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Analysis of human spatial behavior in a GIS environment: Recent developments and future prospects

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Abstract. In recent years, comprehensive geographic data sets of metropolitan areas and individual-level, georeferenced data are becoming more available to social scientists. At the same time, tools for performing spatial analysis in a GIS environment have also become more available. These developments provide many new opportunities for the analysis and theoretical understanding of disaggregate human spatial behavior. This paper examines how these developments may enable the researcher to represent complex urban and cognitive environments more realistically, and to overcome the limitations of aggregate spatial data framework. It explores their implications for the theoretical and methodological development in geography and other social science disciplines.

Key words: GIS, spatial analysis, behavioral modeling, human spatial behavior

1 Introduction

In the past few years, tools for performing spatial analysis in a GIS environment have become more available to social scientists. Along with this development, comprehensive digital data sets of metropolitan areas collected and maintained by public agencies are also becoming widely available. As these geographic data sets often contain detailed information of the urban environment not available before, they render the application of new analytical methods possible, especially when these methods require the data handling or visualization capabilities of GIS. Further, the increasing availability of individual-level, spatially referenced data also makes individual-based spatial analysis feasible.

As a result of these three developments, new opportunities for the analysis and theoretical understanding of disaggregate human spatial behavior are emerging. This paper examines these recent trends and explores their implications for the future development of the spatial analysis of human behavior. It discusses the wider implications this may have for the theoretical and methodological development in geography and other social science disciplines.

2 The spatial analysis of human behavior in the past

The study of human spatial behavior covers a wide range of topics, including travel and wayfinding behavior, migration and residential mobility, decision making and choice behavior, as well as spatial cognition and environmental perception (Golledge and Stimson 1997). It is not only an important research area in economics, geography and psychology, it also constitutes a significant part of the practice normally referred to as spatial analysis (in addition to spatial statistics and neurocomputing, see Fischer and Getis 1997). As much of this research is concerned with the movement of people over space in various time spans where the perceptual environment is a critical element affecting the outcome, the modeling effort can be greatly facilitated by using methods that can deal with complex spatial data and meet the geocomputational requirements of the analytical tasks involved.

The methods or models of human spatial behavior in the past, however, have been greatly limited by the kind of data and analytical tools available. The lack of an effective geocomputational environment and algorithms also hindered the development of spatial analytical techniques in this area. As a result of these constraints, unrealistic or simplifying assumptions about human behavior and the urban environment were often made, and the methods used to operationalize the theoretical constructs were limited. There are four kinds of difficulty in the methods used in past studies of human spatial behavior in general.

First, there was no effective means for representing or dealing with the spatial complexity of a realistic urban environment. Such complexity arises from the uneven distribution of urban opportunities, differences in the speed of movement in different areas, and the effect of the geometry of the transportation network on the travel distance between locations. This has led to the assumption that mobility, travel speed and the distribution of opportunities are uniform throughout the urban environment (Miller 1994). Second, real-world behavioral complexities were greatly simplified or ignored in past studies due to limited means of handling the spatial data involved or the lack of suitable computational algorithms. For instance, without using GIS-based methods, the computation of individual accessibility measures that takes trip chaining behavior into account is almost intractable if not impossible (see Arentze et al. 1994; Kwan 1998). Further, the sequential unfolding of a person's daily activities renders choice behavior highly situational. Without taking such dynamic context of human actions into account, many crucial factors affecting a person's behavior were ignored. As actual human spatial behavior is far more complex than what was assumed, the spatial analytical methods or models used in the past are often limited in these aspects.

Third, the spatial framework through which data were collected, provided and analyzed in past studies is often not suitable for the analysis of human spatial behavior at the disaggregate or individual level. The scale of analysis allowed by publicly available zone-based data (e.g. census tract data) not only led to problems such as the modifiable areal unit problem and the ecological fallacy, they also render the application of more appropriate methods difficult (e.g. network-based and point-based methods). Further, the particular zonal schema on which data are organized may also deviate significantly from the perceptual environment of individuals (Kwan and Hong 1998). Fourth, most past studies either did not incorporate data about a person's cognitive environment into the analytical framework or represented it in a very crude manner (with a few exceptions such as Aitken and Prosser 1990). Due to the difficulty of handling this kind of information, an individual's spatial knowledge about the urban environment is assumed to be perfect or spatially undifferentiated.

3 Recent developments in the analysis of human spatial behavior

Given the recent trends in data availability and analytical tools for handling complex spatial data, there are encouraging signs that these four difficulties will be less of a problem in the future. Perhaps the most important trend is the increasing availability of various kinds of digital spatial data about the urban environment that is not available before. In the past decade, digital "framework data" (Smith and Rhind 1998) provided by national mapping agencies or census bureaus have greatly reduced the costs of generating or acquiring such kind of data for researchers. Further, aided by new spatial data capture technologies such as very high-resolution remote-sensing satellites and global positioning systems (GPS), relatively accurate and comprehensive digital data sets of metropolitan areas collected and maintained by public agencies are now becoming widely (and often freely) available (Longley 1998). As these geographic data sets often contain detailed information of urban areas not available before, such as digital transportation network, street centerlines and attributes of land parcels and buildings, they render the realistic representation of the urban environment more achievable than ever before.

