THE MULTILEVEL MULTIDIMENSIONAL NETWORKS OF COMPLEX URBAN SYSTEMS

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Abstract:

Urban systems have many heterogeneous sets and many heterogeneous relations between them. Network theory has been very successful in analysing binary relations and related dynamics and flows. Urban systems are also characterised by higher level relations between many elements, leading to a multidimensional generalisation of network theory. Many dynamic system properties are dependent on the underlying multidimensional connectivities. New relational mathematics can support a new theory of multilevel systems, in which levels are coherently integrated through lattice hierarchies. This multilevel multidimensional backcloth supports the traffic of human activity at all urban levels. Relational structure is transformed into numerical functions when moving from micro- to macro-levels. The relational backcloth includes the usual infrastructure of roads, buildings and land use activities. Their relatively slow structural dynamics contrasts with the relatively fast dynamics of human activity such as activity use and traffic flows. The backcloth has natural structural events defining system time in a way different to but intertwined with the clock time of physics. This method of representing urban systems allows planners to investigate interconnected multidimensional system trajectories of possible worlds, and to investigate how polices might play out within short and long-term time horizons. Also they support an approach to urban planning and design in which the system is always evolving and coevolving as it adapts to new and changing human requirements. The presentation assumes no prior knowledge and develops through examples illustrating the fundamental ideas.

Keywords: complex, multilevel, urban, systems, dynamics, Q-analysis

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1 INTRODUCTION

Urban systems have many heterogeneous sets and many heterogeneous relations between them. There are sets of streets, squares, car parks, bridges, buildings, parks, and other infrastructure. There are sets of land uses such as residential, retail, industrial, commercial, and leisure. There are sets of transportation modes such as walking, bicycle car, bus, tram, train, and plane. There are sets of vehicles, from buses and trucks to cars to bicycles. There are local councils, with mayors, councillors and officers trying to fulfil their statutory duties enshrined in sets of laws laid down by Government. There are sets of problems, such as traffic congestion, providing housing and other services, constraining antisocial behaviour, supporting poor or homeless people, countering drug abuse, and managing the budget. There are sets of opportunities provided by local initiatives, Government schemes, redevelopment, new technology, and so on. There are sets of panoramas, with views over rivers, buildings, and open space. And there are sets of people of all kinds.

There are many relationships between the elements of these sets. There are relations between the buildings and the activities that take place within them. There are relations between people and the activities they use. There are relations between transportation modes and the activities they serve. There are relationships between urban structure and people's behaviour. There are relationships between people and their employers. There are community relationships between social groups and the authorities.

How can anyone truly understand anything as complex as an urban system? This paper will sketch a way of approaching this question. It involves ways of *building* 'grounded' multidimensional constructs *bottom-up* from a 'soup' of lower level constructs, in the context of resolving systems into lower level multidimensional constructs *top-down*.

The starting point is finding words and constructs at intermediate levels between 'the system' at the highest level and the all the minutiae of the lowest level. This is the process of *set definition*, which requires operational procedures for recognising members of *well-defined sets* and recognising patterns of *relational structure* that make elements at one level well-defined in terms of structured sets of elements at lower levels.

Network theory has been very successful in analysing binary relations and related dynamics and flows. But urban systems are also characterised by higher level relations between many elements, leading to a multidimensional generalisation of network theory. Many dynamic system properties are dependent on the underlying multidimensional connectivities.

2 SET DEFINITION

A *set* can be any collection of objects, called its *elements*. They can be abstract or concrete. Here attention will be restricted to *finite* sets, *i.e.* those sets whose elements can be counted from 1 to N, for some finite number N.

A set X is *well-defined* if there is an operational procedure, P_X, for recognising its elements. The notation $P_X(x)$ = True means that x passes the procedure P_X , in which case we say that *x belongs to X*. This is written:

x belongs to the set X if x passes the operational procedure P_X

$X = \{ x \mid P_X(x) = \text{TRUE} \}$.

Urban systems have many heterogeneous sets and many heterogeneous relations between them. As a small sample, these include:

<u>Humans</u>: individual people, households, neighbourhoods, ethnic group, social group, gender, age, activities (*c.f.* the Standard Industrial Classification)
<u>Urban spaces</u> workplaces (*e.g.* factory, school, shop, office, …), rooms, buildings, plots (lots), architectural types, street furniture
<u>Nature:</u> trees, bushes, lawns, flowerbeds, parks,
<u>Transportation</u> modes, infrastructure *e.g*. roads, rail, bridges, parking, vehicles

3 RELATIONS BETWEEN SETS

Figure 1 shows a parade of shops along the High Street in the small English town of Woburn Sands. Most of the buildings were constructed at the end of the nineteenth century, and are recognisably Victorian (red brick, sash windows, brick chimneys, pitched rooves, gables, etc). At street level they have modern shop frontages, apart from the hardware shop that maintains its original façade complete with decorative tiled portico.

