Title
GIS and Spatial Analysis—NCGIA Research Initiative 14, Closing Report

Authors
Rogerson, Peter A.
Fotheringham, A. Stewart
Pellegrini, Pasquale

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Research Initiative 14:

GIS and Spatial Analysis

Closing Report

by

Peter A. Rogerson
University at Buffalo

and

A. Stewart Fotheringham
University of Newcastle

Report prepared with the assistance of
Pasquale Pellegrini
University at Buffalo

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Abstract

This report describes the results of NCGIA Research Initiative 14 on "GIS and Spatial Analysis." After an introduction, it assesses the initiative in detail, according to five criteria: research accomplished, research agenda development, contribution to GIS education, implications for science policy, and comments on the research initiative process. Included in the report are a list of participants at the initiative's specialist meeting, and a table of contents for the recently held meetings on GIS and Spatial Analysis in Bristol.

1. Background

There is an increasing demand for GISs to include the ability to analyze the spatial data that they store and display. However, traditional forms of statistical analysis are often unsuitable for spatial applications, or are not easily generalizable to the spatial domain. Space, being more than unidimensional, creates a unique set of problems and impediments for the analyst. This initiative focused upon the interface between these spatial statistical problems and geographic information systems, a major goal being to advance the capabilities of GIS in facilitating spatial statistical analyses.

1.1 History of the Initiative

A proposal for a National Center for Geographic Information and Analysis (NCGIA) Initiative on Geographic Information Systems (GIS) and Spatial Analysis was first submitted to the Scientific Policy Committee of the NCGIA in March of 1989. It was formally resubmitted in June of 1991 after being divided into separate proposals for initiatives in “GIS and Statistical Analysis” and “GIS and Spatial Modeling”. The essence of the former of these two proposals was accepted and evolved into the more generic “GIS and Spatial Analysis” initiative that was approved, with the expectation that an initiative emphasizing spatial modeling would take place at a later date.

The initiative was led by Stewart Fotheringham and Peter Rogerson. The Specialist Meeting was held at Humphrey's Half Moon Inn, in San Diego, CA. This meeting was held in April of 1992, just prior to the annual meetings of the Association of American Geographers (which were also held in San Diego). This resulted in significant cost savings on NCGIA-related travel; we were also able to attract an excellent set of participants without offering travel expenses. Approximately $2,000 was also donated by the Mathematical Models Commission of the International Geographical Union toward the cost of the Specialist Meeting. Of the 40 participants, 26 were academics, and the remainder were from government agencies and the private sector. A list of participants is included as an appendix to this report.

A full paper was required of all academic participants, and all complied. A subset of the papers were selected for presentation on Day One of the meeting. Based on the content of these papers, participants were divided into four working groups for Days Two and Three of the meeting. The working groups were as follows:

Linkages Between Spatial Analysis and GIS
Spatial Data Analysis and GIS
Pattern Recognition, Complexity, and Data Models
Locational Analysis and Planning Applications with GIS.

Full reports of these working groups may be found in the Report on the Specialist Meeting (*NCGIA Report 92-11*; Fotheringham and Rogerson, 1992), together with abstracts submitted by each participant.

The impetus for this NCGIA Research Initiative was the relative lack of research into the integration of spatial analysis and GIS, and the potential advantages in developing such an integration. From a GIS perspective, there is an increasing demand for systems that "do something" other than display and organize data. From the spatial analytical perspective, there are advantages to linking statistical methods and mathematical models to the database and display capabilities of a GIS. Although the GIS may not be absolutely necessary for spatial analysis, it can facilitate such analysis and may even provide insights that would otherwise be missed. It is possible, for example, that the easy representation of spatial data and model results within a GIS could lead to an improved understanding both of the attributes being examined and of the procedures used to examine them. This NCGIA Research Initiative helped to lead the way in describing the potential of GIS for facilitating spatial analytical research. A facet of the initiative conceived at an early stage was its focus on substantive applications in the social sciences. There is however an equally strong potential for interaction between GIS and spatial analysis in the physical sciences.

The objectives of the initiative are in keeping with the aims of the National Center, as identified in the original guidelines from the National Science Foundation. The original solicitation for a National Center for Geographic Information and Analysis circulated by the National Science Foundation in 1987 contained as one of its four goals to "advance the theory, methods, and techniques of geographic analysis based on geographic information systems in the many disciplines involved in GIS research" (National Science Foundation, 1987, p. 2). The solicitation also notes that the research program of the NCGIA should address five general problem areas, including "improved methods of spatial analysis and advances in spatial statistics."

Geographic information systems initially developed as tools for the storage, retrieval, and display of geographic information. Capabilities for the geographic analysis of spatial data were either poor or lacking in these early systems. Following calls for better integration of GIS and the methods of spatial analysis, various alternatives have now been suggested for such an integration (Openshaw 1990; Haining and Wise 1991; Rowlingson et al. 1991). As Fotheringham and Rogerson (1993) note, "progress in this area is inevitable and ... future developments will continue to place increasing emphasis upon the analytical capabilities of GIS."

Consideration of the integration of spatial analysis and GIS leads naturally to two questions: (1) how can spatial analysis assist GIS, and (2) how can GIS assist spatial analysis? Under these general headings, a myriad of more specific questions emerge. The following are representative (but not exhaustive) specific questions given to participants prior to the specialist meeting:

1. What restrictions are placed on spatial analysis by the modifiable areal unit problem and how can a GIS help in better understanding this problem?

2. How can GIS assist in exploratory data analysis and in computer-intensive analytical methods such as bootstrapping and the visualization of results?

3. How can GIS assist in performing and displaying the results of various types of sensitivity analysis?

4. How can the data structures of a GIS be exploited in spatial analytical routines?

5. What are the important needs in terms of a user interface and language for spatial analysis performed on a GIS?

6. What are some of the problems in spatial analysis that should be conveyed to a GIS user and how should these problems be conveyed?

