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Theory and application in a post-GISystems world

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This perspectives paper uses the seminal article of Goodchild (1992) as a lens through which to review and reflect upon several longstanding issues that have influenced the field of geographic information science in the past and will continue to be important at least into the next decade. Under the category of theory, the continuing issue of 'tool versus science' now has implications for the defining of geographic information systems (GISs) as a profession. In turn, a brief perspective is offered on how GIS has contributed to 'methodological versus substantive' questions in science, leading to the understanding of how the Earth *works* versus how the Earth should *look.* Both understandings of the Earth are particularly germane to the emergence of tools and applications such as marine and coastal GIS, virtual globes, spatial cyber infrastructure, and the ethics of GIS. And in the realm of marine and coastal GIS, the example of multidimensional data structuring and scaling is used to highlight an underlying lesson of Goodchild (1992) in that theory and application are in no way mutually exclusive, and it may often be application that advances theory, rather than vice versa. Indeed, it may be this reversal that is ushering in a 'post-GISystems' world, where GIS is subsumed into a broader framework known simply as 'the web,' divorced from the desktop, but providing a new paradigm for GIS (aligned with the 'fourth paradigm' of Hey *et al*. 2009). As so much data and information will be collected spatially in a way not possible before (e.g., the 'big data' of global observational science), GIS will need to be both system and science to support the turn toward more place-based research across increasing scientific domains. GIS is needed also by society at large to guide the understanding of the longstanding fundamentals of geolocation, scale, proximity, distance decay, the neighborhood, the region, the territory, and more.

Keywords: geographic information science; domain sciences; Goodchild; strategic directions

1. Introduction

1.1. Theory: systems versus science

It is useful to recall that Goodchild's seminal (1992) paper resulted from two separate but related keynote lectures, the first of which was delivered in Zurich in 1990 at the Fourth International Symposium on Spatial Data Handling, at that time one of the most important international meetings for the geographic information system (GIS) research community. An important quote from that address (Goodchild 1990) states:

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> What, after all, is spatial data handling? It may describe what we do, but it gives no sense of why we do it. It suggests that spatial data is [sic] somehow difficult to handle, but will that always be so? It suggests a level of detachment from the data themselves, as if the USGS were to send out tapes labeled with the generic warning, 'handle with difficulty' . . . We are concerned with much more than the mere handling and processing of data. We are more than the UPS of GIS.

Here Goodchild warned against GIS falling into the trap of being a technology in search of applications, a one-time, one-off, non-intellectual 'bag of tricks' with no substantive theory underpinning it, and suitable only for a static period of time. Indeed, we were learning in the early 1990s with the Internet about to explode onto the scene that technological development often comes in distinct 'bursts,' ushering leaps forward not only in the utility of the tools but in new research questions and insights. The technology driving GIS certainly fulfilled the need to 'handle' spatial data at the time, but failed to reflect the diverse research efforts at play to understand the issues surrounding the use and understanding of the data, and the impediments to that effective use.

The second keynote lecture was delivered in Brussels in 1991 at the Second European GIS Conference and was focused more on an actual research agenda that might drive the technological development (Goodchild 1991):

> Rapid progress was made on algorithms and data structures in the 1970s and 1980s, but many of the hard problems of data modeling, error modeling, integration of spatial analysis, and institutional and managerial issues remain. Some of these may be unsolvable – for example, there may simply be no generalities to be discovered (about) the process of adoption of GIS by government agencies, however easy it may be to pose the research question.

Goodchild (1992) had a profound impact on the thinking of many graduate students at the time. For those students coming to geography and GIS from other natural sciences who were already steeped in theory and tradition, there was great satisfaction in recognizing and helping to develop the role of 'science' in GIS. This generation of young academics was charged with further advancing and legitimizing this new field of geographic information science (GIScience). Having discovered that GIS was more than just a collection of commercial vendors pushing technology, that there was a real GIS research community in existence, one question posed by many students was: To what extent was the GIS research community truly driven by intellectual curiosity about the nature of the technology being built and by the consequences of the use of that technology? What was needed to ensure that GIS, and other kinds of technologies for handling spatial data, played a legitimate role as an enabler of scientific insight, scientific explanation, and scientific interpretation? And finally, how did researching the science of GIS differ from exploring the use of GIS for science?

