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Complexity theory and geographies of health: a critical assessment

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Abstract

The interest of social scientists in complexity theory has developed rapidly in recent years. Here, I consider briefly the primary characteristics of complexity theory, with particular emphasis given to relations and networks, non-linearity, emergence, and hybrids. I assess the 'added value' compared with other, existing perspectives that emphasise relationality and connectedness. I also consider the philosophical underpinnings of complexity theory and its reliance on metaphor. As a vehicle for moving away from reductionist accounts, complexity theory potentially has much to say to those interested in research on health inequalities, spatial diffusion, emerging and resurgent infections, and risk. These and other applications in health geography that have invoked complexity theory are examined in the paper. Finally, I consider some of the missing elements in complexity theory and argue that while it is refreshing to see a fruitful line of theoretical debate in health geography, we need good empirical work to illuminate it.

Keywords: Complexity theory; Geography; Networks; Inequalities; Spatial diffusion

> Every PhD student in everything should get to grips with the "chaos/complexity" programme, not for reasons of fashion or even legitimate career building but because this is the way the world works and we need to understand that (Byrne, 1998, p. 161).

Introduction

This paper considers—in a sympathetically critical way—the rapidly expanding 'complexity turn' within the social sciences and, specifically, the relevance it has for geographies of health (Gatrell, 2002). Complexity has emerged during the past 5 years as a potentially integrating theme in contemporary social science (Byrne, 1998; Urry, 2003). Urry (2003, p. 12) observes that complexity is 'a potential new paradigm for the social sciences, having transformed much of the physical and biological sciences'. He sees it as a means of dissolving some of the binary divides (whether quantitative/qualitative, environmental/social, structure/agency, or medical/sociocultural) within the academy. He even suggests that complexity might help break down divisions between the social and the natural sciences (Urry, 2003, pp. 12–13, p. 17).

The engagement of social geographers with the complexity agenda has, to date, been modest (though see the important paper by Thrift, 1999). Manson (2001) has offered a valuable critique of the relevance complexity theory has for geographical research as a whole. My

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aim here is to locate this critique within the narrower field of health geography and to consider the extent to which complexity theory (hereafter, CT) 'adds value' to existing relevant perspectives in health geography.

I first consider briefly what complexity theory amounts to; what are its key features? I then consider the philosophical underpinnings of CT as an anti-positivist perspective, and its reliance on metaphor. Next, I review several broad areas of research in which health geographers are engaged and discuss and evaluate how complexity theory has been used in each. I conclude with an assessment of some of the missing elements in CT and suggest that while we should welcome any engagement with theory in health geography, we also need sound empirical work to set alongside this.

A simple look at complexity theory

Key characteristics of complexity theory

A system is 'complex' when it displays the characteristics outlined in Table 1 (based on Cilliers (1998) but supplemented with a set of simple illustrations of what is meant by each characteristic). In essence, a system displays complex behaviour when its elements interact in a non-linear fashion, such that it is impossible to predict the behaviour of the system as a whole from knowledge of the elements themselves. I focus on four key aspects of CT that are embedded in Table 1: *relations and networks*; *non-linearity*; *emergence*; *and hybrids*. I end the account with a brief consideration of links to chaos theory (which is associated with, but pre-dates, the emergence of CT).

One must begin with some notion of what the 'system' is that is under consideration, and which is in some way 'complex'. In a biological setting this might be an ecosystem, comprising sets of plants and animals and accompanying soil–climate sub-systems. In social science it might be a transport network that moves people and goods from one place to another, a system that includes 'hybrids' of social and material elements. In a health context it might be the set of elements that permit and constrain the spread of a virus within a local community and beyond. These elements could comprise the virus itself, infected and susceptible individuals, health-care resources, transport systems, and so on. It is the *relations* between system components that are pre-eminent—how these links and connections bind together the system elements (Capra, 1997).

A considerable volume of material—much of a quasi-popular nature (Barabási, 2002; Watts, 1999) is now emerging on *networks*. The relationship of this to complexity is well-expressed by Barabási (2002, p. 7): 'Most events and phenomena are connected, caused by, and interacting with a huge number of other pieces of a *complex* universal puzzle. We have come to see that we live in a small world, where everything is linked to everything else. We are witnessing a revolution in the making as scientists from all disciplines discover that *complexity* has a strict architecture. We have come to grasp the importance of networks' (my italics). Both

Table 1
The main features of complex systems (partly based on Cilliers, 1998)

Characteristics of complex systems	Example (health related)
Large number of elements, interacting dynamically (via flows of material or information) across *networks*	A population in which people influence each others' health-related behaviour, or transmit infections among each other
Interaction is rich and may involve both human and non-human agents (*hybrids*) or elements	People interact with other agents and organisations (health-care providers; health-promoting and health-denying activities and facilities)
Interactions may be short range but the richness of interactions or *relations* across networks means that 'influence' can be wide ranging	'Friction of distance' implies interactions tend to be local, but time-space compression means that interactions having health consequences can be 'at a distance'
Each element is 'ignorant' of the behaviour of the system as a whole; therefore, we cannot understand the system by 'summing' or 'averaging' the behaviour of individual components; system-wide properties *emerge*	One is generally ignorant of the possible system-wide consequences of one's health-related behaviour; the 'public health' is more than the sum of individual disease profiles
Interactions are *non-linear* (which also implies that small causes have large results). There are feedback loops, of varying kinds	Disease outbreaks that are highly localised can spawn epidemics or even pandemics
Complex systems are open systems, interacting with environment	The health system is only closed at a global level, and even then it is open if we consider global environmental change
Complex systems are far from equilibrium	Population growth and movement ensures that the system is never fully stable
Complex systems have a history; their past is 'co-responsible' for their present behaviour	Migration, history of inequalities

Watts (1999) and Barabási (2002) document the apparently complex structure and organisation of networks of various kinds, including the social networks that link complete strangers anywhere in the world by about six intermediaries. This is the so-called 'small-world' problem first developed in detail in the late 1960s by the social psychologist Stanley Milgram. Buchanan (2002, p. 127) considers that 'the small-world discovery and other ideas now growing out of it represent one of the first great successes of the theory of complexity'.