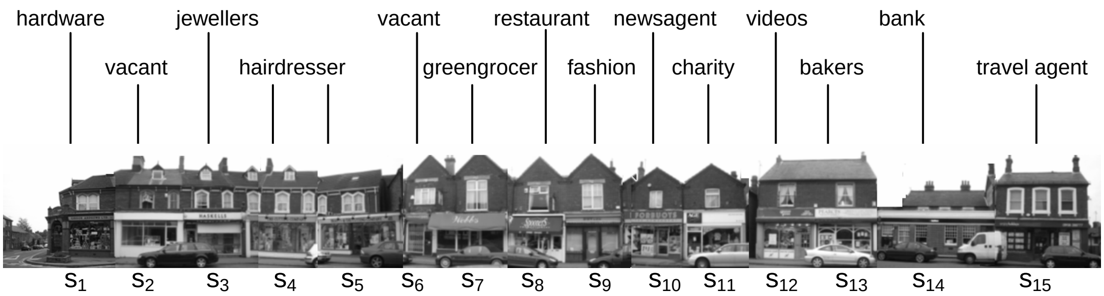
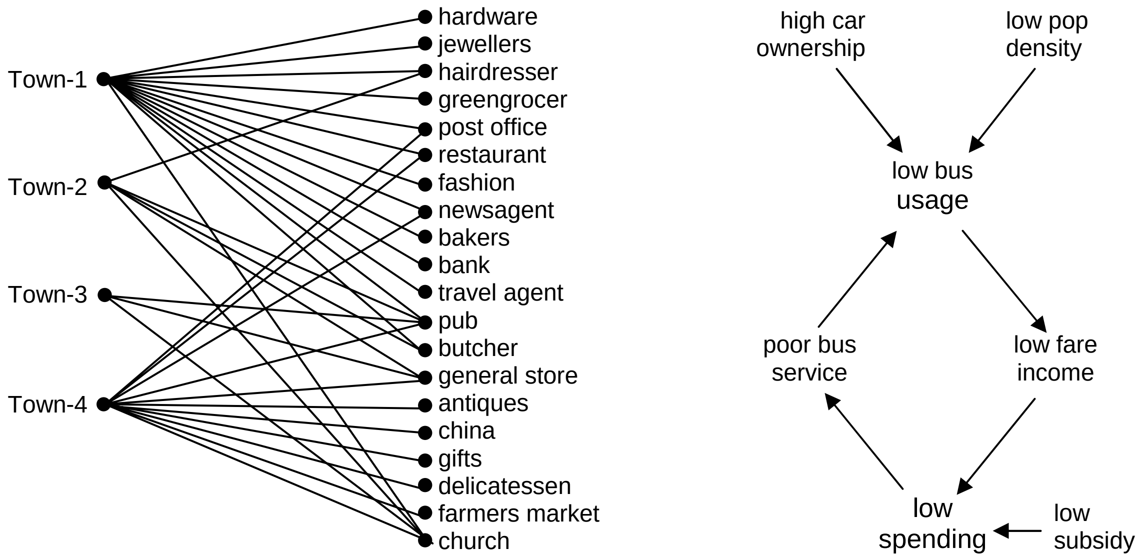


Figure 1. A parade of shops in Woburn Sands

Figure 2 shows Woburn Sands (Town-1) and three small neighbouring towns. The towns are represented by dots called *vertices* or *nodes*, and a set of retail activities also represented by vertices. In this diagram the relationship between the towns and the activities is represented by a line, called an *edge* or a *link*. The number of lines coming out of a vertex is called its *degree*. The collection of vertices and edges is called a *graph*. In Figure 2(a) Town-1 has the highest degree (14), indicating that it has the richest set of retail activities.



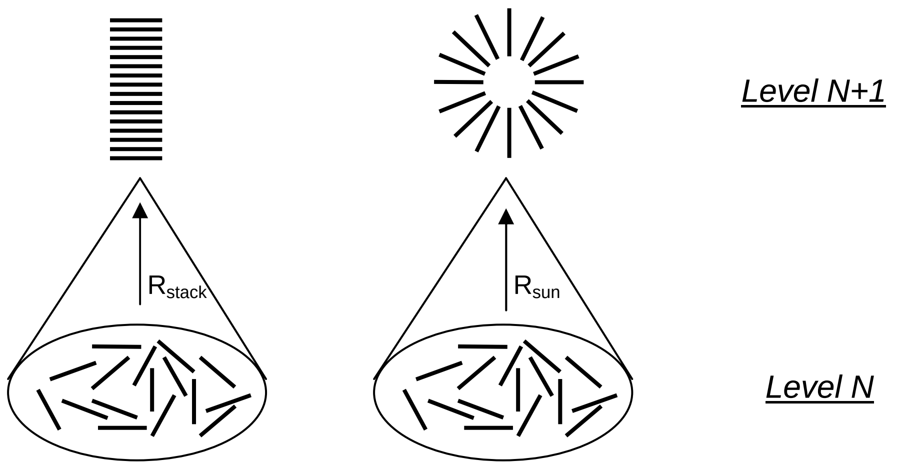
(a) Graph of the relationship between four small towns and their retail activities

(b) graph of a causal relationship

Figure 2. Graphs representing relational structure between elements of sets

Figure 2(b) shows the graph of a causal relationship. Its edges are *directed* and represented by arrows in a *network*. This diagram represents a postulated mechanism underlying poor bus service provision. This diagram can be used to argue that lowering car ownership or increasing population density could improve the service. In low density cities such as Milton Keynes planners are debating new ways of development with higher population densities. In high density cities such as central London, pressure can be put on car ownership by increasing the cost of parking.

4 N-ARY RELATIONS AND EMERGENCE



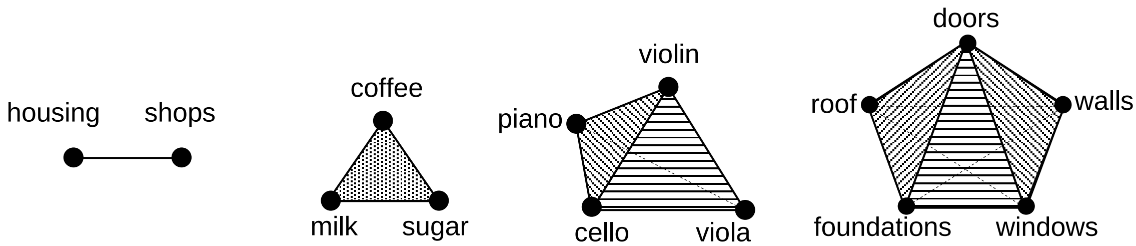
(a) a stack

(b) the sun illusion

Figure 3. Relations assemble sets into higher level structures with emergent properties

The fundamental idea in this paper is that *relations assemble elements into structures*. Furthermore, the structures exist at a *higher level* to the elements. In Figure 3(a) the set of lines is assembled into stack by the R_{stack} relation. In Figure 3(b) the lines are assembled into a sun shape. The remarkable feature about this structure is that it has the *emergent property* of a white circle appearing in the middle of the lines. This circle is not a property of any of the lines by themselves, and it is not a property of the set of lines, since it is not present in the stack. The white circle property emerges from the right set of elements, sixteen lines, being assembled in the right way by the relation R_{sun}. Both R_{stack} and R_{sun} are 16-ary relations, because they assemble the sixteen lines into relational structures.

