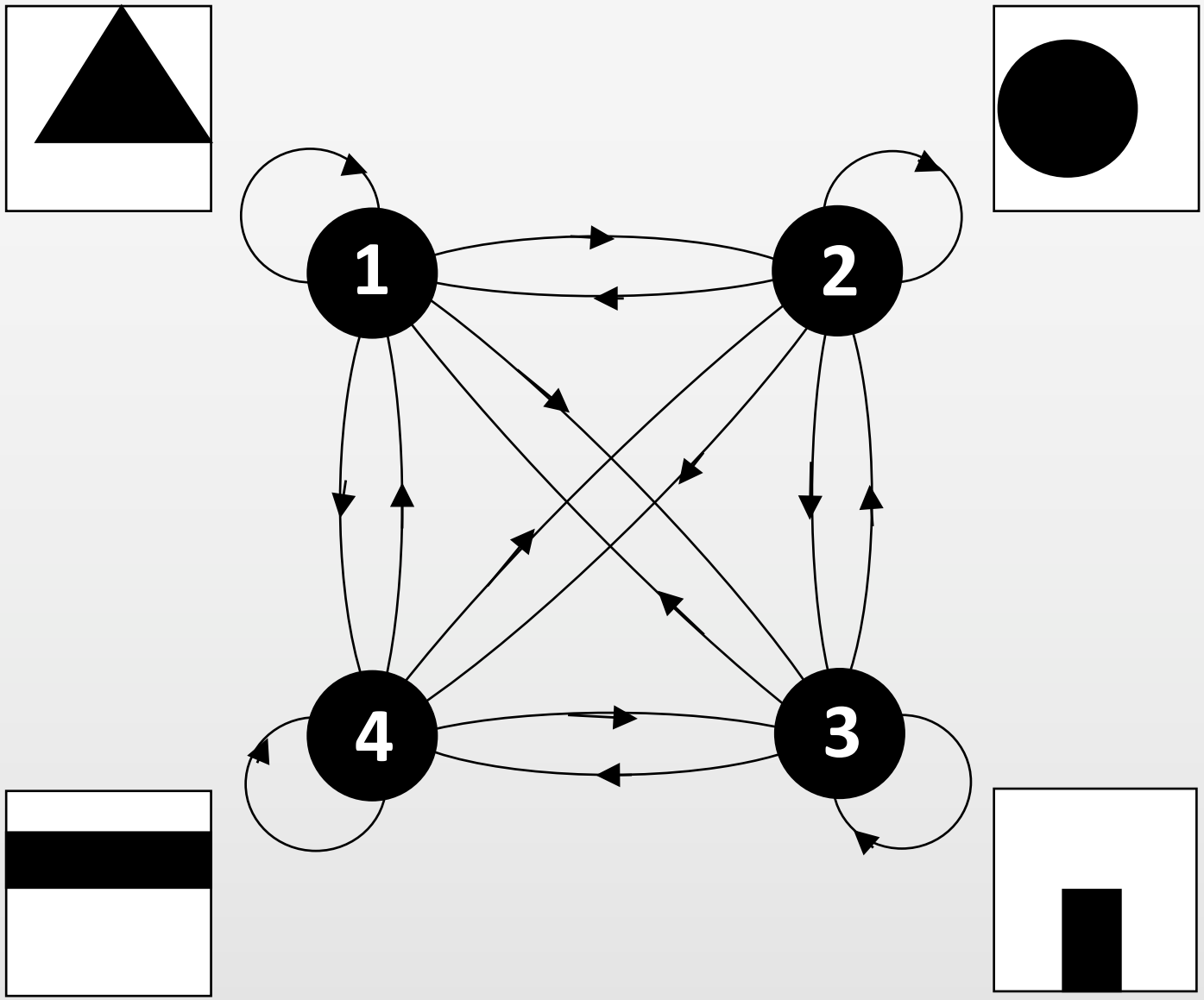
Boolean Operations

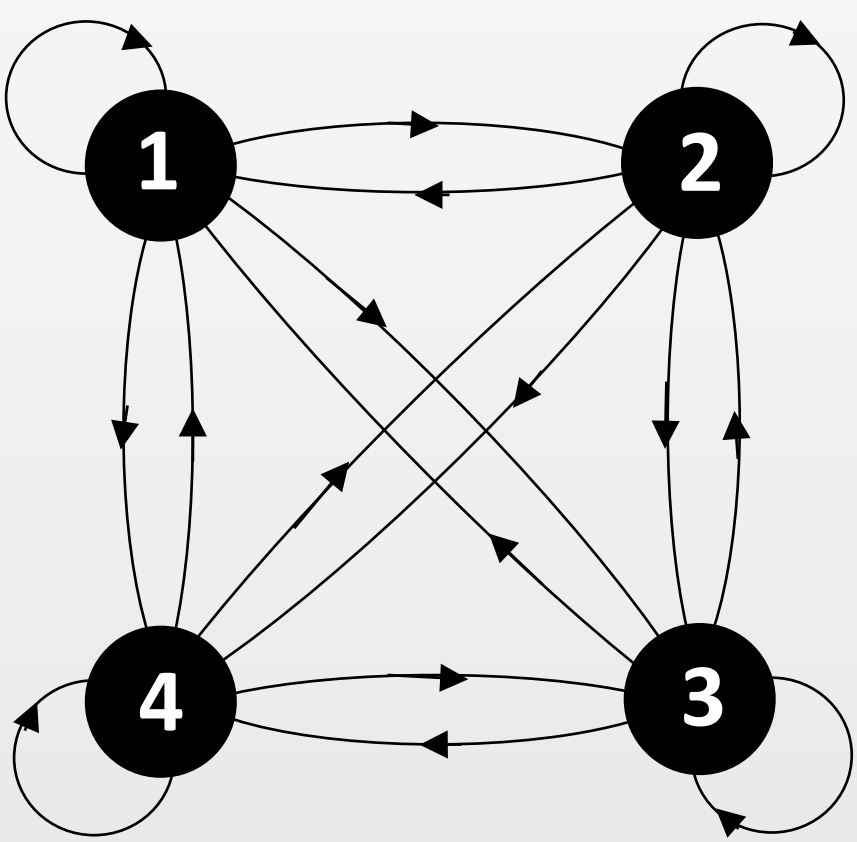

Factor 1
Factor 2
Factor 3
Factor 4
Solution

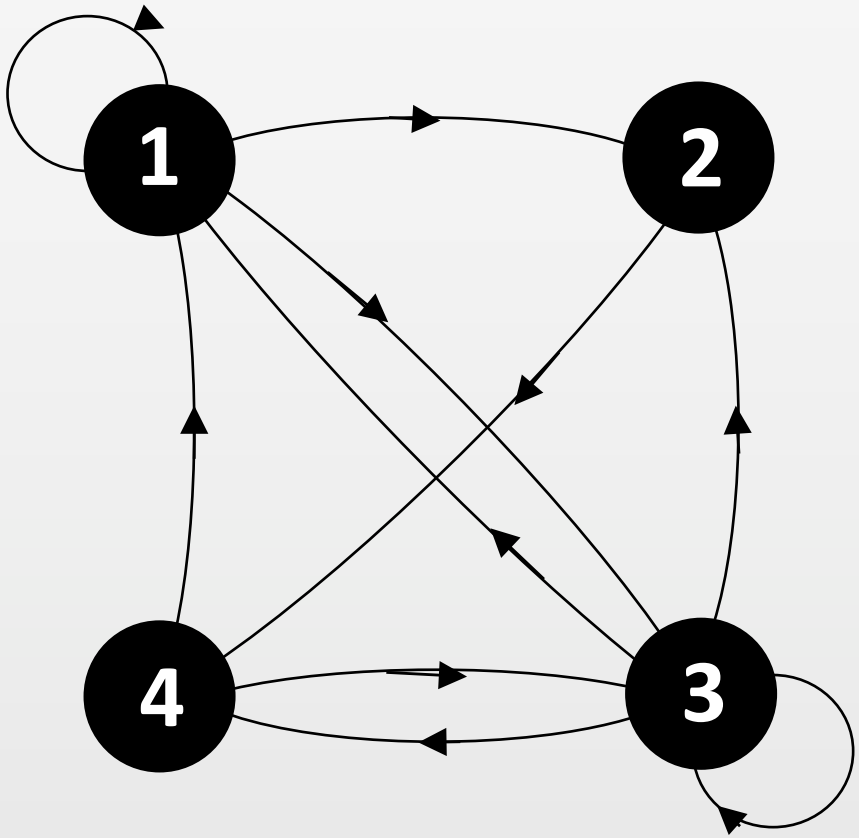

w^1
w^2
w^3
w^4


w^{11}
w^{12}
w^{13}
w^{14}
?

