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Opportunities and Impediments for Open GIS[1]

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Abstract

The field of GIS (S for Systems, Sciences, Services, and Studies) is at a cross-road in the early 2010s. Aiming to link the multiple visions for the next phase of GIS development, this article suggests that the emerging open GIS should serve as a guiding concept. Contextualized in the broader literature of open science, this article proposes open GIS should include eight dimensions related to data, software, hardware, standards, research, publication, funding, and education. For the GIS community, open GIS offers four exciting opportunities: (1) technology-driven opportunities for addressing challenges posed by the (spatial) big data deluge; (2) application-led opportunities for confronting the problems of a rapidly changing planet; (3) curiosity-inspired, crowd-powered opportunities for the development of an open and geographic citizen science; and (4) education-focused opportunities for implementing the vision of a spatial university. Although there are academic, legal, social/political, and environmental impediments for the practice of open GIS, open GIS will become increasingly important in shaping our research and educational agendas in the future.

> What's past is prologue; what's already happened merely sets the stage for what is to come.
>
> (M.F. Goodchild 2012)

1 Introduction

Fifty years after the acronym GIS (geographic information systems) first appeared in the literature (Star and Estes 1990), 20 years after the GIS community rallied behind the banner of geographic information science (Goodchild 1992), and a decade of explosive growth period of various geographic (location-based) information services, GIS is at a cross roads in the early 2010s (Reitsma 2013). Admittedly, we have come a long way as a community to advancing the development of GIS as a field of study. Using the conventional metrics measuring the development of a discipline, such as scholarly journals/publications, textbooks, students taught, research funding, conferences, professional organizations, etc., the field of GIS is healthy and vibrant,

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with a community of growing interdisciplinary researchers working on a wide range of challenging problems from both theoretical and applied perspectives (Haklay 2012). However, as the technological and institutional environment that contributed to the development of GIS has undergone very dramatic and fundamental changes during the past 50 years, we should be mindful of what we have already accomplished and leave no room for complacency. As Goodchild (2012) so eloquently articulated in his keynote address for the 2012 UCGIS summer assembly: "What's past is prologue; what's already happened merely sets the stage for what is to come." As a GIS community, we have built a large stage for GIS over the past 50 years and, all things considered, we have performed quite well for a stable and growing global audience.

Resonating with Goodchild's observations, Couclelis (2012), in her keynote address for GIScience 2012, also noted that GIS may be entering a new age in the early 2010s. It is thus natural to ask ourselves: what does the new age for GIS entail? Should both the scope and method of doing and teaching GIScience change accordingly? In recent years, a wide-range of visions for the next phase of GIS development have been proposed, ranging from GIS 2.0/3.0 to post-GISystem/post-GIS (Wright 2012a; Harvey 2013), real-time GIS (Karnatak et al. 2012; Richardson 2013), neogeography (Turner 2006), CyberGIS (Wang et al. 2012, alt.GIS (Schuurman 2014), spatial media (Elwood and Leszczynski 2013) to the next generation digital earth (Goodchild et al. 2012; Janowicz and Hitzler 2012), GIS as a platform (Dangermond 2013), geoweb and crowdsourcing (Sui et al. 2012), cloud GIS (Yang et al. 2011), qualitative GIS (Cope and Elwood 2009), and spatial computing (CCC 2013; Duckham 2013). While all these different visions have captured important elements for the next phase of GIS development and ground-breaking developments have been made along multiple fronts, the GIS community has yet to articulate an agenda that links the multiple threads and connects the dots among these new and exciting developments in GIS. We still lack a new (or adapted) screen-play to guide our performance on the ever-enlarging GIS stage we have built over the past 50 years.

Obviously, both GIS research and education must adapt to the changes accordingly if we want to maintain the momentum of GIS growth in order to make the field of GIS both intellectually exciting and socially relevant for another 50 years. The goal of this article is to make a modest effort to develop and synthesize an agenda surrounding the vision of an open GIS paradigm, and hopefully to stimulate further discussions on the multiple dimensions of open GIS. By contextualizing GIS in the broader literature of open science, this article proposes that open GIS should include open data, open software, open hardware, open standards, open research collaboration, open publication, open funding, and open education/learning. Through the open GIS framework, I hope to integrate and link the diverse perspectives on the next phase of GIS development. The remainder of the article is organized as follows. After a brief introduction, elements of the emerging open culture and dimensions of open GIS are described in Section 2. Section 3 discusses the research and educational opportunities for open GIS, followed by reviews and discussions on the challenges and barriers of open GIS in Section 4. The article ends with a summary and conclusion in Section 5.

2 The Emerging Open Culture and the Meaning of Open GIS

Inspired by the open source movement in software development and major tenets of the hacker ethic (Levy 2001; Himanen 2001), the meaning of being "open" has expanded to broader territories during the past 20 years (Aksulu and Wade 2010; Gobble 2012). Willinsky (2005) noted that recent years have witnessed the unacknowledged convergence of

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multiple open initiatives, such as open source, open access, and open science. All the different pieces and fragments related to the various open initiatives are now converging to form an emerging open culture (de Rosnay and Martin 2012). Perhaps more importantly, the emerging open culture is rapidly diffusing from the technical realm to the social, political, and economic domain, as evidenced by open planning/community development (openplans.org), open business (Huizingh 2011), open government (McDermott 2010; Nam 2012), and peer-to-peer sharing/collaborative consumption (Botsman and Rogers 2010). This emerging open culture is espousing broader social changes in science, business, politics, education, and even entertainment.

Being open is not a new concept to the GIS community. In fact, the GIS community started practicing open GIS even before the concept became popular or widespread (Hall and Leahy 2008). For example, the GRASS GIS software was developed according to the open source software development paradigm, especially after 1997 (Jolma et al. 2008; Neteler and Mitasova 2008; Rey 2009; Neteler et al. 2012; see also http://grass.osgeo.org/history). But so far, the GIS community's engagement with open GIS has predominantly focused on open source software development. While open source software development is a crucial element, the emerging open culture is much broader. The discussion of open GIS thus should not be confined to open source software development alone. We need a comprehensive framework to embrace the open movement more holistically in the context of GIS. This article aims to move toward that direction, by linking the discussions of "open GIS' to the broader open culture and initiatives.

Advances in open science and all the related technologies that facilitated the open paradigm (Pordes et al. 2008; Cribb and Sari 2010), have vastly enriched the meaning of being open in the context of GIS. By synthesizing the most recent literature on various open initiatives, the open culture, especially in the context of open science, has multiple meanings, which typically includes the following: open data, open software, open hardware, open standards, open publication, open research, open funding, and open education/learning. If we are to link open GIS to the converging themes of the open culture, open GIS has at least eight dimensions (Figure 1) related to data, software, hardware, standards, publication, research, funding, and education/learning. The best way to realize the full potential of open GIS is to engage the GIS community more comprehensively about the multiple dimensions of being open. By casting open GIS to the broader context of the emerging open culture, open GIS should include all the eight dimensions that define the emerging open culture (Figure 1). Although not mutually exclusive, these eight dimensions are nonetheless distinctive features for open GIS.