The *binary relations* (2-ary) in Figure 2 can be viewed as a special case of more general *n-ary* relations between *n* things. Objects formed from *n*-ary relations can be represented by multidimensional polyhedra called *simplices*. E.g. ⟨housing, shops⟩ is a convenient structure for someone based at home, and can be represented by a line (Fig4(a)). ⟨coffee, milk, sugar⟩, a drink that tastes different to coffee by itself, milk by itself, and sugar by itself, can be represented by a polyhedron with three vertices, *i.e.* a triangle (Fig 4(b)). The piano quartet, ⟨piano, cello, violin, viola⟩, can be represented by a polyhedron with four vertices, *i.e.* a 3-dimensional tetrahedron (Fig 4(c)). Putting together ⟨foundations, walls, windows, doors, roof⟩ the right way produces a house which can be represented by a 5-hedron in 4-dimensional space (Fig 4(d)).



(a) 1-simplex (2 vertices) (b) 2-simplex (3-vertices) (c) 3-simplex (4 vertices) (d) 4-simplex (5 vertices)

Figure 4. Multidimensional polyhedra representing *n*-ary relations

The image of the house in Figure 5(a) is composed from the set of visual features $F = \{x_1, x_2, x_3, x_4, x_5, x_6, x_7\}$. The relation, *R*, *assembles* the set of features into the structured object that can be recognised as a house. Since the relation *R* assembles seven features, and it is said to be a 7-ary relation.

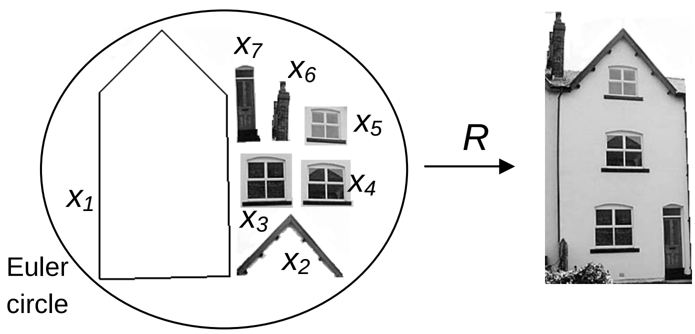


Figure 5. A set of parts assembled into a house by an *n-ary* relation

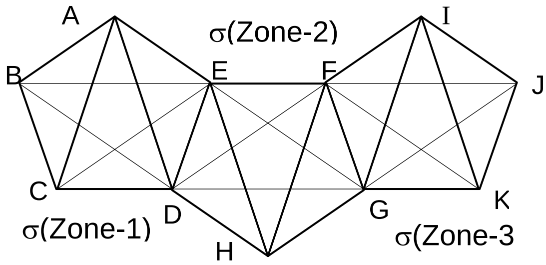
The notation R:$\{x_1, x_2, x_3, x_4, x_5, x_6, x_7\} \rightarrow \langle x_1, x_2, x_3, x_4, x_5, x_6, x_7 ; R\rangle$ is used to show that the relation *R* assembles the set of parts into the whole.

5 TRAFFIC ON THE MULTIDIMENSIONAL BACKCLOTH

Consider a relation between three zones in a town and a set of employment sectors, A, B, C…, K. The relation between the zones and the sectors can be given by an *incidence matrix* (Fig 6(a). Each row of the incidence matrix determines a simplex with vertices the related columns. They are denoted σ(Zone-1), σ(Zone-2), and σ(Zone-3). The set of simplices with all their faces is called a *simplicial complex* (Fig 6(b). Two simplices are *q-near* if they share a *q*-dimensional face, *e.g.* σ(Zone-1) is 1-near σ(Zone-2), and σ(Zone-2) is 1-near σ(Zone-1). σ(Zone-1) and σ(Zone-3) are said to be *q-connected* through σ(Zone-2), where q = 1 here.

	A	B	C	D	E	F	G	H	I	J	K
Zone-1	1	1	1	1	1	0	0	0	0	0	0
Zone-2	0	0	0	1	1	1	1	1	0	0	0
Zone-3	0	0	0	0	0	1	1	0	1	1	1

(a) incidence matrix



(b) the 1-connected simplicial complex

Figure 6. A simplicial complex as the backcloth for employment traffic

Generally it takes time for a zone to gain a new employment sector vertex. For example, opening shop requires months of planning and financial preparation, and time to fit it out and stock it. Relational structure will be called the *backcloth* of a system. Once the backcloth structure is put in place, a shop can support a traffic of goods and sales, with a related traffic of profit. In general, anything that can be represented by numbers attached to the backcloth will be called the *traffic* of the system. By comparison to the slow process of building backcloth structure, the traffic of goods and cash flow can be relatively fast, *e.g.* setting up a factory can takes months but once the backcloth structure is in place it can support a traffic of raw materials in and finished products out. This illustrates what are called *fast* and *slow* processes.

The traffic of employee wages illustrates how the *q*-connectivity structure of the backcloth can constrain the traffic. In Figure 6(b) suppose that business is very good for employer A in Zone 1, and employees' wages are increased to maintain stability and profits. Because it local, it will become known within Zone-1 that employer A pays relatively high wages, putting pressure on the other employers in that zone to increase their wages. Suppose they do. Consider an employer of sector D in Zone-2. For her, the employer of sector D in Zone-1 has increased his wages. Suppose that D-type employees meet for professional reasons, whether or not they work for the same employer. Then those in Zone-2 will learn that their colleagues is Zone-1 are paid more, creating pressure for sector-D employer in Zone-2 to increase her wages. Suppose she does so. Then there is pressure inside Zone-2 for all wages to be increased. If they are, employers F and G in Zone-2 may increase their wages bringing pressure on employers in Zone-3 to increase their wages. Thus the success of employer A in Zone-1 can cause change to be *transmitted* through the *q*-connected backcloth to employer K in Zone-3, even though the zones share no employment sectors.

6 MULTILEVEL STRUCTURE IN URBAN SYSTEMS

The house in Figure 5 is labelled as house *c* in Figure 7, one of four making up a *terrace*. In other words, there is a structure $\langle a, b, c, d ; R_{terrace} \rangle$.

Figure 7. A terrace is a structured set of houses

Figure 8 shows: how Level-1 visual features aggregate into higher level objects recognised as houses at Level-2; how sets of houses at Level-2 aggregate into a terrace at Level-3; how the terrace can aggregate with other features into a neighbourhood at Level N+4; and so on up to the levels of cities, regions, and continents.

