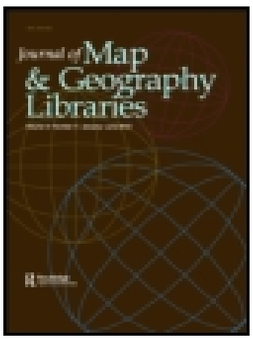

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Understanding the Ecosystem of Geospatial Research and Service in Universities

Weihe Wendy Guan[a] and Elizabeth Hess[b]

[a]Center for Geographic Analysis, Harvard University, Cambridge, Massachusetts, USA; [b]Institute for Quantitative Social Science, Harvard University, Cambridge, Massachusetts, USA

ABSTRACT

The study of location and location-based phenomena is a flourishing field. Many universities have grown their research and/or services in this field (often called GIS), established centers that are primarily engaged in the research of GIS, or applying GIS technologies to support researches of other fields. Some straddle "research of" and "research with" GIS in the same center, engaging in both GIScience research, often by researchers in a department or school, and geospatial technology services, often for users across the university. We conducted an online survey to scour the landscape of such centers in universities worldwide, to understand how they are structured, managed, financed, and sustained. The survey also included units as part of a library, department, or lab. Eighty-one valid responses were analyzed, revealing these organizations' administrative, financial, staffing, and operational status; their history, visions, responsibilities, resources, constrains, challenges, and opportunities. The result showed differences between universities with and without a geography department.

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Introduction

Spatial thinking is recognized for its importance in a wide range of fields (Janelle, Hegarty, and Newcombe 2014; Metoyer, Bednarz, and Bednarz 2015), from STEM (Gagnier and Fisjer 2016) to business (Goldsberry 2013), geoscience (Liben and Titus 2012) to humanities (Goodchild and Janelle 2010). The study of location and location-based phenomena is a flourishing field with many names: geographic information science and systems, geoinformatics, geographic analysis, spatial analysis, geospatial analytics, geo data science, among others. In the past decades, many universities have grown their research and/or services in this field (hereafter abbreviated as "GIS"). In general, these efforts take the form of established centers (or units with other names, hereafter abbreviated "centers") that are primarily engaged in the research of GIS, or applying GIS

CONTACT Weihe Wendy Guan wguan@cga.harvard.edu Center for Geographic Analysis, Harvard University, 1737 Cambridge Street, Suite 350, Cambridge, MA 02138, USA.

technologies to support research of other fields. Some GIS centers straddle both *research of* and *research with* GIS, engaging in both GIS research and geospatial technology services. The distributed and inconsistent nature of GIS service centers at universities makes it challenging to bench-mark against peer institutions and to learn from their experiences. Exploring GIS service centers as a research topic should contribute to determining the appropriate organizational/administrative model and funding source of GIS service activities in universities.

The tight connection between GIS research and service brings benefit to both (Harvey, Kne, and Manson 2012/2013). Research outcomes feed into services, enabling support to other fields, while unmet needs from the serviced fields push the envelope of GIS research, generating new topics and directions. The evolving dynamics between research and service puts GIS in an ambiguous position (or the lack of) in higher education institutions. It is relatively clear that the *research of GIS* belongs to an academic department or research institute, though sometimes not so clear which one; while it is less clear where in the university administrative organization GIS services belong? Considering the financial pressure on public and private higher education institutions (Hillman and Kindschy 2018), it is even harder to determine the adequate scale and appropriate funding source for GIS services. In particular, for the rather "federated" research institutions (Rychkova, Zdravkovic, and Speckert 2013), often times a large proportion of the academic community has the demand for GIS service, while few are willing to pay for it.

The purpose of the present study was to investigate how different academic institutions have structured, managed, financed and sustained GIS services. In answering this question, we also explored the history, visions, responsibilities, resources, challenges and opportunities of GIS service centers. Specifically, our objective was to answer the following research questions:

1. Is there a prevailing administrative home for GIS centers?
2. What are the most common functions of GIS centers?
3. Is there a prevailing funding source for GIS centers?
4. Is there a prevailing size (by funding or FTE) for GIS centers?
5. What are the factors affecting the funding level and functions of GIS centers?
6. What are the most common challenges and promises that GIS centers face?

Methods

The authors developed an online survey instrument implemented as a Google Form with a link distributed via email. The publicized incentive for

taking the survey was to receive the sharable parts of the survey responses in their original format as soon as the survey was closed. The survey was open from February 22nd to April 19th, 2018. It was developed with the following design objectives:

- Easy to understand and able to be completed in less than 10 minutes.
- Supported quantitative analysis. Responses were captured in a spreadsheet, and most questions were multiple choices.
- Flexibility—allowing respondents to enter additional information beyond the choices listed.
- Privacy protection—allowed the participants to specify which part(s) of their answers could be shared upon close of the survey.
- Free for the authors to implement.

