GIS: Tool or Science? Demystifying the Persistent Ambiguity of GIS as "Tool" Versus "Science"

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Source: *Annals of the Association of American Geographers*, Vol. 87, No. 2 (Jun., 1997), pp. 346-362
Published by: Taylor & Francis, Ltd. on behalf of the Association of American Geographers
Stable URL: https://www.jstor.org/stable/2564374
Accessed: 17-01-2020 17:58 UTC

Forum

GIS: Tool or Science?

Demystifying the Persistent Ambiguity of GIS as "Tool" versus "Science"

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Is GIS a tool or a science? The question is clearly important in the day-to-day operations of geography departments. Departments need to know if GIS is a tool that should be taught at the undergraduate level, or a science and thus a legitimate research specialty of faculty and graduate students. We summarize the debate on this question that was conducted on GIS-L electronic listserver in late 1993. In evaluating this discussion it became clear that GIS could be understood not by the two distinct positions taken by the GIS-L discussants but as three positions along a continuum ranging from tool to science. These positions attach several meanings to "doing GIS." These are (1) GIS as tool, i.e., the use of a particular class of software, associated hardware tools, and digital geographic data in order to advance some specific purpose; (2) GIS as toolmaking, i.e., the advancement of the tool's capabilities and facilities (ease of use); and (3) the science of GIS, i.e., the analysis of the fundamental issues raised by the use of GIS. Recognizing the importance of understanding what is meant by "doing science" as well as what is meant by "doing GIS," we conclude that only one of these positions—"the science of GIS"—is a sufficient condition for science. The "toolmaker" position is rarely able to meet the test of science; and the "GIS is a tool" position involves "doing science" only if it yields progress on some substantive problem. The debate is certainly problematic in light of the variety of perspectives on science and on GIS. The persistence of the issue suggests, however, that the GIS community should continue to work toward a resolution.
Key Words: GIS-L, systems, geographic information science, geographic thought, nature and philosophy of science, nature of geographic information systems.

When Roger Tomlinson coined the term "geographic information system" for the Government of Canada in the early 1960s (Coppock and Rhind 1991), he can scarcely have imagined the impact that "GIS" would have on the discipline of geography, or the intensity of the debates that were provoked by this seemingly innocent three-letter acronym. Of course geography is no stranger to methodological debates, and some of the arguments over GIS echo the arguments over quantification in the 1950s. We cannot be certain whether the GIS debate is more or less intense than its precursors, but we can be certain that it is important given the interdisciplinary nature of GIS, albeit a nature in which geography is widely accepted as having a unique role (Morrison 1991; Kennedy 1994). Geography's debates over GIS are thus unusually exposed to general view.

The purpose here is not to review the various appraisals of GIS, which range from GIS as savior putting the "geographic Humpty Dumpty" back

Annals of the Association of American Geographers, 87(2), 1997, pp. 346–362

Published by Blackwell Publishers, 350 Main Street, Malden, MA 02148, and 108 Cowley Road, Oxford, OX4 1JF, UK.

together again (Openshaw 1991) to dismissal as "non-intellectual expertise" (Jordan 1988); from excitement over GIS as positivism's second coming (Heywood 1990) to GIS as a last-ditch rally by positivism's battered survivors (Taylor 1990). More interesting are the social implications of GIS—the message it sends, whom it empowers, and the responsibility its developers should bear for its eventual use (Smith 1992; Pickles 1994; Harvey and Chrisman forthcoming). In the U.K., these debates within the discipline have caught the attention of even so authoritative a source as the *Times Higher Education Supplement* (Davies 1995).

At heart, these debates arise from the ambiguity of GIS as a tool or as a science. While Tomlinson was clear enough in his definition of a GIS as a computer application designed to perform certain specific functions (Coppock and Rhind 1991), it is not at all clear what is meant by "doing GIS," "the GIS community," or "GIS research," since in all these cases the etymological path between acronym and phrase has become hopelessly muddied. At face value, "doing GIS" seems to imply nothing more than interacting with a particular class of software: "the GIS community" is no more than a group of individuals with an intense interest in that software; and "GIS research" seems an oxymoron. By examining the tension between GIS as a tool and GIS as a science—a tension that ultimately defines what it means to be "doing GIS" in geography—we hope to shed some light on these issues, which are clearly important in the day-to-day operations of geography departments. Departments need to know if GIS is either a tool that should be taught exclusively at the undergraduate level or a science and thus a legitimate research specialty of faculty and graduate students. Are students who "do GIS" doing substantive science? Is an association with GIS sufficient to ensure that research is substantive, or if not, what other conditions are necessary?

Much of the motivation for this paper derives from a debate on the GIS-L electronic listserver in late 1993. These electronic lists, or "invisible colleges" (Crane 1972) as it were, span the barriers between disciplines. Since its inception, GIS-L has provided a forum for a variety of discussions of GIS issues (Mark and Zubrow 1993; Thoen 1996). During October–November 1993, the topic "GIS as a Science" generated 64 postings from 40 individuals in 8 states and 6 countries (Figure 1). The usual length and intensity of the discussion made it clear that the "tool versus science" debate sparked great interest among many scientists, technicians, and practitioners, whatever their discipline. One of the objectives of this paper is to explore the relationship between the positions taken in this electronic de-

