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A History of the Concept of Spatial Autocorrelation: A Geographer's Perspective

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Spatial autocorrelation is a concept that helps to define the field of spatial analysis. It is central to studies using spatial statistics and spatial econometrics. In this paper, we trace the early development of the concept and explain the academic links that brought the concept to the fore in the late 1960s. In geography, the importance of the work of Michael F. Dacey, Andrew D. Cliff, and J. Keith Ord is emphasized. Later, with the publication of a volume on spatial econometrics by Luc Anselin, spatial research and the use of the concept of spatial autocorrelation received a considerable boost. These developments are outlined together with comments about recent and possible future trends in spatial autocorrelation-based research.

Introduction

Many academic movements begin, reach a popular peak, and slowly decline. A number of pundits like to say that the ''quantitative revolution'' in geography of the late 1950s and early 1960s died out in the late 1960s and early 1970s. Not usually mentioned in the geographic literature is that the seeds planted in the quantitative revolution produced a steady crop of contributions that has now evolved into a vibrant field, both inside and outside the discipline of geography. By the 1990s, the field of spatial analysis had matured to the point where the methods and concepts it created were becoming fundamental to researchers in a host of disciplines including geography, ecology, epidemiology, sociology, urban planning, geology, and environmental studies. In this paper, I describe this development by choosing the field's fundamental concept, *spatial autocorrelation*, and tracing its evolution. The main emphasis is to explore the concept's beginnings and its place in the academy. Because the number of contributors to the concept is so large, it would be impossible in a paper of this length to review each contribution. I decided to emphasize those works that, in my estimation, were the landmarks that had the greatest influence on spatially oriented research.

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Some of what is contained in this paper was first described in an essay I wrote for the *Regional Science and Urban Economics* journal (Getis 2007). In my presentation on this subject at the IGU meeting in Brisbane (Getis 2006), I mentioned the contributions of over 50 scholars to this field. I have made the power point of that presentation available at my web-site. Not mentioning contributors' names or describing their work in this article has nothing to do with the significance of their contributions. In this article, I describe what I consider to be the landmarks in the development of the concept.

The definition of spatial autocorrelation

The concept of spatial autocorrelation, although it may be viewed as a special case of correlation, has a meaning all its own. Whereas correlation statistics were designed to show relationships between or among variables, spatial autocorrelation shows the correlation within variables across georeferenced space. Of the several definitions of spatial autocorrelation in the literature, that by Hubert, Golledge, and Constanza (1981) is perhaps the most concise:

> "Given a set S containing n geographical units, spatial autocorrelation refers to the relationship between some variable observed in each of the n localities and a measure of geographical proximity defined for all $n\,(n-1)$ pairs chosen from n." (p. 224)

The literature on the subject contains many statistics, measures, and parameters that concisely express this relationship for a variety of types of research questions. The statistics originally were designed to identify a theoretical condition in which no spatial autocorrelation is present. In practice, however, the statistics are used not only to test hypotheses of no spatial autocorrelation but also to gauge the degree of spatial autocorrelation extant in the georeferenced data. For a single spatially distributed variable, these statistics are usually made up of two parts: (1) an expression representing a specified, hypothesized causal relationship between designated pairs of observations (autocorrelation), and (2) an expression representing the geometric (spatial) relationship of those same pairs of observations. The larger the correspondence (or non-correspondence) between the two parts, the greater the degree of positive (negative) spatial autocorrelation. When the matrices representing the two parts show no sign of similarity or dissimilarity, then no spatial autocorrelation is in evidence. Among many measures of spatial association, Moran's I statistic is the most widely used measure of and test for spatial autocorrelation. Some of the others include: Geary's c (global differences), the cross product statistic Γ, Getis and Ord's G (global multiplicative), Ripley's K (cumulative pairs over distance), the spatial autoregressive parameters ρ and λ, Getis and Ord's G_i and G_i^* (local clustering), Anselin's I_i and c_i (local indicators of spatial association (LISA)), Ord and Getis' O (a local representation taking into account global autocorrelation), Matheron's $1/\gamma$ (inverse of the semivariogram; i.e., the correlogram).