The survey was structured into 10 sections (Table 1). Particular attention was given to obtaining permission for sharing and respecting participants' preference for privacy. Participants could choose to share with other participants and the public any, all or none of their responses per section.

Invitations to the survey were sent to the mailing lists of 12 GIS related communities (Table 2) and the contact emails of 44 GIS related centers. The mailing lists included local, regional, national and international communities. Their focuses of interest ranged from libraries to classrooms, from teaching to research, from data creation to mapping to software development, from commercial products to open source tools. Survey invitees included centers in public and private universities in the USA and several other countries. The affiliations of these centers ranged from departments, colleges, divisions, schools, libraries, and central administrations. Their affiliated academic fields included geography, geosciences, earth sciences, architecture and urban planning, environmental studies, natural resources, crop and soil sciences, spatial informatics, computing and information sciences, social sciences, and business.

Analysis of the survey responses were mostly conducted in Microsoft Excel with formulas. Table 3 shows the relationship between the research questions and the survey questions, and the data analytical and visualization methods applied in processing the survey responses.

Results

The survey received 85 responses. After removing redundant entries, valid responses represented 81 centers at 76 universities from 12 countries. Sixty-three universities (83%) were from the USA. The other

Table 1. Structure of the survey.

Section	Description
Introduction	Explaining the purpose and conditions of the survey
General information	Capturing the university, organization and responder's name and contact information
Administrative information	Capturing the age and affiliation of the center
Financial information	Capturing the budget and income sources of the center
Personnel information	Capturing the number of employees and type of jobs
Responsibilities	Capturing the center's roles in teaching, research and services
Operational information	Capturing the center's hardware and software portfolios
Collaboration and communication	Capturing the center's interaction with people and organizations internal and external of the university
Challenges and opportunities	Capturing the center's biggest challenges and most promising direction of growth
Permission for sharing	Capturing the responders' preferences on sharing their answers with others

https://docs.google.com/forms/d/e/1FAIpQLScrcBUkw0EPsNMeYGGCeN2tFScnHy1I8Gt16ROgWLUBn17RxQ/viewform.

countries represented were Canada, Denmark, France, Hong Kong (China), Italy, Japan, Netherland, Portugal, Singapore, Sweden, and Switzerland.

Based on information from the responding universities' website, 49 (60%) of the surveyed centers were in public universities, 32 (40%) were in private universities. Fifty-four universities, (66.7%), had a department of geography or related academic field of study (Table 4). The majority of the universities had a range of 10,000–50,000 total enrolled students (Table 5). Most of the universities had both undergraduate student and graduate student programs. Only three universities did not have graduate student programs, and one university did not have undergraduate student programs.

Administrative Organization of GIS Centers

Among the 81 valid entries, there was no two centers sharing the same name. However, certain keywords were common in the names (Figure 1).

Based on the word frequency report, out of the 81 participating organizations, 33 were named as a center, 6 as a lab, 5 as a department, 3 as a unit, 2 as an institute, 2 as a program, 2 as studies, among other variations. Eighteen names contained the word "GIS", 14 contained "geospatial", 9 contained "spatial", 7 contained "geographic", 11 contained "information", 9 contained "data", 10 contained "science", and 8 contained "service".

Similarly, a text cloud of words was created from the names of the administrative homes for these centers (Figure 2) and the frequency of words reported.

Out of the 81 participating centers, 21 were part of a department, 21 were part of a library, 15 were part of a school or college, 11 were part of

Table 2. GIS communities invited to the survey.

Community	Email	Web
Boston Open Source Geo	boston@lists.osgeo.org	https://www.osgeo.org/
Crisis Mappers	crisismappers@googlegroups.com	http://crisismappers.net/
Esri Higher Education Listserv	HIGHERED-L@atlantis.esri.com	https://community.esri.com/thread/202924-the-esri-higher-education-listserv
GIS for Libraries	gis4lib@u.washington.edu	https://mailman13.u.washington.edu/mailman/listinfo/gis4lib
GIS in National Institute for Technology in Liberal Education	gis@lists.nitle.org	http://nitle.org/
GIS Teaching Alliance (GISTA) Boston	gistaboston@elist.tufts.edu	https://elist.tufts.edu/wws/info/gistaboston
International Association of Chinese Professionals in Geographic Information Science (CPGIS)	CPGIS-L@LISTSERV.BUFFALO.EDU	https://cpgis.org/
Maps, Air Photo, GIS Forum—Map Librarianship	MAPS-L@LISTSERV.UGA.EDU	http://www.waml.org/maplists.html
New England Chapter of the Urban & Regional Information Systems Association (NEURISA)	admin@neurisa.org	http://www.neurisa.org/
Northeast Arc Users Group	NEARC-L@LISTSERV.UCONN.EDU	https://www.northeastarc.org/
Open Geo Portal	opengeoportal@elist.tufts.edu	http://opengeoportal.org/
University Consortium for Geographic Information Science (UCGIS)	all_members@ucgis.org	http://www.ucgis.org/