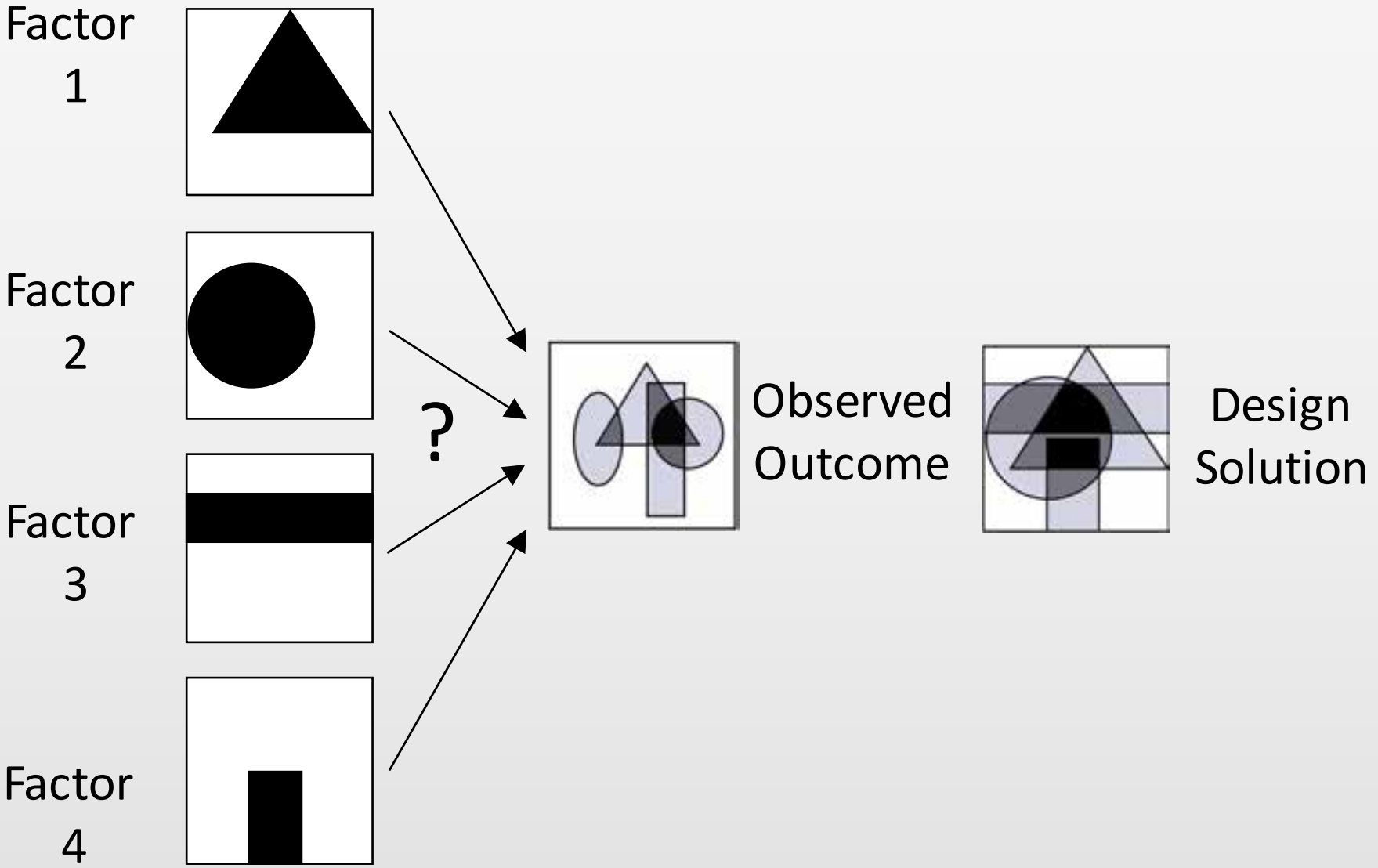

w^{11}
w^{12}
w^{13}
w^{14}
t+m-1
t+m
?

