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Part 1 Spatial analysts and GIS practitioners

The current status of GIS and spatial analysis

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Abstract. The history of GIS is traced, and a working definition is established. The early development of GIS was driven by spatial analysis, but more recent visions of the role of information technology generally, and GIS in particular, have tended to widen rather than narrow the gap between the two fields. GIS is seen as serving a much more populist vision, in which rigorous and mathematically sound analysis is challenged from a number of directions. Four basic tensions are identified, and the current status of efforts to resolve them is reviewed.

Key words: GIS, spatial analysis

1 Development of GIS

Geographic information systems have their roots in efforts begun in the 1960s to bring computation to the processing of mapped information. The earliest GIS, the Canada Geographic Information System (for extensive discussion of the history of GIS see Foresman 1998), was built to automate the processing of the information collected in map form by the Canada Land Inventory, and was justified on the simple proposition that computers could perform numeric determinations of area from digital representations of maps much more accurately and cheaply than humans working from the maps themselves. In somewhat similar vein, the U.S. Bureau of the Census constructed a rudimentary geographic information system in the runup to the 1970 census on the grounds that computerization could reduce the rate of errors in tabulating and spatially aggregating census results. Spatial analysis, in the sense of analysis of data in geographic perspective, clearly drove GIS from the start.

Throughout the 1970s and 1980s the progress of GIS was measured at least in part through its ability to perform complex spatial analyses. GISs were built and marketed as slave-like processors, computer applications that could perform operations on geographic data much more cost-effectively than could humans. Although humans have highly developed visual systems, they are easily misled by optical illusions, and unable to perform the kinds of precise, rapid manipulations of data that computers are clearly good at. The computer seemed much better at the kinds of rigorous and logical analysis demanded by the scientific method than we imperfect mortals.

This concept of the GIS as an integrated software environment for spatial analysis is supported by the economies of scale inherent in the software production process. Once a foundation has been built, in the form of routines for creation, editing, and basic housekeeping for a particular class of information, then it is easy to add large numbers of distinct functions. Thus it was easy to imagine that a GIS equipped with a basic model of geographic information could perform a wide range of spatial analyses, and eventually come to support every type of spatial analysis ever defined. By the late 1970s commercial GISs began to appear that were capable of supporting both of the basic types of geographic data model (raster and vector), all of the necessary housekeeping functions, and many of the most useful analytic operations.

A major hurdle was crossed around 1980, when the price of a computer fell to a level that was affordable by a university department, a regional office of a government agency or corporation, or a single government department. Suddenly GIS became affordable by organizations that could make effective use of it, and a commercial market for GIS software began to emerge. Since then, of course, a sustained improvement in the affordability of computing has produced a geometric growth in GIS applications, so that today there are on the order of 10^5 licensed users of major GIS products costing over $10,000, and on the order of 10^6 users of cheaper products. On the order of 10^7 people make regular use of GIS-like services offered over the WWW, such as the online maps and route selections available from sites like *www.mapquest.com*. Almost every major university offers GIS courses, and there are extensive GIS programs in junior colleges. Approximately 10,000 people attended the most recent user conference of the dominant vendor, Environmental Systems Research Institute (ESRI).

Today, a GIS can be defined as a computing application capable of creating, storing, manipulating, visualizing, and analyzing geographic information. It finds its strongest applications in resources management, utilities management, telecommunications, urban and regional planning, vehicle routing and parcel delivery, and in all of the sciences that deal with the surface of the Earth. GIS textbooks include those by DeMers (1997), Clarke (1997), Worboys (1995), and Burrough and McDonnell (1998); and Longley et al. (1999) provide a recent and comprehensive review.

2 Changing visions

The revolution in computing that began with the introduction of the IBM PC in the early 1980s has had entirely new and largely unexpected impacts on industrialized society. In the vision of Negroponte (1995) and others, computing is individually empowering and populist. It gives individuals new abilities to communicate over distances and to form communities that are no longer constrained by geography. In a wired world "there is no more there", and children learn new ways of doing things that defy the imaginations of their parents, confined as the latter are by mental models of prior technologies.

One of the principles of this new vision of information technology is that computing should be *non-intrusive* – that it should serve its users by matching itself to its users' ways of doing things, and not force its users to adapt to its own methods. The desktop has replaced earlier ideas as the dominant metaphor for communicating with computers, because it allows tasks to be expressed and understood in terms familiar to human users. In this idealistic world, technical matters of format, coordinate systems, map projections, or data sources should be made invisible to the user. Computers should think like humans, rather than requiring humans to think like them. By following such principles, it has been possible for the software industry to create environments that are usable by vast numbers of people, with little or no specialized training, and accessible even to children. Indeed, Negroponte would argue that suitably designed software can be *more* accessible to children than to parents.

A suitably adapted version of this vision is also driving the GIS software industry, as it attempts to increase its potential markets. In one model, GIS began its growth as a desktop application, serving the needs of a single user. But the structured nature of digital data facilitates sharing among users, and the single-user vision evolved into one of a *department* of multiple users sharing a single database, with appropriate division of labor between the tasks of creation, editing, and analysis. Departments within an organization are often organized by theme – the U.S. Geological Survey has divisions concerned with topography, biology, water, and geology, for example. Yet applications often cut across themes, as in a study of the impacts of groundwater supply on vegetation, and require data on each theme to be integrated, a task that is often visualized as overlaying maps, and readily implemented in GIS. Thus the department vision of GIS evolved into the *enterprise* vision, with each department interacting with a common geographic database. The recent decision of the U.S. Geological Survey to appoint a Geographic Information Officer (GIO) at a senior level is driven by this conception.

