EVALUATING THE GEOGRAPHIC IN GIS*

WEIHE W. GUAN, MATTHEW W. WILSON and ANNE K. KNOWLES

ABSTRACT. Despite several decades of discussion and debate around the role of GIS in the discipline of Geography, it would be a stretch to argue that GIS has not irreversibly altered the discipline, both in the scope of research and teaching as well as in the wider imagination of a general public. However, it remains a challenge to incorporate the range of geographic knowledge, born of a diversity of modalities, into operational insights and analytical pre-conditions in a GIS. To be certain, some irreconcilability between GIS and geographical inquiry is to be expected, epistemologically speaking. In what follows, we consider what might be meant by a shift to geographic analysis as scholars from disciplines in the humanities and social sciences turn to GIS as a method of observation, interpretation, analysis, and representation. In this context, we engage in a thought experiment and offer some commentary, fixing the notion of information system, while opening the geographic in GIS to more variable understanding. The point is to pursue greater development of GIS theory and method, encompassing, while not reducing, scientific, social scientific, and humanities research. *Keywords: GIS, GIScience, geographic, geography.*

There is a persistent and perhaps productive ambiguity around the relationship between geographic information systems (GIS) and, more generally, geographic inquiry. This ambiguity takes material form at the level of the organization of faculties, as the teaching of GIS increasingly happens outside of departments of geography, and by instructors who may lack official training in the discipline. Despite this ambiguity, the demand for GIS skills in recent decades has significantly increased enrollment in geography departments across the nation (Murphy 2007; McDonald 2011) and boosted membership of the American Association of Geographers (Goodchild 2007a). Indeed, not all GIS-related research centers are housed in geography faculties or departments nor necessarily employ geographers, as the names of such centers suggest: Center for Geographic (Information) Analysis (the three former NCGIAs at SUNY Buffalo, UCSB, and University of Maine; Harvard; University of Stellenbosch; and others); Center for Spatial Analysis or Spatial Studies or Spatial Data Science (UCSB, Stanford, University of Oklahoma, University of Chicago), Center for Geospatial Analysis/Technology (ASU, William & Mary, Texas Tech), GIS Center (South Dakota State University, Towson) or, most simply, GIS@ (Tufts,

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WEIHE WENDY GUAN, Executive Director, Center for Geographic Analysis, Harvard University, 1737 Cambridge Street, Suite KooA, Cambridge, MA 02138 USA; [wguan@cga.harvard.edu]. MATTHEW W. WILSON, Associate Professor, Department of Geography, University of Kentucky, 817 Patterson Office Tower, Lexington, KY 40506 USA; [matthew.w.wilson@uky.edu]. ANNE KELLY KNOWLES, Professor, Department of History, University of Maine, 5774 Stevens Hall, Orono, ME 04469-5774 USA; [anne.knowles@maine.edu].

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Georgia Institute of Technology, and Middlebury College, where GISatMidd is a YouTube channel for introductory GIS instructional videos). Students, after taking some GIS courses, are perhaps left with the impression that GIS is about spatial analysis, which is perhaps equal to geospatial analysis, which is equal to geographic analysis—which, some conclude, is equal to geography. Some believe that the most scientific part of GIS, as many regard Geographic Information Science (a.k.a. GIScience) to be, is equal to spatial statistics, which is equal to geostatistics… and on it goes.

Indeed, this ambiguity is sometimes felt as a question about the relationship between the discipline of geography and GIS. David Mark stated that GIScience is the basic research field that seeks to redefine geographic concepts and their use in the context of GIS (2000). However, it is unclear whether, and how, geography as a discipline has sought to define GIS or GIScience. Also unclear is what geography might actually be according to users of GIS.

The blurring of terms and their often-overlapping meaning reflects the rapid adoption of GIS across domains of inquiry and practical application. As the use of GIS continues to spread, noticeably now into the digital humanities, it is worth pausing to consider the meaning of terms that embody epistemological differences. Geographers in particular should not take the meaning of GIS and its many associated forms of analysis for granted. In what sense is the study of geography a fundamental or special part of GIS? Does the geographic nature of GIS consist of more than location-based data layers and the fact that GIS is applied mainly on earth? For those who say that geography is simply one domain among many where GIS is used, the "geographic" in GIS may be reduced to location or conflated with mapmaking. This point of view has been debated since the 1980s when GIS (or, more broadly, automated geography) became a more explicit fixture within departments of geography (Schuurman 1999; Dobson 1983). We do not revisit the debates around the importance of GIS to geography here, but rather ask whether there may be unexplored opportunities for geography to contribute to the advancements within, and practice of, GIScience.

