Spatial Analysis in the New Millennium

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> Econometric theory is like an exquisitely balanced French recipe, spelling out precisely with how many turns to mix the sauce, how many carats of spice to add, and for how many seconds to bake the mixture at exactly 474 degrees of temperature. But when the statistical cook turns to the raw materials, he finds that hearts of cactus fruits are unavailable, so he substitutes cantaloupe; where the recipe calls for vermicelli he uses shredded wheat; and he substitutes green garment dye for curry, ping pong balls for turtle's eggs, and, for Chalifougnac vintage 1883, a can of turpentine (Valavanis 1959: 83, quoted in Kennedy 1979: 2)

Ever since undergraduate days in Bristol in the 1970s, I have felt fully imbued with the quantitative spatial-analysis approach to geography—not least because some of the origins to the tradition can be traced to Bristol in the 1960s. Much of today's quantitative geography is carried out in the environment of Geographic Information Systems (GIS), and I hope that some of the enduring enthusiasm that I feel for the approach is evident from the steer to parts of the (almost!) millennial edition of the "Big Book" of GIS (Longley et al. 1999). GIS is fundamentally a facilitating and applications-led technology, which transparently assesses the importance of space, and as such should be central to our geographical understanding of the world. Like some other quantitative geographers, I often find myself browsing the sheer range of applications to be found in professional GIS magazines. I have to say I find this therapeutic because, within the narrower confines of the discipline of geography, I share some of the same frustrations of many "quantitative geographers" in recent years. The spatial "mainstream" to geography has become sidelined in the major geography journals (including this one); quantitative analysis accounts for a reduced real share of intellectual activity in the subject; the interdisciplinary outreach of quantitative approaches has been limited; and GIS practice appears to develop largely separately from academia. At the same time, and in stark contrast to the "real world" of geographical problem-solving through GIS, turn-of-millennium geography remains besieged by doubts about its funding levels, profile, and position in school and university curricula. Like the quantitative-geography paradigm before it (Fotheringham et al. 2000), the apparent cohesiveness of GIS research and applications has made it a target of criticism from within the discipline, yet few protagonists of GIS actively defend its epistemology—many like to think that they are busy with more important things. (In the U.K., GIS and remote sensing will at least together make up one important "specialism" that will be key to central government's ranking of university department performance in 2001, and the discipline itself remains a mainstream high school and university activity.)

In this paper, I should like to comment on the way that research practice and, in particular, data handling, contributes to this state of affairs, and to suggest how a reappraisal of some research priorities in spatial analysis, informed by practice, might be beneficial. The central issues remain those that were raised more than forty years ago by Valvanis (1959) in the quote above, set in a spatial context: is the quality of geographical data commensurate with the task of generalization about spatial systems? In order to answer this, I will try to assess whether developments in geographical data handling have contributed enough to merit reappraisal of the domain of quantitative analysis, and whether reappraisal of research priorities in the data-rich new millennium might usher in a new era of data-led theory. The discussion is framed within the specific context of applications-led urban modeling where, following Johnston (1999), I suggest that new data and a more robust approach to scientific generalization offer a broadening of scope for GIS-based analysis, and that this potentially brings quantitative analysis back toward the heart of geography.

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The Digital Data Revolution in Urban Analysis

Spatial analysis, like econometrics, has benefited from the proliferation of digital data sources in recent years. Thus today's spatial-data models of intraurban distributions amount to far "thicker" depictions of geographical reality than those available during the subject's "Quantitative Revolution" during the 1960s. The environment for such data modeling is GIS, which is fundamentally an applications-led technology, driven by precipitous falls in the absolute costs of computer power, innovations in computer graphics, and the development of graphical user interfaces (Maguire 1991; Longley et al. 1999). Most proprietary GIS software has been developed outside the discipline of geography. To some, this also implies that the GIS "bandwagon" in academic geography is essentially propelled by external developments and, by implication, that protagonists joining it are seeking an "applications fix" rather than a grounded theoretical approach. The academic image of GIS was certainly not well served by some of the early boosterist claims that were made for it, and the failure to deliver solutions to a more grounded class of scientific problems was recognized at quite an early stage (Aangeenbrug 1991). This alienated not only those who had long eschewed allied approaches, but also many of the quantitative geography "faithful" who were better equipped than others to see behind the slick new interfaces.