By *non-linearity* we mean that small changes in one component or element of the network do not lead to correspondingly small changes in others. A change in one element is not directly proportional to change in another; more prosaically, little changes can have big effects. By *feedback* is meant the arrangement of networked relationships such that one element affects others which in turn can, ultimately, affect the original element. A very simple example would be that vehicle exhaust emissions increase the burden of air pollution, which may in turn increase the incidence of asthma. A control mechanism (and hence negative feedback) might be to reduce traffic levels, thereby cutting exhaust emissions.

The *emergence* of new structures, via the interactions of system elements, and of new forms of behaviour, is critical to the understanding of complex systems (Holland, 1998). Relationships 'shift and change, often as a result of self-organisation' (Cilliers, 1998, p. viii–ix), and new system properties may emerge. 'The capacity for self-organisation is a property of complex systems which enables them to develop or change internal structure spontaneously and adaptively in order to cope with, or manipulate, their environment' (Cilliers, 1998, p. 90). Self-organisation does not imply some teleological control mechanism; rather, it implies a process whereby complex structure *emerges* through simple, unstructured beginnings. Others speak of autopoiesis (literally, self-making), where each system component aids the transformation of other components; the network makes itself. What might be examples of emergent properties in the geography of health; what emerges at a collective level that cannot be reduced to statements about individuals? The 'health' of a neighbourhood or community could be said to emerge from the activities and health profiles of the local population, as well as the nature of facilities (health-promoting and health-denying) located there. 'Social capital' would be another example of an emergent property. Conversely, the mortality profile of such a neighbourhood is, in effect, the summation of individual deaths and would not be said to be an emergent property.

Last, we must note that complexity theory entails a fusing of the natural or material and the social. Urry notes that 'the so-called social sciences now deal with *hybrids* of physical and social relations, with no purified sets of the physical or the social. Such hybrids include health, technologies, the environment, the internet, automobility, extreme weather and so on' (Urry (2003, p. 2). The recognition that complexity theory gives to connectedness and hybridity, and to breaking down divisions (whether the social and material, structure and agency, or macro/micro) means that it has much in common with actor-network theory (Milligan, 2001; Law & Moll, 2002), although as yet there seems little coming together of actor-network and complexity theorists.

A brief comment is required on the relationship of CT to the better-known chaos theory. Reitsma (2003, p. 14) sees chaos theory as dealing with simple, deterministic, non-linear, dynamic, *closed* systems that are sensitive to initial conditions. Conversely, complexity theory focuses on non-linear, *open* systems. These respond to perturbation by organising into emergent forms which cannot be predicted from knowledge only of the system parts. As Sherden (cited in Thrift, 1999, p. 61) argues: 'Chaos refers to turbulent behaviour in a system where the behaviour is totally *determined* by non-linear laws which amplify the smallest of errors in the initial conditions of the system, making the system unpredictable beyond the shortest of periods. Complexity refers to the phenomenon of order emerging from complex interactions among the components of a system *influenced* by one or more simple guiding principles'.

What methods do we have that allow us to visualise, describe, and analyse relational structure, without decomposing the system into constituent elements? Possibilities here would include the 'rich pictures' of Peter Checkland's soft systems methodology (Checkland, 1981), qualitative mathematical approaches such as Q-analysis (Gould, 1981), or visual-exploratory forms of statistical analysis, such as correspondence analysis (used in Bourdieu's early work and championed by Byrne (1998, pp. 86–87) as a means of exploring the dynamics of the social world; see Gatrell et al., 2004, for an application). In all of these methods, the emphasis is very much to avoid imposing linear statistical models on reality. In the modelling of complex systems, Cilliers (1998) considers that connectionist models of complex systems (such as those based on neural nets) are useful.

New wine in old bottles?

Some characteristics of 'complex' systems (such as relationality, networked connections, non-linearity and feedback) are shared with systems approaches that have been in existence for 50 years or more. The concern with relations is common to all systems-based approaches (including the General Systems Theory with which geographers toyed in the mid-late1960s; Manson, 2001, p. 406). Further, the argument that relations are more important than the objects or system parts is shared with other accounts in social science. For example, Bourdieu (and his predecessor Elias: see Shilling, 1993) sought to stress the 'profound relationality' of which Urry (2003, p. 122) speaks (Bourdieu, 1984).

Further, the current pre-occupation of complexity theorists with network structure resonates with one of the archetypal areas of positivist spatial analysis, namely network analysis (see, for example, Haggett & Chorley, 1969). It is somewhat ironic to think that this might be reappearing (Barabási, 2002; Watts, 1999; Buchanan, 2002) after being largely ignored by geographers for 25 years. This neglect was occasioned by the emphasis of spatial analysts on network description and spatial form, and the lack of any social content. However, the considerable contemporary effort expended on shedding light on the structure of social networks (and particularly the 'small-world' problem) seems little concerned with the realities of social interaction. A Rwandan refugee may be six steps away from the President of the United States, but the probability of them ever interacting directly is vanishingly small. Comments such as '[t] he global village we've grown used to inhabiting is a new reality for humans' (Barabási, 2002, p. 39) ring rather hollow for most of the billions living in the village. Moreover, a very respectable literature on social networks and health has built up (see, for example, Cattell, 2001), without recourse to complexity theory.