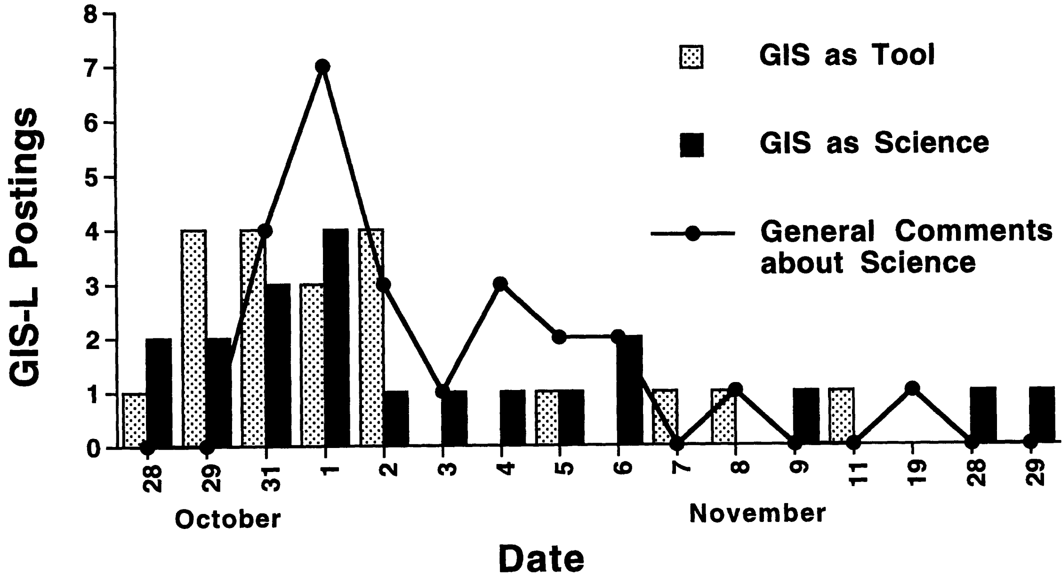

Figure 1. Graphical summary of GIS-L postings on the topic "GIS as a Science" during October and November 1993.

bate and current debates within the discipline of geography.

The "tool versus science" debate has received little mention in the published literature of geography, which is surprising in view of the attention given to GIS the past decade. The closest the literature comes to the debate is Goodchild's (1992) paper on "geographic information science," Sui's (1994) discussion on reconciling the differences between GIS enthusiasts and critics, and the articles on "Automated Geography" that appeared in *The Professional Geographer* in 1993—the latter, a series of reflections on developments in the ten years since Dobson (1983) announced that advances in analytical methods and computer technology had made it possible to automate several aspects of geographical research and problem solving.

In the discussion that follows, the electronic debate on GIS-L serves as the point of departure for an exploration of "doing GIS" from the perspectives of both geography and the society in which the discipline is embedded. The paper frames the tension between the positions of "GIS as a tool" and "GIS as a science," summarizes the GIS-L debate, considers the implications of the debate, explores the position adopted, and proposes a solution and discusses its implications for the profession. One note on terminology is necessary. The term "geographic information science" has appeared with an increasing frequency in the geographic literature (Goodchild 1992; Rhind et al. 1991; Rhind 1992; Abler 1993; Cromley 1993; Dobson 1993; Fedra 1993). Goodchild (1992) has argued that GIS has done much to remove the traditional isolation between the fields of photogrammetry, remote sensing, geodesy, cartography, surveying, geography, computer science, spatial statistics, and other disciplines with interests in the generic issues of spatial data, and it is these disciplines that constitute geographic information science; hence it makes sense for the research community to decode the GIS acronym in this way. Be that as it may, in this paper every reference to the acronym GIS is to "system" not to "science."

The GIS-L Debate

Documenting Electronic Discussions

Scholarly interaction is being revolutionized by the Internet applications of electronic mail, discussion lists, the World Wide Web, electronic journals, and digital libraries (on the Internet's impact in oceanography, see Hess et al. 1993; and likewise on traditional journals, see Odlyzko 1995). Subscribers to an electronic list such as GIS-L are able to reach hundreds of colleagues around the world to discuss an issue or ask a question, thereby crossing all of the traditional structures of the research community (save perhaps structures based on language) within minutes. While it is impossible to determine exactly how many individuals read GIS-L and with what level of interest, Mark and Zubrow (1993) reported that at the time of their analysis, the list contained approximately 1100 individual Internet addresses and was redistributed to more than 30 additional lists worldwide.

Once registered as a subscriber to an unmoderated electronic discussion list, any individual with an Internet address automatically receives all messages posted by any other subscriber. The essential informality of this system of communication is both a blessing and a source of difficulty for anyone attempting to synthesize these discussions. Many of the discussants do not have the time, the inclination, or perhaps the energy to research the positions that they adopt on such topics as, in our case, philosophies of science, geographic methodology, or the interplay between science and technology. Electronic comments posted to a discussion list are not as carefully thought out as writing in the scientific literature. A written synthesis is thus perhaps more akin to the proceedings of a workshop, in which useful ideas are expressed but not yet consolidated or put into perspective.

Another challenge is how best to present the discussion; in other words, how to properly cite communication from an electronic conference. As on-line newspapers, journals, libraries, and data archives become more prevalent on the "information superhighway," and it becomes necessary to refer to information that may exist only in electronic form, formal methods of citation will have to emerge that are as robust and persistent as conventional methods. The use of Universal Resource Locators (URLs, the electronic World Wide Web addresses that commonly begin with "http://") for citations to information available through the World Wide Web is already causing problems with "broken URLs," which occur whenever information is deleted or moved from its existing site, or the name of a server or its file structure is changed. Until better methods are devised, material posted on electronic discussion lists and bulletin board falls into the realm of "personal communication," but unlike oral communication, electronic mail provides a more or less permanent and verbatim record of communication and is precisely quotable. In this paper we follow the electronic citation style proposed by Li and Crane (1993).

A final issue is confidentiality. For this study of the GIS-L discussion, all participants were notified of our intent to present and synthesize their comments in a published manuscript, and given the option of having quotations and references to their comments removed. Before the manuscript was submitted for publication, participants were sent a draft version for review and comment. It should be noted that the views expressed by GIS-L discussants do not necessarily reflect the views of their institutions or organizations.

Summary of the GIS-L Discussion

The GIS-L exchange (summarized in Table 1) began as an offshoot of a discussion about one important aspect of the scientific enterprise: the value of peer-reviewed literature within the scientific community, particularly with respect to its suitability as reading material for students. With the mention of "GIS as a science" in the context of peer-reviewed literature, some correspondents responded that "GIS is a tool, perhaps even a problem-solving environment, but it is most certainly not a science" (Skelly 1993a). The electronic debate launched a discussion that unfolded between October 28 and November 28, 1993 (Figure 1). Table 1 is organized chronologically because the debate was dynamic and evolved via a series of responses to particular statements, claims, etc. The evolutionary course of the debate was also very important in shaping its contents. Space does not permit a presentation of the entire discussion, which when downloaded from GIS-L and printed out comprises fifty pages of single-spaced text. The table is organized according to the two major positions taken during the debate ("GIS as tool" vs. "GIS as science") as well as by the participants' general comments about the scientific enterprise.