2.1 Open Data

Data has always been and will continue to be one of the bottleneck issues for future GIS research and applications. The movement towards open data mirrors earlier efforts for data sharing, which places greater emphasis on keeping data legally open and accessible. Yet legally and accessible does not necessarily mean that data are usable (unless one has the technical expertise); thus they are often not actually used at all. The new open data initiative aims to make data open not only legally but also technically, so that open data are useful, usable, and actually used.

Making the growing spatial-temporal data (from local to global level) open will play a pivotal role in the success of GIS research, education, and applications in the future. One of the major outcomes of the 2013 G8 conference was the signing of the Open Data Charter with the goal of making government data freely available to promote both transparency and innovation (Eaves 2013). All G8 countries have agreed to abide by the following five principles to ensure the successful implementation of the open data charter – open data by default, quality

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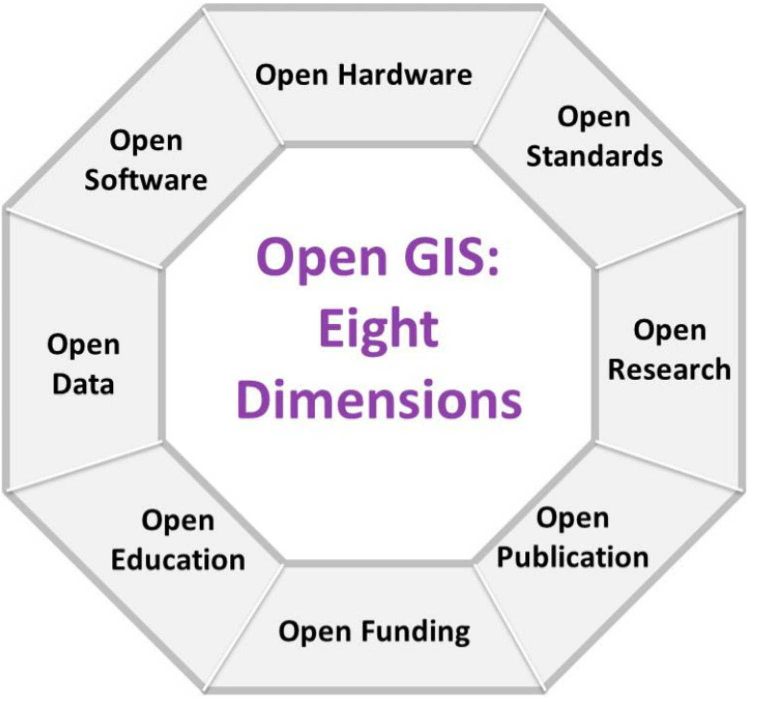

Figure 1 Open GIS: Eight dimensions

and quantity, useable by all, releasing data for improved governance, and releasing data for innovation. Both the UK (theodi.org) and the US (http://www.opendatanow.com) have developed their own specific open data policies. The business and research communities have also developed their own protocols for the practices of open data (Hürlimann et al. 2011).

Although the precise meaning of open data may be different in science, government, and industry, the following six criteria are normally used to evaluate the level of openness:

- Legal – free from restrictions such as copyright or secrecy classifications;
- Financial – free from subscription or other charges;
- Accessible – readily located, free from administrative or procedural hurdles, such as forms to fill out, time to wait for approval and delivery;
- Usable – database tables are presented in clean and structured format, not as poor quality paper printouts; does not require proprietary software to open;
- Understandable – proper metadata is available with meaningful field names; and
- Assessable – reliability and quality of the data can be evaluated.

2.2 Open Software

Open software is perhaps the most well developed aspect of open GIS (Aksulu and Wade 2010). One of the earliest driving forces for the open culture started with open source software development – the release of the source code of any specialized software tools developed for a particular project. Indeed, open source software is one of the methodological driving forces behind the paradigm of open science. According to Steiniger and Hunter (2012, 2013), free

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and open software tools can now perform the spatial data functions of proprietary commercial software tools, especially for advanced spatial analysis functions (Bivand 2011). An on-line map API also gives GIS users more flexibility to visualize geospatial information (Peterson 2012). It's not just a question of "free" catching up with "commercial," the open source software movement has proved to be capable of an accelerated development cycle to meet the user community needs faster through vibrant online forums and interactions.

The FOSS4G (Free and Open Source Software for Geospatial) Conference has – since 2006 – been serving as the primary forum to promote the development of free and open source software (foss4g.org). Although they are closely related and often overlap, open and free software are two different concepts. Stallman (2009) even insisted that open source misses the point, "free" instead of "open" should be the keyword. "Free" in free software has the same meaning as free speech, not necessarily as in free beer. Free software often entails that users have the freedom to access, modify, distribute, and connect (via various API) the source code. There are multiple licensing agreements that have been developed to guide open source software development and distribution, such as MPL, MIT, Apache, GPL, and BSD (http://opensource.org/licenses). These different licensing agreements often define different degrees of openness on source code traceability, patent exclusion, open source obligation, and the commercial interests of code users and code developers (Gangadharan et al. 2009; Walt and Thomas 2012). Web-based platforms such as GitHub.com and RunMyCode.org have greatly facilitated open source software development.

2.3 Open Hardware/Computing Platform

Open hardware in the context of open GIS has two specific meanings. First, it refers to the open source hardware kit GIS users can download to build their own devices for geographic data collection or processing. For example, the hardware kit based upon sensors mounted on kites (http://www.f-l-o-a-t.com) to collect air quality information or the open source device called Arduino (http://www.arduino.cc). Second, it refers to the growing trend that GIS operations are no longer confined to a singled computing platform or hardware device. Instead, following the thin client and fat server model, geographic information can be accessed and processed via a combination of diverse computing platforms ranging from Google Glasses, smart phones, iPADs, Raspberry pi, and traditional laptop/desktops on the client side to local areal networks, workstations, mainframe computers, and supercomputing in the cloud on the server side (The Royal Society 2012; Yang et al. 2013).

Open hardware also relies on licensing agreement similar to those developed for open source software. Recent advances in open science grid (Pordes et al. 2008), open cloud (Nelson, 2009), open distributed processing (Dunfey et al. 2006; Linington et al. 2011), open access networks (Sivaraman et al. 2012), and open systems architecture (Walt and Thomas 2012) could potentially become the new open computing platforms for open GIS. "Open compute project", with the extremely low cost of personal computers, accessibility to vast cloud computing resources, and possibility for high performance computing (HPC), provides a different degree of openness. It should be pointed out that open hardware is not GIS specific, but GIS is apparently benefiting from this trend enormously, as already demonstrated in free online storage, free wi-fi connections, and free cloud hosting/computing.