Is complexity theory therefore merely 1970s systems theory by another name? To what extent is complexity theory just new wine in the old bottle of a systems-based approach? One can read in Stafford Beer's iconoclastic systems-based book, published over 25 years ago, many of the elements of a complexity account (Beer, 1975). However, while classical systems approaches emphasise problem-solving, prediction and control, complexity theorists undertake exploratory research that emphasises explanation and understanding. Moreover, while relations and networks are critical in complexity theory, as they were in classical approaches, CT foregrounds notions of emergence and hybrids. It is these features that perhaps provide 'added value' and which were missing from classical systems-theoretic accounts. In reviewing health geography accounts that have invoked CT, we need therefore to be alert to the extent to which they draw upon these features as well as more conventional system properties.

Philosophical underpinnings and the value of metaphor

I want here to consider briefly the philosophical underpinnings of CT and the extent to which it draws, productively or otherwise, on metaphor.

Byrne (1998, p. 35) argues that complexity accounts are a part of the modernist programme and that 'Bhaskar's scientific realism provides a philosophical ontology which fits pretty well exactly with the scientific ontology underpinning the complexity programme'. Complex accounts are 'absolutely not reductionist and positivist'. Like Urry, Byrne sees complexity theory as a way of relating macro and micro, agency and structure. In contrast, Cilliers (1998) identifies complexity as a postmodern enterprise. For him, postmodern (perhaps, better, post-structuralist) means a sensitivity to complexity. This is roundly endorsed by Henrickson and McKelvey (2002), who suggest that the ontology of postmodernism parallels that of complexity scientists. 'The lesson from complexity science is that natural scientists have begun finding ways to practice normal science without assuming away the activities of heterogeneous autonomous agents. There is no reason, now, why social scientists cannot combine "new" normal science epistemology with postmodernist ontology. Yet very few have done so' (Henrickson & McKelvey, 2002, p. 7293). Stewart sees complexity theory as 'a child of the enlightenment' (Stewart, 2001, p. 334) although he also notes its use as an argument against positivism and instrumentalism in social science.

Stewart is highly critical of the use of metaphor in complexity theory. 'The concepts and the poetic imagery of complexity theories may indeed throw light on social process; however [whether there is] a universal social attractor must be determined by social debates and research rather than by complexity metatheory' (Stewart, 2001, p. 332). For Stewart, 'the application of metatheoretical organismic models to society and its subsystems seems highly pre-mature; and physicalistic accounts of non-linearity in society that exclude the symbolic systems of classification are dabbling with the edges of social structure and systematic features' (Stewart, 2001, p. 351). We therefore need to consider briefly the value, or otherwise, of the metaphors that are part of the currency of CT.

While imploring us to consider the relevance of the physics of complexity for contemporary social science, Urry argues that physical science models should not be directly transplanted into the social sciences. Rather, he wishes to 'consider whether complexity could generate productive metaphors for the social analysis of various "post-societal" material worlds' (2003, p. 121). Thrift, like Urry, considers CT to be 'deeply metaphorical' (Thrift, 1999, p. 36), but, interestingly, the metaphors 'nearly all strongly depend upon the visual register' (Thrift, 1999, p. 37). Thrift further notes (1999, p. 49) that 'the use of "scientific" metaphors adds a touch of legitimacy' for some knowledge networks (such as New Age practices)—echoing the more trenchant (and controversial) critique of Sokal and Bricmont (1998). These authors consider that 'examples of scientism can be found in the alleged "applications" of the theories of chaos, complexity and self-organisation to sociology, history and business management' (Sokal & Bricmont, 1998, p. 181). They are not against 'extrapolating concepts from one field to another, but only against extrapolations made without argument—or throwing around scientific jargon in front of…non-scientist readers without any regard for its relevance or even its meaning' (Sokal & Bricmont, 1998, pp. ix–x). The importing of concepts must have some conceptual or empirical justification. They observe that 'a metaphor is usually employed to clarify an unfamiliar concept by relating it to a more familiar one, not the reverse' (Sokal & Bricmont, 1998, p. 9). Further, 'The natural sciences are not a mere reservoir of metaphors ready to be used in the human sciences…in a scientific context these words (chaos, non-linearity, for example) have specific meanings' (Sokal & Bricmont, 1998, p. 177). They seek theorising that is supported by empirical evidence if it is to be taken seriously and not simply an opportunity to borrow uncritically from the physical sciences.

While, therefore, metaphors are appealing and, in some cases, essential to the development of social science, we need to be wary of those who seek to dress up what might be rather ordinary accounts with the somewhat casual use of concepts drawn from complexity theory.

Complex geographies of health?

Why might complexity theory appeal to health geographers? There are several reasons. First, CT is transdisciplinary (Albrecht et al., 1998); many of the leading exponents are those with training in the physical sciences but who are now working across the physical and social sciences. Traditionally, health geographers have drawn upon many disciplines (including epidemiology, statistics, sociology, ecology, cultural studies) to inform their work and so any post-disciplinary perspective that applauds this fuzziness of boundaries is something to which we might be expected to warm. Second, according to Urry (2003, p. 111) CT subverts the distinction between agency and structure; if we want to gain some understanding of the emergence of structure, we need to understand the behaviours of the agents that form part of the system. However, while this has obvious appeal across much of the social sciences, not exclusively the geography of health, it is a feature shared with other perspectives (for example, the structurationist accounts of Giddens, or Bourdieu's relational sociology).