Research value

The concept of spatial autocorrelation plays a crucial role among spatial modelers. Its explication since the early 1970s corresponds with the ever-growing number and type of models that have been used to explore phenomena in many academic fields. As the use of georeferenced data has increased, so too has the recognition that spatial autocorrelation in one form or another is a fundamental element of *all* spatial models.

The concept in its many forms provides tests on model misspecification; determines the strength of the spatial effects on any variable in the model; allows for tests on assumptions of spatial stationarity and spatial heterogeneity; finds the possible dependent relationship that a realization of a variable may have on other realizations; identifies the role that distance decay or spatial interaction might have on any spatial autoregressive model; helps to recognize the influence that the geometry of spatial units under study might have on the realizations of a variable; allows us to identify the strength of associations among realizations of a variable between spatial units; gives us the means to test hypotheses about spatial relationships; gives us the opportunity to weigh the importance of temporal effects; provides a focus on a spatial unit to better understand the effect that it might have on other units and vice versa ("local spatial autocorrelation"); helps in the study of outliers. No other concept in empirical spatial research is as central to model building as is spatial autocorrelation.

The evolution of the concept of spatial autocorrelation

The concept of spatial autocorrelation has been long in coming, but given its historical roots, when it arrived in the academy, it was already well understood and clear.

Correlation

The subject of spatial autocorrelation had been evolving long before it was given a name. Statistical correlationists go as far back as Sir Francis Galton (a cousin of Charles Darwin), who in 1850 was responsible for the creation of the correlation coefficient. The mathematical framework for correlation that we use today was provided by Karl Pearson in the 1880s and again in the 1920s by R. A. Fisher. The spatial twist on correlation came mainly from a need to compare maps and the realization that georeferenced observations generally are not independent of one another. Such well-known spatial concepts as distance-decay and spatial interaction have a rich history, but not one that can be associated directly with the concept of spatial autocorrelation. Spatial autocorrelation is more closely linked to statistical theory than to spatial theory. This is not to say that the very same scholars who concerned themselves with spatial theory were unaware of the idea of spatial correlation. It was they who, being sensitive to the peculiarities of the spatial point of view, adopted and expanded the use of the concept.

Temporal autocorrelation

Serial autocorrelation has long been a subject of study in econometrics. In the early 1950s, Durbin and Watson presented their test for time series autocorrelation. It is a simple test that answers the question: Is the observation on a variable at t (where t is a specific time or time period) correlated with the $(t-1)$ observation? Normally, the test is applied to the errors in a time series model. Clearly, this is a one-dimensional test, moving from one time period to another. Spatial autocorrelation must not be thought of as the spatial extension to the Durbin–Watson test. For spatial autocorrelation, the need to identify correlation in all geographic directions, as opposed to the one-way temporal direction, does much to complicate and make special its study. Nonetheless, the various operations needed for the study of spatial autocorrelation are similar to temporal autocorrelation. In both there is a need to identify outliers, trends (temporal/spatial), degrees of association, statistical significance, and relevant models. But each of these is calculated and understood much differently, and it is spatial autocorrelation that is the more complex and multi-faceted.

Spatial concepts

In the academic world, finding the first person to have done this or that usually ends up some time in the Renaissance. We are incrementalists, adding a point here, a coefficient, a nuance, an insight, a reworked equation there. Some concepts take hold and are further built upon, and some fall by the wayside. Even those ideas forgotten for many years are eligible for revival as societies and technologies change. In the case of spatial concepts, scholars have been addressing the idea of distance effects for a very long time. Ernest George Ravenstein and his laws of migration written in 1885 can be linked even further back to von Thünen (*The Isolated State*, 1826) and to others before him. But the lines backward are never straight, and it is not always clear what the links are.