1.2 Outline of this Report

The remainder of this report addresses the five questions to be answered in closing reports for initiatives (as suggested by a subcommittee of the NCGIA Board of Directors). In the next section, we describe research accomplished and progress on the research agenda. In Section 3, we discuss the contribution of the initiative to GIS education. In Section 4, on science policy, we discuss recommendations to promote further advancement of knowledge in this area. In Section 5, we discuss the research initiative processes. The report concludes with sections that document publications related to the initiative, and appendices of meeting participants, etc.

2. Research Accomplished and Progress on the Research Agenda

(a) What do we know now that we did not know before about the questions addressed by the initiative?

(b) How has the research agenda in this area changed as a consequence of activities of the initiative?

The specialist meeting resulted in the publication of two substantial works. A book entitled *Spatial Analysis and GIS*, edited by Fotheringham and Rogerson, contains a subset of the papers prepared for the specialist meeting, and was published in 1994 by Taylor and Francis. A special issue of the relatively new journal *Geographical Systems*, with Fotheringham and Rogerson as Guest Editors, also contains a subset of the papers prepared for the specialist meeting; this special issue also appeared in 1994.

A brief description of these publications reveals the nature of the work that was accomplished by the participants of the specialist meeting. The book is divided into three major sections. The first section is entitled "Integrating GIS and Spatial Analysis: An Overview of the Issues." The papers in this section focus upon some of the broader issues associated with the integration of spatial analysis and GIS. All of the authors provide assessments of the potential benefits of improved linkages, and they are unanimously positive and optimistic in their evaluation of that potential. They find room for contributions of both exploratory and confirmatory statistical analyses operating in concert with GIS. The second section is "Methods of Spatial Analysis and Linkages to GIS." The beginning of the section continues to focus on the very substantial benefits to be gained from linking exploratory data analysis and GIS. The other papers in this section pay more attention to the specific linkages between spatial analysis and GIS, including the role of object-oriented programming in facilitating the development of spatial models within GIS. The final section of the book is headed "GIS and Spatial Analysis: Applications." These applications provide an "up close" look at some of the details of linking spatial models and GIS, thereby exposing some of the problems encountered, along with the benefits achieved.

The special issue of *Geographical Systems* on Spatial Analysis and GIS contains five papers, as well as an introduction by Fotheringham and Rogerson. These include some of the more technical papers from the specialist meeting. The papers are in many ways diverse in the problems they address, but they all have important implications for the interface between spatial analysis and geographic information systems. Among the areas of focus are multivariate spatial models, the estimation of correlograms, expert systems, and cellular dynamics. Paul Densham discussed the variety of strategies that may be followed in integrating spatial analysis and GIS, including the programmer's perspective, the user's perspective, and the conceptual perspective. He concludes with the important point that "to develop effective...systems...with reasonable expenditures of time, effort, and money, GIS must provide better tools for integrating modeling capabilities....Modelers and analysts must either take a proactive role in the conceptual design of GIS...or they must accept the *status quo*."

Following the specialist meeting, the work of the initiative proceeded in a coordinated fashion at the Buffalo and Santa Barbara NCGIA sites and at sites outside the center. The publications resulting from these activities are listed below, along with the publications arising from the specialist meeting. Among other areas, significant advances were made in linking spatial and statistical analysis to GIS; in developing teaching materials in the subject matter of the initiative; in furthering our understanding of significant and persistent problems such as the modifiable areal unit problem (MAUP) and areal interpolation; in advancing the theory and methods of spatial statistics, and disseminating the results in the form of a software package (Luc Anselin's SPACESTAT); in working with the software industry to advance the functionality available through their products; in spatial data analysis methods for the spherical surface; and in further developing our techniques of exploratory spatial data analysis.

Several significant meetings were held during the lifetime of the initiative, either to explore significant topics within the overall agenda, or to advance the objectives of the initiative through collaboration with other groups. Numerous presentations were made by the leaders and principal participants on the work of the initiative. In February 1993 Luc Anselin (Santa Barbara) organized a workshop in Santa Barbara with the specific objective of furthering the methodology of exploratory spatial data analysis (ESDA); it was attended by 25 participants from the U.S., UK, and Ireland, who presented papers, demonstrated software, and discussed prospects for future research. A subsequent meeting on ESDA was held in Augsburg in October 1994 under the auspices of the

European Science Foundation's GISDATA program. In December 1993 the GISDATA program held its own specialist meeting on GIS and Spatial Analysis in Amsterdam, at which the NCGIA initiative was represented by Luc Anselin (West Virginia University) and Noel Cressie (Iowa State), and an associated book is in press. Further details on these and other initiative activities can be found in the Annual Reports of the center for Years 4, 5, and 6.

Several general themes have emerged from the initiative. One concerns the relationship between GIS and exploratory and confirmatory modes of analysis and which is the subject of commentary elsewhere (Fotheringham, 1993). The adjective "exploratory" usually describes those analytical methods where the results **suggest** hypotheses, while "confirmatory" analyses are used to **test** hypotheses, although the distinction between the two is at times fuzzy and there are several types of statistical analysis that could fall into both areas. Although connections between GIS and confirmatory statistical packages have been established, there is great potential for new insights in the combination of GIS and exploratory techniques. GIS are data rich and contain excellent display capabilities; exploratory data analysis is data-hungry and generally visual. Real gains in exploratory spatial data analysis may result from the integration with GIS; Fotheringham (1993) describes several specific areas of research that could profit from this integration.

A second general theme is that of the relationship between GIS and the development of geographic theory. Much empirical based research suggests theory or tests it, both actions being integral components of the development process. GIS should be seen as a tool which can assist in the development of geographic theory through facilitating empirical research. The integration of GIS and spatial analysis is aimed therefore at only a subset of spatial analysis; that which deals with applied spatial modeling and with empirical analysis. Within those limits, the technology should prove extremely useful. There is an opportunity to utilize the power of GIS technology to help understand some basic geographic problems such as the sensitivity of analytical results to zone definition, the nature of spatial nonstationarity, and the definition of spatial outliers.