Viewed from the second of these perspectives, the development of quantitative geography in the 1960s appears heroically grounded in scientific orthodoxy in comparison. The "Quantitative Revolution" engendered very emotional debates as to whether and how human geography (in particular) could forge closer links with science, with the particular goal of fostering system-wide generalization. For some, the scientific means almost became ends in themselves—for example, the literature on urban modeling is peppered with papers that emphasize analytical elegance and detail over operational capability (but see Foot 1981). Token empirical applications were typically accomplished using a limited range of standard secondary-data sources (usually dicennial population estimates), or through new data creation using standard survey-research techniques and statistical generalization. Where primary data collection took place, survey-research practice adhered to what Goodchild and Longley (1999) describe as the "linear research design" of hypothesis formulation, sampling, survey implementation, generalization, analysis, and inference. For a while, this became the prevailing scientific orthodoxy in geography: as such, quantitative geography in general and urban modeling in particular adhered to a clearly espoused philosophy of science, and normative applications were often very limited, but always clearly grounded in scientific practice.

Yet, viewed in retrospect, the era of large-scale urban modeling actually revealed rather little about the structure and functioning of real-world systems. General academic disillusionment with the approach has ensued since the late 1970s (Batty 1981), and a common thread to critiques can be traced to the dearth of empirically "successful" applications. Writing in 1989, Harvey (1989: 213) described the achievements of the approach as the "proverbial hill of beans," while for Sayer (1979), a root problem lay in the preoccupation with understanding logical model structures rather than any applications-led understanding of urban systems. The central tenets of geographical theory emphasized the order underlying spatial structure, yet in practice, no urban models appeared able to reconcile this with the ways in which real-world settlements fill space.

Viewed from the turn of the millennium, it now seems almost foolhardy ever to have presumed that workable system-wide models could possibly be built upon the rudimentary foundations of crude, inappropriate surrogate data, limited data collection, and coarse areal zonations that were the building blocks of analysis in the 1970s. Good measurement usually precedes the development of good theory (Mandelbrot 1982), and a detailed understanding of how space is actually filled is an important precursor to simulating spatial distributions and scenario analysis. Secondary data and limited data collection using the "linear project design" were simply not up to the task, and as a consequence, urban modeling today accounts for a greatly reduced share of intellectual activity within academic geography. Paradoxically, however, model applications developed outside the academy are now more successful (certainly in predictive terms) than any of their forbears. This is because, on the one hand, applications are developed for much more specific (spatial and temporal) contexts and, on the other, the data inputs to analysis are far richer—that is, more detailed and pertinent to human behavior. The best examples derive from the private sector (e.g., those from the Leeds, U.K.-based Geographical Modelling and Planning [GMAP] consultancy: Birkin et al. 1996), where applications to retail location and store choice have provided particular success stories for stripped-down, applied models throughout the 1980s and 1990s.

The innovation of GIS has certainly filled a catalytic role in this, largely by allowing the best use to be made of conventional secondary-data sources. This, in turn, has stimulated renewed interest in the problems of modifiable areal units, particularly since today's GIS potentially trivializes the problems of zone design (Openshaw and Alvanides 1999). But there is much more than this to the data-modeling environment of the twenty-first century. By the late 1990s, developments in digital data-capture technologies and a revolution in the way a variety of organizations manage geographical information (Rhind 1997) had more or less removed the "data blockages" that inhibited the range and scope of early GIS applications. The development of the Internet has made data exchange between organizations much easier and more routine than before. The GIS community is gradually developing data standards (Salgé 1999), and interoperability of software has become the norm. And developments in metadata (Goodchild 1998) are beginning to make it easier to gauge the compatibility of different datasets with one another. Together, these developments are creating a seamless environment for data modeling. Allied with this, GIS technology has developed the dual functions of making it much easier to build models of real-world spatial distributions and, latterly, of making the assumptions inherent in such model-building much more transparent.