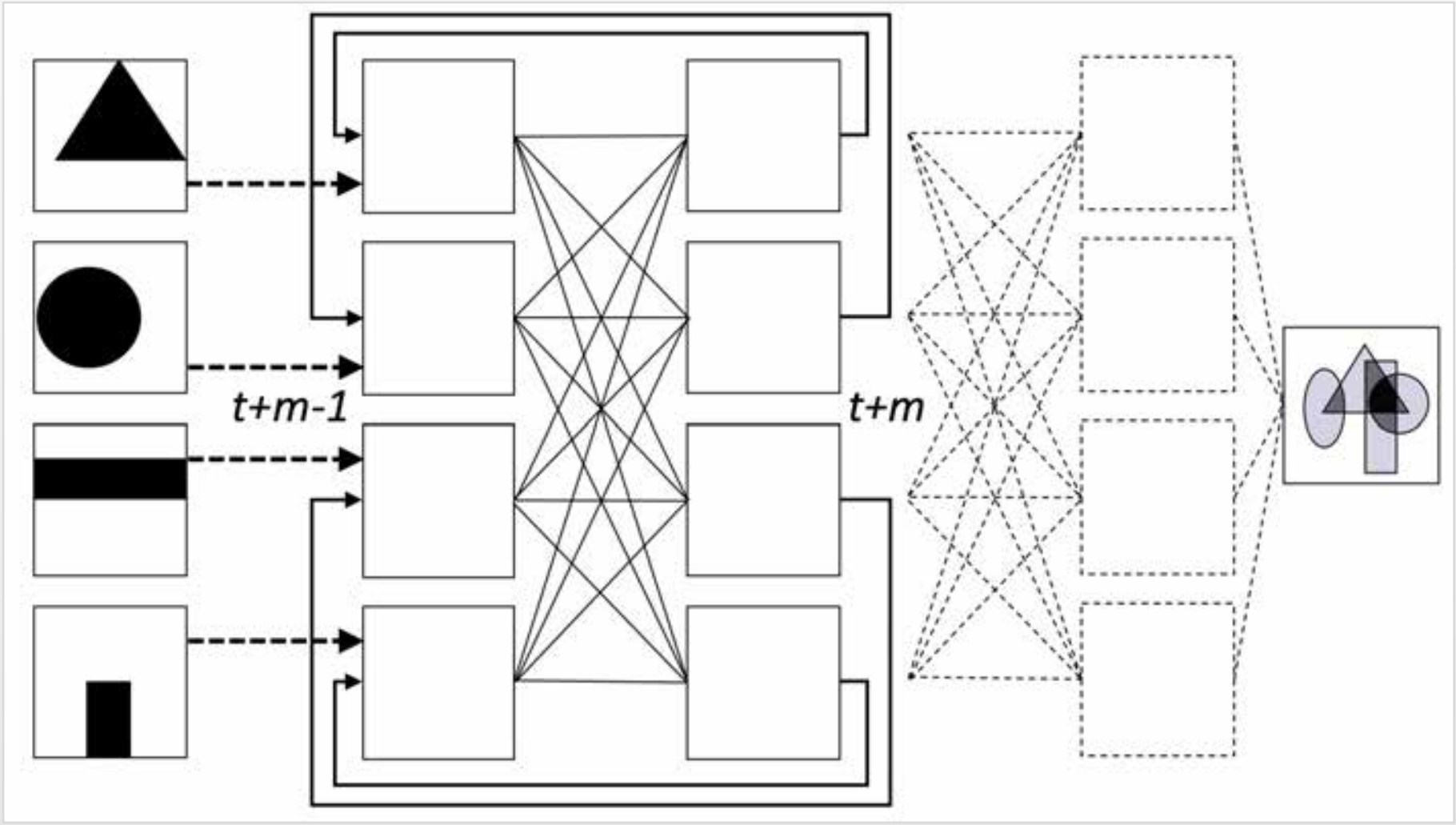

1
2
4
3


1
2
4
3


1
2
4
3

Actual Development using Neural Networks

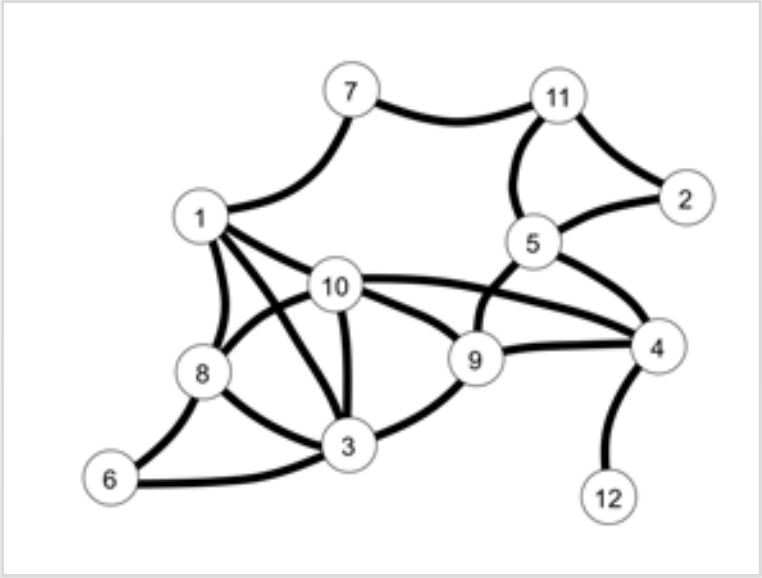


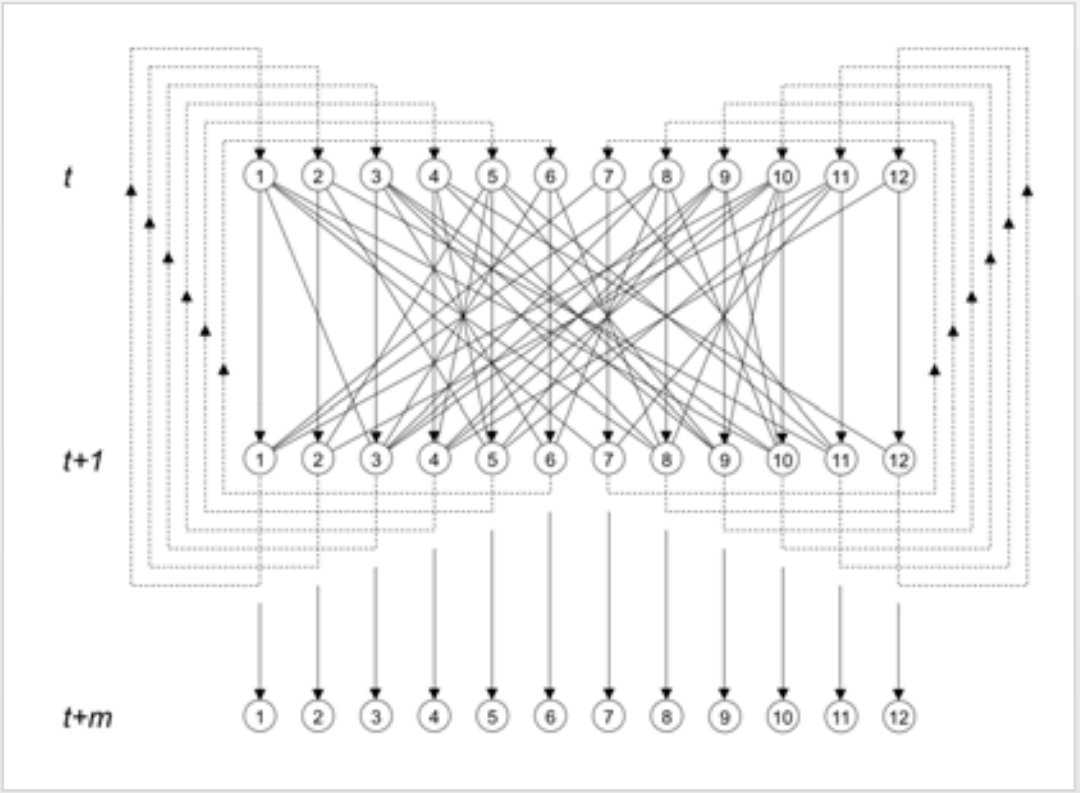

t+m-1
t+m

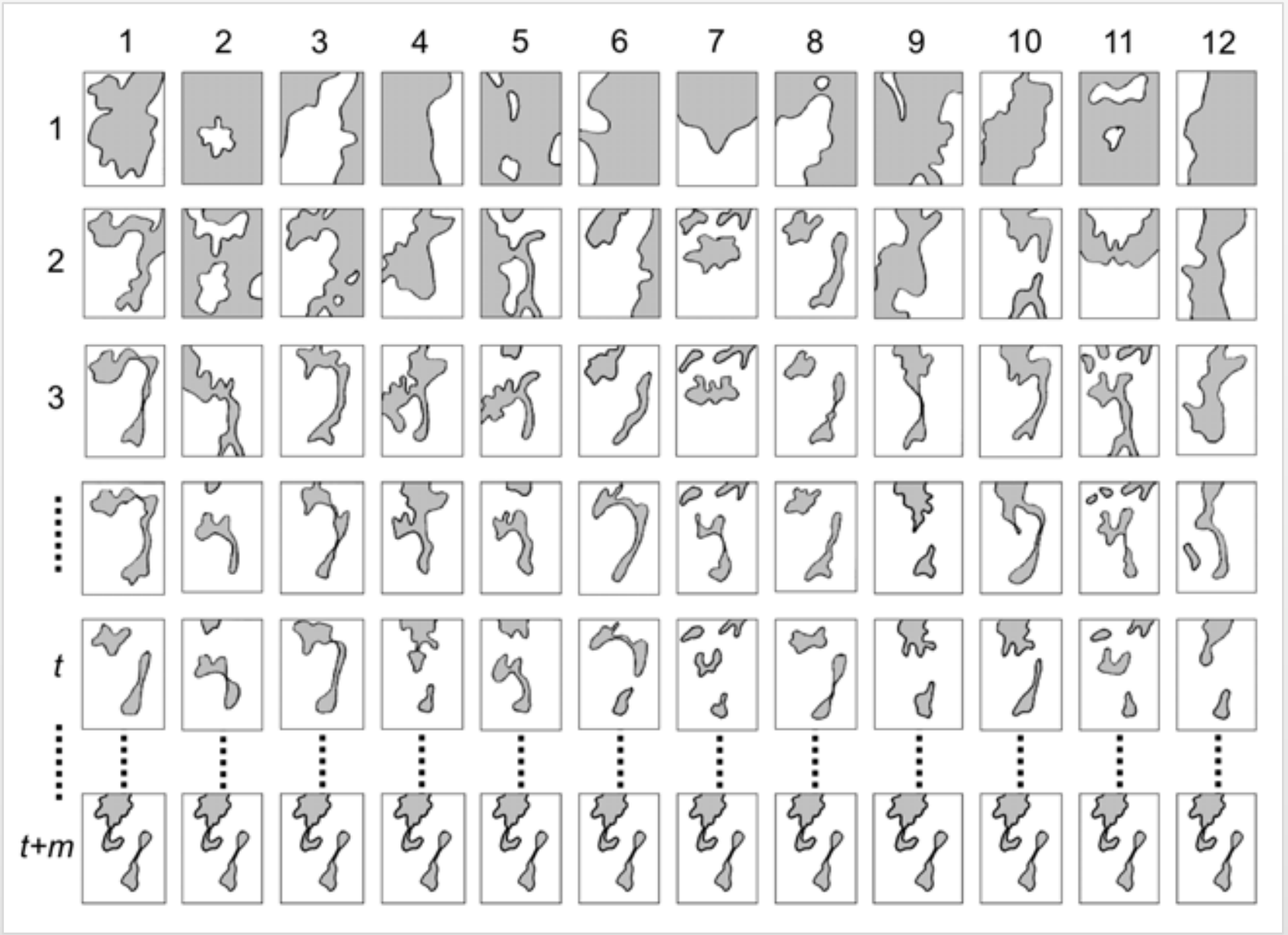
A Simple Example: Averaging by Overlay

The list of factors:

- accessibility to existing urban services,
- costs of spatial congestion,
- accessibility to recreational amenities,
- areas of acceptable micro-climate,
- areas of water catchment and poor drainage, institutional constraints imposed by government,
- accessibility to external urban markets,
- subsidence and extensive industrial pollution,
- areas of suitable topography,
- rural amenity areas,
- historic urban areas, and
- conservation of high quality agricultural quality.


