Steven M. Manson
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Jane Lindelof *Editors*

Building the Spatial University

Spatial Thinking, Learning, and Service Throughout the System

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Preface

This volume summarizes a large body of knowledge and practice on how institutions can encourage spatial research, teaching, and service.

We developed this work in large part because the editors and others at the University of Minnesota were fielding an increasing number of inquiries about how we support spatial research, teaching, and service. By a stroke of good timing, Zachary Romano, then Associate Editor and now Senior Publishing Editor with the Earth Sciences, Geography, and Environment portfolio at Springer Science, approached Len Kne at the Esri User Conference a few years ago and asked whether he would put together a volume on U-Spatial, the University's spatial science infrastructure. Realizing that editing a volume can be both fun and frustrating, Len tapped Steven Manson, and they in turn, brought in Brittany Krzyzanowski and Jane Lindelof to share the joy and pain.

We thought this volume would be primarily about U-Spatial, which is the subject of Chap. 2 and woven throughout this volume. As we engaged with potential readers and authors, however, it became clear that we are really interested in the broader idea of the spatial university. This volume offers an expansive view on the power and possibility of spatial science for research, teaching, and outreach for scholars and institutions more broadly. The role of spatiality in almost all realms of higher learning became even more evident as the COVID-19 pandemic forced so many people to embrace technology as a way to navigate many facets of the crisis.

Given this broader focus on the spatial university, we originally envisioned two primary audiences for this book, and they remained front and center throughout. The first is spatial science practitioners and leaders who work within academic institutions. The second is a range of information technology, physical plant, facilities management, librarians, and research administrators in education, academia, and a host of other sectors who are looking for insight and direction on developing spatial science infrastructure.

In putting the volume together, it became clear that others could benefit from this volume. This work can be a resource for spatial researchers and practitioners interested in a broad view on spatial science as it applies to a range of domains. It can also aid graduate students in a range of fields who are grappling with developing or working with spatial data and analysis in their research, including master's students in geographic information science (GISc), information science, or library science. In terms of domain-specific audiences, social scientists and humanities scholars have always had an interest in mapping and space, but the recent increased visibility and importance of spatial data and approaches has placed spatial science and infrastructure at the forefront of many fields.

We are also seeing an increase in the digital humanities and environmental humanities—areas with an interest in spatial science as both a methodological and technical approach, as well as a subject of critical study. Earth, planetary, ecological, and natural scientists have embraced the role of spatial science in the study of the earth as an integrated human–environment system. These researchers use spatial data and approaches to study ocean, land, and atmosphere processes. Finally, much spatial research is performed by information, data, and computer scientists and engineers. This volume gives these researchers an overview of the major challenges and opportunities in spatial science and infrastructure.

While we believe that many different groups of people will find value in this volume, our larger goal is to demonstrate the many ways in which spatial science and infrastructure are integral to many areas of research, teaching, and service. Given the breadth of the examples, however, the volume should speak to those in the private sector, non-profit organizations, and governmental organizations. We hope it will be useful and comprehensible across this range of inquire and practice for years to come.

Minneapolis, MN, USA Steven M. Manson
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Foreword: Envisioning the Spatial University—An Origin Story

I'm grateful to the editors for inviting me to prepare this foreword to *Building the Spatial University*. I especially appreciate that Steve encouraged me to share my personal perspective on the genesis of the "spatial university" concept. Although the narrative roughly follows my haphazard career path, I trust readers will know that the point of the story is how the University of Minnesota's leading example inspired the spatial university vision.

As a graduate student in geography at the University of Wisconsin-Madison during the early 1980s, I worked in the UW Cartography Lab in Old Science Hall. Cartography then would be unrecognizable to cartographers today. We drafted maps and other information graphics with pen and ink, or etched them onto film, then combined hand-made layers into photographic negatives in darkrooms for printing. GIS software products were just beginning to become available on workstation computers, but their utility was limited for the old-school "photomechanical" map-making we practiced.

The most useful computer application for traditional cartographers was the DOS-based World Projections Package coded by University of Minnesota historian and information technology specialist Phillip Voxland. World allowed us to specify map projection parameters for many of the projections catalogued in John P. Snyder's *Map Projections: A Working Manual* and to plot the result to laser printers via the Postscript page description language. Using one of the massive process cameras in the Cart Lab darkroom, we converted plots to film layers that could be overlaid photographically with other map layers.

A couple of years later, a clever grad student at Temple University created a program that converted the printer Postscript produced by World into a format that we could open and edit in Adobe Illustrator, the new PC-based PostScript drawing package. That small innovation would hasten to the evolution of the illustrative cartography into a digital field of practice. Within a decade, that practice would merge with GIS.

As my studies at UW-Madison progressed, I began to think about how, and where, to begin building a career in cartography. At one point I visited our neighbor to the north—the University of Minnesota's Department of Geography—which hosted a Cart Lab much like the one at UW. I recall asking Greg Chu, then-manager of the University of Minnesota Cart Lab, what the job prospects were for a young cartographer in Minneapolis. Greg made a lasting impression when he said that "there's only one good cartography job in the Twin Cities, and I have it!" Meanwhile, the University of Minnesota's Mark Lindberg was in the vanguard of computer cartographers who recognized the potential of PostScript. Within a few years, GIS and digital cartography displaced traditional methods. The University of Minnesota scrapped the Cart Lab's massive process camera—using a giant crane to haul it out of the fourth floor of Blegen Hall.

After graduating from UW-Madison with bachelor's and master's degrees in cartography, I took a job as a cartographer in Penn State's Department of Geography. Cart Lab director Alan MacEachren charged me to help shepherd Penn State through the transition from traditional to digital cartography. Later, I had the opportunity to develop and teach a new undergraduate course called Mapping Our Changing World, which I first taught in 1997. It was the first mapping course to be listed as a General Education course at Penn State—meaning that many students from across campus could count it toward their Social Science General Education breadth requirement.

Leading the way, the University of Minnesota's Phil Gersmehl and colleagues had pioneered a general studies course called The Language of Maps ten years earlier. That course subsequently evolved to an offering entitled "Mapping Our World." As such, it is—to the best of my knowledge—the first and longest-lasting university course to convince a faculty committee that mapping and spatial thinking are a valuable parts of every student's liberal education.

In the late 1990s, I had the unique opportunity to design and build a new Certificate Program in GIS that would be offered entirely online through Penn State's "World Campus." The venture was successful enough that I was invited to propose an online "Master of GIS" degree. Amidst fears about the "commodification of higher education," the notion of an online master's degree in GIS was controversial in those days. To reassure skeptical colleagues, we modeled the new program after the University of Minnesota's existing MGIS degree—even borrowing the same degree title. Although the University of Minnesota program was, and still is, offered on campus and not online, it was still encouraging to know that a respected peer institution saw fit to create a comparable degree. Both programs continue to thrive now, more than 20 years on. Paul Bolstad's *GIS Fundamentals* text is required reading for Penn State MGIS students.

One of the complaints about our MGIS degree program proposal was that it lacked attention to professional ethics, which seemed inconsistent with the fact that we pitched it as a "professional" program. A few years after launching the program, I joined with the University of Minnesota's Professor Francis Harvey, and Oregon State's Dawn Wright, to request funding for a GIS Professional Ethics project from the National Science Foundation. Francis had been active in earlier efforts to formalize an ethics of GIS, and the University of Minnesota's Will Craig was instrumental in publishing a GIS Code of Ethics in 1992. The National Science Foundation (NSF) funded our project, which eventually produced a collection of 16 GIS-related case studies for ethics education. The University of Minnesota led by example yet again.

Will Craig played leading roles in our field as president of URISA—the Urban and Regional Information Systems Association—and of the University Consortium for Geographic Information Science (UCGIS). Bob McMaster also stepped up to co-organize UCGIS' *Research Agenda in GIScience* (2005). Both those leaders helped inspire me to organize the 1st Edition of UCGIS' *Geographic Information Science and Technology Body of Knowledge*, published by the Association of American Geographers in 2006. Bob especially impressed me as someone who could be counted on to finish what he started. Despite having been elevated to a vice provost position at the University of Minnesota, Bob still faithfully attends UCGIS Symposia and is a fellow of the organization.

In 2011, at a crossroads in my life and career, I welcomed Jack Dangermond's invitation to join Esri as "Director of Education." It was primarily a managerial job with frequent outreach appearances at professional meetings and university campuses. A few months after arriving Esri's headquarters in Redlands, California, I was surprised by an invitation to deliver that year's Borchert Lecture at the University of Minnesota. Jack is a distinguished University of Minnesota alumnus, a former student of Professor John Borchert, and was the inaugural Borchert Lecture Series speaker in 2008. "Jack," I announced proudly, "I've been invited to the Borchert Lecture!" "Great," he replied. "Who's speaking?"

I started that visit at the University of Minnesota Duluth, where I saw firsthand the great work that Stacey Stark was doing there; met with administrators, faculty, and students; and gave a talk at the GIS Day event. Later, at the Minneapolis campus, I met with Steve Manson, Will Craig, Bob and Susanna McMaster, Mark Lindberg, Ryan Mattke and colleagues at the Borchert Map Library, and Dan Sward—the GIS specialist in University Services. I was deeply impressed with the geospatial research and applications I saw at the Center for Urban and Regional Affairs, Minnesota Population Center, the Institute on the Environment, and the Polar Geospatial Center, among others. As described in this volume, the University of Minnesota's Office of the Vice President for Research helped establish U-Spatial in 2011. Even in those early days, U-Spatial's potential to foster campus-wide synergies in geospatial research, teaching, learning, and campus operations was plain to see.

I knew the lay of the land, then, when Jack invited me to accompany him to the University of Minnesota the following spring. Esri colleague (and University of Minnesota Geography alumna) Angela Lee joined us. Jack presented a lecture about the implications of "cloud" technology at the Humphrey Institute, and together we visited the College of Design with our host Tom Fisher. Later in the day, Jack and I had an audience with University President Eric Kaler. Jack had said that he wished to offer President Kaler a vision of the leading role that the University was poised to take. Jack seeks out leading organizations in each of Esri's business sectors and expects his industry managers to find ways (other than financial support) to boost their efforts and influence. His favorite metaphor for such organizations was "lighthouses." In the lead up to our visit I'd pondered what a "lighthouse" institution in higher education would look like, and I was convinced that the University of Minnesota could be it. When Jack asked me to share my thoughts with President Kaler, I found myself describing the "spatial university" vision. After returning home to Southern California, I discussed the idea with Esri colleague Tom Baker, who co-authored the blog post that's referenced in this volume.

I promoted the spatial university concept thereafter in my travels to higher education institutions around the country and abroad. A special emphasis was on the select group of American and European universities represented in the Esri Development Center program (EDCs, now called Esri Innovation Centers). Prominent among those was—and still is—the University of Minnesota. Len Kne and Mark Lindberg participated faithfully in EDC annual meetings held in Palm Springs during Esri's Developers Summit. Esri founded the EDC program in 2008 to encourage higher education institutions to incorporate more coding, app building, and IT in their GIS education programs. The University of Minnesota was a role model for progressive education programs even before Eric Shook organized his Cyber Literacy for GIScience project, which provides a rationale and roadmap for modern GIS curricula. Its stature as a "lighthouse" university was affirmed in 2018, when Len Kne, Tom Fisher, Somayeh Dodge, and two students appeared on the "big stage" at the Esri User Conference—the first university to be so featured.

The spatial university concept seemed to evaporate at Esri soon after I retired in 2019. President Kaler was non-committal about it too, though the University's new leadership may yet embrace the vision. In any event, it's gratifying to see how the U-Spatial community continues to embrace—and embody—that vision 10 years on. There's no definitive list of "Spatial Universities," nor is there like to be (UCGIS considered formalizing the designation, but ultimately passed). However, from where I stand, it's true that the University of Minnesota's long and exemplary record of achievement in geospatial research, development, and applications, teaching and learning, and service inspired the concept in the first place.

August 2021 David DiBiase

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- Jessica Hellmann and Jonathan Foley of the Institute on the Environment
- Brian Swanson, an early supporter for and proponent of shared spatial infrastructure

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And, of course, a huge thanks to Jack Dangermond, who has a long relationship with the University. We presented the core ideas of U-Spatial to Jack soon after being funded (more in Chap. 2) and he had a lot of good feedback and advice to offer.

Thanks to the Springer team to their patience as the pandemic put up roadblock after roadblock.

Finally, we also need to thank all our colleagues at U of M for their adoption and diverse use of GISc (whether they realize it or not). The first U-Spatial email list had 87 contacts; today that list is over 1500 people and continues to grow at a rapid pace. We wish we had the space in this book to share all of the stories about our colleague's research, teaching, and outreach. Check out thespatialuniversity.umn.edu, where we do our best to compile and showcase the great work happening across the U of M system.

Contents

Chapter 1
Three Scales of the Spatial University

Steven M. Manson, Francis Harvey, and Brittany Krzyzanowski

Abstract The spatial university foregrounds the spatiotemporal nature of people, places, and processes in meeting its core missions of scholarship, teaching, and service. The university works across scales by advancing macro efforts that capture the imagination of people on and off campus, developing meso themes that translate macro ideas in specific ways, and engaging in microscale efforts on the ground. We contextualize these three scales by examining key facets that define the spatial university: (1) thinking spatially is an approach for transdisciplinary research throughout the institution; (2) spatial thinking is integrated into liberal or general education requirements, just as writing and critical thinking; (3) specialized degrees at the undergraduate and graduate level in geospatial technologies and related fields; (4) service-based learning or community-based service projects or internships that employ Geographic Information Science (GISc) and other geospatial approaches; and (5) GISc is used to run the institutions administrative functions, such as physical plant and classroom management. This chapter frames how the spatial university operates and set the stage for later chapters that delve into service, teaching, research, and what the future holds.

Keywords Spatial university · GISc · GIS · Spatial thinking · Spatial research · Spatial teaching

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1.1 The Spatial University

The spatial university as a generic concept is one in which missions of scholarship, teaching, and service fully engage with the spatiotemporal nature of people, places, and processes. This engagement involves using spatial concepts and approaches to respond and contribute to a fundamental shift in the way people understand the world around them. Throughout this volume, we'll explore how spatial concepts such as place, space, and distance are increasingly central to scholarship and learning across the arts and humanities, the policy realm, design, and the social, natural, and information sciences, sometimes referred to as the spatial turn. Spatial technologies are also important to this work because they offer new forms of representation and understanding. These include Internet mapping, in-vehicle navigation systems, remote sensing, Geographic Information Systems (GIS), and the Global Positioning System (GPS).

It helps to see the University of Minnesota as a spatial university in, not surprisingly, spatial terms. One way to think about the work centered on campus is seeing it happening at three distinct scales:

- Macro "big picture" efforts that capture the imagination
- Meso themes that translate the big picture in specific ways
- Micro efforts that represent the spatial university on the ground

These three scales help us see how the spatial university is tied to many facets of our world. The macroscale captures intellectual currents moving across research domains and situates the university within broad social and environmental phenomena happening from here at home to around the world. The mesoscale is where we live much of the time and where we translate broader ideas, like people using locationally aware services or governments using remotely-sensed imagery, into general fields and concepts like spatial thinking. The microscale instantiates the mesoscale in specific efforts and practices on the ground at the spatial university. Thinking of the three scales of the spatial university helps us conceptualize how, for example, a broad notion like "space matters" becomes a narrower concept like spatial thinking as it applies to learning and then translates into a lab exercise in a foundational GISc course.

Before continuing, two quick notes. First, the University of Minnesota is a big place, and this relatively thin volume simply cannot do justice to more than a fraction of the work that goes on here. The website thespatialuniversity.umn.edu will showcase a growing assortment of compelling research, teaching, and service at the University of Minnesota. Second, through most of this volume, GIS refers to Geographic Information Systems(s), and GISc is short for Geographic Information Science. There are places in the book where authors may intentionally these usages to reflect experience or history. For example, the Master of Geographic Information Science degree is the MGIS, not the MGISc. Additionally, use of GIS as both singular and plural use is fairly common, and exact usage is context-dependent.

1.2 Macroscale: Big Picture of the Spatial University

This volume lays out the big picture of how and why space matters. As Tom Fisher explores in Chap. 6, virtually every discipline at the university has a temporal sense of itself, a history that is almost always part of the required curriculum. But too few disciplines have a spatial sense of themselves: the physical, cultural, environmental, and geographical implications of their work. That gap in our understanding matters since most of our global challenges demand spatial responses: multiple disciplines adapting solutions to the needs of particular cultures, places, and ecosystems. In essence, the spatial university encapsulates ideas, issues, problems, and approaches that mirror those faced by myriad human and environmental systems.

People on campus and beyond experience how spatial data, analysis, visualization, and thinking are transforming our society in myriad ways. People have used maps for hundreds and thousands of years, likely predating the era where we have evidence in the form of clay tablets, wall drawings, or maps incised into the earth and rock. Spatial technology is a vast and growing sector of the economy and a vital social, cultural, and political phenomenon. Billions of people use technologies such as the Global Positioning Systems (GPS), Google Maps, Yelp, and Uber. Governments use mapping to identify crime hotspots, plan social interventions, and identify routes to evacuate vulnerable populations from harm. Companies use spatial analysis to site stores, evaluate supply chains, and determine how much to charge for goods and services. Geospatial technology and spatially influenced forms of big data and other kinds of technology account for over two trillion dollars of economic activity worldwide and can be tied to millions of jobs and hundreds of millions of users.

At and beyond the University of Minnesota, spatial research is rapidly emerging as a key intellectual focus throughout academia. Of particular importance to the University of Minnesota is research under the broader monikers of spatial science, GISc, and geoinformatics, all of which examine spatial technologies to understand people, places, and processes on the earth. GISc is being discovered by a wide array of disciplines as both an integrative approach and research topic in and of itself. The rise of GISc in particular as an academic field is evident in how leading institutions such as Harvard University, University of Pennsylvania, and Brown University created new spatial science centers and programs focused on infusing spatiality into research, teaching, and service.

Key research agencies—National Science Foundation, National Aeronautics and Space Administration, National Institutes of Health, among others—have targeted GISc and cognate fields for dramatically increased funding. Often, these programs are explicitly spatial in focus, but many more are weaving space into calls for research on an incredible and growing range of topics spanning fields as diverse as public health, dance, climate change, and urban inequality. University of Minnesota scholars have won hundreds of millions of dollars in external research grants to support a range of projects with a spatial focus.

Beyond academia, spatial technologies underpin emerging educational and workforce needs. The National Research Council (NRC) identifies GISc as a key approach for K–12 education. Over the last 20 years, there has been remarkable growth in the development and use of spatial technologies along with other developments in instructional technology. The NRC report Learning to Think Spatially emphasizes that GISc is "an integrator and a facilitator for problem-solving across the curriculum. With advances in computing technologies and the increasing availability of spatial data, spatial thinking will play a significant role in the information-based economy of the twenty-first century" (2006).

Throughout this volume, we will see how people from all walks of life—scholars, policymakers, students, workers, citizens—employ ideas and tools that recognize the spatial nature of people, places, and processes. This activity is part of a broader and vital cross-cutting project to use spatiality to identify the connections within and among the various challenges and possibilities facing humans and the environment. Spatial approaches are useful because they allow us to engage with parts of the world that we can see and experience along with many parts we cannot, such as the bus we are tracking on our phone or the outbreak of disease elsewhere on the earth.

1.3 Mesoscale: Translating the Macroscale Big Picture to Specific Themes

In terms of describing how to translate the big picture to something on the ground, it is helpful to consider mesoscale characteristics of spatial science or, in other words, particular themes in how spatiality matters on campus and beyond. ESRI's Tom Baker and David DiBiase capture several themes for what would make a spatial university in their piece "Envisioning the Spatial University" (2012). They develop an argument for the timeliness of the spatial university:

> Spatial thinking and geospatial technologies remain unrealized opportunities for much of higher education. For example: There's now compelling evidence suggesting that spatial abilities prepare students for success in STEM coursework and early employment. However, no college or university includes such preparation among its overarching general education objectives. Despite the synthetic power of the spatial perspective, research discoveries too often remain segregated and hidden in disciplinary silos. For nearly a decade, the US Department of Labor has highlighted career opportunities associated with geospatial technologies. Still, relatively few higher education institutions offer advanced, practice-oriented educational programs to prepare students for such opportunities. Geospatial technologies enable students to perform valued service learning projects in their communities. Even among those colleges and universities that have institution-wide service learning programs, however, precious few prepare students to leverage GIS. Enterprise GIS infrastructures offer the potential to save money in campus planning, operations, and facilities management. Given the severe fiscal challenges that confront most higher education institutions, it's remarkable that so few institutions have realized this potential. There are plenty of reasons why spatial thinking and geospatial technologies have yet to fulfill their transformative

potential in higher education. However, it's likely that concerted efforts by a few key institutions could have a dramatic impact.