But does this necessarily mean that the data foundations to empirical model-building now provide a panacea for spatial analysis, even within the more limited domains of contemporary applications? As with the development of GIS, there is some irony that most successful practice has developed outside of the formal strictures of the geographical discipline, yet the most successful practice is not necessarily the "best" science. Scrutiny of today's urban modeling practices reveals some aspects that begin to challenge social science orthodoxy, and suggest a possible sea change of direction and emphasis.

A first theme of change in emphasis in scientific application concerns the way in which the potential of "better" data may be unlocked if we develop robust, clear conceptions of meaning as the basis to conflation (or pooling) of different data sources. Honing data to context does not preclude generalization, but it does require a clear conception and a tailoring of data creation to application. This may be illustrated by an example from the realm of urban remote sensing, in which socioeconomic sources are used to improve image training and postclassification sorting. The spirit of remote sensing is to sample and model the (spectral, spatial, temporal, geometrical, and polarization) dimensions of scattered radiation in order to estimate environmental variables of interest (Curran et al. 1998). Despite several false starts in the late 1990s, the start of the new millennium will almost certainly see very high (1–2 m precision) resolution data come on stream from a new generation of satellite sensors, and this will offer improved prospects for measuring these dimensions. This is likely to usher in a new age of urban remote sensing as the quality of measurement becomes commensurate with the task of discriminating individual built structures within city systems (Barnsley and Barr 1997). Yet while the physical, chemical, and biological properties of different *land-cover* categories are objectively measurable, the extension of remote sensing to *land-use* analysis will introduce new subjectivities and uncertainties. Satellite data have very important advantages over conventional data series in that they are both areally comprehensive and frequently updateable. Yet, if we consider the range of potential applications of urban remote sensing, it is clear that even if there is a loose consensus about what constitutes the physical form of the city, there is unlikely to ever be any universal view about the way it functions. If the scope of understanding is to be broadened in a way commensurate with the increased richness of available data, there is a clear need to identify sources of ancillary information that are appropriate to particular applications. In general, this might entail using satellite data as a current "framework" alongside less contemporary, areally aggregated, but substantively relevant, socioeconomic data to classify and analyze the world.

Longley and Mesev (1997) have used small-area census statistics as ancillary information to inform the statistical classification of a satellite image of Bristol, U.K. This was achieved by using a continuous population-density surface interpolation, derived from the Census, to assist in sample training and postclassification sorting. They develop a range of classifications to stimulate rethinking about the way what we describe as "urban development" fills space—and they develop density-gradient profiles for different categories of urban space filling, such as "built form," "residential," "households," and "population." The results clearly show that differences between apparently quite similar categories are more than semantic, and heavily condition the extent to which density profiles might be considered characteristic of particular settlement types. Conception prescribes measurement, which in turn prescribes analysis, yet clear thinking about the nature of "urbanism" makes possible the development of a range of customized indicators of urban morphology.

A second example concerns not just the creation of information that is more relevant to urban analysis than conventional sources, but also uses sources that are less systematic in their collection. For much of the last three decades, the data "fuel" to urban modeling has been geodemographic data. Geodemographics are small-area classifications, created by data reduction of Census data, which bear an identifiable correspondence with observed consumption of goods and services (Brown 1991). They represent a tried and tested technique, applied to data that have been collected to the highest survey standards, and have enjoyed repeat purchases by many providers of goods and services. The development of GIS has certainly allowed more sophisticated analysis to be built around small-area classifications than was possible in the era of large-scale urban modeling. Yet a number of inherent substantive and methodological limitations remain. Census data are usually collected only every ten years, and this snapshot interval is far too infrequent to capture the diversity of fast-changing systems. Many variables that are central to interest in what is going on in advanced societies are simply not collected (the U.K. Census does not even have an income question, for example). In the U.K., the lengthy debate about the relevance of the 2001 Census has not led to inclusion of new questions of significantly greater interest. The inherent problems of data aggregation (designed to ensure confidentiality) make ecological fallacy an ever-present risk. The ascription of a single label to every tile in the urban mosaic masks diversity. None of these problems will dissipate in the foreseeable future.