Finally, it remains to be seen what further insights into the analysis of spatial data will be generated by the access to excellent display capabilities, database operations, and spatial querying facilities a GIS provides. The next decade should see a surge in interest in spatial analysis both from within geography and from other academic disciplines as well as the private sector. It is therefore inevitable that geographic information systems will have increasingly sophisticated spatial analytical capabilities; this volume serves to signal what lies ahead. It is perhaps fair to say that we have spent to this point spent a large amount of time "reinventing the wheel", that is, getting methods that are already operational running in a GIS environment. It is now time, and the future seems promising, to go beyond this to use the capabilities of GIS to enhance models and methods and to make them more efficient.

3. Contribution to GIS Education

How has the education of GIS scientists been enhanced by the initiative?[1]

There have been both direct and indirect effects on the education of GIS scientists. A number of students, including Andrew Curtis and Pasquale Pellegrini at Buffalo, and Uwe Deichmann at Santa Barbara, are carrying out their Ph.D. dissertations in areas directly related to the initiative. The software described in section 6.7 will also prove instrumental in training future generations of GIS scientists, as will some of the publications by specialist meeting participants. For example, Rogerson and others are planning to use the new book by Bailey and Gatrell (*Interactive Spatial Analysis*), which is bundled with the INFO-MAP software, in graduate level training.

4. Science Policy

Does NCGIA have any recommendations to Academe, Professional Organizations, or to NSF on policy decisions that would promote the further advancement of knowledge in the research area addressed by the initiative?

In Section 5 of the closing report for Initiative 13, on User Interfaces for Geographic Information Systems, it was suggested that "topics in the form 'GIS and X' may imply separability of substantive and technical aspects which cannot and should not be separated." We hope that the title of Initiative 14, "Spatial Analysis and GIS," does not connote such separability. In fact we feel that it is extremely important to emphasize the coupling of GIS with other endeavors such as spatial analysis. The ultimate strength of GIS in maintaining and improving the strength of the discipline in geography may well lie not in GIS per se, but rather in how geographers manage to use their comparative advantage in areas such as spatial statistics and modeling together with GIS.

[1] It might be more appropriate for the question above to refer to the training of scientists in the area of geographic information systems and geographic analysis_this initiative in particular does not have as its goal the education of "GIS scientists", but rather the training of students in the interface between GIS and spatial analysis.

5. The Research Initiative Process

What were the strengths and weaknesses of the research initiative process in facilitating the research in the initiative?

Strengths

The initiative process worked very well for I14. The primary intent was to call further attention to, and to encourage research in, the integration of GIS and spatial analysis. The large and significant set of subsequent work spawned by the specialist meeting participants over the last two and one-half years signals the success of this effort. The specialist meeting format_with the first day dedicated to paper presentation, and the second and third days devoted to small groups and discussion, worked well. Numerous activities (e.g., the collaborative book by Bailey and Gattrell and the genesis of the new journal *Geographical Systems*) trace part of their origins to the specialist meeting.

The initiative process also worked well in leading to tangible and significant publication outlets for specialist meeting papers (namely, the book *Spatial Analysis and GIS*, edited by Fotheringham and Rogerson, and the special issue of *Geographical Systems*, also edited by Fotheringham and Rogerson). It also supported subsequent meetings, presentations, and workshops; research by center and other faculty and students on initiative topics, and publication of results.

Weaknesses

One aspect of the initiative process that is a bit nebulous to participants is what is expected from them for the period following the specialist meeting. The specialist meeting of course serves to stimulate collaboration among participants, and “kicks off” research by NCGIA researchers in the area, but one could argue that more in the way of followup events would help to maintain continuity over the life of the initiative. In the case of I14, the Bristol meeting held in the Spring of 1994 helped to serve in this regard, and various conference sessions brought together researchers in the area of spatial analysis and GIS. However, it would be desirable to have a newsletter (one was originally planned for I14, but did not materialize) or some similar device to keep people in touch with one another regarding recent work. A newsletter alone would likely not suffice_what is needed is some sort of vehicle (e.g., small, intensive workshops or funds earmarked for collaborative efforts) to stimulate collaboration and group efforts.

Other comments related to the research initiative

Art Getis responded to the call for I-14 related progress with the following:

"The field of GIS and spatial analysis is an active one. I have noticed an increased interest among students for analysis in a GIS framework. Now that I am intimately associated with the new journal, *Geographical Systems*, I have become aware of a longing among academic GIS practitioners to develop analytically challenging uses for GIS in such fields as spatial decision support systems, neural nets, fuzzy sets, spatial statistics, and spatial modeling. In some ways, the development of this journal is related to the excitement stimulated by the NCGIA Initiative-14 conferences.

The initiative played a useful role in focusing attention on the development of and problems related to GIS and spatial analysis. While it sometimes appears as though the field is not moving rapidly enough because of the lag between discovery and innovation and the inclusion of new ideas into commercially available software packages, in the final analysis it is evident that the link is an active one and progress is being made. One would hope that vendors would continue to stay in touch with academics and that there would be more opportunities for the two to meet.

I hope that Initiative-14 continues in some form. There is the danger that a relaxation of institutionalized interest may impede further development of communication links between interested parties and the dissemination of ideas and innovations. The conferences and resulting publications have done a great deal to encourage new and useful work."

References

Fotheringham, A.S. and Rogerson, P.A. 1992. Report of the Specialist Meeting for Research Initiative 14: GIS and Spatial Analysis. *Technical Report 92-11*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

Fotheringham, A.S. and Rogerson, P.A. 1993. GIS and spatial analytical problems. *International Journal of Geographic Information Systems*, 7(1): 3-19.

Haining, R.P. and Wise, S.M. 1991. GIS and spatial analysis: report on the Sheffield Workshop, Regional Research Laboratory Initiative Discussion Paper 11, Department of Town and Regional Planning, University of Sheffield.

National Science Foundation. 1987. National Center for Geographic Information and Analysis. Directorate for Biological, Behavioral, and Social Sciences, Guidelines for Submitting Proposals.

Openshaw, S. 1990. A spatial analysis research strategy for the regional research laboratory initiative. Regional Research Laboratory Initiative Discussion Paper 3, Department of Town and Regional Planning, University of Sheffield.