Others were writing about the spatial university around this time as well. One year later, Francis Harvey with others wrote an article on U-Spatial, the University of Minnesota's spatial science infrastructure, that explicitly references the touchstone idea of the spatial university (2013). Harvey describes how it "is increasingly apparent to many within academia and beyond that spatial thinking, technologies, systems, and services matter" (p. 11). In terms of research, the concepts of space, place, and spatiality are increasingly central to many kinds of scholarly inquiry. He notes how spatial science runs through many parts of the undergraduate and graduate curriculum at the University of Minnesota alongside various other kinds of instruction, including short courses and daylong introductions to various kinds of spatial science. In terms of service, spatial systems are "essential to community-based service-learning projects and internships in ways ranging from learning to use GIS software to track home foreclosure to helping develop web mapping applications. The concept of service to the immediate university community is also seen in how enterprise GIS helps universities be effective managers of public resources required for operations, facilities, and planning" (p. 13).

Beyond the University of Minnesota, other conversations around the spatial university were occurring. University of California Santa Barbara held a Spatial Thinking Across the College Curriculum Specialist meeting in 2012, providing an additional framework on what it means to be a spatial university (Janelle et al., 2014). There were also sessions at the American Association of Geographers for several years running on topics related to the spatial university. The UCGIS held a seminar on "The How and Why of Spatial Universities" in December 2014, focusing on visions of what could constitute a spatial university. Across these venues, there was some interest in trying to anoint (or propel!) some institutions as spatial universities, but the idea faded over time as unworkable. David DiBiase, in his foreword to this volume, traces some parallel currents.

As a generic concept, "the spatial university" is one in which missions of scholarship, teaching, and service fully engage with the spatiotemporal nature of people, places, and processes. In this volume, we adopt an open posture toward the spatial university as an idea and a specific term. The University of Minnesota exemplifies the spatial university concept as outlined in many discussions throughout the past decade. It is arguably the first "spatial university" in the sense of being recognized as such in a range of venues, and it's a mantle we happily wear. However, in keeping with the tenor of many early conversations around the spatial university concept, choosing a subset of institutions to be anointed as a spatial university seems unnecessarily divisive. It also seems fundamentally difficult to establish who would make these distinctions among institutions and/or decide along what dimensions they would be measured. More importantly, we deeply believe that there should be many spatial universities, and as such, there is no point in claiming to be the singular spatial university beyond the occasional rhetorical flourish (e.g., we maintain thespatialuniversity.umn.edu to highlight spatial research, teaching, and service). In this spirit, the general term “a spatial university” is used throughout this volume with the occasional nod toward “the spatial university” as a platonic ideal.

As evinced by many examples throughout this volume, the University of Minnesota has long been home to research and learning in spatial science. Hundreds of faculties have spatial themes as the core of their research, teaching, or outreach. Several hundred more are interested in using spatial approaches, and they are joined by a wide array of students and staff on campus. Spatial science is integral to the university meeting its many missions because it can measure and model complex information on complex social and environmental phenomena.

Service has always been central to this mission. A notable example is how, in the 1950s and 1960s, the University of Minnesota helped create one of the first Geographic Information Systems, the Minnesota Land Management Information System. To this early success, we can add many of the other service-oriented examples that will be described in Chap. 3. As we will see throughout his volume, even the most basic tools such as mapping or viewing remotely-sensed imagery on a screen can allow us to appreciate basic spatial relationships and highlight features of interest on things we can see alongside things that cannot be directly observed, even if one were standing on the mapped location. We see this in, for example, how the Minnesota Geological Survey collects data and makes maps that make visible to citizens, students, firms, and government phenomena that would otherwise be almost invisible, such as mineral deposits below the ground.

Teaching is a core mission of the university. Chapter 4 lays out how educational activities at the University of Minnesota are arrayed along a deep and broad continuum. They range from daylong GISc short courses run by U-Spatial to over seventy courses in GISc or related topics that contribute to two undergraduate, three masters, and several doctoral programs. The Master of GISc was one of the first professional degrees in GISc and is broadly recognized as one of the best programs in the nation. Similarly, there is a long history of examining the relationships between spatial technologies and society, including the study of ethical, legal, political, and public dimensions. We see continued innovation in the form of Massive Open Online Courses (MOOCs) on spatial computing, broad adoption of Web-based mapping and StoryMaps, and development of open educational resources.

In terms of research, spatiality runs through the work of hundreds of scholars across the five-campus system. As noted in Chap. 5, one of the leading open-source Web-mapping applications, MapServer, was developed here in the 1990s, highlighting our growing strength in computational and technological work in what has become diverse and mutually supporting facets of the spatial enterprise, including Geodesign, Geographic Information Science, Spatial Computing, Spatial Big Data, among others. U-Spatial and other groups on campus have also trained over a thousand researchers on campus and partnered with scholars in every single large research unit on campus, from the School of Public Health to the College of Food, Agricultural, and Natural Resource Sciences to University Extension. It has also forged strong ties with central units including Libraries, Office of Information Technology, and U Services, which provide support for physical plant and facilities.

1.4 Microscale: Specifics of the Spatial University

In moving from the big picture through to mesoscale themes of spatiality, we arrive at specific features of the spatial university. These are the on-the-ground people, places, and programs that come together to create a spatial university. Baker and DiBiase (2012) offer five key criteria that define the spatial university: (1) thinking spatially is an approach for transdisciplinary research throughout the institution; (2) spatial thinking is integrated into liberal or general education requirements, just as writing and critical thinking; (3) specialized degrees at the undergraduate and graduate level in geospatial technologies and related fields; (4) service-based learning or community-based service projects or internships that employ GIS and other geospatial approaches; and (5) GIS is used to run the institution's administrative functions, such as physical plant and classroom management. As an organizing framework, we can borrow from Baker and DiBiase. They note that "some higher education institutions have several of these characteristics, and a few may have all five. However, no institution has made a point of declaring its commitment to fulfilling the potential of spatial thinking and geospatial technology. This is likely a missed opportunity. In an increasingly competitive higher education marketplace, we believe that a commitment to be a spatial university would be a valuable differentiator."

The institution hosts and disseminates multidisciplinary and interdisciplinary research enabled by the spatial perspective and geospatial technologies.

The University of Minnesota clearly engages in a broad array of research that drives, and is driven by, spatial concepts and thinking. Chapter 5 describes many kinds of spatial research on campus, but it only scratches the surface as well over a thousand faculty, students, and staff engaged in spatial research at the University of Minnesota. They combine spatial approaches with spatiotemporal data gleaned from maps, satellites, smartphones, sensor networks, UAV-based cameras, and social media. They help commuters to minimize travel time, farmers to best plant and protect crops, epidemiologists to identify emerging disease hotspots, emergency planners to develop smarter evacuation routes, policymakers to visualize spatiotemporal climate-change scenarios, and first responders to use high-resolution imagery to map areas of need. These are just a few of the many high-impact and relevant spatial topics being pursued on campus.

Spatial thinking is included in the institution's general education objectives. Courses that prepare students to fulfill the objective are available across the general education curriculum.

As described in Chap. 4, spatial thinking is embedded in the curriculum. Many courses on campus highlight spatial thinking as playing a significant role in the Technology and Society theme general education requirement at the University of Minnesota. Faculty have shared their syllabi across departments and colleges in order to encourage greater recognition of spatial thinking as an important part of the liberal arts requirements. There is also much work around developing a full continuum of pedagogically useful tools, such as StoryMaps and Web-based GIS, that enable students and instructors to embrace spatial thinking via the Technology and

Society theme. To this end, U-Spatial, the Libraries, and other units on campus have helped spur broader adoption of accessible spatial tools like Web mapping along with efforts like sharing material across foundational GISc courses. Faculty and staff also worked with the Office of Information Technology to roll out virtual machines or make software packages common goods so that students, staff, faculty, and department are not stymied by cost or access to high-end lab machines.

The institution hosts specialized certificate or degree programs whose curricula align with geospatial workforce needs.

Chapter 4 dives into how the University of Minnesota offers many pathways to spatial education. U-Spatial offers one-day GISc courses that complement a wide array of standard offerings, including over 70 spatial courses that contribute to BA/BS in several units, the undergraduate GISc minor, Master of GISc, graduate GISc minor, and several PhD programs. While this range of courses and degrees offers students a good deal of choice, the decentralized nature of the university means that faculty interested in teaching GISc must work together to reduce replication, increase coverage, and drive more students to extant offerings in addition to help develop new ones. A case in point is the large number of introductory GISc courses; while there will always be a need for discipline-specific GISc classes, departments could probably better coordinate among themselves to reduce overlap and ensure common material to better track into advanced courses.

Students are required or at least encouraged to participate in community-based service-learning projects or internships, and they are prepared to use GIS and other geospatial technologies as part of those projects.

Every chapter in this volume touches on the various ways that University of Minnesota students participate in service projects or internships with a spatial focus. We have a strong start in community-based service-learning projects or internships in the form of project-based courses and community learning courses in CFANS, CLA, CDES, and HHH. The Center for Urban and Regional Affairs (CURA), described in Chap. 5, has long had a service-oriented mission that runs in parallel with learning opportunities for students. The Community GIS (CGIS) Program Director offers a course where up to a dozen students take on a service-learning experience tied to CURA's portfolio. More broadly, many students in undergraduate and graduate GISc programs partake in service-learning programs as part of their coursework. Despite this interest, one challenge is that these courses tend to be offered only semi-regularly, pointing to the room to grow and for the potential for greater coordination across colleges to ensure more uniform opportunities.

An enterprise GIS infrastructure is in place to support campus planning, operations, maintenance, and sustainability.

As detailed by Chap. 3, U-Spatial and U-Services' Enterprise GIS together form a strong university-based GIS infrastructure. While it has a strong sustainability plan, the University of Minnesota will need to commit to the long-term support of GIS infrastructure in order to claim to be a spatial university. In the longer term, U-Spatial is positioned to be this central, go-to place for spatial services, but for now, it is resourced to serve in a background or support role. As explored in Chap. 2, there is potential for U-Spatial to be much more visible and proactive and engage with tireless champions who understand the broader vision of U-Spatial's role. The university must continue, and ideally grow, its support for the vitally important spatially-infused services, training, and outreach.

The chapters in this volume explore these and other ideas as part of what it means to be a spatial university. The following chapters will show why spatial knowledge has value in helping us understand our fields—and the world—in new ways and help us reconsider the spatial distribution of disciplines at universities. The diversity of perspectives about spatiality and the range of its applications show the breadth and depth of the impact GISc, geospatial approaches, and spatial computing have already had on universities like the University of Minnesota. While on one hand GIS is just a tool and only as powerful as the skill of the people using it, on the other hand, GIS brings to mind Marshall McLuhan's observation that the medium is the message. Spatial computing represents a change that will have potential long-term impacts as profound as the printed book.

Myriad examples examined through this volume will forcefully demonstrate how spatiality is a way of knowing and changing the world. Chapter 2 offers a comprehensive look at U-Spatial (the University of Minnesota's spatial science infrastructure) as set against the background of the growth in spatial and computing infrastructure more generally. Chapter 3 examines how the concept of a spatial university manifests in spatial infrastructure that helps the non-research and nonteaching missions of a large university, such as development, facilities, and outreach. Chapter 4 looks at the importance of spatial thinking in teaching and learning, including teaching-oriented examples and how spatial infrastructure enhances student success. Chapter 5 dives into spatial science and research by describing the rapid growth of spatial science and approaches and their importance to a broad array of research domains and illustrates their use with an array of examples. Chapter 6 distills the takeaway messages around the larger discourse of the spatial university and discusses future challenges and opportunities for institutional spatial science infrastructure.

1.5 Conclusion

Given how spatiality has been an active part of human ingenuity for thousands of years and has seen such sweeping changes over the past century, it is hard to predict what the future holds for the idea of the spatial university in general and how the University of Minnesota in particular is seen as a spatial university. We can appreciate how the maps we use today reflect a blend of art and science dating back centuries (e.g., projection systems or color and symbol conventions). At the same time, spatial practices and concepts drive and are driven by larger shifts in society and technology. The students learning the fundamentals of cartography are not using the pen-and-ink that many of their instructors learned in the 1980s and 1990s, but they inherit some of the lessons of that approach while also reaping the benefits of advances in Geographic Information Science and cognate fields, like data science and virtual reality. The spatial university has a special responsibility and duty to treat spatial service, teaching, and research as a fusion of society and technology. Of course, the spatial university also offers many new opportunities for engagement, scholarship, and quality instruction.

References

Baker, T., & DiBiase, D. (2012). Envisioning the spatial university. *Esri Insider*. https://www.esri.com/about/newsroom/insider/envisioning-the-spatial-university/. Accessed 1 Jan 2018.

Harvey, F., Kne, L., & Manson, S. (2013). U-Spatial: A consortium for the spatial university. *Arc News, 34*, 1–6.

Janelle, D. G., Hegarty, M., & Newcombe, N. S. (2014). Spatial thinking across the college curriculum: A report on a specialist meeting. *Spatial Cognition & Computation, 14*(2), 124–141.

National Research Council. (2006). *Learning to think spatially*. The National Academies Press.

Chapter 2
U-Spatial: Nexus of the Spatial University

Len Kne, Steven M. Manson, Stacey Stark, and Kate Carlson

Abstract U-Spatial is the spatial science infrastructure that is integral to making the University of Minnesota a spatial university. At its core is a team of geospatial professionals who advance the mission of the modern land grant university and operate a new kind of infrastructure that encompasses people, places, and tools. It took over a decade to secure the initial support and funding through an Infrastructure Investment Initiative grant, which pulled together departments, colleges, and units from across the university to provide matching funds and expertise. Now after 10 years, U-Spatial operates on a mix of central funding and increasingly, revenue through consulting and sponsored research to fund common good services like a help desk, training opportunities, proposal writing, server hosting, and events to build community. U-Spatial supports the research of hundreds of students, faculty, and staff in every college and center across multiple system campuses and provides a template for integrating spatial thinking into the mission of a large and diverse university.

Keywords Spatial data infrastructure · Research support · Spatial thinking · Research funding · Collaboration · Training

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2.1 Introduction

U-Spatial is the spatial science infrastructure that is integral to making the University of Minnesota a spatial university. At its core, U-Spatial is a nimble team of geospatial professionals creating a vibrant and robust framework that fulfills its mission to both serve and drive the fast-growing need across the university for expertise, data, and tools related to Geographic Information Science, remote sensing, and spatial computing. It is not a center or a department—both terms have specific definitions within the university and higher education in general—nor does U-Spatial have a defined research agenda; instead, it focuses on collaborating with colleagues from across the institution. U-Spatial is an infrastructure meant in the broad sense of people, places, and tools: we like to call it a network or sometimes even more inspirationally—a movement—that has an impact far greater than its relatively small footprint and budget.

A decade after U-Spatial was launched, its mission remains the same as at the beginning. However, how the unit is structured and operated is very different from when it was conceived. In broad strokes, U-Spatial:

- Supports millions of dollars of sponsored research
- Partners with every college and center throughout the university
- Helps meet grand research and teaching challenges
- Creates synergies and research efficiencies
- Helped create the first broadly recognized spatial university
- Serves as a model for other centers sprouting up around the world

This chapter discusses the development of U-Spatial as a catalyst for a range of spatial activities across the university that in many cases extend back decades. Campus-wide Geographic Information Science (GISc) centers are becoming more common at large research universities and take many forms. The centers vary in organization and focus, but their primary mission is a support role for research, teaching, and outreach. To build a spatial university, having a center whose mission is to promote spatial thinking throughout the institution is crucial. This doesn't mean that that center will do everything on its own, but rather, it works as a catalyst to enable units scattered throughout the institution to do amazing work. And while this center can be created via a grassroots approach, the support of university administration is needed to realize the full value of being a spatial university.

2.2 Building U-Spatial

U-Spatial was founded in 2011 to meet the need for efficient and professional spatial infrastructure to support the breadth and depth of research at the university. This infrastructure did not just come into being overnight but instead built on several years of coordinated activity around spatial research, teaching, and service. As a unit working across campuses, the history of building U-Spatial demonstrates what is possible when a university prioritizes spatial thinking as a valued resource to meet its mission. While we collaborate closely with large research centers and programs, U-Spatial purposely seeks to serve researchers working in the so-called long tail of the scientific enterprise. Collaboration is often in the form of smaller or pilot projects for units that cannot support full-time spatial research staff but who can leverage U-Spatial expertise. U-Spatial offers critical support that advances the many missions of a land grant university and offers disproportionately great benefits.

2.2.1 Geospatial Consortium (2006–2010)

The Geospatial Consortium arose out of a need for better communication and collaboration among groups of colleagues in planning and implementing geospatial activities. In the mid-2000s, faculty and staff from several colleges at the University of Minnesota Twin Cities campus began to meet informally to address nuts-and-bolts issues such as software licensing and developing shared data resources that affected students, faculty, and staff. These groups eventually came together to form an informal Geospatial Consortium as a way to compliment disparate and ongoing conversations around spatial science.

The Geospatial Consortium met every semester to share information and discuss concrete steps to improve GISc on campus, such as focusing on getting Geographic Information Systems (GIS) software into more computer labs and departments. There was also a focus on making and maintaining informal ties among different people through activities such as GIS Day or hosting events such as a Geoinformatics Symposium and a GIScience speaker series supported by the Office of the Vice President for Research (OVPR). Consortium efforts focused on topics ranging from how to get better deals on software licenses, sharing teaching materials, and the occasional informal brown-bag workshop on research. The consortium leveraged the long history of GIScience at the university (Chap. 3 provides a further history of geospatial activities at the university, and other examples are found throughout the book). The consortium for several years produced an annual report to which anyone could contribute. As part of the effort around writing these reports, faculty and staff of the consortium canvassed a range of people and centers around campus to offer a snapshot of geospatial activity.

One consistent message from the feedback gathered by the consortium was the need for a more structured and reliable form of GIS infrastructure and support on campus. Attendant conversations on what this support would look like soon converged on how there seemed to be two ways forward in developing spatial infrastructure. The first approach focused on the most established and common form of spatial infrastructure in the United States, namely, delivering spatial data and some analytical capability via the Internet. This was commonly termed spatial data infrastructure (SDI). While originating in data delivery, a growing number of SDI efforts focused on providing limited analytical capacity to expert users in addition to data access as such. Geospatial repositories and geoportals were introduced in the 1990s, and they are now a mature fixture in the spatial science landscape. Spatial data infrastructure contains large volumes of data and recently has started to enable researchers to do analysis, but users must be experts in both their research domain and the intricacies of the technology, which dramatically limits the number of people who can use this infrastructure (Dangermond & Goodchild, 2020).

U-Spatial exemplifies a second approach to spatial infrastructure, one that seeks to address some of the potential shortcomings of more traditional and centralized SDI. U-Spatial is a holistic approach to spatial support infrastructure that combines data, methods, and people to support research, education, and service/outreach. The key innovation of this approach to spatial infrastructure is that it helps the entire range of potential users, from students and scholars who have little computational knowledge to researchers on the leading edge of spatial computation and domain research.

2.2.2 U-Spatial (2011–2015)

Conversations within the Geospatial Consortium about the future of spatial infrastructure on campus converged at a fortuitous time. The Office of Vice President for Research (OVPR) at the University of Minnesota launched the Infrastructure Investment Initiative (I3) in 2010. This grant program was one of the largest of its kind at the university, offering grants in the hundreds of thousands of dollars to create infrastructure that was traditionally difficult to procure through standard federal and state funding programs. The momentum, vision, and support of faculty for the Geospatial Consortium for spatial infrastructure positioned professors Francis Harvey and Steve Manson to bring together a wide array of staff and faculty to seek funding from I3 to create a network to support spatial research activities. The project titled "U-Spatial: Spatial Sciences and Systems Infrastructure" brought together over a dozen college-sized units on campus to develop a common vision for spatial infrastructure.

U-Spatial was funded in 2011 with a $2.5 million I3 grant, and Dr. Harvey was its first director. With the tireless support and leadership of Frances Lawrenz, Associate Vice President for Research, the I3 program was designed to provide investment capital to enhance research competitiveness, transdisciplinary research, and respond to areas of greatest need. As such, U-Spatial was initially conceived as a network to support spatial research activities. Most of the I3 grants went to fund what many people think of as traditional infrastructure, such as large equipment or technology investments like labs or expensive imaging equipment. In contrast, U-Spatial deliberately proposed an alternative kind of infrastructure, one that focuses on centralizing staff expertise, transdisciplinary research, and cost savings through efficiency.

The Geospatial Consortium provided the foundation for a successful I3 grant proposal because it provided an established community of faculty, staff, and students interested in spatial infrastructure. The proposal brought together over a dozen colleges, departments, and centers committed to the creation of U-Spatial by providing staff and matching funds (Table 2.1). These partners represent much of the breadth of geospatial expertise across the university and include not only academic units but also the Libraries, Office of Information Technology, and Facilities Management (more on these units in Chap. 3). Several years into the grant, it became clear that the omission of faculty from all system campuses was an oversight in the original proposal. All of the founding participants were from the Twin Cities campus, but spatial research and activities were certainly happening throughout other campuses. This occasioned greater outreach to all campuses in the university system.

The original U-Spatial proposal created four infrastructure cores (thematic areas) housed within multiple nodes across the university (Fig. 2.1). The cores include (1) Central Core, which provided services including technical assistance, training, resource coordination, and development of the spatial science community; (2) Imaging Core infrastructure, which focused on data and analysis of aerial and satellite imagery of the earth; (3) Data Core initiatives, which included the development of data discovery and archiving tools as well as shared computing infrastructure; and (4) the Analysis Core, which applied on spatiotemporal modeling, geodesign, and mapping (Harvey et al., 2013). The cores were in part a construct to manage the U-Spatial budget and identify key forms of infrastructure, and in reality, there was much cross-pollination among all of the cores.

