12. The dialectic as driver of complexity in urban and social systems

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Abstract: This chapter considers what can be learned from the study of urban systems considered as complex networks of spatial relations that might shed light on the rapid acceleration in human progress after their first invention around 10,000 BC. Using Hillier's key notion of the objective subject, Karl Marx and Vilfredo Pareto's distinct notions of the dialectic are reviewed. The contribution of space syntax research to consideration of the objective and subjective experience of urban systems is described, before finally proposing a dynamic bi-directional process in which the dialectic delivers continued progress in human development.

Keywords: space syntax, complexity, dialectic, human progress, empathy, narrative

This chapter was originally to have been written by Bill Hillier who sadly passed away on the 5th of November 2019 following a long and progressive illness that attacked his body leaving his mind intact. He was working and writing up until days before his death. I have taken on the task of writing the chapter in his stead but cannot possibly hope to emulate either his intentions for it, as we never discussed these, nor his acute and creative intellect which would undoubtedly have given the task an entirely new twist. Instead I will precis an argument he first made in a keynote paper to the Conference on Spatial Information Theory (COSIT) in September 2009, and subsequently published in Digital Urban Modeling and Simulation, edited by Stefan Müller Arisona, Gideon Aschwanden, Jan Halatsch and Peter Wonka and published by Springer. The subject of that paper, 'Cities as Socio-technical Systems' (Hillier, 2009), is entirely appropriate for this volume, and if you have not read it already, I commend it to you. My precis is inevitably partial and fails to do justice to his full argument.

Instead I will build upon this argument and aim to elaborate some key aspects of it that are of direct relevance to this volume. This elaboration is most certainly not what Bill would have written, and although I hope that he would have agreed with the thrust of what I say and would not have disagreed too violently with my interpretation and representation of his ideas, I have little doubt that he would have preferred to take it away, turn it upside down and emerge with a much more eloquent and nuanced version of his own. It was ever thus.

My twin aims are first to locate space syntax theory with respect to complexity science, and second to locate complexity science with respect architectural and urban phenomena. In writing this I will reflect on space syntax as a body of theory and the way that it has developed. In particular, I will use the comparison between space syntax and complexity theory to say something about the process through which space syntax theory has developed, and the way this draws on the phenomena of the world we live in and what this says about Bill Hillier's ways of working and thinking that have led to the unique contribution he has made to science. I have added my own perspective to his key theoretical postulate set out in the COSIT keynote – the objective subject – and I ask whether this can help us resolve two paradoxes, Pareto's paradox in sociology that in spite of people making decisions based on emotion they seek to justify these in rational terms;

and Marx's historical paradox that a materialist history should lead inexorably to an idealist future. In a nutshell, I argue that by combining the objective and the subjective into the two sides of a single dialectic sheet of paper this may reconcile contradictions while simultaneously demonstrating how complexity arises in social and urban systems. However, the implications go further. By considering subjective experience of place and time as objective events, I build a picture of history and human progress, and develop a sketch of this as a dynamic system.

Part of my argument rests on the art of storytelling, and here I know of no better exposition than that given by Dr Greenslade to Richard Hanney in the introductory chapter of John Buchan's The Three Hostages. Dr Greenslade is explaining how to write a thriller:

> *"Quite simple. The author writes the story inductively, and the reader follows it deductively. Do you see what I mean?"*
> *….*
> *"Look here. I want to write a shocker, so I begin by fixing on one or two facts which have no sort of obvious connection."*
> *….*
> *"Well, imagine anything you like. Let us take three things a long way apart--" He paused for a second to consider--"say, an old blind woman spinning in the Western Highlands, a barn in a Norwegian saeter, and a little curiosity shop in North London kept by a Jew with a dyed beard. Not much connection between the three? You invent a connection--simple enough if you have any imagination, and you weave all three into the yarn. The reader, who knows nothing about the three at the start, is puzzled and intrigued and, if the story is well arranged, finally satisfied. He is pleased with the ingenuity of the solution, for he doesn't realise that the author fixed upon the solution first, and then invented a problem to suit it."*
> *(Buchan, J., 1924)*

Now clearly, academic writing does the opposite. We lay out the problem first and then present various pieces of evidence before pulling the solution, like a rabbit, out of the hat.

Space syntax and complexity science

As I write this, I am sitting in the space syntax laboratory along-side Bill's library of books. Amongst these is a yellow four volume hard back set of proceedings of the 1968 International Union of Biological Sciences (IUBS) symposium series 'Towards a Theoretical Biology' edited by C.H. Waddington (2). The first symposium had just 19 scientific delegates and the proceedings aim to capture not only the papers given, but something of the discussion in the room, and subsequent correspondence during the editorial process. Some papers authored by one of the delegates have a written commentary by others. The first paper in Volume 1 by Waddington, for example, is commented on by Rene Thom and so forth. In addition to those that were already elder statesmen at that time, such as Waddington and Thom, the delegates included a younger generation of both biologists and mathematicians: Lewis Wolpert, Stuart Kaufmann and Christopher Zeeman to name a few.

While the IUBS hope to develop a theoretical biology as a parallel to theoretical physics may with hindsight be seen to have failed by comparison to the amazing successes of empirical

and experimental biology, there is no doubt that the attempt was significant in its aim to apply mathematical representations to biological phenomena and processes. It is clear from reading the proceedings that time was devoted to sharing a common understanding of different terminology between fields.

Both the papers and commentaries are replete with Bill's underlining and marginalia and give an insight into those aspects of the discussion in biology that Bill found interesting in his parallel and more or less contemporaneous programme to develop a theoretical approach to architecture, urban phenomena and society.

Both biological and urban phenomena have offered fertile territory for the development of complexity science. Take for example Peter Allen's urban simulations described in Ilya Prigogine's 'Order out of Chaos' (1993), however both the biological sciences and the development of space syntax must be seen as largely independent of complexity science driven as these each were by a desire to understand the lawfulness of their primary phenomena. In the case of biology these include metabolism, heredity and development, and in the case of space syntax it might be seen as the lawfulness of built environments and their relationship to the societies that produce and inhabit them, however I feel that this is too imprecise. In this Chapter I propose to bring more precision to the question by transposing the questions of urban function and urban development into a more directly social form. How do we account for progress in human society over history? How might the ideas on which society is based get from one generation to the next? How do these ideas evolve and change so rapidly on some occasions and yet remain in apparent stasis over generations on others? How does technological innovation and science fit into this picture?

Paradoxes of Marx and Pareto

These questions are not new. Many have written on them, but here I focus on two key thinkers, each of whom raises a paradox that may shed some light on this question. The first relates to the apparent contradiction between Karl Marx's materialist view of history and his apparently idealist view of the inevitability of the end of capitalism. The second was a paradox identified by Vilfredo Pareto, engineer turned economist, and latterly, sociologist and political scientist. Both thinkers deal with the dynamics of progress in human society, each from very different starting points[1], but with different points of intersection. Of relevance to this discussion is that both deal in different ways with the Hegelian notion of opposing positions in philosophical debate and the need to synthesise these. For Marx this formed the basis for dialectical materialism, while Pareto took the opposition between what people stated as their reasons for doing something and their underlying beliefs as the starting point for his synthesis.

Marx's belief is that all history is a history of class struggle. There is a clear element of Darwinian 'survival of the fittest' that underlies this position. In this view, human progress is to be accounted for on the basis of competition – or 'antagonism' – between different

[1] Both thinkers were prolific, and for Marx, certainly the amount written about his thinking far exceeds his own voluminous writing. For a concise overview of both bodies of thought I would point to Raymond Aron's Main Currents in Sociological Thought, Vol 1 for Marx and Vol 2 for Pareto. For a more extensive reading of Pareto short of the full four volume treatise (Pareto, 1916, tr 1935), I recommend Pareto, V. 1976, Sociological Writings, selected and introduced by S.E. Finer and Translated by D. Mirfin.

classes. At this point Marx's economic analysis comes to bear. In the modern capitalist era, he shows that the ruling class maintains its position by extracting surplus value from the labouring class and harnessing new technologies to increase productivity and so surplus value. These profits create the capital required to invest in still greater innovation, productivity and generate further profit. In this way the surplus value created by labour is extracted by the bourgeoisie. The cycle is built upon exploitation of labour by capital and it is this antagonism that Marx holds is destined to see the fall of capitalism to be replaced by socialism, a return to a form of society where each individual is enabled to fulfil their potential.

Here lies the paradox. In spite of his materialist conception of history, Marx – with Engels – adopted an idealist position with respect to individual action. They called for revolution to hasten the inevitable demise of capitalism and to install communism in its place (Marx and Engels, 1848). This tension has perhaps best been summed up by Schumpeter (1942) in his characterisations of Marx the prophet, the sociologist, the economist and the teacher.

Pareto's final treatise was on general sociology (Pareto, 1916). He came to this late in life, having reviewed historical data on salary and wealth in various societies over history as an economist, he drew the rather depressing view that the distribution of wealth in society was always highly skewed with just a few extremely wealthy and the vast majority less well off. His conclusion, that there was always an elite and revolution merely serves to replace one elite with another leaving the majority just as badly off as before, brought him into tension with Marxism and earned him possibly unwelcome support from the Italian far right. It is probably for this reason, more than the fact that his treatise on sociology ran to over a million words and is not the easiest read, that his thesis has not gained the attention it deserves.

In spite of their ideological differences there is agreement between these two thinkers. Marx's economic analysis provides a mechanism to account for the emergence of an elite in capitalism. Where they may differ is in their projections into the future. Marx's view of an inevitable destiny is based on the idealistic belief that we will progress to fulfil our potential. Pareto's more pessimistic view, having looked back over history was that not much has ever changed. One ruling elite is replaced by another. He then seeks to account for this by calling on an essentially psychological argument. We behave all too often non-logically, our decisions governed by instinct or sentiment and yet the reasons we give when we speak of why, are couched in rational terms.

