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Cities: Continuity, Transformation, and Emergence

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Abstract

Cities can be regarded as the quintessential example of complexity. Insofar as we can define a hidden hand determining their morphology, this is based on the glue that stitches together the actions of individuals and organizations who build the city from the ground-up, so-to-speak. When general systems theory entered the lexicon of science in the mid-20th century, cities were regarded as being excellent examples of systems with interactions between basic elements that demonstrated the slogan of the field: the 'whole is greater than the sum of the parts'. Since then, as complexity theory has evolved to embrace systems theory and as temporal dynamics has come onto the agenda, cities once again have been used to illustrate basic themes: global organization from local action, emergent morphology from simple spatial decision, temporal order at global levels from volatile, seemingly random change at the level of individual decision-making, evolution and progress through co-evolution, competition, and endless variety. Here we will sketch these ideas with respect to cities illustrating particularly three key ideas which involve the tension between continuously changing systems, qualitative transformations, and radical change based on emergent properties of the whole. Our analysis has many implications for a new theory of urban planning which is built from the bottom up, rather than from the top down which is the traditional way in which such interventions are currently carried out in the name of making better cities. Contemporary problems such as ethnic segregation, urban sprawl, traffic congestion, urban decline, and regeneration are all informed by the perspective on complexity theory that we bring to bear here.

This paper will be published in a forthcoming book edited by Elizabeth Garnsey entitled **Coevolution and Complexity**, forthcoming 2005

1 Historical Antecedents

Cities are never what they seem. Our usual response when faced with trying to understand their form and function is to revert to the almost reflex actions which are instilled into us from an early age whereby we try to make sense of the world by 'adding things up'. With cities before we even begin, we know that this strategy will not work. Our own behaviour is hard to reconcile with the kind of routine order that we see when we observe the ways in which people travel to work, the places where housing estates are built, and the almost mindless flocking that we see when we visit entertainment centres from sports arenas to large shopping malls. In short, the 'whole is more than the sum of the parts' (Simon, 1962). We cannot assemble the whole by simplifying adding up the parts for all would agree that there is something more that makes cities function as ordered wholes. Equally well we cannot get at their essence by simply tearing apart the whole and examining the parts. Classical science through its reductionist strategy simply fails us when we try to understand such complexity.

Half a century ago, science began to deal with complexity under the banner of 'general system theory' (van Bertalanffy, 1972). Since then there has been a sea change in many sciences as highly centralised, purist explanations from the top down have been found wanting. The idea that science in its classical form could be used as a basis for such control has been widely discredited, in the west at least, as the move to decentralised government and action has gained ground. This has been dramatically accelerated by the miniaturisation of information technologies which have given much greater power to the individual and it is no surprise that in such a world, the dominant mode of explanation has shifted to theorising how systems emerge and are generated from the bottom up. Urban planning which was first institutionalised as a function of government over one hundred years ago, is focussed on making cities more attractive, efficient and equitable places in which to live but its history has been far from successful. Like all controls which are applied to complex systems, it fails to anticipate change which originates from the bottom up.

The failure of urban planning is as much a consequence of our inability to understand how cities work as it is of any political or ideological reaction against the idea of control and government. Cities are not just the sum of their parts and trying to make them workable by tinkering with their parts is borne of a deep misunderstanding as to their nature. In fact contemporary approaches to general systems under the guise of complexity theory take the gestalt implied by the whole-parts continuum-disjunction even further. For example, Anderson (1972, page 393) says that "…the whole … (is) … not only *more* but very *different* from the sum of the parts". It was Jane Jacobs (1961) however who first raised the notion that cities should be treated as problems of organized complexity. In a series of prescient books and essays, she argued vociferously that diversity and variety in cities was their hallmark and that this was being destroyed by contemporary urban planning. She drew her inspiration for a new science of cities from the speculations of Warren Weaver (1948) who in an address to the Rockefeller Foundation, suggested that systems could be classified as being applicable to three kinds of problem: problems of simplicity, problems of disorganized complexity, and problems of organized complexity. It is the latter category that Weaver argued should form the cutting edge of science arguing that most problems in science once they left the controlled conditions of the laboratory, became complex but in an organized sense that required new approaches which treated the systems associated with them as evolving from the bottom up. It was the process of showing how this bottom-up thinking could generate useful theories and applications that represented the all important quest.