university central administration and 3 were part of university IT (Table 6). Based on the word frequency report, the academic field of the hosts (departments, school or colleges), in the order of frequency, included 11 in geography, 7 in environmental science, 6 in earth science, 4 in planning, 3 in engineering, and 2 in social science.

Figure 3 shows the year of establishment for the centers. Except one center that was established in 1964, all the other centers were established after 1980, with a general increasing trend in the number of new centers established each year. Since year 2000, the only year when no new center was established among the surveyed sample was 2009, perhaps reflecting the impact of the global economic recession that year. The year 2015 saw the most centers being established, with 8 new centers born, 10% of the total surveyed.

Functions of GIS Centers

Most of the centers engaged in some sort of teaching programs. Where there was a lack of a geography department, the centers tended to take on more teaching of both credit and noncredit courses (Table 7). Seven out of the 81 centers did not engage in any teaching activities, all seven were in a university with a geography department.

Table 3. Analysis and visualization methods applied to address research questions.

Research question	Survey questions	Analysis and visualization methods
Is there a prevailing administrative home for GIS centers?	Center or Unit's Name (text), Administrative affiliation (check one) and Name of the administrative home (text)	World Cloud Generator (Davies 2018) was used to create a text cloud of words in the center names. WordClouds.com (Zygomatic 2018) was used to report the frequency of words in the cloud.
What are the most common functions of GIS centers?	Responsibilities in teaching, research and service (check all that apply); Operational Information on assets, applications, licenses, data grants (check all that apply) and Collaboration and Communication via organization membership, hosted events, dissemination channels (check all that apply)	Survey responses were exported from Google sheet to Microsoft Excel. Excel formulas were used to identify duplicated entries. After manual remove of duplications, Excel formula was used to generate summary tables and charts.
Is there a prevailing funding source for GIS centers?	10% or more of the center/unit's funding comes from (check all that apply)	
Is there a prevailing size (by funding or FTE) for GIS centers?	Center/unit's annual operation budget (check one), Number of full-time employees on the center/unit's budget (number), Job types of center funded personnel (check all that apply)	
What are the factors affecting the funding level and functions of GIS centers?	Year when the center/unit was established (number).	Additional information was gathered by the authors from the responding centers' websites, on the type of the university (public or private), total number of enrolled students, and whether or not the university has a geography department (regardless where the center was hosted).
What are the most common challenges and promises that GIS centers face?	The biggest challenge the center/unit currently faces (check one) and the most promising direction for the center/unit's growth (check one)	Responses to multiple choice questions were summarized in Excel tables, while open text responses were cited in the Discussion and Limitations of the Survey sections.

Table 4. Number of surveyed centers in public or private universities, with or without a geography department.

Number of centers	Public university	Private university	Total
With geography department	44	10	54
Without geography department	5	22	27
Total	49	32	81

Most of the centers engaged in research projects, regardless of whether or not the university had a geography department. However, for centers with a geography department, more centers were conducting sponsored projects, while for centers without a geography department, more were

Table 5. Distribution of surveyed universities by the total number of enrolled students.

# of enrolled students	# of universities
<1000	2
1000–5000	9
5000–10,000	10
10,000–25,000	28
25,000–50,000	26
>50,000	6
Total	81

Figure 1. Text cloud of words in the center names.

Figure 2. Text cloud of words in the names of the administrative homes for the centers.

Table 6. Administrative homes of the centers.

Administrative homes	Count
Department	21
Library	21
School or college	15
University central admin	11
Other	10
University IT	3
Total	81

conducting projects funded by other parts of the university (Table 8). About 10% of the centers were not involved in research projects.