Third, the metaphors, and some of the methods, used in complexity theory are essentially visual. Despite the disappearance of the graphical and the carto-graphical from much of the research literature, the 'seeing eye' and the ability to detect and describe pattern remains at the forefront of many research methods, including health geography (see, for example, MacKian, 2000). Fourth, there is an attraction to moving away from reductionist accounts. 'Far too often attempts at the development of a quantitatively founded causal account in sociology have been *relatively trivial models of the determinants of outcome for individuals or other entities within a social system*. What is required is a return to the concern with the nature of the social system as a whole…' (Byrne, 1998, p. 56, my emphasis). I find this characteristic particularly persuasive, since far too much epidemiology is of the 'risk-factor' type in which particular factors are controlled in order to reveal the independent effects of others; context and relationship are often marginalised.

Last, Urry's recent landmark text (2003) is entitled '*Global* Complexity'. If we still claim to be geographers, students of the earth, it seems more than a little odd for many of us (but not all: see Mayer, 2000, for example) to be ignoring the 'big' questions of global inequality, global disease burdens, and the large-scale social and economic processes that create patterns of health at the global scale. Might we not seek to use complexity theory to do less work at very fine spatial scales and more at the global scale?

I consider below some areas of research in which a complexity 'take' has been adopted, and, briefly, areas where it might prove productive.

Health inequalities

Brown and Moon (2002, pp. 362–363) note that the new public health has 'advocated a multi-causal approach that saw infectious and chronic, degenerative disorders as being the result of a *complex interaction* between biophysical, social or psychological factors' (my italics). Complexity is about relationships that cannot be *reduced* to simple linear models or their variants (such as logistic regression). It counters much traditional (geographical and environmental) epidemiology and public health that relates health outcomes to determinants at the individual level. Even the now widely used multilevel modelling (MLM) is cast within the same mould, since it fails to capture connection, relationship and context in an adequate way. While Byrne (1998, p. 68) says that 'the world does consist of things which contain things…the hierarchical character of data is real', and Krieger (1994) also applauds the use of MLM as a device for capturing the often-missed contextual factors, it is doubtful that MLM offers an adequate methodology for capturing the complexity of context. It is not just the individuals or a simple aggregation thereof that matter—the containing social system matters too. Interestingly, Byrne goes on to mention Richard Wilkinson's work, in which death rates (from the aggregation of individuals) are related to inequality ('an emergent property of the relationship between individual incomes and wealth'—Byrne, 1998, p. 70). Unemployment rates, tenure patterns, mortality are examples of system properties with social significance and system effects; to this list we could add residential segregation and social capital.

Krieger (1994) discusses the metaphorical 'web' of causative factors and disease outcomes in epidemiology, 'an elegantly linked network of delicate strands…symbolising diverse causal pathways' (Krieger, 1994, p. 890). But, as she notes, the 'web' was 'spiderless', positing a biomedical model in which the orientation was individualistic rather than population-focused and reflecting a concern less with epidemiological theory and more with epidemiological methods. One alternative to a web-based approach would be a political economy perspective in which the health status of different social groups (women versus men, gays versus straights, black versus white, poor versus rich) are compared in terms of the relations between such groups. Krieger, however, prefers an 'ecosocial' epidemiological theory in which population-level approaches are combined with biological thinking. She would replace the web metaphor with a 'fractal' metaphor in which biological and social factors are linked at every level or scale. Admittedly, 'this is not a developed metaphor' (Krieger, 1994, p. 899); nonetheless, at a very broad scale it is very much in keeping with a complexity agenda in which there are no sharp boundaries between global social relations and the environment (Urry, 2003, p. 46).

Rod and Deborah Wallace have traced the dynamics of socially and physically disintegrating inner-city neighbourhoods in the US, particularly the Bronx district of New York City during the 1970s. They see the links between these processes (or urban desertification) and health-related outcomes (AIDS, TB, violence) in explicitly systems terms, speaking of their coming together in a 'mutually reinforcing nexus' (Wallace & Wallace, 1997, p. 789; see also Wallace et al., 1999). Elsewhere, 'the physical decay of community increases social disorganisation leading to behavioural pathology which triggers yet more physical destruction and so on in a destabilising positive feedback loop' (Wallace & Wallace, 1997, p. 798). There is a tipping point at work here: 'We will suggest that relatively ''small'' perturbations of public policy or socioeconomic structure can be amplified by stressed human ecosystems…so as literally to shatter community structures' (Wallace & Wallace, 1997, p. 791). This is particularly so where the community is stressed already or marginalised.

There is a clear and direct link between the Wallaces' work and that emerging from those exploring social capital in public health contexts. For the Wallaces, local communities and neighbourhoods are a complex system of friendship, kinship and acquaintance networks, together with associational ties (churches, social clubs and so on). Disruption of these networks has health consequences: 'public policies of disinvestment in urban minority communities…will, *through a variety of interacting and self-reinforcing mechanisms*, slowly erode the probability of effective interaction between individuals or extended families within those communities. At some point those policies will reduce that probability below threshold, causing a sudden fragmentation of pre-existing community structures' (Wallace & Wallace, 1997, p. 798, my italics).