At the same time, a number of more insidious threats to the provision of conventional data infrastructure are also developing. Increasing pressures for government agencies to recover costs (outside the U.S.) have already led to data-royalty structures that put prohibitive strain on many commercial applications, and the protracted negotiations that have preceded access to the digital national-mapping agency in the U.K. suggest that information commerce retains a sharp edge. The signs are that the cost savings that will undoubtedly accrue from the use of new data-capture technologies to be used in the 2001 Census will not be plowed back into a broadened agenda for public-sector surveys. Rather, the abandonment of some major and long-standing central government surveys suggests a wavering of commitment, even to the renewal of existing public-data infrastructure, much less a willingness to commit to new programs. Yet such renewal and commitment is essential if the increasing complexity of society and fission of urban lifestyles is to be represented using new data-analysis technologies. Restructuring of higher education and research has also meant that social science research budgets, which are already under pressure, are spread more thinly between competing institutions, and for this and other reasons, the generous (in hindsight) funding of projects founded on the linear research design is simply no longer a practical proposition.

The meaning, value, and interpretation of quantitative data remains a contentious theme in geography. Curry (1995: 76), for example, is extremely skeptical of the notion that having "massive amounts of information . . . provides one with a better understanding of the world," concluding that "to develop an understanding of the data adequate to a resolution of the problems which arise in the production of a GIS would very likely render those systems irrelevant" (1995: 82). A very different critical perspective is that the emergent "surveillance society" and GIS-based "revolution in marketing" (Goss 1995: 161) might rewrite entire landscapes of retailing and consumption. The spirit of the more mundane view pursued here is that:

the capture and handling of geographical data has already delivered significant enhancements in the depiction of population characteristics, developments in computer hardware will remain at least commensurate with the increase in available data for the foreseeable future, and this will make it possible to explore and model spatial interactions and activity patterns in more detail than ever before.

Yet if the limits to geodemographic techniques have already been reached, then this intermediate view can only be sustained by the development of a new data infrastructure. In an urban context, an infrastructure of sorts is certainly being created through a range of new technologies, from such sources as shopping surveys, electronic point-of-sale (EPOS) data from retail purchases, loyalty card data, share ownership records, product guarantee returns, and county court judgments. The collective term for such sources is "lifestyles" data, which "capture" (measure) some of the varied consumption choices, shopping habits, and practices of identifiable individuals (Longley and Harris 1999). In the U.K., companies such as ICD, Claritas, Experian, and Psychographics have built huge "data warehouses." CACI claims that their "LifestylesUK" product targets more than 44 million individuals using three hundred lifestyle variables (the U.K. population is ca. 53 million), while Claritas U.K.'s "Micromarketing" product offers information on 75 percent of U.K. households. Many analysts in the applied GIS community are increasingly using lifestyles data to augment, and even replace, conventional geodemographic analysis. The reasons for this are not difficult to fathom, with respect to relevance, detail, timeliness, and aggregation. These same imperatives potentially underpin a reinvigorated and more relevant approach to urban modeling in academia. But a fundamental stumbling block is that most lifestyles data are avowedly unscientific in their collection. The self-selection of respondents, the vagaries in emergent approaches to so-called "data fusion," and the ambiguities of survey standards mean that lifestyle data break almost every scientific rule in the book.

GIS is a data-handling technology that has already been dubbed the "positivist's revenge" by its detractors (Taylor and Overton 1991), and it is only comparatively recently that dialogue has developed to further context- and application-sensitive application (Pickles 1995, 1999). Quantitative geography certainly retains pride in its scientific orthodoxy. Any approach to the sharing, concatenation, and conflation of geographical databases (Goodchild and Longley 1999) may thus provoke condemnation from a diverse and seemingly unlikely alliance of academic views. A new approach to urban modeling based on lifestyles data has apparently weaker epistemological and methodological foundations, yet, in practice, offers the prospect of rich, generalized depictions of what is going on in advanced societies.

A Pragmatic Geographical Data-Handling Orthodoxy for the New Millennium?