In 1994, a course at the University of California Santa Barbara titled 'Scientific Reasoning in Geography,' originally developed by Professor Helen Couclelis but taught at the time by Professor Jim Proctor, led that year's group of geography graduate students to a thorough examination of the philosophical underpinnings of the claim that GIS should have a place among the sciences. This, in turn, led to a deeper exploration of what was meant by the term 'science' in general (e.g., empiricism, logical positivism, critical rationalism; Haines-Young and Petch 1986, Johnston 1986). The course was fortuitously timed not only with the appearance of Goodchild (1992) but with a lengthy debate on the GIS-L international listserve (gis-l@ubvm.cc.buffalo.edu) in October and November of 1993 about whether GIS was in fact just a tool or a science. Reflections upon Goodchild

(1992) and participation in the GIS-L debate eventually became the lead of a Forum section in the *Annals of the Association of American Geographers* (Pickles 1997, Wright *et al*. 1997a, 1997b).

Despite the growth of GIScience since the early 1990s into a 'genuine, challenging, and fruitful area for scientific research with its own unique scientific questions and discoveries' (Goodchild 2006), it is interesting that the articles in the *Annals* forum are used to this day as discussion papers in graduate geography seminars across the United States and Europe, and the debate continues (Goodchild 2010). Graduate students are naturally expected to complete substantive research for graduate theses and dissertations, but many apparently still wonder if students who perform research 'in' or 'on' GIS are doing substantive science. 'Blended' academic departments where faculty and degree programs in geography coexist with those from geology, atmospheric science, or other sciences are particularly susceptible to this kind of tension (Kastens *et al*. 2009).

This simmering issue also lies at the root of questions about the true rigor or marketability of a Master of GIS degree as compared to the more traditional Master of Science or Master of Arts degrees (e.g., Mattix 2001). This concern will likely gain traction as GIS continues to coalesce into a distinct profession (e.g., Obermeyer 1993 and 2007). In contrast to cultivating an understanding of the scientific foundations of GIS, 'professional' practice focuses on the use of GIS in the arenas of local government planning and public works offices, state environmental management agencies, energy utilities, federal agencies and their contractors, and many other market sectors. The need to provide professional education leads to a further related question about if and how GIScience educators and researchers should be involved in activities outside the normal sphere of academia, such as the professional activities of the Geographic Information Systems Certification Institute (GISCI), the Urban Regional Information Systems Association (URISA), and local, regional, and state GIS user groups.

1.2. Theory: methodological versus substantive

The challenge set by Goodchild (1992) to the GIS community to position our work within a scientific context is not unlike the challenges still faced by the broader geography community to achieve legitimacy and relevance for the discipline through articulation of a shared belief system and associated practices (National Research Council 1997). On the other hand, it is also not unlike the challenge to define computing or computer science. Denning and Freeman (2009) ask if computing exemplifies both engineering and science, and if neither engineering nor science characterizes computing, what then characterizes computing? This is where traditional analytic science may be contrasted with the normative pursuits of design, the principles of which are the foundation of engineering.

Science has always been about increasing the fundamental understanding of how the Earth works. However, scientists are increasingly being called upon to translate the relevance of their work, not only to justify support from funding agencies, but also to help inform policymakers, the media, and the general public on issues of societal urgency (e.g., Baron 2010). Major themes of compelling interest to society now drive scientific research. Among the drivers recently identified by the National Research Council (2010, 2011) are: enabling stewardship of the environment, understanding and responding to environmental change, protecting life and property, promoting sustainability, recognizing and coping with the rapid spatial reorganization of economy and society while promoting economic vitality, and leveraging technological change for the benefit of society and environment.

Thus science must now be understood to encompass not only how the Earth *works*, but also how the Earth should *look*, and how we should look *at* the Earth. Humans decide how the Earth should look as they redesign the landscape or seascape for their own purposes and plans. Implemented in GIS analyses and workflows, this is now known as 'geodesign' (Goodchild 2011), a process that allows designers and clients to work closely together to significantly lessen the time it takes to produce and evaluate design iterations. Geodesign crosscuts the physical and social sciences and helps us explore, in a philosophical sense, what the Earth is *for*, and, in a practical sense, how to make the Earth more sustainable.

