THIS PAPER IS TO BE PUBLISHED IN THE ENCYCLOPAEDIA OF HUMAN GEOGRAPHY

Not to be cited without the author's consent

Spatial science (Ms. Number 746)

Prof Ron Johnston[1]
School of Geographical Sciences
University of Bristol
Bristol BS8 1SS
e-mail: R.Johnston@bristol.ac.uk

Keywords: spatial science; locational analysis; quantitative methods; location theory

Synopsis: Spatial science is an approach to human geography formulated in the 1950s-1970s as a response to perceived inadequacies in the then prevailing regional paradigm. It emphasises the study of aggregate spatial patterns, including spatial behaviour, within clear theoretical frameworks, using quantitative methods to evaluate models and hypotheses. The theoretical approaches and quantitative methodologies deployed have evolved considerably over the last four decades, sustaining a vibrant component of human geography's portfolio of practices and production of applicable knowledge.

Spatial science is an approach to human geography which came to prominence in much of the Anglophone world and a number of other countries – notably Sweden and the Netherlands – in the 1960s and 1970s, through what became known as the discipline's 'quantitative and theoretical revolution' (Burton, 1963); it has remained a significant component of the disciplinary portfolio ever since. It deals with aggregate patterns in space and their generating processes, and is characterised by two major features: the description, explanation and (in some cases) prediction – even control – of general patterns of spatial behaviour and their reflection in the landscape; and the application of rigorous mathematical and statistical procedures in that task. The approaches taken within this broad framework have changed considerably over the last half-century, however, as have the methods applied.

This approach within geography is closely associated with parallel work in other social and natural science disciplines. In geology, for example, spatial science is a major component of the enterprise, and some developments within human geography have been stimulated by geologists' work. There is also considerable inter-disciplinary interaction with workers in other disciplines, such as economics, sociology, political science and archaeology, where the spatial approach – as in human geography – is one component of a broader disciplinary framework. And there are applied disciplines – notably city and regional planning – which build on those foundations.

[1] My thanks to Charles Pattie and to my colleagues in the spatial modelling group at the University of Bristol – Becky Aitchison, David Hayes, Rich Harris, Les Hepple, Tony Hoare, Min-Hua Jen, Kelvyn Jones, Joanna Papageorgio and Paul Plummer – for many valuable comments on drafts of this essay.

Origins

With most substantial changes in a discipline's portfolio, harbingers of those changes which nevertheless had little or no impact on its practices can be found in its research literature; they are contributions to knowledge which were not taken up by others and so very largely disregarded. This was certainly the case with spatial science. Innovative pieces of work can be identified from the 1930s, and even earlier, which either went almost entirely unnoticed or attracted no followers among the small number of professional geographers, who chose to avoid such challenges to their established ways of working. Major change in disciplinary orientation usually only occurs when a number of individuals develop an alternative agenda to that currently dominant and promote their ways of working through a variety of aggressive political strategies (Johnston, 2006). They mobilise support for their ideas and seek to change disciplinary practices – not only how research is undertaken and to what ends but also how the discipline is taught to undergraduates and presented in graduate training programmes.

Such academic social movements emerged in both the USA and the UK in the late 1950s and early 1960s, taking the discipline by storm and rapidly ensuring a major shift in its foundations. In the USA, the origins of this shift have been traced by Barnes and Farish (2006: see also Barnes, 2006) to the experience of a large number of human geographers seconded to the Office of Strategic Services (OSS) during the Second World War to provide information that would underpin military campaigns and their aftermath. Unlike the parallel situation in the UK where geographers worked separately (Clout and Gosmé, 2003), geographers in the OSS were required to work in multi-disciplinary teams, in which some became aware of deficiencies in their disciplinary practices that constrained their ability to contribute to various forms of policy development. They were convinced that their discipline had to change if it was to remain viable within academia, contributing applicable knowledge – in effect, it had to become more like economics in adopting the approaches considered typical of the natural sciences such as physics. Some – such as Ackerman (1945, 1958) and Schaefer (1953) – preached this need for change: others began to implement it.

One influential change-agent was Edward Ullman, who produced two pioneering essays on theoretical approaches to urban geography – one, much cited, was co-authored with Chauncy Harris (Harris and Ullman, 1945; Ullman, 1941; see also Harris, 1990, 1997). Ullman returned to Harvard after the war but following the closure of the geography department there moved to the University of Washington at Seattle. In the mid-1950s, a number of graduate students were attracted to work with him on the new theoretically-based approach he was promoting, focused on the role of transportation as a major influence on human spatial behaviour and the resultant spatial patterns of areal differentiation (Ullman, 1956). Ullman was away for some time, however, and they gravitated to work with another professor – William Garrison – who was committed not only to that approach but also to the application of quantitative methods. Together, through a variety of strategies and practices, that remarkably talented and influential group (including Brian Berry, Ron Boyce, William Bunge, Michael Dacey, Art Getis, Duane Marble, Richard Morrill, John Nystuen, Forrest Pitts and Waldo Tobler) stimulated others in the discipline to adopt the 'new geography'. Their subsequent appointments to teaching positions in leading geography departments, from which in turn their students moved to other centres, facilitated a rapid spread of the new ways.

In the UK, a parallel introduction of similar approaches focused on the University of Cambridge in the late 1950s-early 1960s, stimulated by two recently appointed lecturers, Richard Chorley (with an undergraduate degree in geography from Oxford and then trained as a geologist in the USA by one of the pioneers of a new, quantitative, approach to geomorphology – Arthur Strahler) and Peter Haggett, who first encountered the sort of material that later became central to the 'new geography' when teaching economic geography at University College London in the mid-1950s. (Haggett succeeded Brian Law as a lecturer there: Law introduced location theory to undergraduates – including Brian Berry. Similar material – notably the work of Hoover on industrial location – was also taught at the London School of Economics in the 1940s-1950s, but had little wider impact.) Chorley and Haggett introduced the teaching of quantitative methods at Cambridge in 1960 and Haggett later taught a course that became his pioneering text on *Locational analysis in human geography* (Haggett, 1965). Their students – like the Washington graduates a few years earlier – rapidly spread the 'revolution' to other centres, as did those from Bristol after Haggett moved there in 1966.

Chorley and Haggett also fostered the new approach in the UK's secondary schools through five mid-1960s summer schools that were the progenitors of two seminal edited collections (Chorley and Haggett, 1965, 1967). Changing approaches to the nature of geography in British schools – thus influencing the backgrounds of those who studied the subject as undergraduates – were also strongly influenced from another source. Stanley Gregory, a London-trained climatologist, initiated the teaching of statistical methods at the University of Liverpool in the 1950s, published the first textbook on the subject (Gregory, 1963), and inspired a further stream of graduate students who moved into university careers. He was also influential in changing the syllabuses for the public examinations taken at age 18 ('A'-level) that determined potential for university entrance, which included work through the Geographical Association (Balchin, 1993). Meanwhile, John Cole, at the University of Nottingham, pioneered in the development of teaching materials for students at primary (age 5-11) schools.

From these origins, interest in quantitative and theoretical work rapidly spread, not only through those two countries but also a number of others, mostly English-speaking, such as Australia and New Zealand. By the early 1970s a number of pioneering textbooks had been produced conveying the approach – mainly to undergraduates in the UK but postgraduates in the US, reflecting the different positions of geography in the two countries' educational systems. Notable and highly influential among these were Haggett's (1965), plus Abler, Adams and Gould's (1970) *Spatial organization: the geographer's view of the world*, and Morrill's (1970) *The spatial organization of society*: Harvey's (1969) *Explanation in geography* provided a detailed philosophical and methodological foundation for the practices the pioneers espoused. Spatial science soon occupied a major role within the discipline, with compulsory courses in quantitative methods normal in degree schemes and material on location theory central in – if not dominating – many substantive courses. This provided the foundation for continued substantive and technical developments over the next four decades, and also the basis for major critiques and subsequent campaigns to change the nature of geographical practices in different directions: the 'revolution' – if 'revolution' it was – was hardly over before counter-revolutions were launched.