In this essay, we will illustrate how complexity theory might be applied to cities, showing how changes in urban form and function reveal sometimes bewildering patterns and processes which are often pictured in over simplistic ways. The trap that many urban theorists trying to explain urban form have fallen into is to assume that the way cities looked in the industrial age – rather ordered ring patterns around their traditional market centre, the core or Central Business District (CBD) as it is now called – could be explained by equivalently simple processes of growth and change. Cities are formed for exchange and the traditional core was the market place where trade took place. Most urban theories explain cities as a trade-off between getting as close to the core as possible, the value of the goods and products exchanged in the core, and the amount of space required for their production. This model is useful as far as it goes but it assumes little specialization. It cannot reconcile itself to dealing with more than one core, so competing cores or market places are problematic, and it handles travel and transport in far too simplistic a way in a world now full of alternative communications paths. Little wonder that simulating cities using these kinds of theory and making decisions based on these leads to unrealistic plans. Furthermore this type of model is entirely static; it is based on a world in equilibrium and although at first sight, cities look as though they might be in equilibrium, this can never be the case. In fact what might appear to be in equilibrium is their physical artifacts, their structures, buildings and streets, but the economic and social rationale for what goes on inside them is in continual flux. One only has to look at downtown Manhattan or the City of London and think about how different these locales have become over the last half century to know that although nothing appears to have changed physically, everything has changed functionally and behaviourally.

We will explore cities through three related perspectives on change: continuity which contrasts with discontinuity and bifurcation, transformation where forms and functions evolve from one pattern to another, and emergence which concerns the way qualitatively new and novel structures arise. In a sense, these dynamics imply processes operating at different temporal rates and spatial scales although in cities, it is the perspective we take and what we define as relevant to our representation that dictates the kind of change that we focus upon. We will illustrate each of these themes through examples which manifest themselves physically and spatially. One of the key features of cities is that spatial order is never what it seems for the same kinds of pattern can emerge from very different processes. This means that we need to be careful in illustrating complexity through spatial pattern and in each case we will unpack these to reveal the processes that generate them.

Our first foray into urban evolution will deal with continuity where we will dwell on how slow and gradual change suddenly but subtly reveals that bifurcation might have occurred. Transformations are another way of looking at such change and here we will show how systems are resilient at certain thresholds. Theories of self-organized criticality are useful in illustrating such change, particularly the conditions under which dramatic transitions take place which propel the system towards a new state. These perspectives can also be subsumed under the notion of emergence which John Holland (1998) sums up rather nicely as "… much coming from little …" (page 1), entirely consistent with structures being *different* as well as *more* than the sum of their parts. Our thesis will be illustrated with morphological patterns which characterize the contemporary city: urban sprawl, edge cities, bi- or multi-polar CBDs, residentially segregated areas, ghettos of various sorts, and technological changes forced by new transportation, global and world city patterns.

2 Continuity: Relatively Slow Change

The process of city growth is intrinsically different from that of urban decline in that growth at some point involves the transformation of land from non-urban to urban whereas decline does not necessarily imply any such reversibility. Over the very long term, cities have waxed and waned in size but our focus here is on contemporary times where growth is the dominant mode of change. In a world which will be almost entirely urbanised by the end of this century, we may then face a rather different prospect of what constitutes a city and city growth but for these purposes, our discussion is restricted to the growth of cities over the last 200 and the next 100 years. At very fine spatial scales, growth involves individual transitions which are measured with respect to land use, occupancy and density, and change can be slow or fast, gradual or abrupt. But as we scale up, then this volatility is averaged out and at the level of the whole town or metropolis, the change in spatial pattern appears slow and gradual, notwithstanding the fact that growth of absolute volumes of activity may be proceeding exponentially.

A measure of this slow change is captured in the growth of Las Vegas over the last 100 years which is pictured in the movie-like clip which we show in Figure 1. The sprawl does not look very different from time period to time period in that the pattern always looks like more of the same. Inside the city, things have changed rather more dramatically as the place has moved from desert oasis and staging post prior to 1950 to the entertainment and gambling capital of the United States in the modern day. Exponential growth of population, employment and tourism is implied by the volume of urban development in Figure 1 but the pattern is one of continuing but relatively similar peripheral expansion. The fact that the city has grown in some directions rather than others is largely due to a combination of physical and accidental historical factors and does not imply any differences in the way growth has occurred from one time period to the next.