How we should look *at* the Earth encompasses the development of extensive and diverse datasets in the current era of Earth observation from air and space, within the ocean, within the solid Earth. Understanding how the Earth works requires integrative and innovative approaches to analyzing, modeling, and developing these datasets. The current chaotic distribution of available datasets worldwide, lack of documentation about them, and lack of easy-to-use access tools and computer modeling and analysis codes are still major obstacles for scientists and educators alike. GIS plays a big role by abstracting the Earth by way of the data model into knowledge objects that can be created, edited, and maintained.

Perhaps one of the things that motivated Goodchild (1992) was the somewhat condescending distinction often made between 'substantive' research (i.e., science, how the Earth works), and 'methodological' research (how the Earth should look, or how we should look *at* the Earth). The distinction implies that 'pure' science (substantive) is superior to methodological research. However, in GIScience this is not relevant – methods are actually substantive in GIScience. For example, the mathematical theory of point-set topological relations (Egenhofer and Franzosa 1991) has greatly improved query functions in database systems and spatial analytical software, leading to greater understanding of spatial relations in nature. Methods in data mining, clustering, and geodemographics (e.g., Miller and Han 2001, Ashby and Longley 2005) have enabled scientists in many domains to see patterns and structures in large complex data sets, many of which are reflective of actual patterns in nature such as biodiversity and ecosystem function (Maestre *et al*. 2012), paleoclimate (Schmittner *et al*. 2011), or geological surface deformation (Oskin 2012). Such methods have also enabled innovative multidisciplinary research as a result of the integration of many different data sources and analytical methods. And in the emerging set of methodologies known as 'geodesign,' ideas and plans for each new housing development, shopping center, road network, wildlife preserve, etc., will go through many iterations of design evaluation implemented through actual GIS workflows using tools such as ArcGIS ModelBuilder, mind maps, and ecological forecasting models (see, for example, Aditya 2010, Sheldon *et al*. 2011).

Methods solve a problem and are underpinned by questions that are answered in terms of the practical and the local. For instance, aside from global warming, is the average person on the street concerned with the global scale? The societal relevance of the method is fulfilled if emergency management is improved, traffic congestion is solved, charismatic species are protected, goods and services flow, air pollution is decreased, and the like. The linkage of these solutions with spatial decision support systems has been crucial as it has extended the role of GIS from a scientific tool to that of greater societal relevance (e.g., from a generic scientific study of geomorphology to the use of those results to inform collaborative land use planning, from ecology to support for the preservation of endangered species and designation of protected areas, from forest fire susceptibility modeling to the development of plans for evacuation and rescue services, etc.).

2. Applications as science

We now turn to a reflection on the role of applications of GIS within the GIScience context. Quoting again from Goodchild (1992, p. 43):

> It is too easy to see current GIS as hardware and software technology in search of applications, and to see the field of GIS as defined by the functional limits of its major vendor products. We need to move from system to science, to establish GIS as the intersection between a group of disciplines with common interests, supported by a toolbox of technology, and in turn supporting the technology through its basic research. . . . the GIS community can benefit enormously from interdisciplinary research. Statisticians can make a very valuable contribution to solving the error problem in GIS, and research in cognitive psychology may be helpful in designing the cognitive aspects of user interfaces in GIS.

As with many other graduate students at the time, this line of reasoning led the author of this paper, at the time in pursuit of a joint degree in geography and in an allied scientific discipline, marine geology, in which GIS was just beginning to take hold, to a reflection about what might be unique about certain applications of the GIS toolbox – applications that might challenge and extend the theory upon which the allied science was based. Even before Goodchild named GIScience, Anselin (1989) asked 'what is special about spatial'? Having already wrestled with issues of data 'handling' (data capture, collection, and management) in research undertaken about the ocean where the dimensionality and dynamism are quite different than on land, this author asked 'what is special about marine and coastal'? Clearly the persistent complication of two dimensions versus three dimensions versus four dimensions posed unresolved issues. What were the implications of this dynamic environment for GIS data structures and algorithms?