A majority of the centers provided technical services such as data processing and analysis, consultation or project scoping, and data discovery and acquisition. Centers in a university without a geography department were more likely to provide these services and cartographic production or help desk, while centers in a university with a geography department were more likely to provide services on application development and hosting, and automation scripting or tool development (Table 9). It was unclear whether these differences were caused by the composition of staff expertise or by demands from the users. Only 4 out of the 81 centers did not provide any service.

Only three out of the 81 centers did not own or manage physical equipment. Most of the centers had lab computers and GPS units, and many had scanners and plotters. About 30% had drones. More than 60% of the centers with a geography department managed physical servers, while only about 20% of the centers without a geography department did (Table 10). This was consistent with the need for developing and hosting applications.

A majority of the centers used servers (physical or virtual) managed by their university IT. 20–30% used commercial cloud services. Only about 5% used external research clouds (Table 11).

\Over 80% of the centers managed university-wide site licenses for software products. Most had a site license with Esri. A small percentage also had site licenses with other companies. Table 12 shows the major software products with site license managed by the centers. Products not included in Table 12 were Pix4D, AgiSoft, Fulcrum, Mapbox, Avenza, SimplyAnalytics, and "several other GIS, statistics, visualization, and digital humanities licenses" entered in the "other" field of the survey by one or two centers.

A majority of the centers hosted symposiums or workshops and seminars or colloquia. Some also hosted conferences, hackathons or code sprints, or field trips (Table 13). Only 11 out of the 81 did not host any event.

All centers used websites and various other means to communicate with user communities, though a few did not have unit-maintained websites,

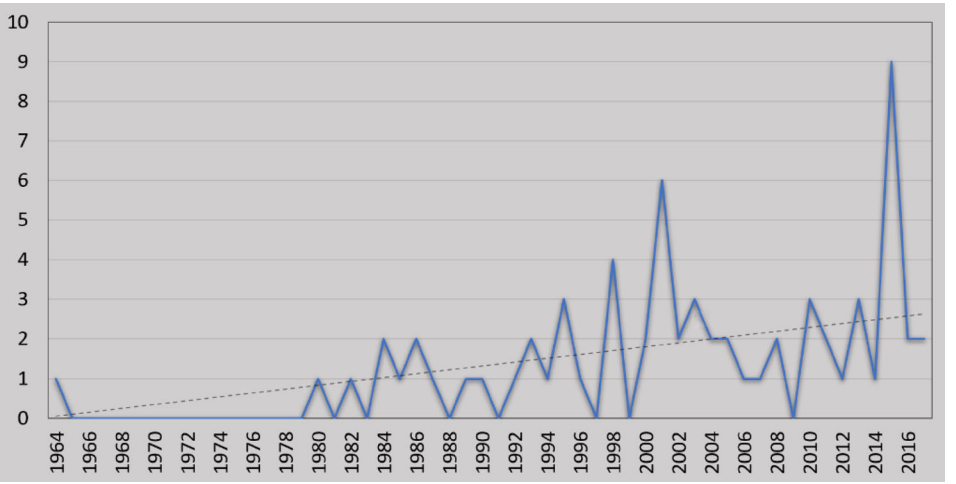

Figure 3. Number of center established by year.

Table 7. Percent of centers offering these teaching programs.

Centers offering these teaching programs	With geography department	Without geography department
Degree or certificate program	41%	48%
Executive education program	2%	4%
Continuing education program	7%	19%
Noncredit training program	39%	56%
MOOC or online courses	7%	4%
Guest lectures or lab modules in credit courses where the lead instructor is not a center personnel	37%	59%
Other or n/a	24%	11%

Table 8. Percent of centers engaged in these research projects.

Centers engaged in these research projects	With geography department	Without geography department
Sponsored projects where center/unit personnel is PI or co-PI	70%	44%
Sponsored projects where center/unit personnel is participant but not PI or co-PI	63%	59%
Projects funded by other parts of the university	46%	70%
Projects funded internally by the center/ unit's budget	41%	41%
Other or n/a	17%	11%

rather they used the websites of their host organizations (department, library, etc.). Table 14 shows the various communication channels used by the centers. Not included in Table 14 are Instagram, physical bulletin boards, or special event booths, which were entered in the "other" field of the survey by a few centers.

Almost half of the centers were members of an organization such as the University Consortium for Geographic Information Science (UCGIS) or the Open Geospatial Consortium (OGC) (Table 15).

Table 9. Percent of centers providing these services.

Centers providing these services	With geography department	Without geography department
Help desk	33%	48%
Consultation or project scoping	69%	70%
Proposal development for grant	50%	52%
Out-sourced contract management	6%	11%
Field data collection	33%	30%
Data discovery and acquisition	59%	67%
Data processing and analysis	69%	78%
Cartographic production	46%	56%
Automation scripting or tool development	37%	30%
Application development and hosting	46%	30%
Other or n/a	11%	7%

Table 10. Percent of centers owning these equipments.