The I3 grant provided incentive for participation by units by providing a two-for-one match. While the participating units had to provide matching funds, their investment was roughly doubled and designed to create sustainable infrastructure. In other words, the university grant offered two-thirds of the total amount, and individual units and colleges offered one-third. As part of developing an integrated proposal, units could propose vital infrastructure that helped meet their internal needs,

Table 2.1 Founding members of U-Spatial with their core specialty and match funds

Unit	Core	Match
College of Design	Analysis	$25,000
College of Food, Agricultural, and Natural Resource Sciences	Imagery and analysis	$280,000
College of Liberal Arts	Analysis	$75,000
College of Science and Engineering	Data	$90,000
Extension Service	Analysis	$25,000
Hubert H. Humphrey School of Public Affairs	Analysis	$50,000
School of Public Health	Analysis	$50,000
Enterprise GIS	Data	$62,500
Office of Information Technology	Data	In kind
University of Minnesota Libraries	Data	$60,000
Center for Urban and Regional Affairs	Analysis	$75,000
Institute on the Environment	Analysis	$165,000
Minnesota Population Center	Data and analysis	$160,000

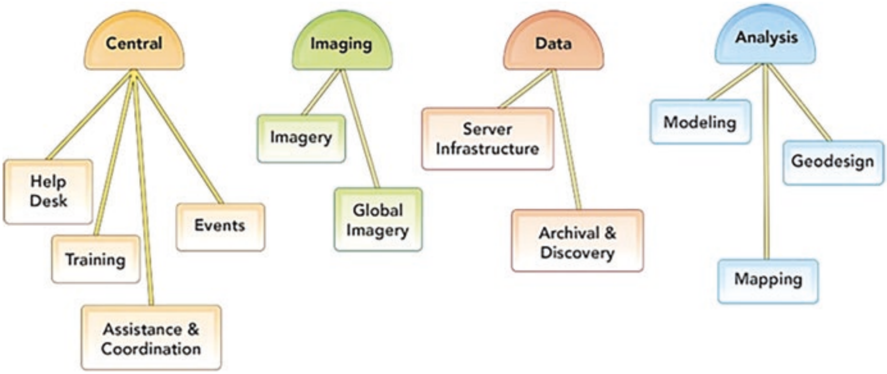

Fig. 2.1 U-Spatial cores (Harvey et al., 2013 courtesy of Esri)

but the infrastructure had to be available to all users of U-Spatial via the Data, Imagery, and Analysis Cores. In addition, about one-third of the funds was used to provide system-wide support services through the Central Core. The Central Core further benefited participating units because they could send colleagues to a new help desk instead of providing ad hoc support that was really not part of their primary mission. Since its inception, U-Spatial has had an Advisory Committee with a membership consisting of faculty first from the founding units and now from across a wide range of disciplines who commit to a 2-year term. The committee meets twice a year to provide strategic direction and oversight.

2.2.3 From Start-Up to Critical Infrastructure (2016–Present)

As U-Spatial reached the end of the original 5-year funding, then-Director Steve Manson joined Tom Fisher and Len Kne in looking for a new funding model. U-Spatial was a large and successful project, but with the grant coming to an end, it was clear that it was very inefficient and even unrealistic to expect for individual units to pool year-to-year commitments to ensure continuity over time. Some base amount of consistent central funding was necessary to continue the common good services that students, faculty, and staff across the university had come to rely on. It was time to see if U-Spatial had shown the value of creating a centralized infrastructure for supporting spatial thinking across the organization.

The new home for U-Spatial would be Research Computing, thanks to the vision of Claudia Neuhauser who at the time was the director. Research Computing is a unit within the Office of the Vice President for Research and includes the Minnesota Supercomputing Institute (MSI) and University of Minnesota Informatics Institute (UMII). Neuhauser, with varied interests in mathematical biology, spatial ecology, and informatics, understood and supported the value U-Spatial was providing to the university and added U-Spatial to Research Computing. Research Computing offered U-Spatial a base level of funding of $330,000 per year, which allowed it to continue work without interruption. At this time, U-Spatial moved from being faculty-led to having a director (Kne) who is a nonfaculty professional and administrative staff. This is in line with the support focus of U-Spatial and other units within Research Computing. Manson happily stepped down as a cofounder and director, and he continues to actively lead U-Spatial as a member of the Advisory Committee.

While all three units in Research Computing—MSI, UMII, and U-Spatial—share the common goal of advancing research at the university, there was at first limited collaboration among them. This situation changed in 2018 with a reorganization of Research Computing leadership when Neuhauser left the university. Instead of appointing a new director for Research Computing, management was shared among the leaders of the three units. This arrangement made clear the synergy across the units and created an environment of collaboration that is still strong today. Later in 2018, James Wilgenbusch was promoted to the director of Research Computing.

In 2019, U-Spatial merged with the Geospatial Analysis Center on the Duluth campus to create true multicampus support. The Geospatial Analysis Center (GAC) was established by Stacey Stark in 2012 in the College of Liberal Arts but can trace its origin to the Geographic Information Science Lab, founded in 2002. The GAC promoted and facilitated the sustainable integration of geospatial tools and perspectives into teaching, research, service, and operational activities. From its base on the Duluth campus, GAC worked with faculty in all five colleges on the Duluth campus and provided excellent undergraduate experiences for GISc students. GAC had a decade-long record of external contract work with state agencies, counties, and regional organizations, including service as a technical resource center for the Minnesota Homeland Security and Emergency Management Division.

Kne and Stark realized that merging the centers would take advantage of a larger pool of expertise and efficiencies, knowing that the merger would strengthen opportunities for faculty to enhance research by supporting a spatial component (often for the first time). This would result in an increase in the number and size of grants awarded and enhance research excellence across the university. The merger also advanced transdisciplinary partnerships by encouraging spatial thinking and providing spatial support. It is still rare for a unit to cross campus divides at the university, but U-Spatial is a trailblazer given the transdisciplinary nature of GIS. There were certainly challenges combining finances, multiple-campus communications, and even some amount of campus rivalry related to the level of funding.

We kicked off the new U-Spatial with a 2-day retreat to create a strategic plan and bring the staff together. There were efficiencies to be gained by sharing administrative functions like using a common file sharing system and Google Drive, as well as reducing the duplication of infrastructure, for example, having one ArcGIS License Server for the university. By far, the biggest gain with the merger was the immediate doubling of staff. Before the merger, each unit had one developer working on Web-mapping applications, Pete Wiringa on the Twin Cities campus and Steve Graham at Duluth. We can now put multiple staff on projects, complementing each other with their varying skill sets to more than double our capacity to build custom applications. Projects now make use of staff from both locations based on expertise and availability. For example, a small project developing a geodesign interface for conserving properties in Hennepin County included from Duluth a developer (Graham), GIS Specialist (Zach Vavra) to work on the Web map interface, and a research assistant from Twin Cities (Roopana Vuppalapati Chenchu) to create the database and API to drive the map. It's more fun and rewarding to collaborate with colleagues who can challenge and teach each other new skills. This same synergy happened with workshops and training, as well as marketing and project development.

2.2.4 Structure and Networks of Collaboration

U-Spatial relies on several different kinds of staffing and a mix of collaborations. In the early years, staffing needs were primarily filled with graduate research assistants. While these students remain a key staffing component, U-Spatial is moving toward hiring a greater proportion of full-time researchers to ensure a certain staffing level and continuity of expertise. In addition to in-house staff, U-Spatial leverages the expertise of a network of faculty and staff from across the university. These relationships give U-Spatial a larger impact than might be expected from a relatively lean unit composed of nine staff and up to five part-time student assistants. While the mix of staffing has changed over time, these three key components—students, staff, and faculty—are all important to the smooth functioning of U-Spatial.

U-Spatial has been home to many graduate and undergraduate student workers since its founding. We are fortunate to have a Master of Geospatial Information Science program at the Twin Cities campus, which provides a strong pool of RA candidates. This body of students is integral to our spatial infrastructure because they serve on many projects. Since 2011, U-Spatial has hired over 50 undergraduate and graduate research assistants. These positions allow students to gain skills and experience while helping others. Students are involved in the entire life cycle of many projects, including defining the project scope, data collection and procurement, data management, analysis, and reporting. Several students were coauthors on journal articles or cartographic credit for maps they created. Students are challenged to learn development languages including Python, JavaScript, HTML, CSS, Java, and SQL. When interested, students also take on server administration, with Esri ArcGIS Server, Postgres, MapServer, and GeoServer. On graduation, many students have stated that they learned more working at U-Spatial than in their coursework. Of course, U-Spatial staff and the colleagues have in turn learned a great deal from the student employees. While RAs allow us to quickly respond to varying project demands, there were instances when multiple RAs graduate (as they should!) at the same time, creating challenges with having enough trained staff to meet our commitments. There are financial considerations as well since graduate RAs, with their tuition benefit, are often more costly than the salary of a comparable full-time staff person. That said, we are committed to always having graduate and undergraduate research assistants in U-Spatial as it is part of our teaching mission and to meet the peaks of demand with projects.

Nearly all of the U-Spatial staff positions fall into the university research job classifications. While we provide technology expertise and support teaching and learning, we do so through the lens of research and discovery. After all, we are a part of the Office of Vice President for Research. While U-Spatial staff are primarily geospatial specialists with master's degrees and predominantly come from outside the higher education sector, they have all received training on best practices for implementing research methodology. We rely on the domain expertise of researchers we are working with to ensure standards are met for the project's area of interest. We have found this works well when supporting projects from public health to agriculture to digital humanities, and we regularly pull in the expertise of faculty and researchers from across the university. It is worth noting that many U-Spatial staff are adjunct faculty in the MGIS and public health programs.

Our collaboration network includes a diverse range of expertise and resources from across the university. The network includes the founding partners noted above along with several other units that are more recent collaborators with the support of geospatial research. Table 2.2 outlines the contributions of many of the units we discuss in further detail throughout this book. This is not an exhaustive list because expertise is found throughout the university. Some provide supporting technologies like managing lab computers (with GIS software), as well as server and data infrastructure. Others assist in the discovery of data and resources, while others advance knowledge on geospatial science, remote sensing, and geospatial computing. In return, in collaboration with University Services (discussed more in Chap. 3), U-Spatial provides server resources to researchers and units across the university. These include geospatial services to allow the visualization and sharing of spatial data, as well as database servers to store large spatial datasets. It is far more efficient for U-Spatial to operate these servers than individual research projects creating their own resources. We currently host data for units such as the Libraries, Minnesota Geological Survey, Geology at University of Minnesota Duluth, Humphrey School of Public Affairs, and many more as described in later chapters. In sum, it takes widespread collaboration to break down the silos in academia and to build the spatial university.

2.2.5 Funding

The U-Spatial annual budget is approaching one million dollars, compared to about half of that in 2011. As described above, the original funding was from the I3 grant, which was a mix of central university support from OVPR and matching contributions from colleges and other units. The current mix of funding is more diversified although centralized research support offers a strong foundation for U-Spatial to respond to the many opportunities and provide benefits to people throughout the

Table 2.2 The U-Spatial collaboration network

Unit	Focus
U-Spatial	Help desk, workshops, badges, consulting, events, ArcGIS Online administration, StoryMaps, licensing (e.g., Planet, LAStools, Erdas), classroom geospatial support, and overall geospatial vision through an Advisory Committee
Borchert Map Library	Data discovery, archiving/preservation, BTAA Geoportal, StoryMaps, and consulting
Digital, Arts, Science, and Humanities (DASH)	Outreach to digital humanities scholars
Liberal Arts Technology Information Services (LATIS)	StoryMaps, classroom geospatial support, and Web hosting
Enterprise GIS	Administration support, facilities management, server hosting, and database hosting
Office of Information Technology	Purchase Esri site license, operate public computer labs, desktop support, VM provisioning, and data storage
Minnesota Supercomputing Institute	High-capacity computing, data storage, and consulting
Department of Computer Science	Spatial database design, machine learning, and AI
Polar Geospatial Center	Remote sensing expertise and access to satellite imagery
Remote Sensing Geospatial Analysis Lab	Remote sensing expertise and drones
Minnesota Population Center	Census, population data, and school district boundaries
Center for Urban and Regional Affairs	Community GIS and PPGIS
Spatial Innovation Lab (SIL)	GIScience and methods
Minnesota Design Center	Geodesign and stakeholder engagement

system. As a result, with a commitment of a consistent level of central funding from university administration, U-Spatial provides important research infrastructure. The Infrastructure Investment Initiative that primarily funded U-Spatial during the first 5 years was the catalyst for an expansion of spatial scholarships at the university. A well-funded initiative sparks collaboration that can lead to long-term energy around geospatial technology.

Central University Support U-Spatial is currently funded with a $330,000 allocation through OVPR by virtue of being part of Research Computing. These funds cover just over a third of the budget (Fig. 2.2) and are a combination of generic university funds and those from MnDRIVE, a legislative program that funds research in areas like robotics, global food, and environment (all areas in which U-Spatial plays a prominent role). Central support flows to U-Spatial because we demonstrate the value of spatial infrastructure to the university research community and beyond. Of course, U-Spatial is always broadening the range of activities that

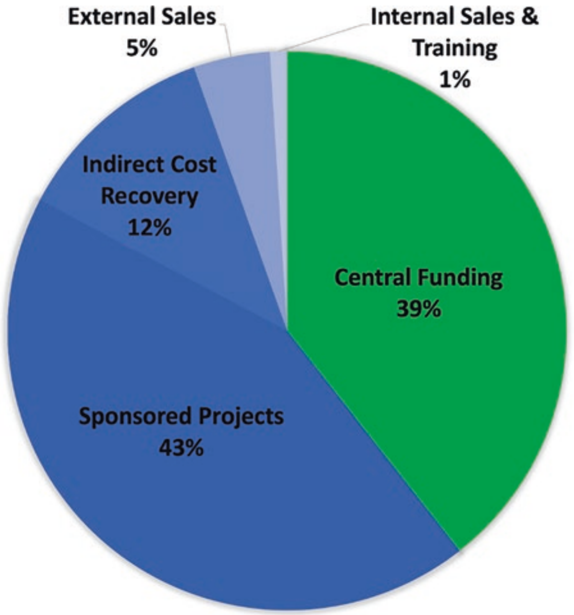

Fig. 2.2 U-Spatial revenue by source (Kne, 2021)

could use more central funding. One example detailed more in Chap. 4 is supporting the great demand for the use of ArcGIS StoryMaps in the classroom. We would ideally have two to three staff dedicated to this need as opposed to the ad hoc support we pull together with staff from U-Spatial, the Libraries, and College of Liberal Arts. Finally, it is important to acknowledge that U-Spatial, by virtue of being part of Research Computing, does not directly pay for all human resources, accounting, and website services. The College of Liberal Arts provides space in Blegen Hall as in-kind support for the Twin Cities U-Spatial lab.

Enterprise Strategies U-Spatial takes what is termed an enterprise approach to provide the more than half of our operating revenue. Under this system, U-Spatial partners with researchers on their funded projects offer consulting services both external and internal to the university and, to a lesser extent, offer in-person workshops for a fee. A brief description of the components of our enterprise approach follows:

- Sponsored Projects. Research with a spatial component is booming across the university. While U-Spatial's service orientation and lean organization limit the range of research grants we can reasonably pursue on our own, we do collaborate with researchers by participating on grant proposals (sometimes as a co-PI, but more often as key staff). Early on, researchers were seeking U-Spatial involvement after the project had started, and they realized spatial expertise was needed. However, more often, U-Spatial is now being written into the original grant proposal as researchers see value in creating a stronger proposal. The key to our enterprise model is that all Indirect Cost Recovery funds from our staff involvement in the project stay within U-Spatial and help fund our common good services.

- External Sales Organization (ESO). We actively seek to develop partnerships with public and private sector organizations that are interested in working with the unique resources of the university. We are not in the consulting business and only take on projects that would benefit from the resources offered by the university. We do not want to alienate private sector consulting companies by directly competing with them for projects, remembering that they are a big employer of our graduates. It is important to note that university policy requires us to charge rates that are competitive with the market rate for GIS services. Our rates range from $140/hour for a GIS Developer to $50 for a GIS Technician. Like Indirect Cost Recovery from sponsored projects, profits from external sales are used to help fund our common good services.
- Internal Sales Organization (ISO). We occasionally provide geospatial expertise to faculty and centers that are funded with non-sponsored funds (i.e., faculty start-up funds and state appropriations). An example is the creation and maintenance of campus maps for the Duluth campus. While there is no overhead with ISOs, they do offset staffing costs, provide a variety of projects for staff and RAs, and help the university meet its missions.
- Training. There continues to be a market for instructor-led workshops on a variety of GIS topics. Our workshops described later in this chapter are already open to nonuniversity participants as this fills empty seats in regularly scheduled workshops while providing revenue for workshops. There is expressed demand for additional topics and custom workshops for university units, state agencies, and nonprofit organizations that provide additional revenue.

In 2021, we reached our goal of having more than 50% of all expenses for U-Spatial paid for by enterprise resources instead of central university funding. By increasing our revenue on sponsored projects and external sales, the Indirect Cost Recovery and profit (respectively) allow us to increase our reach for our common good services.

2.3 U-Spatial Services

U-Spatial offers a broad portfolio of common good services to students, faculty, and staff at the university. U-Spatial can provide the services of a “large” spatial support center for the cost of a small one because we have strategically developed partnerships to eliminate duplication and fragmentation of resources. It is hard to quantify the value of these services, but as seen in Table 2.3, U-Spatial offers a range of services to a growing number of people.

- Classroom support—While we have always provided some support to instructors interested in using geospatial technologies in their classroom, we have more

Table 2.3 Use of U-Spatial services (2011–2021)

Year	Help desk	Training workshops	Classroom support	Events	Hosted servers	ArcGIS online named users
2011	4	53				2
2012	168	267		131		10
2013	328	309		419		100
2014	456	466		327		240
2015	726	415		255	3	1000
2016	741	688		280	5	1800
2017	815	468		200	6	3000
2018	924	1111	60	310	9	6300
2019	866	1179	585	475	9	9000
2020	824	408	1244	550	9	12,000

recently started tracking interactions as the demand for our services have increased. Most often, we help with ArcGIS Online or StoryMaps assignments, discussed further in Chap. 4.

- Events—Over the years, we have tried different formats for building community around spatial thinking at the university. Early on, the focus was on traditional seminars by bringing in a variety of speakers. The past few years, we have focused on one large event, the UMN Spatial Forum held each year on International GIS Day in November.
- Hosted servers—In collaboration with University Services and OIT, we host ArcGIS Enterprise servers, as well as Postgres/PostGIS databases for units across the university with no charge. This reduces the administrative burden for the individual units and ensures the resources are professionally managed.
- ArcGIS Online named users—All students, faculty, and staff can access ArcGIS Online with their standard university sign-on to create maps and perform spatial analysis.

In addition to offering a range of services, U-Spatial is a hub for networking. Our signature event is the UMN Spatial Forum held yearly in November on GIS Day. The forum brings together colleagues from across the university, as well as GIS professionals from the community to share their latest work, culminating with the annual Borchert Lecture. The Borchert Lecture series was established in 2008 to bring in speakers from academia and the private sector to present on GIScience. This annual event honors the late John R. Borchert, Regents Professor in the Department of Geography, Environment, and Society and member of the US National Academy of Sciences.

Another networking initiative is the U-Spatial Mapping Prize, created in 2013 to celebrate great design and cartography through maps. Open to all students across the university, we look for the most informative map, the most revealing map, the most provocative map, the most visually compelling map, and maybe the most transformative one. The map should tell a story and be able to stand on its own with minimal narrative to give context. Nearly all of the submissions in recent competitions are in the form of a StoryMap, although we have had other creative formats including videos, Web applications, and watercolor-painted papier mâché. The best overall map receives a $1000 prize (or a trip to the Esri International User Conference), with other categories generally receiving $100 awards. The Mapping Prize is generously sponsored by Jack Dangermond, founder and president of Esri.

2.3.1 Help Desk

The initial point of contact with U-Spatial for many people is an email or call to the U-Spatial help desk. This service answers questions from students, faculty, and staff from all campuses. The range of questions varies from straightforward requests like looking for software through more complicated issues like finding data or selecting appropriate spatial analytic techniques. The number of help desk contacts has been trending down the last couple of years, somewhat due to COVID, but also largely due to U-Spatial creating and promoting a self-service portal for ArcGIS Online and ArcGIS Desktop access.

The help desk offers three levels of service.

The first level of support, Level 0, is self-service, which is simply using our website and other online resources. Several years ago, we decided to not focus on self-service resources (beyond software access) because we have found that a quick email exchange or Zoom conversation is far more efficient for the person seeking information. For example, many inquiries are about GIS software and ask how to use desktop software like QGIS or ArcGIS Pro when in many cases, it would be far more effective to use a Web-based GIS like Policy Map, Carto, or ArcGIS Online.