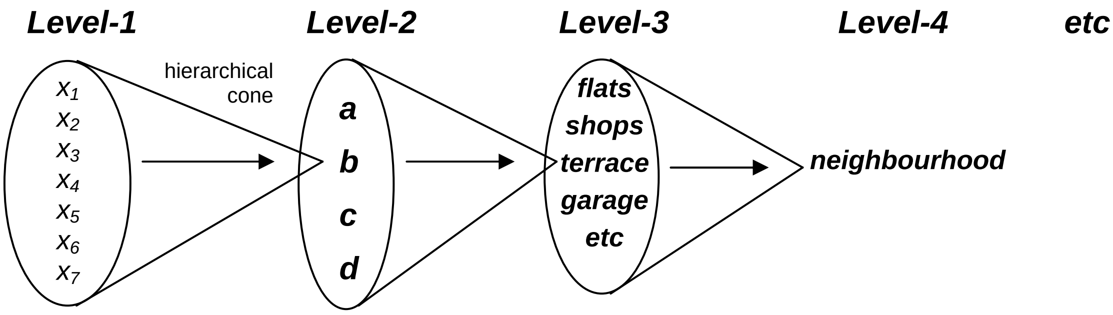


Figure 8. Urban structure defines a multilevel system through hierarchical cones

Figure 8 illustrates the use of *hierarchical cones* to represent the assembly of a set into a structure, R: $\{ x_1, \ldots, x_n\} \rightarrow \langle x_1, \ldots, x_n ; R\rangle$. Generally structures are given symbolic names, *e.g.* the houses were labelled ***a***, ***b***, ***c***, and ***d***.

In principle the way that *n*-ary relations move sets of elements up the hierarchy to become objects at the next level is simple. However, in a complex system such as a city there are many different kinds of set, and many different kinds of relations

Figure 9 shows part of Stockholm. Even visually, the city is very complicated. But each of these buildings is likely to contain complex human systems, with many types of activities. Between the buildings is the road system, supporting many vehicles of many types with their emergent dynamics of traffic jams and parking space occupancy.

Looking at Figure 9, there are many intermediate words between the name of the system, Stockholm, at the top level, and the morass of elements at lower levels. The picture shows various kinds of constructions, including churches, civic buildings, and bridges. There are ships by the quay, and vehicles on the bridge. The buildings have windows and rooves. Some of the churches have spires. There are trees and there are street lamps. If one were to walk around the streets it would be possible to add considerably to this list.

.**Figure 9. A city as a multilevel system**

When putting together a list like this it is easy to produce anomalies. For example, the list includes vehicles and cars. Since cars are a subclass of vehicles, they should be at different levels in the representation. We call such as collection a *hierarchical soup*, because it may contain a heterogeneous mixture of sets and elements at many different levels (Gould *et al*, 1984).

Looking at a whole system such as a city, we face what has been called the *intermediate word problem*, as illustrated in Figure 10. What are the intermediate words between the name of the system at the highest level, here Stockholm, and the hierarchical soup?

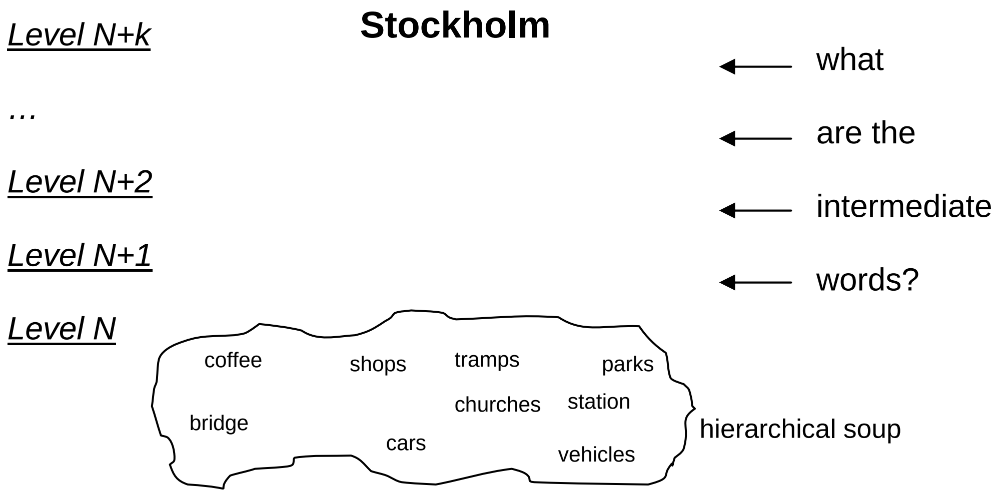


Figure 10. The intermediate word problem

At a lower level of urban aggregation, Figure 11 shows a terrace house in Leicester in the 1950s. Such houses were classified as slums and many were demolished to make way for new high-rise accommodation. A ‘soup’ of words can be abstracted from this picture, including:

boy (~5 years), boy (~9 years), woman (mother, ~20 years), woman (neighbour, ~30 years), terraced houses, windows, doors, bricks, washing tub, junk, corrugated iron sheet, fence, cloths line, washing hanging out to dry, long hair, shoes, damp, drafts, vermin, overcrowding, illness, poverty, communal privy, …

Figure 11. Poor housing conditions in Leicester in the 1950s
(www.le.ac.uk/.../resources/ braunstone/slum1.html)

Simplices associated with this include ⟨boy (~5 years), boy (~9 years), woman (mother, ~20 years); R_{family} ⟩. ⟨ junk, corrugated iron sheet, fence, cloths line; R_{yard} ⟩, and ⟨ washing tub , washing hanging out to dry; $R_{washing}$⟩.

7 HIERARCHICAL SET DEFINITION AND AGGREGATION

In urban systems, there is an intermediate word problem between the level of individual plots and buildings at the micro-level, and administrative areas at the macro-level. The solution to this is the definition of sets of *zones*, which are usually non-overlapping contiguous areas of land covering a larger area.

For example, Figure 12 shows Greater London divided into borough zones, the borough of Haringey divided into ward zones, and the West Green ward divided into streets zones, which could be divided into building plot zones.