Centers owning these equipments	With geography department	Without geography department
Physical servers	63%	22%
Lab computers	80%	93%
Rugged tablets	13%	0%
GPS units	63%	52%
Drones	31%	33%
Scanners	52%	44%
Plotters	48%	41%
Other or n/a	6%	4%

Funding Source of GIS Centers

The survey asked the centers to report all funding sources contributing 10% or more of their current fiscal year's budget. For centers in a university with a geography department, more centers received funding from public or private grants, their school or college, and through external service contracts; while for centers in a university without a geography department, more of them received funding from a library, their university central administration, public or private grant, or their university's IT organization (Table 16).

Size of GIS Centers

This survey did not find a prevailing size (by budget or FTE) for GIS centers. Data shows that the center's size is not in proportion to the size (by number of enrollment) of the university. Both funding sources and administrative homes for GIS centers are diverse, with departmental and libraries being the most common administrative homes. Grant and school/college lead the funding sources when there is a geography department, while library and university central administration lead the funding sources when there is not a geography department.

Factors Affecting Funding Levels of GIS Centers

The age of the centers ranged from newly established to 54 years old. Annual operating budget size ranged from less than $100 thousand to over

Table 11. Percent of centers using these hosting services.

Centers using these hosting services	With geography department	Without geography department
Physical servers managed by the center/unit	44%	11%
Physical servers managed by other IT teams within the university	56%	52%
Virtual servers provided by other IT teams within the university	48%	44%
Virtual servers provided by a commercial company (such as AWS)	24%	30%
Virtual servers provided by a research cloud (such as Mass Open Cloud)	9%	0%
Other or n/a	13%	19%

Table 12. Percent centers managing these site licenses.

Centers managing these site licenses	With geography department	Without geography department
Esri (ArcGIS, etc.)	72%	74%
Hexagon Geospatial (ERDAS Imagine, etc.)	28%	15%
Harris (ENVI, etc.)	13%	15%
Trimble (eCognition, etc.)	17%	7%
Clark Labs (TerrSet, etc.)	7%	7%
Safe Software (FME, etc.)	4%	7%
Google (Google Maps APIs Premium, etc.)	15%	15%
Carto (CARTO Builder, etc.)	6%	26%
Other or n/a	28%	15%

Table 13. Percent centers host these events.

Centers host these events	With geography department	Without geography department
Seminars or colloquia	56%	52%
Symposiums or workshops	70%	74%
Conferences	31%	37%
Hackathons or code sprints	22%	26%
Field trips	13%	19%
Other or n/a	19%	7%

Table 14. Percent centers using these communication channels.

Centers using these communication channels	With geography department	Without geography department
Website	87%	100%
Mailing lists	54%	74%
Newsletters	24%	22%
Blogs	11%	30%
Tweets	31%	41%
YouTube or Vimeo channels	24%	11%
Facebook	37%	11%
LinkedIn	13%	15%
Other or n/a	7%	0%

$10 million. There was no clear relationship between a center's age and its budget size. Some of the youngest centers as well as oldest centers had relatively low budget size, while centers with a relatively big budget (more than $2.5 million) could also have existed for just a few years or a few decades (Table 17). However, the few centers with higher than $5 million annual budget were all 20 or more years old.

Table 15. Number of centers as members of GIS related organizations.

Organization name	Organization abbreviation	Number of centers as a member
University Consortium for Geographic Information Science	UCGIS	23
Open Geospatial Consortium	OGC	13
Washington State Geographic Information Council; NYS GIS Clearinghouse, GISMO, etc.	State or Local	4
Association of Geographic Information Libraries in Europe	AGILE	3
United Nations Global Geospatial Information Management	UNGGIM	2
Open-source collaboration for finding and sharing geospatial data	GeoBlackLight	1
Open Source Geospatial Foundation	GeoForAll	1
North American Cartographic Information Society	NACIS	1
Open GeoPortal	OGP	1
Urban and Regional Information Systems Association	URISA	1
None	N/A	47

The centers' budget size seemed to be independent of the size of the university. Most of the centers had a low budget (less than $100 thousand), which included universities with anywhere between a few hundreds to over 40 thousand enrolled students. The largest universities, with nearly 70 thousand enrolled students, had centers with less than $500 thousand annual budget. While centers with more than $5 million annual budget were in universities with 20–50 thousand enrolled students (Table 18).