Neighbourhood deterioration has severe impacts on all social networks that are health sustaining. Thus, they suggest, deteriorating local environmental context may trigger sudden disruption of social networks, which will fragment communities and enable the emergence of a social context in which disease and unhealthy behaviours emerge. These system shocks, they argue, get transmitted from place to place—from the worst-affected central cities into surrounding suburbs, via commuting fields: 'Ultimate endemic levels of emerging or reemerging infectious disease within the most devastated neighbourhoods of the largest cities…will strongly drive endemic levels in counties and metropolitan regions connected to them by the socioeconomically determined travel patterns which structure the USA at regional and national scales (Wallace & Wallace, 1999, p. 1800). So, at a national scale the prevalence of AIDS in the USA is accounted for by social proximity to (contact with) New York City, as well as a measure of social disintegration (violent crime) and manufacturing employment. Using methods from the study of ecosystem dynamics, the authors show how we might estimate the impact, on the system, of external perturbations such as economic decline, population turnover, or welfare reform. The system resilience is quantifiable. The response is to reconstruct communities and community infrastructure.

In another work (Wallace & Fullilove, 1999), Wallace considers the 'drivers' behind community instability. These include the size of the marginalised community and the level of community resources (aggregate income). The authors warn that: 'batter the vulnerable and generate murder, AIDS, and multiple-drug-resistant tuberculosis, *often in far more than proportion to that battering*, because phase change…is highly non-linear and sensitive to external perturbation' (Wallace & Fullilove, 1999, p. 733, my italics). In his careful overview of the Wallaces' work, Gould (1993, pp. 124–135) draws explicitly on complexity ideas, using a phase diagram that helps scientists to visualise how a complex system changes over time by tracing its trajectory (Gould, 1993, p. 128; see especially his Fig. 10.1).

I consider that the Wallaces' research is among the most persuasive CT-based accounts in health geography, not least because it rises above metaphor to draw upon the literal basis of systems theory, but also it foregrounds issues of emergence that underpin complexity theory. Further, one important conclusion we take from the Wallaces' work is that we neglect spatial diffusion at our peril—this brings it back centre-stage and is considered next.

Spatial diffusion of disease

If we consider disease diffusion at the global scale we can see clearly the impacts that disease outbreaks in one part of the world have, very rapidly, on social life both close by and at some distance. The complexity theorist Buchanan (2002) refers to the sudden break-out of HIV infection from its likely hearth in Lake Victoria. We could also note the Ebola and Lassa fever outbreaks in European countries and, most recently, the SARS (severe acute respiratory syndrome) outbreaks in Hong Kong and mainland China, leading rapidly to infection in parts of Toronto, wholly as a result of air travel. This is dramatic evidence of globalisation, or a borderless world of global relations. It is also a good example of non-linearity and the ability of a small event to trigger disruption on a global scale.

Further, there is, quite literally, non-linearity occasioned by the doubling of airline capacity (doubling the number of seats means a four-fold increase in opportunities for disease spread: Haggett, 2001, p. 646). Perhaps too we can see the change from classical 'contagious' to 'hierarchical' to 'network' diffusion in which disease spread is both rapid and web-like? Buchanan (2002, p. 181) notes that some 'aristocratic' networks (where there are a few highly connected people) do not need a threshold or tipping point. Such networks 'do not possess an epidemic threshold below which diseases cannot produce a major epidemic outbreak or the onset of an endemic state. [These] networks are therefore prone to the spreading and the persistence of infections, whatever virulence the infective agent might possess'. The implication is that the 'connectors' have to be targeted. In other words, change the *structure* of the network and the spread is halted. This was very much the argument in Peter Gould's work on HIV/AIDS (1993). Gould shows very clearly how HIV is 'traffic' on a structure or 'backcloth' formed by relations among human actors; 'to stop the HIV traffic transmission you have to break the connections and so fragment the backcloth' (Gould, 1993, p. 33; see also Barabási, 2002, pp. 123–142; Buchanan, 2002, pp. 170–183).

At a regional and local scale, the existence of a 'tipping point' is crucial in whether a disease becomes an epidemic. For example, Buchanan (2002, p. 163) refers to the epidemic of syphilis in Baltimore in 1995. 'One infection may have been triggering, on average, just less than one other infection, and so the disease was keeping itself in check. But then crack cocaine, a few less doctors, and the dislocation of a localised community out into the larger city pushed the disease over the edge—it tipped, and these little factors made a very big difference'. However, surely we need to understand better the 'upstream' factors—why the doctors were cut, why crack cocaine was being used, why people were removed from their homes, and so on; surely some further social theorising is required? This is provided in the Wallaces' accounts and suggests some potentially fruitful integration between spatial diffusion and health inequalities research trajectories.