Many of those who argued on the "tool side" of the issue could not see how a computer application could be described as a science (e.g., McCauley 1993; Moll 1993; Skelly 1993a, 1993b). They saw GIS as a tool or technique in the same sense that Curran (1987) defines remote sensing as a technique. From this perspective, GIS on its own is meaningless; its gains meaning only by its goals, which generally involve the application of knowledge *by* scientists, but not science itself (McCauley 1993; Moll 1993; Skelly 1993b). In the GIS-L discussion, those who defined GIS as a tool did so in the sense of a physical entity and also as a technique (Crepeau 1993a; Feldman 1993b; Halls 1993; Moll 1993). Viewed in this way, GIS may belong more to the field of engineering than to science (Feldman 1993d; Skelly 1993c, 1993d). Discussants identified engineering as a problem-solving activity, while science was linked to discovery and problem understanding (Al-Taha 1993). That said, the boundaries between the two are often muddied, particularly at the level of basic research where engineers may use scientific methods to identify and understand the problems they will eventually attempt to solve (Al-Taha 1993).

Some of the "tool side" of the issue seemed to feel that if GIS had any scientific aspect, it derived from GIS's place within the discipline of geography (Crepeau 1993a; Feldman 1993c; Halls 1993). GIS is thus a tool applied when going about the business of geographic science (Halls 1993). If "doing geography" is a science, then "doing GIS" amounts to a science (on the "geography as science" issue, see Couclelis and Golledge 1983; Hart 1982; Johnston 1979, 1986; Smith 1992; and Unwin 1992).

Those on the "science side" of the GIS-L discussion spoke mainly about the *use* of GIS as a method or body of knowledge for developing and testing spatial theories (Brenner 1993; Laffey 1993; Sandhu 1993b; Wright 1993a), not about the physical entity GIS itself. While they agreed that the "toolbox" view of GIS was accurate, it was at the same time very limiting (Bartlett 1993b; Sandhu 1993a; Wright 1993b). As important as are the hardware/software components of GIS, it is the conceptual elements of GIS (e.g., the rules governing the creation of spatial models for GIS, the measurement and modeling of error propagation through a GIS, or proofs of theorems on data structures) that enable GIS to claim a place as a science (Bartlett 1993a; Carlson 1993a; Wright 1993b).

Some discussants raised more fundamental questions: "what exactly is science?" and "what specifically allows us to call GIS a science?" (Feldman 1993c; Piou 1993). Although no simple consensus on science emerged, discussants ac-

Table 1. Excerpts from the GIS-L Discussion, October–November, 1993

GIS as Tool	GIS as Science	General Comments about Science
GIS is a tool, a technology, a problem-solving environment, but definitely not a science (Skelly 1993a, 28 Oct. 01:55 PST).	GIS as a science should move away from the technology towards the fundamental aspects of modeling spatial phenomena (i.e., the conceptual underpinnings of CHARACTERIZING spatial phenomena). How NOT to generate erroneous spatial data is a science in and of itself (Carlson 1993a, 28 Oct. 17:34 PST).	Investigating data models and methods of database design is an applied area of interest, perhaps applied science (Crepeau 1993b, 29 Oct. 14:04 PST).
How NOT to generate erroneous spatial data is a problem but not a science (Skelly 1993b, 28 Oct. 20:12 PST).	See the research initiatives of the NCGIA. Aspects of GIS as a science include the study of spatial data uncertainty and error, data lineage, and how GIS is adopted by agencies (Wright 1993a, 28 Oct. 22:44 PST).	Why is computer science called "science," not engineering? What exactly is a science? (Piou 1993, 31 Oct. 18:39 PST).
GIS will become a science when it divorces itself from geography. If GIS is a science, statistical software and its use are science. Theoretical knowledge that forms the design of a model is science, not knowledge of how to run software. In short, geography is the science, not GIS (Crepeau 1993a, 29 Oct. 09:33 PST).	The component of GIS that address the fundamental nature of digital geographic information is a science. Part of the process of design, developing, and improving tools is science (Cooper 1993, 29 Oct. 9:16 PST).	Beware of having too high a regard for science, especially in terms of believing that it provides the "truth" (Britton 1993, 1 Nov. 12:29 PST).
GIS in and of itself is a tool. The science label is merely to attract research money and/or enhance the status/power of GIS users. Important to realize WHY people are making the science argument (Petican 1993, 29 Oct. 12:54 PST; Groom 1993, 1 Nov. 14:03 PST).	GIS may be a discourse which would include both the science and tool views. A discourse is a methodology for studying something. The tool view doesn't give enough credit to geography, the science view takes GIS away from geography to stand on its own (Brown 1993, 29 Oct. 16:22 PST).	Note carefully the implications of your definition of science (Feldman 1993a, 1 Nov. 13:25 PST; Feldman 1993d, 8 Nov. 06:47 PST).
Many are understanding spatial phenomena through the USE of GIS. GIS is a tool USED by scientists (McCauley 1993, 29 Oct. 13:59 PST).	Does investigation of the role of scale in GIS and its relationship to map area, the importance of spatial integrity when all layers of information come from the same base map, or the appropriateness of a spatial control for a particular scale warrant a science? Are answers available from another science? (Carlson 1993b, 31 Oct. 10:48 PST).	The success and acceptance of a given activity in a historic time or for some social groups may well depend on whether that activity is considered as either scientific, philosophical, political, or statistical. Different groups in different times emphasize the importance of one or another perspective (Scalise 1993, 1 Nov. 18:36 PST).
Perhaps a LITTLE bit of science goes into GIS as some science goes into most technology. ENGINEERING DESIGN, not science, primarily goes into GIS (Skelly 1993c, 31 Oct. 14:04 PST).	The answer depends on who is involved. For example, developers of GIS see it as a sophisticated science, salesmen and students recognize it as tool (Rao 1993, 1 Nov. 02:22 PST).	Philosophy of science is an important thing to consider for this discussion. For example, "basic laws" are part of science only in the positivist approach to science, not in approaches such as realism (Feldman 1993b, 2 Nov. 10:05 PST; Feldman 1993d, 8 Nov. 06:47 PST).
The science of what we are about is in the spatial ordering and interrelationships of objects and information. The tool we are concerned with is GIS. GIS is the application of spatial science to the study of earthbound objects, etc. (Halls 1993, 1 Nov. 03:01 PST).		Consideration of the *motivation* for labeling something as science is also important for this discussion. When we label something as "science" without looking critically at what we mean, we are in fact laying the groundwork for the arbitrary exclusion and delegitimization of certain reasonable forms of scientific knowledge (Feldman 1993b, 2 Nov. 10:05 PST, 1993c, 5 Nov. 12:56 PST).