7
11
2
1
5
10
4
9
8
3
6
12

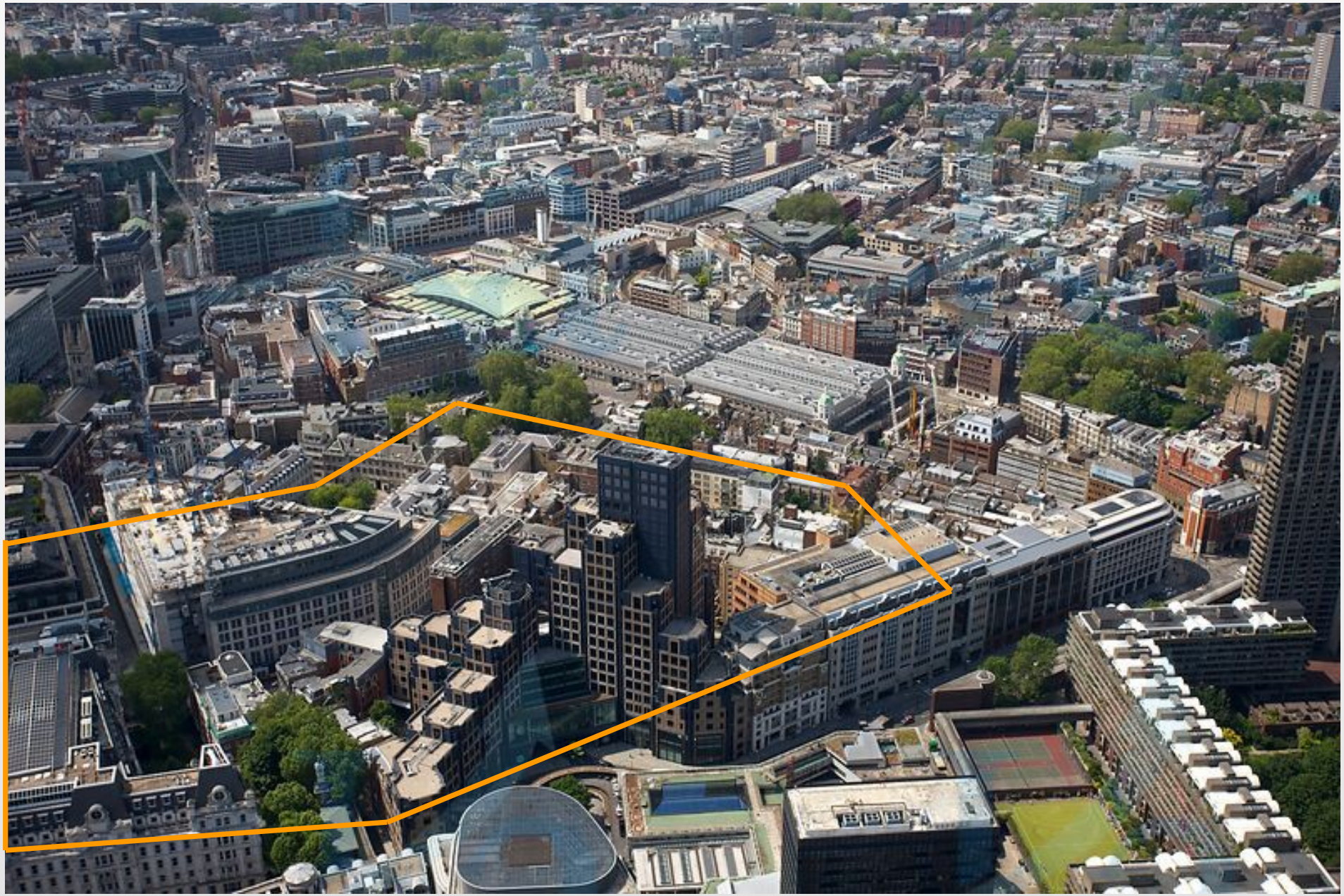

t
t+1
t+m
1
2
3
4
5
6
7
8
9
10
11
12

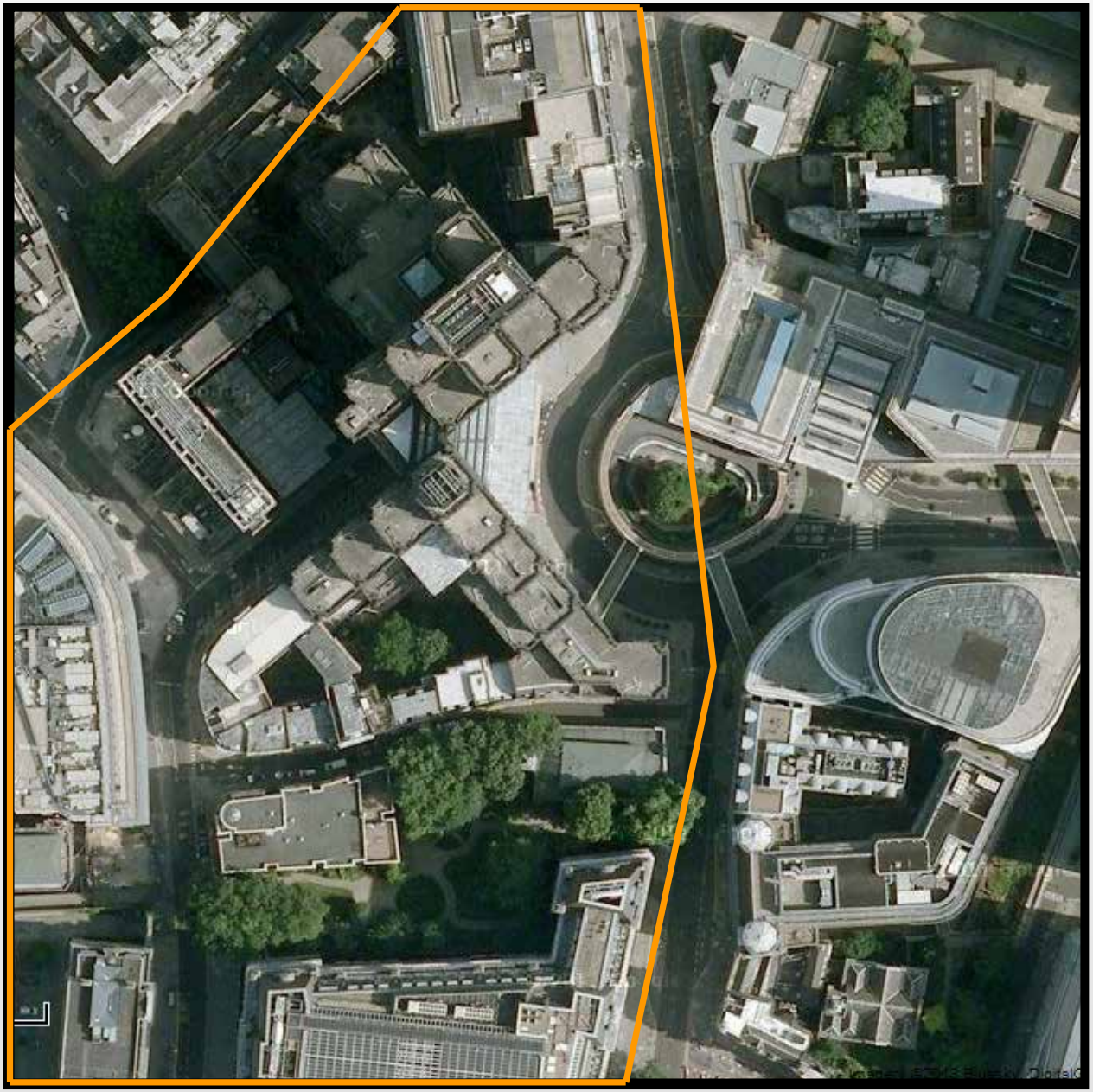

1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
t
t+m

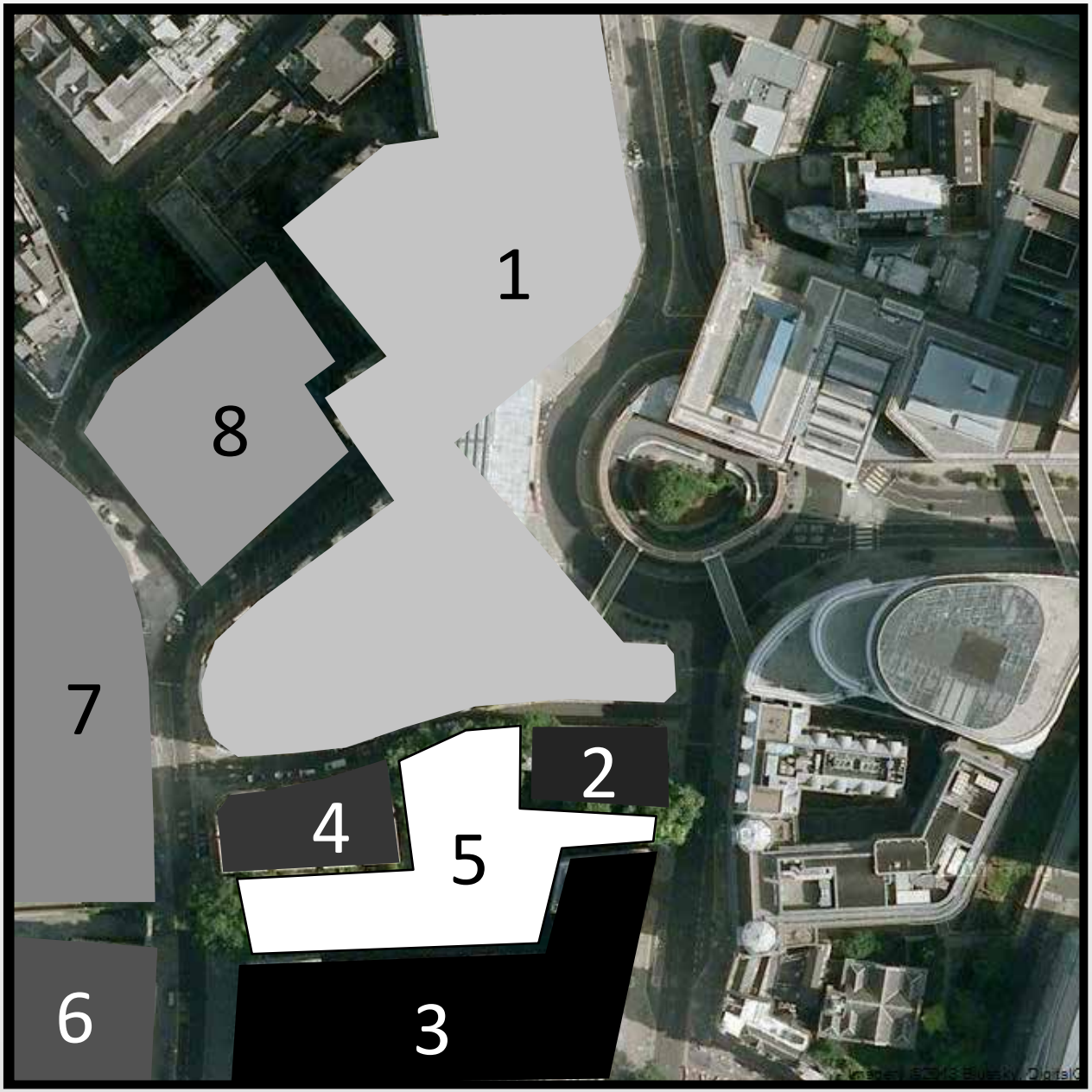
Generalisation: Modelling at the Very Local Scale

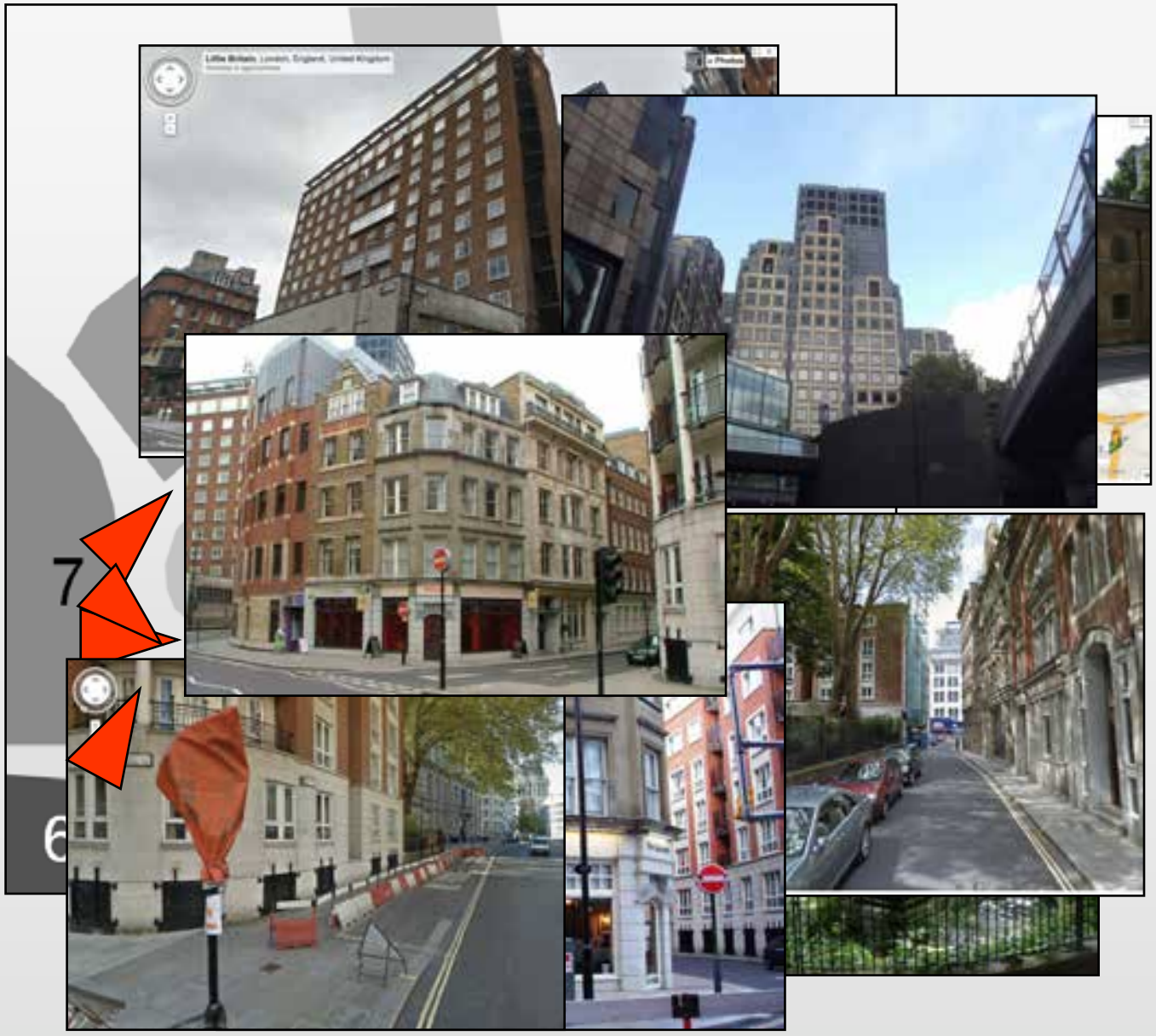
- The network of relations between factors: actors &agents
- The problem – the resolution of conflict over a change in use of land in a dense urban area – design maybe, decision
- The agents in the models – actors, stakeholders versus sites/buildings
- The way the agents interact across the maps of what they consider significant to change of use
- The way the agents effect compromise – two problems which are duals of one another – rather technical but a sketch of how we might proceed