Pareto based his social theory on a question which I paraphrase as follows: 'why is it that in spite of the fact that people make decisions based on instinct and emotion, they seek to justify these in rational terms?'. The distinction he draws between emotional and rational or heart and mind, aligns closely to that between the subjective and objective.

This raises a methodological problem. How should we study non-logical behaviours scientifically? How do we know what is in people's minds if we can only observe their actions or listen to what they say? Usually, he says, we rely on what people say to explain their behaviours. However, there is another factor that is important, and that is what people believe. Sometimes this is formalised as a creed, but often it is not. By studying the

relationship between beliefs or creeds, acts or behaviours and what people say (their expressions), we can go some way toward deducing what might be their state of mind (their sentiments). Since each of these factors may in principle affect the others – the way people act may affect what they believe for example – the challenge is complex. In this way Pareto places an analysis of the dialectic – a key, if differently defined concept for Marx – centrally in his treatise, although he does not state it as such.

Cities as sociotechnical systems

Hillier's view of the relationship between social systems and complexity is characteristically clear. He argues that an essential component of complex systems is that they are characterised by emergence. The emergence we see in cities happens in two primary ways. First, they are built over time by many different builders, each responding to the conditions and existing geography of the city at that time, each building according to the geometric and physical constraints of materials and the affordances of space, and out of this emerges a more or less comprehensible urban structure. Second, they are used by individuals and groups of people who engage in communal social and economic activities. They work, shop and party; they socialise and travel; they rent and invest; and, from time to time, they build. The city is socio-technical in the sense that it arises out of a technical process of construction and a social process of function, and the two are intrinsically related, each causal to the other and each emerging from the other. This form of 'two-way causality' is one of the things that distinguishes Hillier's thinking from reductionism and determinism and relates it directly to theories of complexity.

Bill Hillier's 2009 COSIT paper explicitly sets out to discuss how space syntax can be seen in relation to complexity science by developing this discussion. He draws on Jack Cohen and Ian Stewart's dual insights, that although the world is complex, living in the world requires us to see it in terms of its simplicities (Cohen & Stewart, 1994); and that complexity arises through the interactions of numerous simple entities at a level below. It is through the interplay of the simple and the complex that urban form and function are related. However, I will suggest it is by extracting the simple from the complex that the whole edifice of Western science has been built, and that this more than any other factor, influences the destiny of humans and the planet we live on.

Hillier's argument in the COSIT paper develops in stages. He shows how restrictions on aggregation probabilities can lead to the emergence of patterns of open space. A pattern in this sense is not merely a visual form of the kind that one might see on wallpaper, but a systematic regularity of a more general kind. He shows how these in turn can be more or less 'intelligible' in that local properties of space can be correlated or uncorrelated with global properties (one kind of regularity). If local and global are correlated, then a human subject inhabiting that environment can learn to infer information about their global position from their perception of local context. In effect, they can learn the correlation and so make a prediction and act accordingly. If uncorrelated, then learning to make that inference is certainly more difficult and may be impossible.

Next he demonstrates the lawfulness of spatial configuration. By investigating the effects on distance to all other points, of placing a block to movement or visibility in different locations within a space, he shows that the results of configurational choices are both systematic and

quantifiable. Most importantly, local choices have global effects. This lays a basis for his key insight that cities comprise two main systems: First, a vertical system of emergence of form through many discrete actions of those that build them over time. If for example each builder places their next building (which acts as a block to visibility and access) in a location selected so as to maximise the total distance between all other locations, a very different global form will emerge than if they place it to minimise total distance; Second, a lateral process of function, exploiting or appropriating the pattern properties of space for socially meaningful action. So, for example, if shop owners choose more accessible locations in preference to more isolated ones, then these will attract shoppers and so amplify the effects of accessibility on occupancy and movement behaviour. Conversely, if they choose less accessible locations, they will need to invest in marketing of their wares or in the relative quality of product and service to attract customers.

He concludes that human cognition is centrally related to both vertical and lateral processes, and that, in the generalised form of the 'objective subject', cognition acts to link these processes together. To put it simply, the objective subject comprises those aspects of cognition and action that are common to multiple individuals – a kind of statistical average that characterises a whole population. We might think of the objective subject as 'that which is learned about the regularities in the environment and which acts to inform individual action or behaviour'. Hillier's objective subject resolves a fundamental dualism that has dogged urbanism; that of a divide between the urban environment and the experiencing human subject. He shows instead that the mathematical laws of space can be internalised and act to inform behaviour. While behavioural decisions remain subjective, their basis is neither arbitrary nor random, but objective and encoded in the configurational patterns that human society builds and uses.

In this way human cognition is intimately related to both the production of spatial configuration and to the behaviour and patterns of use people make in and of space. By coupling the vertical and lateral processes he accounts for the way that humans can appropriate found and natural environments as well as the way that they can construct new environments to suit their purposes. At the same time, he accounts for the fact that an environment constructed by one group or generation can function for another, although the way it functions may be quite distinct since the 'objective subject' of the new generation or group may be quite different to that of the original builders.

For Hillier the built environment, produced as it is by cognitive agents, but always subject to the mathematical laws that determine possible configurations and their functional consequences, is both objective and subjective at the same time, so resolving the dualism and the paradox. Viewed this way the apparent divide between the experiencing subject and their environment evaporates to be replaced by a single functional complex. So too the divide between multiple individual subjects who instead, and at the same time, can be seen to compose dynamic social groups that give form to the objective subject.

Cohen and Stewart's proposition is that rather than to explain complexity, the more rewarding question is to explain the simplicities that seem to characterise the world 'one level up'. They note that science generally explains complex phenomena through simpler theories. They give the example in statistical physics of simple gas laws relating

temperature, pressure and volume arising out of the massively complex interactions amongst numerous gas molecules. Hillier uses the analogy of our ability to throw a ball of paper to land in a waste basket. It seems that we have learned to compute trajectory, gravity and air resistance just by living in the world. Hillier's objective subject can be thought of in similar terms if we take that to be the commonalities amongst different individuals' perceptions of, and actions in, their environment that we each learn and which enable us to predict enough about the reactions of others to our own actions, to allow us to behave with intention in a social world. Here is the twist. While the objective subject is based on the similarities exhibited by multiple individuals, it is this that allows each individual to behave with autonomy and intent.

There is an obvious distinction between physical and social phenomena. While gas molecules are inanimate, humans have beliefs, intentions and desires. We have perceptions and memories. We behave purposefully and appropriate and shape our environments to satisfy our needs and preferences. This requires that a theoretical account of a social phenomenon must be cognitively plausible. Crucially however, we have imagination and can envision different worlds to any that we have yet experienced. We can communicate these plans to others and then we can work together to create them. This gives a dynamic to the historic process that might be described as 'progress' and gives a central place in this to the practice of architecture.

Before I turn to this however, I first describe two ways that space syntax research seems to have approached the issue of identifying simplicities in a cognitively plausible manner. I will argue that these illustrate general principles that apply to science as well as to practical intervention in the world.

What is simplicity?

Two key features of the pursuit of underlying simplicity have emerged in space syntax research. The first involves identifying the most appropriate representation. The second involves something rather like convolution developed in machine learning in the search for regular or repeated patterns of behaviour amongst sets of variables. Humans are inveterate 'pattern makers' in that we continually search the phenomena of experience for pattern and meaning.

Hillier's objective subject places cognition as the central link between urban and social systems, but how exactly might that link work? The kind of mechanism of interest are those that that relate human cognition to the configuration of their environment. Here there are two key pieces of evidence. The first passes through the nature of representation in analysis. One of the defining characteristics of space syntax research lies in a (possibly perverse) concern with exactly how best to represent the phenomena of interest – the configuration of space through which people move and in which they are brought into contact or kept apart. Within the discipline there is continual debate over whether one form of representation or another is 'better'. What exactly is meant by 'better' is too often poorly defined but there is a general consensus that it has to do with the ability to explain or discover hidden regularities in observed human behaviours. Over time, different representations are devised and put to the test. Most often this test is against data on

observed aggregate movement through space. Here there is much to be learned from traffic engineering which builds models to inform the management of traffic in cities.

Representation as a simplifying assumption

Current engineering practice in modelling movement behaviour in urban systems is based on an essentially economic assumption that rational humans must seek to maximise benefits and minimise costs. In the case of moving around urban space the view is that they will be attracted by specific destinations and will select routes to these so as to minimise cost. Costs are most often considered in terms of metric distance or time taken. Traffic modelling starts this way. First an origin-destination matrix is constructed to represent the demand for movement from all origins to all destinations – from home to work for example on the basis of survey data. Next the minimum distance routes between all origin-destination pairs are calculated and trips assigned to these. In most models there follows a process to take account of congestion in which the capacity of each link is considered and if the trip demand exceeds the capacity on any link a new fastest route avoiding that link is calculated and trips are reassigned. In a detailed model traffic management is considered, such as speed limits on links or traffic light timings at intersections. It is generally assumed that after a number of iterations the model will converge to an optimal solution.

There are several assumptions behind this kind of model:

- The 'prime mover' that drives human movement is the distribution in space of attractor land uses such as places of work or exchange.
- Time in transit is a cost to be minimised and time depends on distance and speed.
- People have perfect knowledge not only of the different routes available to them but also of other users demands, capacity and so of congestion.
- That in order to minimise cost people will change behaviour.
- That ultimately the model will converge on an optimal solution.