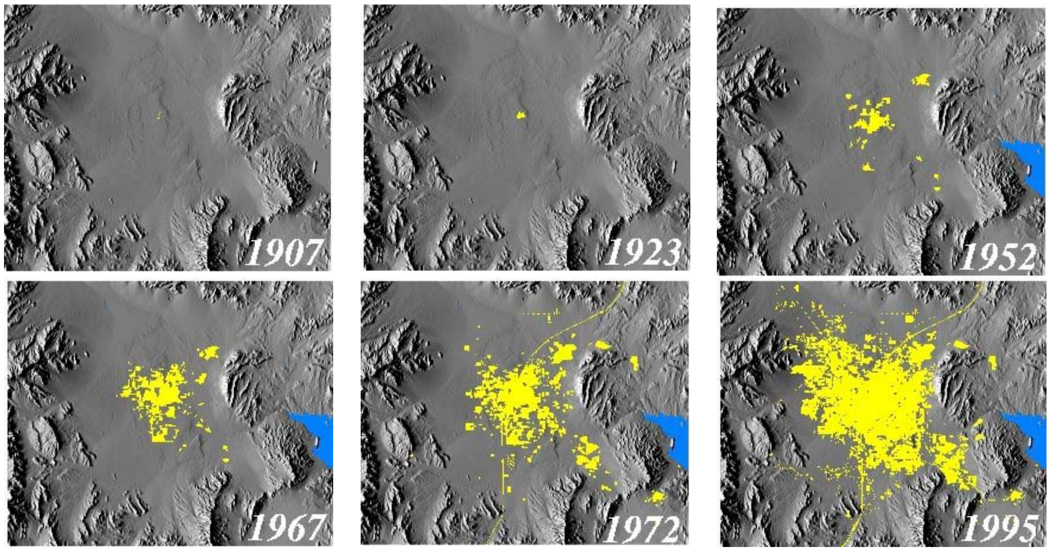

Figure 1: The Growth of Las Vegas from 1907 to 1995
(from Acevedo et al., 1997)

This kind of change has convinced many that cities are comparatively simple structures whose urban form and pattern is explicable in general terms that apply to many time periods of their growth. Whether large or small, the same bottom-up development processes are at work, and large structures are correspondingly similar to small. Idealised models where entirely local development rules are operated uniformly across the space to grow a city from a single seed lead to fractal patterns, patterns that are self-similar in form with respect to scale, of the kind observed in real cities. In Figure 2, we show how the operation of deterministic rules where a cell is developed if there is one and only one cell already developed in its immediate neighbourhood, leads to a growing structure. This is a typical example of a modular principle that preserves a certain level of density and space when development occurs but when operated routinely and exhaustively leads to cellular growth that is regular and self-similar across scales. Idealistic Renaissance towns were often patterned in this fashion as templates for an urban utopia based on classical architectural principles. Throw in some noise or error into this structure however and any symmetry is immediately broken. If we relax the growth rule to one where the probability of the growth of a cell varies directly with whether or not adjacent cells have already been developed, then we generate something more like an amorphous mass, a radially-concentric-like structure closer to that we see in the development of Las Vegas. We show the resulting patterns in Figure 3 where the shape of the structure is now circular in that development eventually occurs everywhere. The city fills up completely but the order in which this takes place is a result of development taking place at each time period with random probability.

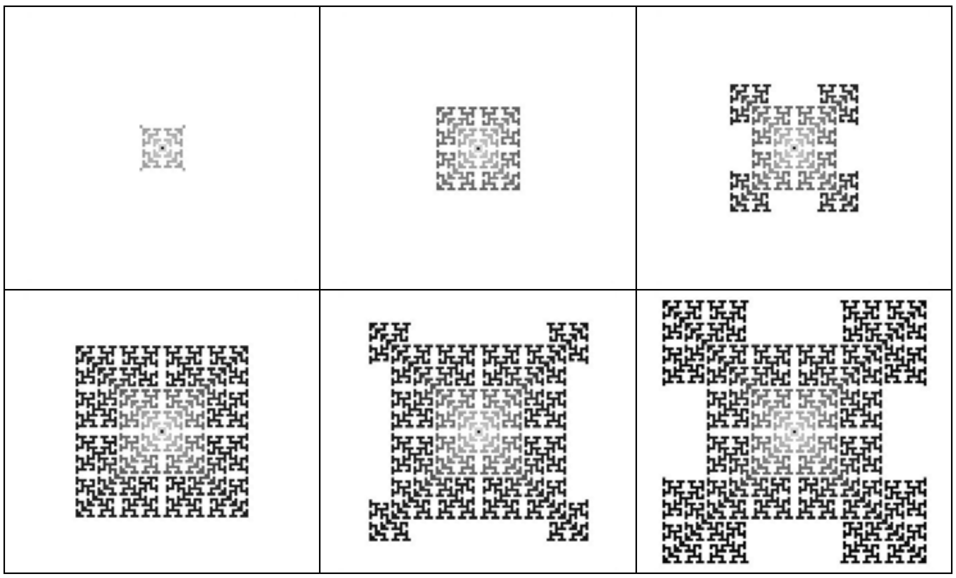

Figure 2: Deterministic Growth from the Bottom Up: based on developing cells if one and only one cell is already developed in their 8 cell adjacent neighbourhood