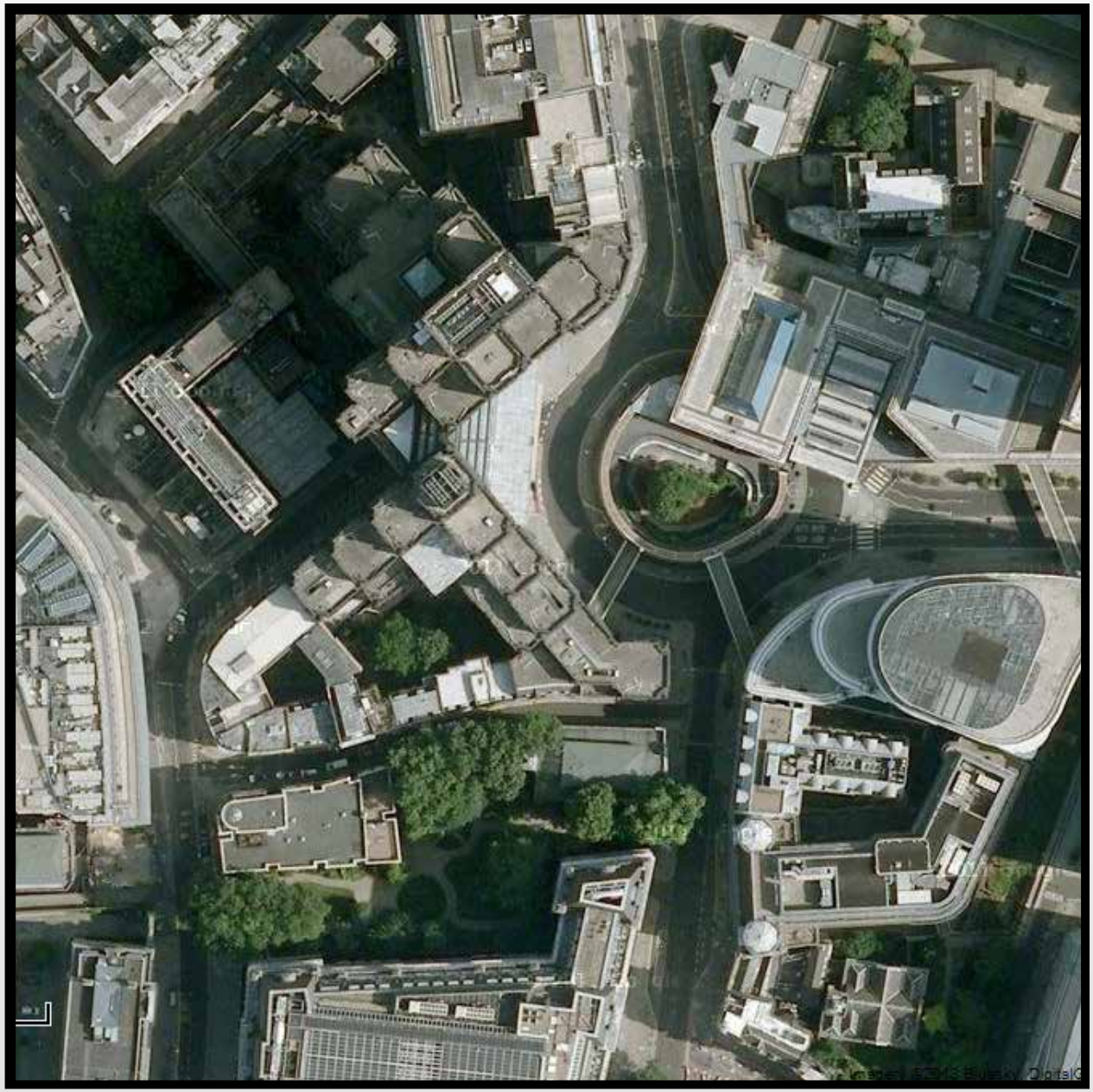
- A long preamble I know but let me begin with the problem first and then I will sketch the model
- The problem is one of reconciling different interests in land development in the heart of a world city: London
- It is as close to the heart of the city as possible for it centres on the postcode EC1A 1AA which is the old General Post Office and is now adjacent to the new London Stock Exchange (which is almost virtual now) –
- A very historic area with enormous development pressures
- It's a TOY MODEL with 6 agents or actors and 8 sites – let us see how it works
- Of course to make it real we can scale it in many ways – many actors many more buildings etc. and a lot of data on processes






1
8
7
2
4
5
6
3





Actors/ Stakeholders

1 City Corporation

2 Residents

3 Hospital NHS

4 Developers

5 Property Spec

6 Banks

Sites/Buildings/ Locations

1 Aldersgate Complex

2 St Botolph's

3 Nomura House

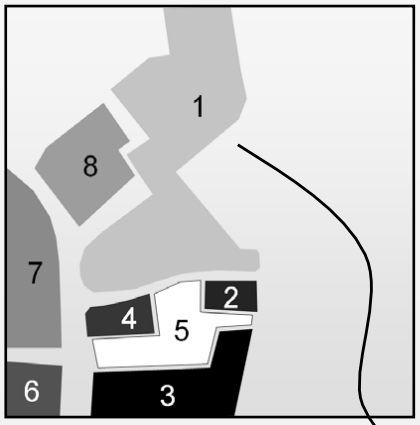
4 Milton House

5 Postmans' Park

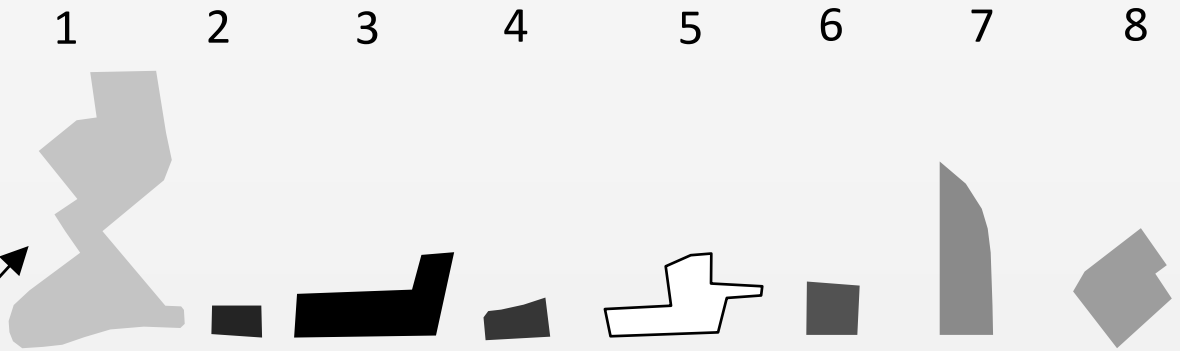
6 Bank of America

7 Barts New Building

8 Barts Old Building



Sites/Buildings

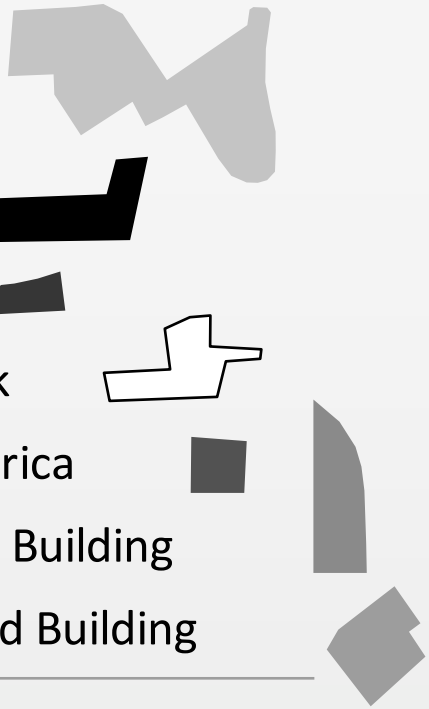


Agents

	1	2	3	4	5	6	7	8
1 City Corporation	0	0	1	0	0	1	0	1
2 Residents	0	0	0	0	0	0	0	1
3 Hospital NHS	0	0	1	0	0	1	0	1
4 Developers								
5 Property Speculators	●	●	●	●	●	●	●	●
6 Banks								

Sites/Buildings

1 Aldersgate Complex
2 St Botolph's
3 Nomura House
4 Milton House
5 Postmans' Park
6 Bank of America
7 Barts New Building
8 Barts Old Building



Agents

1 City Corporation
2 Residents
3 Hospital NHS
4 Developers
5 Property Spec
6 Banks

$$\begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \end{bmatrix} = M(ap)$$

