GIS for the people: cognitive errors and data restrictions

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Abstract: Public Participation GIS (PPGIS) has become a popular tool for integrating diverse groups of people into complex decision-making processes. Not only do PPGIS scenarios provide under-represented groups the opportunity to participate in a component of decision making and planning from which they might have traditionally been excluded, they broaden the experience and knowledge base from which decisions can be made. Traditionally PPGIS has involved giving new groups access to the technology traditionally available to institutional, governmental, and other administrative decision-making bodies. While these strategies are not new, innovation is possible by changing the boundaries of GIS data to include knowledge and information that does not conform to the Euclidian rules of the world. Specifically this includes the information and knowledge held by individuals in the cognitive representations of space; representations that are often at the root of their personal decision-making. Such innovation may help define a new era of spatial decision support.

Key words: PPGIS, behavioural geography, community participation, data integration

Introduction

Humans store, represent, and process information in many ways. Geographic information systems (GIS) have been designed to complete operations on spatial information in a reliable fashion that has very little in common with how human minds complete the same tasks (Albert and Golledge 1999). Understanding the nuances of how humans process spatial information has been a topic of concern for geographers, psychologists, and cognitive scientists for quite some time. Over the past decade the relationship between human information processing and digital information processing in a GIS domain has become increasingly important (Medyckyj-Scott and Blades 1992). While others have describe the nature of human cognition and its importance to developing user friendly GIS environments, less has been done on the need to develop systematic spatial database structures that can readily accept the diverse set of inputs required for many real world problems (Mark 1988).

Geographic information systems offer an environment for the input, storage, and processing of spatial information. While the majority of decision-making problems faced at an institutional or administrative level can be solved with aggregate spatial data available from government and private data providers and vendors, there is an array of community level problems that present unique data needs that are difficult to address with currently available aggregate data. Some data are still available in aggregate form, such as census, land-use, transportation, and other forms of physical (e.g., elevation and land cover), and human data, but there are undoubtedly data needs that can only be acceptably met on a case by case basis and may be in a form that cannot be readily represented within current GIS data models. These data may take the form of externalizations of internal, cognitive representations of space, and are commonly referred to as a cognitive or mental map. The former data type (standard data) works seamlessly with existing data models while the latter (public participation or community data) is difficult to integrate with existing data models and often is left out of geographic analysis performed in a GIS environment.

In the context of participatory GIS communities can include any sub group of the population for whom GIS represents a viable decision-making tool. Within the realm of Public Participatory GIS (PPGIS), community includes both marginalized and minority groups (e.g., aboriginal peoples, developing countries, the poor) but can also include any non-institutional or non-government group that would like to participate in the decisions that affect them. While only a fraction of the world's population currently has access to geographic technology, the issues raised here will have an increasingly important impact as these groups gain access to geographic tools and data. In light of this proliferation of GIS technology it is important to consider the different ways these 'community groups' envision relevant spaces and places. This will likely require novel techniques for incorporating new data types into tradition GIS models, or changing GIS data models to accommodate a wider array of data sources (Seiber 2001a).

Systematic Cognitive Distortions

Much is known about the human cognitive map; systematic errors associated with non-Euclidean representations of space underlie many of the differences between reality and how reality is represented in a person's mind (Tversky 1992). Justifying the inclusion of information from cognitive maps in geographic analysis is critical to understanding the importance of these data to making real world decisions. Nowhere is the need for this type of information more critical than in the area of PPGIS. Gathering information from public and community participants involved in the decision-making process and giving these groups access to the tools used to catalogue and process spatial data (GIS) are hallmarks of PPGIS, and have been in use in a variety of areas around the world, including developed, developing, and less developed countries (Harris and Weiner 1998; Jordan 1998; Meredith 1997). Current implementations of PPGIS tend to use existing aggregate data sets that are not a product of the communities or populations that are being directly affected by the decision making. Such data sets include, but are not limited to, census data, data from government mapping agencies, and institutional data (Harris and Weiner 1998; Jordan 1998). As a result it has become clear that new techniques for GIS data collection and processing are necessary to accommodate the emerging needs of the community groups that are currently implementing, as well as those that might in the future introduce, GIS technology (Seiber 2001b). Much of the data collected from public input are in a form that is ill suited to the strict models of GIS data currently in use. Individual differences in the nature of cognitive maps and the potential for a wide range of responses to the environment make it difficult to fit personal perspectives and community attitudes into a GIS domain.