Points of Confusion, Productive Ambiguity

Geographic information systems (GIS) is concerned with the description, explanation, and prediction of patterns and processes at geographic scale (Longley and others 2016). In this well-accepted definition, the modifier geographic denotes the focus of GIS applications, but it leaves ambiguous the centrality of the field of geography and the role of geographic inquiry in GIS. Is the geographic a limiting or a contributing factor to the development and practice of GIS? Might the geographic even be inconsequential to GIS?

Let us first examine how GIS represents space in general, and geographic space in particular. As in most information systems, computation is an essential component in GIS. While the sophistication of the quantitative functionality of GIS software has been debated (Pavlovskaya 2006, 2009), most GIS programs to date emphasize their capacity for spatial analysis, as a set of methodologies that analyze objects' properties and behaviors in a Cartesian space. However, spatial analysis is not limited to the geographic, per se. It is equally effective in the study of astronomy, neuroscience, electronic engineering, architecture, or any other domain in which Cartesian coordinates can be used to represent spatial relationships. A Cartesian space can represent a physical space of any scale (as large as the cosmos in astronomy, or as small as a computer chip in electronic engineering) or a conceptual space ordered by mathematical relations.

Methods of spatial analysis must be applied with caution to the irregular shape, magnetic properties, and other peculiarities of the earth surface, as defined and measured by geodesy (Miller and Wentz 2003). Furthermore, there might be general truths to be discovered about geographic space that are not equally true of other kinds of space, such as the space of the human brain or the genome (Goodchild 2010). When engaged in analysis and representation of the space of the earth's surface, one might more specifically use the term "geospatial analysis." Furthermore, the utilization of statistics in spatial analysis may be identified by at least two terms: spatial statistics or geostatistics. These imprecisions in terminology may further complicate our understanding of the role of the geographic in GIS.

We should note that just as we propose greater clarification of the importance of geographic representation to various forms of spatial analysis, we also recognize that the leap toward statistics within the discipline of geography is fraught (Schaefer 1953; Bunge 1968; Mattingly and Falconer-Al-Hindi 1995; Bergmann and others 2009; Bergmann 2016). Debate over the framing of geography as a spatial science is long-standing and certainly the emergence of GIS has only fanned the flames of this issue. Given that the breadth of geographic inquiry cannot be reduced to a scientific epistemology, the specifically geographic aspect of analysis and representation may always exceed the geospatial. In other words, there are some forms of geographic research that cannot be reduced to the inputs and constraints of today's GIS software programs (see Giordano and Cole 2018).

In what follows, we suspend these suspicions of irreducibility in order to think through the specific challenges for the greater use of GIS in a range of fields, including but not limited to the discipline of geography. What follows is not intended to be a comprehensive or final evaluation of the role of the geographic in GIS, but merely a thought experiment where we examine three different issues that emerge as GIS is utilized in a diversity of disciplines. In doing so, we address a perceived gap between the theoretical and empirical research of the discipline of geography and an information systems approach in GIS. We invite other evaluations and readings of the role of the geographic in GIS.

Geospatial and/or Geographic Analysis?

The slippage from spatial analysis to geospatial analysis might be understood as the transition from studying objects in an abstract and perfect two- or three-dimensional Cartesian space, to studying objects in a mathematical model of the earth surface defined by geodetic measurements. We propose that the move from geospatial analysis to geographic analysis introduces further complexity, including social and physical processes, patterns, and relationships. Others may productively operate with different definitions, and yet, we still wonder what these ideas might mean for the wider discipline and its reception.