Another aspect of data availability important to the future development of the analysis and modeling of human spatial behavior is the increasing availability of individual-level geo-referenced data, and the recent development of new methods for collecting this kind of data. In past studies, spatially referenced individual-level data had to be generated through the process of geocoding using detailed survey data of individual activity-travel behavior (e.g. Kwan 1999a,b). To be able to create this kind of data, not only detailed street addresses of subjects' home, workplace and activities are needed. Reliable digital street network with accurate and complete address coverage is also needed. Data limitation in this area, however, is rapidly changing as many metropolitan planning agencies had recently made large sets of geo-referenced activity-travel diary data available to the research community. Further, the Federal Highway Administration in the US has experimented and is planning on the collection of real-time activity-travel data using GPS and notebook computers. Given these recent developments that make individual-level spatially and/or temporally referenced data more available, the spatial analysis of human behavior at the individual level will become more possible in the near future.

As large amount of spatially referenced data about the urban environment and individual behavior become available, appropriate tools for handling large geographic data sets and performing spatial analysis using these data are also needed. Particularly helpful in this context are spatial analytical methods implemented in a GIS environment and 3D visualization techniques, since both of these can greatly facilitate the exploratory analysis of spatial data. In the past (at least up to about the mid-1990s), tools for performing spatial analysis in a GIS environment have been rather limited although there were many special-purpose spatial analysis or GIS packages (e.g. SPLANCS, SpaceStat, INFOMAP and TransCAD). But the analytical tools for performing spatial analysis in a GIS environment have become more available to social scientists in recent years. For instance, many functionalities of both S + SpatialStats and SpaceStat are now accessible through the more user-friendly interface of ArcView GIS (Anselin 1998; Anselin and Smirnov 1998; MathSoft 1998). Three-dimensional visualization techniques can now be performed in much less demanding GIS environments than before (e.g. the use of ArcView 3D Analyst in Kwan 1999b,c, 2000). As these GIS-interfaced spatial analytical tools become more available to behavioral researchers, they render the application of new analytical methods possible, especially when these methods require the data handling or visualization capabilities of GIS.

4 New opportunities in the analysis of human spatial behavior

In light of these recent trends in data availability and analytical tools, it has become possible to overcome many of the limitations in traditional methods in the study of human spatial behavior discussed above. The most important of these pertain to the representation of the objective and subjective environment within GIS, as well as the possibility of person-based and frame independent spatial analysis.

Recent trends in the availability of spatial analytical tools and digital data allow the realistic representation of the complex objective environment for the analysis of human spatial behavior (Kwan 1997; Miller 1998). If detailed attributes of land parcels and the transportation systems can be represented through incorporating the relevant information into a comprehensive geographic database, the analyst may go beyond the simplified geometric operationalization of geographic constructs as often done in traditional spatial analysis. For example, instead of using the straight-line distance between two locations, the actual travel distance over the transportation network can be used (as in Entwisle et al. 1997; Kwan 1998; Miller 1999; Talen 1997). Further, given the more realistic geographic environment represented in the GIS, it is possible for the analyst to perform "non-isotropic" spatial analysis, which does not depend on any assumed spatial distribution of opportunities in the urban environment (Tobler 1993).

With appropriate data collection effort and using the spatial data handling capabilities of GIS, elements of individual cognitive map that bear upon spatial behavior may be incorporated into analytical models (Golledge et al. 1994). By taking into account factors which affect human spatial behavior (e.g. cognitive and space-time constraints) through establishing more realistic representations of the subjective environment, spatial analysis in a GIS environment can be based upon the more relevant "effective" environment of individuals (Kwan et al. 1998). This will extend the theoretical foundation of spatial analysis to include the behavioral dimensions into the analytical framework (Fotheringham 1993). Further, instead of basing the analysis on certain behavioral assumptions, the researcher can now use GIS-based deductive methods such as neural networks to deduce or "discover" the behavioral rules or principles underlying various spatial behaviors (including route choice, spatial search and choice set formation). These behavioral rules can in turn be built into behavioral models for obtaining more realistic or accurate results. For example, complex spatial search heuristics that better approximate actual human behavior such as second or higher-order search can be used when delimiting a person's spatial choice set (Kwan 1997).

Using geo-referenced individual-level data in a GIS environment, spatial analysis will no longer be affected by any prior zonal or areal partition of the study area (as in the case where socio-demographic data are aggregated based on a zonal schema) (Kwan 1998; Wegener 1998). This implies a shift from traditional methods to new techniques for specific problems. For example, point-pattern techniques such as cross K-function may be more appropriate than conventional zone-based methods for measuring individual accessibility to urban opportunities when individual-level data are used. This, in other words, allows the use and development of "frame independent" spatial analytical methods (Tobler 1989), which may help ameliorate the modifiable areal unit problem. Even when dealing with traditional zone-based data, surface modeling and spatial statistical method can be used for overcoming the limitations caused by the zonal scheme (Immergluck 1998; Scott 1999; Talen 1997; Tobler 1979).

5 Future prospect

Changes in the above three areas will allow the application of new methods to specific problem areas pertaining to human spatial behavior. Further, by placing the individual into the focus of spatial analysis, and with consideration of both the objective and subjective environment, such person-based and frame independent framework will enable the examination of fine-scaled, inter-personal differences based on gender, race, or other socially significant categories. This, perhaps, could be the beginning point for a mode of spatial analysis which is more sensitive to the effect of local context and more congenial to post-structuralist and feminist conception of space and the individual (Fotheringham 1997). Obviously, much research is needed to examine this possibility.

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