Rowlingson, B.S., Flowerdew, R., and Gattrell, A. 1991. Statistical spatial analysis in a geographical information systems framework. Research Report 23, North West Regional Laboratory, Lancaster University.

6. RESEARCH PUBLICATIONS AND SOFTWARE PRODUCTS

6.0 Preface

The following lists represent a subset of the work that has taken place on initiative-related topics since the specialist meeting. Due to a less than 100% response from specialist meeting participants for I-14 related work, the lists are not complete. Inevitably, some material that is related to the initiative in a peripheral way may be included, but the list has been pared reasonably well in this regard. Again, there are undoubtedly many other papers, software programs, etc. that have been completed, and which are directly related to the initiative.

6.1 Refereed Journal Articles

Anselin, L., and A. Getis. 1992. Spatial statistical analysis and geographic information systems. *Annals of Regional Science* 26: 19-33.

A discussion of the role of spatial statistical analysis within a GIS. The emphasis is on the implications of the choice of data model for statistical analysis and the role for exploratory spatial data analysis (ESDA) versus confirmatory analysis. The paper also discusses the implications of GIS and GIA for research in regional science in general.

Anselin, L., and S. Hudak. 1992. Spatial econometrics in practice: a review of software options. *Regional Science and Urban Economics* 22(3): 509-536.

Batty, M., and Y.C. Xie. 1994. Modelling inside GIS. 1. Model structures, exploratory spatial data analysis and aggregation. *International Journal of Geographical Information Systems* 8(3): 291-307.

Batty, M., and Y.C. Xie. 1994. Modelling inside GIS. 2. Selecting and calibrating urban models using ARC/INFO. *International Journal of Geographical Information Systems* 8(5): 451-470.

Cressie, N., and J.D. Helterbrand. 1994. Multivariate spatial statistical models. *Geographical Systems* 1: 179-88.

One of the strengths of a geographic information system (GIS) is its capability to handle multiple layers of information through common georeferencing. Thus, statistical methods that are both multivariate and spatial should, along with the GIS, be an integral part of the

"analysis engine" that interfaces between multivariate spatial data and multivariate spatial models. Any analysis of (multivariate spatial) data has its roots in a more or less vaguely specified statistical model. This paper brings together several well-known multivariate spatial statistical models and asks what data analytic tools they engender.

De Cola, L., and N. Montagne. 1993. The Pyramid system for multiscale raster analysis. *Computers and Geosciences* 19: 1393-1404.

De Cola, L. 1994. Simulating and mapping spatial complexity using multiscale techniques. *International Journal of Geographical Information Systems* 8: 411-427.

A central problem in spatial analysis is the mapping of data for complex spatial fields using relatively simple data structures, such as those of a conventional GIS. This complexity can be measured using such indices as multi-scale variance, which reflects spatial autocorrelation, and multi-fractal dimension, which characterizes the values of fields. These indices are computed for three spatial processes: Gaussian noise, a simple mathematical function, and data for a random walk. Fractal analysis is then used to produce a vegetation map of the central region of California based on a satellite image. This analysis suggests that real world data lie on a continuum between the simple and the random, and that a major GIS challenge is the scientific representation and understanding of multi-scale fields.

Densham, P.J. 1994. Integrating GIS and spatial modeling: Visual interactive modeling and location selection. *Geographical Systems* 1: 203-219.

A variety of strategies can be used for integrating GIS and spatial modeling. These strategies can be viewed from several perspectives: the technical or programmer's perspective; the functional or user's perspective; and the conceptual perspective. Each perspective is discussed and used to evaluate software integrating location selection and GIS capabilities. When evaluated from the functional perspective, these systems are shown to support only a restricted form of human-computer interaction. GIS model linkages that support higher forms of human-computer interaction are discussed.

Ding, Y., and A.S. Fotheringham. 1992. The integration of spatial analysis and GIS. *Computers, Environment and Urban Systems* 16(1): 3-19.

Dubin, R.A. 1994. Estimating correlograms: A Monte Carlo study. *Geographical Systems* 1: 189-202.

In analyzing data that is spatially arrayed, it is often necessary to measure the spatial dependence between the observations. This dependence may be summarized by a correlogram or, alternatively, a variogram. These functions model the relationship between two observations as a function of the distance separating them. Estimating the parameters

of either the correlogram or the variogram provides a measure of the spatial dependence in the data. Estimating these parameters is, however, not straightforward. Different techniques have been proposed in the literature for this purpose. In this paper, I use Monte Carlo experiments to examine the performance of four different estimation techniques.

Engelen, G., R. White, I. Uljee, P. Drazan. 1995. Using cellular automata for integrated modeling of socio-environmental systems. *Environmental Monitoring and Assessment* 34(2): 203-214.

Fischer, M.M. 1994. Expert systems and artificial neural networks for spatial analysis and modeling: Essential components for knowledge-based geographical iInformation systems. *Geographical Systems* 1: 221-235.

Current commercially available geographic information systems tend to suffer from three major limitations: first, the logical foundation based on the classical concept of Boolean logic and classical set theory which do not tolerate imprecision in information; second, the limited built-in analytical and modeling functionality; and third, the low level of intelligence in terms of knowledge representation and processing. Geographical problems are highly complex in nature, and effective solutions require an intelligent use of large data bases, structured and unstructured knowledge. This paper makes a modest attempt to describe the architecture of a knowledge based geographic information system from a simplified view. Emphasis is laid on discussing the spatial expert system and the neural network components in conceptual rather than in technical terms.

Fotheringham, A.S. 1993. On the future of spatial analysis: the role of GIS. *Environment and Planning A Anniversary Issue* NSI: 30-34.

Fotheringham, A.S., P.J. Densham, and A. Curtis. 1995. Location-allocation modeling and the zone definition problem. *Geographical Analysis* 27(1): 60-77.

Fotheringham, A.S., and T.C. Pitts. 1995. Directional variation in distance-decay. *Environment and Planning A* 27(5): 715-729.

Fotheringham, A.S., and P.A. Rogerson. 1993. GIS and spatial analytical problems. *International Journal of Geographic Information Systems* 7(1): 3-19.

