MODELING GEOGRAPHICAL SYSTEMS AND PREDICTION

Robert G.V. Baker
School of Human and Environmental Studies, University of New England, Armidale, Australia

Keywords: Modeling, quantitative revolution, scale, prediction, relevance, public policy

Contents

Summary

Geographic modeling has its origins in the 1950s and 1960s where it was introduced as part of the application to scientific method to study problems of geographic form and process. Many ideas have been borrowed from other disciplines and the success of modeling was questioned in the 1970s and 1980s. The advent of geographical information systems (GIS) has re-focused modeling and there are a number of guidelines proposed for the future of the model in geography. Firstly, it has to be more relevant, testable, and reproducible. Secondly, the data gathered must be robust, where inherent bias must be understood. Thirdly, there is no set way to come up with a good model and it must be accepted that there can be many different equally valid representations of observed phenomena. Fourthly, modelers have to respond to criticisms from postmodernist geographers, to come in from the margins, and to occupy once again an integral part of the discipline. There is a place for both quantitative and qualitative methodologies aiming for generalizations and individualization, respectively, of geographic form and process. Fifthly, modelers must understand the mathematical language that is being used. Sixthly, there has to be an increasing realization of the role that the geographical model has in public policy. Finally, geography is an integrative spatial science where the parts are summed into the whole and this is what makes it distinctive in the sciences. Our models should therefore show this distinctiveness. Examples of such modeling and prediction are described from shopping trips to malls, sea level change over the past, and climatic change based on cycles within the Sun.

1. Modeling and the Quantitative Revolution

1.1. Introduction

Geography can be defined as the study of the organization of spatial form, the explanation of process, and how both of these change over time. In order to describe and explain the resulting areal differentiation, geographers have applied scientific method to give objective answers to relevant questions. Scientific method is defined as the logical structure of the process by which the search for trustworthy knowledge advances. This occurs in geographic study through three stages:

(i) researchers raise some questions about spatial organization;
(ii) a theory is built in order to answer the questions, starting with axioms and deducing various statements; and
(iii) the statements are tested using empirical observations and evaluated for their statistical validity.

A scientific theory is designed to provide a deeper understanding of observed regularities, especially laws, by attempting to uncover the mechanism or process behind them. David Harvey in 1969 argued that the development of theory is at the heart of all explanation whilst Alan Wilson in 1972 emphasized the word "explain" in his definition of a theory as "a set of propositions which purports to explain the structure of some system and/or how that system develops." One of the most dramatic tests of a theory occurs when it is successfully applied to predict the outcome of an experiment or observation never before conducted. The key elements of a theory may therefore be summarized by:

- testing for internal and external consistency;
- the successful prediction of events; and
- the measurement of phenomena.

In particular, geographers have become interested in measurement and statistical inference. The attraction is that population characteristics can be determined from a sample of observations and is a means of overcoming the complexities of transient human behavior.

Beguin in 1989 argued that a useful geographical theory requires a rigorous axiomatic approach in order to be consistent and successful. It must allow the derivation of relevant and significant statements. The choice of axioms is critical and the underlying assumptions determine the relevance of these propositions to the real world. They can become significant, scientific statements when they are evaluated against empirical data samples within certain confidence boundaries. As Popper in 1959 argued in a famous statement, any theory claiming scientific status must be falsifiable, refutable, or testable. The lack of these fundamental qualities has led many geographers such as Guelke, Tuan, Ley, Daniels, and Barnes to doubt strongly or to dismiss the scientific status of geographical theories and their relevance to the study of spatial phenomena. However, David Harvey in 1969 in his book *Explanation in Geography* argued less stringently that science does not demand that all propositions be capable of direct empirical testing, but does demand that some deduced propositions should be stated so that empirical testing becomes possible. Whilst abstract propositions may not be observable, the results obtained from these theoretical statements must be applied empirically for evaluation.

Geographical modeling and quantitative techniques have had a revival since the 1980s. A major catalyst has been the development of geographical information systems (GIS) and this has re-focused interest in how to ask good theoretical questions and to present spatial data in particular ways that can be visualized and tested. Further, the quality of this data and its statistical inference has become paramount. The evolution of modeling in the twenty-first century therefore has to show how theoretical relationships can be tested against robust data.