Level 1 is the initial contact with an actual person at the help desk. This contact is most often in the form of an email routed to our ticketing software, Request Tracking (RT). We share this system with the Minnesota Supercomputing Institute and are able to assign tickets to the appropriate queue as needed. The help desk has daily walk-in hours (and telephone coverage) for people looking for immediate help. We also monitor the central university ticketing system to access queries that come in through the OIT Help Desk. While we don't enforce a time limit for responding to help desk tickets, most are resolved within a few business days. Level 1 support is staffed primarily by undergraduate and graduate research assistants, typically three to five students during any semester. This group answers the vast majority of questions and refers questions to Level 2 (full-time U-Spatial staff) as needed.

Level 2 is when full-time staff step in. As noted above, when truly complex questions are received, we have experts throughout the university that we can contact for assistance. As part of our Esri site license, U-Spatial staff are authorized to open cases with Esri support as needed. We have found that it works well to have colleagues describe their issue to us to see if we can find a solution (sometimes, it is an issue specific to the university). Then as needed, we will open a case with Esri, making the requestor the primary contact so they can work directly with Esri technical support.

2.3.2 Training Workshops and Credentials

U-Spatial offers a range of workshops to hundreds of people each year. We started our training program by taking over the GIS 101 course created at the Minnesota Population Center and have been teaching a version of this course for over a decade. Now called Desktop GIS, the course was originally taught with Esri ArcGIS Desktop and has been updated through the years to include versions for Esri ArcGIS Pro and Quantum GIS. Desktop GIS is taught in a computer lab so that we do not have to take time installing software on student computers. This workshop is a great marketing resource because it introduces people to what is possible with GIS and introduces students to the idea of contacting the help desk for further assistance.

In addition to Desktop GIS, we have a catalog of additional workshops that introduce Web mapping, field data collection, raster data analysis, and StoryMaps:

- ArcGIS StoryMaps: Visual Storytelling with Maps
- Web GIS: Introduction to ArcGIS Online
- Web GIS: Advanced Topics—Content Management in ArcGIS Online
- Desktop GIS: Analyzing Data and Creating Maps
- Desktop GIS: A Brief Introduction to ArcGIS Pro
- Spatial Data Collection: ArcGIS Field Maps and Survey123
- Spatial SQL with Postgres/PostGIS
- ArcGIS Notebooks: The Basics
- An Introduction to Image Analysis on Google Earth Engine

Building and maintaining instructor-led, synchronous workshops is very time-consuming, so we focus on material that lends itself to being taught synchronously. If people are interested in online resources, we point them to the Esri training pages where they have access to hundreds of individualized tutorials that often focus on a specific function or tool. We struggle with the amount of staff effort needed to keep workshops up to date given how quickly Web-based platforms are being enhanced. All of our workshop materials have a Creative Commons license and are available for download from our website. For several years now, we have been charging a small fee ($10) to students, faculty, and staff to participate in a workshop. This is not for the revenue; rather, the small fee has greatly reduced our no-show rate, which in turn has reduced the number of people turned away unnecessarily because most workshop offerings fill. Students are able to reserve a seat in the workshop via online registration and use a credit card or a university account to pay.

The issuing of digital badges is a recent addition to our training program. The graduate school implemented a badge program that encourages students to develop and attain other transferable skills related to their disciplinary path. Badges result in micro-credentials through Credly that can be added to a portfolio demonstrating skills not described by accredited courses or research interests. This badge program presented an opportunity to promote spatial thinking and technology through StoryMaps and easily accessed cloud software.

Fig. 2.3 University of Minnesota Geospatial Storytelling Badge

Available to all university students, faculty, and staff, the Geospatial Storytelling Badge (Fig. 2.3) offers an introductory path to build GIS software competency, to understand basic GIS tools and spatial data resources, and to communicate effectively with maps in a multimedia environment. The badge requires two introductory U-Spatial training workshops and the submission of a final assessment. The assessment may be a completed StoryMap or a reflective essay describing how these newly attained skills contribute to their discipline and career path. In its first year, over 60 people are expected to complete the requirements and earn the badge.

2.3.3 System-Wide Software and Subscriptions

Esri provides the most commonly used suite of GIS applications in use at the university. The Office of Information Technology (OIT), along with the Minnesota State System (54 campuses statewide) procure the Esri site license (learn more in Chap. 3). U-Spatial was a huge proponent for making all Esri software a common good resource, similar to Microsoft and Google applications. While OIT purchases the Esri site license, U-Spatial is the primary support unit for Esri desktop, server, and online applications. We do this through training workshops and help desk support.

In addition to Esri applications, we support a long list of open-source and proprietary applications used throughout the university. We have purchased software and memberships that benefit a large number of university colleagues, including LAStools, SHELDUS, Esri Conference Videos, University Consortium for

Geographic Information Science (UCGIS), and Open Geospatial Consortium memberships. In the past, we had a subscription to DigitalGlobe Basemap service, and beginning in spring 2021, we now have a site license for Planet Imagery, specifically the PlanetScope product, which provides global coverage on a daily basis at 3- to 5-m resolution. We are currently working on tutorials and process workflows that will allow students, faculty, and staff to make full use of Planet Imagery.

While we are primarily funded to enhance spatial research throughout the organization, we have always provided infrastructure that supports teaching as well. For example, faculty are recognizing the value of cloud-based GIS tools in their classrooms. Computer labs, specialized software, and complex workflows are no longer required to teach about the power of geography and spatial thinking within their disciplinary contexts. Removing these software and computing accessibility barriers has opened up a new path to teaching and learning with GIS. U-Spatial classroom support has more than doubled with 585 students in 2019 and 1244 students in 2020 (Table 2.3). See Chap. 4 for more details. With improved and simplified access to GIS technologies, virtually all students and faculty can access the tools from their own computers.

A primary vehicle for U-Spatial supporting spatial thinking in the classroom is administration of our ArcGIS Online subscription. The University of Minnesota was an early adopter of ArcGIS Online, creating our first subscription in December 2011. Very early on, we saw the importance of using single sign-on enterprise login to reduce administration effort and had implemented them within the first year. This enabled anyone that can authenticate with a university sign-on to access all of the resources available in ArcGIS Online. We also decided that we would have only one subscription for the entire university, which greatly reduces administrative overhead by having students, faculty, and staff from all campuses accessing the same subscription. We take a hands-off approach to administering ArcGIS Online. We rarely delete user accounts because there is no need to, and it is extra work. With the Esri site license, it's useful to keep students who have graduated on ArcGIS Online so that they can share the maps and apps that they've created. This ability to continue having map access is good for the students because it allows them to have an online portfolio, and this is good for the university because we get to show the breadth and depth of the amazing work being created by our students and beyond. Chapter 4 has more information on how ArcGIS Online is used across the university.

2.3.4 Consulting Services

U-Spatial offers a range of consulting services. These services vary greatly and can include cartography, data discovery, data formatting, spatial analysis, and proposal writing. Many projects are conducted under the aegis of U-Spatial's common good framework. Many students, faculty, or staff who request these services are affiliated with a department that has not yet used much mapping or spatial analysis, such as Nursing, Pediatrics, History, Fine Arts, or Economics. As such, these services often open doors to more projects once a quality product is delivered, and providing these services without charge is well worth the impact. Depending on how busy we are, we are able to provide up to 10 hours with no charge. In addition to helping develop new collaborations, the simple fact is that the overhead of trying to recover costs associated with small amounts of effort is not cost-effective and is more than offset by the attendant goodwill we develop across the university.

U-Spatial staff help scholars and community members make proposals. We support faculty and graduate students with proof-of-concept mapping or spatial analysis in the pre-proposal stage of grant writing to increase the odds of proposals being funded. When colleagues have access to geospatial expertise, they are more likely to include this expertise at the outset of their project, creating a better proposal and a better outcome of the project. U-Spatial supports faculty to improve their language for use of geospatial data, as well as to contribute to other aspects of the proposal such as outreach, broader impacts, and data management. For example, geospatial products such as Web applications are often overlooked as great tools for meeting outcomes for training, National Science Foundation (NSF) Broader Impacts needs, or other outreach requirements.

As discussed above in terms of the U-Spatial funding model, while many services are treated as a common good, there is interest in growing revenue to support services and defray the cost of common good services. Importantly, the general posture of U-Spatial is that it is not in the business of competing against consulting companies or other private sector firms. The university is a land grant institution with a service mission that extends to supporting a strong set of public and private groups who can hire university graduates and serve a range of geospatial needs. This said, there are some projects that lend themselves to the expertise of U-Spatial and the university in general. For example, U-Spatial will offer consulting that contributes to larger, funded projects. These consulting services usually fill a gap within the institution in terms of expertise or effort (e.g., large amounts of undergraduate student time) that makes a research project more efficient and cost-effective.

U-Spatial has offered consulting services for projects that have spanned nearly every discipline and department at the university. Much of the work we do centers around Web-based map applications. For example, in collaboration with university researchers and other organizations, we developed the Minnesota LakeBrowser, for natural resource managers and the public to access current and historical water clarity and other attributes for water bodies in Minnesota. Other projects center on producing new data, such as statewide solar insolation dataset at 1-m resolution. The original impetus for this project was to explore the viability of solar installations on residential locations. Interestingly, like many geospatial projects, this effort had unanticipated benefits in the form of finding other uses for these data. In one case, the data were used as a proxy for trout stream temperatures because it turns out that temperature is heavily influenced by shading. A final example is a long-running collaboration at the University of Minnesota Duluth with the State of Minnesota and county governments to help them prepare for a range of natural disasters. This research, driven by U-Spatial staff, results in spatial information and tools to help communities develop effective hazard mitigation plans and actions to address the

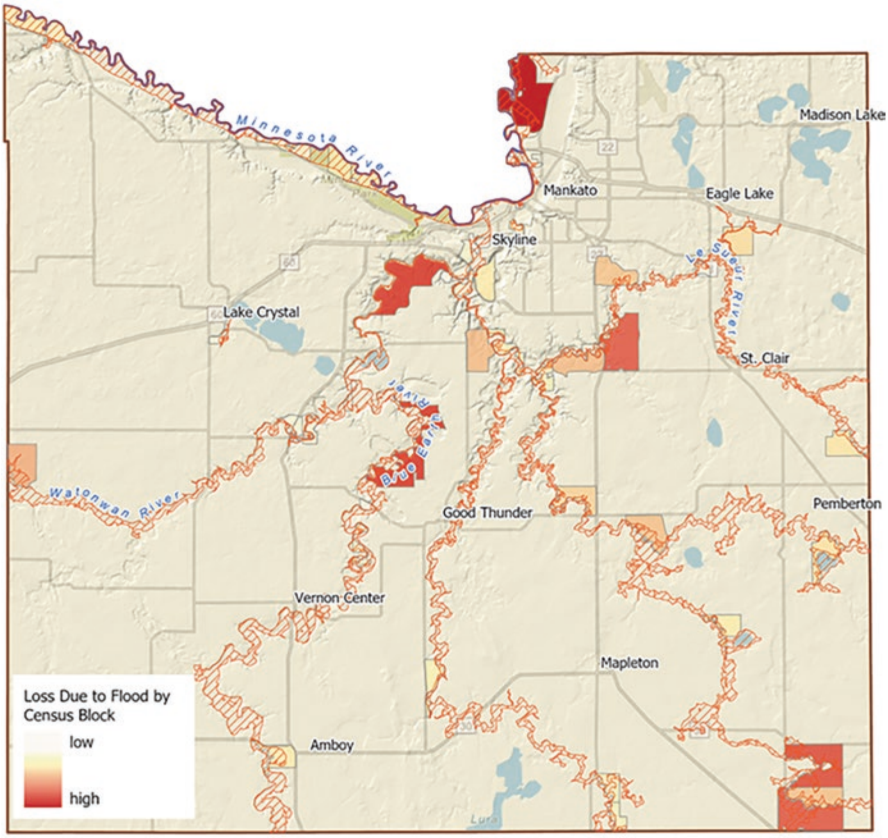

Fig. 2.4 U-Spatial hazard mitigation planning developed a map of potential economic loss by census block for a 1% annual chance flood in Blue Earth County

long-term risks associated with extreme temperatures, fires, floods, tornadoes, landslides, hailstorms, and coastal erosion (Fig. 2.4).

Another kind of U-Spatial consultation is cultivating spatial thinking in K–12 education. In 2006, the National Research Council (NRC) identified GISc as a key approach for K–16 education. The NRC report "Learning to Think Spatially" (2006) notes that GISc is "an integrator and a facilitator for problem solving across the curriculum. With advances in computing technologies and the increasing availability of spatial data, spatial thinking will play a significant role in the information-based economy of the twenty-first century." Minnesota has been touted as a clear leader in adopting GIS use in K–12 classrooms (Fitzpatrick, 2020), although a relatively small number of classrooms are using geospatial technology. The spatial university is well positioned to address needs of educators new to spatial tools given the breadth and depth of expertise throughout the system. U-Spatial connects students and educators with classroom activities, webinars, workshops, and mentorship opportunities. For example, its suite of Minnesota-based "geoinquiries" modules help students build spatial skills as part of their middle school social studies classwork.

Last year, U-Spatial launched the University of Minnesota GIS in the K–12 Collaborative (UMNGK12) to promote the attainment of geospatial literacy and skills in Minnesota K–12 students. The collaborative has a growing membership with faculty from across the university and seeks to leverage expertise, research, infrastructure, and connections to advance methods for teaching GIS in K–12 environments and to build the spatially literate workforce and citizens of tomorrow. Through training, research, outreach, and technical support, the UMNGK12 partners with educational institutions, educators, GIS professionals, and others to integrate GIS into teaching. UMNGK12 members participate in local, national, and international conferences to share outcomes related to spatial thinking and technology in K–12 education programs. Many members have been actively involved in the Minnesota geospatial professional community, providing connections with the K–12 community through years of service.

2.4 Conclusion

U-Spatial was created to meet the need for spatial infrastructure in support of research, teaching, and service. This infrastructure came together through the efforts of dozens of staff, students, and faculty and with the support of multiple levels of university administration and grant programs. U-Spatial is a new kind of infrastructure focused on a broad definition that encompasses people, places, and tools. At its core is a team of geospatial professionals who advance the mission of the modern land grant university. U-Spatial supports the research of hundreds of scholars in every college and center across multiple system campuses, as examined in Chap. 5. It has branched out from a research focus to support service and teaching as detailed in Chaps. 3 and 4. Throughout its activities, U-Spatial seeks to create synergies and efficiencies and has helped bring into being the first broadly recognized spatial university in the United States.

References

Dangermond, J., & Goodchild, M. F. (2020). Building geospatial infrastructure. *Geo-Spatial Information Science, 23*(1), 1–9.

Fitzpatrick, C. (2020). *Fun with GIS 274: Minnesota model*. https://www.esri.com/en-us/lg/industry/education/minnesota-offers-roadmap-for-expanding-gis-literacy-k12-schools. Accessed 17 September 2021.

Harvey, F., Kne, L., & Manson, S. (2013). U-Spatial: A consortium for the spatial university. *Arc News, 34*, 1–6.

Kne, L. (2021). U-Spatial 2021 Budget. Unpublished report.

National Research Council. (2006). *Learning to think spatially*. The National Academies Press.

Chapter 3
Spatial University for Service and Support

Dan Sward, Will Craig, Kirsten Delegard, Lucinda Johnson, Jeff Matson, Ryan Mattke, Stacey Stark, and Deborah Tafil

Abstract Spatial information systems and approaches are central to the provision of many forms of service and infrastructure at the spatial university. Geographic information systems are used to maintain inventory and service records, plan real estate transactions, and create campus maps and other tools for outreach and development. The University of Minnesota has been a spatial university for years in the sense of long being home to many precursors of modern spatial scholarship including spatial analysis, cartography, and remote sensing. The university hosted one of the first geographic information systems, the Minnesota Land Management Information System, and was home to other significant spatial projects from the 1960s onward. Groups on campus tasked with services, facilities, and management of physical plant, real estate, and other functions were also early adopters of spatial technologies that matured into a full enterprise-scale geographic information system and attendant services. Other units employ a range of spatially enhanced service, including the Office of Information Technology, University Libraries, and Natural Resources Research Institute. Spatial approaches are used in a myriad of other capacities and offices ranging from alumni development to extension activities.

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Keywords Spatial university · Enterprise GIS · Foundation · Physical plant · Libraries

3.1 Introduction

Spatial systems and approaches are crucial to many forms of service and infrastructure in the university. These include keeping inventory and service records, helping plan real estate transactions, and developing campus maps and tools for outreach and development. The University of Minnesota has always been a spatial university in many respects, tracing many precursors of spatial science, such as cartography and analysis with mapping, back almost a century. The university was home to one of the first geographic information systems, Minnesota Land Management Information System, alongside other significant projects from the 1960s onward. No less important was the early adoption of spatial approaches in University Services, facilities, and management of physical plant, real estate, and other functions that served as the foundation of a full-fledged enterprise geographic information system (GIS). Spatially enhanced service is also integral to the University Libraries fulfilling a range of missions on campus and beyond. Spatial approaches are used in a myriad of other capacities and offices, ranging from centralized information technology support to alumni development to a range of extension activities.

3.2 A Spatial University From the Beginning

The University of Minnesota can trace antecedents of spatial science back a century, and it embraced subsequent decades of development and growth in both precursors (e.g., cartography, remote sensing, spatial statistics) as well as nascent and current facets of spatial science, including geographic information systems, advanced remote sensing, and spatial computing. The university boasts almost a hundred years of using mapping to pursue service activities. Porter (1991) notes that cartography at the University of Minnesota, which is a key component of the spatial university, can be traced before World War II, back to the mid-1920s, and the work of Richard Hartshorne, Ralph H. Brown, Samuel Dicken, and Daryll H. Davis. The roots of the spatial university run long and deep in how the University of Minnesota has offered dozens of courses in cartography and mapping along cognate fields such as spatial aspects of climate, spatial statistics tied to locational data, and air photo interpretation (see Chap. 4 for more information).

3.2.1 Minnesota Land Management Information System

Geographic Information Science (GISc) in its modern form originated in part in the 1960s with the Minnesota Land Management Information System (MLMIS). Professor John Borchert in the Department of Geography developed an atlas of the state's natural resources in 1958 and conducted studies examining linkages between population and highway traffic in Minnesota (1963). This work was the foundation for a study of Minnesota's lakeshores funded by the state legislature in 1967. Lakeshore was being developed in the state at a rapid rate, and Borchert proposed looking at the land surrounding lakes across the state his basic unit of analysis being based on the Public Land Survey System. Environmental data from university colleagues in the soils and forestry disciplines, combined with data about seasonal and year-round homes gathered from county courthouses around the state, was coded into those cells. The technology was crude, using computer cards for data entry and line printers for output, but it was the kernel of modern GIS. The results were unlike anything else at the time, leading to the development of the state's Shoreland Management Program in 1969. That program is still in force today with the Minnesota Department of Natural Resources, designed to protect shorelines in the face of changing land use.

The next step for Borchert was to extend his grid mapping approach to covering the state, and the Minnesota Land Management Information System (MLMIS) was born. The project was massive, requiring 1.36 million punch cards, which were cardboard cards with holes that encoded computer instructions and could be read by machine. Land use and proximity to both roads and water were captured through air photo interpretation. The initial product of that work, a large color *Land Use Map (1969)*, won a national award for Art Holt in the University Print Shop. The innovative work produced a color map showing the earth's curvature. Additional data came from other sources. Dick Rust and Lowell Hanson in the Soils Science Department raced to complete the statewide generalized soil atlas, and public ownership data came from federal and state sources. These additional data sources were overlaid with each other to produce maps of state-owned peatlands. The MLMIS, developed at the University of Minnesota, was handed off to the Minnesota State Planning Agency and became nationally known as an early model of GIS.

Al Robinette from Landscape Architecture was critical in proving the utility of the MLMIS database. Robinette had been a student of Ian McHarg at the University of Pennsylvania. McHarg (1969) developed a map overlay system to inform environmental decisions, and Robinette had learned from McHarg both in the classroom and during intern work at his consulting firm. Robinette taught that method at the University of Minnesota, inspiring two of his students, Paul Sand and Mike Cohen, to develop a computer program that performed the map overlay and other spatial analysis functions. EPPL, the Environmental Planning and Programming Language, was born. Robinette began using that language first in his own work and then at MLMIS. When Matt Walton, director of the Minnesota Geological Survey, saw a plan to place a landfill in a gravel pit adjacent to a wild and scenic river, he called on Robinette and MLMIS to find an environmentally sound alternative. Another way in which MLMIS had real-world impact was its use in exploring Minnesota's potential energy resources, namely, a study of the potential for wetland biomass for energy production. A University of Minnesota team, led by Doug Pratt in Botany and in collaboration with the Center for Urban and Regional Affairs (CURA), went to work looking at the energy potential of wetland biomass. This work spurred discussions about preserving these areas and led to the Wetland Conservation Act of 1991. Rules were established about how much more could be drained, based on what percent of the county's wetlands had already been drained. The success of that project and a range of other successful applications proved that MLMIS had moved beyond the research and development phase and was ready for operational use.

MLMIS was transferred to the State Planning Agency in July 1977 as the Land Management Information Center (LMIC), with Robinette as its first director. Today, its inheritor is the Minnesota Geospatial Information Office, a national leader among the states in developing, and advocating for, use of geographic information systems and science to address a range of challenges. MLMIS and Robinette are mentioned multiple times in Foresman's 1997 *History of Geographic Information Systems: Perspectives from the Pioneers,* particularly in the chapter by Nicholas Chrisman, "Academic Origins of GIS." (1997) Chrisman points to the University of Minnesota as a rare example of success in moving a system from academia to mainstream use in the sense of becoming part of state government.