GIS as Tool

What are the accepted scientific methods of a science of GIS? Software development is engineering, not science. Math and statistics are not science either. Both spatial analysis development and its application through GIS assist science, but like math they are not science (Skelly 1993d, 1 Nov. 16:50 PST).

GIS is a tool that describes processes relating to the manipulation of spatial data; GIS is an entity that describes organizations; GIS is a technique employed by a scientist, not a science unto itself (Moll 1993, 2 Nov. 09:17 PST).

GIS may be a revolution-driving tool rather than a scientific revolution in and of itself. For example, the telescope is the revolution-driving tool whereas optics and metallurgy are the sciences that extend it (Murphy 1993, 2 Nov. 14:27 PST).

Is GIS sufficiently distinct as to be separate from other sciences? Does it have formal properties that are distinct from those investigated in statistics, computer science, cartography, etc.? For GIS to be considered a separate science, the problems it addresses must be unique to GIS, and the extension of GIS must be towards a greater understanding of GIS problems rather than towards solving specific technical issues (Feldman 1993c, 5 Nov. 12:56 PST).

PARADIGM shifts occur when the limits of a design are reached. The problem of deriving a new design is treated as science—the design PRINCIPLES of GIS are "scientific," even though the process of building one is engineering (Geissman 1993, 6 Nov. 12:00 PST).

GIS as Science

The science of GIS is not the development of tools (i.e., what the ESRI programmers do). GIS theory is science assuming that the development of algorithms, proper methodology, is science (Brenner 1993, 1 Nov. 07:04 PST).

The toolbox view limits GIS. Devising a representation of spatial data, developing an algorithm (method) to solve a spatial problem and applying it to test a theory are part of science. GIS embeds the knowledge a scientist has about a region and provides ways to test theories and alternatives. Devising new methods to test a theory may constitute a PARADIGM shift in Kuhnian terms (Sandhu 1993a, 1 Nov. 18:14 PST).

Developing new methods of using GIS is part of the larger science of geography, computer science, etc., not a separate science. GIS does not represent a PARADIGM shift in Kuhnian terms or a scientific revolution comparable to Quantitative Revolution of the '60s or the onset of Humanism and Marxism in the '70s and '80s (Feldman 1993b, 2 Nov. 10:05 PST).

GIS is part of a broader spatial information science. GIS in these terms is not merely the hardware/software component but the ISSUES surrounding its use (e.g., spatial data uncertainty, its measurement and modeling). The toolbox view is limiting. GIS encompasses the way in which geographical info. is collected, perceived, managed, and used (Wright 1993b, 2 Nov. 19:05 PST).

Are people who look for newer ways to analyze data not doing science? This would involve developing theory on entities such as time and spatial phenomena. For the scientist using it, it is a tool, for the producer of GIS, it is the engineering of a tool, for the scientist extending GIS, it is science (Sandhu 1993b, 3 Nov. 10:27 PST).

General Comments about Science

HYPOTHESIS TESTING is neither necessary nor sufficient for science. Science is concerned with understanding, which is often an aid to invention, but invention is not science (Feldman 1993d, 8 Nov. 06:47 PST).

Could it be the "authority" or "stature" suggested by the term "science" that causes its adoption in naming an emergent area? "Science" lends a sense of validity, one that may not always be warranted (Elliott 1993, 19 Nov.).

Engineering is problem-solving while science is discovery and problem understanding. At the professional level, the distinction is quite clear (e.g., geologist and civil engineers studying soil mechanics for different reasons). At the research level, the boundaries are less apparent (e.g., engineers may use scientific methods to identify and understand the problems they will eventually attempt to solve) (Al Taha 1993, 29 Nov.).

A GIS database is a structured subset and abstraction of reality. The rules governing the creation of spatial models for GIS were formulated on the basis of scientific thought and experimentation, and now that they are in place, they form a PARADIGM whereby GIS users can seek to analyze the real world. Every time one applies these data modeling rules, one is TESTING THE HYPOTHESIS that it fits reality (Bartlett 1993b, 6 Nov. 10:21 PST).

GIS is a science which, like geology for example, draws from other sciences to create new ways of looking at data and analyzing it. The spatial aspect draws from math, geomorphology, and other disciplines to get at the business of data (Calef 1993, 28 Nov.).

GIS as Tool	GIS as Science	General Comments about Science
Complex technology that evolves is a field of engineering, not science. Abstractly considering data that exists in an n-dimensional space and how such data can be joined, intersected, etc. in this n-space would be a scientific problem. Still, this does not make GIS a science (Feldman 1993d, 8 Nov. 06:47 PST).	GIS is an environment as well as a method used to discover, explore, and test spatial theory. It is also a tool of the hand and mind (Laffey 1993, 4 Nov. 16:56 PST).	
Unless we can find some scientific object that is distinct to GIS, then GIS is an area of application combining elements of computer science and geography, and not a science unto itself (Feldman 1993d, 8 Nov. 06:47 PST).	A technocentric view of GIS is very limiting. As important as the hardware and software are the conceptual elements of GIS (data modeling, visualization, communication, legal aspects, etc.) These theoretical and conceptual aspects give GIS at least a foot in the realm of the sciences. GIS is a technology, so is the paper map. Denying that aspects of GIS are science is like denying that aspects of cartography are science (as well as art). The concepts that the tools seek to facilitate, automate, and develop are strongly rooted in science (Bartlett 1993a, 5 Nov. 11:13 PST).	
	What specifically allows us to call GIS a science? Maybe we should think in terms of formal science (purely abstract thought as in math and computer science) vs. substantive science (phenomena that exist outside of thought). GIS may have a scientific component as a formal science (Feldman 1993c, 5 Nov. 12:56 PST).	

cented the conceptual elements mentioned above, along with activities such as "obtaining theoretical knowledge to form the design of a model," "development theory on entities such as time and spatial phenomena," and "development algorithms to test a theory." These were thought to be parts of the scientific enterprise (Crepeau 1993a; Sandhu 1993a; Wright 1993b), and hence a possible basis for testing the scientific status of a given activity. There was also a distinction made between "formal science" (purely abstract thought, as in mathematics) and "substantive science" (phenomena that exist outside of thought) (see Feldman 1993c). Accordingly, one must consider the implications of his or her definition of science so as not to arbitrarily exclude or delegitimize certain reasonable forms of knowledge (Feldman 1993a, 1993c, 1993d).