A description of the evolution of modeling in all its forms is a much larger task than can be tackled here. The evolution of GIS is dealt with in another section of the encyclopedia. This treatment is selective and case studies are used from a narrow perspective of the experience of this particular author. The field is much richer and the subtleties more pronounced than presented in this article. Nevertheless, there are a number of points that will be raised that are appropriate to the whole discipline. Firstly, models in general should be relevant, testable, and reproducible (RTR). Secondly, the data that we gather must be robust, where inherent bias must be understood. Thirdly, there is no set way to come up with a good RTR model and this is why modeling is seen here as more of an art form, where there can be many different representations of observed phenomena. Fourthly, modelers have to respond to criticisms from postmodernist geographers, to come in from the margins, and to occupy once again an integral part of the discipline. Fifthly, modelers must understand the mathematical language that is being used. Sixthly, there has to be an increasing realization of the role that the geographical model has in public policy. Finally, geography is an integrative spatial science where the parts are summed into the whole and this is what makes it distinctive in the sciences. Our models should therefore show this distinctiveness.

1.2. The Quantitative Revolution: A Brief Review

The aim of the quantitative revolution was to displace an ideographically based geography for a more rigorous and objective form of methodology. In human geography, it had its interdisciplinary roots in the late 1940s, where concepts and techniques were borrowed from economics, physics, and mathematics. This new geography was both confident and arrogant. For example, the social physicist J.Q. Stewart in 1947 stated in the *Geographical Review*:

> There is no longer excuse for anyone to ignore the fact that human beings, on average and at least in certain circumstances, obey mathematical rules resembling in general some of the primitive laws of physics.

The 1950s was a time when quantitative techniques were applied in both physical and human geography. The Regional Science Association was formed in 1956 and it was a sign that science had arrived at spatial and regional analysis. By the early 1960s, the new geography was firmly established. As Burton in 1963 noted:

> The revolution is over, in that once revolutionary ideas are now conventional. Clearly this is only the beginning . . . it is a direction that an increasing number of geographers are likely to follow. Let us hope that the effort will meet with success.

It was surprising that it was not until 1969 that an exclusively theoretical geography journal—*Geographical Analysis*—was produced. This was also the time that doubts were raised over the quantitative revolution in the very first volume of this journal. As Olsson in that volume stated:

> . . . the widespread dissatisfaction with existing geographic theories may be due to the preoccupation with spatial patterns and the neglect of small-scale generating processes.

David Harvey in his seminal 1969 work *Explanation in Geography* argued that the challenge was to stake out a new and more positive philosophy of geography and thus, on this basis, create theoretical structures that would yield a discipline with identity and direction. Harvey viewed the history of geographical thought as "a history of misapplied models." Whereas some geographers, such as Ackerman, had argued that physical analogies had proved their power and welcomed the growth of such methods, others, such as Harvey, saw this approach as a fundamental problem. Such a point of contention needs further elaboration.

Reasoning by analogy presumes a similarity in nature and is based on the notion of the transferability of one real system to another. A system is simply "sets of interrelated parts" and is composed of three parts (elements, states, and relationships between elements and states). This framework can be applied within any context and, as such, there is one "general system" that can be superimposed upon all geographical phenomena and their interactions. Von Bertalanffy in 1962 argued that it is possible to use the information on the properties of one real system to present the properties of another little-known system. This leads to the concept of a general system with characteristics of various real systems. General systems theory has been argued to be a system of general models. This idea of a unified analytical framework led to criticism even at that time. For example, Chisholm in 1967 regarded general systems theory as an irrelevant distraction. Yet Boulding in 1964 asserted that it was the path towards interdisciplinary communication:

> . . . it provides scientific endeavor with a unified vision and . . . it provides an imaginative framework for formulating the questions we ask of the complex world around us.

Such an argument has not changed since then, as geographers use general systems thinking to simplify their worlds and to impose order upon complexity. General systems theory is like the plans for a "kit home" that can be modified to suit local conditions and taste, but the structure is identifiable and reproducible. It has underpinned much of the theoretical applications in both human and physical geography.