The Primal: Interactions between actors wrt sites

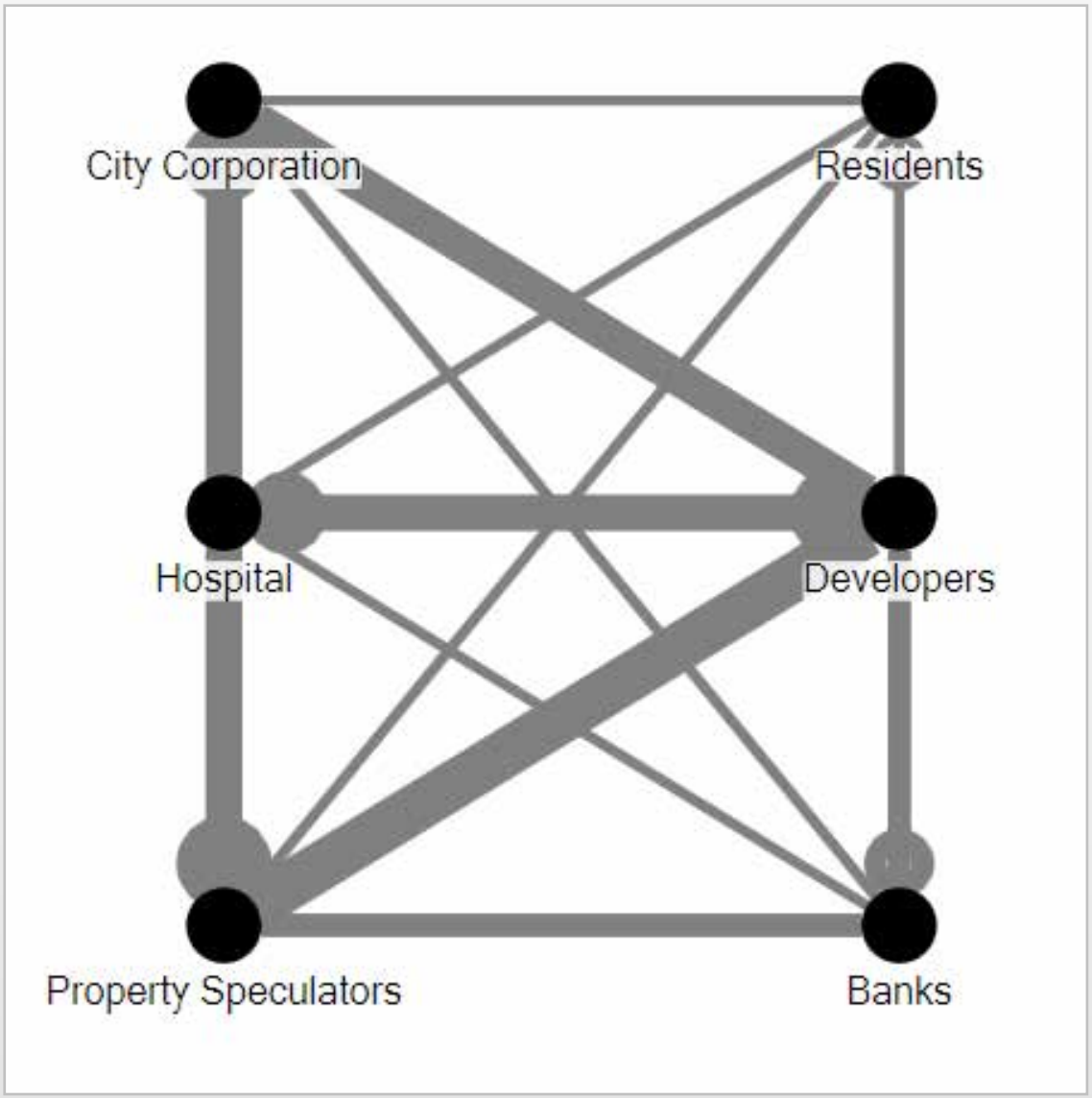
$$\begin{bmatrix} 3 & 1 & 3 & 3 & 3 & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 \\ 3 & 1 & 3 & 3 & 3 & 1 \\ 3 & 1 & 3 & 5 & 4 & 2 \\ 3 & 1 & 3 & 4 & 7 & 2 \\ 1 & 0 & 1 & 2 & 2 & 2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix}$$

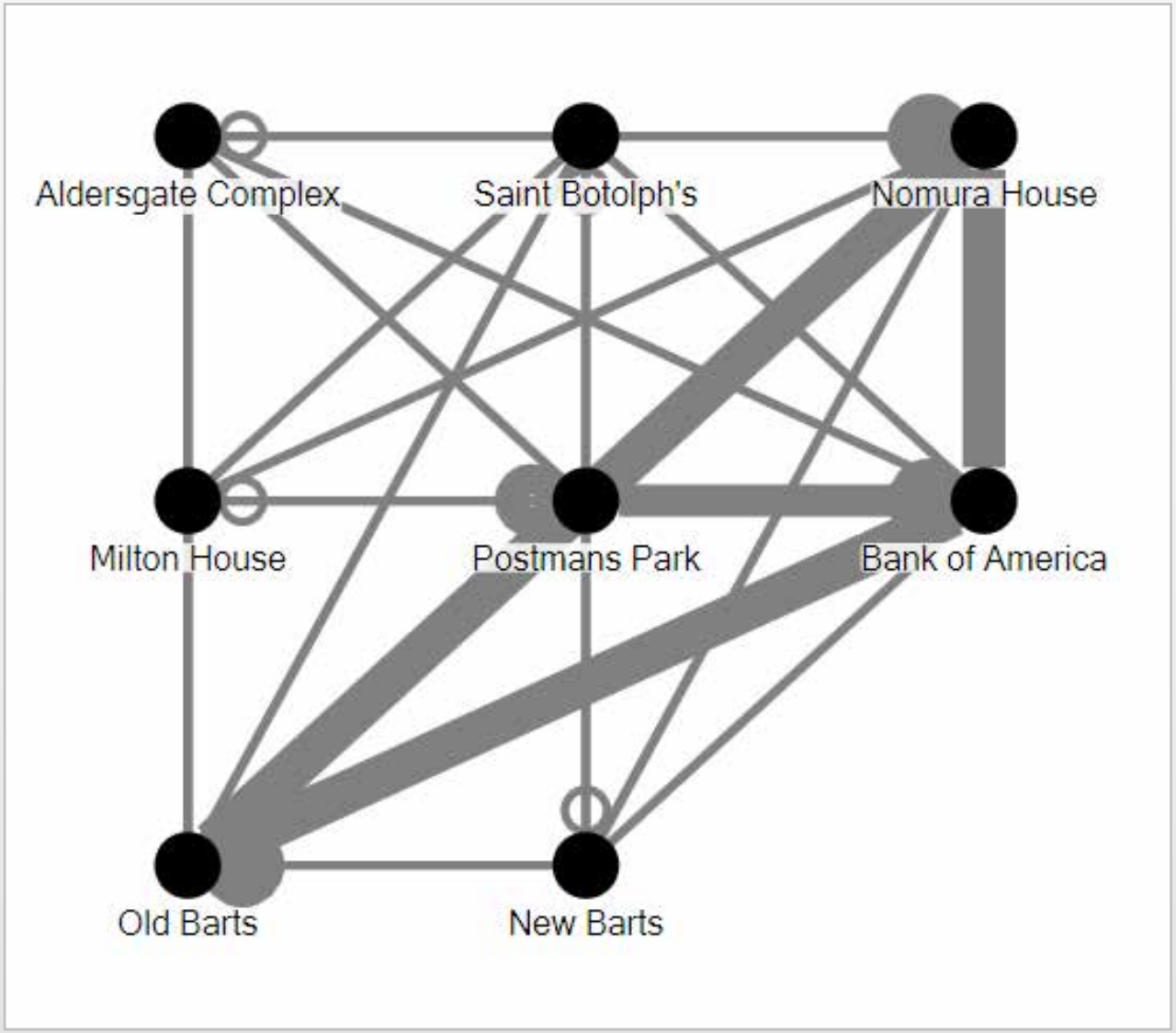
$$A = M M^T$$

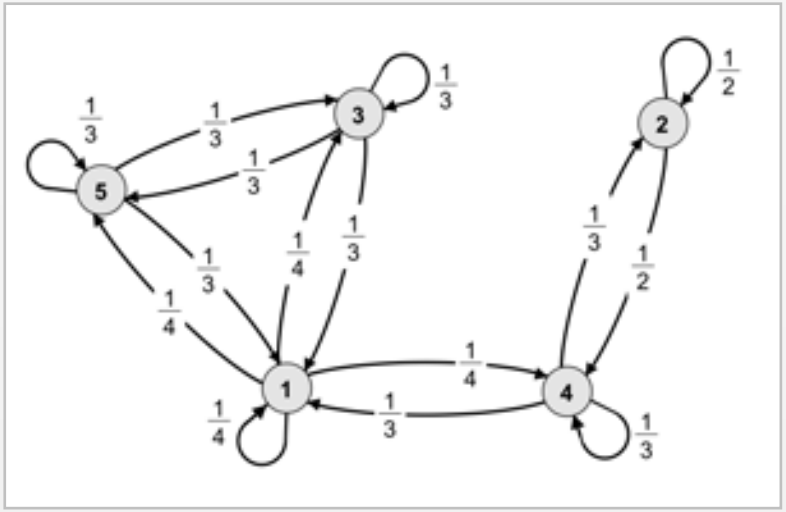
The Dual: Interactions between sites wrt actors

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 4 & 1 & 2 & 4 & 1 & 4 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 2 & 1 & 3 & 3 & 1 & 2 \\ 1 & 0 & 4 & 1 & 3 & 5 & 1 & 4 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 4 & 1 & 2 & 4 & 1 & 5 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \end{bmatrix}$$