These attempts at defining science naturally led to the question of whether GIS is significantly distinct from sciences such as computer science or geography. In other words, if GIS is a science in some respects, is it a science unto itself, with its own unique, logically coherent object of knowledge (Carlson 1993b; Feldman 1993d; Skelly 1993d)? Hence Dobson's (1993) query: "Is GIS prompting a scientific revolution? The most severe test would be whether there are hypotheses and theories that can only be conceived and tested through GIS." GIS is special in that it is uniquely visual and able to make explicit the implicit features of data. Those on the "science" side or in the middle of the GIS-L discussion, however, did not seem to require a separate body of knowledge for GIS. Instead, they viewed the science of GIS as a subdiscipline of geography or computer science (the way biogeography or geomorphology are sciences within the larger field of geography, or paleontology is a science within the broader field of geology) (Bartlett 1993a; Calef 1993; Wright 1993b). Discussants voiced strong agreement that the connections between GIS and the science of geography are the strongest, and that GIS is not merely a subset of computer science (Bartlett 1993a; Wright 1993b). It was pointed out that many of GIS's early pioneers were geographers, e.g., Coppock, Rhind, Bickmore, and Unwin in Britain; Tomlinson, Garrison, Berry, Tobler, and Marble in North America (Bartlett 1993b); and that geographers more than anyone else actually identified, conceptualized, and formalized the initial connections between spatial concepts and computer technology (Bartlett 1993b).

Putting the Debate into Perspective: Definitions of Science

A lengthy foray into the philosophy and sociology of science is beyond the scope of this paper, but some considerations of these matters is unavoidable in order to know what scientists do, the significance of what they do, and the relationship of science to other knowledge-generating mechanisms. There is one caveat at the outset: there are probably as many definitions and viewpoints of science as there are scientists (Feibleman 1972), and not all of these are necessarily correct! A concise definition of science cannot hope to capture the full meaning of the term. Science encompasses a wide range of fields that differ widely from each other in philosophy, knowledge content, and methodology. The term "science" may be viewed as shorthand for a logical and systematic approach to problems that seeks generalizable answers. This is the position by Robinson et al. (1984) in describing how cartography employs "the scientific method" in constructing its products. Given Robinson et al.'s emphasis on logic, most computer applications would pass the test of being "scientific," though it leaves unanswered the question of whether "doing cartography" is "doing science." Nonetheless, many participants in the GIS-L debate were probably unaware of the finer shades of meaning conveyed by the term "science," or that many users of GIS might think of themselves as "scientists" in the unqualified sense of that term.

Depending on one's inclination, there are several different approaches to science, each with its own ontology, epistemology, and methodology. These so-called -isms are defined variously by geographers. Johnston (1986) uses the terms "positivism," "humanism," and "structuralism" to describe human geography's three main scientific approaches; Haines-Young and Petch (1986) accent "empiricism," "positivism," "relativism," and "critical rationalism," and Cloke et al. (1991) focus on "Marxism," "humanism," "structuration theory," "realism," and "postmodernism." Thus to ask the simple question, "Is GIS a science?," is usually to presume the superiority of one or another approach to generating knowledge. For example, the GIS-L discussion pointed out that the concept of "basic laws" is part of science only in the positivist approach, not necessarily in approaches such as realism or humanism (Feldman 1993b, 1993d). Many argue that the positivist approach is privileged with regard to GIS (Heywood 1990; Taylor 1990; Smith 1992; Lake 1993; Shepherd 1993), but Goodchild (1994) sees in the growing literature on the epistemology of GIS (e.g., Pickles 1991; Wellar et al. 1994) the entire spectrum of approaches, from the positivist to the postmodernist. If in the past certain approaches to science have been preferred in GIS, GIS need not preclude other approaches in the future.

If aspects of GIS are to be considered as "science," according to what philosophical approach are they scientific? This issue was raised briefly in the GIS-L discussion (see Table 1; Feldman 1993b, 1993c) but was not examined in detail. In the longstanding debates that have occurred in geography over the appropriateness of different approaches, "positivism" and the "critical rationalism" of Karl Popper (1959) are conventionally associated with "science" (Haines-Young and Petch 1986; Johnston 1986), but the rigorous collection and evaluation of data in the production of knowledge are not exclusive to positivism or critical rationalism (e.g., Keat and Urry 1975; Johnston 1986; Sayer 1992). It is not our wish to downplay the explanatory power of these alternative, nonpositivistic approaches; indeed various philosophies of science have succeeded in *undermining* positivism's claims to being a superior method for understanding the world (e.g., Willer and Willer 1973; Hindess 1977; Couclelis and Golledge 1983; Sheppard 1993).

Why Does Science Matter?

Why should one care whether GIS is a science or not? The technological (toolbox) face of GIS is widely successful in government, business, and education, and it appears to have affected and improved the lives of far more people than have many theoretical advances (e.g., the theories of spatial data and of data structures, data models, and algorithms). Technology in general has the potential to contribute greatly to society and culture.

Science, though, is often held in high regard, and labeling a field as a science may sometimes help to ensure it a place in the academy or to secure it greater funding and prestige. "Science" is often used as a generic synonym for "research," particularly research of a basic, systematic, and generalizable kind. Thus "science" often functions as a rather crude but convenient shorthand for academic legitimacy; if "doing GIS" is "doing science" then its claim to a place in the academy, as a topic of research and graduate-level instruction, is clearly strengthened.