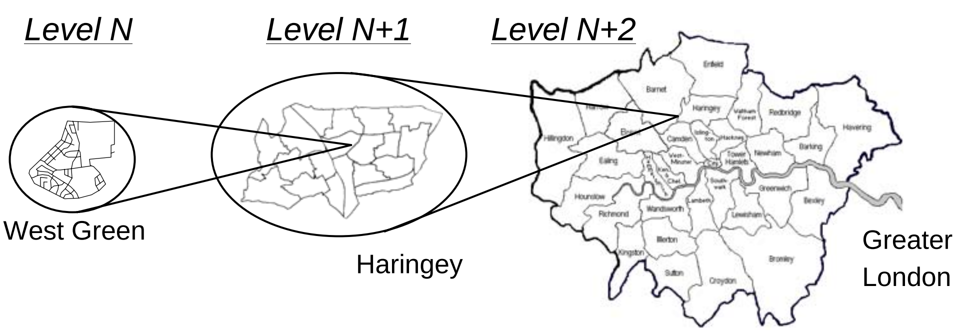
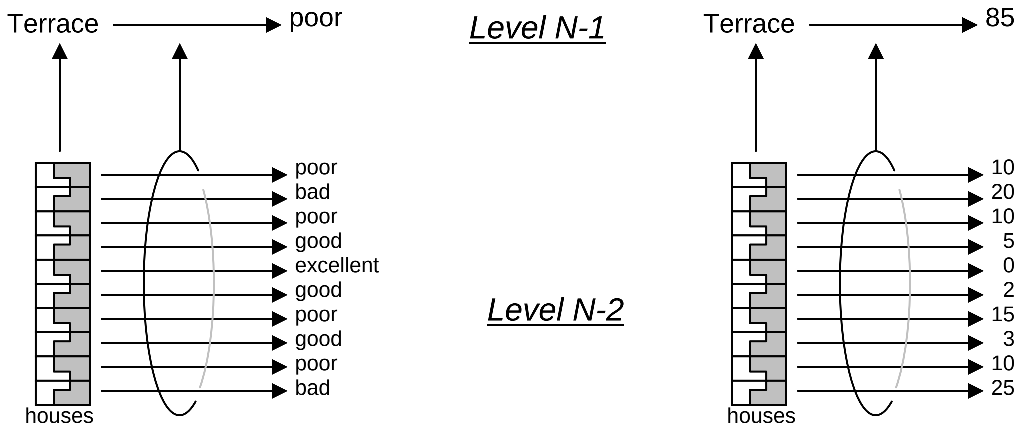


Figure 12. Hierarchical zones: streets in West Green in Haringey in Greater London

The planning officers responsible for local authorities often experience the intermediate word problem. Many of the things that concern them are ‘problems on the ground’. For example, Figure 13 shows an evaluation of the condition of houses in a terrace, at the level of the individual building. Usually policy cannot be made at the level of the individual building, but is made at a more aggregate level, *e.g.* the terrace, or study area neighbourhood.



(a) estimating condition of houses

(b) estimating repair cost

Figure 13. Hierarchical aggregation of condition and cost traffic on the backcloth

In Figures 13, the structural details of the terrace are left behind on moving up the hierarchy, to be aggregated into a number attached to the word terrace. Similarly, in Figure 14, the detailed structure of the study area is left behind, to be replaced by a poor/bad weighting, and a related decision to redevelop.

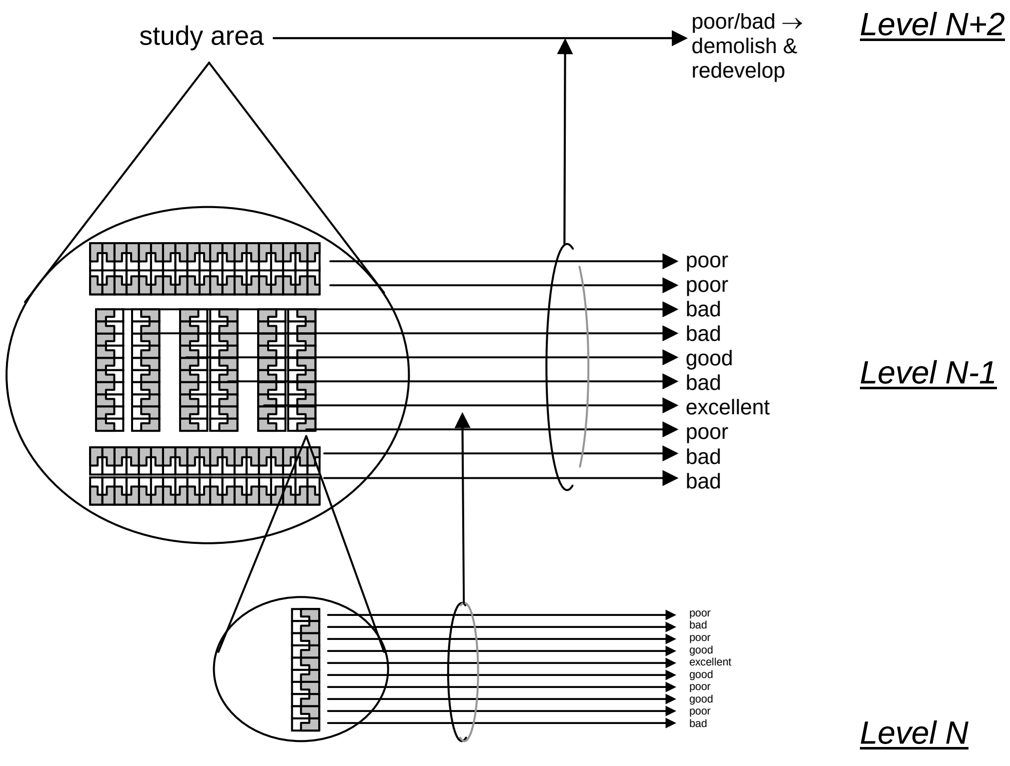
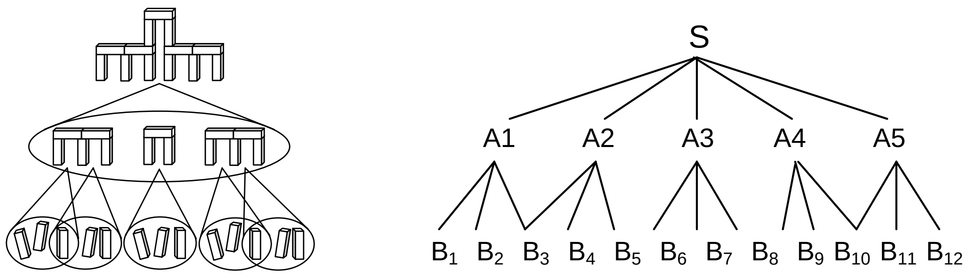