In our opinion, much of the innovation in GIS has occurred in the information system component of the technology, with greater capacities for computation and representation, new forms of user interface and mobility, and the expansion of platforms for use. As Michael Goodchild and Paul Longley pointed out, "GIS has been at the mercy of trends and changes within the larger computing industry"—from relational database management systems of the 1970s to high-performance computing and parallel processing in today's CyberGIS (2014, p.1116). At the same time, new fields and disciplines have increasingly recognized the geographic aspect of their work (DiBiase and others 2006), even when their discoveries are couched in terms of the spatial turn (Bodenhamer and others 2010; Knowles and others 2014). Recent decades witnessed the emergence of geodesign in the fields of landscape architecture and planning as well as the geohumanities and digital spatial humanities. Their discovery of geography, often through GIS, shifts the strongest link from "IS" to "GI." Generally speaking, scholars outside of geography and GIScience are likely to understand GIS as a set of systematic analytical capabilities that are put to the service of understanding geographical information. This upwelling of interest in geographical information from fields outside of geography recasts our question: Should geographers take on the difficulties of making GIS capable of more kinds of geographic analysis? Might GIS better serve new users, and perhaps geographers and GIScientists as well, if it were more deeply geographic and better connected to other domains of research knowledge?

Data and/or Information?

Historical geographers and geographically aware historians have for years been trying to develop omnibus, comprehensive data layers for a world historical GIS, in addition to historical gazetteers. There are also more crowd-sourcing efforts to collate masses of material for geovisualization, beginning with all the KML files posted to Google Earth, and more coordinated projects such as the OpenStreetMap and Esri's Living Atlas of the World. But a GIS knowledgebase should be more than a digital, geographical Encyclopedia Britannica. Accumulating digital content is fundamentally important, and many systems can already do that (such as ArcGIS Online, Google Earth, and WorldMap). Yet, as

Dawn Wright argues, GIS should contribute to the understanding of how the earth works, not just how the earth looks (2012).

There are many ways to store and present digital content. For example, a scanned street map cannot support address lookup, even though it may be useful as a backdrop to localized data; and a vector street layer without traffic capacity cannot support traffic routing. We have accumulated satellite images for decades, but we still do not have open and easily accessible annual landuse/landcover data series for the globe, in whatever resolution. Weather, soil, and hydrology data are abundant, but there is no systematic work to incorporate them and derive growth indices for agriculture or climate change. GIS needs not only more data, but more derived data—knowledge that is produced by subject-matter experts—that can be used openly by others.

The political economy of data presents challenges for this vision (Elwood and Leszczynski 2013). Data are still being created in silos, using different formats, structures, encoding, and terminology. Until subject matter experts transform their data into a common ontology, the plethora of data will remain piecemeal and largely useless for people outside of small circles of specialized knowledge. To achieve wider intelligibility, it is critically important to develop semantic ontology for linking geographic data. A small community of scholars has been working towards this (Janowicz, and others 2012). The effort is closely related to the more general semantic web initiative, except that they are focused on geographic data, which requires expertise in both information technology and geography. We suggest renewed efforts to more effectively transform geographic data fragments into interconnected and inherently intelligent geographic information. How might geography and geographers champion and contribute to such efforts? What might a more critical perspective on the beneficiaries of these transformations yield for users of GIS?

Time and/or Space-Time?

Any serious attempt to build a geographic knowledgebase will need the support of mature temporal and fuzzy/uncertain object models. As Goodchild has suggested, by the late 1990s, relational data modeling was transitioning to object-oriented data modeling thereby allowing spatial objects to be associated with multiple shapes and attribute values with varying length of duration (2008). This resulted in "a rapid expansion of interest in the use of GIS to improve our understanding of historical and other time-dependent phenomena" (2008, p.196). However, the common practice remains to record time as a static attribute field of the geographic features, or classify geographic data in set time series. Even though time is often conceptualized as the fourth dimension of the spatial domain, it is rare to see time recorded as a coordinate value along with latitude, longitude, and altitude. Where this has been done, it has been as a means of visualizing movement in a space-time cube, where the height is replaced by time, sacrificing variation in altitude in order to visualize variation in time (Kwan 1999a, 1999b; Kraak 2003). While such visualizations may assist viewers to imagine a subject's progress through a landscape over the course of time, the result does not lead to analysis in the sense of determining quantitative or qualitative relationships between time and space.