Disease ecology and 're-emerging diseases'

Albrecht et al. (1998, p. 73) argue, in their 'pitch' for complexity, that: 'The interaction of host and parasite, the role of vectors, the host's state of health, genetic predisposition, standards of hospital infection control, the way humans produce food and a multitude of social factors will all have some influence on disease outcomes'. They refer to a study of Japanese encephalitis in northern Thailand, which illustrates 'the characteristic in complex systems of interactive causality among people, the mosquito, the virus, domestic animals, and introduced technology' (Albrecht et al., 1998, p. 72). Clearly, in the light of statements such as these we need to develop further the connections between the complexity agenda and the disease ecology tradition that predates it by several decades (Meade & Earickson, 2000: Chapter 2; Levins & Lopez, 1999). Mayer (2000, p. 937) notes that a key principle of disease ecology is that 'population, society and both the physical and biological environments are in dynamic equilibrium'. But a key feature of CT is that systems may be far from equilibrium (Table 1), in which case we need, as Mayer argues, a good understanding of the impact that land-use change, climate change, population turnover, and so on have on population health. In particular, the emergence and resurgence of particular diseases needs to be set in the wider context of changes that are economic, political and social, as well as environmental. A good example would be Lyme disease, where '[t]he chain of events that have led to the emergence and recognition of Lyme disease in New England is complex' (Mayer, 2000, p. 942). It is, Mayer argues, 'reductionist' to suggest that the 'cause' of Lyme disease is to be found simply in a good understanding of the pathogen involved. But to take other examples (such as TB and HIV/AIDS) we need to develop a better understanding of the links between population health and the processes of globalisation. Among these processes Mayer gives prominence to those of population movement.

Similar views are expressed by the Harvard Working Group on New and Resurgent Diseases (1996, p. 170): 'if one lesson has emerged from the spectacular failure of Western medicine to eradicate certain diseases, it is that diseases cannot be reduced to a single cause or explained within a prevailing linear scientific method: complexity is their hallmark'. I think we need to carve out research agendas that fuse globalisation debates, disease ecology and complexity theory, informed by imaginative empirical work.

Complexity and risk

A good case can be made for taking a complexity approach to global system shocks (technological risk). Nuclear and other localised technological accidents can have global consequences (Chernobyl or Three Mile Island are obvious examples). In other cases, the health impacts of other disasters are contained or more localised, though nonetheless potentially devastating at that scale. For example, radioactive contamination from Sellafield is thought by some to have given rise to localised leukaemia clusters (though this remains a contentious theory), while the Bhopal disaster in India had a local and regional impact on thousands of people, mostly the poor living in the vicinity of the plant (Gatrell, 2002, Chapter 7). Health risks are not necessarily global but may be locally, regionally or perhaps nationally contained; distance is not yet dead.

The 2001 foot-and-mouth disease outbreak in the UK was a monumental upheaval to the British agricultural and countryside system. It resulted from one tiny 'blip' in the constant movement of cattle to abattoirs, a blip that nonetheless carried the infection from one farm to a market from whence the disease spread rapidly. Again, it is the movement (flow) that matters, a set of relations that involves hybrids of human and non-human actors. Loss of income to farmers and those institutions and businesses sustaining the farming community, together with the tourist sector, were all unintended consequences, forcing, in effect, the virtual closure of the countryside (Convery et al., 2005) for about 12 months. 'This has in part led to a loss of self-esteem, an increasing sense of isolation amongst livestock farmers and called into question a "whole way of life" and social identity' (Convery et al., 2005). In Cumbria, 40 per cent of farms were subject to animal culls (rising to 70 per cent in the north of the county), with over 1 million sheep, 215,000 cattle, and 39,000 pigs slaughtered. The scale of slaughter impacted on local sense of identity and 'on their everyday living and working relations with the landscape, livestock and with others in their community…there was a clear breach of *normal* relations' (Convery et al., 2005, original italics). 'Death was in the wrong place (the farm rather than the abattoir), but it was also at the wrong time (in relation to the farm calendar) and on the wrong scale (such large-scale slaughter seldom occurs at the same time)' (Convery et al., 2005).

So, a small perturbation can have dramatic consequences (in this case for the mental health and psychological well-being of many rural dwellers), just as 'countless unorchestrated historical events have left their traces all over our social and ecological networks, the World Wide Web, and so on' (Buchanan, 2002, p. 97).

Ordinary lives in ordinary places

Graham Rowles (2000) is interested, and has been for over 25 years, in the lives of older people and how these are played out in places, particularly in rural Appalachia (such as the anonymised rural community of Colton). He seeks to understand both their daily, taken-for-granted, habitual lives and how 'they accommodate to turning points and transitional events in their lives' (Rowles, 2000, p. 53S), appealing to complexity theory in the search for this understanding. He looks at the daily routines of older people within their communities as 'part of a whole, a social ecology that functioned as a delicately balanced homeostatic system' (Rowles, 2000, p. 55S). Interestingly, he cites Roger Barker's ecological psychology here and, as an aside, this approach to psychology and place is something that geographers in general, and health geographers in particular, seem to have missed (Barker, 1968). But Rowles seems keen to move from interesting biographical accounts to 'consider each resident of Colton as immersed in a complex system of inextricably interrelated actions, relationships, and environmental meanings that are in a state of homeostatis. This homeostasis has its own dynamic, with consequences reverberating throughout the system when any element changes' (Rowles, 2000, p. 59S). Thus, the ecology is disrupted when people die or become ill (and the network of relationships thereby changes). Their lives are 'immersed in messy, complicated, interconnected systems that are not linear, static, or absolutely predictable' (Rowles, 2000, p. 61S). Aside from wondering what 'linear' means in this context this remark seems rather uncontroversial, since all of us live lives that have the same characteristics. I am not convinced that our understanding of the mental well-being of older Appalachian folk is significantly enhanced by Rowles' appeal to complexity theory. I would argue that we gain as much—maybe more—from the time-space geographies that Hägerstrand (1970) proposed, long before complexity theory emerged, and which Rowles himself cites. Alternatively, very sophisticated and engaging accounts of lives lived in particular places (for example, Davidson, 2003) have been developed without a wholly metaphorical use of complexity theory.