Increasingly, methods of spatial analysis are being integrated within geographical information systems. As this integration occurs, it is important to ensure that (i) users of GIS recognize the limitations of spatial analysis, (ii) researchers continue to work on removing the impediments to accurate spatial analysis, and (iii) developers of GIS consider these limitations. In this article we discuss eight general impediments that arise in spatial analyses that span a diverse range of substantive applications. Geographical information systems offer not only the opportunity to integrate various methods of spatial analysis, but also the chance to learn more about the underlying impediments.

Fotheringham, A.S., and D.W.S. Wong. 1991. The modifiable areal unit problem in multivariate statistical analysis. *Environment and Planning A* 23(7): 1025-1044.

The modifiable areal unit problem is shown to be essentially unpredictable in its intensity and effects in multivariate statistical analysis and is therefore a much greater problem than in univariate or bivariate analysis. The results are rather depressing in that they provide strong evidence of the unreliability of any multivariate analysis undertaken with data from areal units. Given that such analyses can only be expected to increase with the imminent availability of new census data both in the United Kingdom and in the USA, and the current proliferation of GIS technology which permits even more access to aggregated data, this paper serves as a topical warning.

Getis, A., and J.K. Ord. 1992. The analysis of spatial association by distance statistics. *Geographical Analysis* 24(3): 189-206.

Spatial association of a variable can be identified in a number of ways. Typical measures are Moran's I, Geary's c, join-count statistics, and the estimation of the spatial autocorrelation coefficients found in spatial autoregressive models. Introduced in this paper is a family of new statistics, G, that can be used as a measure of spatial association in a number of circumstances. The basic statistic is derived, its properties are identified, and its advantages explained. Several of the G statistics make it possible to evaluate the spatial association of a variable within a specified distance of a single point. A comparison is made between a general G statistic and I for similar hypothetical and empirical conditions. The empirical work includes a study of sudden infant death syndrome by county in North Carolina and a study of dwelling unit prices in metropolitan San Diego by ZIP code districts. Results indicate that G statistics, in general, should be used in conjunction with Moran's I in order to identify characteristics of patterns not revealed by the I statistic alone and, specifically, the G_i and G_i^* statistics enable us to detect local "pockets" of dependence that may not show up when using global statistics.

Goodchild, M.F., R.P. Haining, and S.M. Wise (and 12 others). 1992. Integrating GIS and spatial data analysis: problems and possibliities. *International Journal of Geographical Information Systems* 6(5): 407-424.

This paper is an agreed summary of a workshop held at the University of Sheffield in March 1991. The focus here is on three themes of the workshop: the mutual benefits of closer links between GIS and the methods of spatial data analysis; the specific areas of SDA that should be linked with GIS; and how the linkage should be made in practice. Directions for future research were discussed and are also reviewed. The emphasis throughout is on statistical SDA.

Goodchild, M.F., B. Klinkenberg, and D.G. Janelle. 1993. A factorial model of aggregate spatio-temporal behavior: application to the diurnal cycle. *Geographical Analysis* 25(4): 277-294.

Goodchild, M.F., L. Anselin, and U. Deichmann. 1993. A framework for the areal interpolation of socioeconomic data. *Environment and Planning A* 25(3): 383-397.

Spatial data are collected and represented as attributes of spatial objects, embedded in a plane. Basis change is defined as the transfer of attributes from one set of objects to another. Methods of basis change for socioeconomic data are reviewed and are seen to differ in the assumptions made in each about underlying density surfaces. These methods are extended to more general cases, and an illustration is provided using Californian data. The implementation of this framework within a geographical information system is discussed.

Ord, J.K., and A. Getis. 1995. Local spatial autocorrelation statistics: distributional issues and an application. *Geographical Analysis* 27(4): 286-306.

The statistics $G_i(d)$ and $G_i^*(d)$, introduced in Getis and Ord (1992) for the study of local pattern in spatial data, are extended and their properties further explored. In particular, non-binary weights are allowed and the statistics are related to Moran's autocorrelation statistic, I. The correlations between nearby values of the statistics are derived and verified by simulation. A Bonferroni criterion is used to approximate significance levels when testing extreme values from the set of statistics. An example of the use of the statistics is given using spatial-temporal data on the AIDS epidemic centering on San Francisco. Results indicate that in recent years the disease is intensifying in the counties surrounding the city.

White, R., and G. Engelen. 1993. Cellular automata and fractal urban form: a cellular modeling approach to the evolution of urban land use patterns. *Environment and Planning A* 25: 1175-1199.

White, R., and G. Engelen. 1994. Cellular dynamics and GIS: modeling spatial complexity. *Geographical Systems* 1: 237-53.

Both observation and theory support the view that spatial complexity is a necessary feature of many systems, and that far from representing mere randomness, complexity constitutes the real, information-rich order inherent in these systems. Cellular automata are particularly suited to modeling the dynamics of spatially complex systems. The approach permits an increase of several orders of magnitude in the spatial resolution of dynamic models compared to what is possible with traditional techniques, and thus permits the models to address the issues of spatial complexity directly. The cellular approach is illustrated in two models - an urban land use model which is purely cellular, and a model of a Caribbean island which combines cellular and traditional techniques. Since the models require large

quantities of data with high spatial resolution, the full power of the cellular technique can only be realized when the models are integrated with a GIS. More generally, cellular automata have the potential for converting a GIS into a dynamic modelling tool.

White, R. and G Engelen. 1994. Urban system dynamics and cellular automata: fractal structures between order and chaos. *Chaos, Solitons, and Fractals* 4: 563-83.

6.2 Books

Bailey, T.C., and A.C. Gatrell. 1995. *Interactive Spatial Data Analysis*. London: Longman.

This book consists of over 400 pages, in five parts: A Introduction: Spatial Data Analysis, Computers and Spatial Data Analysis; B Analysis of Spatial Point Patterns; C Analysis of Spatially Continuous Data; D Analysis of Area Data; E Analysis of Spatial Interaction Data. The book includes a software package, INFO-MAP, a DOS based spatial data analysis toolkit.