In fields with a strongly held paradigm such as this, assumptions tend to disappear and to insert themselves more or less unquestioned into practice. For example, the first assumption that the prime mover in urban systems is the distribution of attractors of movement leads directly to land use planning as a primary tool. This in turn leads to plans characterised by functional zones linked by efficient transport networks. The second assumption, that efficiency is to be measured in terms of transit time, leads to networks whose prime function is to move people from origin to destination.

A transport model of this kind is relatively data and computationally hungry and although computer power has increased massively, when these methods were first developed this had a significant effect on the development of models. The early models were based on zonal data, for example on employment and residence in administrative areas, for which census data allowed one to construct the origin-destination matrix, and on skeleton representations of transport networks between these zones. In these it was simplest to represent administrative areas as nodes in a network and the distances and capacities of the network as properties of the links. In this way the detail could be reduced to that which was computationally feasible given the power of computers at the time. The graph created this way is generally planar and from a mathematical point of view this has attractions.

As computational power and more granular geographic data have allowed models to be built at ever finer spatial resolution, this form of representation has been maintained. Ultimately, in models that seek to represent the full urban street grid in detail, metric distance (cost) and street width (capacity) are properties of street segments between intersections and so these are considered to be links, and the intersections between streets as nodes. I suggest that this representation has become another hidden assumption within practice.

The findings of space syntax research have brought the assumptions and the planning practices based on them, into question. First, it found that a representation of the street network in terms of axial lines considered as nodes, and intersections between lines as links could explain a high proportion of the variance amongst observed movement flows on streets in urban areas. An axial line is the longest line of sight and access that can be drawn down a street. In a long, straight street an axial line will pass through many intersections with other cross streets. Since the axial line is represented as a node in the graph, this representation does not include metric distance in a direct manner. Neither does this representation incorporate the density or scale of attractor land uses. In other words, it creates a topological representation that when transformed into a graph loses explicit metric information. These graphs are non-planar.

The issue of planarity turns out to be important. In a planar graph the nodes near the geometric centre of an area will be closer to all other nodes in the network, while those near the edge will be deeper. This makes measures of centrality in a planar graph representation almost entirely dependent upon choice of boundary, something that in most continuous urban areas is more or less arbitrary, while those of the non-planar axial graph are much less sensitive to one's choice of boundary and are determined instead by connectivity. A well-connected line is likely to have a high closeness centrality regardless of where it is located relative to the boundary.

The axial representation drew criticism from those closely wedded to the conventional modelling paradigm (Steadman, 2004; Ratti, 2004[2]) who noted that the reduction of a long line to a single node in the graph left no scope to account for variation in function along the length of a long street. Neither did it distinguish between a slight angular deviation between lines and a right angle turn or hairpin bend. To address these issues a 'segment angular' representation was developed. This maintained the space syntax approach of considering 'space as the thing'. Each segment of a street between intersections was represented as a node in the graph with the link to other street segments weighted according to angle of intersection. Continuation straight ahead was given a zero weight (thus in effect salvaging the axial line) while a right or left turn is weighted according to the angle in radians, thus a 90 degrees turn would be weighted at 1 and a hairpin bend returning on oneself would gain a weight approaching 2.

The segment representation also allowed the incorporation of metric distance between segments by using the metric distance from centre to centre of each segment as a weight

[2] It should be noted that the editors published a rebuttal of Ratti's paper in the same issue of the journal (Hillier & Penn, 2004), together with Ratti's response to that. As Thomas Kuhn noted, paradigm shifts often elicit this kind of reaction.

on that link. Bill Hillier and Shinichi Iida (2005) turned this representation to effect by asking a different question. By setting graph measures of the axial, angular and metric representations as the independent variable against four pedestrian and vehicular movement datasets for areas in London, they asked which best accounted for observed pedestrian and vehicular movement flows. The result, they suggested, would provide circumstantial evidence for the way that individuals must be representing and thinking about the urban environment. If people generally were behaving rationally to minimise metric distance, then metric measures of centrality would be expected to better explain observed movement behaviour than measures of the representations without a metric component.

Their findings were clear. The metric representation had only poor explanatory power, with the segment angular representation providing strong and significant correlations, closely followed by the axial representation. Although nothing in these findings could be described as conclusive, it is notable that there has been considerable doubt in cognitive science that humans depend on metric understanding of the world (eg. Montello, 1991, Tversky, 2019). Instead we should entertain the idea that a simpler relational representation of space in the world may underpin cognition. If that is the case, then the question I turn to next is how might this representation 'get into people's heads'?

From egocentric to allocentric, or from multiple individual to one social view

It is a truism that we inhabit and move through space and time linearly, but that in an important sense we experience both as multi-dimensional. Although I may only be here in this place at this precise moment, my experience is informed by my immediate perceptions as well as both my memory of this and other places, and my anticipation and expectations of here and wherever next I plan to go. Equally with respect time since both memory and anticipation are temporal (Rovelli, 2017).

This experience is amplified by architecture. Although I may be physically present at just one location in space at any moment, my perceptions extend into the distance ahead and around me, shaped as these are by the architecture of my surroundings and the perceptual fields of sight, sound, touch and smell that this affords. The objects and people in my immediate vicinity are to be made sense of in the context of objects and people in the distance; the music and traffic noise or smells from around the corner or the babble of voices across the square. It is this that converts an apparently linear route through space and in time into a multi-dimensional construct. The choices I make of which way to turn, of where to focus my attention, or where to move next, are all part of this sense making. Space is never one dimensional in the choice it affords for movement – at the very least we can always turn around and return the way we came. My choices of how to move are an active component in this, but so too is the spatial context which affords me these choices. Neither is prior to the other. A peripatetic viewer is not merely a passive observer, but an active agent in constructing a sense of place by synthesising these multiple dimensions.

A possible mechanism for this synthesis is implied by the notion of 'intelligibility' defined in (Hillier, 1989). As I have described above, space syntax research is based on representations of spatial configuration in terms of local spatial entities – for example, the axial line – connected to one another through a relationship of intersection. This allows the

construction of a graph representing properties of the whole configuration in consistent terms. Graph properties can be thought of as local, those that we can measure standing where we are without moving; and global, those that require us to explore the whole graph. A local measure is the connectivity of a node in the graph (ie. the number of other axial lines each line intersects with). A global measure might be the closeness centrality of a node in the graph (ie. the average number of other axial lines that must be traversed to visit every axial line in the system, taking simplest, fewest changes of direction, trips). The degree of correlation between a local and a global measure defines the 'intelligibility' of a system. In essence this correlation asks a cognitive question: 'how confidently can I estimate a global measure of the graph from local information?' or, 'from what I can see standing here, how well can I infer where I am in the whole system?'

Intelligibility in the axial graph is a property regularly found in urban systems, however, this is by no means a foregone conclusion. It is possible to construct graphs (and their axial maps) which show a positive, a negative or no relationship between local and global, or even where the correlation is degenerate due to exactly the same conditions being replicated multiple times. It happens however, that the environments we build regularly show this local-global correlation. There are notable exceptions. Certain cultures produce relatively unintelligible urban forms, and modern social housing projects of the 1960's and 70's in the UK were often characterised by repetition and so the degenerate case. It may be unsurprising that these were spoken of at the time as unintelligible or labyrinthine.

Intelligibility as defined here is the correlation between two variables and so the question of how this might be realised by human experience requires a cognitively plausible mechanism. One possible mechanism for information compression is that offered by Hermann Haken and Juval Portugali as information adaptation (Haken and Portugali, 2015). Machine learning offers a different analogy in the form of convolution (LeCun et al, 1989). Convolution is a method for embedding information in a neural network on the way that two functions overlap. By taking a series of 'windows' of different sizes on the data, patterns at different scales can be captured. From this after training a neural network, given the state of one function, the corresponding state of the other can be retrieved. This method has proven highly effective to derive patterns from graphic data for applications such as face recognition and from temporal data for speech processing.

Now consider the peripatetic observer as capturing a 'window' on their environment. As they move, the window shifts. Their memory allows the relative size of the window to vary from an instantaneous snapshot to, say, several minutes. This allows the integration of different observable features of the environment at different scales. Let me describe an example from an imagined walk through London. As I walk along a street, I am aware of its extent and width, the height of its buildings, their architectural style, the kind of land uses - residential, retail, commercial, institutional - the traffic speed and volume, the ambient noise, the pedestrians and their behaviour. In general these factors are fairly uniform along the length of the street, but when I turn a corner they all change – the street narrows, the buildings reduce in height, the nature of property uses changes perhaps from predominantly commercial to more retail, the volume and speed of traffic reduces but relative to that there seem to be greater number of pedestrians. The micro-behaviours of the pedestrians change, people walk more slowly and browse the shops, perhaps in couples

or groups. There is a smell of cooking from restaurants or street vendors. Turn the corner again and the property use changes from retail to predominantly residential. Pedestrian and car traffic reduce, and the street is lined by parked cars, and so on through the neighbourhood.

Here I am describing a kind of urban experience, something that will be different in detail in every city, or part of city, that we might visit around the world. However, at the same time I hope that the experience is recognisable and generic – cites vary in the way that different features come together and in the way that these change as we move through space, but they are consistent in that their features *do* vary together along with the physical geometry and network topology of space. It is this co-variation which makes cities 'learnable' with features that can, at least in principle, be extracted by a convolution-like process and then used to make predictions: 'if I do this, then that is likely to follow'. This is the move from an egocentric peripatetic observer to an allocentric compressed description of the spatial and socioeconomic function of the urban landscape; a set of internal consistencies that comprise one of Cohen and Stewart's 'simplicities.' If instead of co-variation and some degree of consistency, the features of our environment were randomly distributed with respect one another then there would be nothing for it but to map or to learn their disposition in the full detail of their complexity. It is the possibility to derive a compressed description – a simplicity – that not only makes cities intelligible and meaningful to us, but which gives us autonomy and allows us to behave with intention. This is central to providing subjectivity to Hillier's objective subject.