Within the realm of urban modeling, the separation of practice from academia has been to the detriment of both parties. Successive attempts to supplant analysis of sterile, static, and surrogate mosaics have instead led urban geography to chart a course through repeated idiographic case study (Longley and Clarke 1995). Idiographic does not mean "dataless," and the intention here is not to use the term in a pejorative sense, but the discipline of geography is weakened by the near abandonment of the quest for generalization in many realms of urban analysis. Yet a resumption of this quest clearly cannot be achieved through the adopted, narrow scientific orthodoxies of the 1960s, for the models of this period largely evaded meaningful empirical specification, estimation, and/or testing. Taken together, the broader point is that a discipline that wholy eschews generalization about the real world is likely to remain on the sidelines of all but academic discourse. Conversely, the authority and conviction with which business- and service-planning applications of GIS can be developed is handicapped by lack of expertise in handling data plagued by omission, error, and uncertainty. Despite the hype surrounding data-warehousing and data-mining technologies, and a few honorable exceptions aside (e.g., Sleight 1997), no consultants appear to have made time to begin a rational and wide-ranging appraisal of the broader applicability and usefulness of lifestyles data.

It is deeply ironic that, in the data-rich world of the early twenty-first century, confidence in quantitative generalization is far lower than it was forty years previously. Yet there is much to play for. In a preliminary analysis, Longley and Harris (1999) compare the application of data-reduction techniques to lifestyles data with one of the best available geodemographic systems (Brown 1991). Their case-study region comprised the 1,668 1991 Census enumeration districts (EDs, the U.K. equivalent to U.S. census tracts) with "BS" (Bristol postcodes, the U.K. equivalent to U.S. zipcodes). Their lifestyles dataset (supplied by a private-sector data warehouse) comprised responses from adult individuals in 51,882 households—11.8 percent of the adult population, representing 16 percent of all households in the study region. Comparison of some survey characteristics with those from the 1991 Census, from which the geodemographic classification was derived, revealed some under-representation of younger age cohorts, but no overwhelming evidence that the survey was otherwise unrepresentative of the population at large in conventional socioeconomic terms. Yet the scope of the lifestyles questionnaire was considerably broader than that of the Census, and some 241 variables from the lifestyles survey were fed into a cluster analysis. The variables encompassed a far broader range of household and individual characteristics than conventional Census-based geodemographic indicators, and the outcome of the classification (see Table 1) reveals the importance of leisure, holiday, and consumption interests, as well as other characteristics such as health. In a number of instances, these groupings are as much built around consumption as conventional age, socioeconomic status, and family life-cycle considerations, if not more so. Of course, the outcome of all such classifications is fundamentally conditioned by the nature and range of the variables that are put into it. Yet the advantage of the use of lifestyles data is that the variables available for analysis are much more suggestive than conventional geodemographic indicators of whether people are sedentary, limited in physical mobility, participate in neighborhood or city-wide activities, patronize "traditional" or "edge city" retailing, and so forth.

Perhaps of equal importance is the fact that, although anonymized to the unit postcode scale, lifestyles analysis can be built around individual observations. This allows a picture to be built up of the heterogeneity of urban lifestyles at the finest scales. Longley and Harris's (1999) analysis suggests that conventional geodemographic classifications of small areas conceal a quite staggering diversity of lifestyles within small areas. Figure 1 shows that when cluster analysis is used to classify lifestyle data, most of the cluster types occur in most of the EDs. The implication for conventional geodemographic analysis is that few Bristol EDs can be described as homogeneous in any real sense. Thus, at least for this particular geographically extensive study area, most areas are neither ghettos of "have nots" nor islands of "haves"—with the implication that

Table 1. Variables Used in the Formation of the Household Typology

Type of Variable	Number of Variables
Age of household member	6
Alcoholic beverages consumed	9
Children: number in household and age	8
Consumer goods owned	7
Daily newspaper read	10
Household income	7
Financial investments and plans	15
Gender	2
Have credit cards, store cards, etc.	7
Hobbies and pastimes	32
Holiday choices	22
Home improvements made	11
Home type, tenure, and value	13
Household size	4
Illnesses	9
Duration of residence	6
Mail order purchases	7
Marital status	4
Charity support	14
Number of cars owned, make, and value	23
Smoking	2
Socioeconomic group	5
Supermarkets regularly visited	10
Other	3

Source: Longley and Harris 1999.