2.1. Exploring theory through applications

Addressing this question, Wright and Goodchild (1997) explored the challenges posed by oceanographic applications of GIS at the time and outlined a proposed research agenda on new spatial data models, data structures, and processing functions to add to the body of knowledge of GIS design and architecture, as well as the broader body of knowledge of GIScience. That paper illustrates how there should be (and can be) a two-way street, where the application is made possible by the theory, but the difficulties posed by the application could also advance the theory (in this case, theory underpinning technology that was developed largely to deal with problems on land). It was posited by Wright and Goodchild (1997), and subsequently by Wright and Bartlett (2000), that while the application of GIS in the ocean and coast context presents considerable problems of scale and accuracy, representation of time-varying information, persistence of objects through time, and issues of generalization, much could be learned from applying existing GIS technology to this challenging new environment.

An important example of what can be learned in this way arises in research utilizing numerical models of ocean processes such as the commonly used Regional Ocean Modeling System or ROMS (Shchepetkin and McWilliams 2003, 2005). ROMS is one of the most widely used models in the oceanographic scientific community due to its algorithms for understanding a wide array of processes, including vertical mixing and biogeochemical processes in the open ocean, sediment transport and storm-surge inundation of coastal areas, and sea ice movement. However, ROMS and other numerical models like it, as effective as they are, pose great challenges for GIS, particularly if there is an intention to integrate them with traditional GIS data sets. The spatial frameworks of these numerical models are often not uniformly spaced, composed of either unstructured triangles or structured curvilinear grids. Unstructured triangular grids allow for high-resolution curvilinear orthogonal coordinates in the horizontal direction and stretched free-surface following vertical coordinates (different levels of z, Figure 1). There is a great need for tools to handle these grids in a more standardized way, and GIS may be able to provide it. Hence it is the computing system needs posed by the scientific application that may push the GIScience theory.

So far, only a partial solution has emerged. At present the climate forecast (CF) convention of the Network Common Data Form-4 data model (netCDF-4, Jenter and Signell 1992, Rew *et al*. 2006) is able to work well with varying vertical coordinates. CF allows these to be specified in a standard way, allowing the possibility of standard access to data on the model's native grid. In addition, netCDF Markup Language (NcML), an XML representation of netCDF metadata, provides for the coding of CF attributes. This solution does work much more effectively with that third dimension than GIS libraries such as the Geospatial Data Abstraction Library (GDAL) and does provide virtual standardization of original files that can also use new services.

Using these standards, a standards expert could work with a data provider to generate NcML to aggregate and standardize their files (i.e., add metadata, change incorrect metadata, create unions or joins of data). This would allow the data to be served by way of