Creating consistencies: from the cognitive to the economic, and back

How might these consistencies arise? Here I must hypothesise. I suspect that what we are seeing is the outcome of a series of closely coupled processes and it is this close coupling that produces co-variation and consistency. The first is Hillier's vertical process of production of urban form through many individual acts of building. The second is through the processes by which the resulting spaces are appropriated for social and economic purposes – Hillier's lateral process.

I start with an example. Anybody who has ever camped in drifting snow soon learns three things. First, pitch your tent with the door facing into the wind; second, don't pitch it in the lee of another tent; third, don't pitch your tent too close upwind of another tent. The reason for this is all to do with the way that snow drifts accumulate downwind of an obstacle. You really don't want to wake up in the morning with your door buried in your own drift, having been buried in a neighbour's drift or having caused a drift to bury your neighbour.

The moral is that every act of construction is a response to at least two things. First, an existing environment with an inherent set of constraints and affordances. Second, a desire on the part of the builder to change these affordances to be more conducive; to create a more comfortable or pleasing setting for life. This might be considered an aesthetic pursuit (Penn &Turner, 2018). Close coupling occurs because the first act of building changes the environmental affordances for the next builder, and their reaction takes this into account. The second builder's action in turn will change the environment for the first and may require them to adapt. This cycle is close coupled. What emerges through this process are a

set of consistencies that reflect both the underlying physics, in this case of wind and snow, and the social obligation not to bury the neighbours. Our driving motivations are to camp comfortably despite the blizzard and to get on with our neighbours. Accomplishing these successfully brings fulfilment, and I would argue this is largely emotional rather than rational in nature.

Harold Hotelling's observation that two ice cream sellers will tend to gravitate together toward the centre of a beach is an example of a similar kind of close coupling (Hotelling, 1929). It is also an economic example and calls into play not only the actions of the two ice cream sellers as stall builders, but of the whole population of their customers along the length of the beach. Here the phenomenon shifts from Hillier's vertical process of construction to his lateral process of appropriation for a desired socio-economic outcome. No longer are we only concerned with the inanimate actions of drifting snow or the way the wind blows, but with the purposeful actions of people looking to buy and sell. It turns out that this kind of process drives many of the consistencies we observe in cities. Here I would argue in contrast, our driving motivations as economic agents are more rational.

In 1993 Bill Hillier published a paper describing a 'law of natural movement' (Hillier et al, 1993). This made what at the time seemed a rather bold claim. That the prime mover in cities was not the distribution of land uses, but the distribution of pedestrian movement that served to attract those land uses. The claim was based on logic and empirical data. Observations of pedestrian movement in urban areas regularly found that there were greater flows of pedestrian movement on shopping streets than on streets without shops. Indeed, it was this observation that formed the basis for the prevailing conventional view that people were attracted by retail land use and that land use distribution was the prime mover in urban systems. This led to land use and transport models based on an assumed Newtonian distance decay from 'attractor' land uses. However, Hillier showed that using the axial map and measures of closeness centrality ('integration' in Hillier's terminology) that both the distribution of shops and of pedestrian movement correlated with the configuration of space. Since the axial model contained no reference to the land use distribution the implication was clear. The correlation between pedestrians and shops was due to each being correlated with an intervening variable – the configuration of the street grid. Taking the evidence one step further he showed that in areas without shops the relationship between integration and pedestrian movement was broadly linear, but in areas that contained retail land uses there was a power or exponential relationship. This suggested that pedestrians moved through the street network according to patterns of accessibility, and that shops located preferentially to take advantage of the passing trade. These shops then attracted additional pedestrian movement creating a multiplier effect. The following diagram and caption from Hillier et al, 1993 explain the implications:

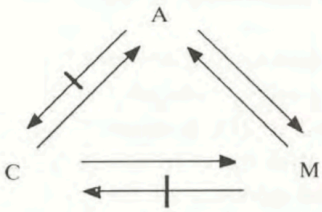
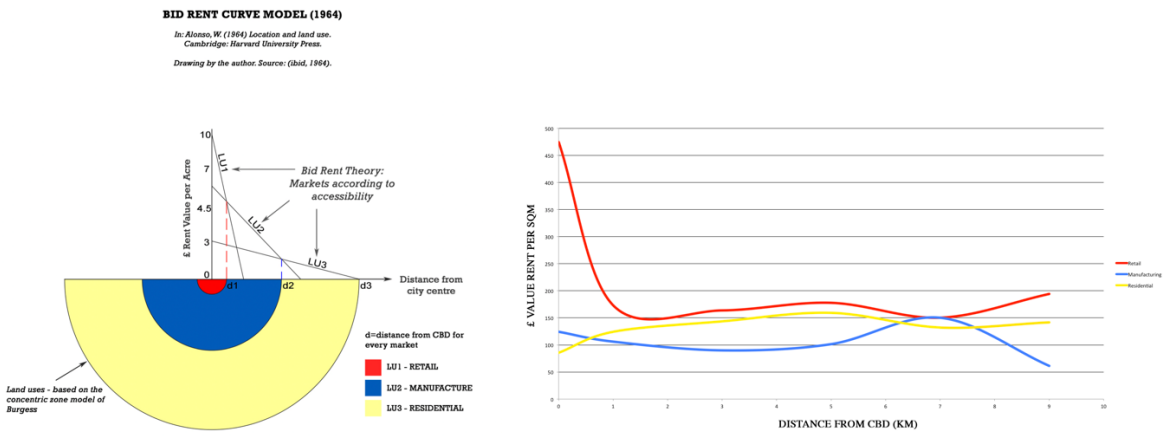


Figure 3. A is attraction, C is configuration, M is movement. Attractors and movement may influence each other, but the other two relations are asymmetric. Configuration may influence the location of attractors, but the location of attractors cannot influence configuration. Likewise, configuration may influence movement but movement cannot influence configuration. If strong correlations are found between movement and both configuration and attractors, the only logically possible lines of influence are from configuration to both movement and attractors, with the latter two influencing each other.

The close coupling of spatial configuration, pedestrian movement and retail land use distribution seems to be a primary consistency in urban phenomena. However, this has been found to propagate through other land use types as a result of the market in land and the ability of retail to out-bid other land uses for the most accessible sites. Research by Laura Narvaez-Zertuche (2013; 2015), has shown that urban bid rent curves postulated by William Alonso (1964) are seldom concentric, as he suggested (Figure 12.1a), when looked at in detail but are defined by the axial configuration of the street network rather than 'as the crow flies' distance on the map. Figure 12.1b. shows that retail out bids other land uses throughout the radius of the city, suggesting that axial integration which links edge to centre, better explains retail location.



a. b.

Figure 12.1 a.) William Alonso's theoretical bid rent curves; b.) Laura Narvaez empirical bid rent curves for Cardiff, UK (from Fig 4.4, Narvaez Zertuche, L. 2015).

Here is one explanation for the experience of 'turning a corner and everything changing' described earlier in our imagined walk through London. The peripatetic observer retrieves a set of consistent co-variations of stimuli – as they turn a corner, new things come into view, traffic changes, land uses change and so forth – but this is as a result of an underlying set of economic processes that govern these distributions in the first place. Central to this

patterning is that the configuration of the network of space governs both the movement opportunities for the observer and the economic process through which urban functions locate in space. In this way the observer is in effect retrieving a description of the underlying social and economic processes that gave rise to the city and maintain its function.

If I am correct that the process through which the observer learns these consistencies may operate in a similar way to convolution, it implies that somewhere in their cognitive capacity exists a compressed description of these same social and economic processes, learned through experience. Now, let us imagine that the observer is an active agent in the system, say someone searching for a good meal in an unfamiliar city. In many cities in the world there is a cluster of restaurants catering for the tourist market, often along a single street. The maîtres d' tout for business and show their menus, each competing with their neighbours for your custom. What leads to this cluster if all are competing; surely it would be better to move away from your competitors? This is Hotelling writ large. By clustering together, they all benefit by attracting the tourist trade from across the city. As a result, more of the passers-by are looking for a meal than would be the case on an average street. More of them no doubt are tourists, and unlikely to return or provide repeat custom. This makes the task of business strategy relatively straightforward. Employ a persuasive maître d', ensure that the menu and the front of house looks attractive, pay a premium rent for the pitch on the restaurant street, but save on the chef and quality of ingredients. Given that the game here is to optimise on a first sale to tourists who will be unlikely to return, this sets the parameters for a dissatisfied customer. The maître d' may be accomplished in fending off complaints by offering a complimentary aperitif, but what the tourist learns is either to take a local with them – not all restaurants on the street operate the same business model, but without local knowledge it is hard to tell them apart – or failing that, to turn the corner once or twice. Look for a restaurant in a more isolated, lower rent location but with a thriving clientele. Spatial isolation coupled to good custom is a sure sign of a restaurant that competes on quality and is known locally for that.

Let us imagine instead that the observer is not the customer but someone who wants to set up shop. They walk the streets and from what they see of the local context, they retrieve from their compressed description learned over a lifetime of experience, a forecast of the possible implications of any choice they might consider. They use this to inform their actions – whether to bid for premises here or there; how much to pay; what business model to operate – whether to compete, for example, on price or quality. Of course, I am suggesting neither that the compressed description is a construct that the individual has direct and conscious access to, nor that they explicitly and consciously perform a search like this. Anecdotally, shop owners searching for new premises (or more likely their agents) walk the streets and count the footfall of passing trade. They look at other shops in the area that may be similar and judge how successful they are. Just as customers looking for a meal look at how popular a restaurant appears to be. These all form a part of informing our actions.