Fischer, Manfred M., and P. Nijkamp, editors. 1993. *Geographic Information Systems, Spatial Modelling, and Policy Evaluation*. Berlin: Springer-Verlag.

The book contains contributions from a wide-ranging group of international scholars and demonstrates the progress which has been achieved so far at the interface of GIS technology and spatial analysis and planning. The various contributions bring together theoretical and conceptual, technical and applied issues. Topics covered include the design and use of GIS and spatial models, AI tools for spatial modeling in GIS, spatial statistical analysis and GIS, GIS and dynamic modeling, GIS in urban planning and policy making, information systems for policy evaluation, and spatial decision support systems.

Fotheringham, A.S., and P.A. Rogerson, editors. 1994. *Spatial Analysis and GIS*. London: Taylor and Francis.

The thirteen chapters of this book are based on presentations made at the I14 specialist meeting in April 1992.

Lam, N. and De Cola, L., editors. 1993. *Fractals in Geography*. Englewood Cliffs, NJ: Prentice-Hall.

The book is an edited collection of original contributions on the multiple implications and applications of fractals in geography.

Longley, P., and M. Batty, editors. In press. *Spatial Analysis: Modeling in a GIS Environment*.

The book is based on presentations made at the Bristol conference in Spring 1994 which served as the closing conference for the initiative.

6.3 Book Chapters

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Bracken, I. 1994. A surface model approach to the representation of population-related social indicators. In *Spatial Analysis and GIS*, edited by A.S. Fotheringham and P.A. Rogerson. London: Taylor & Francis, pp. 247-260.

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Getis, A. 1994. Spatial dependence and heterogeneity and proximal databases. In *Spatial Analysis and GIS*, edited by A.S. Fotheringham and P.A. Rogerson. London: Taylor & Francis, pp. 105-120.

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Macmillan, W., and T. Pierce. 1994. Optimization modelling in a GIS framework: the problem of political redistricting. In *Spatial Analysis and GIS*, edited by A.S. Fotheringham and P.A. Rogerson. London: Taylor & Francis, pp. 221-246.

O'Kelly, M.E. 1994. Spatial analysis and GIS. In *Spatial Analysis and GIS*, edited by A.S. Fotheringham and P.A. Rogerson. London: Taylor & Francis, pp. 65-80.

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6.4 Conference Proceedings

De Cola, L. 1992. Multiscale interactions between topography and vegetation in Colorado. ASPRS/ACSM/RT'92, Washington DC, 12 pp.

De Cola, L. and B.P. Buttenfield. 1994. Multiscale mapping for the NSDI: data modeling and representation. GIS/LIS'94 Phoenix, 12 pp.

De Cola, L. and N. Falcone, N. 1994. Exploratory analysis of environmental interactions in central California. Electronic Open-File Report, USGS.

Fischer, M.M. 1993. From conventional to knowledge based geographical information systems. In *Proceedings, UDMS'93, 16th Urban Data Management Symposium, September 6-10, 1993*. Vienna: ADV Arbeitsgemeinschaft FCr Datenverarbeitung, pp. 17-25.

Artificial Intelligence (AI) has received an explosion of interest during the last five years in various fields. There is no longer any question that expert systems and neural networks will be of central importance for developing the next generation of more intelligent geographic information systems. Such knowledge based geographic information systems will especially play a key role in spatial decision and policy analysis related to issues such as environmental monitoring and management, land use planning, motor vehicle navigation and distribution logistics. This paper sketches briefly the major characteristics of conventional geographic information systems, and then looks at some of the potentials of AI principles and techniques in a GIS environment where emphasis is laid on expert systems and artificial neural networks technologies and techniques.

Rogerson, P. 1992. A nonparametric test for pattern detection and its use in GIS. *Proceedings, GIS/LIS '92* 2: 646-51.

6.5 Monographs and Discussion Papers

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Anselin, L., S. Hudak, and R.F. Dodson. 1993. Spatial data analysis and GIS: interfacing GIS and econometric software. *Technical Paper 93-7*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

Ding, Y., and A.S. Fotheringham. 1991. The integration of spatial analysis and GIS: the development of the STATCAS module for ARC/INFO. *Technical Paper 91-5*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

Dodson, R.F. 1991. VTGIS: the von Thunen GIS package. *Technical Paper 91-27*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

Dodson, R.F. 1993. Teaching introductory geographical data analysis with GIS: a laboratory guide for an integrated SPACESTAT/Idrisi environment. *Technical Paper 93-5*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

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Getis, A. Identifying spatial heterogeneity in a geographical information system.

In many empirical situations, knowledge of spatial dependence, that is, spatial autocorrelation or association in the data, is essential for the proper specification of models. Rather than identify the spatial assocation as an outcome of an estimation procedure in a regression analysis, I suggest that spatial homogeneity and heterogeneity be identified before any formal modeling take place. In this paper, I outline a procedure for evaluating the extent of hetergeneity in a spatial data base by use of a concept called “proximal” space. This idea brings together the geographers notions of “site” and “situation” into a single concept. An operational definition is given, and a mathematical formulation is outlined. The approach lends itself to exploratory data analysis in a geographic information system. Two typical raster data sets based on pixel values for land use in the San Diego region are used to demonstrate the usefulness of the concept and techniques. One of the sets of data represents an area of similar values with several slight trends while the other displays widely varying values over short distances.

Getis, A. Social science analysis in a geographic information systems environment.

In this paper structural elements are identified for the preparation of GIS-based data for use in social science modeling. These elements include the need to know about the special characteristics of spatial data, such as map scale, spatial dependence, spatial variance heterogeneity and spatial trend heterogeneity, and the usual problems faced by modelers, such as nonspherical disturbances, stationarity of data, heteroscedasticity, and temporally and spatially autocorrelated disturbances. Detective work proceeds on the basis of the varying structures implied by the cross product statistic. These include measures of spatial differences, covariance, and interation, and the exploratory data analysis function included in the S-Plus statistical package.

Getis, A. Exploratory spatial data analysis in a geographical information systems environment.