The mid-1950s

In geography, the cartographer Arthur Robinson (1956) sensed that it was necessary to take the geometry of spatial units into account when evaluating map correspondence. He thought it necessary to weight observations according to the influence of each observation, especially by size. Following from Robinson, Edwin Thomas, in his search for missing independent variables, recognized the importance of mapping residuals from least squares regression (Thomas and Anderson 1965). He saw that weighting observations for the study of the pattern of residuals increased the legitimacy of any resulting research outcomes.

The spatial autocorrelation concept was bred at the University of Washington in the late 1950s, principally by Michael F. Dacey, mainly in the presence of William L. Garrison but also Edward Ullman, two geographers very much influenced by the central place work of the 1930s German economic geographer Walter Christaller. Among others, Garrison and Ullman's students included Dacey, Brian Berry, William Bunge, Duane Marble, Richard Morrill, John Nystuen, Waldo Tobler, and this author, all of whom became spatial analysts. The "Washington

School'' defined a discipline where spatial concepts were fundamental to geographic understanding. That is, the School emphasized the role of relative location as a major factor in the need to better understand the nature of human activity. To this end they searched for meaning where locations and distances between locations are strongly taken into account. This intense spatial research environment was extended to a Chicago-Northwestern axis when Berry went to the University of Chicago in 1958 and Garrison, Marble, and Dacey took positions at Northwestern University in 1960, 1963, and 1964, respectively. Interestingly, the sense of spatial autocorrelation was felt in these environments but the term was not coined until Andrew D. Cliff and J. Keith Ord's 1968 paper presentation.

The pioneering work of Walter Isard in the 1950s that created the field of regional science had a substantial impact on those economists, planners, and geographers who were inclined to study economic location problems. Isard was much influenced by the work of early economic spatial analysts such as von Thünen, Weber, Ponsard, Christaller, and Lösch, among others. His book *Location and Space Economy* (Isard 1956) was studied at the University of Washington and by Isard's adherents at the University of Pennsylvania and at Harvard University's Regional Science Research Group. His energy, intelligence, and organizing abilities not only helped to create a new academic field, regional science, but he singlehandedly introduced regional science to Pennsylvania, Harvard, and Cornell Universities. Although Isard, an economist, did not deal with the concept of spatial autocorrelation, he did emphasize spatial interaction models where distance-decay and cost-distance were fundamental concepts. He influenced many regionally oriented economists and the spatial analyst geographers, and, in fact, hired both Marble and Dacey in 1960 and 1961, respectively, at Penn before they left for Northwestern to join Garrison again.

Development of join count statistics

Three statisticians laid out the mathematical characteristics of spatial autocorrelation, although they used the term *contiguity ratio* to describe their work. Moran (1948), Krishna Iyer (1949), and Geary (1954) developed join count statistics based on the probability that neighboring spatial units were of the same type (black or white) more than chance would have it. Their work was extended to take into account interval data. Geary emphasized that the mapped residuals from regression analysis (ordinary least squares) must display the characteristic of independence. All that remained were for applied spatial analysts to find this work and translate it into operational terms that they could best understand. This link was created by Brian Berry and Duane Marble who included papers on join count statistics by Dacey and Geary in their influential book *Spatial Analysis: A Reader in Statistical Geography* (1968).

The 1960s

In the mid-1960s, Andrew D. Cliff, a Master's graduate student influenced by Dacey at Northwestern University, returned to his native England to continue studies toward a Ph.D. at Bristol University. At Bristol, Cliff met John Keith Ord, a newly minted Ph.D. in theoretical statistics from the London School of Economics, who taught in the economics department. For the next two decades Cliff and Ord together would originate and contribute heavily to the specifically spatial autocorrelation literature. Bristol was a hotbed of spatial analysis research headed by Peter Haggett, who had been in touch with and was in regular contact with the Washington spatial analysts, especially Brian Berry.