Intentional behaviour and search

Alasdair Turner and I conducted a series of experiments (Penn & Turner, 2004) to investigate the effects of spatial configuration and shop location on the time it took a random search using a sampler/agent with long distance, forward facing 'vision' to search an environment and to find something they were looking for. Alasdair's implementation of

long-distance vision was cunning (Turner & Penn, 2002). He used a visibility graph of an environment in which an arbitrarily fine grid of points are connected if they are intervisible through open space in an environment. Next, for each point in the graph he constructed a lookup table of the connected points divided into 32 bins according to orientation. This allowed precomputation and so a very rapid search on the fly for visible locations within the field of view of a forward facing 'sampler' at any location and facing in any direction. Additional features of the environment could be stored as variables associated with nodes in the graph and accessed rapidly. Thus, 'shops' could be located at the faces of buildings and the 'sampler' could 'see' them. This simulation was called 'exosomatic visual architecture', EVAs for short.

The samplers search an environment by moving through it stochastically. They select a point at random from those in their visual field, turn towards it and move three steps, then repeat the process. The turn and move change the visual field of the sampler at the next iteration. They are in effect doing a random search of a graph, albeit a complex graph involving as it does orientation and a forward-facing and long-distance field of view constrained by the placement of blocks to vision in the environment. This search was found to replicate observed pedestrian movement patterns in a range of urban and built environments, including decidedly unusual environments such as the show room in IKEA stores (Penn, 2005) which have been designed intentionally to induce in shoppers a disorienting and characteristically sinuous movement pattern (Figure 12.2).

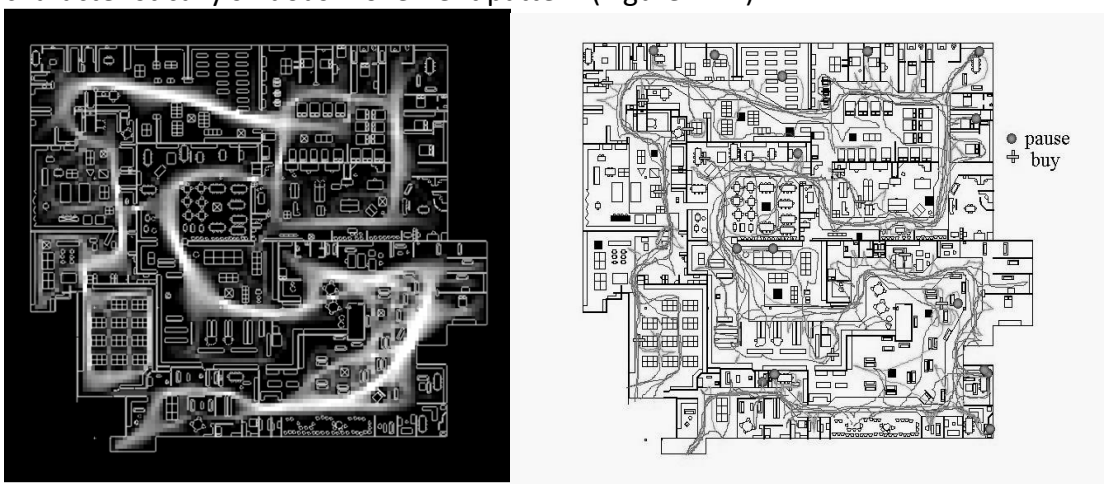


Figure 12.2 a.) IKEA show room floor analysed by EVAS, b.) Observations of shopper movement patterns by Farah Kazim.

The experiments with search efficiency are described in detail in (Penn & Turner, 2004), but the significant findings were: 1. That the time it took for an agent to find a first shop depended on how dispersed shops were in the environment. 2. Clusters of shops took longer to find, but once found the second, third etc. were already available. 3. That if the agent was searching for a specific 'flavour' of goods the more shops searched, the more likely they were to find the desired item (Figure 12.3). The conclusion was that dispersion supported convenience while clustering supported comparison shopping. The restaurant street is attractive to a tourist who wants to compare a number of menus before making a choice, while corner shops are located to be close to a local market catchment.

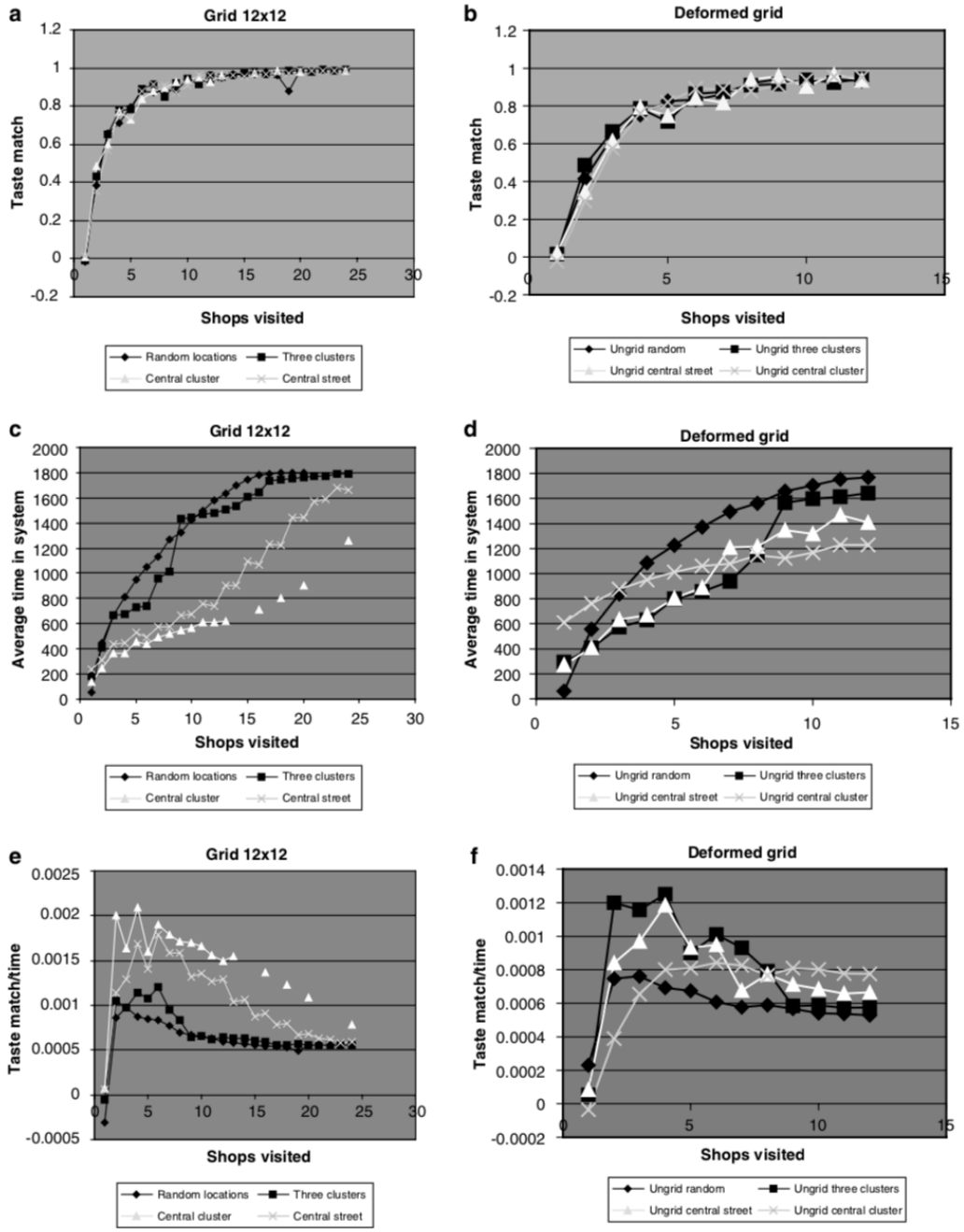


Figure 12.3. Graphs of agent search performance (from Figure 11, Penn & Turner, 2004).

It is important to note that the samplers in the EVAS simulation are not 'agents' in any conventional sense of social simulation (see for example Bratman, 1987). They hold no internal model of the world, nor beliefs, desires or intentions. They have no processing power or memory. In fact, all the 'intelligence', if any exists, is inscribed exosomatically in the environment and its structure. The search differs from Brownian motion in just two precise ways. First, interaction is over a long distance – as far as the eye can see constrained by the built form in any given environment. Second, the interactions are anisotropic. The 'sampler' has an orientation and a forward-facing field of view, and gains information from the environment from one direction at any given moment. In this way the stochastic search of the visibility graph can be thought of as emulating some important characteristics of

embodied human visual perception. However, since the EVAS algorithmic simulation is essentially a stochastic search of a graph structure the process is Markov and so deterministic. From this point of view, it may be surprising that the EVAS analysis shows any relationship at all to observed human behaviour.

This shows that what may appear as the most intentional of behaviours – when we actively set out to find something specific in our environment to satisfy our wishes – are determined to a significant degree by a set of objective structures in the world, including the way that we have evolved forward-facing vision and how this affects our route choices, the configuration of the built environment that we have constructed and the way that markets in land have allocated functions. How can we square this with the strong feeling that we are autonomous subjects behaving with intention?

My suggestion is that people engage as active agents in 'meaning making', and this is a process that may account for our feelings of subjectivity and intention. We bring our individual experience to bear in interpreting the physical, spatial and social phenomena that we encounter, and then we act to achieve our subjective aims. Against this background however, we face and play out a number of constraints defined by the possibilities inherent in the way that urban form is constructed, the way that functions are located, and the restrictions and affordances that this imposes on its use. These constraints are both lawful and objective in nature.