Two extensive data sets, remotely sensed data showing different qualities of land in the San Diego region and detailed tuna catch data over a ten year period in the eastern tropical

Pacific Ocean, are described by modern exploratory spatial data analysis techniques. A rationale based on the kinds of structural elements used in regional science modeling is developed for the data description. These elements include the need to know about the special characteristics of spatial data such as map scale, spatial dependence, spatial variance heterogeneity and spatial trend heterogeneity, and the usual problems faced by regional modelers such as nonspherical disturbances, heteroscedasticity, and temporally and spatially autocorrelated disturbances. Having laid out the framework for the exploratory analysis, the detective work is carried out for portions of the two data sets. The exploration proceeds on the basis of the varying structures implied by the cross product statistic. These include measures of covariance, interaction, differences, and the graphic techniques of box plots, pocket plots, and median polish. The results are displayed as a series of maps and graphics.

MacLennan, M. 1991. The use of a geographic information system for second-order analysis of spatial point patterns. *Technical Paper 91-19*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

MacLennan, M., A.S. Fotheringham, and M. Batty. 1991. Fractal geometry and spatial phenomena. *Technical Paper 91-1*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

Raskin, R. 1994. Spatial analysis on the sphere. *Technical Paper 94-7*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

Tobler, W.R. 1993. Three presentations on geographical analysis and modeling: Non-isotropic geographic modeling; Speculations on the geometry of geography; and Global spatial analysis. *Technical Paper 93-1*. Santa Barbara, CA: National Center for Geographic Information and Analysis.

6.6 Other Publications

Engelen, G., R. White, I. Uljee, S. Wargnies. 1993. Vulnerability assessment of low-lying coastal areas and small islands to climate change and sea level rise. Report to the United Nations Environment Programme, Caribbean Regional Coordinating Unit, Kingston, Jamaica. 100pp.

Fotheringham, A.S. and P.A. Rogerson. 1994. Spatial analysis and GIS: An introduction. *Geographical Systems* 1: 175-177.

Fotheringham, A.S. 1994. Commentary: What does "Doing a Ph.D. in GIS" mean? *Environment and Planning A* 26(1): 6-8.

Fotheringham, A.S. 1993. Commentary: Spatial musings. *Environment and Planning A* 25: 156-158.

Fotheringham, A.S. 1992. Commentary: Exploratory spatial data analysis and GIS. *Environment and Planning A* 24(12): 1675-78.

Fotheringham, A.S. 1991. Commentary: GIS and spatial analysis: an NCGIA research initiative. *Environment and Planning A* 23(10): 1390-91.

6.7 Software Products

1. Doug Martin reports that StatSci has developed the S-PLUS for ARC/INFO product in a partnership with ESRI, funded by a NASA EOCAP II contract to the StatSCi Division of MathSoft, and is now working on an S+SpaceStat add-on toolkit for S-PLUS, funded by a NASA EOCAP III contract. Rusty Dodson and Joel Michaelsen tested elements of the S-PLUS ARC/INFO interface at Santa Barbara, and developed associated tutorial modules.

2. Included with the book *Interactive Spatial Data Analysis* is a copy of INFO-MAP, wholly written by Trevor Bailey, a DOS-based product for interactive spatial data analysis and including facilities for such things as kernel estimation, K functions (univariate and bivariate), variogram estimation and kriging, spatial (auto)correlation analysis, together with a "language" that allows the user to fit models of various kinds, such as spatial regression models. "Standard" non-spatial analyses (e.g., principal components analysis, multivariate classification, non-spatial regression) are also included. To allow the user to get the "feel" of these tools the book includes 29 datasets on disk and a large number of exercises at the end of each chapter.

3. SPLANCS (the Lancaster point pattern analysis add-on to S-Plus) has been extended in areas of space-time clustering and kernel estimation by Tony Gatrell and Peter Diggle, with funding from the UK Economic and Social Research Council.

4. Members of the Department of Economic Geography, Vienna University of Economics and Business Administration developed a software package called SIM (Spatial Interaction Modelling) in July, 1994. SIM is a C-program which has been extensively tested in research situations and has proven to provide robust and efficient algorithms. The methodological and programming specifications are available from Prof. Manfred M. Fischer and Dr. Jinfeng Wang.

5. SPACESTAT is a package designed by Luc Anselin for spatial regression analysis. It is available from the author at West Virginia University.

6. SAM is a spatial analysis module designed by Ding and Fotheringham (1992) aimed at integrating specific spatial statistical measures and GIS. It is available in the NCGIA software series.

7. A beta test version of SAS/GIS will soon be released.

Conferences and Meetings Organized by I14 Participants

As a contribution to I14, NCGIA Santa Barbara hosted a workshop to examine progress and impediments to exploratory spatial data analysis, February 24-28, 1993. The meeting was organized by Luc Anselin, Associate Director at Santa Barbara. Some 25 participants presented papers, demonstrated software, and discussed prospects for future research. Attendees came from the UK and Ireland as well as from the US and Canada. The following participants attended: Michael F. Goodchild, Waldo Tobler, Uwe Deichmann, Frank Davis, Lauretta Burke, Rusty Dodson, Joel Michaelsen, Art Getis (San Diego State University, Geography), Noel Cressie (Iowa State, Statistics), Dan Griffith (Syracuse, Geography), Richard Becker (AT&T Bell), Paul Fatti (UC Riverside, Statistics graduate student), Stewart Fotheringham (SUNY NCGIA), John Haslett (Trinity College, Dublin, Statistics), Leigh Ihnen(SAS Institute, North Carolina), Ruben Klein (UC Riverside, Statistics graduate student), James Majure (Iowa State graduate student), M. Jammalamadaka, (UCSB Statistics), Neal Oden (Applied Biomath, New York), James Press (UC Riverside, Statistics), Lauren Scott (Cal State Fullerton, Geography), Robert Sokal (SUNY Stony Brook Ecology), Anthony Unwin (Trinity College, Dublin, Statistics), Mark Schildhauer (UCSB Social Science Computing Lab), and Allan Murray (UCSB Statistics).