2.4 Open Standards

To make open data, software, and hardware work seamlessly and interoperably, it is an imperative that all the parties involved follow a common set of standards. The Open

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Geospatial Consortium (OGC) (formerly Open GIS Consortium), founded in 1994, played a pivotal role in achieving interoperability in data, software, and hardware for spatial data handling (OpenGeospatial.org). Over the past two decades, OGC has been a pioneer in developing open standards to facilitate interoperability of geospatial data across platforms (OGC 1998). OGC has been a liaison for coordinating efforts from industry, government, and academia on open standards to support geographic information research, software development, and various geographic services. Despite reservations and concerns expressed by the academic community in recent years, we nonetheless should acknowledge the multiple milestones achieved by OGC in developing open GIS standards. For example, OGC rolled out the two key specifications for Open GIS software interfaces: (1) Implementation Specifications that provide standard methods for systems to share and integrate feature data and images of various types of geospatial information; and (2) Catalog Specifications that provide standard methods for publishing and discovering geospatial data on the web. In 2012, OGC published 56 implementation standards with the goal of achieving interoperability among industries and domain applications, particularly with a suite of OGC baselines of adopted standards (Percivall 2010).

As more and more digital data are being collected by players of different kinds for diverse purposes, the demands for standards will continue to grow. But these standards, like the data, software, and hardware they plan to guide, should be open and dynamic, always adjusting to the latest technological advances and user needs. Unless open standards are rigorously developed and followed, open GIS will not be truly open for access, integration, and applications. So the real challenge is how to develop standards that have broad appeal to multiple constituents on the one hand, and keep the standards open and adaptable to innovations and new developments on the other. Most of OGC standards seem to maintain this delicate balance. For example, OGC's City GML (http://www.3d-stadtmodell-berlin.de) has been used to develop the urban model of Berlin. OGC's Water ML2.0 is implemented as an application schema of the Geography Markup Language version 3.2.1, which has proved to be an effective representation of in-situ hydrological observations data.

2.5 Open Research and Collaboration

GIS research, under the growing influence of the open culture, should be conducted under the general umbrella of "open science". Also known as eScience or networked science, open science research has been gaining in popularity in recent years (Nielsen 2012). As reflected in the presentations made during the recent Open Science Summit (http://opensciencesummit.com), exciting advances are being made every day in diverse scientific fields ranging from mathematics (the Polymath Project), astronomy (Galaxy Zoo, Sloan Digital Sky Survey), and geology (the OneGeology project), to environmental science (Water Keeper, Global Community Monitoring), health, and medicine (the HapMap Project, CURE Together).

The growing interdisciplinary effort towards "open science" represents a broad and potentially transformative trend. Although the precise meaning of open science may differ according to disciplinary context and practices, Gezelter (2009) has argued that open science's two defining characteristics are increased scholarly collaboration (facilitated by web-based tools) and transparency in research methods (e.g. data collection, processing, analysis, mapping, visualization, and data curation). The open-science paradigm has been touted as one of the defining characteristics of the contemporary scientific enterprise (Cribb and Sari 2010). It has gained momentum across multiple disciplines, especially in the physical sciences, and in geography particularly among those interested in mapping and GIS. Open participation and

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collaboration among and between both GIS experts and volunteers in all tasks related to research – data collection, analysis, and writing/publication – are in line with the spirit of crowdsourcing and citizen science. It is a general consensus within the scientific community that science's capacity for self-correction comes from transparency and openness to critical review and scrutiny/replication (The Royal Society 2012). By setting the default to open, we can not only disclose provenance of scientific data and methods (including algorithms, tools, and versions of software used to generate it, etc.) but also move towards the goal of reproducibility. The closed approach motivated by myopic self-interest tends to deplete a common resource, whereas open research encourages open participation and open evaluation.

2.6 *Open Publication*

The open culture is also subversive to the traditional publication process. The accelerated move towards open publication entails both open review and open access. Different from the traditional peer review process via either the single-blind or the double blind processes, open review simultaneously calls for multiple reviews by both specialists and non-specialists who have vested interests in the research reported (instead of the traditional pre-publication peer reviews by a small number of experts) (Kriegeskorte 2009). Such peer-review is not confined to the pre-publication stage, but continues post-publication. Indeed, publication, like knowledge itself, may become much more iterative. An even more ambitious proposal is to eventually make research articles "live" so that data, analysis, results, and conclusions can be dynamically updated (Ahlqvist et al. 2011), thus sustaining a real-time dialogue among the interested parties. The dataverse network (http://thedata.org) is a significant step towards open publication by sharing research data with those interested in sustaining the dialogue.

Another dimension of open publication is the push for open-access publication led by influential academic institutions such as Harvard (https://osc.hul.harvard.edu/policies), namely to make scholarly publications available free of charge. During the past decade or so, the public and the academy have grown impatient that most publicly funded research published by commercial publishers is accessible only via (library) subscription. In what is known as the "gold model" of open access, one option for authors who wish to make their work openly accessible is to publish in an open access journal ("gold open access"). Commercial publishers ask that authors (and their funding bodies or institutions) pay article-processing charges to make their content freely available to readers (Finch 2012). Self-archiving, also known as the green open access, refers to the practice of depositing articles in an institutional or subject repository. Pioneered by computer scientists in their local FTP archives in the 1980s, open access self-archiving was first formally proposed in 1994 by Stevan Harnad. There are different shades of gold and green to govern the open publication license and open content. In GIS, open publication often entails making data used in publications available for both replication and continuing research. Jiang's (2011) special issue on data-intensive geospatial computing made all its data available on-line. The *Journal of Spatial Information Science (JOSIS)* (http://www.josis.org), launched in 2010, has also adopted the open-access policy.

2.7 *Open Funding*

The open culture is also changing the funding mechanism for scientific research. Open funding, otherwise known as crowd funding, is based upon a very simple formula: little money * lot of people = power of crowd funding. Instead of writing proposals to request a large sum from a single funding agency, crowd/open funding uses the Internet to solicit a large number of

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small contributions from a crowd. Obama's victory in 2008 demonstrated the success of open/crowd funding in political campaigns (Lawton and Marom 2012). The initial success in arts and businesses has inspired crowdfunding for scientific projects (Wheat et al. 2012; Johnson 2013).

In general, open funding has followed three models: (1) the donation model: contributors simply make a donation to the project they want to support without expecting compensation or recognition in return; (2) the reward model: contributors are rewarded with non-monetary recognition and appreciation; and (3) the equity model: contributors are given a fair share of the profits and returns if the project has commercial value or potentials.

A wide variety of web-based platforms have been developed to host crowdfunding initiatives. Some are general platforms, such as Indiegogo (http://www.indiegogo.com), kickstarter (http://www.kickstarter.com), rockethub (http://www.rockethub.com). There are also quite a few platforms devoted to fund-raising for scientific research, such as Microryza (http://www.microryza.com), Petridish (petridish.org), SciFund challenge (scifundchallenge.org).

Open funding mechanisms for GIS-related projects are still in their infancy but, due to the growing public interest in things spatial, there is great potential for the GIS community to beef up our efforts to explore open/crowd funding as an alternative funding model to supplement the traditional funding mechanism that has dominated the scene for so long. Crowd funding will not replace government funding for research in the near future, especially in areas of basic research that are of little public interest, but it certainly offers a supplemental funding mechanism that the GIS community needs to pay attention to.