Neural networks is an example of one recent manifestation of general systems theory. Based on an analogy to the "real" neurons found in the brain, neural networks describes a communication network where input signals combine to produce output signals. These inputs can be weighted and aggregated and when a threshold is reached the output jumps from zero to one or by some other distribution function. Each neuron is interconnected through a number of layers, where each layer produces its own outputs, which in turn are the new inputs for the next layer. The responsiveness of different connectivities identifies the characteristics of particular features within the layers. Each input can be set to one variable in a data set, and the network can provide a "response" to individual observations by reading values from the final layer. The layers identify the patterns within the data or features within a physical or cultural landscape. Such an approach was applied first to human geography by Openshaw in 1994 and then to physical geography (such as hydrological modeling in 1997).

Systems theory was adopted by physical geography much earlier than in human geography, such as the application of the concept of an ecosystem proposed by the botanist Tansley in 1938. Likewise, quantitative techniques were first considered in physical geography. For example, in analyzing rainfall records, probabilistic modeling of tendencies for wet and dry weather were applied by Newnham in 1916, although the seminal work of daily rainfall occurrence is found in Gabriel and Neumann in 1962, where a simple Markov chain model fitted patterns of the frequency distributions for wet and dry spell lengths. Such a statistical idea (of Markov chains) soon appeared within human geography, where Golledge in 1967 applied it to learning strategies for retail shopping opportunities.

One of the interesting observations of the quantitative revolution is that new ideas were quickly adopted in both physical and human geography (such as a Markov chain in the 1960s or a neural net in the 1990s). As Macmillan in 1995 observed, geographers have been fashion victims, readily fascinated by each new intellectual garment but tending to lose interest as the next style comes along. The negative exponential or gravity model was first applied to longitudinal stream profiles and their degradation over time (Strahler, 1952) and it took another 20 years before it appeared in a trip generation model in human geography (Wilson, 1967). Likewise, the Poisson and binomial distributions were applied in the 1960s to the topographic elements of terrain summits (McConnell, 1965) but appeared in the 1980s, via applied statistics, only in the consumer selection of shopping centers (Wrigley and Dunn, 1984). Other examples show a parallel adoption, such as stream networks generated by random walks (Leopold and Langbein, 1962) or random walks for settlement patterns (Curry, 1964); entropy in stream profiles (Leopold and Langbein, 1962) and in trip assignment (Wilson 1967). Human geographers, though, have provided the initiative in some instances, for example, fuzzy set theory appeared in behavioral geography in 1972 (Gale) but was applied to climatology much later (Cao and Chen, 1983).

The evolution of theoretical geography since 1969 has focused on many different areas and an indication of these directions are seen (in Table 1) of topical themes in papers by frequent contributors to *Geographical Analysis* (1969–1999).

Cross-fertilization and the use of analogy has been one of the major characteristics of the quantitative revolution, but this process has been one of the underlying reasons for many of the problems that were highlighted by geographers as far back as Hartshorne in 1939. It is some of these problems that we will now briefly review.

Author	**Date of contribution**		**Theme**
	Earliest	**Most recent (excluding this issue)**	
Casetti E.	1969	1992	Generating models by the expansion method
Clark W.A.V.	1969	1992	Aggregation and categorical data in spatial models
Curry L.	1965	1985	Stochastic processes in spatial economic theory; random spatial economy
Tobler W.	1969	1994	Extending mathematical techniques to spatial problems
Smith T.E.	1970	1989	Concepts and axioms for interactions
Revelle C.	1970	1999	Location modeling using optimization
Ord K.	1970	1995	Spatial statistics
Rushton G.	1970	1999	Location theory
Golledge R.	1970	1993	Behavior and cognition
Papageorgiou Y.	1971	1994	Urban economic theory
Webber M.	1971	1981	Models of urban and regional systems
Getis A.	1971	1995	Spatial association and dependence: local statistics
Boots B.	1972	1997	Point processes; geometric modeling; interpreting eigenvectors
MacKay D.B.	1973	1991	Scaling applied to consumer behavior
Church R.	1975	1990	Location modeling using optimization