The few centers with the highest budget size are all in public universities (Table 19) and are part of a Geography Department (Table 20).

Challenges and Opportunities for GIS Centers

The survey asked respondents to select one biggest challenge they were currently facing, among a list of choices. It also asked for the most promising direction for growth among a list of choices. Both questions had an "other" field for free-text entries.

After submitting their responses to the survey, some respondents reached out to the authors saying that they wished they were allowed to select multiple challenges or multiple opportunities, since it was hard to pick just one as the "biggest" or "most promising." It was too late to alter the survey at that point, thus we were not able to accommodate this request. However, this does anecdotally suggest that there are multiple challenges and opportunities currently being faced by GIS centers.

Even though the lack of financial stability was the biggest challenge for more centers, especially those in a public university with a geography department, the answers to the "biggest challenge" question were

Table 16. Percent of centers with 10% or more funding from these sources.

Centers with 10% or more funding from these sources	With geography department	Without geography department
A department	15%	15%
A school or college	35%	22%
A library	24%	33%
University IT	11%	19%
University central administration	20%	30%
Public/private grants	41%	26%
Internal service charges	13%	7%
External service contracts	26%	7%
Product sales/royalty	4%	0%
Donation/gifts	9%	0%
Endowment	0%	0%
Other or n/a	4%	4%

Table 17. Center age by budget size.

Center/unit's annual operation budget	Minimum age	Average age	Maximum age
LT$100,000	1	18	38
$100,000–$250,000	2	16	54
$250,000–$500,000	1	13	32
$500,000–$750,000	3	10	17
$750,000–$1,000,000	7	9	10
$1,000,000–$2,500,000	3	20	36
$2,500,000–$5,000,000	3	6	8
$5,000,000–$10,000,000	20	25	29
GT$10,000,000	33	33	33

rather diverse, with a long list of "other" text going beyond the provided choices (Tables 21 and 22).

The "other" biggest challenges could be grouped into inadequate staff skillset or lack of time or capacity, both reflected insufficient staff to meet demand. The following are examples of each.

- Inadequate staff skillset:
  - Hiring and staff retention
  - Current staff skillset does not match current responsibilities/ opportunities
  - Lack of professional educators
  - Can't keep up with power users' demands
  - Majority of employees are "off-campus"; nation (and world) wide
- Lack of time or capacity to:
  - Build the center's awareness and capabilities
  - Build a proper GIS infrastructure to creative works
  - Transition from traditional stats/admin data to big data
  - Manage scale and support dispersed geospatial research

Sponsored research and support services were the two most promising opportunities for centers. Centers with a geography department or at a public universities favored sponsored research, while centers without a

Table 18. Size of universities by center budget size.

Center/unit's annual operation budget	Minimum student number	Average student number	Maximum student number
LT$100,000	680	18,234	44,831
$100,000–$250,000	831	21,538	67,580
$250,000–$500,000	6434	26,202	67,580
$500,000–$750,000	4899	28,333	51,848
$750,000–$1,000,000	20,607	35,865	51,123
$1,000,000–$2,500,000	3400	28,251	52,669
$2,500,000–$5,000,000	6509	21,498	36,487
$5,000,000–$10,000,000	20,077	33,128	51,164
GT$10,000,000	33,237	33,237	33,237

Table 19. Number of centers by annual operating budget, grouped by university type.

Center/unit's annual operation budget	Number of public universities	Number of private universities	Total number of universities
LT$100,000	23	10	33
$100,000–$250,000	6	7	13
$250,000–$500,000	6	4	10
$500,000–$750,000	4	2	6
$750,000–$1,000,000	0	2	2
$1,000,000–$2,500,000	4	2	6
$2,500,000–$5,000,000	0	2	2
$5,000,000–$10,000,000	3	0	3
GT$10,000,000	1	0	1
N/A	2	3	5

Table 20. Number of centers by annual operating budget, grouped by with or without geography department.

Center/unit's annual operation budget	Universities with a geography department	Universities without a geography department	Total number of universities
LT$100,000	21	12	33
$100,000–$250,000	7	6	13
$250,000–$500,000	7	3	10
$500,000–$750,000	6	0	6
$750,000–$1,000,000	0	2	2
$1,000,000–$2,500,000	4	2	6
$2,500,000–$5,000,000	2	0	2
$5,000,000–$10,000,000	3	0	3
GT$10,000,000	1	0	1
N/A	3	2	5

geography department or in private universities favored support services internal to the university (Tables 23 and 24).