These issues, cognitive inputs to GIS, and removing the restrictions inherent in GIS data models, are necessary for the application of new data types to public participation GIS based research. There are real problems that GIS can help solve and in many cases the most important data will not fit into current data models; dominant data models include raster, vector and object oriented. While common problems among these models exist, there are also unique limitations of each that restrict easy co-ordination of community and standard data. Inputs cover a range of data types, including imagery, sketches, diagrams, attitudes, affective responses, and pictures, among others. While some of these data can be incorporated into standard data models, other types are limited to lists of non-spatial attributes referenced to a discrete location within the area of study, an option that ultimately limits analytical options.

Understanding the distortions inherent in how humans process and represent spatial information in their cognitive maps is a first step towards creating an understanding of how existing data models might be augmented and how new types of data for community and non-institutional decision making might drive the development of new data models. It is interesting to compare the shared conceptual and nominal characteristics of standard data models and cognitive irregularities in such a way that will benefit the larger community of GIS users. It is important to note however that while cognitive maps often distort reality, the nature of many of these distortions is that they are systematic and can be understood and modelled in a limited heuristic fashion. A prominent example is the hierarchical storage of spatial information (Toronto is in Canada, Canada is north of the continental USA, therefore Toronto is north of all locations in the continental USA), which is used to make judgements about relative spatial relationships, and has been identified at multiple scales (Hirtle and Jonides 1985; Maki 1981; Stevens and Coupe 1978). Errors resulting from this systematic bias are predicable and can be used to establish parameters for GIS databases in which such data can be stored and later analyzed. That cognitive maps are based on reality implies that individuals use information present in the environment to develop working models upon which decisions can be made, and that across cultures the shared experience with the common spatial elements of the world suggests that certain internal spatial structures are shared by all people. At the same time there is need to accept that not everyone's cognitive experience is the same and that individuals will develop unique understanding of their surroundings. That both shared and unique experiences contribute to one's representation of the world is a powerful argument for developing tools for collecting inputs from a wide range of participants and shareholders involved or affected by decisions supported by analytical GIS.

Hierarchical reasoning is just one of numerous systematic distortions that enables an individual to store large amounts of spatial and non-spatial information about the world within their cognitive map, and to operate on that information to solve simple and complex spatial problems. Others include, but are not limited to, the presence and absence of prominent landmarks and decision points producing errors in distance and angular judgements about space (Montello 1991); the alignment of newly experienced spatial information with existing knowledge at various scales which results in errors in both the position and arrangement of the new information (Tversky 1992). While each of these distortions is important, the critical question for GIScience is developing techniques and tools for accommodating these and other known, and potentially unknown, errors in how spatial information is stored and processed. Understanding that any model of human cognition is flexible and openly affected by personal experiences (past and present) means that bridging the GIS – cognitive map divide will require certain limits being placed on both the data model and the cognitive model used to integrate relevant inputs.

Data Inputs and GIS Models

Altering the expectations of what can reasonably be used in even the most ambitiously open data model will require re-thinking the potential inputs for GIS-based community decision making. While spatial inputs are necessary, the collection of these inputs should be reconsidered in light of the intended application. With non-profit and other community and citizen groups making increased use of GIS technologies the demand for systems that can adapt to new data needs is necessary (Seiber 2001a). As GIS adoption moves into new areas the limitations of current data and processing conceptualizations become more obvious. Currently community groups want to use the spatial analytic tools offered by GIS technology, but they also demand that data related to their causes be accommodated.