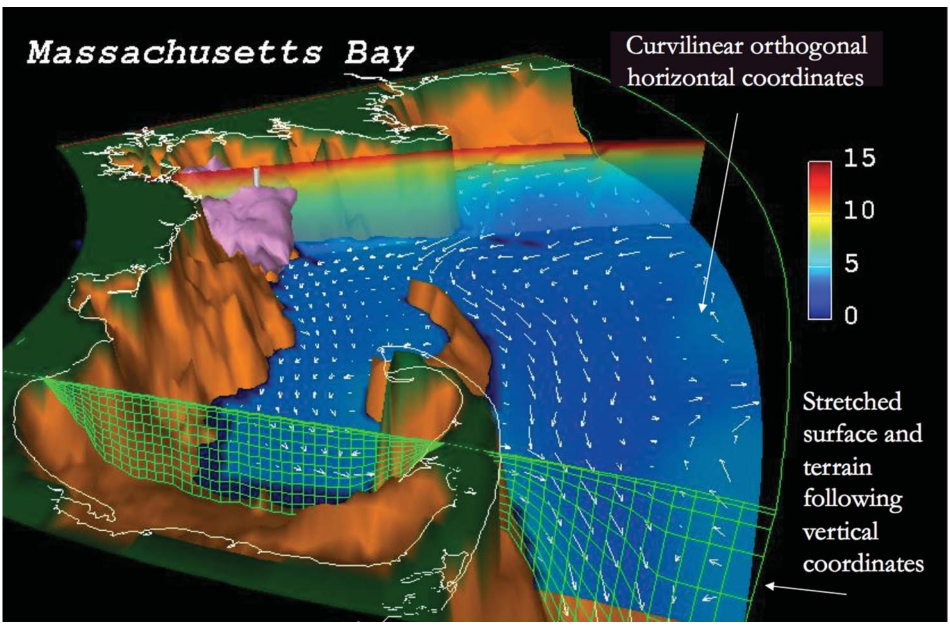

Figure 1. Example of a structure curvilinear orthogonal grid for modeling a variety of physical oceanographic processes in Massachusetts Bay as part of the US Integrated Ocean Observing System (IOOS) from Signell (2010). The pink region is a simulation of Boston Harbor sewage effluent from an offshore pipe (500:1 dilution), shown within the context of a vertical section of ocean temperature (0–15°C) and a horizontal slice of ocean current velocities (blue base with white current vectors). Running in the background is an ocean forecast model that uses IOOS conventions for serving data on the grid. The modeling is part of a series of testbeds designed to evaluate multiple models on specific environmental issues, as well as to improve the existing IOOS framework for data interoperability among models and related GIS operations.

a variety of services (Signell 2010), including the Open-source Project for a Network Data Access Protocol or OPeNDAP (http://www.opendap.org), the only service that supports irregularly spaced grids. A variety of clients can then be used and can be interoperable using a common data model such as NetCDF Java. This is as far as it gets now, however, since OpeNDAP still does not work effectively with CF, and there is a critical need for translational bridges to netCDF4-python and GIS.

This discussion highlights a continuing challenge for GIScience and the application of GIS to science: that of interoperating between different languages for expressing data models in order to make geoscientific data more accessible and broadly useful. The traditional GIS community uses relational database schemas for their data models (e.g., the Consortium of Universities for the Advancement of Hydrologic Science or CUAHSI Hydrological Information System Observational Data Model, http://his.cuahsi.org). The Open Geospatial Consortium uses XML schemas for encoding data models for the Geography Markup Language (GML) or for use of Unified Modeling Language (UML) diagrams to specify abstract data models. Other projects such as the VisAD Java component library for visualization and analysis of numerical data use human-readable language (http://www.ssec.wisc.edu/~billh/visad.html). With terabytes to petabytes of observational data points, a multiplicity of information encoding standards, and a large community of disparate users, information needs to be encoded as simply as possible. The best governance may be to merely let usage and utility drive the system (as with the common acceptance of netCDF or the closely related Hierarchical Data Format or HDF; http://www.hdfgroup.org), allowing the most useful to rise to the top.

Advancements in the application of GIS in the marine and coastal domain are often now included in discussions of GIS-related topics such as high-performance computing, spatial cyber infrastructure, and virtual globes. For instance, one cannot build a next-generation Digital Earth as described by Craglia *et al*. (2008) without a 'Digital Ocean' (Goodchild *et al.* 2008). As part of the spatial cyber infrastructure, preparations are in place for abundant and complex streams of data from instruments and vehicles being deployed in ocean observatories and coastal long-term ecological observatories (Andrade 2008, Robertson 2008). For the oceans, sensing means more than just observing the sea surface for ocean–atmosphere interaction or climate-change studies, but all throughout the water column and onto the ocean floor. A Global Ocean Observing System (GOOS, Summerhayes 2002) has been in the works for several years now, as nations slowly build and test networks within networks of sensors, many resulting in the production of their own cyber infrastructures and virtual globes.