Missing themes and added value: concluding remarks

There must, in principle, be scope for other complexity accounts in the geography of health. Urry (2003, p. 44) asks us to examine 'the complex sets of social relations *between* the national and the global. They constitute each other'. Thus we need to examine how health profiles and health policies within the nation state impact on global patterns of ill-health, and how processes operating at the global scale (such as climate change, global spread of infectious disease, or investment decisions by global companies and international organisations) impact nationally. For example, global health-care organisations (large pharmaceutical companies) and global institutions such as the World Bank have major impacts on health-care delivery in particular countries. 'Through their interdependence, these institutions of governance and civil society are organising the rules, structures and regulations of the newly emergent global order' (Urry, 2003, p. 81). But, set against this, and notwithstanding the cross-border flows to seek faster and perhaps better health care abroad, we still have in most of the developed world largely autonomous *national* health-care policies and structures.

I think we can claim at least three missing 'elements' in CT accounts. First, the human voice seems to be missing from much of the complexity theory. The qualitative is there, but in the *form* of qualitative structures and patterns, not in the nature of the embodied actor. An exception might be Rowles' work, though I have argued above that a complexity perspective offers relatively little in our understanding of lived worlds in small rural communities. Is the behaviour of a small number of older people in an isolated setting so very complex? Stewart (2001) considers that '[T]he bulk of writing on social complexity is decidedly limited in its relation to social relevant philosophical traditions such as phenomenology, hermeneutics, psychoanalysis, and modernist retrieval of lived experience in a devastated world' (Stewart, 2001, p. 334). He bemoans the neglect of real lives and actors (real people in contested history—Stewart, 2001, p. 354). Some complexity theorists appear to agree. As Barabási has it: 'The goal before us is to understand complexity. To achieve that, we must move beyond structure and topology and start focusing on the dynamics that take place along the links. Networks are only the skeleton of complexity, the highways for the various processes that make our world hum. To describe society we must dress the links of the social network with actual dynamical interactions between people' (Barabási, 2002, p. 225).

Second, *gender* too seems to be a missing strand from existing uses of CT. Complexity theory appears to be a singularly male enterprise, with women invisible as authors within this particular 'invisible college'. I cannot explain why this might be so, and am reminded of an interesting passage in John Fowles' 'complex' novel, *The Magus* (revised edition, Granada Publishing, London, 1977):

> Men see objects, women see the relationships between objects. Whether the objects need each other, love each other, match each other. It is an extra dimension of feeling we men are without and one that makes war abhorrent to all real women—and absurd. I will tell you what war is. War is a psychosis caused by an inability to see relationships.

Thrift (1999) notes that complexity theory is 'heterarchical' rather than hierarchical and for this reason it might be thought to appeal to feminist audiences. It is puzzling that few writers in this field are women and that, as yet, complexity theorists have not engaged with gender debates.

Third, I would argue too that, despite assertions of interconnectedness, globalisation, and the linking of 'everything to everything else' (Barabási, 2002, p. 7), we have not yet presided over *the death of distance*. Territory and a sense of identity with particular places still matters. Spatial segregation has health impacts, our social connections and support at local level still matters, and the connections and relations stressed by complexity theorists are still very firmly local, at least for some. Those living in affluent countries might be exposed to viruses circulating in Africa or elsewhere (Haiti, for example, Farmer, 1992, 1999) and such viruses may well have impacts that become global in their reach. But the impact, in terms of disease burden, is surely many times more acute in the poorest regions of the world.

We should welcome any considered attempt to introduce new theoretical perspectives into health geography, a field that has been traditionally under-theorised (Litva & Eyles, 1995). However, the success of complexity theory in the health sciences in general, and health geography in particular, is not yet assured. 'For example, in biology a reductionist molecular approach (typified by the human genome project) still holds away' (Thrift, 1999, p. 39). The same point might be made of randomised controlled trials in medical and health research and in many of the geographies of health that we write that rely on (largely regression-based) methods that are reductionist in nature.

If health geographers are to engage seriously with CT, we need to move beyond purely metaphorical uses and to conduct empirical work that genuinely uses its concepts in a rigorous way. One cannot help avoiding the conclusion that it is easier to talk about complex interacting systems, emergence and non-linearity than to knuckle down and do useful empirical research on such systems. Haggett's comment that 'one can do little with the unique except contemplate its uniqueness' (Haggett, 1965, p. 3) is equally true of some invocations of complexity. There is a clear need to move beyond the casual use of metaphor and to explore further the added value of CT for our research in disease ecology, health inequalities and spatial diffusion, all traditional—and still critically important—areas in health geography.

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References

Albrecht, G., Freeman, S., & Higginbotham, N. (1998). Complexity and human health: the case for a transdisciplinary paradigm. *Culture, Medicine and Psychiatry*, *22*, 55–92.

Barabási, A-L. (2002). *Linked: the new science of networks*. Cambridge, MA: Perseus Publishing.

Barker, R. G. (1968). *Ecological psychology*. Stanford, CA: Stanford University Press.

Beer, S. (1975). *Platform for change*. London: Wiley.

Bourdieu, P. (1984). *Distinction: a social critique of the judgement of taste*. London: Routledge.

Brown, T., & Moon, G. (2002). Placing geographies of public health. *Area*, *34*, 361–369.

Buchanan, M. (2002). *Nexus: small worlds and the groundbreaking science of networks*. London: W.W. Norton & Co.

Byrne, D. (1998). *Complexity theory and the social sciences*. London: Routledge.