The conceptual expression

Dacey realized that the study of spatial structure as it had evolved to 1960 in geography failed to create a ''well-developed conceptual and methodological framework that organizes and structures the description, classification and analysis of spatial distributions.'' (1973, p. 131). Dacey pointed out that in geography those who studied map distributions overlooked the patterns' potential for the construction and testing of geographic theory. Since the study of and specification for spatial autocorrelation are so closely tied to the geometry of the spatial units in question, it would seem that spatial autocorrelation theory would evolve from the study of patterns of variables on maps. As Fred Schaefer, a geography theorist whose work was read by Dacey and his fellow graduate students at the University of Washington, said, ''Geography . . . must pay attention to the spatial arrangement of the phenomena in an area and not so much to the phenomena themselves. Spatial relations are the ones that matter'' (1954). It was Dacey's recognition of the possible effect of the shapes, sizes, and boundaries of regions (he called it *topological invariance*) on the results of analyses that helped to create the concept of spatial autocorrelation (1968). Dacey, the first geographer to cite Moran, Krishna Iyer, and Geary, further explicated join count statistics, extending the number of colors studied from 2 to k, and showed clearly the link between the study of nominal and interval data (1968).

First mention

Until 1968, spatial autocorrelation had been called ''spatial dependence,'' ''spatial association,'' ''spatial interaction,'' ''spatial interdependence,'' among other terms. In fact, in the 1950s, a motivating force that revived a moribund geography discipline was focused on the near neighbor association between all sorts of human phenomena. The social physicist, John Q. Stewart and his colleague and adherent at Princeton, the geographer William Warntz, did much to explicate the nearness hypothesis. For 200 years, since the early 1800s, scholars had identified a distance decay effect that George Kingsley Zipf, in 1949 would elevate to law status in his landmark book, *Human Behavior and the Principle of Least Effort: An Introduction to Human Ecology*. But it was not until the regional science conference paper by Cliff and Ord of 1968 that the term spatial autocorrelation made its way into the lexicon of phrases used by spatial analysts. Moran (1950) had used the term spatial correlation and Whittle (1954) refers extensively to autocorrelation in a spatial context, although the words are not juxtaposed.

Cliff and Ord had realized, as others before them, that the special case of correlation in space, when there is a relationship between nearby spatial units of the same variable, would need to be identified if answers to research questions were to be answered carefully (Cliff and Ord 1973, 1981). The 1968 conference paper was published in 1969 under the title ''The Problem of Spatial Autocorrelation'' (Cliff and Ord [1969]). They recognized what is known as the misspecification problem in spatial analysis, that is, models that required traditional statistics for their evaluation were misspecified if they did not take spatial autocorrelation into account. In addition, Berry and Marble, in their introduction to their 1968 edited volume, while discussing the contributions contained therein, use the term ''spatial autocorrelation'' as an alternative to Moran's use of the term ''contiguity'' (1968, p. 2).

Formal explication

The monograph *Spatial Autocorrelation* by Cliff and Ord was published in 1973. I have written on the academic association of Cliff and Ord before (Getis 1995). Suffice it to say here that their explication, mathematization, and examples laid the groundwork for what was '' . . . a path-breaking monograph that came to have an enormous impact on geographical data analysis . . . They shed light on the problem of model misspecification owing to spatial autocorrelation and demonstrated anew statistically how one can test residuals of regression analysis for spatial randomness.'' (1995, p. 243). Perhaps their most important contribution was to explicate and generalize Moran's earlier work. The moments of Moran's distribution, called *Moran's I,* were fully developed by Cliff and Ord under varying sampling assumptions. Tests on nominal as well as interval-type data were outlined in detail. A second book by the same authors, published in 1981, clarified a number of spatial autocorrelation issues by further developing theory and providing examples over a range of geographic problems.