Modifying the GIS model is one alternative, and one that has been argued for by others. There is an equal need to consider the development of data collection tools that might normalize data inputs from human cognition (Seiber 2001a). Creating more systematic, or normalized, techniques for collecting data related to sense of place and, more generally, place based cognitive responses to the environment will allow for more systematic use of this class of data. Emotions, values, judgements and perspectives represent some of the ways in which individuals and groups respond to the environment and should be part of the decision-making process, independent of whether that decision is being supported by a GIS or an informed decision maker. Data inputs from cognitive representations for GIS-based decision making include, but are by no means limited to, sketch mapping (various methods), survey responses, diagrams, distance and direction judgements, field based imagery, and text based, or other procedural descriptions, of the environment. In the following section each of these data collection methods will be presented along with some suggestions as to how they can be adapted to produce data useful within the current structure of GIS data.

Sketch mapping:

Sketch mapping has a long history in geography has been employed in many studies of cognitive mapping (Saarinen 1999). There are numerous limitations of the sketch mapping method, some of which can be overcome by adjusting methods of data collection. While sketch mapping gives an individual the opportunity to develop a free form ‘map’ (drawing) of an environment, it is the free form nature of this opportunity that is its primary limitation. At the same time it is important to recognize the cross-cultural flexibility of the sketch mapping paradigm (Stea *et al*. 1996; Stea *et al*.

1997; Whittaker and Whittaker 1972). Determining the frame of reference, scale, orientation, and limits of a single sketch map are often difficult; doing so for sketch maps collected from a large group of individuals may be impossible. Providing limits (i.e., boundary, or set of well-known locations) to the space being sketched can provide ‘sketchers’ with a frame within which their own judgements can be placed. The limits or ‘control points’ can be used in most conventional GIS software packages to map the location indicated by the ‘sketchers’. This will not only provide locations for known or important locations for a specific issue it can also be useful for determining the amount of distortion in an individual’s or group’s cognitive maps of the environment.

By having individuals include a set of ‘control points’ and providing limits or a boundary, the sketch mapping task loses much of its free form nature but can still provide very useful data that can be incorporated seamlessly into contemporary GIS environments. However, this does not remove all of the limitations of the technique. Sketch maps will still include distortions that are inherent in the cognitive map of the individual. Drawing skill, knowledge, experience, and personal values will still affect the final outcome of the map. This is a characteristic of most methods designed for collecting data from individuals and should not be ignored. In order to account for these errors, several options are available. First, the analytical nature of the GIS can be used to determine error values. These might take the shape of error ellipses or uncertainty measures (Golledge and Stimson 1997, 248). Error data in either form can be mapped to represent the accuracy of knowledge or catalogued in metadata files for future analysis. Second, an *a priori* decision can be made as to what data will be collected from the sketch map and in what form, even though other data are likely to be present. For example, this would enable the individual the opportunity to select categories or perform counts of occurrences from any type of sketch map. This can create data that are less affected by individual differences in drawing proficiency (Jacobson 1998).

Survey methods:

Survey methods offer a researcher the ability to collect data on specific components of community or group concerns. While survey responses can vary from open ended to limited choice alternatives, the themes developed in the preceding sketch mapping section continue to govern how a survey is developed. Survey responses that limit the alternatives available to an individual will be better suited to a GIS data environment than more open-ended responses. Furthermore, responses tied to a specific area of the earth's surface will have more utility in a GIS/mapping environment than responses with no links to space or place. For example, having respondents rate mapped regions on some scale for a specific variable (e.g., "How suitable would each of these regions be for locating a shopping mall?") lends itself well to various mapping techniques (e.g., choropleth mapping) and can be adapted to existing data model constraints. As GIS architecture becomes more open to variable data inputs the constraints on the types and variability of data inputs will lessen (Seiber 2001b). The result will be an opportunity to collect potentially richer data in new ways. This includes, but is not limited to, data collected via both survey methods and sketch mapping.