Capra, F. (1997). *The web of life: a new synthesis of mind and matter*. London: Flamingo Books.

Cattell, V. (2001). Poor people, poor places, and poor health: the mediating role of social networks and social capital. *Social Science & Medicine*, *52*, 1501–1516.

Checkland, P. (1981). *Systems thinking, systems practice*. Chichester: Wiley.

Cilliers, P. (1998). *Complexity and postmodernism: understanding complex systems*. London: Routledge.

Convery, I., Bailey, C., Mort, M., & Baxter, J. (2005). Death in the wrong place? Emotional geographies of the UK 2001 foot and mouth disease epidemic. *Journal of Rural Studies*, in press.

Davidson, J. (2003). *Phobic geographies: the phenomenology and spatiality of identity*. Aldershot: Ashgate.

Farmer, P. (1992). *AIDS and accusation: Haiti and the geography of blame*. Berkeley: University of California Press.

Farmer, P. (1999). *Infections and inequalities: the modern plagues*. Berkeley: University of California Press.

Gatrell, A. C. (2002). *Geographies of health: an introduction*. Oxford: Blackwells.

Gatrell, A. C., Popay, J., & Thomas, C. (2004). Mapping health inequalities in geographical and social space can Bourdieu help us? *Health & Place*, *10*, 245–257.

Gould, P. R. (1981). A structural language of relations. In R. Craig, & M. Labovitz (Eds.), *Future trends in geomathematics* (pp. 281–312). London: Pion.

Gould, P. R. (1993). *The slow plague*. Oxford: Blackwell.

Hägerstrand, T. (1970). What about people in regional science? *Papers and Proceedings of the Regional Science Association*, *24*, 7–21.

Haggett, P. (1965). *Locational analysis in human geography*. London: Edward Arnold.

Haggett, P. (2001). *Geography: a global synthesis*. London: Pearson.

Haggett, P., & Chorley, R. (1969). *Network analysis in geography*. London: Edward Arnold.

Harvard Working Group on New and Resurgent Diseases. (1996). Globalization, development, and the spread of disease. In J. Mander, & E. Goldsmith (Eds.), *The case against the global economy* (pp. 160–170). San Francisco: Sierra Club Books.

Henrickson, L., & McKelvey, B. (2002). Foundations of "new" social science: institutional legitimacy from philosophy, complexity science, postmodernism, and agent-based modeling. *Proceedings of the National Academy of Sciences, USA*, *99*(Suppl. 3), 7288–7295.

Holland, J. H. (1998). *Emergence: from chaos to order*. Oxford: Oxford University Press.

Krieger, N. (1994). Epidemiology and the web of causation: has anyone seen the spider? *Social Science & Medicine*, *39*, 887–903.

Law, J., & Moll, A. -M. (Eds.). (2002). *Complexities*. Durham, NC: Duke University Press.

Levins, R., & Lopez, C. (1999). Toward and ecosocial view of health. *International Journal of Health Services*, *29*, 261–293.

Litva, A., & Eyles, J. (1995). Coming out: exposing social theory in medical geography. *Health and Place*, *1*, 5–14.

MacKian, S. (2000). Contours of coping: mapping the subject world of long-term illness. *Health and Place*, *6*, 95–104.

Manson, S. M. (2001). Simplifying complexity: a review of complexity theory. *Geoforum*, *32*, 405–414.

Mayer, J. (2000). Geography, ecology and emerging infectious diseases. *Social Science & Medicine*, *50*, 937–952.

Meade, M. S., & Earickson, R. J. (2000). *Medical geography*. London: The Guilford Press.

Milligan, C. (2001). *Geographies of care: space, place and the voluntary sector*. Aldershot: Ashgate Publishing.

Reitsma, F. (2003). A response to simplifying complexity. *Geoforum*, *34*, 13–16.

Rowles, G. (2000). Habituation and being in place. *Occupational Therapy Journal of Research, Supplement*, *20*, 52S–67S.

Shilling, C. (1993). *The body and social theory*. London: Sage.

Sokal, A., & Bricmont, J. (1998). *Intellectual impostures: postmodern philosophers' abuse of science*. London: Profile Books.

Stewart, P. (2001). Complexity theories, social theory, and the question of social complexity. *Philosophy of the Social Sciences*, *31*, 323–360.

Thrift, N. (1999). The place of complexity. *Theory, Culture & Society*, *16*, 31–69.

Urry, J. (2003). *Global complexity*. Cambridge: Polity Press.

Wallace, R., & Fullilove, R. (1999). Why simple regression models work so well describing 'risk behaviors' in the USA. *Environment and Planning A*, *31*, 719–734.

Wallace, R., & Wallace, D. (1997). Resilience and persistence of the synergism of plagues: stochastic resonance and the ecology of disease, disorder and disinvestment in US urban neighborhoods. *Environment and Planning A*, *29*, 789–804.

Wallace, R., & Wallace, D. (1999). Emerging infections and nested martingales: the entrainment of affluent populations into the disease ecology of marginalization. *Environment and Planning A*, *31*, 1787–1803.

Wallace, R., Wallace, D., Ullmann, J. E., & Andrews, H. (1999). Deindustrialization, inner-city decay, and the hierarchical diffusion of AIDS in the USA: how neoliberal and cold war policies magnified the ecological niche for emerging infections and created a national security crisis. *Environment and Planning A*, *31*, 113–139.

Watts, D. J. (1999). *Small worlds*. Princeton, NJ: Princeton University Press.