If urban growth is modular and scales in the simplistic way that is portrayed in these models of fractal growth, then it is not surprising that there is a tendency to explain such patterns generically, without regard to growth *per se*; to study these as if they represent systems with an equilibrium pattern that simply scales through time. But this is a trap that must be avoided. Dig below the surface, and examine the processes of growth and the activities that occupy these forms, disaggregate the scale and change the time interval, and this image of an implied stability changes quite radically. During the era pictured in Figure 1, technology has changed dramatically. Las Vegas did not acquire its gambling functions until the 1950s but by then it was already growing fast and the subsequent injection of cash into its local economy, the largest per capita in the western world for those who reside there, did little to change the pattern of explosive growth that followed. The manner in which people moved in the early Las Vegas was by horse and wagon but the city could only grow with the car, the plane and air-conditioning, not to say the incredible information technologies that now dictate how one gambles, wins, and loses.

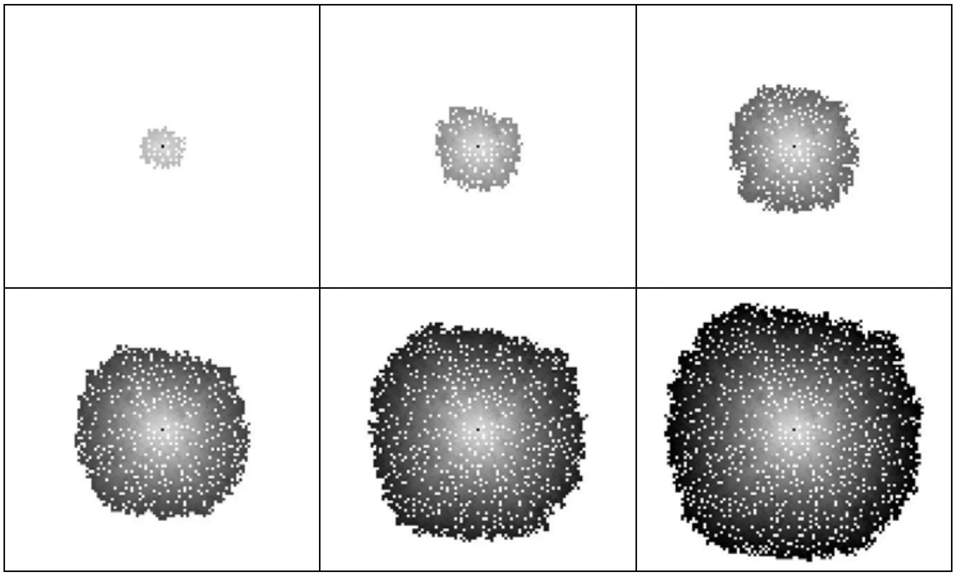

Figure 3: Stochastic Growth from the Bottom Up: based on developing cell if any cell is developed in the adjacent neighbourhood according to a random probability

Has a subtle bifurcation occurred during this 100 years of growth? If it has, you cannot see it in its spatial pattern but bifurcation there has surely been as anyone who knew Las Vegas in 1945, again in 1970 and thence today would easily attest. Cities are never what they seem.

3 Transformations: Persistence and Self-Organised Criticality

Our six frame movie of the growth of Las Vegas does reveal that the established pattern of adding to the periphery is not entirely the complete story for small blobs of development seem to attach themselves and then are absorbed back into the growing mass as growth catches them up. In this case, this is simply housing being constructed a little beyond the edge due to the mechanics of the development process. In older, more established settlement patterns such as those in Western Europe for example, this might be the absorption of older villages and freestanding towns into the growing sprawl. Consider the picture of population density in London recorded in 1991 and illustrated in Figure 4. Here there are many towns and villages that existed long before London grew to embrace them. One kind of dynamics that this picture reveals is the transition to a metropolitan area. Let us define the metropolis as the connected pattern of settlement that fills an entire space where everyone can connect to everybody else either directly or indirectly. Connection in this sense is simply the ability to circumnavigate the system, from one side to another if you like. In the days before the towns and villages in Figure 4 were part of the metropolis such connection was not possible for one could not proceed across the system in this way without entering empty space, countryside. Moreover our definition of a metropolis is an urban form where such connection exists in as simple a fashion as possible but not more so.