2.8 Open Education/Learning

Last, but certainly not least, open GIS also entails that we make an effort towards open education and learning to educate and train the next generation of GIS researchers, developers and spatially informed citizens. Following the open courseware developed by MIT and most recently the growing popularity of MOOCs (Massive Open Online Courses), open education/learning is gaining momentum rapidly. Although researchers and educators are still debating the nature and details of spatial thinking across the curriculum, the demand and needs for spatial thinking across both college and K-12 curriculum are apparently there (Hegarty et al. 2012). The success of Anthony C. Robinson's 2013 MOOC course on "Maps and the Geospatial Revolution" offered through Coursera (https://www.coursera.org/#course/maps) demonstrated the great potential for the future of an open GIS education/learning paradigm.[2]

Open education/learning is more than taking an online course (Peters 2009). It means fostering a new academic culture that values the core practices of open science and creating new cyber-infrastructure that facilitates and seamlessly integrates all of the above in open scholarly practices. Perhaps more important for us as individual researchers and scholars, scholarly social networking sites, such as Open Scholar (http://openscholar.harvard.edu), Wikiversity, Citizendium, and Scholarpedia can potentially further propel openness, sharing, and collaboration among researchers and scholars following the open-science model in general and open-publication in particular. However, it remains to be seen whether public intellectuals can be transformed into open scholars via real-time scholarship (Burton 2009) and open innovation (Nam 2012).

3 Opportunities for Open GIS

The emerging open culture is on a fast track to be a game changer that will have far-reaching impacts in technological development, scientific research, business practices, government

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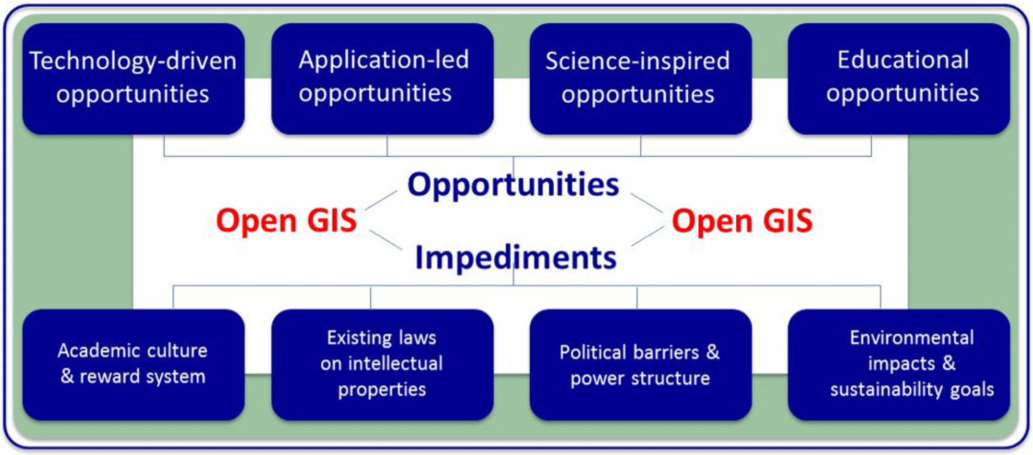

Figure 2 Opportunities and impediments for open GIS

operations, and even individual behaviors/consumption patterns. Consistent with the trends in other fields, the open GIS paradigm offers one of the best hopes for us to address the multiple challenges the GIS community faces in the most effective and possibly intelligent way. Moving forward, I see at least the following four exciting opportunities for open GIS (Figure 2): (1) technology-driven opportunities for addressing challenges posed by the (spatial) big data deluge; (2) application-led opportunities for confronting the problems of a rapidly changing planet; (3) curiosity-inspired, crowd-powered opportunities for the development of an open and geographic citizen science; and (4) education-focused opportunities for implementing the vision of a spatial university.

3.1 Open GIS and the (Spatial) Big Data Deluge

Led by the ever growing volume, variety, and velocity, the big data deluge is flooding pretty much every corner of our society. The general consensus within the GIS community is that the big data deluge is obviously a big deal for GIS researchers and educators alike. Although it is a challenging task to estimate the precise volume of geospatial data out there, we can safely say that geospatial data is becoming an important part of the big-data torrent. Geospatial information in general and volunteered geographic information (VGI) in particular should be understood in the context of big data. Crowdsourcing, the Internet of Things, and big data are rapidly converging in the domain of geospatial technologies. Of course, due to rapid technological advances, what is considered big or small is a moving target. In the McKinsey Report (Manyika et al. 2011), "personal location data" has been singled out as one of the five primary big data streams. With approximately 600 billion transactions per day, various mobile devices are creating approximately one petabyte (1,015 terrabytes) of data per year globally. Personal location data alone is a $100 billion business for service providers and $700 billion to end users (Manyika et al. 2011). The other four streams of big data identified by the McKinsey Report – health care, public-sector administration, retail, and manufacturing – also have a significant amount of data either geocoded or geo-tagged. So geospatial data are not only an important component of big data, but are actually, to a large extent, big data themselves. For the geospatial community, big data presents not only bigger opportunities for the

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business community (Francica 2011), but also new challenges for the scientific and scholarly communities to conduct ground-breaking studies related to people (at both individual and collective levels) and the environment (from local to global scale) (Hayes 2012).

Here is a summary of the major research questions discussed during recent GIS conferences and workshops on Big Data, including the GIScience 2012 Panel on Big Data (Wright 2012b), the UCSB Panel on Big Data (Janowicz 2012), the OSU Workshop on Big Data (Sui 2013), and the NSF Workshop on Big Data and Urban Informatics:

- What kinds of spatial big data are accessible and assessable by GIS users and researchers?
- How can we better assess the quality of big data? What are the challenging issues of modeling uncertainty in big data?
- What kinds of cyberinfrastructure are needed to deal with the big data deluge?
- What new fundamental problems does big data pose to GIScience? What is the role of theory in the age of big data?
- How can we best foster and synergize research on big data across pertinent research communities?

To address these challenging issues posed by the big data deluge effectively, key concepts behind the open GIS paradigm offer us the best approach. Open data and open standards provide us the norms on big data accessibility and quality standards. Although we are still quite far from that goal, we at least know that making big data both legally and technically open is absolutely the very first step, without which all the other challenges are out of the question. Among the "V" tenets of big data, variety may be the most challenging for the research community, with data coming from more sources and types (photo, video, audio, text, map, field observation, model/simulation results), organizations (governments, military, NGOs, etc.), and the diverse purposes and goals for contributing data (e.g. industry vs. government vs. researcher vs citizen scientist). The big data torrent will eventually be more powerful if they can be made to conform to open standards such as those developed by OGC over the years. Among the three possible solutions to assess big data quality – the crowd, social, and geographic approaches that Goodchild (2012) proposed – all hinge on being open in order to make them work. The recent call for an open data initiative during the G8 summit, the World Bank's pioneering effort in its open data program (data.worldbank.org), plus the White House's new open data mandates for various federal agencies (http://OpenDataNow.com) are all significant steps towards addressing the big data challenge.