Location theory, hypothesis-testing, and quantitative analysis

Many of the stimuli for this fresh approach to human geography came from outwith the discipline; geographers found both substantive and methodological inspiration in a range of disciplinary literatures, notably economics in the first instance. There was no coherent body of work within those disciplines that focused on the approaches taken up by geographers, but the contributions of a number of workers – mostly considered to be on the fringe of their discipline by economists – provided the initial stimuli that geographers followed up. Many – such as Hoover, Hotelling, Lösch, Palander, Alfred Weber and also von Thünen, whose work was published in the early nineteenth century – concentrated on the location of economic activities, especially manufacturing industries. They sought to account for observed distributions not by identifying the rationales for particular decisions through empirical case studies but rather by uncovering general principles underpinning all locational decisions through theoretical development followed by hypothesis testing: model became a key word in their vocabulary.

This impetus for a 'new' approach to human geography occurred in parallel with the inauguration of regional science, led by an economist – Walter Isard (2003) – wanting to introduce spatial perspectives to mainstream economics. Isard enrolled a number of geographers in his long-running, extensive campaign to gain disciplinary status for regional science; many became (and some geographers remain) active in the Regional Science Association, which has branches throughout the world. But an autonomous separate discipline represented in major universities never eventuated, and although the Association remains a vibrant inter-disciplinary organisation – running conferences and publishing journals – it has never threatened geography's separate existence, as some originally feared.

For the pioneering geographers, the key principle in the theories and models they were attracted to related to transport costs – reflecting an assumed importance of distance (or space) in decision-making. Of the various costs involved in manufacturing products, it was the one that could be promoted as clearly geographical – a case made by Ullman (1956) and adopted by his followers. Manufacturing industries, for example, have to bring raw materials and component parts for a product together – which involves costs (both time and money) – and then distribute them to their markets, involving further costs. The more that these costs can be held down, the more efficient the production and distribution of the product and hence the lower the price to the consumer – assuming all other costs are held constant. Thus the core geographical problem was presented as identifying the least-cost location, at which transport costs were minimised. Knowledge of an industry's cost-structures, including those of transporting its various inputs as well as its outputs, could thus be deployed to suggest where factories should optimally be located, given information on where the raw materials and other inputs could be obtained and the geography of demand for its products.

This 'ideal' was a model of the 'real world', a presentation of what the distribution of an industry should be in a country or region if those involved in location decisions were making the most economically-rational choices. Elements of that model could then be tested empirically: hypotheses – speculations about what the world should look like – could be generated whose validity could be assessed by, in effect, comparing a hypothetical map of an industrial distribution against the 'real thing'. Most geographers, following Harvey (1969), chose to test their hypotheses using the verification approach, favoured by positivists – is my hypothesis right? – rather than the falsificationist approach favour by Popper – is my hypothesis wrong?

The importance of transport costs was not constrained to studies of industrial location, particularly when broadened to the more general impacts of distance – closely linked to transport costs. As geographers discovered through searching cognate discipline literatures, others were studying the impact of distance on a wide range of behaviours. With migration, for example, it was argued that it is easier to get information regarding a potential destination for a move about a nearby place than about one further away: there is a friction of distance to information flows. As a result, people are more likely to search nearby than distant places when planning to move. They are also more likely to select a nearby destination, because longer-distance moves are more costly. The result is a postulated distance-decay effect – what one sociologist, Zipf, called a 'law of least effort' – in a wide range of spatial behaviours, not only permanent migrations but also, for example, journeys to work, to shop, to a doctor's surgery, to university, to church and so on: the greater the distance between two places, the lesser the interaction between them.

The hypothesised existence of distance-decay effects could be tested by analyses of movement patterns, many of which were set in the context of the so-called gravity model, using an analogy from Newtonian physics (on which Olsson, 1965, provided an early introduction). According to the basic formula:

$$I_{ij} = a(M_iM_j)/d_{ij}^2 \qquad [1]$$

where
M_i is the mass at point i;
M_j is the mass at point j;
d_{ij} is the distance between points i and j;
a is the coefficient of proportionality; and
I_{ij} is the amount of interaction between points i and j.

In modelling migration flows between places i and j (I_{ij}), the two terms in brackets M_i and M_j might refer to the populations of towns i and j respectively: the more people in i the more who would move to j (and vice versa); the more people in j, the more attractive it would be for people in i. And the shorter the distance between i and j (which is squared in Newtonian physics), the more people who would move between them – ceteris paribus.

Alongside industrial location and migration, a third area of work dominating much early spatial science was central place theory, addressing issues relating to settlement patterns. A number of nineteenth and early twentieth century scholars had explored regularities in the distribution of central places – where consumers purchase goods and services from shops and offices – but a German geographer (with a strong background in economics), Walther Christaller, first formalised this, although his 1993 publication was not taken up by English-speaking geographers until the 1950s (Christaller, 1966). Christaller's work was also based on the 'law of least effort', assuming that people visit the nearest centre offering their needed goods and services. Arguing that some baskets of goods and services are needed daily, some weekly, and others less frequently, Christaller hypothesised that service centres would be organised in hexagonal patterns across the landscape (assuming no major topographical barriers), with denser patterns of small centres providing the most frequently-demanded services, nested within less dense patterns of larger, less frequently visited, centres etc. This theory – and a more complex variant developed by Lösch, which doesn't assume baskets of goods/services all bought with the same frequency – was the basis for much data collection and hypothesis-testing, seeking regular patterns with hexagonal foundations.

Finally among the most influential sets of ideas – though taken up a little later than some of the others – was work on spatial diffusion developed by a Swedish geographer, Torsten Hägerstrand (1968). This, too, was founded on the 'law of least effort' – reformulated by Tobler (1970) as 'the first law of geography: everything is related to everything else, but near things are more related than distant things'. If flows of information are spatially structured, ideas should diffuse outwards from innovation centres in wave-like formations, thus producing ordered geographies of change. Hägerstrand's initial work on migration was later extended by him and – after his 1959 visit to Seattle (Morrill, 2005) – others to a wide range of phenomena which have spread over landscapes, such as diseases. He also pioneered use of Monte Carlo methods to simulate patterns of spread and diffusion, and was one of the first human geographers to promote use of computers.

Most of these approaches were summarised by Garrison (1959) into six basic spatial problems:

1. *The transportation problem* – what is the most cost-efficient flow of goods through a network of supply and demand points?;
2. *The spatial price-equilibrium problem* – what prices for goods and services will result from such flow patterns?;
3. *The warehouse-location problem* – what is the best set of locations for a series of supply points, to serve a given geography of demand?;
4. *The industrial location problem* – what is the optimum location for an industry given the geography of supply for its inputs and that of demand for its outputs?;
5. *The interdependencies problem* – what is the best pattern of linked plants so as to maximise profits jointly?; and
6. *The boundary-drawing problem* – what is the most efficient set of boundaries for the hinterlands of places (such as schools), which minimises transport costs?