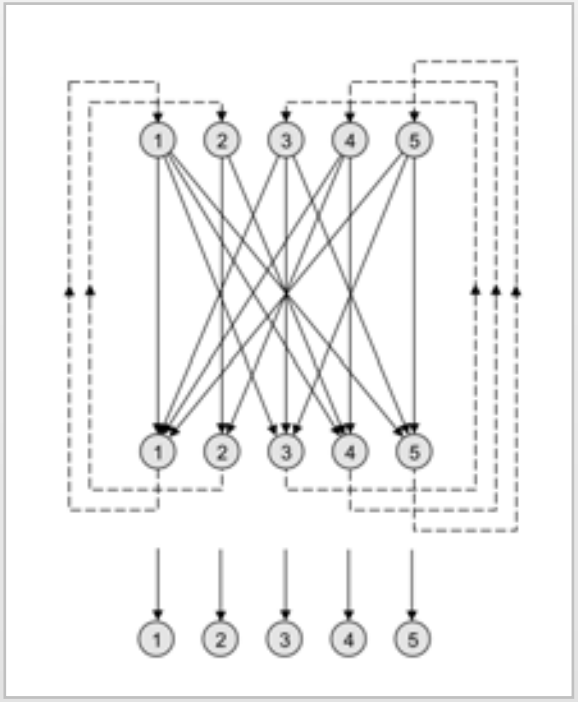
$$S = M^T M$$

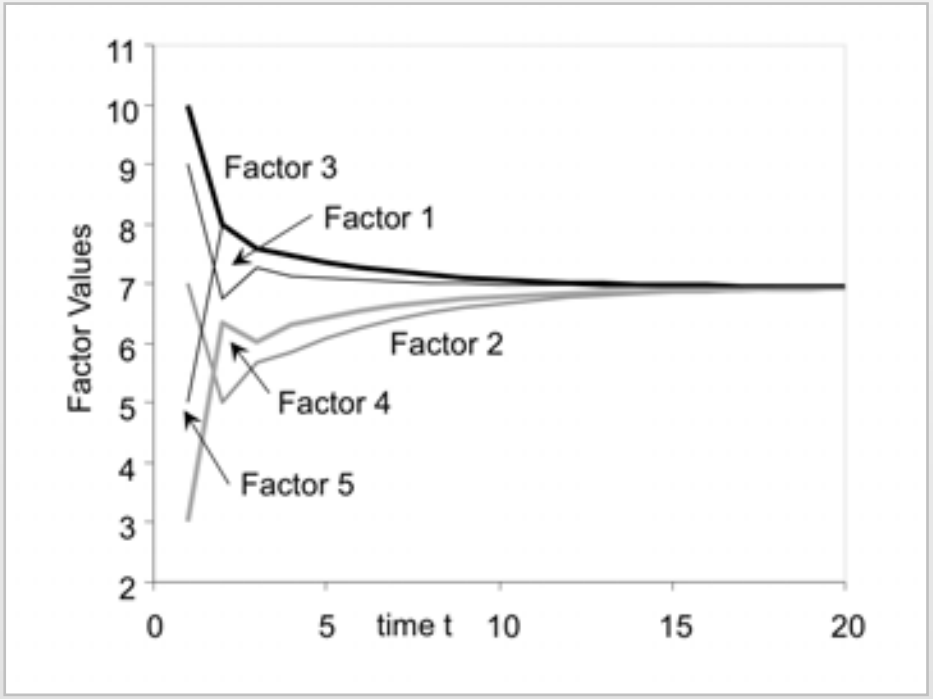

City Corporation
Residents
Hospital
Developers
Property Speculators
Banks


Aldersgate Complex
Saint Botolph's
Nomura House
Milton House
Postmans Park
Bank of America
Old Barts
New Barts



$$\begin{bmatrix} 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} 1/4 & 0 & 1/4 & 1/4 & 1/4 \\ 0 & 1/2 & 0 & 1/2 & 0 \\ 1/3 & 0 & 1/3 & 0 & 1/3 \\ 1/3 & 1/3 & 0 & 1/3 & 0 \\ 1/3 & 0 & 1/3 & 0 & 1/3 \end{bmatrix}$$





The Network Averaging X Set of Maps

$$\begin{bmatrix} 3/14 & 1/14 & 3/14 & 3/14 & 3/14 & 1/14 \\ 1/5 & 1/5 & 1/5 & 1/5 & 1/5 & 0 \\ 3/14 & 1/14 & 3/14 & 3/14 & 3/14 & 1/14 \\ 3/18 & 1/18 & 3/18 & 5/18 & 4/18 & 2/18 \\ 3/20 & 1/20 & 3/10 & 4/20 & 7/20 & 2/20 \\ 1/8 & 0 & 1/8 & 2/8 & 2/8 & 2/8 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \end{bmatrix}$$

yields

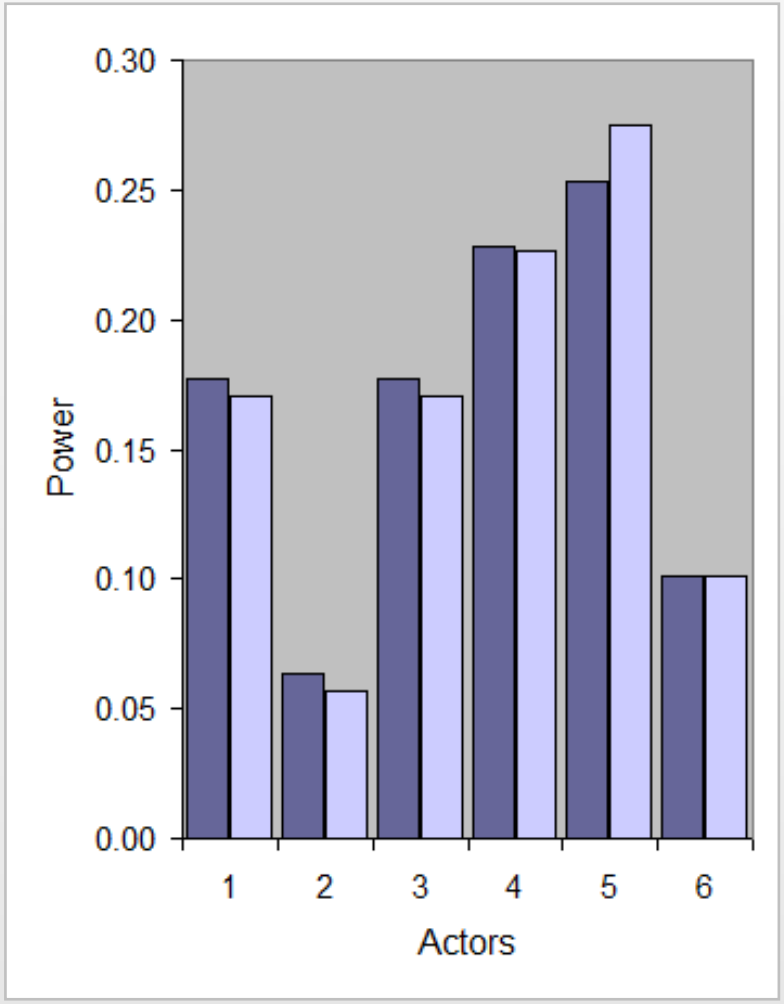
A New Averaged Set of Maps

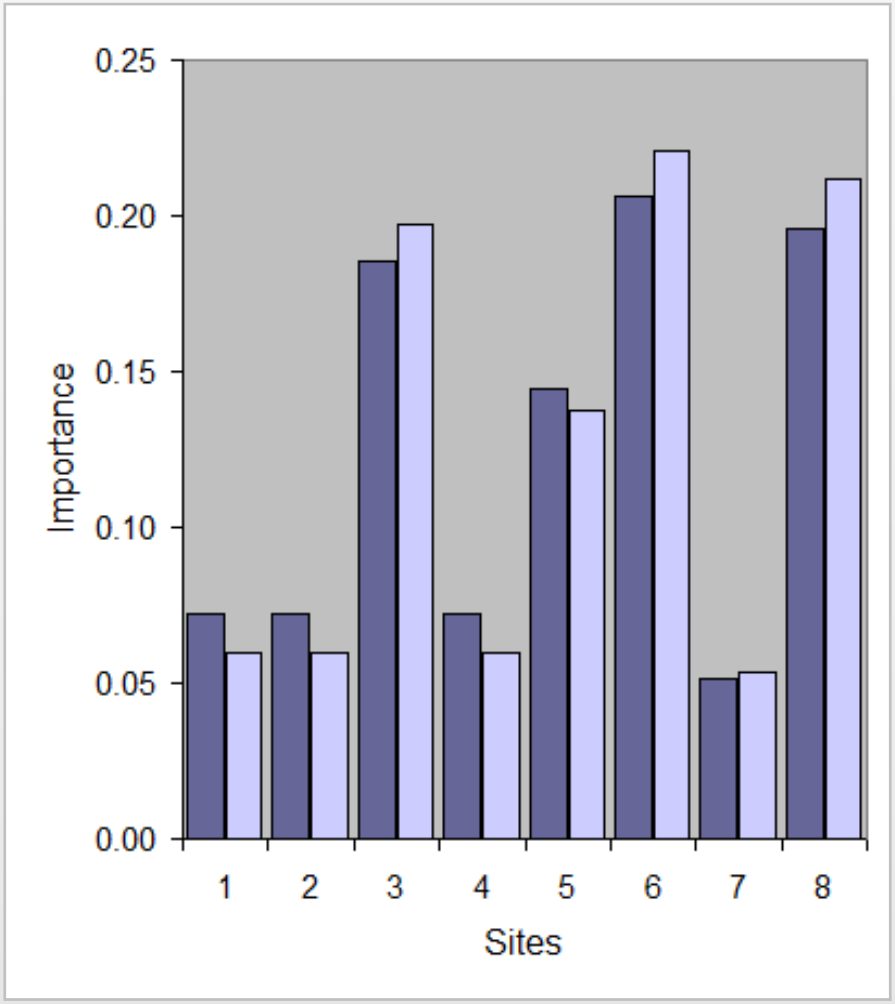
$$\begin{bmatrix} 0.21 & 0.21 & 0.86 & 0.21 & 0.50 & 0.93 \\ 0.20 & 0.20 & 0.80 & 0.20 & 0.40 & 0.80 \\ 0.21 & 0.21 & 0.86 & 0.21 & 0.50 & 0.93 \\ 0.22 & 0.22 & 0.83 & 0.22 & 0.61 & 0.94 \\ 0.35 & 0.35 & 0.85 & 0.35 & 0.65 & 0.95 \\ 0.25 & 0.25 & 0.75 & 0.25 & 0.75 & 1.00 \end{bmatrix}$$