Opening big data is a necessary step, but certainly not sufficient. We also need a new spatial cyberinfrastructure that equips us with the best software and hardware tools. Again, the open GIS paradigm hit the issue right on the nail. Wright (2012) noted that most GIS algorithms need to be rewritten to handle big data. Instead of following the traditional proprietary approach, the open source and free approach offers the most effective approach for developing software tools. Instead of reinventing the wheel, we can modify/revise a plethora of free and open software tools (Steiniger and Hunter 2012), ranging from Web map servers for managing data and images (such as mapserver.org, geoserver.org), Web GIS servers for data processing (52north.org, zooproject.org), and data storage software/spatial DBMS (http://postgis.refractions.net, http://mysql.com), to registry/catalogue and metadata software (geonetwork-opensource.org, wiki.deegree.org), desktop GIS clients for data updating and analysis (qgis.org, openjump.org), Web GIS development toolkits for browser-based clients such as geo-Linux (Câmara et al. 2012), OpenLayers, OpenScales, or MapBender (Brovelli et al. 2012).

Furthermore, the on-going effort towards developing a new geospatial Platform is an important step for us to take on the big data challenge (Linington et al. 2011) . The geospatial

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platform fosters a partnership among federal government agencies upon common data, common services, and common applications. Technologically, the partnership is enabled by the GeoCloud Initiative that provides agencies access to Amazon EC2 cloud hosting environment and open-source and commercial geospatial server instances for data services to the platforms. While still in its early development, Geospatial Platform subscribes to much openness in its architecture design that promotes community efforts to address Big Data challenges as well as ensuing needs for analytical functions and communication protocols.

To improve both our analysis and synthesis capabilities, more than ever, we need to transcend disciplinary boundaries to take a more holistic approach. The new spatial cyber infrastructure will further improve the prospects of open collaboration for GIS research, which will lead not only to technical advances but also to the development of rigorous new theories and practices beyond narrowly defined disciplinary boundaries. For example, as early as 2007, our capacity to produce data had outpaced our abilities to store them (NRC 2009). Although the time-lag of practical implementation is still considerable, recent advances in DNA-inspired data encoding techniques are promising (Hotz 2012). We therefore need to continue our efforts in redesigning our cyber-infrastructure according to the open GIS paradigm in order to make GIS the Noah's ark in the current big data flood. The Obama administration's new initiatives that specifically target the challenges created by the big data deluge (OSTP 2012) will further advance research on spatial big data.

3.2 Open GIS and New Applications for Improving Individual and Collective Decisions

Validating Peter Gould's (1999) early anticipation of the arrival of a spatial century, the spatial big data deluge has made not only geospatial information ubiquitous, but also the growing recognition of the importance of geography in general and the role of space and place in particular, as often dubbed by the popular media the "revenge of geography". More than ever before in human history, geospatial/locational information will play important roles in both our individual and collective decision-making processes. As a result of accumulative advances in geospatial technologies led by GPS, GIS, RS, LBS, and RFID during the past 20 years, we have now reached an unprecedented moment in human history: we can know where everything is from the genetic to the global level at all times. The web has enabled geographic information to be stored, accessed, and disseminated through multiple platforms from cell phones to cloud computing. Geographic information can now be found in the contents of wikis, photos, videos, blogs, tweets, and many other forms of user-generated content, and with geotags, the entire Web is fast becoming a potential source of geographic data, information, and perhaps even knowledge, which can be searched, mapped, analyzed, and synthesized. Also, with recent advances in indoor navigation, GIS has finally found its utility indoors – where most humans spend 85% of their time. At the individual level, we increasingly use geospatial information to decide which route to take from home to work, where to shop and eat, whom to hang out with and where.

At the collective level, policy makers have also realized the crucial importance of space and place in understanding the complexity of the world's problems, thus finding vital solutions to these problems that will work well under the diverse local circumstances. The World Bank (2009) framed its world development report entirely from a geographical perspective, concluding that alleviating, and eventually eliminating, the world's poverty problems must start with reshaping the world's economic geography. The Obama White House also issued a memo in 2011 urging all US federal agencies to develop place-based policies for fiscal year 2011 (http://www.whitehouse.gov/omb/assets/memoranda_fy2009/m09-28.pdf). Kaplan (2012) alerted US

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foreign policy makers on how the revenge of geography could be manifested in Afghanistan and Iraq if useful geographical lessons are not drawn from history by the Pentagon. To mitigate the "revenge of geography", we need to be not only location-aware but also geographically educated.

Indeed, as we are witnessing the spatial century unfolding right in front of our eyes, geospatial information and perspectives are becoming an imperative for major decisions at both the individual and collective levels. Many of the world's challenging problems, from global financial crisis, to world poverty reduction, to global warming, can not be solved without enlightened geographical perspectives. In this sense, the arrival of a spatial century is truly revolutionary as "the location of anything is becoming everything" (http://geospatialrevolution.psu.edu). This means unprecedented opportunities to apply GIS to all kinds of issues that are only bound by our imaginations. Again, the open GIS paradigm as outlined above offers the best approach to further promote the diverse GIS applications at both individual and collective levels for issues from local to global scales. We have seen many exciting new advances in the spirit of open GIS, following on the phenomenal success of Open Street Map (Sui et al. 2012). Particularly noteworthy is the area of emergency management and disaster relief. We now have Ushahidi, InRelief, Sahana, and Crisis Commons playing crucial roles in various disaster relief efforts – all relying on volunteered geographic information as a primary data source, open/free software tools, cloud-based platforms for their implementation, and collaboration of amateurs and experts alike around the globe (Hürlimann et al. 2011; Karnatak et al. 2012; Radinger et al. 2013). These new developments, in turn, have further encouraged governments to be more open and transparent; more geocoded data is now available on-line (e.g. geo.data.gov) and new government-supported platforms are being developed to facilitate these developments (www.geoplatform.gov).

3.3 Open Geographic (Citizen) Science for Understanding the Changing Planet

In addition to those technology-driven and application-led opportunities described above, the growing trend for an open geographic (citizen) science also offers curiosity-driven, crowd-powered opportunities for the development of open GIS. Citizen science is an optional component of the open science. Countering the argument that big data and advances in computing technologies have put an end to theory, the next phase of development of open GIS should contribute to a better understanding of our changing planet via curiosity-driven open science, which should aim for better theories.

The US National Research Council's (NRC) 2010 report "Understanding the Changing Planet: Strategic Directions for the Geographical Sciences" is an excellent summary of strategic directions for a better understanding of the changing planet Earth. According to the report, there are 11 strategic questions a broadly defined geographical science should tackle for the next decade (Table 1). These 11 questions/directions can be grouped into four major categories. The three questions in category A (how to understand and respond to environmental change) are closely related to the concerns of physical geographers/earth scientists. The three questions in category B (how to promote sustainability) lie in the realm of human-environment interaction (or environmental geography), whereas category C covers major areas of traditional human geography. The two questions in category D address issues related to geospatial technologies and their implications for society and environment.