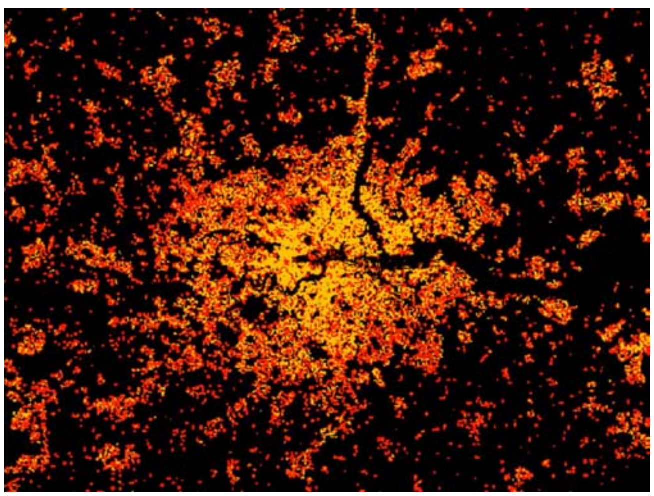

Figure 4: London: Connected Villages and Towns within the Sprawl
(as population density on a 200m grid from the 1991 Census of Population)

In Figure 4, one could envisage London being connected in this way with a much sparser network of links while at the other extreme the entire space could be filled. In fact, it would seem that the level of connectivity which has evolved with respect to the density of the space filled is just enough for the city to function as a whole, and it this morphology and degree of connectivity that marks the fact that the city has reached a level of self-organisation which is regarded as critical. If connectivity were greater than this with more space being filled and many more connections in place, then the structure would contain certain a degree of redundancy making it inefficient. Below this, the system would not be connected at all and it would not function as a metropolis.

Again this is a rather obvious point but what it serves to show is that cities evolve to a self-organised level and persist at this level until some radical change in technology pushes such systems into a another regime. For example, London's form is largely dependent on a mix of transportation technologies, dominated by the car but overlaid on fixed rail lines. Prior to the 19^{th} century, such a system could not exist and the London that was based on walking and the horse and carriage was a very different structure. New transport technologies possibly based on substituting electronic for physical movement would change the form of the city quite radically in that the critical threshold would be breached and activities would probably readjust themselves in space in ways that we find almost impossible to envisage. This kind of technological change does indeed mark different regimes and it tempting to think of different eras as being based on the evolution of resilient systems that when radical change does eventually take place, pushes the system beyond the threshold that takes it to a new level of criticality in which the processes at work then self-organise to another critical level. Several commentators describe this process as some sort of social phase transition analogous to those which are well defined for physical phenomena. For example, Iberall and Soodak (1988) describe the process by which Europe underwent such a transition, " … not unlike that between H_2O molecules changing from the fluid state of water to the crystallized state of ice: for centuries the population is liquid and unsettled – and then suddenly a network of towns comes into existence, possessing a stable structure that would persist more or less intact until the next great transformation in the nineteenth century during the rise of the industrial metropolis."

To give some form to this rather mystical perspective on urban dynamics, it is easy to show how a system self-organises to the point where it becomes critical but not beyond. Imagine a series of 5 small villages randomly located and spaced on a regular lattice such as we show in Figure 5. We gradually increase the density of these villages which is equivalent to growing them into larger towns, and as we do this we compute the average distance between all the occupied points. However for a long time it is not possible to travel between every occupied point because they are not connected. Suddenly however we reach a density where around 59 percent of the lattice is randomly filled where every occupied point can be linked to every other. At this point, there is an abrupt change as the average distance falls from 'infinity' to a realistic level. If we then continue increasing the density, this average distance does not fall much further and little is gained by continuing in this way. In terms of cities, the point of criticality where everything becomes connected marks the emergence of the metropolis in this space, like London, and this only becomes possible when transportation technology reaches a level where it is feasible to realise such connections. In sense, this is also an oblique way of saying that very large cities of the kind that are now dominant world-wide are only possible with current technologies, not just transportation technologies but others which enable large-scale urban living. In the ancient world where one could not travel faster than by chariot, the largest city that could be sustained was Rome and this did not grow much beyond one million.