Beyond its inherent success in terms of embodying the service mission of the spatial university, MLMIS showcases how many parts of the university were integral to the success of MLMIS and promulgating GIS in service capacities more broadly. Soil Science has already been mentioned. Rod Sando in the Department of Forest Resources became intrigued with the technology and was an early user; he later moved on to be Director of Lands at the state's Department of Natural Resources and then Commissioner of that department. David Briden from the Law School was involved because of his interest in environmental issues. University Computer Services provided significant support, including access to a new Dicomed image processor that had been acquired for producing color X-rays but was also highly suitable for producing color maps for MLMIS. Researchers in the Department of Geography, including Dwight Brown, Phil Gersmehl, and Richard Skaggs, developed a Water Resources GIS with funding from the Legislative Commission on Natural Resources, a state body tasked with a range of natural resources issues (Brown & Gersmehl, 1987). Many people from many units across the university were integral to the early development of GISc on campus.

3.2.2 Formative Moments in the Spatial University

Work on MLMIS was joined by other activities on campus from the 1960s onward. Mei-Ling Hsu joined the Department of Geography in 1965 and was a highly respected scholar in cartography and cartographic symbolization, and Richard

Skaggs and Dwight Brown worked in remote sensing and spatial analysis. Porter (1991) notes how the Department of Geography was graduating PhDs working in cartography and embracing the potential of computers in mapping, thereby laying the groundwork for what became GISc. For example, Avi Degani graduated in 1971 with a dissertation on building a computerized atlas and along the way developed one of the first works on three-dimensional automated mapping and its application to deriving attribute and statistical surfaces from spatial data (Degani, 1969). He went on to found a large private research and planning company, Geocartography Knowledge Group. Other notable alumni include Barbara Elfman (1959, Defense Mapping Agency), Ki-Suk Lee (1977, Seoul National University), Su-Chang Wang (1981, University of New Orleans), and John Woltner (1975, Library of Congress). These are just a few of many people who could be named (see thespatialuniversity.umn.edu for more).

Other early spatial activity centered on remote sensing as it moved to digital processing. The Earth Resources Technology Satellite (ERTS) was launched in 1966, quickly followed by Landsat in 1972. Marv Bauer in Forest Resources was an early pioneer in using that technology. Dwight Brown in Geography was an early adopter as well. These remote sensing experts made significant contributions in determining water quality and land use patterns. Scholars in what is now the College of Food, Agricultural, and Natural Resource Sciences led the way on the development, use, and teaching of remotely sensed imagery. As was often the case in spatial work more broadly, some of this work with remotely sensed imagery was not well connected to the world of GIS. For example, there was a disagreement over people discarding files of scanned soil maps instead of moving them into the LMIC database. The excuse at the time was that there was limited storage capacity available for such uses. We examine the use of remotely sensed imagery more broadly in Chap. 5.

Spatial science scholarship on campus continued at a deliberate pace through the 1980s and then began to pick up in the 1990s. Some highlights include Robert McMaster and Susanna McMaster coming to the Department of Geography in 1990, joining Roger Miller, Gregory Chu, Phil Gersmehl, Eric Sheppard, Helga Leitner, and Sona Andrews (later work is examined in Chap. 5). They helped spur scholarship in GISc beyond the use of off-the-shelf software as part of a larger conversation kicked off by the National Science Foundation launching a competition for the National Center for Geographic Information Science (NCGIA) in the late 1980s spearheaded by Ron Abler who got his Geography PhD in 1968 (Abler, 1987). David Pitt joined the Department of Landscape Architecture around this time, and he was joined by Jeffrey Crump and others in what eventually became the College of Design. Marvin Bauer carried on with remote sensing in the Department of Forest Resources and was joined by Paul Bolstad in 1995, who had a focus on teaching and research in GIS. Will Craig anchored work in the Center for Urban and Regional Affairs (CURA) and grew the portfolio of GISc work applied to a range of service and research opportunities. Vipin Kumar and Shashi Shekhar joined the Department of Computer Science in 1989. These are just a few of the many scholars working at the university in this period of growth and development of spatial science.

Another early example of using GISc to serve societal needs was the work of Pierre Robert in Soils Sciences, an early pioneer in the development of precision agriculture, the use of spatial and other technologies to reduce inputs and increase yields. Beginning in the 1980s, he digitized soil maps, adding the characteristics of each soil type. Everyone knew that each soil type and each location needed a different treatment to maximize its productivity. Robert figured out a way to transfer those needs to a tractor crossing over a field with different soil types. Fertilizer or lime could be parsed out as needed. Farmers gained productivity and cut costs. The environment benefited because no extraneous fertilizer was applied. Robert figured out how to map fine-scaled spatial locations using on-site location transmitters before GPS technology was available. He was an international leader in the field and hosted a series of International Conferences on Precision Agriculture starting in 1990.

Around the same time, in the late 1980s, a new GIS laboratory was established within UMD's Natural Resources Research Institute (NRRI). Through a National Science Foundation (NSF) grant led by Carol Johnston, John Pastor, and 10 other researchers from the university system, the lab focused on applying GISc analysis to natural resource issues and led to some of the earliest publications using GISc in ecological research. The center used Esri's ArcInfo v. 3.0 software, ERDAS, and EPPL7 as the primary software tools. The hardware platforms evolved over time, beginning with running software on UMD's VAX computer, then moving to SunSpark workstations, high-end PCs, and porting processor-intensive calculations to MSI's supercomputers. The NRRI GIS Lab served as a beta test site for PC ArcInfo and subsequent software releases through the 1990s. Dozens of training workshops conducted by Lucinda Johnson, the first GIS manager, focused on the use of GIS for environmental research, and decision-making were conducted across the university, the state, and at national and international conferences. More broadly, the University of Minnesota was an early adopter of the use of GIS for basic ecological research and especially in the field of aquatic ecology (see the review article Johnson, 1990).

A more recent example of use of GISc to further the university's service mission is the UMN MapServer. MapServer is a long-running open-source project that allows developers to build spatially enabled Internet applications centered on Web mapping. Originally developed by Stephen Lime and Thomas Burk at the University of Minnesota (Lime was also with the Minnesota Department of Natural Resources) as "UMN MapServer," the project that eventually became the MapServer had its origins in a project to build a decision support system for users of the Boundary Waters Canoe Area Wilderness (BWCAW) in northern Minnesota. The project was developed with funding from NASA as a way to share satellite imagery via the Internet as part of the program "Public Use of Earth and Space Science Data Over the Internet" (Lime, 2008). Later work in collaboration with scholars in the Department of Computer Science focused on expanding the capability of MapServer (Vatsavai et al., 2006) (Chap. 5). It achieved popularity in part by integrating with, or drawing on, other key systems like PostGIS, Ka-Map, and OpenLayers and by supporting most major Open Geospatial Consortium Web service specifications. It made it relatively easy to develop mapping capacity in websites and application by offering a common gateway interface (CGI) and MapScript, a scripting interface for popular languages such as C#, Java, Perl, PHP, Python, and Ruby. MapServer found great success around the globe in addition to enacting the service mission of the university in projects including a remotely sensed imagery catalog and image browser, advancing the mapping wildfire location and status, land change detention, a forest stand inventory access system, and a system for digital aerial photograph distribution.

As described in Chap. 2, U-Spatial supports a broad array of activities on campus and is built on the work of the geospatial consortium in the 2000s. Many of these activities fall under the aegis of service, and while there are too many to note in the present volume, it helps to briefly examine their scope. For example, U-Spatial provided routing services to evaluate different supply chain scenarios during natural disasters using Esri ArcGIS Server to route food to retail stores as part of a multi-institutional grant with the Department of Homeland Security and private funding. It developed a Web application for Twin Cities Housing Market Index for thousands of locations, which included developing standardized block indices that are calculated and rendered in real time based on user selection (neighborhood, community, city, or hand drawn). It also provided training and created data, ArcGIS Online maps, and static maps for presentations to the public and practitioners for the Caribbean Health Data and Minnesota Cancer Alliance. In terms of the broader state community, U-Spatial developed an interactive map of building energy use, appending parcel data to lidar-derived building footprints to identify structures with high potential for energy efficiency measures. At the University of Minnesota Duluth, U-Spatial collaborates with One Roof Community Housing and the Metropolitan Interstate Council to analyze data from a community survey in Duluth's Central Hillside neighborhood to produce maps showing patterns of perceptions of safety, service needs, and community. These are just a few of the dozens of projects that U-Spatial has taken on to increase the reach of the university's service activities.

3.3 University Services, Facilities, and Management

Geospatial technology has been used for decades at all levels of government—city, county, state, and beyond. City government applications of GIS often include parcel mapping, public works and other asset management, crime mapping, and a host of other applications. A large land grant institution like the University of Minnesota must manage its physical assets much like a city. The same parcel mapping, asset management, crime mapping, and other GIS use cases apply, and campus physical asset management activities are increasingly supported by geospatial tools and thinking. University Services, for example, is the University of Minnesota's central planning and facilities hub, and it employs spatial information systems to manage Web-based campus maps and maintain the physical plant through asset management.

As noted earlier in this chapter, GISc has a long history at the University of Minnesota through geospatial pioneers like John Borchert; however, it was not until many years later that the university began leveraging geospatial tools for managing aspects of its day-to-day campus business. In 2007, university leaders Kathleen O'Brien and Robert Kvavik established a "GIS Steering Committee" and GIS project whose goal was implementing so-called Enterprise GIS at the University of Minnesota. O'Brien and Kvavik saw many campus-use cases for GIS. Significantly, O'Brien came to the university from a leadership role at the City of Minneapolis, where she had a direct hand in implementing GIS as a tool for managing public works data and standardizing geospatial data such as addresses. O'Brien led the University Services organization on campus which represented most of those departments that managed and maintained the campus physical plant from cradle to grave.

Some University Services departments include:

- Real Estate: Oversees land acquisition and sales and leasing activities
- Capital Project Management: Designs and manages large-scale construction projects such as new building construction
- Planning: Oversees master planning activities on campus. This is especially important for the Twin Cities campus, which is located in the center of a major metropolitan area.
- Facilities Management: Responsible for day-to-day maintenance of the built environment. The university owns over 32 million square feet of space and significant above and below ground utilities, all of which require care and maintenance.
- Space Management: Tracks interior spaces, how they are used, and how they are allocated. Space allocation data is foundational to the university's budget model and provides critical support for Facility and Administrative ("F&A") Cost negotiations with the federal government.
- Public Safety: Police Department and Campus Security
- University Health and Safety: Oversees environmental health, safety, and protection activities. Also includes campus emergency management
- Auxiliary Services organizations including Housing and Residential Life (student housing) and Parking and Transportation Services
- Student Life: Supports student support through disability resources, recreation, diversity and inclusion, sustainability initiatives, and more.

Consider that many of these University Services departments mimic the work done at cities, and you can understand why O'Brien took her city experience to the university and saw an opportunity for GIS. Kvavik brought his background as a University of Minnesota Senior Associate Vice President for Planning and was a great proponent of GIS as a tool for campus planning activities.

Once the GIS Steering Committee and project was established by O'Brien and Kvavik in early 2008, Bill Kanfield, Project Management Office Director, and Daniel Sward, GIS Analyst, began the work of implementing GIS. Significant effort was put into defining the scope and scale of the implementation. GIS was not a familiar technology to most on the GIS Steering Committee; many thought of it as akin to computer-aided facility management software, so Sward in particular was charged with helping the GIS Steering Committee and future customers understand what was possible with GIS. Only then could project scope and deliverables be defined. This work continued through the fall of 2008 when Kanfield and Sward issued a Request for Information (RFI) document soliciting vendor input on our planned project scope and rough cost if we were to engage with those vendors. The original intent was to staff a GIS Service Center, build a significant GIS dataset and robust technical infrastructure, and develop early applications such as an interactive campus map. This RFI generated great information and significant interest from many companies, which left the university confident of our approach and ability to find partners to make it happen. Unfortunately, this project timeline coincided with the 2008 economic collapse, and the necessary funding dried up, but the focus on expanding GIS capacity continued into 2009 despite these new budget realities.

The project team had to consider ways to methodically build out GIS capabilities in ways that could both fit the current budget setting and keep an eye to the future. A more formalized—though much smaller than planned—GIS department was established at University Services. One full-time GIS staff member was hired, and responsibilities for GIS technical support were shared among existing IT staff. Providing the new GIS department with dedicated IT support from a database analyst, systems analyst, and business analyst proved critical over time because it brought a vitally important mix of aptitudes and skills to thinking about GIS services on campus.

The primary goals of the new GIS department included refining its scope to those deliverables that offered near-term tangible benefits and bringing demonstrated capabilities of GIS that were of interest to a broad range of users. One geospatial application that met both these goals was an interactive campus map. For many years, campus maps were offered as print and online maps in formats such as Portable Document Format (PDF). These maps were static in nature and infrequently updated, which presented accuracy challenges for a dynamic, frequently changing urban campus. The late 2000s was a time of great physical plant change on campus, and the ability to quickly share information about construction activities and their impacts on all modes of transportation was deemed important to many university stakeholders. Further, the Twin Cities metropolitan area began construction on its first light rail line. Running right through campus, the line promised major construction impacts and would permanently change vehicular access to campus. The GIS team and Steering Committee agreed that an interactive campus map offered the benefits of more frequent updates to the base map (the foundational map on which other attributes are added) and an ability to share information about light rail and other construction impacts on campus.

The GIS team also recognized that an interactive campus map required geospatial base map data and technical infrastructure that could later be used for other purposes. In essence, building the interactive campus map would lay the foundation for future geospatial applications. Today, many organizations would consider building a basic Web map as a fairly simple effort achievable through preconfigured GIS

Web application templates that include data and technical infrastructure hosting services. In 2009, an interactive map was a much more complex and time-consuming effort because the University of Minnesota base map data needed to be built and hosted. This required digitizing layers from existing static maps and converting AutoCAD data to a GIS format. A spatially enabled database is needed to be built to host the data and Web server technology needed to be built to host the application. The university chose database and GIS server software offered by Esri and configured these software tools on a combination of university-hosted physical and virtual servers. The university developed application requirements and then contracted with Esri to develop the programming necessary for this first iteration of a campus map. The Twin Cities campus interactive map went live in 2010 (campusmaps.umn.edu) and has since gone through many upgraded versions and has expanded to other university campuses. The combination of new data development, novel technical infrastructure, and extensive coding made this a significant effort for a seemingly simple deliverable. However, this effort resulted in initial base map data, as well as database and Web application server infrastructure, that would be leveraged for years to come to support other projects and uses.

The successful launch of the interactive campus map grew awareness of and interest in GIS at University Services, which led to new projects. For example, the university's Landcare team pursued and received a federal grant for GIS-based technology to support a campus tree inventory. This would enable Landcare to better track emerald ash borer mitigation activities. Before GIS, tree inventory efforts relied on disconnected AutoCAD maps, spreadsheets, and paper inspection sheets. GIS was seen as a way to connect these into one dataset and would also enable mobile data collection work. The GIS and Landcare teams ultimately delivered a tree inventory and mobile data collection program that persists to this day. While GIS was new to many at University Services, an influx of new employees with GIS experience from their previous positions was underway, and this led to other new projects. For example, a new Principal Civil Engineer, Cathy Abene, began at University Services just as the fledgling GIS unit was taking off. Abene brought her past knowledge and experience from Hennepin County (Minnesota), where her team used GIS to inventory and manage public works assets. Abene worked with the University's GIS team to build out a substantial water infrastructure asset inventory coupled with a mature, mobile application-based inspection program. This project was especially interesting as the University Services team partnered with the university's Department of Geography on digitizing the initial water infrastructure data, demonstrating an early and successful partnership between administrative and academic units. This GIS data and inspection program showed a clear return on investment and is still used today.

Many GIS development efforts occurred in the years that followed. The University Services GIS team has developed many Web-based and mobile-based applications for collecting asset data in the field. This has become a core business for what is now referred to as University Services GIS. These applications range from a Web application in support of the university's exterior lighting infrastructure to a student-focused application that allows students to find study spaces based on location and attributes. One mechanical engineer in Duluth was overwhelmed with excitement when introduced to the custom-built mobile application that allowed him to locate a water main turn-off valve in minutes under a snowbank. In his previous experience, this task took hours of shoveling and resulted in extensive damage.

GIS use continues to expand beyond University Services GIS. The university's Real Estate Department committed to using GIS for mapping of parcel and easement data. The university is a major landowner and manages frequent land-based transactions ranging from buying and selling parcels to receiving donated land parcels. As of 2019, the university owned over 28,000 surface acres of land, and GIS has become a primary tool for inventorying this land ownership data. The university's master planning team frequently uses GIS to show map-based development alternatives for mapping existing site conditions at locations where future development efforts are planned. The university's Parking and Transportation Systems group leverages GIS for a variety of purposes including asset management, mapping of bus routes, and inventorying of bicycle racks to name a few. These maps and applications serve a range of needs on campus.

So far, the example applications of GIS for physical asset management have focused on outdoor assets, but there is significant potential in indoor uses, for example, mapping of trees, buildings, roads, hydrants, and other features one might see outside. But what about using GIS for mapping the indoor-built environment? Applying GIS solutions indoors is still a relatively new idea. For example, major GIS software vendor Esri only launched its "ArcGIS Indoors" tool in 2019 despite being in business since 1969, and most other vendors are similarly new to the field (Knoth et al., 2019). That said, the University of Minnesota has not been alone in seeing value in applying GIS solutions to indoor data. For many years, the university has managed AutoDesk AutoCAD-formatted floor plans. These are very feature-rich files, but with nearly 3000 individual files in a specialized format, they can be very difficult to access quickly for most users. The GIS team sought ways to translate AutoCAD floor plans to a GIS format and make these GIS-based floor plans accessible to those who need them. Thankfully, data translation tools have become more pervasive and mature over time, and this includes tools that can transform between spatial data formats such as AutoCAD and Esri geodatabase. The university leveraged a data translation tool from Safe Software that allowed it to automate a nightly routine that identifies recently updated AutoCAD floor plans, translates these to an Esri geodatabase format, and saves these data to the university's enterprise geodatabase. GIS floor plans are now akin to another form of base map data used for applications ranging from mapping of space occupancy data to identification of critical asset locations inside buildings. Initially, the floor plans were not spatially aware, but later georeferencing was added to our workflows based on an approach originally developed at the University of Washington and graciously shared by Aaron Cheuvront, GIS Solution Engineer. These georeferenced floor plans have proven invaluable for mapping of critical assets such as water shut-off valves and fire panels. The availability of floor plans in an electronic format has proven to be a sensitive topic, particularly when it comes to making floor plans easily available to students and/or the general public. Some in the University of

Minnesota law enforcement and emergency management communities consider easily accessible floor plans as a risk as those with ill intent could easily plan routes in and out of buildings. This concern has so far limited the use of floor plans for wayfinding applications at the University of Minnesota. The widespread use of electronic floor plans at universities is fairly new, and some have raised security concerns. Perhaps we should watch for a growing acceptance of floor plans for public wayfinding as this becomes more common in Web maps such as those hosted by Google.

The investment in GIS by University Services has led to an awareness of mapping needs and an acceleration of mapping standards adoption across the system. Over 40 staff at UMN were trained to use the ArcGIS Online application with university base map data to make custom maps for construction updates, visiting faculty maps, public programs, and more. The resulting widespread use of standard base maps led to solving a decade-old issue with the propagation of campus maps in a variety of orientations, styles, and quality.

In another example, the georeferenced floor plan data made it easy to regularly update dynamic locations of gender-inclusive restrooms across the University of Minnesota Duluth system during a period of extensive renovations. During the COVID-19 pandemic, classrooms and hallways were converted to study areas that allowed appropriate social distancing, and these locations needed to be quickly communicated. The communication of critical resources through maps was efficient and timely. Much like the growth of GIS applications for indoor data, the University of Minnesota as well as other universities have seen significant growth in remote sensing. The use of unmanned aerial vehicles (UAV; commonly known as drones) for physical asset management is growing quickly. The capabilities of UAVs have risen while costs have come down, making them viable tools. The University of Minnesota has dipped its toes into using UAVs for capturing orthoimagery and in assessing land change on university-owned land. The university has also contracted for plane-flown thermographic imagery capture as a means to identify leaks in its steam utility infrastructure and building roofs. The university has also considered using UAVs and other remotely sensed data for inspections building exterior envelopes, roofs, sidewalks, and other assets. As UAV capabilities continue to rise while their costs fall, it is reasonable to expect their use will become more and more common. One ongoing obstacle, in addition to cost and need for expertise, is an evolving regulatory landscape. As the federal government clarifies the use of UAVs, it is reasonable to expect that their use will grow to supplement the spatial university's use of GIS and other geospatial technologies to provide a range of services.