The two directions in category D are closely related to the multiple threads of ideas for an open GIS. Further, I believe the nine strategic directions for geographical sciences as outlined in

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Table 1 Strategic directions for the Geographical Sciences

A. **How to understand and respond to environmental change:**
   1. How are we changing the physical environment of Earth's surface?
   2. How can we best preserve biological diversity and protect endangered ecosystems?
   3. How are climate and other environmental changes affecting the vulnerabilities of coupled human-environment systems?

B. **How to promote sustainability:**
   4. Where and how will 10 billion people live?
   5. How will we sustainably feed everyone in the coming decade and beyond?
   6. How does where we live affect our health?

C. **How to recognize and cope with the rapid spatial reorganization of economy and society:**
   7. How is the movement of people, goods, and ideas changing the world?
   8. How is economic globalization affecting inequality?
   9. How are geopolitical shifts influencing peace and stability?

D. **How to leverage technological change for the benefit of society and environment:**
   10. How might we better observe, analyze, and visualize a changing world?
   11. What are the societal implications of citizen mapping and mapping citizens?

Source: NRC (2010) Report.

categories A, B, and C also provide new science-driven opportunities for open GIS, especially related to the fifth dimension of open GIS – open research collaboration. For lack of a better vocabulary, science-driven opportunities for open GIS most likely will promote the practice of an open geographic citizen science through an artful integration of open and citizen science.

Scholars across the disciplines in science, engineering, social science, and the humanities are turning more and more to a geospatial perspective in their research (Scholten et al. 2009). In recent years, we have seen mathematicians, physicists, computer scientists, and ecologists conducting ground-breaking work in complex networks, visual analytics, and spatial modeling that offer the GIS researcher a golden opportunity to collaborate with researchers in other disciplines. Space has become an integrating theme across the social sciences, as evidenced by the emerging spatially integrated social sciences (csiss.org). Economist Paul Krugman was awarded the 2008 Nobel Prize for his work in economic geography. Scholars across the disciplines in humanities have also made GIS and spatial analysis an integral part of research methodologies (e.g. Knowles 2008; Warf and Arias 2008; Bodenhamer et al. 2010). Again, open GIS offers us the framework to practice open science in the fullest sense.

In addition to scholars, advances in geospatial technologies during the past 10 years have enabled ordinary citizens with little formal training to participate in the production of geographic data and knowledge through diverse forms of user-generated content and volunteered geographic information. Examples of such efforts include OpenStreetMap, one of a number of efforts to build global maps as patchworks of voluntary contributions; Wikimapia, which is attempting to build a world feature directory under the mantra "Let's describe the whole world", the hundreds of thousands of Google Earth mashups created by individuals, and Geonames that provides access to eight million place names in all the countries in the world (http://www.geonames.org). Both neogeographers and domain experts are doing these for fun and they have their annual symposium (http://whereconf.com). Others have more serious goals in the tradition of citizen science such as ctisci.org, niiss.org, and whoissick.org. Another

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example is the global project to find coal-fired power plants using a crowd-sourcing approach (http://ventus.project.asu.edu).

Open science and citizen science have not only contributed to big data but also fundamentally changed the questions we may ask for a better understanding of the changing planet (Dickinson and Bonney 2012). The future development of Open GIS will not only help us better understand the "what" question, but also the "why" questions.

3.4 Open GIS and the Vision for a Spatial University

The arrival of a spatial century has added a new level of urgency about spatial thinking and geographical literacy among the public and policymakers alike. It is obviously the duty of the discipline of geography in general and the GIS community in particular to push for a more aggressive life-long geospatial education and training agenda. Educators across both sides of the Atlantic have started ground-breaking work (e.g. http://www.visualspatial.org, http://www.spatial-literacy.org, http://teachingspatial.org).

More ambitiously, the GIS industry leader Esri has presented its vision of the so-called "spatial university," with the goal to push higher education institutions to embrace spatial thinking as a key educational objective, and to use geospatial technology to its fullest potential. According to Esri (2013), the spatial university should have the following four defining characteristics:

- **Spatial thinking across the curriculum:** There is now compelling evidence suggesting that spatial abilities prepare students for success in STEM coursework and early employment. However, no college or university to our knowledge includes such preparation among its overarching general education objectives. Nor do many institutions have campus-wide programs to prepare students to use GIS in community-based service learning projects or internships.
- **Geospatial workforce development:** For nearly a decade the US Department of Labor has highlighted career opportunities associated with geospatial technologies. In 2010 it published a Geospatial Technology Competency Model that clearly defines workforce needs. Still, relatively few higher education institutions offer advanced, practice-oriented undergraduate and graduate programs that prepare students for geospatial career opportunities.
- **Geo-enabled research:** Research discoveries too often remain segregated and hidden in disciplinary silos. GIS and the spatial perspective it embodies is inherently integrative. The spatial university hosts and disseminates multidisciplinary and interdisciplinary research enabled by the spatial perspective and geospatial technologies.
- **GIS for smart campuses:** The spatial university has an enterprise GIS infrastructure in place to support campus planning, operations, maintenance, and sustainability. Given the proven potential of such infrastructures to realize efficiencies and save money, it is remarkable that more institutions have not yet fulfilled this potential.

Indeed, both the US National Research Council (NRC) report and the competency model developed by the US Department of Labor's Employment & Training Administration (DOLETA) have played a major role in publicizing GIS and spatial skills to a broader audience, and as a result, a lot more bright young minds have been attracted to the field during the past decade. Both the field of GIS and geography have undergone major changes in recent years. I believe that it is strategically important for the geospatial community to continue thinking about the educational challenges of GIS in order not only to better prepare the future labor force of the geospatial industry but also to make spatial thinking an integral component of citizenship and liberal education. The open GIS paradigm will greatly facilitate the implementation for the vision

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of a spatial university, as demonstrated by the initiatives spatial@UCSB (http://spatial.ucsb.edu) and U-Spatial at University of Minnesota (http://uspatial.umn.edu; Harvey et al. 2013).

4 Impediments for Open GIS

By all accounts, the emerging open culture is certainly disruptive, as it challenges the conventional ways of doing business, conducting scientific research, running government, and providing education. However, we should bear in mind that if any useful lesson can be learned from the history of technological and scientific advances, it perhaps is this: the emerging open culture, similar to all other well-intentioned human endeavors throughout history, will not be immune from roadblocks and its own unintended consequences. While the potential to advance both our research and educational agenda via the open paradigm can not be underestimated, we must realize that the open paradigm clearly has its limits, depending on the specific issues involved. Although it is quite breathtaking to witness these developments under the general umbrella of open culture, there are still plenty of issues that need to be resolved along multiple fronts. There exist considerable barriers and challenges. To fulfill the promises of open GIS, the GIS community needs a broader conversation about these challenges and impediments (Figure 2).