Figure 14. Multilevel aggregation: from structure to numbers to decisions

Figures 13 and 14 show these aggregations for two levels. In most analyses of urban systems the underlying hierarchical structure is not made clear, and the way the traffic aggregates over the hierarchical backcloth is not clear. In turn this makes it difficult to understand how the backcloth is supporting the multilevel traffic and its dynamics, and the system becomes unpredictable with relationships between high and low levels obscured.

8 LATTICE HIERARACHIES AND MULTILEVEL SYSTEMS

We say that x is *at a lower hierarchical level* than y if there exists a set X with an assembly relation R such that $R : X \rightarrow y$ and x belongs to X. Figure 15 illustrates this for a set of blocks built into arch structures.



(a) hierarchically assembled blocks (b) the lattice hierarchy of the assembly

Figure 15. Low level elements may have multiple aggregates in lattice hierarchies

Designed objects often exploit the possibility of sharing lower level structure. For example, Figure 16 shows a terrace of houses, with adjacent buildings sharing a party wall. This also creates a *lattice hierarchy*, as shown.

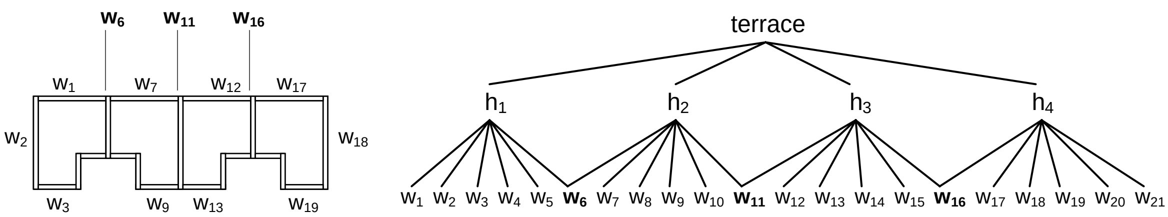


Figure 16. Shared walls between buildings reduce construction costs

When designers specify shared components, they create connectivity and coupling (Figure 17). Here the shared wall has the desirable property of reducing construction costs, but also enables the transmission of traffic between the houses. This could include a desirable traffic of negative heat loss but an undesirable traffic of noise and related nuisance.

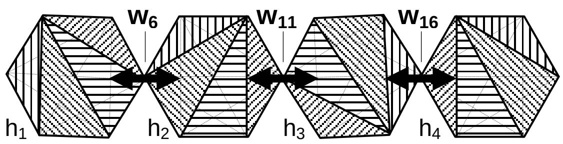


Figure 17. The building connectivity allows the transmission of heat and noise

More generally, there are descriptive hierarchies, such as the Standard Industrial Classification (HMSO, 2003), whose highest level is listed below:

A Agriculture
B Fishing
C Mining and quarrying
D Manufacturing
E Electricity, gas and water supply
F Construction
G Wholesale and retail trade; repair.
H Hotels and restaurants
I Transport, storage and communication
J Financial intermediation
K Real estate, renting and business activities
L Public administration and defence
M Education
N Health and social work
O Other community, social & personal service
P Private households employing staff
Q Extra-territorial organisations and bodies

Officially these are *tree hierarchies* in which lower level characteristics can only aggregate into one higher level class. However, one can find anomalies in almost all tree classifications. For example, *Le Manoir au Quat'Saisons* is a hotel with a gourmet restaurant (Class H), but it also offers cooking courses (Class M). In our terms the complete description is ⟨H, M⟩.

The Standard Industrial Classification is used to collect statistics. As noted previously structures become numbers, so the cookery courses should presumably be classified as an occurrence of '*80.42/1 Activities of private training providers*', and add 1 to the frequency of 80.42/1, 80.42, 80.4 and 80.

<u>Section M Education</u>

- 80 Education
  - 80.1 Primary education
    - 80.10 Primary education
  - 80.2 Secondary education
    - 80.21 General secondary education
    - 80.22 Technical and vocational secondary education
  - 80.3 Higher education
    - 80.30 Higher education
      - 80.30/1 Sub-degree level higher education
      - 80.30/2 First-degree level higher education
      - 80.30/3 Post-graduate level higher education
  - 80.4 Adult and other education
    - 80.41 Driving school activities
    - 80.42 Adult and other education not elsewhere classified
    - 80.42/1 Activities of private training providers
    - 80.42/2 This code is no longer in use
    - 80.42/9 Other adult and other education not elsewhere classified

Tree hierarchies are preferred by statisticians because of fears that double counting will make their statistics distorted when lattice hierarchies are used. This relates to the meaning and interpretation of the numbers associated with the classes. Assigning things to just one class when they belong to two certainly distorts the statistics of the suppressed class(es). Lattice hierarchies can be used without giving misleading statistics, and are preferable.

9 SYSTEM EVENTS AND SYSTEM TIME IN URBAN PLANNING

Urban systems are in a constant state of flux, but there are no scientific theories that explain these dynamics in a coherent and holistic way. One of the reasons for this is that the evolutionary dynamics of cities are not just governed by clock time in the way that physical dynamics are.

Physics has successfully based its dynamics on clock time. However, clocks are physical systems and the dynamics of physics is based on a tautology, illustrated by the observation that time can be measured by a pendulum, but a pendulum is a physical system operating in physical time.