In 1977, when the concept of spatial autocorrelation was just being understood by spatial analysts, Reginald Golledge, a colleague and friend of such spatial analysts as Leslie Curry and Leslie King, arrived at the University of California Santa Barbara. Golledge and Lawrence Hubert, a pyschometrician interested in clustering who was there at the time, began discussing the principles of spatial association (Hubert and Golledge 1981). In his own work, Hubert had already begun to look for generalizations of spatial structure. Their collaboration resulted in a series of papers that developed the general principles of the spatial association of georeferenced variables. The work (with Constanza) appeared in several journals, most importantly *Geographical Analysis* and *The Journal of Mathematical Psychology*. When their articles were published in 1981, the work represented a part of the beginning of a field that still had only a modest number of adherents. By the late 1980s, however, the field of spatial structure by means of the study of spatial autocorrelation had advanced significantly. Golledge must be seen not only as an eminent spatial behavioralist but also as one of the founders of the spatial autocorrelation movement. In an article, Getis provides a table listing a wide variety of spatial association formulations that conform to the spatial cross product statistic of Hubert and Golledge (Getis 1991).

Fundamental to the field of geostatistics

In the field of geostatistics, the geologist-statistician Matheron (1963; the shortened English version of the 1962 French volumes) developed the idea of intrinsic stationarity and the resulting variogram, but did not use the term spatial autocorrelation. Nor did Noel Cressie (1991) in his 800-page discussion of geostatistics, *Statistics for Spatial Data*, a defining text for the field of geostatistics, mention the term spatial autocorrelation, although he spelled out the implications for the study of spatial dependence in dazzling detail. The term correlogram, used in a few instances, represents spatial autocorrelation. Interestingly, Cressie says, ''I do not advocate cross-validation for confirmatory data analysis (e.g., hypothesis testing, standard error estimation, etc.) at this time, because the correlations between data give rise to complicated distribution theory that needs further study.''(p. 104) In essence, the field of geostatistics assumes spatial autocorrelation exists by adopting for spatial data the concept of intrinsic stationarity, a term that implies that spatial effects can be described by the variogram, a distance decline, increasing variance function.

Fundamental to the field of spatial econometrics

In 1966, Jean H. P. Paelinck discussed a new field that he named *spatial econometrics* in 1974 (Paelinck and Klaassen 1979). The field of spatial econometrics is held together by various tests on the spatial autocorrelation that might exist in spatial economic and related data. Although they recognize the usefulness of the Moran-type tests outlined by Cliff and Ord, Paelinck and Klaassen describe tests on spatial parameters that embody spatial autocorrelation effects. These parameters are fundamental to the creation of spatial autoregressive models, the current mainstay of spatial econometrics.

Residual study

When we realize just how much researchers depend on ordinary least squares (OLS) models, it becomes clear that regression analysis is at the center of most social science research. The assumptions required for OLS include that residuals from the model are normally distributed. All explanatory variables are contained within the model proper, and any residual or unexplained variation must be just that, unexplained. There is to be no discernible spatial pattern to the error term. All properly specified OLS regression models must have normally distributed residuals about the least squares line for each location (observation) *and* residuals must be randomly distributed in the mapped region of study. It is now *de rigueur* for all OLS models that employ georeferenced data to be evaluated for the existence of spatial autocorrelation on the mapped residuals.

Spatial weights

In recent years, an infant industry has emerged where spatial econometric researchers specify new and different types of spatial weights matrices as they seek verification of their spatial models. Aldstadt and Getis (2006) spell out the nuances of this selection process. Needless to say, there are many ways to come to grips with this modeling requirement. In the literature, well over a dozen different schemes have been created.

Models containing spatially autocorrelated variables

Luc Anselin, who studied economics, econometrics, and urban and regional planning in Belgium, and who was infuenced by the writings of Tinbergen and Theil, came to the United States in 1977 to do M.A. and Ph.D. work in regional science at Cornell. His dissertation and research writings at Cornell in the early 1980s, in the presence of Walter Isard and his regional science colleagues, inspired Anselin to prepare *Spatial Econometrics: Methods and Models* (1988). In so doing, Anselin brought the various writings of the spatial analysts to bear on the study of spatial econometric models. The book became the fundamental text on spatial econometrics, a field that centers on the spatial autocorrelation concept. Anselin's later contributions to the field of spatial econometrics and his work on sophisticated software have had an enormous effect on theoretical scientists and practitioners interested in better understanding the nuances of the concept.