Others synthesised the spatial science approach in different ways. Haggett (1965; Haggett, Cliff and Frey, 1977), for example, used a diagram to identify the six major components of spatial systems (Figure 1), comprising: movements; the channels along which they flowed; nodes on those networks of channels; hierarchies of nodes according to their size and importance; surfaces, representing inter-nodal patterns; and diffusions – which could flow down the hierarchies, along the channels and across the surfaces. Later work included classification and regionalisation – dividing the surfaces up into relatively homogeneous areas on selected criteria.

These idealisations of spatial structures and processes stimulated a large number of empirical studies seeking ordered patterns in the landscape – point patterns of settlements and hierarchies, for example; line patterns of transportation routes; smooth (trend) surfaces of inter-nodal land use patterns and land values; diseases diffusing down through urban hierarchies and across the surfaces – as well as ordered patterns of behaviour, such as distance-decay patterns in various forms of interaction. The emphasis was very much on pattern. As Bunge (1966), Harvey (1969) and others argued, geometry was the language of this 'new geography'. To test the geometric hypotheses, the literature of statistical applications in a range of disciplines was explored for relevant procedures – such as nearest neighbour analysis for point patterns, graph theory for line patterns, the gravity model for migration flows, and trend surface analysis. Alongside theoretical exploration there was a great deal of methodological experiment in spatial science's early years.

One set of procedures came to dominate, however – the general linear model, developed in statistics for testing hypotheses regarding associations and (putatively causal) relationships, and widely applied in other social sciences. Within this still evolving family particular attention was given to regression and associated measures of correlation. Regression relates two or more variables – one of which is the hypothesised effect and the others the postulated cause(s) – to inquire how well, if at all, the causes (the independent variables) predict the effect (the dependent variable). The gravity model (equation [1]) for example, could be expressed in a regression framework as:

$$\log I_{ij} = a + b_1 (\log M_i) + b_2 (\log M_j) - b_3 (\log d_{ij}) +/- e \qquad [2]$$

In this, the regression coefficients b_1, b_2, and b_3 indicate the relative importance of the size of M_i, the size of M_j and the distance between places i and j respectively as influences on the amount of migration between those two places; the constant term a is equivalent to the coefficient of proportionality in Newton's formulation [1], and e is the (normally-distributed) error term. The positive signs for b_1 and b_2 indicate expectations that the volume of migration increases the larger each of the places, whereas the negative sign for b_3 indicates an expectation that the amount of migration between two places – holding constant their size – will decline, the greater the distance between them. (In Newton's model b_3 is equal to 2, but in social science applications no theoretical justification could be found for that; empirical models had to be calibrated to the data sets deployed to obtain domain-specific estimates.) The associated correlation coefficient – r, or R in multiple regression with more than one independent variable – varies between 0 and 1.0: the associated coefficient of determination – r^2 or R^2 – indicates the proportion of the variation in the dependent variable that can be accounted for statistically by the independent variables.

When fitted to data, statistical models such as these provide technical answers to the question 'to what extent are variations in the dependent variable (in this case, migration) accounted for statistically by variations in one or more of the independent variables?'. (When applied geographically, they, in effect, ask questions about the correlations among two or more maps: how similar is the mapped distribution of *x* to those of *y* and *z*?) Such statements of association are frequently given a causal interpretation, within the context of the theory that stimulated the test: the volume of migration was generated/caused by the size of the places involved and the distances between them. Statistical relationships are thus taken as means of verifying theoretical expectations – or testing hypotheses. If the expected patterns are observed, then the postulated causative mechanisms can be assumed to operate: they are provisional statements of the processes governing spatial patterns, open – as always – to critical scrutiny and modification (perhaps even falsification) by further research.

Regression modelling – and associated techniques such as factor analysis – remain at the heart of much spatial science. But over the half-century since they were introduced to human geography applications have become much more sophisticated, allowing a wider range of hypotheses to be tested and data sets of different types to be explored. Log-linear modelling, logit analysis, multi-level modelling and a range of other procedures are now widely applied: all are based on the general linear model and allow similar interpretations. The testing is undertaken in one of two ways:

1. *Deductively*, formal hypotheses regarding the size, strength and direction of relationships among variables are stated and those expectations compared against empirical data; and
2. *Inductively*, patterns are identified in data sets which suggest ordered behaviour.

Both approaches use measures of statistical significance to assess the importance of their findings. How likely is it that the pattern uncovered in my data set is a chance occurrence? Or, could it have occurred so rarely if chance were the only operating factor that I am justified in claiming there is a pattern with substantial meaning? The answers to such questions are only valid if the data meet (or at least substantially approximate) the major assumptions of the general linear model – the regression residuals should be independently distributed, for example.

Whereas a fundamental goal of the 'revolution' that brought spatial science to the foreground of human geography was to demonstrate that its approach provided not only better descriptions of the world but also reasonable explanatory accounts for what was described, this was not necessarily an end in itself. For many involved – including the Seattle group – the representations they produced were also to be deployed in changing the world. As Yeates (2001) noted when reviewing research stimulated by Brian Berry during his immediate post-Seattle years at the University of Chicago, it was characterised by a strong utilitarian purpose with much of it undertaken for external sponsors, both public and private sector. Similarly, all of the modelling of urban and regional systems undertaken by Alan Wilson and his co-workers at Leeds was aimed at more efficiently planned and operating cities and regions (Wilson et al, 1977): a company he established – GMap – uses those models as the foundations for consultancy work seeking optimal locations for a range of commercial activities.

Wilson is one of the few examples of a geographer who took an alternative approach from most of the early spatial scientists. Formally trained as a mathematician, he did not test hypotheses statistically. Instead, he sought to model entire systems. Most researchers took the gravity model as the source for hypotheses about flow patterns, for example. Wilson (1970) restructured it as a way of representing an entire system, concerned, for example, not just with the decisions underpinning travel behaviour – as with commuting in a city – but also those regarding where homes and jobs are/might be located. His models, based on the thermodynamic concept of entropy, represent the system as a whole, and data were collected to illustrate that, rather than extract one element of the system for testing against empirical data. And then, by changing certain system elements, such as new home and job locations, he can estimate their impacts on other components – such as traffic flows.

The concept of a system attracted considerable attention among spatial scientists, largely as a rhetorical device rather than as a format for undertaking detailed research. Only Wilson and a relatively small number of others (such as Batty and Bennett) extended the interest in mathematical models, looking, for example, at catastrophe and chaos theories to explore system dynamics in space-time (Wilson and Bennett, 1985; Bennett, Haining and Wilson, 1985; Batty, 2006). This approach was marginal to most spatial scientists' concerns, however.

Moving on I – from normative to behavioural theory

Many reactions to/critiques of early spatial science argued that its models were too simplistic, reducing decision-making in a complex world to a single key influence – transport costs; distance was presented as a basic determinant of behaviour (thereby sustaining geographers' claim for a separate place within the social sciences: Cox, 1976). The result was deterministic models of spatial patterns based on rather simplistic assumptions about spatial behaviour. Although transport costs are undoubtedly important to much decision-making, large and small (which shop shall I go to today for a newspaper?; where shall I locate the next supermarket in the chain I am developing?), many other factors influence spatial decisions. Furthermore, very few – if any – decision-makers have all of the information needed to resolve a particular locational problem optimally, and/or have the capacity, when making major decisions that require large volumes of data, to make the optimal decision (Pred, 1967-1969). In addition, the outcomes of many decisions are affected by those made by others – the profitability of my new supermarket may well depend on how close to it competitors put their new outlets (so once sunk costs are incurred optimal decisions may not be not possible). Perfect decision-making is rarely feasible; people make rational decisions using the information available to them, which will in many cases reflect not only who they are but also where they are because, as Hägerstrand has shown, information is not evenly distributed. A consequence is that the equilibrium patterns at the core of models such as central place theory are unattainable: systems are continually in flux, which requires models built into a dynamic location theory (Plummer and Sheppard, 2006). The 'traditional' location theories with their relatively unsophisticated expected geographies based on the operation of a spatial single variable only – distance, or travel costs – are thus largely obsolete: nevertheless, as a small number of researchers continue to demonstrate, it remains possible to derive testable hypotheses from economic theory – of variations in wages, for example (Fingleton, 2005).