Diagrams:

Not unrelated to sketch maps, diagrams can provide data on spatial and non-spatial relations that may or may not include cartographic, or environmental, features. Sketch maps represent a type of diagram and contain spatial information about the geographic features experienced by an individual. Diagrams, more generally, can include hierarchical information about non-spatial structures (e.g., hierarchical nature of a storm sewer system or management charts) that are also represented in a person's cognitive representation of the world. Again, limitations associated with the drawing process present obstacles to the incorporation of knowledge from an individual's mental representation in this manner. However, by creating artificial and real limitations on the type of data collected the researcher can establish guidelines, again *a priori*, for what data will be incorporated into an existing GIS data structure. This has the additional benefit of reducing the amount of interpretation that is necessary when coding data from these types of sources.

Distance and direction estimation:

There is a long history of using distance and direction judgements to establish an individual's knowledge of different environments, including but not limited to cartographic representations of the world, virtual environments, other graphical representation of the real world, and, indeed, the real world itself (Golledge *et al*. 1995; Richardson *et al*. 1999; Thorndyke and Stasz 1980; Thorndyke and Hayes-Roth 1982). These data can be used to establish an individual's geometry of a field site or study location, as well as the potential to describe group biases or distortion in how a space is represented. These biases might be helpful in explaining group decisions or values associated with a particular place. One's judgement that a region is unsuitable for some type of development or conservation effort might be based on a representation of that space as being much smaller (and therefore inadequate) than its actual dimensions. As these data are generally collected as angle and distance measures that are consistent with GIS data models establishing the nature of these types of biases should be a reasonable expectation of most GIS software packages.

Image and text inputs:

Written descriptions of space are notoriously difficult to code and most attempts at quantifying them leave researchers wanting more from their data (Ward *et al*. 1986). While qualitative methods have been devised for coding verbal and written passages the ability to incorporate them into existing data models is restricted by inability to quantify the contents. From the perspective of the GIS software this could be stated as the GIS's inability to store, and operate on (analyze) qualitative data. This is one area for which a viable alternative to a free form data collection method is difficult to devise. While memos and tags that contain the verbal passages can be added to most spatial data sets, the ability to incorporate them into analysis is currently negligible. New conceptions of GIS data models will have to account for this type of data as the majority of the lay public prefer to respond (sketch mapping is not a universally preferred method for communicating, even for spatial information) (Seiber 2001a).

Image data, collected in free form using still cameras, video cameras, and photo selection (i.e., selecting a representative set of images for an area) present similar limitations to those offered for verbal and text passages. Image data, collected by individuals, is a novel technique for developing the 'vision' or understanding for a particular space by a group of people (Herman 1999). Creating a structure for the incorporation of these representations of space and place will open the doors to qualitative analysis and data developing within the GIS environment.

Conclusions: Qualitative versus Quantitative

Developing tools for analyzing qualitative data has, in general, lagged behind that for quantitative data. Arguably the use of qualitative methods is essential to the integration of 'sense of place', community based research, and public participation into the GIS forum. While it is essential that new data models for GIS must be pursued to allow for the incorporation of new data types, research must also examine two other critical components, namely data collection techniques and qualitative data analysis. While the preceding sections covered several community based data collection techniques, and methods for adapting them to current data model constraints, very little has been said about qualitative data analysis. Qualitative analysis has generally been pursued by social scientists, among them prominent geographers, but these techniques have historically not been part of the array of data collection or analytical techniques associated with GIS. It is time to open the doors to these methods in order to support the analysis of new problems at the community level. The creation of an open data model that will provide an environment for a wider range of data types should be a goal for the GIS community. Developing analytical and data collection tools (such as those suggested and reviewed above) that can be used by community groups as well as a wider body of social scientists will make GIS, truly, a tool for the people.

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