The fundamental goal of the book is to create a comprehensive approach to understanding the spatial effects contained in the kind of econometric models that require georeferenced data for their estimation. Anselin developed a typology of spatial autoregressive models and then dealt with the requirement that they be estimated and tested properly. In the process of explaining the characteristics of spatial econometric models, he explored the subjects of spatial dependency and spatial heterogeneity. In his discussion, he outlines clearly the characteristics and subtleties that spatial autocorrelation brings to bear on spatial modeling and emphasized the importance of the spatial weights matrix and of the various spatial autocorrelation statistics.

In the book, Anselin spells out in detail an econometric perspective on spatial effects. If economists were so inclined, they would have seen in the book a treatment of their subject that follows in the tradition of the then current econometrics texts. They would have learned that a failure to treat spatial effects when it was appropriate to do so would misspecify their models. Although it took years for Anselin's message to begin to affect the thinking of economists, Anselin's treatment of economic models was not lost on a cadre of regional scientists and geographers. They saw in his work the beauty of a formal spatial analysis that when fully understood could create a spark of scientism that would help them bypass the difficulties of making spatial theory empirically testable.

The recent literature

A large literature has now been developed that considers spatial autocorrelation from many vantage points. At the risk of omission, I will mention briefly those most closely associated with contributions to the conceptual understanding of spatial autocorrelation after the publication of Anselin's (1988) book. Perhaps most publications can be found in the fields of ecology and biology (see *Google Scholar* on Sokal, Oden, Legendre, and Fortin, for example). The concept also has become of considerable interest to geneticists (see Epperson). The contributors to the exploration of the concept in geography and regional science now number over 100 scholars. Besides those mentioned above, Griffith, Haining, Boots, Wartenberg, Hepple, Openshaw, Mulligan, Tiefelsdorf, Rogerson, Bivand and Arbia have contributed significantly to deepening and broadening our understanding of the concept (see *Google Scholar* for specific contributions). Rey, Florax, and Fingleton have delved deeply into the mathematical structures of spatial autocorrelation statistics. The economists Le Sage, Kelejian, McMillen, Pace, Can and Dubin have done much to create new and sophisticated statistics, particularly geared to economic data. An entirely new approach to the use of the concept is the geographically weighted regression work of Fotheringham, Brunsdon, and Charlton. Those in remote sensing are becoming aware of the concept through the work of Congalton and DongMei Chen. In the medical field, writers such as Jacquez and Wilson have had considerable impact on the emerging spatially oriented research in that field. Statisticians such as Diggle, Ripley, Goovaerts, and Kulldorff continue to create new ways to explore patterns on maps. Insights on uses of the concept have come from many—for example, Fischer and nueral nets; Leung and fuzzy sets; Bivand and software tools; Tobler, Mulligan and Fik and spatial flows; Okabe and Sadahiro and networks; Aldstadt and clustering; Baker and Timmermans and spatial behavior in the marketplace. In addition to some of those scholars mentioned above, important text books on the subject have been prepared by Goodchild, Odland, Upton, Bailey and Gatrell, Arlinghaus, Bennett, Griffith, and Batty and Longley. A further list of empirical contributions would be extensive indeed. Clearly, this is an active field.