The realisation of the power of these arguments stimulated a major shift in the nature of much spatial science. The models and theories that dominated its early years – such as central place theory – became much less important (indeed, some almost disappeared from the disciplinary portfolio), and were replaced by approaches that initially went under the name of behavioural geography. These now so predominate within the spatial science component of the discipline that the term is rarely used. They haven't entirely taken over spatial science, however. Some formal modelling has been undertaken using alternative approaches to economics from the neo-classical (such as welfare economics – Chisholm, 1966 – Marxian – Webber and Rigby, 1996 – and Ricardian/Sraffian approaches –Sheppard and Barnes, 1990). Over the last decade a school of 'new economic geographers' has emerged from within economics – see Martin (1999). The *Journal of Economic Geography* was founded to bring them together with geographers who deploy formal modelling approaches based on neo-classical economics, seeing transport costs as a significant element underpinning the creation of spatial patterns – such as trade flows and agglomeration/urbanization.

The core argument from behavioural geography's promoters is not that people are irrational decision-makers but rather that they are boundedly (as against perfectly) rational: the boundedness reflects the limits to their information, their ability to process it, and the utility functions they apply when evaluating options. This does not mean that everybody has to be treated as both unique (having characteristics that nobody else shared in total) and singular (sharing no characteristics with others), so that no general patterns can be found and theories developed. Rushton (1969) makes this point in contrasting studies of *behaviour in space* – e.g. mapping individual journey-to-work routes – with those identifying *rules of spatial behaviour*, the general patterns within all those choices that can be uncovered from the individual pieces of data and which suggest common behavioural decisions. The reasons for such commonalities can then be explored by, for example, identifying shared information underpinning such decisions, as in Peter Gould's pioneering work on mental maps, the spatial depictions we use when evaluating the places we want to visit, move to etc. (Gould and White, 1974).

Most of this work is theory-driven, based on generalised hypotheses of how people behave, but much of the analysis involves exploring data assembled to identify patterns rather than explicit hypothesis-testing – most of those tested are general expectations rather than firm statements that can be rigorously evaluated. This very largely reflects the 'immaturity' of such studies; our knowledge of how people make spatially-relevant decisions and behave is limited and so the best we can come up with at this stage is broad expectations. In electoral studies, for example, there are strong theoretical arguments that self-interest will strongly influence how people vote, and that economic concerns will underpin that self-interest. But it may be expressed in different ways: some may vote sociotropically, according to their views of the national, regional and/or local economic situation (voting for the governing party[ies] if they are optimistic about the economic situation but against it if they are pessimistic); some may vote egocentrically, according to their perceived personal financial situation; and some vote altruistically, in the interests of their (geographical) neighbours even when these don't coincide with their own (Johnston and Pattie, 2006). Those theoretically-based, expectations generate testable hypotheses but – as with the gravity model – they cannot predict in advance the size of the relevant coefficients for each type of voting, because of the many other contingent factors (some of them spatial in nature) which influence electoral behaviour.

The results of such analyses provide understanding of general trends and patterns in behaviour and its outcomes, but the term 'law' – widely deployed in the early years of spatial science – now rarely appears. Indeed, much contemporary spatial science adopts a less formalistic approach to knowledge-acquisition. Early efforts to identify laws of spatial behaviour were criticised as not only over-simplistic approaches to appreciating complex realities but also for treating individual decision-makers as lacking free will – models were perceived as deterministic despite early essays separating macro- and micro- approaches to cause and effect (Jones, 1956). Spatial scientists still make generalisations – identifying general patterns of behaviour within a given context (data set) – but no longer imply that these are widely applicable, invariant law-like statements.

In searching for these generalisations, a great deal of spatial scientific work now involves alternative data acquisition strategies. Much locational theory – such as central place and industrial location theory – concerned patterns observable in the landscape; settlement distributions, for example, and shopping centres within cities. The data were there – on maps, or in the field. The shift to a behavioural approach requires new forms of – usually bespoke – data, recording not only what people do but why, what information they have, how they evaluate it and on what criteria etc. Such data have to be collected from individual subjects, in most cases using questionnaires, requiring geographers to develop new skills. Not all studies require bespoke data collection by the researcher, however. A variety of data sources – such as national censuses and surveys – can be used to address many geographical questions, and there is an increasing tendency for researchers to deposit their data sets in archives so that others can re-analyse them.

A wide range of studies, in most of human geography's sub-fields (urban, rural, political, social, electoral, economic etc.), illustrates the great variety of subject matter studied within these rigorous approaches. Electoral geographers examine spatial variations in turnout, for example, arguing that the more intense the local campaigns by political parties the more of their supporters who go to the polls. At aggregate scales this has been tested by relating voting patterns to the amount spent on local campaigns: the more spent, as an index of campaign intensity, the better a party's performance (especially by challengers to the incumbent party). This is complemented by individual-scale studies, showing that those who report having been contacted by a party during a campaign are more likely to vote than those who do not, but that in addition the more spent on the campaign there the more likely they are to vote (Johnston and Pattie, 2006). And a substantial programme of work on a variety of diseases by Haggett (e.g. Haggett, 2000) has similarly thrown light on the processes involved in their diffusion through environments where geographical contingency plays crucial roles in rates of exposure and contraction.

Moving on II – methods

In the early years of spatial science, geographers adopted methods developed in other disciplines, such as the 'family' of methods later categorised as the general linear model (regression, correlation, principal components and factor analysis, discriminant analysis and canonical correlation analysis: Johnston, 1978): these continue to serve them very well. But problems with applications to geographical (spatial) data were identified, which require alternative – more sophisticated – procedures, some developed by geographers themselves, often working in collaboration with statisticians and others.

The first of these problems – *spatial autocorrelation* – reflects Tobler's first law of geography. The general linear model assumes that the residuals from a regression are independent, that the value for one sample point is not affected by the values for neighbouring individuals: if it is, the estimated coefficients are imprecise. But Tobler's law says that they must be so affected, that spatial autocorrelation is the core of geography. Instead of deploying the general linear model, researchers – notably a group based in Bristol (Cliff and Ord, 1973) – created procedures that provide accurate estimates of relationships in the presence of spatial autocorrelation. Others argue that the presence of spatial autocorrelation indicates (as-yet unidentified) spatial patterning needing investigation: the model being tested is mis-specified in at least one of a number of ways. Important spatial variables may have been omitted, for example: the message is that more research is needed.

The issue of spatial autocorrelation continues to inform much spatial science. As an example, O'Loughlin, Flint and Anselin (1994) analysed the geography of voting for the NSDAP party (the Nazis) at the Weimar Republic's 1930 general election and found, using regression, that the main predictor of NSDAP success was the percentage of the *Kreis* (electoral district) population who were Protestants: the more Protestants in the area the more votes for the NSDAP. Residuals from that regression (which included other, less important independent variables) are spatially clustered – i.e. autocorrelated. A range of measures collected under the generic term *local statistics*, developed as part of a larger programme of work in spatial statistics/econometrics led by Luc Anselin (Anselin et al, 2004), separated this geography from the generic pattern associated with Protestantism. Local statistics identify 'hot spots', clusters of values out of line with the general pattern – in this example clusters of areas with either unexpectedly high or low levels of Nazi support characterised by O'Loughlin (2002) as 'islands that are distinctive from surrounding regions'. These are where support for the NSDAP deviated significantly, either positively or negatively, from the general pattern which could only be accounted for by particular reasons applying to those places alone. In this way, statistical analysis is linked to a growing argument among geographical researchers that 'place matters': local statistics identify places where general relationships don't operate, suggesting the importance of spatial context (locale in the language of structuration theory) as an influence on behaviour.