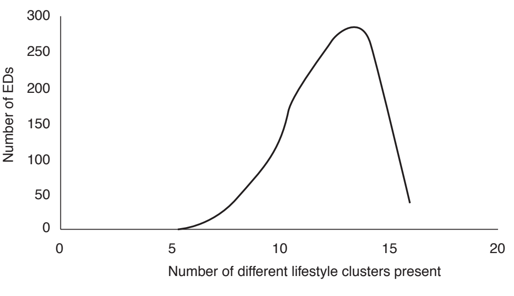

Figure 1. Heterogeneity of lifestyles characteristics within small census tracts (enumeration districts). Source: Longley and Harris (1999).

prescriptive modeling should move away from such crude conceptions of social patterning and neighborhood function.

These conclusions are tentative and, in some senses, preliminary, but they begin to suggest that while the new digital data infrastructure of lifestyles data is, in some ways, piecemeal, it nevertheless offers new insights over conventional data sources. The unweighted classification of lifestyles data suggests a wide range of consumption attributes and lifestyle factors that might contribute toward a model of the functioning of urban areas, and the analysis points toward ways data might be weighted in future analyses.

Conclusion: Some Implications for Geographical Theory in the New Millennium

I have already suggested that improved measurement often precedes the development of better theory in science. The simplest theories in social science are often the most enduring at the pedagogic level, such as the notions of scale and hierarchy in central-place theory, or those of the process of ecological invasion and succession in Burgess's model of Chicago. Yet in research, such theories have often been reworked into dysfunctional, "advanced" model specifications, or have simply been discarded altogether. The consequence is a misassociation of poor prediction with fundamentally sound theory, when the major failure really lies in poor empirical measurement and representation. Improved measurement has already led to nascent attempts to rework our conception of urban settlements into one of strongly ordered systems, which reveal clear hierarchies and self-similar patterning. The theory and techniques of fractal geometry, for example, provide one framework for measuring and simulating the structured irregularity that characterizes real-world systems (Batty and Longley 1994; Batty 1995). Developers of this approach are beginning to use ideas from complexity theory to create new theories of urban change and dynamics, which can be used to show how activities are located at the microlevel through the decisions of individuals, groups, and institutions. Such work requires the integration of macro- and microconceptions of the way that settlements function, as well as data-led understandings of rapid-change dynamics in urban activities and infrastructures (Batty 1997).

In all of this, emergent urban theory is predicated upon continued improvement in our abilities to measure what is going on in urban areas. Theory requires refinement and testing through empirical analysis, and the lead of improved measurement has already made the new theory more amenable than the old to notions of diversity, fragmentation, and apparent irregularity of spatial structure. The preliminary lifestyles analysis presented here begins to suggest that the functioning of cities is structured according to interpenetrating social networks, and that rational planning policy should build upon this concept to harness the actions of individuals, groups, and institutions to positive effect. In policy terms, the generality properties of digital depictions of reality may help local planners understand what drives the local economy, how the global economy affects local development, and how these functional relationships become manifest in the spatial form of the built environment (Batty 1997).

In a broader academic context, Johnston (1999) has offered that, while digital data-handling technologies have become the domain of the spatial science (or "quantitative") fraternity in geography, they remain grossly underused by exponents of social theory. The lifestyles analysis developed here suggests that quantitative approaches now have the prospect of moving beyond the "mosaic metaphor" of social-area analysis and that the fission and diversity of urban lifestyles may now be depicted through GIS. Yet this can only likely be accomplished through a rethinking of conventional scientific standards and the use of GIS as a medium for concatenation and conflation of the huge range and variety of nonconventional data. This might also act as a precursor to the use of hypermedia to express contemporaneity in a more immersive way.

In the shorter term, it is ironic that, in the U.K. at least, the digital age has coincided with a new low in the esteem in which rational planning policy is held. Geography has lost its confidence in its ability to generalize, and rational planning policy is much the poorer as a consequence. In this paper, I have suggested some ways in which new perspectives on the practice of science, allied to better error modeling, more transparent representation of data standards, and developments in data sharing, can unlock more of the potential of digital data. Old approaches to urban modeling and quantitative analysis never presented a panacea in practice, and while a pragmatic refocusing of research priorities brings with it some things for us all to be wary of, there is much to play for.

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