In the GIS-L discussion, some participants implied (Groom 1993; Petican 1993) that those arguing for "GIS as science" might be driven by ulterior motives. Some participants warned of having too high a regard for science, especially in believing that it provides the "truth" (Table 1). In the opinion of these correspondents, science does indeed greatly influence our everyday lives and our ideas about the world, but does it deserve special reverence? Is there something special about science and the contributions it has made? One must strike a balance between debunking science and dragging it off its pedestal, on the one hand, and falling into scientism (the claim that the scientific method is the only true method of obtaining knowledge), on the other. The point has already been made eloquently by Bauer (1992:144):

> That science does not have all the answers does not mean that it has no answers. That science now has inadequate answers in some areas does not mean that the answers will not become adequate in the future; in fact, history teaches that science's answers become better and better as time goes by. That science is fallible does not mean that science is *entirely* fallible or that it is *as* fallible as such other modes of human knowledge and belief as folklore, religion, political ideology, or social science. That science has no answers in some matters—such as the value of human life or the purpose of living—does not mean that it has no answers in other areas—those areas that are within its purviews, matters of forces and substances and natural phenomena. And that science has no direct answers on matters of human purpose does not mean that its answers on other matters have no bearing on how, and how well, we are able to think about human purpose, free will, and other such things.

Clearly it does matter whether or not "doing GIS" is "doing science," if for no other reason than that "doing science" is often regarded as a code-phrase for academic legitimacy. We will now argue that "doing GIS" may express at least three meanings that are represented by three positions. Our strategy, therefore, is to examine the role and legitimacy of each of these three positions within the academy in general and within the discipline of geography in particular.

Three Positions on GIS

In synthesizing the general themes of the GIS-L discussion, it became clear to us that GIS could be understood not by the two distinct positions taken by the GIS-L discussants but as *three* positions along a *continuum* from tool to science. These positions focus on the several meanings attached to "doing GIS" rather than to GIS alone. These are (1) GIS as tool; (2) GIS as toolmaking; and (3) the science of GIS. It seems clear from the GIS-L discussion that the label "GIS" is simplistic, since it fails to indicate by itself whether the research involves fundamental scientific questions and hypotheses, or whether GIS merely adds gloss to the research through the use of a complex and sophisticated tool—whether it decodes as "science" or "system." We have derived three positions on GIS from the GIS-L discussion; these represent a "fuzzy" continuum of opinion which recognize that positional labels are not perfect. Although these three positions do not capture all of the nuances of argument during the GIS-L debate, they do represent the principal points of view along a "tool-science" continuum.

The "GIS is a tool" position sees GIS as the use of a particular class of software, the associated hardware tools such as digitizers and plotters, and digital geographic data in order to advance some specific purpose. The tool itself is inherently neutral, its development and availability being largely independent of its use, which is driven by application.

The "toolmaking" position sees GIS as concerned with advancing the tool's capabilities and ease of use. Besides using the tool, toolmakers regularly promote the adoption of GIS, play a role in educating users, and work to ensure responsible use.

Finally, the "science of GIS" position insists on a more intimate and reciprocal connection between tool and science—one that involves research on a set of basic problems, each of which probably existed prior to the development of GIS, but whose solution is more pressing now *because of* the technology. This practice of collecting sets of basic problems under new names has a long history in science. It occurred, for example, with the emergence of computer science, when the development of computing technology provided the impetus for solving certain fundamental research problems that had previously been associated with mathematics.

Discussion of the Three Positions on GIS

GIS Is a Tool

For those who take this position, "doing GIS" amounts to making use of a tool to advance the investigation of a problem. If the investigation merits the label "research," then "doing GIS" is probably "doing science" as well, but the existence and use of the tool are separable from the substantive problem. The documentation and write-up of the research tend to focus on the substantive problem, and indeed the tool may not be mentioned at all. In some cases, GIS may be only one of a number of tools used, each of which has been selected strictly for its efficacy in the research project. In these cases, the tools do not drive the research.

If the research objectives are to some degree "methodological," then the rules of engagement with tools such as GIS may be somewhat different, as may the content of the paper documenting the research. In these cases, the tool may assume a greater role in directing the research, and hence be given greater prominence in documentation, and case studies may be used to illustrate the technique rather than to provide generalizable empirical results. In papers of this sort, phrases such as "The Use of GIS in . . ." may appear in paper's title, although the processes responsible for the tool's development are independent of the substantive research problem. Because their primary motivation is to advocate the use of the tool, methodological demonstrations of GIS are more appropriately included under the second position discussed in the next section.

Scientists use many types of tools in their research. Some, such as typewriter or telephone, are generic in nature, with no particular association with any discipline. Others are developed strictly for one discipline, or even for one project or for one group of scientists. GIS falls somewhere in the middle, being of interest, in principle, to any discipline dealing with the distribution of phenomena on the surface of the Earth. It seems neither a generic tool whose use is so ubiquitous that one can reasonably assume universal familiarity (word processor, calculator), nor the exclusive tool of a single discipline. Perhaps a useful analogy is the tool of statistics, which in some disciplines (e.g., agronomy) is close to universal, while in others (e.g., anthropology) usage is mixed and its value is the subject of continuous debate.

For these less-than-universal tools, the academy traditionally provides the necessary infrastructure in the form of technical courses and technical support. But in addition, the academy satisfies the need for education in the associated concepts. In the case of statistics, for example, it would not be adequate to provide a laboratory of statistical tools without at the same time providing courses to ensure that students have the necessary understanding of concepts. The same distinction between technical training in the use of tools and education in the underlying concepts applies to GIS. While the concepts of GIS may be familiar to professional geographers, they must be taught anew to each generation of students. Without conceptual courses, the use of GIS is likely to degenerate to data management and map making, however complex the tool's capabilities for scientific analysis and modeling.

If GIS is a tool of particular value to geography, and if geography has traditionally taught many of the concepts that the tool implements, then it would seem that formal courses in GIS are most appropriately taught in geography. In the absence of departments of geography, universities have found a variety of solutions to the need for GIS instruction. In some cases, courses are taught by faculty or staff in computing facilities; in others, they are taught in departments such as surveying, civil engineering, or forestry (Morgan and Fleury 1993). But wherever they are taught, these courses serve two purposes—they prepare students to do their own research, and they provide students with useful job skills.