An alternative approach to spatial autocorrelation issues developed by geographers is *geographically weighted regression* (GWR), which explores spatial variations in a defined relationship across a set of areas, autocorrelation having been detected (Fotheringham et al, 2002). There may be a positive relationship between electoral turnout and voters' average age in most parts of an area (suggesting that older people are more likely to vote), but a negative link in some (younger people are more likely to vote). A single regression equation fitted to all districts in the area would not identify this difference: GWR, which focuses on the relationship in various parts of the area by giving greater weight to nearby observations – the first law of geography again – can do so, and pose further questions for the analyst.

GWR is linked to a wider range of inductive, *exploratory spatial analysis* procedures developed by Openshaw. These were initiated with his Geographical Analysis Machine (GAM) which identified significant clusters of points – such as childhood leukaemia cases – unlikely to have occurred randomly and which therefore raised questions regarding their cause: did local sources of radiation generate such outbreaks? This was extended into a Geographical Explanations Machine (GEM), which explored spatial variations in relationships, such as regression equations. As in many other areas of science and social science, such inductive rather than deductive approaches (data-led rather than theory-led) are becoming more important. We have a great deal of information about the world: exploring it is a very fertile source of ideas and knowledge, as a first stage to developing fuller understanding of spatial variations.

Also deployed for exploring variations across places in relationships, *multi-level modelling* was developed by educational statisticians to evaluate differences between different settings (e.g. schools, classrooms) in student achievement, holding constant other influential variables such as family social class background. The method explores whether there are differences among places (levels in the terminology) in relationships, suggesting that processes vary across space; it can incorporate a number of levels, such as districts within counties, within states. For example, Datta et al (2006) show that the prevalence of smoking among black women in the US is greater the lower an individual's educational attainment, and also greater among those 'living as married' than those who were married; it also varies by age group (younger and older people were less likely to smoke than the middle-aged), and professionals are less likely to smoke than those in non-professional occupations. They also find higher smoking rates among those who live in neighbourhoods with higher poverty rates, as well as in states with higher poverty rates. Individual characteristics are important determinants of behaviour, but similar people living in different places apparently act differently when presented with the same stimuli – reflecting the context within which they make those decisions. Multi-level modelling identifies and evaluates those geographical contingencies – the importance that place makes – dealing with places as discrete, pre-defined entities. (GWR treats space as continuous, although it may have to conduct its analyses using pre-defined entities.)

A major issue for much spatial science is the *modifiable areal unit problem*. Much spatial analysis – across the social sciences – uses data for areal units, such as census data for counties. Analysts may explore whether there is a relationship between average house prices and the percentage of the workforce employed in managerial and professional occupations. There may be 50 counties in the study area, but this is only one way of amalgamating a large number of smaller areas – census tracts, for example – into such areas. Will the relationship between the two variables be the same whichever amalgamation is used? Experiments by Openshaw and Taylor (1981) showed not, but rather that different configurations can produce different – sometimes markedly different – results. So 'which is the right one?'; even 'is there a right one?' – and if not, what are the implications for spatial analysis?

Openshaw and Taylor showed that the modifiable areal unit problem results from the interaction of two separate problems operating when creating larger spatial units from smaller, spatially-identified, building blocks. The first is the aggregation problem: the same set of *x* building blocks can be aggregated into *y* larger units in a (possibly very large) number of ways, while meeting pre-set criteria – each *y* unit should comprise the same number of *x* building blocks, for example, and all *x* building blocks in a *y* unit should be contiguous. The second is the scale problem: different sizes for *y* (i.e. numbers of *x* per unit *y*) can be produced. In many cases, there is a clear relationship between the scale of the analysis and the size of the correlation coefficient. But the interaction of scale and aggregation effects can considerably blur such a general tendency.

The modifiable areal unit problem is significant not only because of the analytical difficulties it raises – what reliance can I place on one set of results given that the same data aggregated in a different formation could generate different results? – but also its practical relevance. The definition of electoral districts exemplifies this. There are many ways in which UK Parliamentary constituencies and US Congressional Districts can be produced as aggregations of smaller areas meeting size, shape, compactness and contiguity criteria, and they may generate very different election results (Morrill, 1973). Even where relatively neutral non-partisan procedures are deployed it is possible to generate equivalents of both major potential abuses in electoral cartography – malapportionment (the scale problem) and gerrymandering (the aggregation problem). This is illustrated by the biased outcomes in UK general election results: the Labour party has recently benefited very substantially in the translation of votes into seats because of the geography of its support relative to that of constituency boundaries (Johnston et al, 2006). But Openshaw realised that the problem is also an opportunity, because with experimentation it should be feasible to identify the optimum zoning of an area to meet pre-determined criteria. Such zone design principles were deployed to create homogeneous small areas as reporting units for 2001 UK census data (Martin, 2002).

Closely linked to the modifiable areal unit problem is that of *ecological inference*, which involves drawing conclusions about individuals from aggregate data. In the classic presentation, Robinson (1950) found a correlation of 0.946 between the percentage of the population Black and the percentage who were illiterate, using 1930 aggregated data for American census divisions. Using data for the 48 states, the correlation was somewhat weaker, at 0.773, and using individual data it was much weaker, at 0.203. Relying on aggregated data at either scale, analysts might conclude that Blacks were much more likely to be illiterate than whites, but the individual-level data show a weaker relationship (16 per cent of blacks were illiterate, according to the 1930 census, as against 3 per cent of whites, a 5-fold difference: the aggregate data analyses suggested a 10-15-fold difference). Robinson could point-up these differences because individual-level data were available, but if they are not, ecological inference appears to offer the only – although potentially flawed way – of drawing conclusions about individual behaviour from aggregate data. Such inferences may be very weak. The vote for the British National Party – BNP – is generally higher in areas with large ethnic minority populations than where there are few representatives of those groups. But this should not be taken as indicating that members of ethnic minority groups vote for the BNP. Very few do, and higher levels of voting for the party in areas where such individuals are relatively common reflect voting by white residents there expressing support for an anti-immigration party. This is, in part at least, a scale problem reflecting the size of the area used to analyse the voting patterns: few of the whites who vote BNP actually live in the same streets as non-whites, so at a fine enough scale you would get a negative relationship between per cent of the population who are non-white and voting for the BNP.

It is possible, however, to use aggregate data to draw fairly robust inferences about individual relationships and behaviour. One of the most widely-used methods was developed by a political scientist – Gary King (1997) – but geographers have developed alternative procedures. Entropy-maximizing methods, for example (first used by Alan Wilson (1970) to model traffic flows and other interaction patterns more successfully than the gravity model), have been deployed to disaggregate voting patterns, for example (Johnston and Pattie, 2000), and the associated method of micro-simulation (developed in economics) produces similar types of estimate (as in Ballas et al's – 2005 – study of the impact of various social policies). Johnston, Pattie and Allsopp (1988), for example, show that between the 1983 and 1987 general elections in the UK, whereas the national percentage remaining loyal to the Conservative party was 70, across the country's 627 constituencies it varied from 37 to 84. They use these estimates to explore reasons for that spatial variation, finding that Conservative loyalty was lower than average in areas where support for the party was already relatively weak in 1983, but especially in those with high levels of unemployment, where voters were much more likely either to switch their support to another party or to abstain in 1987.