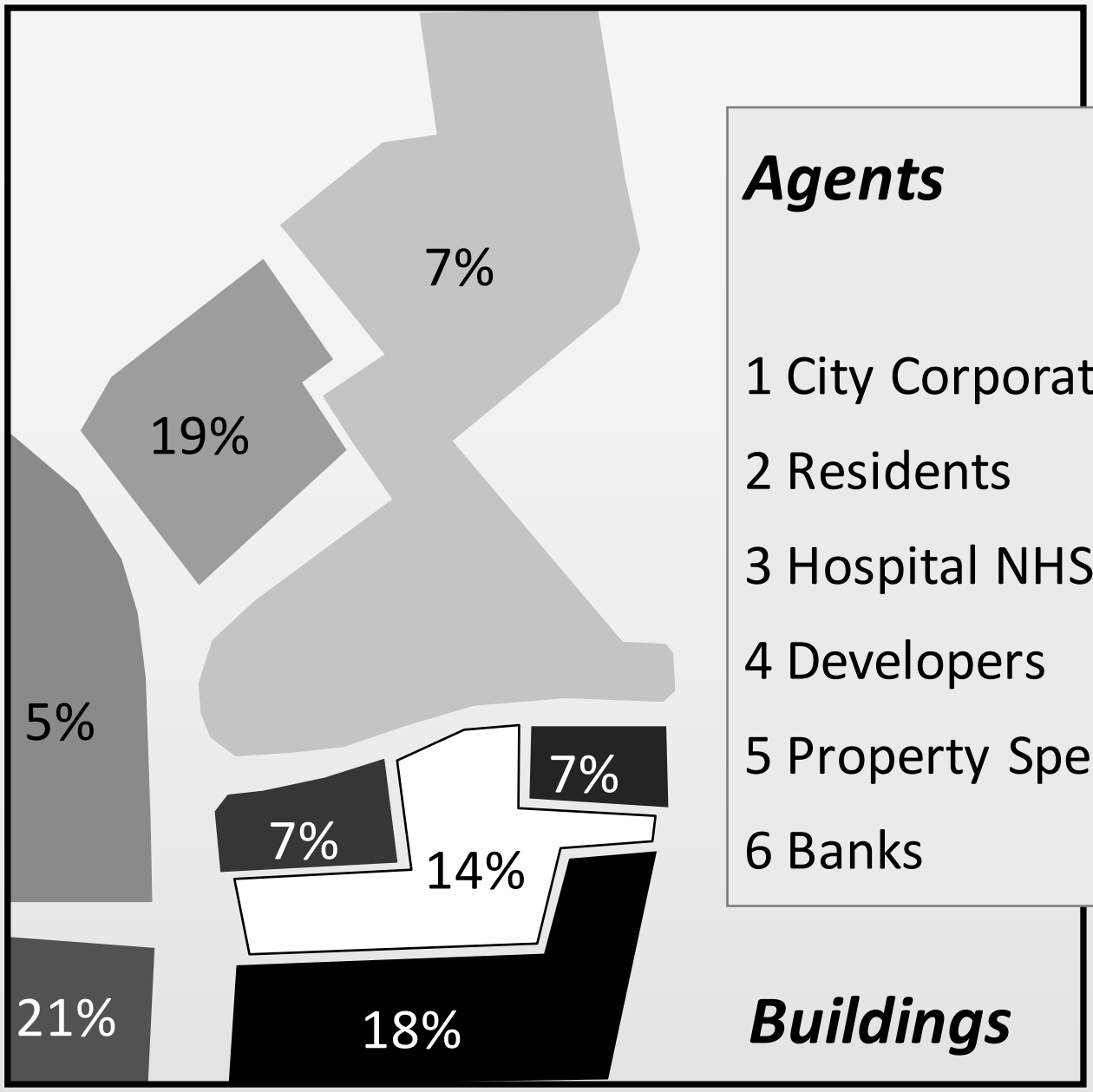
And then we average them again using the same network And this yields a new map, And so on until all the differences between the actors with respect to their maps are ironed out and we get the following map

0.25	0.25	0.84	0.25	0.58	0.94
0.25	0.25	0.84	0.25	0.58	0.94
0.25	0.25	0.84	0.25	0.58	0.94
0.25	0.25	0.84	0.25	0.58	0.94
0.25	0.25	0.84	0.25	0.58	0.94
0.25	0.25	0.84	0.25	0.58	0.94

We can do this on the dual problem, on the sites and iron out the differences between sites with respect to their actors


0.30
0.25
0.20
0.15
0.10
0.05
0.00
Power
1
2
3
4
5
6
Actors


0.25
0.20
0.15
0.10
0.05
0.00
Importance
1
2
3
4
5
6
7
8
Sites



Agents

1 City Corporation	17%
2 Residents	6%
3 Hospital NHS	17%
4 Developers	23%
5 Property Spec	25%
6 Banks	10%

Buildings

Next Steps

Real problems – very large networks, types of connection

Intensity or desirability maps; spatial averaging as developed quite widely in overlay analysis in GIS

Rational averaging, simple averaging, weighting averaging, dominance, and other strategies of compromise or not; networks that don't lead to solutions

The model is longstanding – not new, what is new is the dual primal and the embedding of maps into it

References over Many Years

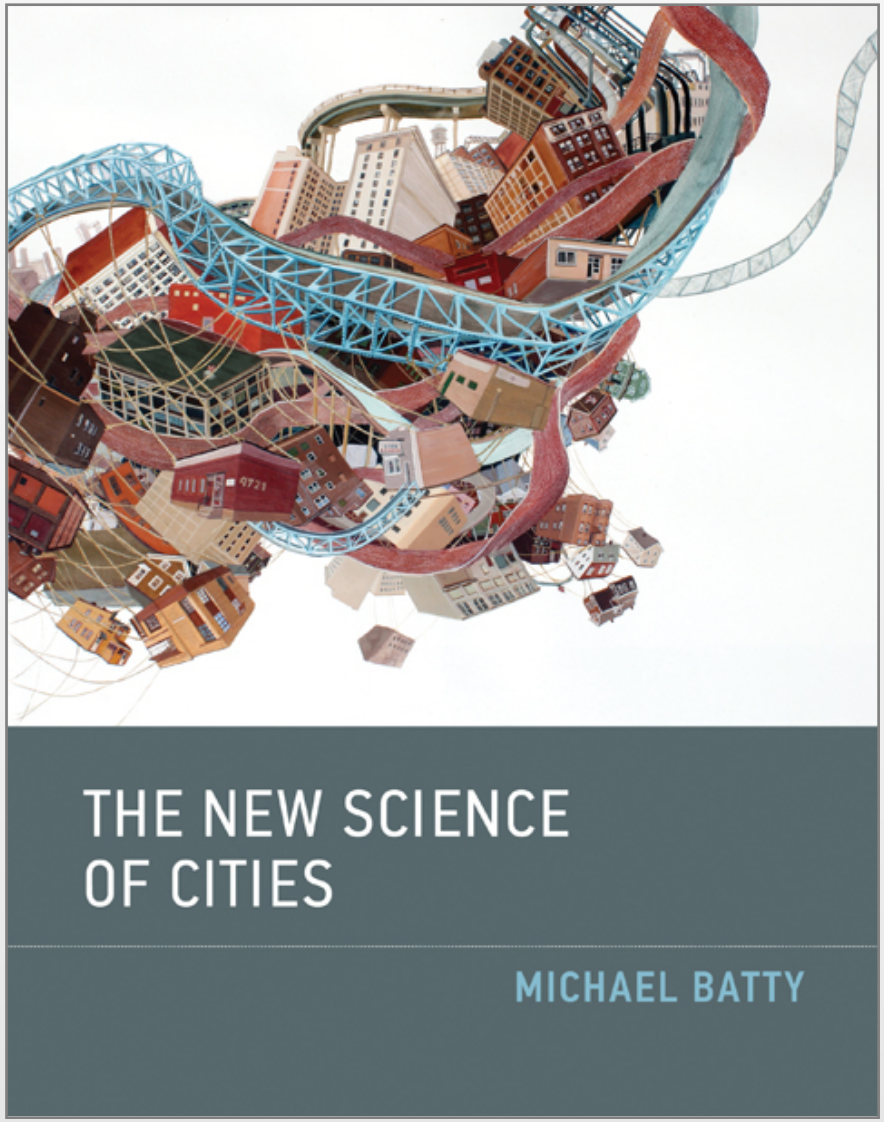
French, J. R. P. (1956) A Formal Theory of Social Power, **Psychological Review**, **63**, 181-194.

Batty, M. (1971) An Approach to Rational Design: Part 1: The Structure of Design Problems, Part 2: Design Problems as Markov Chains, **Architectural Design**, **41**, 436-439, 498-501

Batty, M. (1984) Plan Design and Committee Decision-Making, **Environment and Planning B**, **11**, 279-295.

Blondel, V. D., Hendrickx, J. M., Olshevsky, A., and Tsitsiklis, J. N. (2005) Convergence in Multiagent Coordination, Consensus, and Flocking, In **Proceedings of the Joint 44th IEEE Conference on Decision and Control, European Control Conference**, Seville, Spain, December 12-15, 2005,

Batty, M. (2013) **The New Science of Cities**, MIT Press, Cambridge, MA, in press



http://www.mitpress.mit.edu/

Thanks

http://www.spatialcomplexity.info/
http://www.complexcity.info/
http://blogs.casa.ucl.ac.uk/

http://www.casa.ucl.ac.uk/