While this technical line of argument provides a solution that is satisfactory for students, it creates problems for the faculty assigned to teach them, particularly untenured faculty. Technical courses require very heavy commitments of faculty time, and teaching them is unlikely to boost the instructor's scholarly research career. The time required to maintain the GIS teaching laboratory and to deal with students' technical problems cuts down on the time available for research—and for securing tenure. Some departments deal with this issue by relying on sessional teaching staff or on technical staff, much as they did in the past when offering courses in technical fields such as cartography or remote sensing.

GIS Is Toolmaking

Advancing along the continuum between "GIS as tool" and "GIS as science," we reach the middle position on GIS, that of toolmaking. For toolmakers, the tool is inseparable from the substantive problem, i.e., "doing GIS" implies involvement in the development of the tool itself. Geographers who are makers of the GIS tool participate directly in its specification, development, and evaluation, as well as in its use.

In reality, the developers of GIS tools have backgrounds in many disciplines, including computer science, engineering, design, and mathematics, as well as geography. Few geographers have the necessary technical skills to build major software systems or to write "industrial-strength code"; but for that matter, academics in general are not regarded as suited to the development of reliable software. Indeed, most current GISs originated in the private sector in companies employing a mix of disciplines (GRASS and Idrisi are notable exceptions).

Geographers possess two unique and powerful abilities as GIS toolmakers. The first of these is an excellent understanding of the geographic concepts that form the primitive elements of GIS databases and processing and the ways that these concepts are embedded in theories, methods of analysis, and models. Second is that geographers are trained in a discipline that integrates understanding of a wide range of processes influencing phenomena on the earth's surface. Both of these abilities are essential to "doing GIS" if one adopts the position that "doing GIS" is toolmaking. A GIS toolmaker thus requires a basic education in geography together with technical courses that emphasize critical analysis of the technology's capabilities.

At the research level, the view of the toolmaker presumes critical analysis and reflection. The result is an extensive research literature that focuses on GIS as a generic tool (Goodchild et al. 1991); at the same time there is remarkably little published research on specific systems, perhaps because of the propriety nature of most GISs and because of scholarly fears that principles of academic freedom and the First Amendment would not protect them against a suit brought by a private-sector GIS vendor against publication of a critical academic evaluation of a product.

Critical analysis and reflection extends beyond the techniques of toolmaking to encompass questions about the social responsibilities of toolmakers and the social implications of the widespread adoption of the tool (Smith 1992; Pickles 1991, 1994; Harvey and Chrisman forthcoming). This involves evaluating a tool that has applications spanning the full range of human activities—from economy to politics to society. In this case, the issues become complex indeed. The scope of research is determined not by the tool's value to geographers, but rather by the multifarious applications of GIS, to include all of the societal effects of the computerization of geographic information. Whether "GIS" can withstand the stress of such varied usages remains to be seen.

The Science of GIS

It was evident from the GIS-L debate that GIS is widely viewed outside the discipline of geography as a subset of geographical science. Although geography is a small, unevenly represented discipline, and doubts about its legitimacy in the academy are widely held (Smith 1987), the recent growth of GIS and its affiliation with the discipline has meant increased visibility in the academy. Moreover GIS is associated with clear physical imagery, hence it is much easier to imagine "doing GIS" than "doing geography" if one has no familiarity with the latter. Geography's affiliation with GIS thus pairs it with the computer (however inappropriately). Computerization automatically confers precision, rigor, and replicability in the popular imagination, all of which contribute to the flawed notion of GIS as a subset of geographical science.

The very rapid growth of technology and the emergence of a technology-based society in recent years have prompted new groupings and priorities within science. Few would have predicted, for example, that the development of the digital computer would eventually lead to the discipline of computer science, or that information would itself become the basis of a scientific discipline. Four conditions seem necessary for the emergence of a science out of a technology: first, the driving technology must be of sufficient significance; second, the issues raised by its development and use must be sufficiently challenging; third, interest in and support for research on those issues must be inadequate in the existing disciplines; and fourth, there must be sufficient commonality among the issues to create a substantial synergy.

Two terms have evolved to describe the emergence of a science *based on* GIS. The first is *geomatics,* a term favored in many countries because of its simplicity and its ease of translation into French; the second, *geographic information science,* a term that is well-known in the English-speaking world. The latter is used here.

Geographic information science, the science of GIS, is concerned with geographic *concepts*, the primitive elements used to describe, analyze, model, reason about, and make decisions on phenomena distributed on the surface of the earth. These range from the geometric primitives of points, lines, and areas to the topological relationships of adjacency and connectivity through the dynamic relations of flow and interaction to domain-specific concepts such as neighborhood, geosyncline, or place. In their current state of developments, GISs are comparatively crude digital systems for representing and manipulating geographic concepts, capable of handling only the most primitive of these concepts. But while current technology may constrain the science of GIS, it does not limit its development, just as computer science is not limited by the current state of computer technology. Indeed the research problems raised by GIS and their solutions will help to define the future form of GIS technology. Perhaps the most crucial of these problems for geographic information science is the limitation of digital representation, i.e., are there geographic concepts which can never be represented in or manipulated by GIS?

The digital representation and manipulation of geographic concepts raise a number of fundamental research issues, many of which, though long-standing in traditional disciplines, have been reenergized by the development of GIS. Although the capabilities of GIS are improving, geographers who use it still look forward to the stage at which all geographic concepts and procedures are implemented digitally (Dobson 1983, 1993; Couclelis 1991). In the interim, GIS research will most likely implement those concepts and procedures that are the simplest, most logical, and most rigorously defined, i.e., the most primitive and/or the most scientific. These include issues of recognition and measurement in the field, the choice between alternative representations, the roles of generalization and multiple representations, the representation of uncertain information, methods of analysis and modeling, problems of describing the content of geographic data and evaluating its fitness for use, and methods of visualization. These sorts of issues underscore the multidisciplinary nature of geographic information science. Besides geography, it includes such traditional geographic information disciplines as geodesy, surveying, cartography, photogrammetry, and remote sensing along with spatially oriented elements of such other disciplines as information statistics, cognitive science, information science, library science, and computer science.

Evaluation

In light of these three perspectives on GIS, what can be said about the significance of "doing GIS?" If "GIS is a tool," then its use has little to do with the legitimacy of the research; in this case, significance derives strictly from the progresses made on the substantive research problem. In this sense "doing GIS" is not necessarily the same as "doing science"; the latter depends on the methods deployed on the substantive problem, i.e., are they scientific? Courses in GIS are more likely to be offered at the undergraduate level and reflect their essentially technical, service orientation. A geography department using GIS on this basis probably would not claim GIS as a research specialty, nor would it encourage its students to regard GIS as a substantive subfield of the discipline.