Spatial science analyses spatial patterns and processes using rigorous quantitative procedures on data sets (many large and complexly-structured). Its development has been much assisted – in many cases only made possible – by improvements in the speed and power of computer hardware and associated software. In particular, much recent development has been closely linked to that of Geographical Information Systems (GIS) and Geographical Information Science (GISc). These combined hardware and software resources for the collation, visualisation, integration and analysis of spatially-referenced data not only facilitate the creation and analysis of large data sets in spatial science but also provide platforms without which many analyses are virtually impossible. Spatial science is about the analysis of maps: GIS is about creating those maps and facilitating their analysis. The field of geodemographics, for example, builds on work classifying areas according to their population characteristics using census data by adding other data sets and identifying common patterns of consumer behaviour, on which marketing strategies are based (Harris et al, 2005).

Many of these approaches to spatial statistics can now be applied using bespoke software packages, some of them developed by geographers – such as Anselins's spatial econometrics package, GeoDa (Anselin et al, 2006). Furthermore, the approach is increasingly being taken up for the analysis of spatial data in the other social sciences: sociology, for example, has 'taken a significant spatial turn' (Downey, 2006, 567) and realised the value of GIS, as have economists (Dietz, 2002), and political scientists (Beck et al, 2006; Simmons and Elkins, 2004).

Contemporary spatial science

Spatial science is a substantial component of contemporary human geography. It is very closely associated with quantitative methods: without them and associated technologies for their application much (most?) spatial science would not be feasible. The methods are a means to an end, however, for answering the basic question posed by Fotheringham (2006, 237): 'Does what I'm doing provide useful evidence towards the better understanding of spatial processes?'.

Most answers to this question from spatial scientists use aggregate data sets to research broad patterns. Spatial science is about patterns and processes involving large numbers of decision-makers, seeking order in even the most complex situations (Haggett, 1990; Law, 2004). Even when data are available on individual decision-makers, the goal is to distil general patterns – as in Rushton's distinction between behaviour in space and rules of spatial behaviour. Unlike other approaches to human geography, therefore, spatial science is macro/meso in scale, rather than micro – though it may deploy micro-scale data in its search for macro/meso-scale patterns. Its findings might pose questions that can only be addressed by studying individuals, but its core methodologies focus on wholes rather than parts.

In some situations this approach is the only one possible given the subject matter. Patterns of (changing) regional development and under-development, for example, can only be studied as statistical aggregates – as can many indices linked to this concept, such as inflation, unemployment rates, land values, house prices, productivity etc. Aspects of our worlds are only accessible in such formats, and these are sensibly analysed using spatial science approaches. In other cases, whereas individual-level data are available (or can be obtained through bespoke surveys) – on illness, turnout at elections etc. – much can be gained from aggregating them and studying general patterns, of morbidity and mortality rates, for example. Much work in, for example, population, medical, social and electoral geography is of this type – though such sub-disciplines are not constrained to spatial scientific approaches.

A further justification for macro-/meso- approaches lies in the probabilistic nature of much of our understanding and representation of the world. For example, it is now generally accepted that smoking causes lung cancer – but not all people who smoke get lung cancer and not all people who get lung cancer have smoked at some time in their lives. It is a probabilistic relationship – albeit one with a high probability. Part of the reason why we cannot say that smoking causes lung cancer without qualification is because other variables can either accelerate or decelerate, even block, the processes involved; and part is because is because our knowledge is incomplete – the scientific work continues to explore all the processes involved, and is to some extent constrained because of the difficulties of conducting controlled experiments. Similar arguments apply to a whole range of behaviours studied by (physical and well as human) geographers: the processes involved are so complex and difficult to unravel – because we cannot conduct experiments (although a range of techniques is being developed in other disciplines that may be of value in such situations: Sherman, 2003; Sherman and Strang, 2004). Hence work in spatial science is almost of necessity conditional; it represents the state of our current understanding and can only be phrased in probabilistic rather than deterministic terms.[2]

The meso/macro- patterns in many aspects of contemporary society described and analysed by social scientists are very relevant to people's daily lives and experiences – the 'meaningful nature of life' explored in other geographical practices. Levels of

[2] Take the example of tossing a coin. We invariably treat this as a random process: assuming there is no bias in either the coin or how it is tossed we assume – and can demonstrate experimentally – that the probability of heads being the outcome is 0.5. But if we could control every possible influence – where the coin is placed on the thumb; the distance between thumb and floor; how strongly it is flipped; the nature of the surface it lands on; etc. – then we could predict the outcome much more precisely.

ethnic segregation in neighbourhoods and schools in many cities provide the context within which not only lives are (partially) lived but also people's life chances and relationships within civil society are influenced. Geographical concentrations of poverty similarly structure many people's life chances while biased election results – reflecting the operation of the aggregation and scale issues underpinning the modifiable areal unit problem – strongly influence government-formation, and policies directed at those concentrations, in many countries.

Alongside their intrinsic interest and importance to understanding spatial patterns and behaviour, therefore, meso/macro-scale work is relevant to public policies – either studies of their impact on geographies or analyses of geographic patterns that call for public intervention. Geographies of mortality, for example, may identify areas where further investment of medical resources is warranted. Much public policy has impacts – direct and indirect – on topics of interest to human geographers and, although directed at individuals, is delivered to areas, as with the location of health-care clinics: if the world operates through spatial aggregates, then it should be analysed accordingly (though not exclusively so).

Similarly, whatever the immense variety of human spatial behaviour, public policy which intervenes in it in some way (and much private sector policy too) is almost invariably phrased in aggregate terms. New highways are planned to link places where demand either currently outstrips supply or modelling suggests that it soon will. New commercial establishments are located where potential (unfulfilled) demand is deemed greatest (and usually implies some distance-decay pattern in usage, as represented by the gravity model): much of the work by GMap (see above) is based on this aspect of Tobler's law.

Many critiques of spatial science from the 1960s on equated its approach with the philosophy of positivism, and its goal – as in the natural sciences – of establishing general laws. (Harvey's, 1969, *Explanation in geography* set out the basic tenets of this approach – without ever referring to it as positivism.) This aspect of the positivist approach has long been abandoned by almost all spatial scientists: they adopt some of the precepts of the approach – particularly that the things they study can be observed and measured; that the statements which they derive can be tested for their veracity; and that their studies can be replicated. For them knowledge-production involves careful observation, measurement, analysis and interpretation, generating statements which identify synoptic patterns – the broad pictures which might then be decomposed to see how they are produced and what they mean for the people who live in them. They don't – as Fotheringham (2006, 239) puts it – ignore 'all the emotions and thought processes that are behind what is sometimes … highly idiosyncratic behaviour'; they accept those as valid topics for study, calling for different approaches. For spatial scientists a whole range of subjects can be addressed at the aggregate level, from which valid generalisations can be drawn to illuminate aspects of the human condition.

Spatial science is not – and should not be considered – an approach to human geography having few points of contact with other disciplinary practices. At the core of much contemporary geographical scholarship is the concept of contingency, with particular reference to place as the locale within which that contingency is played out.