Storytelling and emotional engagement

The process I am suggesting may be analogous to storytelling. On the face of it a story consists of a sequence of episodes or events, the scenes in a play or film, chapters in a book, told or heard over time in a linear sequence. However, according to Marie Laure Ryan (1991), a well told story is not a linear construct transmitted from active storyteller to a passive listener, but it engages the listener actively in meaning making. The characters of the protagonists are developed, the events and clues in the context described and the listener forms hypotheses and expectations of the meaning of past events and what will happen next. In doing this we construct causal hypotheses – the 'who done it' of the detective thriller or the 'who will marry prince charming' in a fairy tale.

These are informed by the listener's knowledge of the genre of the story: the types of narrative structure and knowledge of these structures guide the listener in terms of what to expect. But equally, a well told story keeps the listener guessing and it is this active engagement in meaning-making and revising one's guess as new information is revealed, that makes the story more than linear and so 'tellable'. The conversion from a linear sequence into a multi-dimensional network of events and relationships between events, possible events and causal hypotheses, happens because the listener is not a passive receiver of information but is engaged as an active 'meaning-maker'. They imagine possible futures for the story which may or may not transpire in the narrative as it is presented linearly in chapters on the page. It is this that creates anticipation and suspense in the listener, surprise at events, or sympathy and antipathy to the characters. This is how emotion is created, and the way that any underlying moral message hits home.

It will not have escaped you that the active listener's path through a story bears a resemblance to our imagined 'peripatetic observer's walk' through London. I suggest that the process of meaning-making in narrative may also involve a similar 'convolution like' process to construct emotional engagement.

Here we can return to Pareto since now we have a plausible mechanism through which beliefs, behaviours and what people say – their expressions – may be related to emotion and state of mind. I suggest that it is through the active engagement of the subject in the objective act of meaning making that emotion and sentiment enter the subject's state of mind. By becoming personally engaged in active interpretation of the phenomena we perceive, we internalise our own place amongst these phenomena and it becomes part of our own identity. I notice that when waking from a dream often the events dreamt make little or no rational sense, but the emotion is palpable. Current theories of dreaming as memory consolidation and reconsolidation (Zhao,2018) suggest that this may form part of the way we have evolved to consolidate our memories of the most important of our daily activities. If Pareto is correct that sentiment and emotion drive people's choices and decisions, then this may be one mechanism underlying both Hiller's objective subject and the dialectic.

The space of ideology

I have described elsewhere a possible relationship between the architectural construction of spatial configuration and the emotions of empathy (Penn, 2018). Empathy – the ability to put oneself in another's place, to see their point of view and to infer how they might act – is a fundamental emotion for both a social species and a predator. We see examples every day, when traffic slows apparently for no better reason than to rubberneck an accident on the other carriageway, or when we see the cook slice their finger and cringe involuntarily, feeling their pain.

To summarise the argument briefly, the act of construction of built form shapes intervisibility in open space in its immediate surroundings. The effects of shelter construction on intervisibility of points in space and so on human occupancy, is no less lawful than their effect on the way that snow drifts accumulate. Construction creates the affordances which humans as social animals appropriate and, I argue, amongst the primary emotions which this serves to structure are those associated with empathy, especially for strangers. Although we can empathise with people we know well purely through imagination, it is hard to empathise with someone that you do not know unless you can see or hear them.

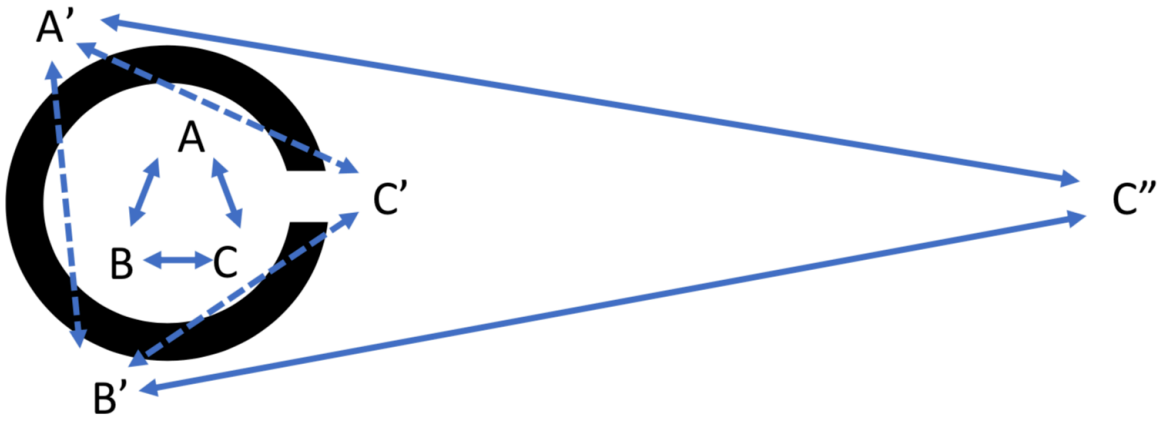


Figure 12.4. The effect of built form on potential social relations. (Figure 1 in Penn, 2018).

The same affordance of visibility that allows the social animal to empathise, allows the predator to watch and to anticipate the likely behaviour of its prey. It allows Jeremy Bentham's panopticon to act as a machine of surveillance and control for a prison or a machine of supervision and care for a hospital. That such similar machinery of the brain and environment can work to accomplish such different ends is what allows it to support both collaborative and competitive forms in social relations.

Both Marx and Pareto saw the evolution of society in essentially Darwinian terms. For both, survival of the fittest entails competition and struggle. Marx held that class struggle explained the history of human development. Pareto also saw that a governing elite maintains its power through a show of strength. It was his apologia for authoritarian government that endeared him to the Italian right in the early decades of the 20th century. Both thinkers held that human destiny was to some extent inevitable, however they differed on the nature of that destiny. For Marx it was inevitable that capitalism would fall through revolution to be replaced by communism. For Pareto revolution would merely lead to one elite replacing another and effectively for the masses there would be no change.

And yet there is another view. Jane Jacobs sees human progress as largely due to humanity's superior ability to cooperate and to collaborate for a common purpose based on empathy and altruism (Jacobs, 1969). Jacobs does not deny that on occasion people have built city walls as defensive structures to protect from aggression, but as often as not she says they were used to define boundaries for the purpose of taxation, and this is about trade and exchange; necessarily cooperative activities. This highlights that the key ideological divide in politics is not between the extremes of right and left, but between those that hold human progress to result from competition, struggle and revolution, and those from the liberal centre that hold the primary driver to have been collaboration[3].

[3] We might go further to describe the space within which ideology is embedded rather than as a plane with left and right, as a cylinder in which these two wings come together at the far side. It is tempting to go one step further and suggest they might be embedded in a non-Euclidean Mobius strip where left and righthandedness are themselves undefined!

Pareto recognised this distinction, noting that the imperative of the former was largely emotional while that of the liberal was logical and rational. He went further to note that one problem of liberal rationality was that it lay itself open to being usurped by authoritarian regimes that valued force over legitimacy. It was this that he held accounted for a pendulum or cycle in history that swings between authoritarian/emotional and liberal/rational regimes.

In his discussion of complexity, Bill Hillier alighted on Jack Cohen and Ian Stewart's notion that the most interesting aspect of complexity was in fact the simplicities that seem to arise one level up. This mirrored Bill's idea that although emergence of new forms was interesting, the phenomenon that required explanation was the convergence that could be seen onto a relatively small number of specific spatial types; streets and the deformed wheel integration core that seem regularly to occur through history, for example. It is these structures that deliver mechanisms to allow controlled access by strangers into the middle of a settlement for the purpose of trade and transaction. In effect they are mechanisms to allow one to 'have one's cake and eat it'. To allow access by strangers for the purpose of collaboration, but to maintain control and safety.

On many occasions and at different levels in this discussion it seems that space syntax provides a unifying structure allowing the reconciliation of apparently opposite tendencies: collaboration/competition; material/ideal; convenience/comparison; rational/emotional. Hillier's key conceptual tool in achieving this reconciliation is the 'objective subject', and it is by unpacking potential mechanisms at play in both the human mind and the environments they build that space syntax contributes to our understanding of urban phenomena.

The thrust of my argument is that while space syntax bears a relationship to complexity its prime motivation was not to understand complexity per se but to develop a theoretical understanding of the phenomena at hand; of human society, the environments it designs and builds and the interplay between the two. I reflect that the scientific process that Bill and his colleagues pursued during the construction of this body of architectural theory have been characterised by a set of principles of scientific practice that have proven remarkably effective in breaking theoretical new ground. In each case, however, the science is related to architectural practice.

Architectural practice like science proceeds by testing hypotheses. The hypotheses I am thinking of are the ideas for a building that respond to the client or community's needs or wishes. These wishes are not generally for the building itself, but for a social or economic outcome that the building helps realise. Here James Gibson's (1966) notion of an affordance is useful. What architects design is an environment along with a set of affordances. It is

these affordances rather than the physical object itself that create value; it is less about what the building *is* than what it *does* and what it allows its occupants to do. Three main principles of science and architectural practice seem to have emerged from space syntax research.

Representation
Representations are active agents in science, and so never accept current representations as given – keep inventing new representations. Bill called this 'creating phenomena', after Ian Hacking (1984). No single representation will capture the full spectrum of any phenomenon, so develop multiple representations and use these to triangulate a problem. Since a representation is active, it must also be subject to critique and design. For example, the choice to represent the space of a street as a node in a graph and the intersection as a link (or the reverse) as I have shown is not an arbitrary one.

Architectural practice also makes use of representations. Representations are most often thought of in terms of their role in communicating the idea for a building from the architect's mind to others; other designers, the client and the builder. They allow the act of designing to become social. By externalising onto physical media, a representation of the idea for a building currently in one architect's mind, that conception can be shared. Using physical, tactile and graphic representations these engage with the experiential as well as the rational senses. This opens the concept to analysis and critique by others, and in a design-team this allows the creative process to shift from an individual to a social basis. Donald Schön described this process as 'reflective practice' (Schön, 1983; 1990). This dynamic and emergent process of design can be thought of as a complex system in which ideas for a building and representations of those ideas iterate until a specific design proposition is agreed.