In addition, software development, external consultation and online teaching were identified as other promising directions for growth by several centers. There were also some one-off answers entered into the "other" field, most of which could be grouped into data development or course development. Examples of entries to the "other" field are as follows:

- Data development:
  - Diversification outside of GIS in data management and visualization

Table 21. Percent of centers identifying these as their biggest challenge (with or without geography department).

Centers identifying these as their biggest challenge	Universities with a geography department	Universities without a geography department
Lack of financial stability	33%	7%
Lack of space, equipment or other resources	17%	19%
Lack of institutional recognition	9%	15%
Lack of professional development for adopting new technologies	7%	7%
Lack of user awareness	6%	11%
Lack of faculty support	2%	0%
Other	26%	41%

Table 22. Percent of centers identifying these as their biggest challenge (public vs private university).

Centers identifying these as their biggest challenge	Public universities	Private universities
Lack of financial stability	33%	13%
Lack of space, equipment or other resources	20%	13%
Lack of institutional recognition	12%	9%
Lack of professional development for adopting new technologies	6%	9%
Lack of user awareness	8%	6%
Lack of faculty support	2%	0%
Other	16%	41%

    - Creating and providing access to data and maps for open access
    - Providing access to historical geographic data
    - Developing data-related instruction and services in library
- Course development:
    - Spatial Sciences Initiative and Degree Granting Program
    - Delivering spatial analysis courses to students across the curriculum
    - More students

A few survey responders granted permission to share their optional comments. Some pointed out that financial growth or stability did not necessarily mean the center was free of challenges. There were competing priorities for where to spend the funding and staff time. Two examples of free-text comments are as follows:

> We are growing in external contracts and internal sales (last question). Internal sales is growing faster, but the contracts are smaller … The hardest thing is actually finding money to do the non-project stuff that helps us grow (administration, marketing, outreach, organization).

> Allowing us rank challenges and opportunities would be helpful because financial stability only scores a hair behind the fact that I don't have time to keep up on new tech because I'm expected, with two people: to run a support center for the school,

Table 23. Percent centers identifying these as their most promising direction for growth (with or without geography department).

Centers identifying these as their most promising direction for growth	Universities with a geography department	Universities without a geography department
Sponsored research	28%	26%
Support services (internal to the university)	22%	33%
Product (tools and systems) development	15%	4%
Consulting services (external contract)	13%	7%
Online teaching	7%	15%
Other	15%	15%

Table 24. Percent centers identifying these as their most promising direction for growth (public vs private university).

Centers identifying these as their most promising direction for growth	Public universities	Private universities
Sponsored research	31%	22%
Support services (internal to the university)	18%	38%
Product (tools and systems) development	16%	3%
Consulting services (external contract)	14%	6%
Online teaching	10%	9%
Other	8%	16%

> to run an external consultancy, manage software licenses and a physical lab space, give workshops, perform research, and run one (and soon to be two) certificate program(s).

Finally, many expressed interests in this research topic, eager to share ideas and information, and ready to participate in discussions. Comments that demonstrated this were as follows:

> Thanks for starting this conversation! It'd be great to at least commiserate with other lab/center leaders.

> Thank you for doing this!

> I hope that you will share whatever data people allow.

> Please publish or otherwise make available the results of this survey for everyone's benefit.

Discussion

Universities have been forming centers to conduct research *of* GIS and research *with* GIS since the 1980s, accompanying the growth of GIS as an applied science and technology. This practice seemed to be on the rise in recent years, and included both public and private universities in a wide range of sizes.

The survey called for participation from centers conducting GIS research OR service. In the response received, only 10% did not engage in research, and only 5% did not engage in service—evidence that research and service covers the general functions of GIS centers well. The overwhelming majority were straddling research AND service in the same center. The individuals responding to the survey might have had varying interpretations on where to draw the line between research and service, particularly when GIS was used to support research of another field versus research on GIS tools and practice (i.e. GIScience). Yet this ambiguity reflected the fact that GIS, as any applied science, often plays a dual role in practice. GIS researches produce outcomes that enable services to other fields; at the same time, unmet needs from the supported fields in turn generate new topics and directions that further GIS research. This is in many ways how technological innovation commonly happens—tools and methods developed for application in one field are applied in a new and innovative way in another field. In this context, what constitutes research and practice is not clear.