If, according to this argument, places matter, then with certain types of behaviour this should be demonstrable through approaches associated with spatial science. This was the goal, for example, of Openshaw's original work with his Geographical Analysis Machine: exploring whether places had significantly different cancer rates, as a preface to identifying why that was the case. (The answer, higher rates were found close to nuclear power plants, which suggested that the cause was radiation either from exposure to the reactors or from the waste.) Geographically Weighted Regression similarly explores large and complex data sets to identify places with particular characteristics, and work using bespoke neighbourhood data enabled Johnston and Pattie (2006) to produce strong circumstantial evidence that people are influenced by talking to their neighbours when making electoral decisions. Spatial science's core purpose is to generate rigorous descriptions of complex realities, through clear pictures which suggest general patterns of behaviour within those complexities. It is theory-driven, with foundations based in beliefs about how people behave (individually and in aggregates), and its findings contribute to theory-development – but contemporary spatial scientists are neither as ambitious nor as naïve as the pioneers; complex realities continue to take much effort to understand.

References

Abler, R. F., Adams, J. S. and Gould, P. R. 1971: *Spatial organization: the geographer's view of the world*. Englewood Cliffs NJ: Prentice-Hall.

Ackerman, E. A. 1945: Geographic training, wartime research and immediate professional objectives. *Annals of the Association of American Geographers* 35: 121-143.

Ackerman, E. A. 1958: *Geography as a fundamental research discipline*. Chicago: University of Chicago, Department of Geography, Research Paper 53.

Anselin, L., Florax, R. J. G. M. and Rey, S. J., editors, 2004: *Advances in spatial econometrics: methodology, tools and applications*. Berlin: Springer.

Anselin, L., Syabri, I. and Kho, Y. 2006: GeoDa: an introduction to spatial data analysis. *Geographical Analysis* 38: 5-22.

Balchin, W. G. V. 1993: *The Geographical Association: the first hundred years 1893-1993*. Sheffield: The Geographical Association.

Ballas, D. M., Rossiter, D. J., Thomas, B., Clarke, G. and Dorling, D. 2005: *Geography matters; simulating the local impacts of national social policies*. York: Joseph Rowntree Foundation.

Barnes, T. J. 2006: Geographical intelligence: American geographers and research and analysis in the Office of Strategic Services 1941-1945. *Journal of Historical Geography* 32: 149-168.

Barnes, T. J. and Farish, M. 2006: Between regions: science, militarism and American geography from world war to cold war. *Annals of the Association of American Geographers* 96: 807-826.

Batty, M. 2006: *Cities and complexity: understanding cities with cellular automata, agent-based models, and fractals*. Cambridge MA; The MIT Press.

Beck, N., Gleditsch, K. S. and Beardsley, K. 2996: Space is more than geography: using spatial econometrics in the study of political economy. *International Studies Quarterly* 50: 27-44.

Bennett, R. J., Haining, R. P. and Wilson, A. G. 1985: Spatial structure, spatial interaction, and their integration: a review of alternative models. *Environment and Planning A* 17: 625-645.

Bunge, W. 1966: *Theoretical geography*. Lund: C. W. K. Gleerup.

Burton, I. 1963: The quantitative revolution and theoretical geography. *The Canadian Geographer* 7: 151–62.

Chisholm, M. 1966: *Geography and economics*. London: G. Bell and Sons.

Chorley, R. J. and Haggett, P., editors, 1965: *Frontiers in geographical teaching*. London: Methuen.

Chorley, R. J. and Haggett, P., editors, 1965: *Models in geography*. London: Methuen.

Christaller, W. 1966: *Central places in southern Germany* (translated by C. W. Baskin). Englewood Cliffs NJ: Prentice-Hall.

Cliff, A. D. and Ord, J. K. 1973: *Spatial autocorrelation*. London: Pion.

Clout, H. and Gosmé, C. 2003; The Naval Intelligence Handbooks: a monument of geographical writing. *Progress in Human Geography* 27: 153-173.

Cox, K. R. 1976: American geography: social science emergent. *Social Science Quarterly* 57: 182-207.

Datta, G. D., Subramanian, S. V., Colditz, G. A., Kawachi, I., Palmer, J. R. and Rosenberg, L. 2006: Individual, neighbourhood and state-level prediction of smoking among US Black women: a multilevel analysis. *Social Science and Medicine* 63: 1034-1044.

Dietz, R. D. 2002: The estimation of neighborhood effects in the social sciences: an interdisciplinary approach. *Social Science Research* 31: 539-575.

Fingleton, B. 2005: Beyond neoclassical orthodoxy: a view based on the new economic geography and UK regional wage data. *Papers in Regional Science* 84: 351-375.

Fotheringham, A. S. 2006: Quantification, evidence and positivism. In S. Aitken and G. Valentine, editors, 2006, *Approaches to human geography*. London: Sage, 237-250.

Fotheringham. A. S., Brunsdon, C. and Charlton, M., 2002: *Geographically weighted regression: the analysis of spatially varying relationships*. Chichester: John Wiley.

Garrison, W. L. 1959: Spatial structure of the economy II. *Annals of the Association of American Geographers* 49: 471-482.

Gould, P. R. and White, R. R. 1974: *Mental maps*. London: Penguin Books.

Gregory, S. 1963: *Statistical methods and the geographer*. London: Longman.

Hägerstrand, T. 1968: *Innovation diffusion as a spatial process* (translated by A. Pred). Chicago: University of Chicago Press.

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

Haggett, P. 1990: *The geographer's art*. Oxford: Balckwell.

Haggett, P., Cliff, A. D. and Frey, A. E. 1977: *Locational analysis in human geography (second edition)*. London: Edward Arnold.

Harris, C. D. 1990: Urban geography in the United States: the formative years. *Urban Geography* 11: 403-417.

Harris, C. D. 1997: 'The nature of cities' and urban geography in the last half-century. *Urban Geography* 18: 15-35.

Harris, C. D. and Ullman, E. L. 1945: The nature of cities. *Annals of the American Academy of Political and Social Science* 242: 7-17.

Harris, R., Sleight, P. and Webber, R. 2005: *Geodemographics, GIS and neighbourhood targeting*. Chichester: John Wiley.

Harvey, D. 1969: *Explanation in geography*. London: Edward Arnold.

Isard, W. 2003: *History of regional science and the Regional Science Association International: the beginnings and early history*. Berlin: Springer

Johnston, R. J. 1978: *Multivariate Statistical analysis in geography: a primer on the general linear model*. Longman, London.

Johnston, R. J. 2006: The politics of changing human geography's agenda: textbooks and the representation of increasing diversity. *Transactions of the Institute of British Geographers* NS31: 286-303.

Johnston, R. J. and Pattie, C. J. 2000: Ecological inference and entropy-maximizing: an alternative estimation procedure for split-ticket voting. *Political Analysis* 8: 333-345.

Johnston, R. J. and Pattie, C. J. 2006: *Putting voters in their place: geography and elections in Great Britain*. Oxford: oxford University Press.

Johnston, R. J., Pattie, C. J. and Allsopp, J. G. 1988: *A nation dividing? The electoral map of Great Britain 1979-1987*. London: Longman.

Johnston, R. J., Rossiter, D. J. and Pattie, C. J. 2006: Disproportionality and bias in the results of the 2005 general election in Great Britain: evaluating the electoral system's impact. *Journal of Elections, Public Opinion and Parties* 2: 37-54.

Jones, E. 1956: Cause and effect in human geography. *Annals of the Association of American Geographers* 46: 370-377.

Law, J. 2004: *After method: mess in social science research*. London: Routledge.

King, G. 1997: *A solution to the ecological inference problem: reconstructing individual behavior from aggregate data.* Princeton: Princeton University Press.

Martin, D. J. 2002: Geography for the 2001 Census in England and Wales. *Population Trends* 108: 7-15.

Martin, R. L. 1999: The 'new geographical turn' in economics: critical reflections. *Cambridge Journal of Economics* 23: 65-92.