The university has made great strides in adopting GIS for physical asset management in a relatively short period of time. Industry innovations will keep us moving forward. As discussed earlier, there is much room for growth in the application of spatial information systems for indoor data, and the use of UAVs will likely continue to expand. In addition, the last several years have seen growth in spatial functionality built into other tools such as Integrated Workplace Management System (IWMS) software and business intelligence (BI) software. IWMS focuses on management of physical assets, and industry leaders have integrated GIS functionality within their offerings. BI tools focus on reporting and analysis of data, and visualizing and analyzing spatial data has become more common in BI tools. Industry leaders such as Microsoft Power BI and Tableau now offer advanced geospatial capabilities. The use of Building Information Models (BIM) has grown quickly in the last few years. BIM models digitally represent a building's infrastructure, typically in 3D, and are often geospatially aware. Imagine being able to virtually walk into a building and "see" behind the walls of that building based on a BIM model—this is a capability offered by these tools. In 2017, GIS industry leader Esri and BIM industry leader AutoDesk announced their plans to collaborate to "to advance infrastructure planning and design," which is a great sign for those who wish to create 3D campus models both indoors and out.

The University Services GIS unit has come a long way since 2007, and many lessons have been learned along the way:

- GIS champions are key to success. Strong support from University of Minnesota leaders such as O'Brien and Kvavik was critical as was support from managers such as Abene.
- Communication is critical. While the university's GIS Steering Committee was charged with providing direction to the people tasked with implementing GIS on campus, its newness to the field of geospatial data and tools was made for an interesting experience. And while GIS was not a new technology in 2007, it was still new to many potential end users at University Services. Building a shared understanding of what GIS is and is not, what it excels at and what it does not, would have helped the GIS Steering Committee and potential end users alike. More communications generally would have helped in other ways. For example, University Services already had a Records Department that used CAD, and there was room for better integration across these teams and earlier teamwork.
- Developing tangible proof-of-concept work examples and giving greater emphasis to early communications and demonstrations would likely have paid dividends later. As interest in GIS grew at University Services, GIS staff took on almost all work customers requested as a means to build its business. In reality, being more strategic and selective about GIS project and service work may have led to a more focused group today. Right now, the University Services GIS team is going through an effort to cull data and applications that have languished over time—perhaps this could have been prevented with a more strategic work planning focus.
- It pays to focus on collaborations. What started as a GIS department of one person in 2007 has become a team of four full-time GIS analysts plus a manager, and many end users were distributed throughout many university departments. In the spring of 2019, GIS staff merged with teams in charge of interior space data and infrastructure records (e.g., blueprints, CAD utility records, paper documents, etc.) and became a larger Facility Information Services department. In keeping with the spirit of collaboration, University Services GIS has had a strong relationship with U-Spatial since its inception, which helped both units. University Services has provided U-Spatial with technical support and some

funding over time. And in return, University Services can leverage U-Spatial training offerings and get assistance on geospatial project work. The spatial future looks bright for physical asset management.

Overall, there is clear value in building out expertise and seeking collaboration between teams that have a common interest and responsibility for spatially aware interior and exterior physical asset data. Interestingly, Facility Information Services departments have become more common at higher education institutions—perhaps this shows disparate and historically unconnected spatial technologies and data are starting to integrate and work better together. Additionally, having several spatially oriented service units on campus helps keep our professional relationships strong, which benefits all GIS professionals on campus and the broader communities they serve.

3.4 Office of Information Technology

The Office of Information Technology (OIT) is a system-wide unit providing a broad range of technology services to all university campuses. A long-running focus in OIT has been provision of advocating for the university's central Office of Information Technology's move to a broader statewide license for the ArcGIS software package and the University Libraries' ongoing investment in geospatial expertise.

In 2009, the University of Minnesota entered a joint Esri site license agreement with the Minnesota State Colleges and Universities (MNSCU, consisting of several dozen 2-year and 4-year colleges). Thus, all public higher education institutions in the state are under the same site license. The cost of the license is evenly split between the University of Minnesota and MNSCU.

OIT made all Esri software and applications a common good resource in 2017. The process for making this happen took several years. This switch meant that people and groups on campus were no longer asked to help defray the cost of the software contract. By removing the yearly license fee to use the ArcGIS software, OIT hoped that departments that have previously not used it because of the fee will take advantage of this and will now be able to use it in their teaching, learning, research, and administrative needs. A few years later, ArcGIS Pro installation packages became supported by the OIT Help Desk for use in University Services, which means that the central generic support team is providing some level of support as they do for other standard applications such as Microsoft Word.

Removing the cost and administration of individual license requests supported the University of Minnesota's mission. By removing barriers that previously stood in the way of ambition and innovation, it gave units across the entire University of Minnesota system the opportunity to try it, essentially opening up the possibilities that Esri software could be used to help solve issues related to any field being taught on campus. OIT operates a central Esri license server that all desktop computers on the Twin Cities and Duluth campus connect to. In 2020, U-Spatial issued hundreds of "student" authorization files for people to use ArcMap on their home computers. With the rapid adoption of ArcGIS Pro, the university is seeing a reduction in the number of students, faculty, and staff using the desktop version. Big picture, moving the Esri contract from a Cost Recovery model, where individual units pay for software, to a Common Good model, where the institution pays for software, supports and promotes the Systemwide Strategic Plan, including a 5-year framework for advancing the quality, impact, and reputation of the university. The plan makes commitments in areas including student success; discovery, innovation, and impact; improve people and places in the state; community and belonging; and fiscal stewardship. Providing software and support for spatial service helps faculty, staff, and students meet these commitments.

3.5 Libraries and Geospatial Information Infrastructure

Libraries have taken on a key role in incorporating spatial science approaches to meet many needs. As service entities with a mission of providing access to information, libraries are looking to provide a federated system to make spatial data discoverable and accessible. The University of Minnesota has several library locations concerned with spatial science and cognate areas. The John R. Borchert Map Library is the primary home to many maps and has an adjoining computer lab. The James Ford Bell Library collections consist of rare books, maps, and manuscripts that focus on the history before the 1800s. One highlight is a copy of the Ricci Map, a 400-year-old map created for the Chinese in a collaborative effort among Chinese and European scholars and artisans led by Jesuit missionary Matteo Ricci. Finally, the Natural Resources Library holds extensive collections of remote sensing-related materials (McMaster et al., 2011).

In terms of advanced spatial science, a new position in the libraries—a Spatial Data Analyst and Curator—was proposed in 2013 in order to manage content recruitment, workflow analysis and process development, and metadata creation, in addition to a consultation and advocacy role. One result was Spatial Data at Minnesota—launched in 2014—which was a federated spatial data discovery interface utilizing OpenGeoportal software. Encouraged by the utilization of open-source geoportal software, the University of Minnesota Libraries took the lead role in a proposal to develop a collaborative geoportal for the Big Ten Academic Alliance (BTAA), at that time known as the Committee on Institutional Cooperation (CIC). The initial proposal was coauthored by two additional institutions and sought a fourth institutional partner. As it turned out, ten BTAA institutions expressed interest, the proposal was rewritten, and in the end, eight institutions signed on to the Geospatial Data Project, which began work in 2015. In addition to the Spatial Data Analyst and Curator, the project also hired a Metadata Coordinator and Project Manager. This new role oversaw the day-to-day activities of the project and took on the metadata creation and coordination, allowing the Spatial Data Analyst and

Curator role to step more fully into the data curation realm, spurred in part by the launch of the data repository for the University of Minnesota in 2015.

The most visible output of the BTAA Geospatial Data Project is the BTAA Geoportal, which launched in 2016 and uses GeoBlacklight open-source discovery software. As of 2020, there are now 13 institutions collaborating on the project, and the geoportal provides access to spatial data from ten states and scanned maps from 11 of the partner institutions. While the geoportal is the most visible output, the community created to support the work of the project has also shown benefits. Through the project, participants established a multi-institutional network for sharing expertise and a community that has produced numerous published academic articles, usability studies, metadata documentation, conference workshops, and geospatial resource tutorials.

In addition to providing access, libraries are increasingly developing tools to actively spatialize their collections in order to provide enhanced access. Two examples of this are Campus History and the Minnesota Historical Aerial Photographs Online (MHAPO).

Launched in 2013, Campus History is a Web application showcasing over 150 years of buildings, maps, and aerial photographs, as well as linking out to still photographs of campus buildings from the University Archives. Creation of the application involved scanning over 500 historical maps of the campus in order to digitize the building footprint data, resulting in a dataset of over 550 buildings. Further research attached date information to the footprints for year of construction, renaming, and/or demolition. This allowed for the use of a time slider function, where a user can pick a year and see which buildings were present. The application also integrates some of the historical map scans, as well as selected years of aerial photography. Creation of the application also spurred the digitization of the building photograph collection in University Archives—users can now click through to access nearly 5000 historical photographs. In addition, the building footprints dataset is now available for use by researchers.

Minnesota Historical Aerial Photographs Online contains photos from 270 different sets of historical aerial photographs of Minnesota, covering the time period from 1923 to 1991. The site provides access to over 121,000 photos that have been scanned and geo-located for all 87 Minnesota counties. With instant access to resources, the application facilitates the discovery of unique cartographic resources not available elsewhere. By enhancing access, the library is moving beyond the role of a passive information repository and is increasing access to collection materials. Since its launch in the fall of 2012, the collection has averaged nearly 900 pageviews per week and, in 2018, received a governor's commendation for their pioneering work in offering new ways to provide access to aerial photograph collections.

3.5.1 Mapping Prejudice

The John R. Borchert Map Library also served as the incubator for Mapping Prejudice, a transdisciplinary community-driven research project that documents and maps racial covenants. These were clauses that were inserted into property records during the nineteenth and twentieth centuries to keep people who were not white from buying or occupying land. Scholars and activists have long understood how racial covenants were used to create highly segregated cities in the United States, providing the foundation for a cascading set of racialized housing policies that undergird contemporary American inequality. But the sheer number of records involved made it impossible to establish with precision the number and location of racial covenants in the built environment. By creating a workflow that leveraged optical character recognition (OCR), crowdsourcing, and GIS with tried-and-true library outreach methods and principles of community organizing, Mapping Prejudice was able to cull through millions of property records to break this research logjam.

Since the project began, more than 6000 volunteers have read approximately 425,000 property deeds from Hennepin and Ramsey Counties. By inviting people from outside the walls of the university into the work of documenting structural racism, Mapping Prejudice has provided a bridge between a public, flagship institution of higher education, and the communities it is mission-bound to serve. More specifically, it has illuminated the power of academic libraries to link people outside of the academy to research of social and intellectual importance.

When Mapping Prejudice released the digital map of racial covenants in Hennepin County (the first comprehensive spatial dataset of racial covenants for an American community), it unleashed a flood of interest from policymakers and researchers. Since it was published in the University of Minnesota open-access data repository, the project dataset has been downloaded more than 5000 times (Fig. 3.1). Besides fueling new scholarship, this data serves as the backbone of the Minneapolis 2040 plan, which has been hailed around the country as a daring new approach to land use guidelines.

The Mapping Prejudice dataset did not just capture the imagination of professional researchers. General audiences have been electrified by the geospatial visualization that makes it possible to understand the ways that history literally hits home. The team circulated the map as it was constructed by community members, who watched in horror the time-lapse spread of covenants into their own neighborhoods and streets. This visualization provides a transformative history lesson for people who had never heard of racial covenants—in less than 1 minute, they grasped the devastating impact of these racially restrictive deeds and considered, often for the first time, how they are implicated in this history. This experience has changed popular understandings of structural racism in Minnesota.

Mapping Prejudice has inspired an Emmy Award-winning documentary with millions of views; a nationally recognized museum exhibit; more than 300 speaking invitations from a wide range of civic, professional, educational, and research

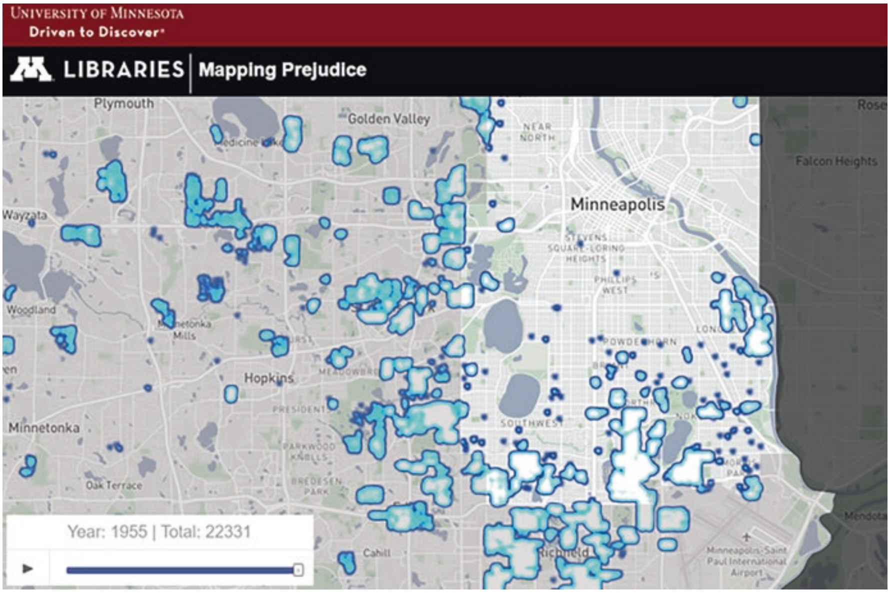

Fig. 3.1 Mapping Prejudice Web-mapping interface

groups; a research convening at the Minneapolis Federal Reserve; state legislation that helps property owners “discharge” these racial restrictions; a coalition of municipalities across the state of Minnesota that helps property owners fill out the paperwork to discharge the deeds; the Just Deeds group of lawyers, real estate professionals, and planners that has committed to fighting structural racism; and hundreds of media pieces. The project was recognized in 2021 as the Outstanding Public History Project from the National Council of Public History and honored with the John R. Finnegan Freedom of Information Award from the Minnesota Coalition on Government Information. Mapping Prejudice received the Catalyst award from the National States Geographic Information Council (NSGIC) in 2020 and a Governor’s Geospatial Commendation Award from the State of Minnesota in 2019.

3.6 Natural Resources Research Institute

The Natural Resources Research Institute (NRRI) was founded by the Minnesota legislature in 1983 as an applied science and engineering research organization to inform the decision-making of many stakeholders around the state. In the late 1980s, GIS was a tool that was routinely used in urban planning and management, as noted above, but was not used extensively for research applications in other disciplines. The field of ecology was still relatively new, and studies tended to take place in discrete experimental plots or as site-based comparisons across locales. Tools were lacking to characterize spatial relationships within and across landscapes and watersheds. The establishment of NRRI's Natural Resources Geographic Information System Laboratory (NRGISL) in 1989 led to a broad range of research that informed policy and practice, beginning with a novel application using GIS to map the dramatic changes to the Kabetogama Peninsula as beavers recolonized the landscape (leading to highly cited work, including Johnston & Naiman, 1990).

NRGISL provided a platform for NRRI and other university scientists and research partners to learn and apply GIS to critical resource issues. Among its goals were to demonstrate and advance use of GIS in applied and basic natural resources research, derive new research methods, conduct training, and transfer methods to university researchers, government agencies, and industries. Numerous groundbreaking projects were conducted by researchers at NRRI and across the University of Minnesota system demonstrating the power and utility of this new tool and the resulting new analytical approaches. In addition to the beaver impact work, other early projects with wide-reaching impact include work by Carl Richards, George Host, and Lucinda Johnson, quantifying impacts of regional land use and geology on the structure and function of Midwestern stream ecosystems (Johnson et al., 1997) and impacts of moose movement and herbivory on vegetation patterns and ecosystem processes on Isle Royale by John Pastor and colleagues (e.g., Pastor et al., 1998).

In the early 2000s, NRRI developed a map depicting the extent of human activities and disturbance across the US side of the Great Lakes Basin as part of the Great Lakes Environmental Indicators (GLEI) project led by Jerry Niemi. This map and underlying database used 207 variables derived from 19 different data sources (Fig. 3.2). A novel protocol was used to map the boundaries of all coastal watersheds on the US side of the basin so that stressor data could be summarized for local and regional watersheds. A spatially explicit stressor gradient was subsequently used to calibrate biological stress-response relationships for the purpose of assessing environmental condition of shoreline ecosystems. These products formed the basis of basin-wide stress mapping and indicator development that has informed US and CA management agency programs and policy.

NRRI and university scientists contributed to the foundational research and method development that turned GISc into a prolific research tool that, more than 30 years after the creation of NRGISL, is central to the research and service that NRRI conducts. A hallmark of NRRIs programs is a strong consideration of data dissemination through the development of online GISc applications and decision support tools. Applications were developed to identify coastal ecosystems at risk from human activities, guide habitat and wetland restoration, and predict the distribution of breeding birds and aquatic invasive species. More recent efforts have focused on removing the barriers that prevent people and organizations from using spatial data. The Minnesota Natural Resource Atlas (MnAtlas.org) is intended to democratize access to spatial data to better inform decision-making and management, especially for people and organizations with limited access to GISc expertise. Ultimately, the application of GISc to better understand ecological and geological

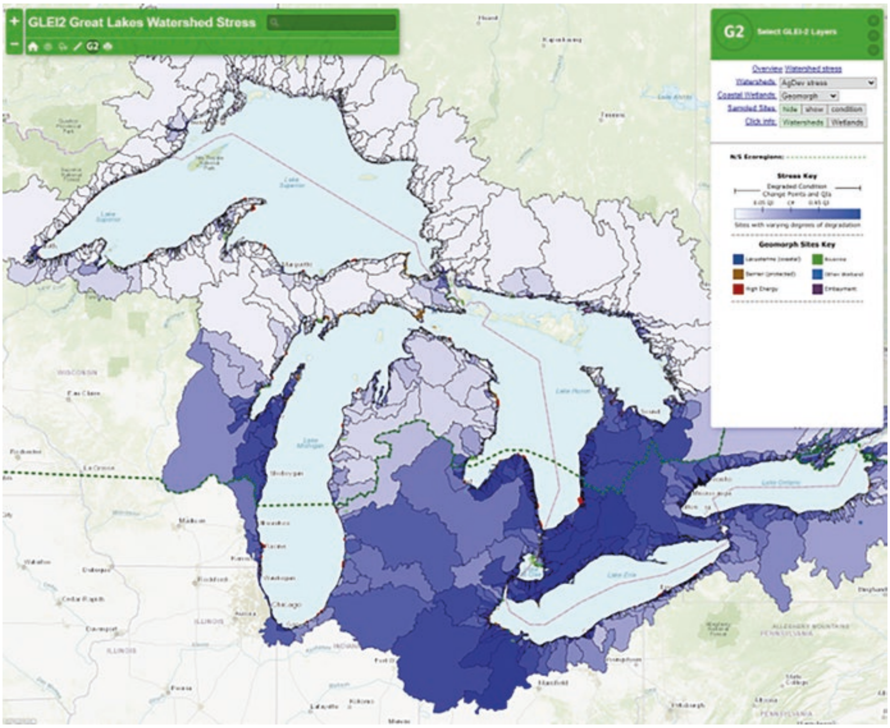

Fig. 3.2 Great Lakes Environmental Indicators (GLEI) Web-mapping interface

systems and processes leads to better management and outcomes for our state's natural resources and unique natural environment.

3.7 Center for Urban and Regional Affairs (CURA)

The Center for Urban and Regional Affairs (CURA) was formed in the 1960s, a period of unrest and foment concerning many aspects of urban life: poverty, inequality, poor housing, and underperforming education and health-care systems. The University of Minnesota's Board of Regents viewed CURA as consistent with its land grant mission to serve the state's needs as it does in its service in agriculture, health care, engineering, and other areas, emphasizing the importance of innovation, community engagement, and multidisciplinary effort to tackle a range of issues. CURA is a central place in a vast university that has fostered the ability to listen to community partners, to identify what needs to be done in cities across the state, and to bring the resources of the university to bear on those that are most pressing.

This role has meant conducting research on new spatial science methods and technologies, taking risks, and fostering perspectives open to new questions and experimentation. Fifty years of stories, relationships, programs, and results demonstrate that what the Regents created in 1966 is an urban and regional center that is responsive, innovative, and pragmatic to the core. It is somehow fitting that CURA's first acting director and first permanent director were both professors of Geography: Fred Lukerman (appointed in 1966) and John Borchert (started serving in 1968), respectively. CURA was and remains an all-university multidisciplinary center addressing public problems through building community relationships and connections to faculty and students in order to explore, incubate, and share. The use of spatial approaches at CURA can be traced back as far as the 1970s with studies in land use, wetland conservation, and statewide planning.

This important work remained active through the 1980s and 1990s with work in environmental justice and housing culminating in a formal position of GIS coordinator established in 2000. Two highly successful projects—MNIS and M3D, supported by federal grants—helped make GIS data widely available to the public. The Minneapolis Neighborhood Information System (MNIS) was a partnership with the City of Minneapolis that helped create the first known publicly accessible parcel database available for download as GIS shapefiles. Minnesota 3-D (M3D) expanded access to another publicly available census dataset, Longitudinal Employer-Household Dynamics, which had lacked a visual user interface. The LEHD data connects the home and work locations of all employed workers across the United States as well as some demographic data. These projects, and the training provided with them, increased the capacity of neighborhood groups, nonprofits, and local government planning agencies to use data for more effective decision-making. These and other public-facing service projects were occurring at a time of growth in spatial activities at the university. The National Science Foundation in the mid to late 1980s launched the National Center for Geographic Information and Analysis. CURA's Will Craig helmed an effort of the Urban and Regional Information Systems Association (URISA) to develop a research agenda from the user perspective. Craig and others presented this work at an international symposium the AAG sponsored in 1987 to establish the criteria used to judge NCGIA applicants and helped lay the foundation for initiatives that generally fell under the rubric Public Participation GIS (Craig, 1998).