Despite the prevailing understanding that space and time are ubiquitous and essential to all scales of geography as well as to exciting new areas of research, such as Big Data, Internet of Things, smart and connected communities, and self-driving cars (Yaun 2016), geographers have long observed that GIS handles time poorly (Langran 1992; Peuquet 2002; Gregory 2008; Lammes and others 2018), precisely because time is not just one attribute among many. Mathematical, regular time has its own properties, as does any mathematical space, and experiential time is as multidimensional and subtle as perceived space (Knowles and others 2015). The complexities naturally multiply if a geographical feature's location, shape, or attributes change over time, which is all too common. Vector GIS typically captures time only as a moment of existence (often implied to be unchanging for whatever period of time the GIS represents). A more advanced GIS may record a start and end time for each feature; at best, each distinct instance of a feature may have its own record with a start and end time. (Raster GIS usually records only the time when an image was created or a transformation performed.) Treating time as a simple attribute can support temporal visualization, as in map animations, but there is little connection between the different temporal representations of the same spatial object other than perhaps a shared object ID. This makes quantitative analysis of the temporal behavior of spatial objects difficult.

The First Law of Geography, as attributed to Waldo Tobler (1970), is regarded as the foundation for quantitative techniques for analyzing correlation relative to distance or connectivity, forming core knowledge of spatial dependency and spatial autocorrelation statistics (Miller 2004). Does the same law apply in the space-time continuum? Are things that happened closer in time also more related than things that happened further apart in time? In the First International Symposium on Spatiotemporal Computing held in July 2015 at George Mason University, one of the panelists suggested revising the First Law of Geography to include temporal proximity. However, spatiotemporal interpolation methods have been applied widely for decades (Li and Revesz 2002), even incorporated in popular statistical software packages such as R (Gräler, and others 2016). Some of these methods assume that distance in space and in time are interchangeable at some rate, and that rate can be determined by the sample data through covariance modeling (Stein 2005). We suggest that support for temporal measure be part of an evaluation of the geographic in GIS.

Some Conclusions: Systems and/or Science

As scholars with an interest in the relationships among the many branches of geography, we advocate further evaluation of the geographic aspects of GIS. In doing so, we point to some confusion in terminology and how various kinds of spatial analysis are related to the fields that make use of GIS. We suggest that the geographic aspects of this software-dependent technology are far from sufficiently developed, and propose continued discussion and creative development to support a more geographic GIS. We recognize that the interpretation and implementation of this suggestion are likely nontrivial.

We have developed these ideas in the context of the dynamic field of GIScience, first defined in the early 1990s (Goodchild 1992). The study of GIScience has undoubtedly helped advance GIS (Maguire 2007/2008), but it has also sharpened disagreements over the nature and value of GIS for geography as a discipline (Schuurman 1999; Wilson 2017). The boundaries between studying GIS as tool usage, tool construction, methodology, and theory remain blurry, yet pinning GIS to one or the other of these purposes to some extent continues to define, and divide, GIS users within geography. Even though GIScience has been an acknowledged and vigorous field for more than two decades, there remains little agreement as to the exact contents and boundaries of the technology that initially defined it (Couclelis 2012; Blaschke and Merschdorf 2014). Longley and others describe GIS as "a science, a system technology, a discipline, and an applied problem-solving methodology" (2016, p.xxi). This definition indicates that the system in GIS is more than software. We suggest to further define the system in GIS as a systematic approach in pursuing the development of theory, method, tools, and how they are used. This echoes Wright's (2012) call for making GIS "both system and science to support the turn toward more place-based research across increasing scientific domains" (2012, p.2197).

The fundamental value of GISystems as a unique field of inquiry resides in its systematic nature, its capacity for integration, and its embracing of scientific, social scientific, and humanities research. GIS is not well suited, conceptually or in its basic design, to picking apart objects and studying each isolated or controlled component of a natural or human system or phenomenon. It is well suited, we suggest, for studying the many objects that constitute natural and/or social systems and their relationships, differences, interactions, and connectivity.

Scholars who were influenced by the "tool vs. science" debate in the late 1990s may hesitate to agree that GIS is itself a field (Pickles 1997; Wright and others 1997). Indeed, we will need a field, no matter what it is called (critical GIS, computational geography, spatial science, or the like), that focuses on the system level, as the uniquely comprehensive and integrated digital means of analyzing geographic phenomena. If we regarded GIS not as a hammer, but as carpentry, that is, a practice that builds spatial understanding, geographers might take it more seriously as a field that calls for fresh investment of ideas and vision. We hope we might contribute to a broadened debate by those engaged in spatial analysis, however defined, to evaluate the geographic in GIS, to understand how this evolving technology and mode of inquiry is shaping our work and how we might shape it in our pursuit of a range of scholarship.

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