The final stage in this process, it is argued, is *societal* GIS, with citizens and stakeholder groups sharing and accessing a common database describing their knowledge of their community or region. The idea draws on the populist vision of information technology, and is explicitly recognized in the six demonstrations of community-based GIS being sponsored by the Federal Geographic Data Committee (*www.fdgc.gov*) in selected areas of the U.S. It can also be found in discussions of *public-participation* GIS (PPGIS; *www.ncgia.ucsb.edu/varenius/ppgis/ncgia.html*), which conceives of GIS being redesigned to accommodate personal views and opinions about the world, as a tool for community-based planning.

Thus while the GIS software industry has expended much effort in recent decades to extend the spatial analytic capabilities of its software, it is being driven at the same time by broader trends in society. The next section explores the tensions that this creates.

3 Four tensions

3.1 Populism and elitism

Early versions of GIS were very difficult to use, requiring long hours of training, learning of specialized command languages, and patience. Graphical user interfaces have done much to ease the load, and recent versions of software (e.g. ESRI's ArcInfo8) are both easier to use and easier to learn. Online help obviates the need to learn in many cases, and helps to shorten the time required to become a competent user. GIS producers are well on the way to achieving the populist ideal.

At the same time, use of GIS requires a certain level of understanding of basic principles, and ignorance of them opens the way to misuse and misinterpretation. Little has been done to identify these principles, or to make them readily accessible to users, and in this regard GIS is unlike the statistical packages, which are embedded in a well-documented and well-researched body of statistical theory. Thus current GIS illustrates well the basic tension between the populist view, in which technology is easy to use and accessible to all, and the elitist view in which only those well versed in the principles of spatial theory and geographic information science are able to use it effectively. Earlier versions of the software resolved the tension because only a well-trained elite could struggle through their complex interfaces. But improvements in the software expose it starkly.

In these circumstances a pessimist might demand restrictions on access, or the appointment of a GIS police to expose misuse. To some extent the technology can police itself, by preventing users from attempting operations that are obviously meaningless or invalid. An optimist would hold that easier access will promote a need for education and a demand for better exposition of principles, and pressure for GIS applications to be readily understandable and clearly explained.

3.2 *Visual and numeric*

Traditional spatial analysis replaces the inherent imprecision of visual communication through maps with the precision of numeric analysis, and the Canada Geographic Information System of the 1960s dispensed with visual display altogether in favor of numeric tabulations. This theme continued through much of the development of spatial analysis in the heyday of the 1960s and 1970s: the visual eye-brain system could not be trusted, and only numeric analysis could provide the rigor demanded by scientific method.

GIS is inherently visual, and much of its power lies in the potential to display information visually. Visual communication is very efficient, allowing large amounts of information to be scanned very quickly. Visual skills are learned early in life, and a visual technology may be more accessible to children as a result. Yet the bias in favor of numeric analysis is very strong, and reflected in commonly heard disdain for GIS applications that "only make maps".

Recent developments have done much to relieve this tension. Exploratory spatial data analysis (Anselin 1999) focuses on active collaboration between the visual and the numeric, and is emerging in many commercial products. Data mining relies on both visual and numeric techniques in searching for anomalies, outliers, and patterns.

3.3 *Open and closed*

One of the tenets of the scientific method is that the investigator should be aware of all of the details of analysis – and experiments should be reported with detail sufficient to allow others to replicate them. Yet the populist notion of hiding details from the user works to some extent against this principle.

Consider, for example, the concept of *slope*. This property is readily calculated from elevation data in GISs, and it is easily understood at an intuitive level. At a more technical level, however, there are many ways of calculating slope from elevation data, each with specific advantages and disadvantages. To meet the scientific criteria of awareness and reporting detail, all aspects of the calculation should be exposed; but from a populist perspective they could be regarded as unnecessarily intrusive. Certainly it is not always possible to discover the full details of algorithms and calculations in the documentation and online help provided by GIS software vendors – and yet details are essential to meet the normal scientific criteria. Can a tool such as GIS serve both populist and scientific applications? This issue is likely to become even more important in the future as new versions of software, such as ESRI's ArcInfo8, make advanced statistical tools such as geostatistics readily accessible to very large numbers of users without respect to technical background.

3.4 *Local and global*

Finally, current GIS forces a tension between local and global perspectives. The history of geography as a discipline is replete with debates over whether the focus should be on discovering general principles, through their manifestation in spatial patterns, or on documenting the unique properties of places. Unique properties are of course identified in the contents of GIS databases, which contain representations of spatial variation. But recently it has become clear that a third option is worth considering: principles that are general in the sense that they persist from place to place, but are nevertheless not constant over the globe, perhaps through variation in their parameters. Construction of GIS databases has drawn attention to the fact that the Earth's surface varies at many different scales, and the exhaustive nature of these databases supports scales of analysis ranging from the resolution of the data to the full spatial extent of the database. Recently developed techniques of local analysis, supported by GIS, are capable of exploring patterns that persist over various scales, and at the same time extracting variation in these patterns at the scale of the globe.

From this perspective, patterns and principles are persistent, but rarely globally. The Earth's surface is inherently heterogeneous, and even if general principles exist their manifestation over limited domains is likely confounded by model mis-specification. Thus the historic positions in the debate – between the documentation of the uniqueness of places and the search for general principles – are now seen as two extremes of a continuum that is defined by the explicit scale of analysis.

4 Concluding comment

GIS and spatial analysis have enjoyed a changing relationship over the years, as computing has shifted its focus from processing to populist communication, and exerted its influence on the evolution of GIS software. GIS offers an unprecedented set of opportunities for the popularization of spatial analysis, and ready access to complex and sophisticated routines by a large user community. The four tensions identified in this paper are not the only consequences of this evolution, but it seems essential that they be recognized and debated within both spatial analysis and GIS communities.

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