By-products of the movement

From global to local

In the 1990s, the idea of spatial autocorrelation was extended to local conditions. Getis (who met Ord at Bristol in the 1960s) and Ord showed how, by a relatively simple variation on a basic autocorrelation statistic that they called G, one could focus on the possible spatial association of designated observations to a single observation i. They developed a local statistic called G_i and another called G_i^* (Getis and Ord 1992). The first considers the ith observation but does not include it in its calculations, while the second includes the ith observation in the analysis. These local statistics helped to distinguish the more general, global statistics like Moran's

I, from the apparent need to identify hot spots in mapped variables. Anselin introduced local Moran's *I* and local Geary's *c* statistics (Anselin 1994). He was able to show that the local values were proportional to their global values. These statistics were named by Anselin as *LISA*, Local Indicators of Spatial Association. All of these local statistics are used to identify hot spots or possible centers of statistically significant clustering. The use of one or another of these statistics is contingent on what question is being asked of the data. As a sidelight, Ord and Getis in (2001) developed what is called an *O* statistic. The need for such a statistic became evident when it was realized that local statistic outcomes are influenced by the degree of spatial autocorrelation in the global statistic.

Explicit spatial effects (filtering)
It is not an uncommon question for researchers to want to know the degree to which the spatial effects influence model outcomes. To this end, Getis and Griffith (2002) have proposed spatial filtering procedures. The idea is to separate the spatial effects (remove the spatial autocorrelation from variables included in spatial models) and then insert them into models so that the spatial element can be evaluated separately from the substantive variables. Getis' technique depends on the use of local statistics to identify the spatial influence extant in each observation, while the Griffith method is aimed at extracting the spatial effects in the form of eigenfunctions from a matrix containing the spatial relationships between all pairs of observations (the spatial weights matrix). The main point, however, is that Griffith produced a volume which integrates the literature on filtering with that on spatial autocorrelation (2003).

The future

In recent years, perhaps the most important contributions to the study of spatial autocorrelation have evolved from the outstanding software that has been created to deal with many of the questions mentioned in this paper. Most recently, *GeoDa* by Anselin, an outgrowth of *SpaceStat*, a sophisticated spatial econometrics package, has done much to popularize and educate researchers about spatial autocorrelation (Anselin, Kho, and Syabri 2006). In some ways, these user friendly programs have revolutionized scientific inquiry. In the future, scientists will have much to say about the acceptability of a data-driven approach to research. GeoDa emphasizes the exploration of spatial data and aids in the selection of useful research models. Just 30 years ago, it was much less acceptable to search for appropriate models—the idea among social scientists had been to state or create a theoretical model for testing purposes, not start with the data.

In addition to GeoDa, special packages such as Rey's *STARS* hold considerable promise for social scientists (Rey and Janikas 2006). The STARS package emphasizes the study of spatial autocorrelation over time and the creation of space-time models. Moreover, ESRI, the leading GIS software company, is constantly upgrading and expanding its presentation of spatial software. In the future, we can expect a great deal more from ESRI that will cover specific types of spatial problems.

An area of great interest is the further understanding of just what is meant by ''spatial relations.'' As we have discussed it in this article, the geometric matrix is supposed to embody the distance or other spatial relationships between spatial units. Currently, there is much experimentation on how that matrix should be constructed. One can expect a great deal of research on the ''spatial'' side of the spatial autocorrelation concept. It remains to be determined just what is the worth of a unit of distance. Should these units be translated into variables such as cost, effort, friction, decay effect, and so on? With societies more conversant with distance concepts—in particular, spatial autocorrelation—surrogates for distance effects that are well understood and accepted in the research environment will be found.

Although research using the concept of spatial autocorrelation increased in the 1970s, it was not until desktop computers became widely used in the early 1980s that empirical examples of its use could be carried out with relative ease. Today, there seems to be no bounds on the size of data sets and the complexity of software packages. With GeoDa, an entire generation of spatial researchers, small in number when Anselin first wrote but now numbering in the thousands, is learning how to present data in new and spatially provocative ways. Researchers in the medical, environmental, and earth sciences as well as the social sciences are flocking to spatial research as never before. Nearly all the major journals that concern themselves with the ecological aspects of their subjects print articles having a spatial autocorrelation foundation.

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