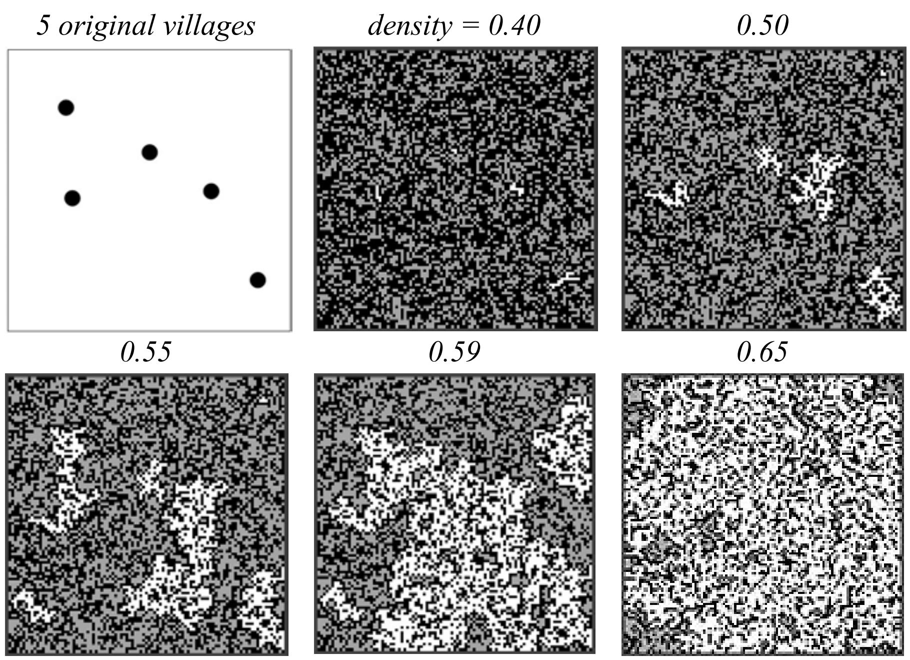

Figure 5: Increasing Density and Connectivity to the Self-Organised Critical Threshold

In Figure 5, we provide a graphic demonstration of the effect of increasing density and connectivity for a hypothetical distribution of settlement in 101 x 101 grid space where we show the how the villages merge into one another when somewhere between 40 and 65 percent of the lattice is occupied. If we were to plot a graph of the transition to a realistic average distance between all the occupied points to establish the level of criticality, there would a dramatic change at around 59 percent which is known in the physics of porous media as the percolation threshold. At this threshold, average distance falls from infinity to a proper value. By the time the density reaches 65 percent, this travel distance has stabilised in that rises in the density of the media above this level do not change the distance very much at all.

4 Emergence: Qualitative, Sometimes Abrupt Change

The abruptness of change in cities depends very largely on the scale at which we observe it and the time interval over which it occurs. For example, traffic jams simply build up as density increases with wave effects due to differential acceleration and braking happening over minutes while stock market crashes usually happen over days and weeks, sometimes months. Booms and busts in the housing market with respect to prices as well as effects on subsequent mobility usually happen over months, rarely over years, while gentrification and related migrations take place usually over years. Sea changes forced by technological innovations happen over centuries or parts thereof portrayed for example as Kondratieff waves over half centuries or more. All these events can reveal abrupt change in terms of their measurement if observed at particular scales and time intervals but averaging over time and space certainly smoothes this abruptness. What can appear as abrupt change at one level becomes gradual at another.

All that can be said is that although there may be an ideal scale and time period consistent with the operation of such change which is usually defined with respect to the purpose of study or application in mind, abrupt change is a relative phenomenon defined with respect to the change before and after it takes place. Moreover it is in the eye of the observer as to whether such change is meaningful. Abrupt change may not be qualitative change for such changes can take place gradually and only with respect to the past might they reflect some discontinuity whose actual happenstance cannot be dated. For example, the industrial city is clearly now very different from the post-industrial. Compare any 21st century western city that has continued to grow with its form in the 19th in terms of its spread and sprawl, the incomes, occupations, and so on that define each. Yet it might be argued that the contemporary city which we are calling post-industrial is merely a reflection of the outcomes of industrialism – based on the automobile and related technologies – and that we have in not yet glimpsed what modern information technologies might do to the future city during the next 100 years. Qualitative change can in fact be pinned down to the invention or emergence of new categories of object, new classifications of the old that only have meaning for the contemporary world. All the great technological innovations that we loosely referred to in the last section – the agricultural revolution which began some 10000 years BC, the emergence of the modern world from the 12th century onwards, industrialism, perhaps post-Fordism, and the computer revolution – are all candidates for the kind of qualitative change that is clearly manifest in the form of the city.