These projects, while being valuable in and of themselves, also positioned CURA to create the permanent position of Community GIS (CGIS) Program Director in 2007. CGIS provides wide-ranging support and capacity-building opportunities for partner organizations in the university and community. It supports other CURA research, students in classes across the university, and continues to provide assistance to nonprofit organizations and local governments statewide. Collaboration with other university units like U-Spatial, Minnesota Population Center, Institute on the Environment, and the Humphrey School of Public Affairs has also been central to the mission. In order to support capacity building on an ongoing basis, CGIS offers training, data access, and technical assistance to community organizations and local governments in addition to mentoring and employing students.

In terms of projects, CGIS supports about 75–100 per year and has 5–10 active projects at a time, exemplifying the combination of research and service that is central to the university's land grant mission. One of those projects, undertaken at the behest of the East Side Neighborhood Development Corporation (ESNDC), highlights the importance of community-centered initiatives, which can both affect policy and improve neighborhood conditions. ESNDC was concerned that capital spending in St. Paul was inequitable and skewed away from neighborhoods with the most need. Following an analysis of the past decade's spending on capital improvements, we were able to show that this was indeed the case in terms of spatial variation in investment, leading the city to modify its selection criteria to reflect equity and geography into future spending decisions. Finally, CGIS connections to national organizations such as the Urban Institute's National Neighborhoods Indicators Partnership (NNIP) have been an important component to this work. This peer-learning network has fostered further collaboration, allowing us to lift up our work nationally and share our learnings and research with a broader audience. CURA was the first recipient of the Urban Institute's G. Thomas Kingsley Impact Award for its important work in St. Paul.

3.8 Expanding the Footprint of Spatial Service

It is impossible to capture the full gamut of activities around service on campus and beyond. Many activities focus on outreach and spatial approaches that serve the university's larger outreach mission, and we look at some of these in Chaps. 4 and 5. Mapping the lived experience of communities, and involving people in addressing the challenges they face, enables university staff to help develop better insights about the world. The University of Minnesota is often sought out by people and groups outside of the institution to provide spatial expertise on issues ranging from facilities planning, disease surveillance, and responding to climate change. Finally, U-Spatial and the university more generally offer community-based service-learning projects and internships alongside project-based courses and community learning courses, all of which harness our deep expertise in spatial data and approaches for the benefit of the broader community from local to global scales. Chapter 4 examines many of these efforts.

Another form of outreach and engagement focuses on alumni and a broader network of donors. Much of this work is by the University of Minnesota Foundation (UMF), a separate nonprofit that raises and manages gifts to the university. The foundation has brought spatial thinking into philanthropy, first exploring GIS with assistance from U-Spatial, which trained a UMF analyst in geocoding, mapping, and the use of demographic and marketing data within ArcGIS Desktop. UMF uses a combination of demographic data and individual donor data; due to the confidential nature of individual donor data, additional security protocols are necessary, and maps made within the foundation are primarily used internally. The foundation began to use mapping as a way to better inform their researchers and development officers in regard to who their donors are and how they maintain connections to the university. Using available spatial tools helps identify potential donors and inspire generosity. The usage of GIS has expanded since then, and analysts now use spatial tools to summarize donation trends, prospect for major gift donors in innovative ways, and support fundraising partners on campus with business intelligence. Another example of harnessing GIS to engaging with donors and alumni is how the university produced alumni maps by state legislative district since 2010 to help legislators understand the reach of university activities. The spread of alumni across the state was previously under-communicated and surprisingly unknown. The project illuminated untapped resources and recruiting markets, as well as some gaps in record-keeping in the university databases. The use of GIS for recruitment, student networking, and advocacy has been popular in admissions and alumni offices ever since.

Another form of using GIS to advance the university's service mission is to examine life on campus. The communication of university business and stewardship of its resources have been aided by spatial tools and data. For example, the Sustainability Office at University of Minnesota Duluth (UMD) used spatial data analysis in their Greenhouse Gas Report, a required document for signatories of the American College and University Presidents' Climate Commitment. Carbon attributed to vehicle emissions was estimated from a commuting distance analysis of faculty, staff, and student resident addresses. Another example is the student-driven crowdsourcing application was designed to gauge how students feel about the UMD campus. Students confidently identified areas on campus where they feel like doing certain activities such as studying and hanging out or where they may feel unwelcome. The data collected using this Web app was connected to student demographic data and used directly by UMD Student Life to steer campus design and programming in the future.

3.9 Conclusion

Spatial thinking and systems are central to many forms of service and provision of infrastructure at the University of Minnesota. This work reflects how the university has long been a spatial university in many ways and can build on many facets of spatial science that existed before the term "spatial science" came into use. The university can boast many successes, including the Minnesota Land Management Information System, MapServer, and other early foundational technologies and systems. Spatial approaches are used across a wide array of University Services and by organizations. It is important to focus on how the road to system-wide adoption and use of GIS and spatial technologies is often winding with the occasional dead end. The success of spatially enabled service at the University of Minnesota was made possible only by the work of hundreds of individuals over the course of decades. This effort in turn has laid the foundation for decades more.

References

Abler, R. F. (1987). The national science foundation national center for geographic information and analysis. *International Journal of Geographical Information Systems, 1*(4), 303–326.

Borchert, J. R. (1963). *Projection of population and highway traffic in Minnesota*. Minnesota Highway Research Project.

Brown, D. A., & Gersmehl, P. J. (1987). *File structure design and data specifications for water resources geographic information systems*. Water Resource Center.

Chrisman, N. R. (1997). Academic origins of GIS. In T. Foresman (Ed.), *History of geographic information systems: Perspectives from the pioneers* (pp. 33–43). Taylor & Francis.

Craig, W. J. (1998). The internet aids community participation in the planning process. *Computers, Environment and Urban Systems, 22*(4), 393–404.

Degani, A. (1969). Some computer and isodensitracer applications in geography. *Journal of the Minnesota Academy of Science, 36*(2), 104–109.

Foresman, T. (Ed.). (1997). *History of geographic information systems: Perspectives from the pioneers*. Taylor & Francis.

Johnston, C. A., & Naiman, R. J. (1990). The use of a geographic information system to analyze long-term landscape alteration by beaver. *Landscape Ecology, 4*(1), 5–19.

Johnson, L., Richards, C., Host, G., & Arthur, J. (1997). Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology, 37*(1), 193–208.

Johnson, L. (1990). Analyzing spatial and temporal phenomena using geographical information systems: A review of ecological applications. *Landscape Ecology, 4*, 31–43.

Knoth, L., Mittlböck, M., Vockner, B., Andorfer, M., & Atzl, C. (2019). Buildings in GI: How to deal with building models in the GIS domain. *Transactions in GIS, 23*(3), 435–449.

Lime, S. (2008). MapServer. In *Open source approaches in spatial data handling* (pp. 65–85). Springer.

McHarg, I. L. (1969). *Design with nature*. American Museum of Natural History.

McMaster, S., Edsall, R., & Manson, S. (2011). Geospatial research, education and outreach efforts at the University of Minnesota. *Cartography and Geographic Information Science, 38*(3), 335–337.

Pastor, J., Dewey, B., Moen, R., Mladenoff, D. J., White, M., & Cohen, Y. (1998). Spatial patterns in the moose–forest–soil ecosystem on Isle Royale, Michigan, USA. *Ecological Applications, 8*(2), 411–424.

Porter, P. W. (1991). Geographic cartography—A Minnesota tradition. *Cartography and Geographic Information Systems, 18*(3), 208–216.

Vatsavai, R. R., Shekhar, S., Burk, T. E., & Lime, S. (2006). UMN-MapServer: A high-performance, interoperable, and open source web mapping and geo-spatial analysis system. In *Proceedings 4th international conference on geographic information science* (pp. 400–417). Springer.

Chapter 4
Spatial Thinking and Learning

Brittany Krzyzanowski, Mark Lindberg, Paul Bolstad, Kate Carlson, Laure Charleux, Shana Crosson, Len Kne, Susanna McMaster, Robert McMaster, Steven M. Manson, Christopher Saladin, and Stacey Stark

Abstract The spatial university aims to help students learn to think spatially. This chapter outlines the many different ways in which spatial thinking presents throughout the University of Minnesota, beginning with an overview of the history of spatial science on campus and a discussion of how the curriculum has evolved over time. A description of the current curriculum is provided starting with the introductory level Geographic Information Science (GISc) coursework and spanning through the recently instated BA minor and the highly regarded MGIS program. We then present the ways in which spatial learning permeates beyond coursework and curricula using specific examples of organizations that facilitate spatially learning at the university including U-Spatial, GISSO, the GeoCommons, and the Esri Innovation Program. In addition to teaching GIS, we present a discussion of the use of Geographic Information Systems (GIS) as a tool for teaching, providing specific examples to convey the broad array of departments on campus that use StoryMaps

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and ArcOnline to teach a variety of topics. The chapter concludes with an examination of the impacts of the COVID-19 pandemic on the ways spatial science is being taught, focusing specifically on the shift to online learning. In sum, the spatial university builds upon its solid foundation to support spatial learning for a diverse assortment of departments and organizations in ways that ensure the continual growth and adaptation of GIScience education into the future.

Keywords Learning · Curricula · Coursework · Programs · Organizations

4.1 Introduction

This chapter describes the innovative ways in which the University of Minnesota is part of a larger movement focused on including spatial thinking across the curriculum. The NRC report *Learning to Think Spatially* emphasizes that spatial thinking is "an integrator and a facilitator for problem solving across the curriculum. With advances in computing technologies and increasing availability of spatial data, spatial thinking will play a significant role in the information-based economy of the twenty-first century" (2006). In addition to spatial thinking being a natural companion to instruction and student learning, education often serves as an entry point into spatial research, and there are many projects that combine research with learning, such as community-based service-learning courses or various kinds of outreach and extensions. Over the last 15 years, the US Department of Labor has highlighted the many career opportunities associated with geospatial technologies and pointed to the fast-growing geospatial economy (Adaktylou et al., 2018). Nevertheless, relatively few universities offer advanced programs to equip students to take advantage of these opportunities. This shortfall is especially troublesome given that spatial technologies enable students to excel in classroom activities and develop exciting service-learning projects in their communities.

4.2 Training the Next Generation of GIS Professionals

It's easy today for anyone with an Internet connection to create maps and perform *real* spatial analysis. Web-based applications ("web apps") make it simple to enrich datasets without days of searching for and harmonizing datasets. For this reason, Web-based GIS has exponentially increased the number of people using GIS. It's no longer the case that you need to be a GIS professional, nor do you need to learn complicated software to make maps, perform spatial analyses, access a wealth of data, or share maps with the world. Anyone can "do GIS"—and this is encouraging as it brings the broader workforce one step closer to achieving spatial awareness.

On the other hand, given the rise of free, easy-to-use GIS and the onslaught of new, inexperienced users, we must acknowledge the fact that being able to do GIS does not necessitate spatial thinking, and this means that a novice GIS user is at risk of misusing, misrepresenting, and misinterpreting spatial data. Building a spatial university is a crucial first step toward pushing our systems and structures to engage in good science. An important job in education (K–12 as well as higher education) is to ensure that everyone entering the workforce can engage in spatial thinking.

Spatial literacy is critical because the misuse of easy-to-use GIS tools can have dire implications. For example, it is now easy to drag and drop a file of addresses into ArcGIS Online and have the data instantly geocoded without any effort from the GIS user. Moreover, with ArcGIS Online's enrichment tools, the map creator has access to thousands of variables from the US Census, American Community Survey (ACS), and other proprietary datasets that can be unreliable in certain instances. There is no feedback on the accuracy of the geocoding and underlying data, and oftentimes, huge variances exist within the freely available ACS data when it is provided in small geographic areas (Spielman et al., 2014). In other words, a novice user is less aware of important problems in data science such as the modifiable areal unit problem (where analytical results can change according to how data are aggregated) or spatial p-hacking (rerunning analyses until the results look good). There are a variety of ways in which the results obtained by novices could easily be inflated or inaccurate.

Another example of the risks can be seen in Artificial Intelligence (AI), which has become commoditized and democratized with inexpensive cloud computing on Microsoft, Amazon, and other platforms. More and more people are getting into geospatial computing through machine learning—many from data and computer science. The problem is that if training in GISc fundamentals is not emphasized in other domains, the analysis produced on these systems can overlook the influence of key geospatial factors such as map projections, scale, topology, and spatial autocorrelation. The implications can be great, as when neglecting to account for the distortion in distance and area calculations found in the near-ubiquitous Web Mercator (Battersby et al., 2014).

In order to encourage proper use and interpretation of spatial tools—in this time when GIS is easy to use, widely available, and increasingly being taken up by novice users—we need to integrate spatial thinking into as many aspects of learning as possible. Building the spatial university does just this by merging technical and scholarly infrastructure in ways that encourage the adoption of GIS a broad range of learning and research. A spatial university offers to stimulate interdisciplinary collaboration and provide new approaches to data sharing, technical training, and cutting-edge geospatial applications in ways that support campus facilities and foster interaction with local communities.

In order to achieve the spatial university and support the broader learning and research goals of academic institutions, GISc departments must evolve with the direction of spatial science. As GISc and technology advance, the duties and roles of the GISc professional also evolve. The field is changing fast, and it's no longer enough to teach GISc students the software packages as was done in the early 1990s. Now, teaching must focus on improving students' critical thinking and problem-solving skills. These students will be challenged to continually learn new tools and techniques as the discipline grows in accordance with the zeitgeist of data science, and students must learn to take advantage of disruptive change in the field by changing along with it.

4.2.1 Evolution of GIS Infrastructure

Change is inevitable in every discipline, but GIS data and systems have rapidly evolved. They are driven to stay relevant by keeping up with the advances of fundamental technologies in the field of computer science. There were two major transition periods that marked the evolution of GIS, the first being the workstation-to-desktop transition and then the desktop-to-ubiquitous revolution that kicked off in 2005 (Fig. 4.1).

The workstation-to-desktop transition began in the 1980s. The Sun SPARC Workstation was the favored hardware platform for much of the 1980s and 1990s, but the workstation-to-desktop transition saw GIS was moving away from this expensive specialized hardware to relatively less expensive commodity personal computers. "Doing GIS" changed from running command-line software on a high-end workstation to running software on much less expensive PCs equipped with operation systems and programs employing graphical user interface (GUI). This change allowed for many more GIS users, and the production of data was no longer limited to government agencies, large utilities, or universities because GIS relied less than before on highly skilled specialists to program the software in a command-line interface.

The desktop-to-ubiquitous revolution started in the mid-2000s. That decade saw the launch of Web-based mapping systems that eventually included household names like Google Maps, Google Earth, and MSN Virtual Earth (now Bing Maps). This second major transitory period came during a time when immense changes were happening in the way we connected across the globe through Web 2.0, the term given to Internet applications that allowed users to create and share content. The fact that content could be created by anyone with an Internet connection gave rise to the concept of neogeography, the use of GIS by nonexperts to create maps for personal or community applications (Turner, 2006). The number of Web-mapping

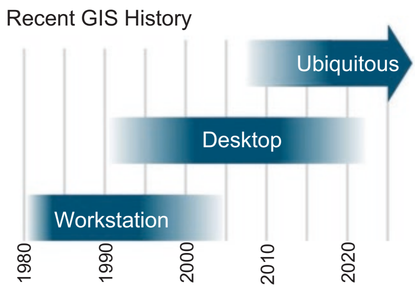

Fig. 4.1 The three different phases of GIS as they overlap through time

platforms available to the public grew rapidly, making it so that projects that were once restricted to the desktop could now be performed readily by anyone with a Web browser. In the span of four decades, GIS transformed from one characterized by expert control of geospatial information on high-end workstations to an open and nearly ubiquitous public enterprise.

Given how quickly these two major transitions occurred, there is much variability in terms of the strategies, tools, and expertise that characterizes the workforce. For example, freshly minted students know more about the newest GIS software and scripting languages than most actively working GIS professionals because, as students, it was their full-time job to explore and learn the latest and the greatest. That being said, students and recent graduates may be required to work with older GIS even when they are prepared to start over with newer systems. Therefore, students and graduates must strike a balance between learning existing systems while continually advocating for change. The spatial university helps them achieve this balance by offering adaptable GIS coursework and curricula that evolve in line with the ever-changing nature of the field.

4.3 Courses and Curricula

The University of Minnesota offers courses and curricula with both breadth and depth in spatial thinking. There are over 70 courses in GIS or related topics that contribute to five undergraduate, three masters, and several doctoral programs. This number is expected to increase as interest in spatial science grows and GIS is taken up by more and more disciplines. For decades now, the University of Minnesota's various degree programs drive, and support the need for, a range of courses.

Since the 1970s, academic cartography and other spatial science precursors existed on campus via a focus on teaching basic cartography, but computerized cartography and mapping were among the topics covered, along with cognate areas like air photo interpretation and spatial methods. The University of Minnesota was in the top ten universities nationally in terms of offering coursework in cartography, alongside other larger land-grant institutions, including the Ohio State University, University of Wisconsin, and University of Michigan (Dahlberg, 1977). As one would guess, the key to having course offerings was having at least two faculty members working in cartography and related areas, and the University of Minnesota fit the bill. While the Department of Geography was (and remains) home to much of this activity, teaching capacity continues to be spread out among many departments, especially when considering expertise in photogrammetry, remotely sensed imagery, databases, and engineering. As explored in Chap. 3, there have long been dozens of scholars teaching and doing research in spatial science or its precursors. Porter (1991) examines past course offerings and provides a fascinating snapshot of the evolution in what are essentially spatial science courses before spatial science existed (Fig. 4.2).

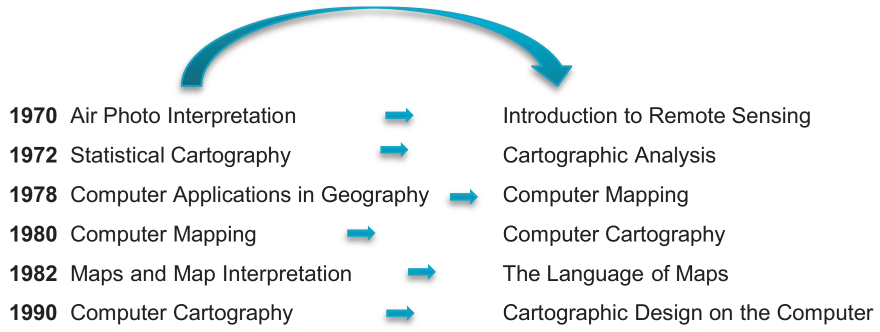

Fig. 4.2 The evolution of the computerized mapping and other spatial technology courses

Today, the University of Minnesota offers several interrelated programs and degrees. One of these, the Master of GIS program, was one of the first professional degrees in GIS and is among the most recognized programs in the nation. In terms of degrees that offer GISc specialization, there are also two MS programs (Forest Resources and Geography) and three PhD programs (Computer Science, Forest Resources, and Geography). PhDs specializing in GIS are available from both the Geography and Forest Resources Departments. Computer Science has an informal focus on spatial databases and spatial data mining. Geography offers one undergraduate GISc major and one minor that informally specializes in GISc. It was in the best interests of students (and the general campus GISc enterprise) to emphasize an interdisciplinary minor as opposed to formalizing the existing GISc minor.

Similarly, there is a long history of non-GIS courses that examine the relationships between spatial technologies and society, including the study of its ethical, legal, political, and public dimensions. Thousands of faculty, staff, and students on campus work with mapping software, and hundreds more are picking up a range of mapping and spatial analysis resources through engagement with a variety of academic units in addition to central units such as the Libraries. Of note, the University of Minnesota has long had a relationship with Esri. The firm's founder, Jack Dangermond, attended the university in the late 1960s, and he received a Master of Architecture degree in 1969. While here, he took courses from John Borchert. Dangermond, who had an undergraduate degree in landscape architecture and environmental science, came to the University of Minnesota to take courses from Buckminster Fuller, a visiting professor. Dangermond went on to found Esri, the world's leading GIS firm, and when he received his honorary doctorate from the University of Minnesota in 2008, he stated, "I learned to think spatially from John Borchert."

There is a concerted effort to get more people interested in teaching GIS courses and to better link the various people offering courses to reduce replication, increase coverage, and drive more students to existing offerings and help develop new ones.

While there will always be a need for discipline-specific introductory GIS classes, we seek to better coordinate to reduce overlap, to ensure common material, and to provide better pathways into advanced courses. While many of the courses and curricula at the university are focused on spatial science topics, we have many more courses that incorporate spatial thinking alongside other foci. As part of this effort, U-Spatial has joined other units, such as Enterprise GIS (part of U-Services described in Chap. 3) and the Libraries, in making spatial tools like Web mapping and spatial data readily available to instructors. These units also exemplify the spatial university by developing strategies that encourage adoption of spatial approaches in teaching, such as setting up assignments, developing StoryMaps (Web-based maps and text), and providing free and open educational materials like textbooks and labs. Finally, the University of Minnesota is a leader in developing massive open online courses for tens of thousands of students on spatial topics including Spatial Computing, Health Informatics, and GeoDesign.