2.2. Coastal and marine spatial planning

As discussed in the previous section, while many science questions for the ocean and the coast are Earth-process oriented (how does the Earth work?), much related science can be motivated by designing and managing the Earth as well. A prime example of this is the emerging field of coastal and marine spatial planning (CMSP), currently a central focus of President Obama's National Ocean Policy (http://www.whitehouse.gov/administration/eop/oceans/policy). CMSP, as defined by Ehler and Douvere (2007), and expanded upon in Douvere and Ehler (2008), Ehler (2008), and Foley *et al*. (2010), is a systematic and stepwise process (not an outcome) whereby the spatial and temporal distribution of human activities in coastal and open ocean areas is analyzed and allocated, often with input from various stakeholders (commercial fishermen, conservationists, non-governmental organizations, the academic research community) and the wider public, all to achieve sustainable ecological, economic, and social objectives that have been specified through a political or social process.

CMSP is perfect fodder for GIS, particularly as a means for compiling and synthesizing data on varying ocean uses, on ecosystems, and on coastal and ocean governance, for mapping of the data into usable formats and for understanding multiple scales of space and time for multiple users. Perhaps most importantly, GIS can provision decision-support tools that can aid in the assessment of tradeoffs among conflicting locations, resources, ecosystem services, sectors, and time periods. While the need is clear to identify both the potential conflict between coastal and ocean uses and the ways of mitigating that conflict, there is no comprehensive documentation of the spatial uses, values, or potential economic contributions of these regions. There is also no *comprehensive* catalog of GIS spatial decision tools or workflows, although work toward that end is progressing and will be part of a longstanding research agenda in GIScience (e.g., Coleman *et al*. 2011, Wright *et al*. 2011, Li *et al*. 2012, Merrifield *et al*. in press). A dominant trend is the provision of these tools and workflows over the Internet (e.g., http://ebmtools.org; http://icoastalatlas.net).

3. New spaces for science

As Goodchild (2006) notes, one factor missing from his 1992 treatise was the impact of the Internet and the way that it has greatly influenced the GIScience research agenda since about 1993. Today we see this in the emergence of the open source movement, grid computing, and especially spatial cyber infrastructure (Yang *et al*. 2010, Wright and Wang 2011), which synergistically incorporates GIS and spatial analysis for problem solving and decision making on the surface or subsurface of the Earth, in the atmosphere, or under the ocean. But space need not be limited to the Earth, it could be in the realm of virtual space (e.g., digital worlds, or understanding how and where computers are connected worldwide), information space, mental space, and more. The popularity of cloud computing has exploded, including GIS in the cloud, and as Clarke (2011) notes, modeling and simulation in these spaces as supported by cyber infrastructures are the 'new test tubes and scales of science.'

These spaces can now be explored and also probed and invaded in ways that are unwelcome to many. Even in the early 1990s there was increasing concern over the power of GIS for surveillance and invasion of privacy. With the production of detailed, micro-level spatial data, and the ease with which users on the web can create mashups by linking information around common geographic locations, there is a growing concern about the misuse of private information (National Research Council 2010). Moreover, as noted by the National Research Council (2007): 'precise information about spatial location is almost perfectly identifying: if one knows where someone lives, one is likely to know the person's identity.' The societal issues raised by GIS and other location-based tools are more urgent today than ever.

Goodchild (1992) called for an education system able to respond rapidly to new developments such as this, with the ability to quickly build new concepts into degree and certificate programs. Oftentimes, academia is slow to change, but 20 years on the GIScience community finally has access to some curricular resources that rigorously explore the ethical implications of GIS, including issues of privacy and surveillance, societal inequities, and the related consequences for policy decisions (DiBiase *et al*. 2008, 2012). These welcome developments coincide also with the recent emergence of the GIS Certification Institute Code of Ethics and Rules of Conduct, the American Society for Photogrammetry and Remote Sensing Code of Ethics, and similar codes in allied disciplines such as computer science.

4. Conclusion: Are we in a 'post-GISystems' world?

As changes continue to descend rapidly upon science, academia, the private sector, and society, should we also be preparing for a post-GISystems world? The term 'post-GISystems world' follows on the metaphor of Fareed Zakaria's most recent book, *The Post American World: Release 2.0* in which he points out that the US share of the 'global pie' of long-term economic growth and scientific advancement has decreased as the rest of the world begins to catch up. At first blush this appears to be a thesis on the decline of the United States, but Zakaria (2011) makes clear that it is more about the rise of everyone else. It is no longer about the dominance of one or two nations, but a whole host of nations becoming stronger and richer, and in the process ushering in a truly global order. It is therefore not an anti-American world, not a world where America is necessarily in decline, but a *post*-American world.