Without trespassing further on this minefield of definition, we will return to abrupt change and in particular emergence in its narrower context to demonstrate a last example of the way cities can restructure themselves in ways that are surprising. One of the best examples is how different residential neighbourhoods change in their social composition, becoming gentrified or ghettoised due to very mild preferential differences amongst their populations. To avoid any racial connotations, we will in fact assume in more light-hearted fashion that the population is divided equally into those who support the Yemeni soccer team and those who support the Norwegian which we define as Y and N respectively. Let us array the population on a square grid of dimension 51 x 51 where we place a Y supporter next to an N supporter in alternate fashion, arranging them in checker board style as in Figure 6(a). The rule for being satisfied with one's locational position viz a viz one's own and the other supporters is as follows: supporters of a different team will live quite happily, side by side with each other, as long as there are as many supporters of the same persuasion in their local neighbourhood. The neighbourhood in this instance is the eight cells that surround a supporter on the checkerboard in the N, S, E, W, and NE, SE, SW, and NW positions. If however a supporter finds that the supporters of the opposing team outnumber those of their own team, and this would occur if there were more than 4 opposition supporters, then the supporter in question would change their allegiance. In other words, they would switch their support to restore their own equilibrium which ensures that they are surrounded by at least the same number of their own supporters.

There is a version of this model that is a little more realistic in which a supporter would seek another location – move – if this condition were not satisfied rather than change their support, but this is clearly not possible in the completely filled system that we have assumed; we will return to this slightly more realistic model below.

In Figure 6(a), the alternative positioning shown in the checker board pattern meets this rule and the locational pattern is in 'equilibrium': that is, no one wants to change their support to another team. However let us suppose that just six supporters out of a total of 2601 (51 x 51 agents sitting on the checker board) who compose about 0.01 percent of the two populations, change their allegiance. These six changes are easy to see in Figure 6(a) where we assume that four supporters shown by the black colour, the Norwegians say, change in their allegiance to white, to support the Yemeni team, and two Yemeni's change the opposite way. What then happens is the equilibrium is upset in these locations but instead of being quickly restored by local changes, this sets off a mighty unravelling which quickly changes the locational complexion of the system to one where the Ys are completely and utterly segregated from the Ns. We show this in Figure 6(b). From a situation where everyone was satisfied and mixed completely, we get dramatic segregation which is a most unusual consequence. At first sight one would never imagine that with so mild a balance of preferences, such segregation would take place. The ultimate pattern implies that Ys will live nowhere near Ns unless they really have to and there is nowhere else to live and vice versa. If a Y or an N would not tolerate more than one person living near them, then such segregation would be understandable but this is not the case: Ys are quite content to live in harmony with Ns as long as the harmony is equality.

This model was first proposed more than 30 years by Thomas Schelling (1969, 1977). In fact we can make this is a little more realistic if we provide some free space within the system. In this case, we assume that 1/3 of the lattice is empty of supporters of any kind 1/3 composed of Ys and 1/3 of Ns and we mix these randomly as we show in Figure 6(c). Now the rule is slightly different in that if there are more opposition supporters around a supporter of one persuasion, then that supporter will try to move his or her location to a more preferential position. This sets up a process of shuffling around the checker board but as we show in Figure 6(d), quite dramatic shifts take place in location which leads to the segregation shown in Figure 6(d). This is the kind of effect that takes place in residential areas in large cities where people wish to surround themselves with neighbours of their own kind. What is surprising about the phenomena which makes it ‘emergent’ in this sense is that for very mild preferential bias, dramatic segregation can take place. Of course if the preferences for like neighbours are very strong anyway then segregation will take place. But in reality, such preferences are usually more mild than strong, and extreme segregation takes place anyway. The conclusion is that cities often look more segregated around racial and social lines than the attitudes of their residents suggest.