4.1 The Academic Culture and the Reward System

For academic researchers, the inertia of academic culture and the existing reward model are not conducive to the development of an open paradigm at either individual or institutional levels. Despite the calls to set the default to "open" in scientific/scholarly research (Bailey and Borwein 2013), some researchers are reluctant to practice "open science", and especially to share the original data used in their research, for fear of being scooped, poached, or misused. More specifically, Fernandez (2010) documented the following as the primary reasons for academic researchers not sharing information with colleagues: (1) not receiving attributions; (2) potential loss of future publications; (3) competitors may get an advantage; (4) time needs to document and clean up; and (5) dealing with questions from users. These are all real issues that researchers must confront before they decide when, where, and with whom they should share or not share information about their ongoing research.

Detailed survey data of 1,694 bio-scientists were collected by Thursby et al. (2009), which enabled them to detect similarities and differences between academia- and industry-based scientists. By invoking the social capital theory to explain why individuals share information even at (temporary) personal cost, Thursby et al. (2009) discovered that in both realms, the likelihood of sharing decreases with the competitive value of the requested information. Furthermore, expected reciprocity and the extent to which a scientist's community conforms to the norm of open science also influences information-sharing or moderate competitive interest considerations on information-sharing. The pros and cons of being open vs. closed is similar to the prisoner's dilemma. Learned from the experience of the open source community, trust among contributors is of paramount importance in the practice of open science (De Laat 2010). The lack of trust among researchers, perhaps due to the highly competitive nature of academic research, is a real impediment for the development of open GIS. Further, Obembe (2013) argued (with empirical evidence) that a predisposition to knowledge sharing tends to occur in the context of sustained relations, which could pose problems in light of the increasingly fleeting nature of relations in the digital age.

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For those of us in academia, there is the harsh reality that the current academic reward system is designed for practicing closed science. New practices in the spirit of open science are often discouraged or at least insufficiently rewarded. The current academic reward system is organized around a system that rewards individual achievement. And because the academic reward system was designed for the scientific and scholarly practices of a previous era, the academy has yet to develop new procedures for evaluating and rewarding open scholarship. In the field of GIS, Rey (2009) noted that software development is not given the same credit as journal publication although in several disciplines (statistics, computer science) there have been some recent pushes that the true scholarship lies in the software code while the papers are merely advertisement for the software codes. Both Rey (2012) and Mitasova (2012) noted that due to the disconnect between contribution and attribution, more people, especially those in academia, are consumers rather than producers in the FOSS4G community.

Evidently, not all fields and disciplines are suited for open science, much less open note book science. One size fits all will not work. The collective aspects of knowledge production through open science are important, but we should be mindful of the depersonalization of crowd-sourcing and open science, which could be another barrier (Lanier 2010). Universities should play a leadership role in fostering global exchange of public goods although in reality, universities are often ridiculed by the media as the second most conservative industry – second to classic opera. To encourage and facilitate the practice of open science, academic reward system needs some serious reforms and rethinking to move toward a better appreciation of community infrastructure and the diverse/non-traditional contributions to scholarship. This is the only way to ensure a collective-private innovation model down the road (von Hippel and von Krogh 2003).

4.2 Existing Laws on Intellectual Property Rights

Besides the barriers erected by the academic culture and the conservative reward system, there also exist formidable legal barriers for the practice of open science. The ground-breaking work by legal scholars such as Larry Lessig – occasionally called an intellectual property communist by his critics – has resulted in creative commons and copyleft. Despite the progress made, we must nonetheless face the reality that the law still favors a closed instead of open practice in society. The intellectual property clause of the US constitution confers two distinctive powers: (1) providing the basis for the copyright law, securing for a limited time a creator's exclusive right to the original work; and (2) foundation for the patent law, giving an inventor a limited term exclusive right to their discoveries in exchange for disclosure of the invention (Stodden 2014).

Existing laws on intellectual property rights (primarily those covering copyright and patents) work counter to scientific progress by preventing the full release of code and data. Existing copyright laws were intended to give authors of creative work exclusive rights. The author believes that open licensing and broad fair use exceptions should be made at the legislative level for all scientific work. Scientific knowledge should be promoted as a public good. This is because copyright laws act against fundamental scientific norms in two key ways: (1) preventing copy of the research for broader application and/or for assessment through replication; and (2) establishing rights for ownership over the creation of derivative works using copyrighted work.

In addition to copyright and patent laws, trade secrets in business and industry are still well protected by trade secrets law. Legal protections include non-disclosure agreements (NDA) and non-compete clauses. In contrast to patent or copyright laws, which are set for a certain time frame in exchange for exclusive rights, a company or an individual can keep the

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business secrets indefinitely. Ironically, some notoriously secretive companies, such as Apple, have been quite successful, which raises a whole set of issues regarding open vs. closed in business operations (Truong 2012). Stodden (2009) has been advocating the reproducible research standards (RRS) that encourage scientific research by rescinding the aspects of copyright law that prevents scientists from sharing important research findings.

As an integral part of the growing gift (also known as sharing or peer-to-peer) economy, open source is becoming a new economic paradigm (Perens 2005), and yet the boundary between open and closed is constantly changing, contingent upon multiple factors (Dahlander and Gann 2010; Simeth and Raffo 2013). Companies often pursue an open source strategy through a combination of inbound processes (via sourcing and acquiring) and outbound processes (via revealing and selling). For everybody in business, there is this new reality of competing against "the free," which often requires business people to imagine a new business model with which to gain a slice of the increasingly competitive market and ensure profitability (Bryce et al. 2011). Shirky (2011) noticed that technology has made consumers into collaborators, but should they be compensated in order to sustain the growth of this new economic/business paradigm? For example, their compensation could be the product they contributed in developing, and/or a reduced cost for certain products or services due to their input/contributions.

4.3 Social/Political Barriers and the Changing Power Relationships

Existing laws and regulations on intellectual property and trade secrets are not friendly to encouraging practices of open science, but changing society's legal framework to promote the open culture and practices may be a long and arduous task. In addition, the social and political atmosphere and practices at both the individual and institutional levels can be important impediments for practicing open GIS, especially when dealing with controversial or sensitive issues related to privacy and security (Crampton et al. 2013).

During the early days of the Obama administration, an aggressive agenda for an open government initiative was proposed (Ginsberg et al. 2012), yet before long we witnessed the explosive growth of whistle-blowing web sites (http://www.whistleblowers.org), most of them relying on Web 2.0 technologies and open computing platforms. GlobaLeaks is an open source project aimed at creating a worldwide, anonymous, censorship-resistant, distributed whistleblowing platform. Perhaps the most famous one is Julian Assange's Wikileaks, which later (ironically) metamorphed into OpenLeaks. In the wake of Wikileaks, the Obama administration is reevaluating its open-government initiatives, redefining the boundary between openness and secrecy (Greenwald 2012). This also triggered a series of discussions on the virtues of openness vs. secrecy by both policy makers and scholars (Birchall 2011). In light of Edward Snowden's case, more steps and procedures were taken by government agencies to move toward secrecy, rather than openness. In fact, the US government spent more money in security (aiming to keep the secrets) than in science (with the goal of being open) (Crampton et al. 2014).