The toolmaking position confers a more significant status on GIS. In this case, GIS includes case studies that demonstrate the methodology, advocacy of GIS usage, and, perhaps also, the development of software. In the absence of indisputable instances of scientific insights uniquely attributable to the use of GIS, toolmaking will remain more akin to engineering than to science. Consequently, tests of toolmaking's progress would be based on indicators of improvements in the tool's utility. Critical reflection on and the evaluation of GIS are also included in the toolmaking position. While these are clearly legitimate activities of the academy, they are not as easily characterized as "doing science" (or "doing engineering").

A department adopting the toolmaking position would probably offer a range of undergraduate and graduate courses in GIS, including courses in the toolmaker's tools—programming languages—and the faculty would regard GIS as a research specialty and encourage students to make significant contributions as toolmakers. But such a department might also expect continuing tension between research and teaching in GIS and in more substantive fields (i.e., where research is measured by the accumulation of knowledge rather than by the improvement of tools).

The third position, "science of GIS," is concerned with the analysis of the fundamental issues raised by the *use* of GIS in geography or in other disciplines. As noted earlier, these issues may not be unique to GIS, but rather are remotivated by it; many of these issues continue to be regarded as problems in cartography or surveying or spatial cognition. A department taking this position with regard to specialization in GIS would recognize it as a substantive research field on a par with other such fields and would measure progress based on the accumulation of research results and contributions to human understanding, rather than from improvements in the tools themselves. This position is therefore the only one that provides sufficient grounds on which "doing GIS" is "doing science," and for the legitimacy of GIS as a research field in the academy.

Proponents of this position, however, must be careful not to confuse the use of GIS itself (e.g., entering a sequence of spatial analysis commands) with an *analysis* of the issues *surrounding* the use. Some may try to derive legitimacy from the proposition that GIS is so uniquely fundamental to geography that to do GIS is necessarily to do science—or, more extremely, that to do GIS is to do geography scientifically. This argument is somewhat flawed because it implies that GIS is vastly more effective than it currently is, and because it ignores the limitations of current GIS in dealing with time, scale, interactions, and a host of other sophisticated geographic concepts. Whether GIS is a geographical science in and of itself depends on both the rigor with which the tool is employed and the scope of the tool's functionality given the nature of the substantive problem. These issues clearly must be resolved on a case-by-case basis. Therefore the use of GIS is not a sufficient condition for science.

Conclusion

Goodchild (1993:445) notes that "an encouraging recent trend has been the willingness of a broad spectrum of geographers to see GIS not as a tool that they can use in their own research, but as a phenomenon on which they can reflect and comment." We have chosen to reflect and comment on "the phenomenon" of GIS because, as noted earlier, some of the interest in the GIS-L debate may have stemmed from the uncertainty faced by young scholars in particular over whether departments will accept "GIS" as a topic for scientific research. In these situations, because the label "GIS" is not altogether perfect, what is probably needed to fully describe the entity "GIS" is a shift from "black-and-white" boxes of description to "fuzzier" continua. We find that GIS represents just such a *continuum* between tool and science. The technologies of GIS (i.e., the tools and the toolmaking) clearly have the potential to motivate a host of interesting and fundamental scientific research questions. The science *based on* GIS (i.e., geographic information science) may advance the tools and toolmaking of GIS, as well as scientific research done with aid of using a GIS. Surely the desired end from all perspectives is the building of an intellectual foundation for GIS by geographers and members of allied disciplines alike, which will ensure its survival long after the novelty of the technology has worn off.

Debates arising out of the ambiguity of GIS as tool or science must be understood within the context of broader trends in science and in society generally. Older notions of science as the equivalent of "hard science" are being replaced by a more open view. Warning against conflating science and its positivistic expression, Johnston (1986:6) proposes a more generous view of science as "the pursuit of systematic and formulated knowledge, and as such [it] is not confined to any particular epistemology." In this context, GIS may represent a new kind of science, one that emphasizes visual expression, collaboration, exploration, and intuition, and the uniqueness of place over more traditional concerns for mathematical rigor, hypothesis testing, and generality (Goodchild 1992; Kemp et al. 1992; Rhind 1993; Fedra 1993; Muller 1993; Burrough and Frank 1995).

As a discipline, geography has long struggled with the tension between the general and the particular (Bunge 1962). Maps and geographic data capture the essence of the geographically particular, the boundary conditions that influence the outcome of physical and social processes; in that sense, GIS illuminates the particular. But unlike maps, the purpose of GIS is to maintain geographic data in a state(s) that may be transformed, processed, and analyzed in ways that are geographically uniform. Thus GIS is a technology of both the general and the particular, implementing the former in its formalized algorithms, concepts, and models, and the latter in the contents of its data sets. GIS as a technology seems uniquely appropriate for geographic research and, more specifically, for transforming geographic knowledge of processes into predictions, policies, and decisions. In this sense GIS captures geography's tensions between basic research and application, and between the geographically general and the geographically particular.

The demands for basic and applied knowledge are several in the new worlds created and encountered by GIS. Whether GIS serves as a technological means to acquire and develop knowledge or as an end for scientific inquiry in its own right, these systems will undoubtedly play a central role in knowledge making in the future. But it is important to understand what is meant by "doing science," as well as what is meant by "doing GIS." This paper has identified three well-defined positions on this matter, only one of which confers the kind of academic legitimacy associated with "doing science." In other cases, "doing GIS" is more akin to using a tool (to be evaluated by the appropriateness of the tool to the substantive problem) or to engineering better tools (to be evaluated on the degree of improvement in the tool). In such cases, GIS appears not to constrain its users to any particular epistemological stance.

Acknowledgments

The authors wish to thank Pete Peterson, Kristin Lovelace, Steve Behnke, and Ray Smith at UCSB for fruitful discussions. The critical reviews of Helen Couclelis and Alan Brenner significantly improved the manuscript. The National Center for Geographical Information and Analysis is supported by the National Science Foundation under Cooperative Agreement SBR 88-10917.

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