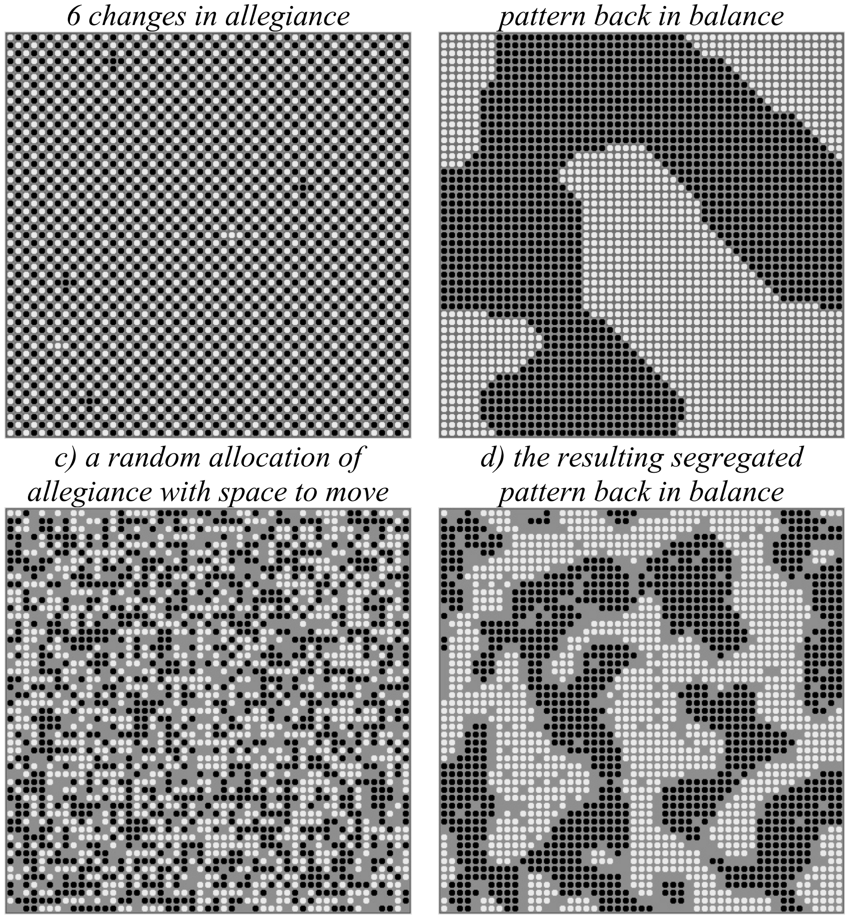

Figure 6: Emergent Segregation: A Fragile Equality (a) gives way to Segregation (b); A Random Mix (c) gives way to Segregation (d)

It is hard to find clear examples of this process taking place in that by the time it is clearly underway, then this is revealed by the very segregation itself and a detailed chronology becomes impossible to reconstruct. There are plenty of examples of this in western cities with comparisons at the level of census tracts over 10 year periods easily accessible from the many social atlases that have been constructed for cities in the last decade.

5 Ever Greater Complexity

In this short essay, we have barely scratched the surface of the study of complexity in cities for at every twist and turn and from every perspective, there are signals that indicate surprise, novelty, innovation, and emergence in the way cities grow and change. Symmetry is forever being broken and urban processes display a bewildering variety in terms of the reversibility and irreversibility. In all of this what is very clear is that we cannot take at face value what we observe superficially. If there is one message that complexity theory forces on the social sciences, it is that the search for an understanding in terms of regular pattern must be viewed with suspicion for beneath such patterns often lie volatile change and unstable processes of the most extreme nature. A generation or more ago, our study of cities was dominated by explanations that suggested that cities were rather stable kinds of structure as revealed in the patterning of their land use and transport systems that revealed itself as highly ordered. People mainly worked in the centre, with richer people who could afford better transportation and more space living on the periphery. In fact we now know that this was never as clear cut as was believed. What we were enticed by was the fact that cities through their built form are rather long lasting kinds of artefact but that what goes on within that form is subject to quite rapid change. Take a city like London which we illustrated in Figure 2. At first sight, it appears strongly monocentric with small towns being absorbed in its growth as it has exploded outwards. But in fact most people do not work in the centre. Cross-movements are substantially greater than any movements from the edge to the core and most 'Londoners' never visit the centre, even to shop or for entertainment. Cities are more complex than this, and complexity theory refocuses our attention on the need for such a deeper understanding (Batty, 2005).

Our quest in this chapter has been to show that complex systems must be understood from the bottom up and that prior reductionist strategies simply fail to grasp the way such systems work. Process rather than product, function rather than form, time rather than space are all important for a better understanding. Missing from our argument however is the notion that cities like many other social systems might be becoming more complex, certainly more complicated as they evolve through time. Some would argue that our theories and models must inevitably adapt to embrace new forms and categories that get invented and which are not intrinsic to the system when we observe it at any one time or even over past time periods. This is a subtle issue that is taken up by others writing in this book but it is important because it further reinforces the relativism that complexity theory tends to bring to the social sciences. Nevertheless, the issues posed here which involve surprising features of temporal urban processes and which lead to spatial patterns which are unexpected, appear to have been a part of cities for a much long time than we have alluded to here. And in fact as we learn more about these through the lens of complexity theory, it is likely that we will gain a much greater understanding of how we might intervene in these processes to effect better cities through their design.

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