However, representations also play an active role which has received relatively scant attention. They allow the architect to detach themselves from the design in their mind's eye and by distancing themselves to flip between synthetic and critical analytic roles. Architects sometimes speak of this in terms of 'holding a conversation' with the design. The use of multiple representations and of layering representations in series, are amongst the tricks of architectural craft. 'Turning the tracing paper over', changing scale of representation, changing media and shifting between plan, section, elevation and perspective all allow one to sense the implications of a design configuration that otherwise might elude the mind's eye and at the same time to conceive of new opportunities.

Universality
A valid theory must be universal – it is pointless to have an urban theory that only holds for, say, western cities but cannot account for the full range of urban phenomena found around the world in the archaeological and anthropological record – so do not accept boundaries to the application of a theory. If you discover an anomaly, place it centrally in your research programme as this is the only way that progress can be made. This derives from the principle of universality. Anomalies point towards the boundaries of application of a theory and in order to be universal a theory must expand to encompass anomalous phenomena. In fact, this pinpoints an important feature in the dynamics of progress in science. Creating phenomena is often a process of developing a representative framework within which new

anomalies become apparent. These then become the central driver for new theory to explain all pre-existing phenomena and the new phenomena within a common theoretical model. In this way the explanatory power of the theory – its universe – expands.

In architecture universality also applies; everything is endogenous and there is no such thing as an exogenous variable. What I mean by this is that a single architectural construction must resolve functional and ideological challenges of all types. One cannot exclude any variable and claim that it lies outside your problem definition. Equally, there is no boundary to a given site – you have to consider the context relevant to your design, however proximate or distant.

Caveat deceptae
Beware of importing theoretical frameworks from one field of science to another ('caveat deceptae' literally translates as 'beware misconceptions'). While there are lessons to be learned, the temptation to make the evidence fit the theory can lead you astray. This has perhaps best been described by Richard Feynman in his famous 'cargo cult' critique of the social sciences (Feynman, 1974). Architectural history is also littered with examples of the application of ideas drawn from other fields. Ideas such as the territorial behaviour of birds are adduced in support of designs that segregate neighbourhoods. Newton's theory of gravity is used as a basis for traffic modelling. Too often these imported ideas are found at best to be unhelpful and often to be dangerously misleading.

Of course, as with biological systems, space syntax bears a relationship to theories of complexity – it would be surprising if it did not since urban and social systems are highly complex in both structure and function – but the principles outlined above are also architectural in a deep sense that relates to the epistemology of science as an emergent process.

Considered in the dynamic way I describe, the progress of scientific understanding can be seen to emerge from a cycle of phenomena > representation > pattern or anomaly > hypothesis, then (following Karl Popper, 1969) further empirical evidence > phenomena … and ultimately, new theory. As time passes anomalies arise and new phenomena require new theory, and so the cycle continues. There is no reason to expect an imported theory that has emerged in this way out of the phenomena of one field, to capture the structures involved in a different field. It is for this reason that the use of theoretical frameworks derived in one field to explain another can at best be considered as metaphors or thought experiments. There are those who differ with this in a search for underlying mathematical structures that explain phenomena of widely different systems. Complexity theory may be one of these, however my ambition here is less. I believe that complexity and simplicities arise out of the kind of dynamic and virtuous cycle I describe. If this cycle helps describe the process through which science has developed, then I argue there is an equivalent cycle that relates to other aspects of human progress.

The progress of civilisation as a dynamic system
I have proposed elsewhere (Penn, 2018) a model for the emergence of organised social structures and institutions around 10,000BC on the Anatolian plateau. The essence of my argument was that the appearance at that time and over the space of just a few millennia of

dense proto urban settlement, writing, token currency, specialisation in production, domestication of staple foods, storage and irrigation infrastructure, law and the apparatus of the state, were not coincidental. Nor was it the intentional act of some external agency although it has been suggested that the climatic transition from the Pleistocene to the Holocene brought the stability required for settled agriculture, and so settlement (Richerson et al, 2001). I suggest instead that the series of innovations were the product of a self-reinforcing cycle of cause and effect, or perhaps a set of coupled cycles as depicted in the Figure 12.5.

The nub of my argument was that the built environments that began to be constructed at that point in history served a very specific role, that of providing a common setting for social action. They provided an objective background for the objective subject. Equally, they were the creation of the objective subject – an externalisation that allowed for sharing and collaboration. It was this externalisation of part of our cognitive machinery into the configuration of the environment that served to shift the trajectory of development of the species into the social sphere. Rather than development and innovation passing away within the lifespan of the inventor, the scale and density of settlement increased the chances of innovations being learned and passed on. This in turn made possible specialisation and division of labour, but as a consequence required increased transaction between specialised producers – obsidian workers must have traded for food for example. Transactions in turn spawned innovations including symbolic recording – token currency and ultimately writing. Increased transaction will have resulted in dispute and required arbitration and ultimately law and the machinery of state.

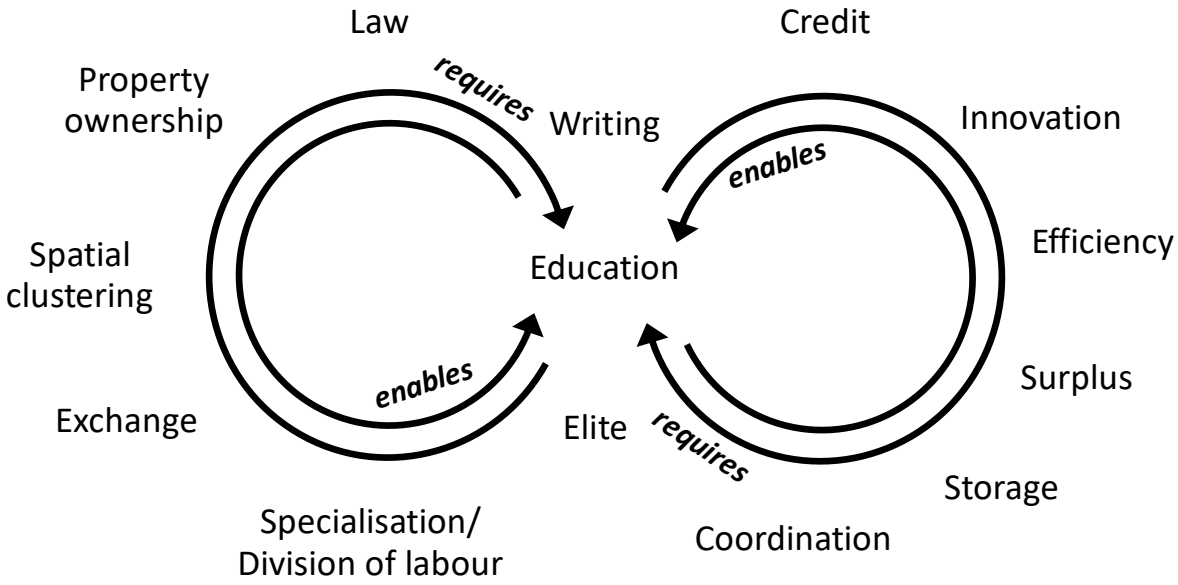


Figure 12.5. Cycles of feedback and reinforcement: spatial clustering requires property ownership which requires law. Conversely, law enables ownership which enables clustering. The two cycles are held together through a common dependency on writing, education and the development of an elite. (Figure 4 in Penn, 2018).

On the diagram above I use two opposing arrows to indicate 'enabling' and 'requiring' directions in the cycles, but this is merely a shorthand to indicate a more complex idea. It is central to my argument that these interdependencies are not 'causal' in the sense of having a temporal arrow of time but are strictly two way. The invention of symbolic writing for example required learning and must divide the population between the literate and illiterate. The former gain access to additional information and power. This creates an elite. However, an elite with power may have time to invest in learning rather than surviving and so can become literate. This is akin to Marx's dialectic, or to the relation between objectivity and subjectivity in Hillier's objective subject, or between the logical and non-logical in Pareto's schema.

A similar duality exists between science and technology. It is generally unclear and probably not useful to discuss which predates the other. The steam engine was invented before the laws of thermodynamics for which it was probably a major stimulus. Physics in turn has become a primary tool for the engineer. Considered in terms of the progress of scientific understanding described above, engineering innovation designed to solve practical problems of living in the world has been a major contributor of precisely those anomalies that require new scientific theory to explain them. In this way the duality is in fact another of those two direction cycles.

It is for this reason that rather than search for some kind of family tree in the history of human progress, we may be better instead to consider a series of bifurcations between different states, triggered by innovations that took hold and propagated if they were found useful, so becoming self-reinforcing. Undoubtedly, dense urban settlement was one such, as were the division of labour, currency, writing and the apparatus of state formation. So too the emergence of science and the technology.

There still exist today – on the verge of extinction – hunter gatherer groups whose social structures and lifestyles are in all likelihood similar to those of our ancestors before 10,000BC. It is not useful to think of these as in any sense 'primitive' and our own society as 'modern' if by this we imply some kind of temporal dimension. Both they and we are equally a part of humanity in 2020. More than that, it was exactly this type of group that decided to settle and build on the Anatolian plateau and so triggered the explosion of human progress we are still experiencing today.