Liaw K.L.	1975	1994	Migration theory and methodology
Okabe A.	1976	1996	Point processes; geometric modeling
Smith T.R.	1976	1989	Spatial choice; cognition, and behavior
Haining R.	1977	1994	Fundamental problems using spatial data
Griffith D.	1978	1994	Spatial statistics (sampling correction techniques)
Jones D.W.	1978	1984	Neoclassical spatial economics
Sheppard E.	1978	1985	Foundations of gravity model; price equilibrium
Fotheringham A.S.	1980	1996	Spatial interaction; geographically weighted regression
Hanson S.	1980	1997	Travel behavior
Ghosh A.	1981	1992	Spatial competition
O'Kelly M.	1981	1995	Optimization for location and network analysis
Odland J.	1982	1992	Migration theory and methodology
Rogerson P.	1982	1999	Spatial search; spatial chi-squared test
Davies R.B.	1982	1992	Stochastic models for panel data
Hanink D.	1984	1993	Trade theory and function
Anselin L.	1986	1995	Spatial model specification and diagnostics
Nijkamp P.	1987	1998	Dynamic models
Ficher M.	1988	1999	Models for complex systems

Source: M.E. O'Kelly, Introduction to the thirtieth anniversary special issue, *Geographical Analysis* **31** (1999), 315

Table 1. Selected themes of major contributors to *Geographical Analysis*, 1965–1999 (*Source*: M.E. O'Kelly, Introduction to the thirtieth anniversary special issue, *Geographical Analysis* **31** (1999), 315)

1.3. Some Problems of Geographical Analysis

There are a number of concerns with the geographical application of scientific method. Beguin argues that this occurs from the twin facts that geography, as a whole, deals with multivariable open systems and that human geography deals with knowing subjects. The fundamental problem is that it is seldom possible to identify two completely identical spatial forms and understand the underlying causation. Such uniqueness in geography has led to the school of thought developed by Hartshorne that the generalization of form and process into laws and theories is doomed to failure.

The problem of observation and correlation in geography occurs because spatial organization strongly depends upon spatial behavior, which is determined by individual decisions that cannot be directly observed. This should not be an insurmountable problem because the same happened in quantum physics, where the position of an electron cannot be directly observed but is, rather, limited in its definition by a probability distribution. In human geography, there is an interdependence between observers and the phenomenon observed. If the researchers are known to the consumers it may lead to conscious or subconscious changes in behavior deviating from normal form and process. A similar problem occurs in quantum physics where the observation inherently changes the observed patterns. The expectations of the researchers of behavior may influence the format and composition of the research design and what is deemed to be important. Quantitative geography can deal with these problems (as in the case of quantum physics), but it must be quite clear as to what we can and cannot achieve with scientific method and mathematical language.

-
-
-

Bibliography

Fotheringham A.S., Brunsdon C., and Charlton M (2000). *Quantitative Geography*, 270 pp. London: Sage. [This is an excellent overview of current trends and issues in quantitative geography.]

Gregory K.J. (2000). *The Changing Nature of Physical Geography*, 368 pp. London: Arnold. [A good overview of the current issues facing physical geography.]

Johnston R.J. (2000). On disciplinary history and textbooks: or where has spatial analysis gone? *Australian Geographical Studies* **38**, 125–137. [Looks at changes in the discipline of geography and the relevance of spatial analysis today.]

Longley P. (2000). Spatial analysis in the new millennium. *Annals of the Association of American Geographers* **90**, 157–165. [Reappraises data-handling techniques and examines the future of spatial analysis.]

Macmillan B., ed. (1989). *Remodelling Geography*, 320 pp. London: Basil Blackwell. [This book summarizes the issues facing theoretical geography.]

Biographical Sketch

Dr. Baker is senior lecturer in the School of Human and Environmental Studies, University of New England (UNE), Australia. He holds a B.Sc. with honours in geography and a DipEd from the University of Sydney, and an M.S. and a Ph.D. in applied geography from the University of New South Wales. Dr. Baker serves as vice-chair of the International Geographical Union's Commission on Modeling Geographical Systems (1996–2004). He is on the editorial board of three international journals and has published about 30 research papers. He received the UNE Vice-Chancellor's Award for Excellence in Research in 2000.