While there is an advantage in combining research and service under one center (as stated in the Introduction section), there is also a disadvantage for such centers, given how universities are traditionally structured, which tends to separate academic (i.e. research) and support (i.e. practice) functions. A disadvantage was reflected in this survey by the diverse scenarios in hosting organizations and funding sources for the centers. There was no clear consensus among the universities as to where such a center should belong, and how it should be funded. There was also no clear consensus even on how such a center should be named. Every university seemed to be exploring its own way. Initiatives that are not well-understood and/or lack administrative champions at universities can be vulnerable. If GIS centers were singularly identified as serving an academic (or support) function they might benefit more from traditional administrative support for those functions. This observation begs a further question that was not addressed by the present study, "by what measure(s) should we evaluate the success of GIS centers?"

Although the survey was not set-up to detect differences between universities that had and did not have a department of geography, this post-hoc factor appeared to be important to understanding survey results. Only 10% of public university respondents did not have a geography department, while two-thirds of private universities did not. Where there was no geography department, the GIS centers were hosted in libraries or university IT organizations, among other options. Most of these centers offered technical trainings and provided services with mature GIS

technologies, such as finding spatial data or creating maps. Fewer of them received grants or conducted external contractual services; none received gifts or had royalty products. In universities with a geography department, many of the centers were hosted either in the department or in an organization related to the department (college, school, etc.). These centers were more likely engaged in sponsored research, and in projects that involved newer or more complex methodologies and techniques, such as application development and hosting, remote sensing, customized web mapping, etc.

Centers in universities with a geography department were more likely to rank the lack of financial stability as their biggest challenge, perhaps because they were more heavily relying on research grants as main funding sources, while centers in universities without a geography department were more likely to rank the lack of institutional recognition and user awareness as their biggest challenges. Keeping up with technology development and updating staff's skill sets were also a bigger concern for centers in universities without a geography department. How the presence of a geography department at universities affects the administrative home, functions and support for GIS centers deserves further research that is beyond the scope of the current study.

Limitations of the Survey

The authors did not know how many people were subscribed to the various mailing lists, or how many among the 44 centers directly invited to the survey were also on the mailing lists, and as a result did not have data on response rate of the invitations. Although responses included universities from 12 countries, the sample set was heavily skewed toward universities in the USA. Because the implementation of the survey was on Google Forms, countries and regions without access to Google (such as mainland China) could not participate in this survey.

In a few cases, two individuals affiliated with the same center submitted separate responses. In these situations the authors combined their answers and removed the redundancy. There were occasional discrepancies between the duplicated responses for the same center, reflecting differences in knowledge about the center's operation, or interpretation of the questions. Due to resource limitations, the authors were not able to follow up with the responders to verify the information entered into the survey.

Some respondents pointed out that organizational complexity could result in misleading responses to the survey. "Our unit includes 7.5 FTE, but only 1.5 FTE has primary responsibility for provision of GIS services.

Libraries ITS hosts and manages physical servers that provide GIS related applications in consultation with our unit. My answer to our unit's annual operations budget is misleading because it includes all 7.5 FTE, collection development funds for different areas within the unit (gov pubs, microforms, etc.) and student hourly funds. The annual budget for just GIS services within the unit would be in the <$100,000 category." "There's a lot of nuance in my answers (I'm sure that's true for everyone) and follow-up conversations would likely be very informative because I don't think the survey can effective capture the constraints and challenges we operate under."

The survey was designed to focus on information about how the centers are organized, funded and operate. It did not include questions on the specific topics of research or teaching the centers conducted, nor the academic fields of the researchers who received GIS services from the centers. Such questions would be hard to answer by multiple choices, and some centers might not have such records readily available. These topics could be better developed in targeted follow-up surveys.

Future Perspectives

The present study revealed the current situation of GIS centers in a wide range of universities. It also raised new questions that it did not provide definitive answers for like how the presence of a department of geography impacts GIS center organization, activities and support. Given the diverse status of the centers, it was not clear which were the key factors determining the scale of the centers, or how they balance research and service. Additional investigation, perhaps a redesigned survey, or a different and more effective survey tool, is needed for identifying and demystifying the specific factors that determine the scale of centers and/or how they balance between research and service.

In recent years, the focus on data science has become elevated in many universities and in some cases has led to the creation of new departments, schools, and programs of study (e.g. MIT's Schwarzman College of Computing, University of Virginia and City University of Hong Kong's School of Data Science). … The relationship between existing GIS centers and the new data science centers would be interesting to observe. The authors plan to repeat the present survey in 5 years in order to produce longitudinal data for trend analysis that we hope captures broad-scale changes like the introduction of data science centers at universities. Complimentary to a follow-up survey could be convening panel with leaders from various centers at a professional conference (such as an annual meeting of the American Association of Geographers) to continue to

explore the organization, activities and support of GIS centers at universities across the USA and around the world.

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