The Snowden case further revealed another subtle shift in societal power structure – that is how much the private sector knows about the intimate details of ordinary citizens, which triggered new rounds of discussions about personal privacy, but millions of consumers seem to be allured each day by the larger numbers of free and open applications on the web, which can be conveniently accessed by their smart phones. Inadvertently, each time they touch or key in a keyword, they "voluntarily" give up their privacy by contributing to the growing big data stream. Renewed interest and discussion of the virtues of secrecy do not necessarily diminish

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the agenda or value to push for more openness (Posner 2013), but they do create unintended barriers for making things more open for economic efficiency, social equity, and environmental sustainability. Ideally, we would like to steer the discussion towards how to make various open initiatives work better with considerations for both national security and individual privacy.

By offering the public services for free via the open paradigm, corporate giants are now capable of collecting a vast amount of data. As a result, big corporations now have more data about citizens than government agencies. This represents a subtle, yet major, shift of power in society, and both the short- and long-term implications of this shift remain to be seen. This shift of power may lead to the growing Balkanization of the web controlled by big corporations rather than interoperability across the platforms. As Horn (2011, p. 103) observed, "instead of seeing secrecy as the opposite of a political culture of transparency, it is more productive to regard secrecy as transparency's complement – a counterpart, however, that is marked by the profound paradox of being both a consolidation of and a threat to democracy".

4.4 Environmental Impacts and Sustainability Goals

Finally, we should also query the environmental implications of the emerging open culture, in which open GIS is deeply implicated. More specifically, is the open movement truly green? If not, what additional things we can do to make open science in general and open GIS in particular green? Open innovation has led to not only collaborative production but also collaborative consumption, also known as peer to peer sharing, peer to peer organization, or collaborative consumption.

These innovative trends towards a sharing ecomomy include the growing practice of collaborative consumption (Botsman and Rogers 2010), a rapidly evolving model that leverages the tools of Web 2.0, smart phones and social media. The values and practices of the expanding sharing economy have become more popular during the economic down-turn in the developed world. In addition to well established sites such as eBay, Craigslist, and Alibaba, we have witnessed the growth of reputable on-line platforms for the sale or exchange of used goods and other products and services. New leaders in the sharing economy, such as holiday rentals site Airbnb, carsharing marketplace RelayRides and errand service Task Rabbit, have gained momentum by harnessing the ability of social media to create social connections and credibility (Barros 2013).

Consequently, there are now three generally accepted trends with the growth of collaborative consumption:

- Access to services is more important than actually owning the product. The value of a product is beginning to be seen in terms of its use, not in its outright ownership, as per traditional consumer models;
- The growing level of acceptance of used products, thanks partly to the popularity of online platforms for buying and selling used goods. Moving beyond recycling, peer-to-peer reuse is gaining momentum among consumers;
- More broadly, people are also adopting what could be called the collaborative lifestyle, in which not only goods and products are shared and reused but also people share their passion, time, space and expertise through which they gain a level of gratification that cannot be attained by the mere ownership of certain products.

In their book *What's Mine Is Yours*, Botsman and Rogers (2010) argue that there are four factors needed for a successful business model based on collaborative consumption: (1) sufficient critical mass; (2) available capacity; (3) belief in the commons; and (4) trust and credibility

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between strangers. Barros argued that all of these are present to varying degrees in developing markets such as the BRICs, which are collaborative consumption giants in the making. The only unknown is the speed with which collaborative consumption services will emerge and be taken up as an alternative to traditional hyperconsumption. But currently we still lack empirical studies about the potential environmental impacts of growing collaborative consumption, and to what extent this new trend will help us achieve (or distract us from) sustainability goals.

As an integral part of the emerging open culture, we need to be vigilant about the potential environmental impacts of open GIS. We need to strive to use open GIS to achieve sustainability goals, but until and unless we know what exactly are the environmental impacts of open GIS, any further promotion of open GIS as green practice may be premature. Barros contends that there will be a reinvention of business models in various sectors as a result of the disruptive influence of collaborative consumption in developing countries, the growing populations and expanding middle classes of developing BRIC (Brazil, Russia, India, and China) economies will exert increasing pressure on natural resources, collaborative consumption, stimulated by the emerging open culture. This offers humanity a possible alternative to our current paradigm. More studies are needed in this area to clear the air.

5 Summary and Concluding Remarks

In 50 years of development, both the social and technological environments have changed dramatically. GIS has reached a crossroads. There are both centripetal and centrifugal forces shaping GIS development in this post-GIS age. What happens in the next five years will be critical for the next phase of GIS development. This article argues that the GIS community should fully embrace the value of the emerging open culture. Open GIS should be promoted as the driving force to guide the development of GIS in this new era. By embracing the full values of the emerging open culture, open GIS should include open data, open software, open hardware, open standards, open research collaboration, open publication, open funding, and open education/learning. Open GIS offers the best hope for us to tackle the challenges of big data, for a better understanding of the changing planet, practicing the open/citizen science, and implementing the vision towards the spatial university. To move forward, these technology-driven, application-led, science-inspired, and education-focused opportunities will propel GIS to a new level excellence; but we must also be mindful of the academic, legal, political, and environmental barriers for the development of open GIS. The "Geo for All" movement led by the Open Source Geospatial Foundation (OSGeo) and the International Cartographic Association (ICA) has attracted global attention (http://www.geoforall.org) since its launch in 2011. As of November 2013, a total of 55 labs across the globe have joined the cause, which will surely maintain the growth momentum for open GIS.

Apparently, the booming development of open GIS in recent years is heavily influenced by and deeply embedded in the emerging open culture, but GIS is not simply a free-rider on the "open" tide generated mostly by IT advancements. Efforts in open GIS, as reviewed in this article, have also contributed to the open movement in general along all of the eight dimensions of the open culture. Moving forward, I am a strong advocate for open science in general and open GIS in particular, but I do not believe that the free and open paradigm will be a panacea for all the problems and challenges we are facing in our profession. Due to a variety of technical, cultural, and legal reasons, open GIS and the traditional/closed GIS will co-exist – sometimes complementary, sometimes substitutable, and occasionally one taking a more dominant role than the other. Similar to the hybrid economy where both the proprietary (copyright

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and patent) and the open/free paradigm will play crucial roles as we move forward, a hybrid model – an artful combination of both open and proprietary practices for GIS businesses, applications, and research may be the most realistic option. Although the boundary between open and closed may be changing significantly due to social, political, and technological conditions, open GIS is a promising route to move GIS toward achieving the goal of liberation technologies (Diamond and Plattner, 2012) – to empower individuals, promote innovation in business and governance, facilitate independent communication and mobilization, and strengthen an emergent civil society.

Notes

1 The "S" in GIS in this paper stands for systems, science, services, and studies.
2 Based on the information from the course page, here is the enrollment information:

> "Out of more than 47,000 registrants, more than 34,000 were active in the class at some point; 3,064 passed the course (1,211 with Distinction, 1,853 Normal). That makes for a completion rate of 8.8% for those who logged into the course at least once. It appears that around 9,000 were active during the last week of the class."

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