Epilogue

I started writing this chapter sitting in the lab at UCL surrounded by Bill Hillier's library of books. Little did I know then that I would spend the rest of the year working from home. I have spent most that time as chief scientific adviser to the UK Ministry of housing, communities and local government, and as a member of the Government's scientific advisory group for emergencies (SAGE), on the response to the pandemic. There is no doubt that this has shaped my thinking. At the most practical level, lockdown gave me the excuse for a 'project', to read Marx and Pareto, and aside from that, and various DIY jobs around the house, to watch the full HBO box set of Game of Thrones. At a more fundamental level it has allowed me to observe the effect of crisis and epidemic on the way that government works, and in particular on the way that science fits into this. This seems to me to be

central to the issue of human progress which has long been a personal interest but became the guiding motivation for this Chapter.

The dense urban settlements that I suggest were a sparking point for a surge in human progress, must at the same time that they created the conditions for an early economy, have provided the density of contact needed to support epidemics of contagious disease. I suspect that the response may have involved the development of organised religion, medical practice and the apparatus of the early state. Viewed this way, the evolutionary influence of epidemics and war may have been ultimately to stimulate both the development of science and state building.

It is no coincidence that in developing the argument for the chapter I turned to Pareto's distinction between logical and non-logical reasons for deciding how to act. I am left in no doubt following experience of recent years; of Brexit, Trump and others, and the debate surrounding each; that winning both hearts and minds are key to the function of government and politics in the modern state. They are also key to managing a pandemic, itself a task that falls to the machinery of government.

The SAGE group has three main sub-groups, one on virology, one on epidemiology and one on human behaviour. There are others, but these three have been the drivers of policy in the UK. Ultimately, the hope is that understanding the virus will help us treat the disease and reduce mortality of those infected, and then produce an effective vaccine. However, we know that this takes time, and during that time we need to understand as much as possible about what to expect so that we can prepare and build capacity in our hospitals to treat the ill.

Here the epidemiologists develop models that chart the spread of the disease through the community. These models are rational but built on assumptions that come from data, and these data are inevitably imperfect at the outset. The early models made use of data from previous epidemics of respiratory influenza virus, before building in data from the current SARS-CoV-2 virus epidemic in other countries, and eventually data on our own. Every virus is different in terms of how and who it affects, how it transmits and its time course. Every country is different in its geography, its culture and social connectivity as well as in its health care systems, government and approach to management of an epidemic. They also differ in capacity to test for infection and in the way that they count mortality making the data variable and the job of modelling an imperfect one. This means that rationality in epidemiological modelling is inevitably bounded.

Epidemics are defined by exponential growth. Until effective treatments or vaccinations have been developed all that one can do is try to reduce transmission. Transmission from person to person for a respiratory illness is by people coughing out droplets and aerosols containing the virus, and others either breathing these in directly or possibly touching surfaces where the droplets have landed and transferring the infection to mucosa in the mouth, nose or eyes. This means that to reduce transmission we must change human behaviour: wearing face coverings, washing hands and so called 'social distancing'. Also, so far as possible to reduce the chances of people being in the same space at the same time – to reduce connectivity in society. All of these measures can be fed into the parameters of

the epidemiological model to see what effect they might have on the 'r' – the reproduction rate. This is where the behavioural science group comes in, to help determine how best to implement policies designed to change behaviour, how best to communicate these and what level of compliance might reasonably be expected. Now, as we know from Pareto, human behaviour is driven in part by rational decision making, and in part by sheer instinct and emotion. If we fail to recognise this our interventions may not work, or they may even backfire.

For the government however, there is a conundrum. Connectivity in society is a driver of both the epidemic and the economy. In order to stop transmission, we have effectively to shut down a major slice of the economy. This in itself carries long term consequences for every walk of life; for jobs, innovation, culture, sport, health, education and the rest. The pain falls unequally on society with the poorer suffering most as these tend to be most dependant on face to face services for employment. This then is the realm of politics. The most difficult decisions in society are those for which there is no single rational way of arriving at an answer. This life or that one? The infection or the economy? This is the role of government and the primary rationale for building the apparatus of state; to make difficult and contested decisions on behalf of society where no single option is obvious. In this situation politicians will listen to the rational evidence supplied by scientists and economists, but ultimately, they will make decisions based on their gut instinct for political survival.

In the modern western state government depends for legitimacy on a democratic mandate and its record of good government. In order to achieve the democratic mandate at the ballot box, politicians set out their views and principles – their ideology – alongside a set of much more prosaic manifesto pledges. What really counts in the election is ideology, and this is a matter of instinct and belief for the voter. Reputation for good government is decided on track record, after the fact. Management of the pandemic will be seen as defining good government in every nation.

I would argue that the rational and the non-rational are also key to science. This may strike you as odd. Surely science is eminently rational; wasn't this the basis of Pareto's thesis? Here I point to Thomas Kuhn (1962) who observed that the history of scientific thought shows us that scientists as a species often behave in ways far removed from Karl Popper's objective ideal. They seek to defend their theories against new theory and all too often this becomes a matter of emotional attachment to something that they have invested in heavily rather than a purely objective analysis of evidence. What Kuhn demonstrated was that science is a social product, and that scientific debate, like any other area of debate in society is driven to a large degree by emotion. Arguments are heated, scientific positions become ideological and personal identity becomes bound up with which side of the argument you join. These issues serve to polarise opinion.

This seems to be a paradox. If non-rational thinking plays such an important role in the progress of science, how can we consider science to be objective? It was one of Bill Hillier's working principles that a paradox indicates a questionable assumption in the underlying paradigm, and so paradoxes offer fertile territory for Kuhnian paradigm shifts. In this case the underlying assumption is that rational and non-rational thought are somehow in

opposition to one another. Advances in psychology and neuroscience since Pareto's time suggest instead that gut instinct and emotion are integral aspects of the way rationality itself has developed and operates. Sigmund Freud's Interpretation of Dreams (1899) pointed the way, but it fell to more recent neuroscience to provide an explanation.

Briefly, the thinking is that instinct and emotion were very early behavioural traits and sit deep in the brain. When rational thought evolved it did not emerge separately or replace but was built out of these structures. There are several theories about how this might work. Seymour Epstein (1994) proposes a direct incentive to act induced by positive or negative feelings. For him the experiential and analytic systems run in parallel. Antonio Damasio (1994) proposes the 'somatic marker hypothesis'. 'Somatic' since it is related to gut feelings which are bodily. Imagine the sinking feeling you get when you realise that you have just been subject to a con trick, or the feeling of embarrassment when you make a social faux pas. These gut feelings are instinctual early brain warnings and they serve to train our neural networks in a rational processing system of what to avoid. Sometimes we wake in the night sweating to think of how stupid we have been. This presumably is when consolidation or reconsolidation is taking place and the somatic marker is involved. There are equivalent positive feedback feelings, of ecstasy or exultation that serve the opposite purpose, of reinforcing the networks.

Here we have an argument that rather than consider rational and non-rational traits as in opposition, both form an integral part of decision making. Perceptions of risk are of course important in delivering behaviour change in the face of a pandemic. For example, epidemiologist Geoffrey Rose defined the 'prevention paradox' that faces many public health interventions (Rose, 1981). We call on many people at low risk of a disease to change their behaviour in order to protect a smaller number of people at high risk. It turns out that this creates tension especially when behavioural interventions are not zero cost but have negative effects for the individual and the economy. Paul Slovic (Slovic, 1999; Slovic et al, 2004) review the evidence for the way people consider risk. He defines 'risk as analysis', 'risk as feelings', and, when these two come into conflict, 'risk as politics.' This last is precisely where the tension between managing the infection and maintaining the economy become political.

Contrast the effectiveness of authoritarian China, the origin of the epidemic, with 4800 fatalities out of a population of 1.4 billion, and libertarian USA with its sophisticated disease control system as well as forewarning of the epidemic, with 240,000 fatalities out of a population of 330 million by November 2020. The scientific understanding of the virus and epidemiology is equal in both nations. I suspect that it is the difference in ideology between the two that accounts for these different outcomes. In China the individual is subsumed to the collective, in the USA the reverse. Against these ideological backgrounds the two governments were free to make different choices. In seeking to protect the economy Donald Trump chose to let the epidemic run its course. The result has been an 8% reduction in the US GDP and a recession projected to last several years. China chose to quash the epidemic rapidly, like pulling a tooth or lancing a boil. The result has been that China has after just nine months almost recovered its pre-COVID GDP.

I suggest in this chapter that there are just two fundamentally different ideologies at play in the world today: the first holds that human progress is based on survival of the fittest and competition. This carries the Spartan implication that those that are less fit do not deserve to survive. It also justifies prioritising the individual over the collective. If there is an elite, that is because they are fitter. If the least fit fail to thrive that is the will of nature. The alternative ideology holds that human progress is due to our ability to collaborate, to empathy and altruism. This places Geoffrey Rose's paradox at its centre. It argues that the many may need to reduce their social contacts in order to reduce the transmission rate of the virus and so protect a small number of the vulnerable.

So, a question remains. Why do these two ideologies coexist? If one were right and the other wrong, surely the latter would eventually wither and die out? One answer could be that both ideologies are of value, perhaps at different times or in different contexts. These seem to me however, to offer yet another example of the two way 'each produces the other' processes that we might describe as a dialectic at work in the social realm. I suggest an alternative. Rather than see these as two separate processes, working in relative isolation, or one replacing the other in a Paretian cycle of elites, or a Hegelian cycle of thesis, antithesis and synthesis, I prefer a different conception. The close coupling of competitive and collaborative ideologies, each intimately related to and each driving the other, may provide the source of the apparent direction of advance in science, of state building and ultimately human progress.

Under this conception the force that powers progress and development is the continual tension between competitive and collaborative ideologies. It is this that defines 'in-group' and 'out-group' structures, and by keeping these in a state of dynamic tension, maximises both conservation of valuable traits and innovation. Perhaps it is this that keeps social forms far from equilibrium and provides an impetus to progress.

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