Tony Gatrell organised, at Lancaster University in June 1993, a successful meeting on “Spatial Analysis in ARC/INFO” which attracted 30 participants, including Paul Densham and Mike Goodchild.

A meeting on “GIS and Spatial Analysis” was organized under the auspices of the European Science Foundation's GISDATA program in Amsterdam, December 1-5, 1993. U.S. participants sponsored by NSF through NCGIA were Luc Anselin (West Virginia University), previous Associate Director of NCGIA at Santa Barbara, and Noel Cressie, spatial statistician from Iowa State University and author of *Statistics for Spatial Data* (Wiley, 1993). A book is in preparation, titled *Spatial Analytical Perspectives on GIS into Environmental and Socio-Economic Sciences*, edited by Manfred Fischer, Henk Scholten, and David Unwin, and published by Taylor and Francis.

Paul Longley and Mike Batty organized a conference at Bristol, held in June of 1994. An edited book is in progress. Chapter headings are as follows:

INTRODUCTION

Chapter 1: Analysis, Modelling, Forecasting and GIS Technology
by Michael Batty and Paul Longley

PART ONE: ANALYSIS OF SPATIAL DISTRIBUTIONS

Chapter 2: Solving the Ecological Fallacy
by Neil Wrigley
Chapter 3: The Aggregation Problem in GIS

CONCLUSION

Chapter 18: GIS in Spatial Analysis: Spatial Analysis in GIS by the contributors

Initiative 14 Specialist Meeting Participant List

T. R. Bailey
Department of Mathematical Statistics and Operational Research
University of Exeter
Laver Building, North Park Road
Exeter EX4 4QH
UNITED KINGDOM

Michael Batty
NCGIA/Department of Geography
SUNY at Buffalo
Buffalo, NY 14261

Graeme Bonham-Carter
Geological Survey of Canada
Energy, Mines, and Resources
601 Booth Street
Ottawa, Ontario K1A 0E8
CANADA

Ian Bracken (deceased)
Department of City and Regional Planning
University of Wales, Cardiff
P. O. Box 906, Colum Drive
Cardiff CF1 3YN
UNITED KINGDOM

Ayse Can
Department of Geography
Syracuse University
343 H. B. Crouse Hall
Syracuse, NY 13244-1160

Noel Cressie
Department of Statistics
Iowa State University
102 Snedecor Hall
Ames, IA 50011

Andrew Curtis
NCGIA/Department of Geography
SUNY at Buffalo
Buffalo, NY 14261

Lee De Cola
United States Geological Survey
National Mapping Division
521 National Center, Room 2D330
12201 Sunrise Valley Drive
Reston, VA 22092

Paul Densham
NCGIA/Department of Geography
SUNY at Buffalo
Buffalo, NY 14261

Uwe Diechmann
NCGIA
3510 Phelps Hall
University of California, Santa Barbara
Santa Barbara, CA 93106-4060

Rusty Dodson
NCGIA
3510 Phelps Hall
University of California, Santa Barbara
Santa Barbara, CA 93106-4060

Randall Downer
Applied Biomathematics
100 North Country Road
Setauket, NY 11733

Robin Dubin
Department of Economics
Case Western Reserve University
Cleveland, OH 44106

Chuck Ehlschlaeger
US Army Construction Engineering Research Lab
2902 New Mark Drive
Champaign, IL 61821-1076

Manfred M. Fischer
Department of Economic and Social Geography
Vienna University of Economics and Business Administration
Augasse 2-6, A-1090
Vienna
AUSTRIA

Robin Flowerdew
Department of Geography
University of Lancaster
Lancaster LA1 4YB
UNITED KINGDOM

A. Stewart Fotheringham
Department of Geography
Daysh Building
University of Newcastle
Newcastle NE1 7RU

Tony Gatrell
Department of Geography
University of Lancaster
Lancaster LA1 4YB
UNITED KINGDOM

Art Getis
Department of Geography
San Diego State University
San Diego, CA 92182

Michael Goodchild
NCGIA/Department of Geography
University of California, Santa Barbara
Santa Barbara, CA 93106

Bob Haining
Department of Geography
University of Sheffield
Sheffield S10 2TN
UNITED KINGDOM

Dale Honeycutt
Environmental Systems Research Institute
380 New York Street
Redlands, CA 92373

Sheri Hudak
NCGIA
3510 Phelps Hall
University of California, Santa Barbara
Santa Barbara, CA 93106-4060

Clifford Kottman
Intergraph Corporation
2051 Mercator Drive
Reston, VA 22091-3413

Paul Longley
Department of Geography
University of Bristol
University Road
Bristol BS8 1SS
UNITED KINGDOM

Bill MacMillan
School of Geography
Oxford University
Mansfield Road
Oxford OX1 3TB
UNITED KINGDOM

R. Douglas Martin
STATSCI
1700 Westlake Avenue, N., Suite 500
Seattle, WA 98109

Giulio Maffini
INTERA TYDAC Technologies Inc.
2 Gurdwara Road, Suite 510
Nepean, Ontario K2E 1A2
CANADA

Morton O'Kelly
Department of Geography
The Ohio State University
103 Bricker Hall
190 North Oval Mall
Columbus, OH 43210-1361

Stan Openshaw
CURDS
Newcastle University
Newcastle upon Tyne NE1 7RU
England
UNITED KINGDOM

Bruce Ralston
Department of Geography
University of Tennessee
408 G and G Building
Knoxville, TN 37996-1420

Peter Rogerson
NCGIA/Department of Geography
SUNY at Buffalo
Buffalo, NY 14261

Peter Rosenson
Geographic Files Branch
U. S. Bureau of the Census
Washington, DC 20233

Gerard Rushton
Department of Geography
San Diego State University
San Diego, CA 92182

Howard Slavin
Caliper Corporation
1172 Beacon Street
Newton, MA 02161

Waldo Tobler
NCGIA/Department of Geography
University of California, Santa Barbara
Santa Barbara, CA 93106

Roger White
Department of Geography
Memorial University of Newfoundland
Elizabeth Avenue
St. John’s, Newfoundland A1B 3X9
CANADA