So to with GIS, where it is not a world where GIS is anywhere near decline; GIS is actually more popular than ever in the scientific pantheon. For example, a search for 'GIS' in engineering and science literature databases such as IEEE Xplore, the Thomson Reuters Web of Knowledge, or Mendeley returned just a few hundred articles in the early 1990s, whereas now several thousand can be found. But at the same time we are witnessing the rise of many related technologies, ones that are often at odds with each other. Consider the concurrent emergence of spatial cyber infrastructure (also known as cyberGIS) that must handle huge volumes of data (the so-called big data of global observational science, e.g., Staff 2008, Wang and Liu 2009) at the same time as the rise of the simpler, faster geobrowsers that are not even considered to be a 'GIS,' certainly not in the 'professional grade,' desktop sense. These simpler geobrowsers are the stock and trade of the volunteered geographic information (VGI) community, the citizen scientists, the neogeographers whose users are very comfortable with maps and spatial concepts but may have little knowledge of spatial analysis and the related issues of error and uncertainty (Goodchild 2007, van Rees 2009, Goodchild and Glennon 2010).

As such, there are new and important perspectives to consider. For example, with the emergence of server GIS, cloud computing, cyber GIS, and even VGI, is GIS being subsumed into a geographical post-modernist existence, divorced from the desktop? To wit, the concept of ArcGIS is evolving to mean a 'destination' on the web, in addition to the familiar desktop software package. The user community can go to this destination and find the best available content where GIS vendors seek to do for science and geographical user communities what Google did for consumers and businesses. Using a Software as a Service (SaaS) model in the cloud (e.g., Allen *et al*. 2012), users will soon be able to stand up GIS analysis models as application services on a routine basis. In this sense, it is not just about technology, but information feeds, information services, even information 'surfaces.' As with Zakaria's point about the United States, this is not necessarily anti-GIS, this is not the decline of GIS, but it may whimsically be known as 'post-GISystems' or 'post-desktop GIS.'

In all of this, GIS is subsumed into the broader framework known simply as 'the web.' But is this now a world in which the pushpin of Google Earth or smartphone geolocation apps rule? Could VGI and neogeography be leading (ironically) to more of a focus on systems than science? As Goodchild (1992) notes with regard to the general enthusiasm and excitement about GIS, 'there ought to be more to it than that.' Where is the spatial thinking, the spatial intelligence to go beyond the pushpin to understand its broader context? Why is the pushpin there and not somewhere else? What does one think about that? What is the effect of scale (particularly in measuring the length of something such as a coastline)? Is there an ecological fallacy imposed? What Earth processes are at play here? What should the Earth look like at this particular spot? And, by the way, what do you mean by 'spot'? What other data are needed? And what should people be thinking about when they do GIS *at* this particular place?

Goodchild (1992) speaks of 'a cleavage in GIS between two traditions, that of spatial information on the one hand and that of spatial analysis on the other.' GIScience will be needed more than ever before to help people understand what they need to know in a post-GIS world – concepts of scale, location, proximity, distance decay, the neighborhood, the region, the territory – as we continue to seek a merger of these traditions.

To end on a final, positive note, the post-GISystems world is nicely aligned with what Hey *et al*. (2009) refer to as the 'fourth paradigm.' They posit a new paradigm for scientific discovery beyond the existing paradigms of empiricism, analysis, and simulation to a fourth where insight is discovered largely through the manipulation and exploration of large data sets. As so much data and information are collected spatially now in a way that was not possible before, we are seeing a turn toward more spatial, more place-based research across many of the sciences. GIS will continue to be, as both systems and science, intensely computational, with the ability to study systems even more complex, answering new questions, integrating new data streams, implementing new use cases, enabling new applications. And even though cyber-enabled, it will hopefully, in the end, fulfil the most important goal for GIScience of Goodchild (1992): a continual quest to understand how the Earth works, how the Earth should look, and how we should best look at the Earth.

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