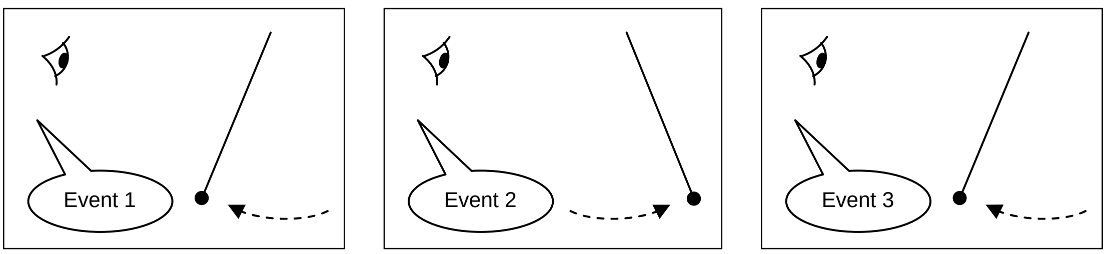
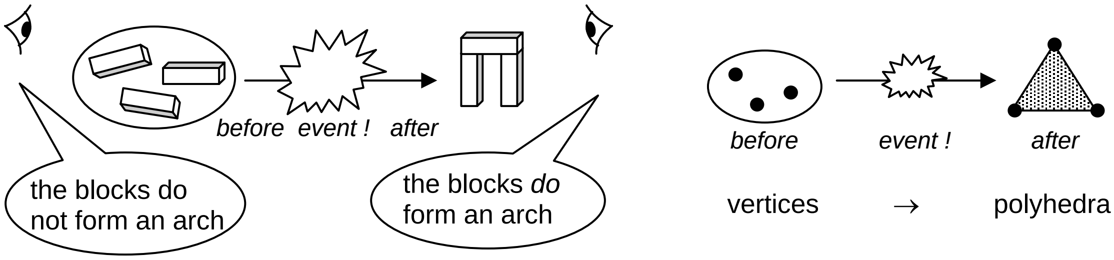


Figure 18: Pendulum events used to measure clock time

Since the swings of a pendulum mark *events* in clock time, with clock time intervals measured by successive pendulum events, Atkin (1974, 1977) proposed that social systems may have time measured by social events, marked as the formation of relational simplices (polyhedra). Thus the formation of an event can mark system time. Before the *polyhedral event* the vertices have not come together, after the event they have formed a simplex.



(a) assembling elements to form a structural event (b) a polyhedral event

Figure 19. The formation of polyhedral structure marks system events

To illustrate this consider the event of a bridge being built. Before the event, whenever it happens in clock time, it is unable to carry traffic. After the event it is able to carry traffic. This event will coincide with other systems events, such as the new traffic patterns enabled by the bridge changing flows and possibly generating more trips.

Consider the event of building of hypermarket. Before the hypermarket opens it carries no customer traffic. After it opens it sucks customer traffic through the connectivities of the backcloth from shops and retailers elsewhere.

The planners of Milton Keynes do not want the nearby shops of Woburn Sands to lose customers and close down, but what can they do if a large supermarket chain submits a planning application for a hypermarket three miles away? Can they predict the financial implications for the traditional shops? Using conventional economic and planning tools they cannot.

To develop this case as an example, before the request for the nearby hypermarket, the shops of Woburn Sands each carries their own levels of customer traffic and related income traffic. For many people this is multidimensional traffic, with a typical shopping trip involving the micro-microlevel activities ⟨buying bread, buying cornflakes, filling up the car with petrol, getting some cash, posting a letter⟩. These activities are associated with the simplex ⟨ grocer, garage, bank, post-office; $R_{single\_journey}$⟩.

Moving up the hierarchy, the micro-traffic aggregates into meso-traffic, with economic activity measured by numbers attached to vertices such as those in the Standard Industrial Classification. It can be predicted that the retail takings in Woburn Sands will decrease as a result of the hypermarket opening, but with wide margins of error. It can also be predicted that some of the shops will be more vulnerable than others, such as a local delicatessen selling high priced rarities that will become lower-priced hypermarket commonplaces. However, unless one looks at the inter-relations between such activities and others (connectivities in the multilevel backcloth), it is impossible to predict the effect on apparently less vulnerable activities.

10 PLANNING & DESIGNING WOULD-BE-WORLD TRAJECTORIES

At any instant of time, one can imagine the *state* of an urban system to be a snapshot that captures all the sets, the instantaneous relations between their elements, and the instantaneous values of the traffic. The dynamics of the system involve the transition from one state to another through time. Thus the system can be represented by a *trajectory* of states through clock time. The traffic trajectories for a fixed multilevel backcloth are illustrated in Figure 20.

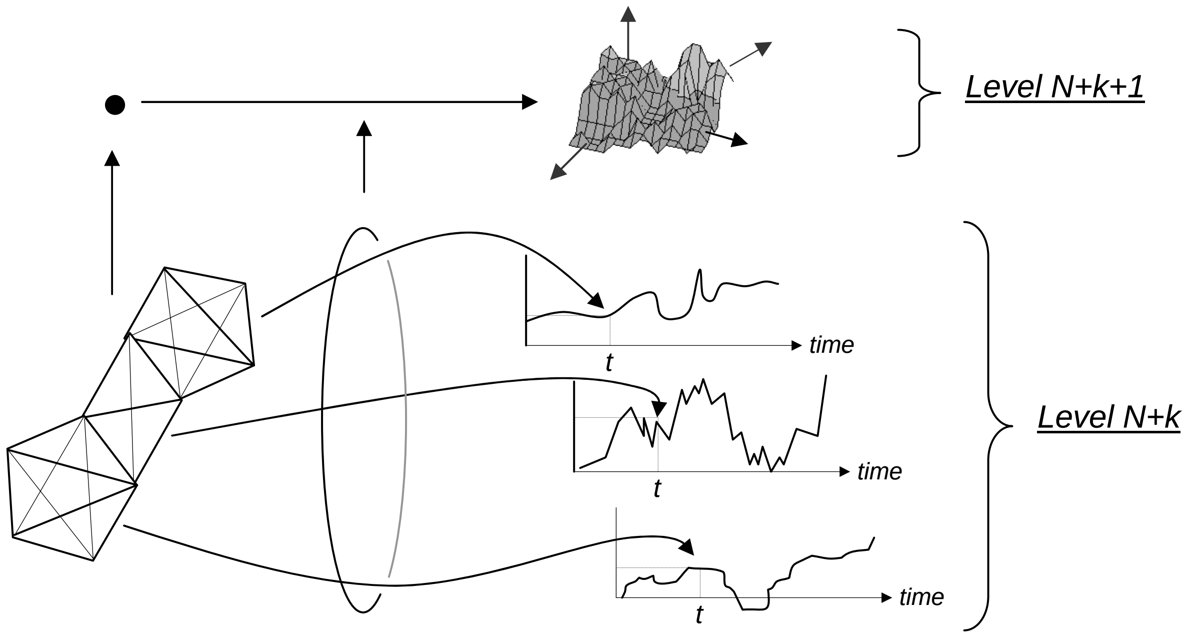


Figure 20. System dynamics as traffic trajectories on an fixed multilevel backcloth