Morrill, R. L. 1970: *The spatial organization of society.* Belmont CA: Wadworth.

Morrill, R. L. 1973: Ideal and reality in reapportionment. *Annals of the Association of American Geographers* 63: 463-477.

Morrill, R. L. 2005: Hägerstrand and the quantitative revolution: a personal appreciation. *Progress in Human Geography* 29: 333-336.

O'Loughlin, J. 2002: The electoral geography of Weimar Germany: exploratory spatial data analyses (ESDA) of Protestant support for the Nazi party. *Political Analysis* 10: 217-243.

O'Loughlin, J., Flint, C. and Anselin, L. 1994: The geography of the Nazi vote: context, confession and class in the Reichstag election of 1930. *Annals of the Association of American Geographers* 84: 351-380.

Olsson, G. 1965: *Distance and human interaction: a review and bibliography*. Philadelphia: Regional Science Research Institute, Bibliography Series 2.

Openshaw, S. and Taylor, P. J. 1981: The modifiable areal unit problem. In N. Wrigley and R. J. Bennett, editors, *Quantitative geography: a British view*. London: Routledge and Kegan Paul, 60-70.

Plummer, P. S. and Sheppard, E. S. 2006: Geography matters: agency, structures and dynamics at the intersection of geography and economics. *Journal of Economic Geography* 6: 593-617.

Pred, A. 1967-1969: *Behavior and location: foundations for a geographic and dynamic location theory (two volumes)*. Lund: C. W. K. Gleerup.

Robinson, W. S. 1950: Ecological correlations and the behaviour of individuals. *American Sociological Review* 15: 351-357.

Rushton, G. 1969: Analysis of spatial behaviour by revealed space preferences. *Annals of the Association of American Geographers* 59: 391-400.

Schaefer, F. K. 1953: Exceptionalism in geography: a methodological examination. *Annals of the Association of American Geographers* 43: 226-249.

Sheppard, E. S. and Barnes, T. J. 1990: *The capitalist space economy: geographical analysis after Ricardo, Marx and Sraffa.* London: Unwin Hyman.

Sherman, L. W. 2003: Misleading evidence and evidence-led policy: making social science more experimental. *Annals of the American Academy of Political and Social Science* 589: 6-19.

Sherman, L. W. and Strang, H. 2004: Experimental ethnography: the marriage of qualitative and quantitative research. *Annals of the American Academy of Political and Social Science* 595: 204-222.

Simmons, B. A. and Elkins, Z. 2004: The globalization of liberalization: policy diffusion in the international political economy. *American Political Science Review* 98: 171-189.

Tobler, W. R. 1970: A computer movie simulating urban growth in the Detroit region. *Economic Geography* 46: 234-240.

Ullman, E. L. 1941: A theory of location for cities. *American Journal of Sociology* 46: 853-864.

Ullman, E. L. 1956: The role of transportation and the bases for interaction. In W. L. Thomas, editor, *Man's role in changing the face of the earth.* Chicago: University of Chicago Press, 862-880.

Webber, M. J. and Rigby, D. L. 1996: *The golden age illusion: rethinking postwar capitalism*. New York: Guilford Press.

Wilson, A. G. 1970: *Entropy in urban and regional modelling*. London: Pion.

Wilson, A. G. 2000: *Complex spatial systems: the modelling foundations of urban and regional analysis*. Chichester: John Wiley.

Wilson, A. G. and Bennett, R. J. 1985: *Mathematical methods in human geography and planning*. Chichester: John Wiley.

Wilson, A. G., Rees, P. H. and Leigh, C. M. 1977: *Models of cities and regions*. Chichester: John Wiley.

Yeates, M. H. 2001: Yesterday as tomorrow's song: the contribution of the 1960s 'Chicago School' to urban geography. *Urban Geography* 22: 514-529.

Further Reading

Abler, R. F., Adams, J. S. and Gould, P. R. 1971: *Spatial organization: the geographer's view of the world*. Englewood Cliffs NJ: Prentice-Hall.

Chisholm, M. 1975: *Human geography: evolution or revolution*. London: Penguin Books.

Chorley, R. J. and Haggett, P., editors, 1965: *Models in geography*. London: Methuen.

Fotheringham, A. S., Brunsdon, C. and Charlton, M. 2000: *Quantitative geography: perspectives on spatial data analysis*. London: Sage.

Hägerstrand, T. 1968: *Innovation diffusion as a spatial process* (translated by A. Pred). Chicago: University of Chicago Press.

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

Haggett, P., Cliff, A. D. and Frey, A. E. 1977: *Locational analysis in human geography (second edition)*. London: Edward Arnold.

Harvey, D. 1969: *Explanation in geography*. London: Edward Arnold.

Johnston, R. J. and Sidaway, J. D. 2004: *Geography and geographers: Anglo-American human geography since 1945 (sixth edition)*. London: Arnold.

Morrill, R. L. 1970: *The spatial organization of society*. Belmont CA: Wadworth.

Wilson, A. G. 2000: *Complex spatial systems: the modelling foundations of urban and regional analysis*. Chichester: John Wiley.

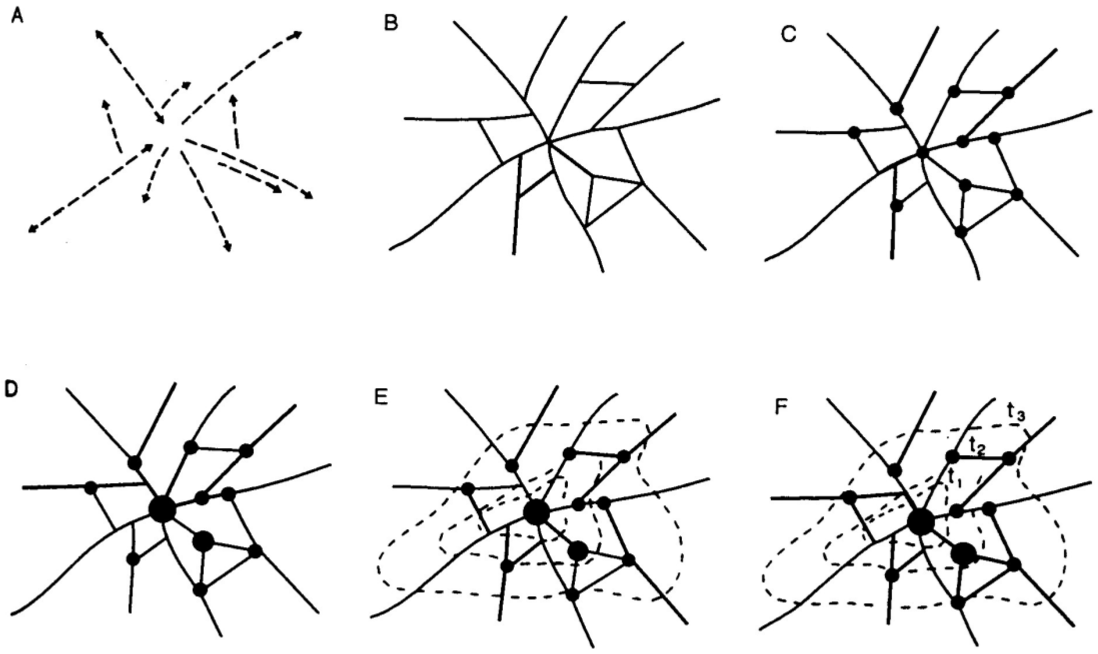

Figure 1. Haggett's representation of the six core components of a spatial system: A – flows; B – channels; C – nodes; D – hierarchies; E – surfaces; F – diffusions.