System traffic is constrained by the backcloth in two ways. First, the lattice-hierarchical structure determines the way that the traffic aggregates from micro- to macro-levels. Second, the backcloth constrains the traffic dynamics, both allowing and obstructing changes.

The TRANSIMS system developed at Los Alamos National Laboratory over the past decade illustrates the first of these. TRANSIMS models urban systems at the level of the *individual traveller* (Level N-3), and families or households (Level N-2). Travellers are located in sets of zones defined by where they park their cars or begin the pedestrian part of their journeys. By starting at the lowest level of representation, TRANSIMS simulates *synthetic micropopulations*: from sample data it generates synthetic data to represent the whole population, with the same distribution statistics.

TRANSIMS then generates trips to satisfy the activity demands of the synthetic populations, and creates travel plans for those trips. Bottom-up microsimulation of the road traffic and other transportation modes produces emergent travel patterns and traffic flows across the whole urban system. TRANSIMS runs on high powered microprocessor clusters using parallel algorithms. It has been applied to systems with a million or more travellers in US cities, and is being developed to support transportation planning support for the hundreds of metropolitan planning areas in the USA.

Although it is one of the foremost planning tools being developed, TRANSIMS is based at the microlevel with no high-level meso or macro structure. It has been proposed that a multilevel representation based on the principles in this paper could make TRANSIMS a much more powerful planning tool, including adapting it for land-use – transportation co-evolution (Serras, 2005).

TRANSIMS allows the behaviour of the traffic to be simulated on a given infrastructure backcloth. This allows planner to ask what-if questions, such as the implications of building a new bridge or undertaking a new development, in the spirit of what have been called 'would-be worlds (Casti, 1997).

Apart from the dynamics of system traffic on a fixed backcloth, urban planning involves system trajectories in backcloth time-space, where polyhedra are formed and deconstructed through clock time. Figure 21 illustrates a simple backcloth trajectory, and shows that the polyhedral dynamics may not be linear in clock time.

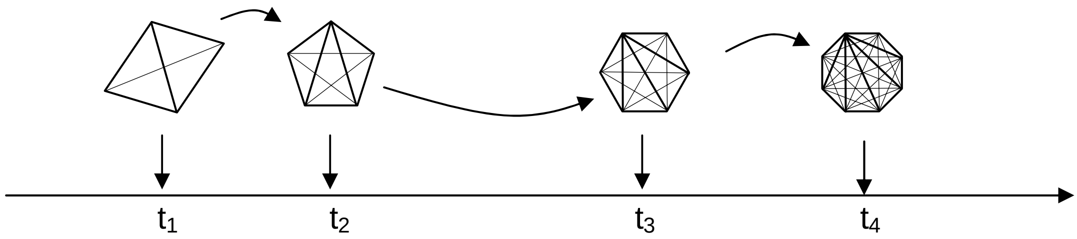


Figure 21. System event dynamics form trajectories in a non-linear way in clock time

The challenge for urban planners is to try to predict the outcomes of policies which are often intended to regulate the multilevel traffic by making changes to the multilevel backcloth. System dynamics involve the *transition rules* between system states, and the meta-rules that govern which rules are applicable when. Being able to predict emergent traffic behaviour for very large systems is a big step forward, but understanding how the backcloth can evolve to support desirable traffic is an exciting new challenge for the future.

11 BACKCLOTH TRAFFIC CO-EVOLUTION IN URBAN SYSTEMS

A major problem in land-use transportation planning is that changing land uses can create new travel demand patterns, and changing the transportation infrastructure can change the demand to develop and change land-uses. In practice this means that developers usually want sites with well developed transportation links, but once developments are allowed, they generate new and unpredicted traffic demands and flows, leading to new transport infrastructure being developed, leading to new pressure on development.

However, solving one congestion problem may, unpredictably, lead to others in a self-defeating downward spiral of global congestion. For example, the motorway system built across Birmingham, including the notorious Spaghetti Junction. Initially built to ease urban congestion by separating through traffic from local traffic, the motorways are now integrated into local road system and have become some of the worst sites of congestion in the UK.

In 2003 the new M6 toll motorway to the North of Birmingham was opened. Its impacts on the local and regional road traffic are unknown and, using current methods, unknowable. Certainly the new road will generate development pressures where it connects to the local road system. If development occurs the new road will become as congested as the road it was designed to relieve.

The challenge is how to design *trajectories* in which the land-use – transportation backcloth and traffic *co-evolve* in a well ordered way, rather than going from one crisis event to another.

12 CONCLUSION

Whereas cities and urban systems are complex in many ways, current approaches to planning, designing, and managing them are often simplistic, and lack coherence. Currently planning is based on weak and inadequate theory to support the great complexity of urban systems.

Related to this, the tools available to planners are simplistic, weak, and sometimes downright misleading. Few computer systems provide coherent hierarchical aggregation of backcloth and traffic, because there is little theory on which to base the necessary new data structures. In the absence of a coherent multilevel representation, there is little hope for a scientific theory on which to base predictions on the outcomes of implementing policy, or to manage the evolution of urban systems and their subsystem co-evolutions.

The major conclusion to be drawn from this paper is that if the multilevel multidimensional structures presented underlie urban dynamics, as argued here, then planners and those who create computer tools for planners must engage with these new ways of looking at urban and metropolitan systems and formulate new ways of representing them inside computers. This presents many exciting theoretical and practical challenges.

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