4.3.1 Introductory Courses in Spatial Thinking

Another avenue for weaving spatial thinking into a wide array of courses, including introductory ones, is focusing on the general education requirements that most universities use to ensure that students get a broad education. The University of Minnesota terms these "liberal education requirements," and they are designed to be woven through the undergraduate experience, reflecting how our faculty are dedicated to offering an education that invites students to engage in new ways of thinking as an active citizen and lifelong learner. The "Technology and Society" thematic requirement has been very helpful in rolling out spatial thinking as a part of many courses, although other themes, including mathematics and social sciences, are also good entry points for spatial approaches.

Courses that meet the goals of the Technology and Society theme explicitly consider how technology acts in society along with how society shapes, uses, and responds to technology. To satisfy the Technology and Society theme requirement, a course must meet key criteria where students (1) examine one or more technologies that have had some measurable impact on contemporary society; (2) build understanding of the science and engineering behind the technology; (3) discuss the role that society has played in fostering the development of technology as well as the response to the adoption and use of technology; (4) consider the impact of technology from multiple perspectives that include developers, users, consumers, and others in society affected by the technology; (5) develop skills in evaluating conflicting views on existing or emerging technology; and (6) engage in a process of critical evaluation that provides a framework with which to evaluate new technology in the future.

By way of example, one of the largest courses on campus that meets the Technology and Society theme requirements is "Mapping Our World." In terms of meeting the six goals described above, the course examines one or more technologies that have had some measurable impact on contemporary society. Specifically, it examines the measurable impacts mapping technologies have on society. Students discuss how mapping is a trillion-dollar enterprise that fuses fast-evolving technologies with rapidly changing societal practices. The course asks questions about what these changes mean for individuals and society, such as asking students to consider how the ubiquity of both Web-based and mobile-mapping technologies has impacted the way we understand and relate to the world.

The course also builds student understanding of science and engineering behind geospatial technology. In examining data, for example, students examine how the Global Positioning System (GPS) works and the limitations of its functionality. They look at similar issues around the basic science and engineering of spaceborne platforms, drones, and ground-based cameras or how crowdsourced maps compare to more traditional atlases in their accuracy and adaptability. Students discuss how these different methods of gathering mapped data affect the way these maps are used.

Students discuss the role that society has played in fostering the development of technology as well as the societal response to the adoption and use of technology. Throughout the course, students examine the role that society has played in fostering the development of mapping technology, including the long-standing impact that society has had on developing mapping technologies, ranging from the impact of the printing press on paper maps to development of computers and satellites on digital mapping. They dig into the social and technical dimensions of the fact that mapping technologies such as satellite imaging of the earth, GPS units, or the spatially aware Internet owe their existence and continued evolution to military research. They also examine the implications for individuals and society of how private companies, and not governments, are now the largest collectors of spatial data about people and places.

Students consider the impact of technology from multiple perspectives that include developers, users, consumers, and others in society. This includes exploring how many different cartographic methods can be used to bend the truth, sell a specific perspective, or simply lie about the state of the world. Students develop skills in evaluating conflicting views on existing or emerging technology and engage in a process of critical evaluation that provides a framework with which to evaluate new technology in the future. Students create their own maps and experiment with different technologies of map creation and step through questions necessary to understanding the ethical dilemmas posed by situations such as security camera surveillance, crime mapping, and gerrymandering electoral districts.

Mapping Our World is just one of many courses in which spatial thinking plays a significant role. Beyond the theme itself, many courses are well served by focusing on spatial tools like Web mapping that are readily available to instructors so they can use this approach to the point where meeting the thematic requirement is a small step.

4.3.2 Teaching a Foundational GISc Course

A spatial university requires broad access to the foundations of spatial science, and one core way of ensuring access is teaching a foundational GISc course. Extending the curricular reach of a large university requires teaching the many students, often with diminishing resources, across the arts, social sciences, and physical sciences. This is particularly challenging in combined lecture and laboratory courses, with active synthesis using current commercial software new to much of an expanded target audience. A combination of old and new teaching approaches, deep cooperation across departments, and purpose-written materials have helped immensely in offering foundational GISc courses on campus.

There are two foundational GISc courses on the Twin Cities campus that offer deeper engagement than what is usually found in an introductory course (although these other courses offer valuable education in GIS). GIS for Natural Resource Management is offered in the Department of Forest Resources, and its companion is the Principles of GISc in the Department of Geography, Environment, and Society. Both courses use the same text and offer much in common, which allows students on campus to substitute them for each other as necessary to meet degree requirements in addition to having more scheduling options. The primary difference is that as one would presume, GIS for Natural Resource Management uses examples that are drawn from the natural, biological, and environmental sciences, while principles of GISc have more socially oriented subject matter. Both courses are four credits (as compared to the standard three-credit class), which allows instructors to build in more hands-on experience alongside a deeper engagement with the material. This said, there are other valuable three-credit introductory GIS courses on campus that focus more narrowly on specific domains, such as public health or planning and policy analysis.

Here, we focus on GIS for Natural Resource Management. This course exemplifies how to create scalable introductory courses offered year-round, with the goal of never rejecting a student due to course capacity, while maintaining high learning standards. This entry course mixes in-person and online instruction, synchronous and asynchronous presentations, and flexible learning modes. Enrollments over the past two decades have grown from approximately 80 students to over 500 students annually, with the addition of only 0.5 instructor full-time equivalents (FTEs). All lectures are provided both in person and online, which students may attend and/or review at their option. Online lectures are split by topics, typically 5 to 20 minutes, so students may learn, review, and apply more difficult concepts a la carte. Each week starts with a reading quiz, spurring students to come prepared for lectures, along with weekly labs that reinforce theory and teach practical software skills. Any student may come to in-person lecture as needed when they find a topic particularly challenging or worthy of in-person interaction. Exams are viewed as learning opportunities. Online, timed, multiple-attempt exams every 2 to 3 weeks cement knowledge, with students encouraged to review materials and discuss solutions between attempts. A large bank of related questions drawn at random within each topic prevents "studying to the test," and fixed drop-in and scheduled help sessions, both in person and online, allow individualized attention for specific topics. Recurring requests on any topic or concept spur new or more explanatory videos, an example case study, solved example problems, or other resources to help reach the learning objective, creating a rich online library of resources over time.

Teachers in multiple departments engage in varying degrees of coordination across introductory courses across the university in order to make them interchangeable prerequisites for advanced offerings. Topics, the required textbook, sequencing, and coverage are coordinated across departmental versions of the foundational course so that the versions are interchangeable programmatically across majors. This coordination has helped students by reducing duplication and has led to collaborative undergraduate and graduate minors; freed up resources for mid-sized, advanced courses; and enticed a wide range of students and majors into advanced courses. Purpose-created materials are also important. The success of the two four-credit foundational courses is due in part to sharing the same introductory text. Paul Bolstad, in the Department of Forest Resources, has written a comprehensive 700+ page textbook, *GIS Fundamentals*, which has been adopted at the University of Minnesota and at over 400 other colleges and universities (2002). Currently in its sixth edition, it is written in a chapter sequence corresponding to each week's topic, is software-neutral, and describes the concepts behind data, structures, processing, and analysis, with study questions and worked examples. Weekly quizzes are based on readings, and example videos reinforce topics with case studies, worked examples, and alternate explanations. Custom-written laboratory exercises focus on key concepts while also teaching practical skills in common commercial software.

In sum, quality student-centered instruction tied to cross-departmental cooperation and institutional flexibility is key to offering a successful and broad-service foundational course experience. Given current funding models and long-standing disciplinary rivalries and biases at many universities, there are strong centrifugal forces toward an "only taught here" mentality. This is particularly true for large enrollment, revenue-generating courses. There are strong incentives to balkanize base instruction, often to the detriment of building a taller pyramid of more-specialized courses. Resisting these incentives can lead to a stronger and more cohesive student experience while freeing up resources to build out other parts of the spatial science curriculum.

4.3.3 Interdisciplinary Undergraduate Minor

The university created an undergraduate minor in GISc in 2009. At the time, the rise in demand for GISc research and education at the national and international scale was mirrored on campus with demand for this undergraduate minor. The University of Minnesota's MGIS program was very successful, and many PhDs graduated with

GISc or geospatial technology as a primary or secondary focus. Due to this success, there was a pivot on the part of several departments (including Geography, Forest Resources, and Computer Science) toward further developing the undergraduate experience in GISc. Given that there were several existing undergraduate majors that had GISc elements, multiple stakeholders in these departments decided to develop one of the very few interdisciplinary undergraduate minor programs on campus.

The motivation for developing the minor was the sense that the missing piece for GISc education at the University of Minnesota was a cohesive undergraduate experience in GISc. Faculty spoke to many undergraduates, alumni with GISc experience, and members of the GIS Student Organization (GISSO) about GISc on campus. These students and alumni indicated they are very satisfied with their decision to focus on GISc. Graduates have an excellent record of going on to graduate school in a variety of fields and getting challenging jobs with employers in the private sector, academia, government, and nongovernmental organizations. This success complements the long history of GISc development and application in the Twin Cities and Minnesota. It was clear (and remains clear) that the University of Minnesota is home to a large number of students who are interested in GISc as part of their undergraduate career.

The level of interest in GISc and the success of undergraduates existed despite the absence of a cohesive undergraduate GISc experience. Many of the students with whom the faculty members spoke expressed the desire for a formal minor in GISc. There was an undergraduate GISc "track" in a number of majors, but students said they felt pressure to double major in one of the existing degrees in Geography, Computer Science, or Forest Resources to take advantage of the track. There was an undergraduate minor in Geography that informally specialized in GISc, but students argued that this informal focus did not send a strong enough signal to potential employers or graduate programs. A dedicated GISc minor gave these students what they wanted while also addressing the needs of the larger communities and publics of which they are part.

The minor is going strong a decade after it was created. It serves about 50 students at any one time and has consistently grown over time. A faculty committee meets regularly to employ several complementary strategies to keep the minor relevant to students and employers. These strategies include conducting periodic nationwide assessments of GISc education, review of existing university courses and degrees in GISc, and consulting with GISc faculty and students. This process ensures that the minor remains accessible and relevant to a broad range of students from almost every college. At the same time, the minor is designed to complement existing offerings and create synergies for students while not taxing instructional, infrastructural, and advising resources. Faculty members believe the minor creates efficiencies by reducing curricular overlaps and by pooling resources and experience across departments and colleges.

4.3.4 UMD GIScience BS Degree

The University of Minnesota Duluth campus (UMD) offers the only undergraduate GIS major in the state and is one of the earliest in the country (2012). As a city, Duluth is seated within one of the largest counties in the United States and is home to industries and agencies whose operations span the Northland Region. Motivated by sheer scale, many of these actors have been longtime innovators in the implementation of GIS operative solutions, leading to the establishment of a strong local professional GIS community. UMD has played an organic role in this community, including through the gradual development of curriculum. It started with computerized cartography, which was integrated to the Geography curriculum in the 1990s, and continued with the introduction of a GIS certificate in the 2000s, which led to the creation of a GIS major and a GIS minor in the early 2010s. While the majority of GIS students, like the majority of UMD's students, are from the Twin Cities area and develop careers there, each graduating class adds UMD alums, trained on the latest technologies, to the local GIS community.

In turn, local professionals play a critical role in mentoring students as internship supervisors and in strategizing the evolution of the program. While GISc is a fast-evolving and growing discipline, university resources are limited, and students graduate with a fixed number of credits. This means a continuous process of evaluation, forecast of needs, and reallocation of resources is necessary. Each year, the graduating class conducts a program assessment based on their experiences and shares the results with faculty and professionals during a retreat, where action steps are collectively discussed and adopted. This process, for example, identified years ago the growing need for GISc graduates to know how to use and write scripts in various programming languages. UMD was one of the very first GISc programs to introduce programming classes at the undergraduate level, which are now required for all students.

The vast majority of UMD's GISc graduates begin their careers upon graduation. Ninety-three percent of them work in the GISc or a GIS-related industry, despite half of them graduating with a double major in a different field. The occasional students who want to pursue graduate studies have all been successful in different programs. The MGIS degree on the Twin Cities campus, however, is a favorite and is seen as a natural progression for UMD's students.

4.3.5 MGIS Program

The Master of Geographic Information Science (MGIS) program at the University of Minnesota is highly regarded by its graduates. Minnesota's MGIS program was initiated in 1997 in the midst of booming interest in GISc, and as one of the first of its kind, the program served as a model for other institutions that were interested in expanding their degree offerings. The program intentionally evolves along with the dynamic nature of the highly technical and ever-changing discipline of GIS. In order to achieve this, the program maintains state-of-the-art facilities, associated IT support, and outstanding GISc faculty while at the same time frequently revising its curriculum to align with the zeitgeist of the field and feedback from students.

One way to ensure the program's curriculum is keeping up with the times by cross-checking the content of our courses to ensure that they address the central topics of the field, and the most official catalog to date is the UCGIS Body of Knowledge (BoK) Project (DiBiase et al., 2006). The BoK was created to fill the need for a resource that summarizes all things GIScience in a domain that is always growing and evolving. The first edition of the BoK was written in 2006 as a part of the Geographic Information Science and Technology (GIS&T) Model Curricula initiative. This book has been elaborated on over the years, and today, the BoK includes more than 330 topics organized into 73 units and 10 knowledge areas. Each topic reflects a formal educational objective that GISc instructors can use to help guide the development of assignments, readings, and activities.

Curriculum planners can use BoK as a reference to help them serve learners at all levels of higher and continuing education. At the University of Minnesota, the curriculum planners use the BoK to ensure that the key elements of GIScience are addressed within the coursework in the MGIS program. Figure 4.3 illustrates the extent to which 31 GISc courses offered at the University of Minnesota address the ten main knowledge areas of BoK. At the university, 9 out of the 10 BoK knowledge areas are completely covered by the coursework offerings, and one knowledge area (GIS&T and Society) is nearly completely covered. The BoK allows curriculum planners at the University of Minnesota to stay up to date with the directions of the field while also making better judgments about what knowledge areas are being neglected and might require more attention by existing coursework or the potential development of a new class.

The University of Minnesota's MGIS program enrolls approximately 12–14 new students each year with an intended 2-year completion time frame. As online education increases, the program is one of the few remaining residential programs. This allows the program to be customized, enabling students to pursue a degree suited to their career goals, whether that has them focusing on coursework related to earth science or computer science or emphasizing much-needed professional experiences by strongly encouraging internships and hands-on projects and requiring portfolio building and professional presentations. Whatever the route, the MGIS program promises to expose students to critical knowledge as well as practical experience. In addition to offering a top-notch academic experience, the University of Minnesota's MGIS program is connected to various organizations on and off campus, which has provided professional and volunteer service experience in the context of the real world. The majority of MGIS students work actively on GIS projects around campus and in the community in areas including public health, veterinary medicine, and University Services, as well as local community organizations and local, state, and federal government agencies. Additionally, it is not uncommon for MGIS students to serve as teaching assistants or to have research assistantships during their time in the program. In fact, even though funding is not guaranteed for MGIS students, GIS&T BoK Topic Area Coverage by Course

○ Introduces
● Comprehensive coverage

	Analytical Methods	Conceptual Foundations	Cartography & Visualization	Design Aspects	Data Modeling	Data Manipulation	Geocomputation	Geospatial Data	GIS&T and Society	Organizational & Institutional Aspects
Algorithms & Data Structures	◔	◔	◔	◔	◑	◑	◔	◔	○	○
Internet Programming I	◔	◔	◔	◔	◑	◑	◔	◔	○	○
Internet Programming II	◔	◔	◔	◑	◑	◑	◔	◔	○	○
Spatial Databases (CS)	◔	◔	◔	●	◕	◑	◑	◕	○	○
Introduction to GIS	◕	◑	◑	◑	◕	●	◔	◕	◔	◑
Geodesy for GIS	◑	○	◔	◕	◕	◔	◑	●	◔	◔
Remote Sensing	◔	◔	◔	◔	◔	◔	◑	●	◑	◑
GPS for GIS	◑	○	◔	◑	◑	◑	◑	●	◔	◔
GIS Practicum	◔	◑	◔	◕	◑	◑	◔	◕	◔	◑
Drone Remote Sensing	◑	◔	◑	◕	◑	◑	◑	●	◔	○
Real Estate	◔	◑	◔	◔	◔	◔	◔	◔	◕	◑
Cartography	◔	◑	●	◑	◑	◕	◑	◕	◕	◑
Numerical Computing	◑	◔	◔	◕	◑	◕	◕	◔	◔	○
Geocomputing	◑	◔	◑	●	◑	◕	◑	◑	◔	○
Spatial Analysis	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑
Principles of GIS	◑	◑	◑	◑	●	◕	◔	◕	◑	◑
GIS Practicum	◑	◑	◑	◑	◕	◑	◑	◑	◑	◑
Advanced GIS	◕	◕	◑	◑	◕	◕	◔	◑	◑	◔
Urban GIS	◑	◑	◔	◑	◔	◑	◔	◔	◑	◑
Advanced Geovisualization	◕	◑	◕	◑	◕	●	●	◕	◑	◑
Analysis of Human-Environment Systems	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑
ArcGIS 1	◑	◕	◑	◑	●	◕	◑	◕	◑	◑
ArcGIS 2	◕	◕	◑	◑	◕	◕	◑	◑	◑	◑
Digital Mapping	◑	◔	◑	◑	◕	◑	◑	◑	◔	○
Web GIS	◔	◔	◕	◑	◑	◑	◑	◕	◔	○
Spatial Databases (GIS)	◔	◔	◔	●	◕	◑	◑	◔	◔	○
Spatial Humanities	◔	◕	●	◔	◔	◑	◔	◔	◑	◑
GIS Programming	◑	◔	◔	◑	◔	◑	◔	◔	◔	○
Seminar in GIS, Technology & Society	●	●	◕	◕	◑	◑	◕	◕	◑	●
Project Management & Professional Dev.	◑	◑	◑	◑	◑	◑	◑	◑	◕	●
Max	●	●	●	●	●	●	●	●	◕	●

Fig. 4.3 Matrix of GIS&T Body of Knowledge topic area coverage by University of Minnesota course

between 50 and 65 percent of these students are at least partially supported by a TA or RA position. This figure is rather impressive considering that not all students seek support.

After completing the MGIS program, University of Minnesota graduates are considered rather competitive, working in both the public and private sector. The MGIS website includes a complete listing of program graduates and their job placement. Most students get job placement within 0 to 3 months postgraduation; some even secure jobs when they are still in the program. Forty to fifty percent of students find jobs out of state or the country, but a surprisingly high number of students stay local (50–60 percent). Increasingly, a number of MGIS students pursue doctoral degrees either at the University of Minnesota or at other institutions, nationally and internationally. The program also benefits from maintaining strong ties with their alumni who serve as mentors, instructors, advisers, board members, and donors.

4.4 Learning Beyond Coursework and Curricula

There are a variety of centers, programs, and organizations on campus that provide collaborative learning environments and training experiences above and beyond that which is offered through our courses and curricula. These institutions help to further prepare our students to apply the knowledge and skills garnered from their classroom experiences in higher education or professional positions. In this section, we present the specific programs at the University of Minnesota that help to prepare the workforce of tomorrow, including U-Spatial, the GeoCommons, GISSO, and the Esri Innovation Program.

4.4.1 U-Spatial

In expanding on our discussions of U-Spatial from previous chapters, we now touch on the ways in which U-Spatial serves as a hub for spatial teaching and learning. U-Spatial works with hundreds of graduate students across campus by providing spatial support for their projects, ensuring the next generation of faculty and researchers will be thinking spatially. In one instance, U-Spatial consulted with graduate students in preparation for a trip to Jamaica in which students mapped breadfruit trees for the Trees That Feed Foundation. U-Spatial advised the group on purchasing a GPS camera, provided training on mapping the photos, and developed a simple Web map that the students could use during data collection. In another example of spatial support, U-Spatial assisted a PhD candidate from the Sociology Department with finding and managing data for conducting spatial analyses of genocide events in Bosnia, Rwanda, and Sudan. In another instance, U-Spatial modified a GeoDesign drawing app for use in a Landscape Architecture class (Slotterback et al., 2016). Students used the app to familiarize themselves with the concepts and then designed real features using an ArcGIS Online template map. U-Spatial also assisted with the River in the Classroom Project, which involved two undergraduate classes that wanted to learn how to integrate ArcGIS Online StoryMaps within their class projects. One class created a swipe map that allows users to compare imagery from the I-35 bridge collapse in Minneapolis with current aerial photos.

In addition to providing free spatial research consulting for students, faculty, and staff, U-Spatial offers short training courses, such as GIS 101, that may be used for general introductions to a topic or tailored for specific classes, such as an undergraduate history course in which students used mapping for their final projects. While there is a vast catalog of online training available, there continues to be a steady demand for in-person, instructor-led workshops. Other training courses offered by U-Spatial focus on teaching cartography, Web mapping, and specialty topics such as lidar. Each class is generally half a day long and offers lectures, exercises, and data. A small $10 charge for most workshops helps ensure attendance. While community members are charged to attend U-Spatial workshops, it is seen as a small but consistent revenue source.

In sum, U-Spatial continually develops partnerships on campus to aid scholars addressing the mounting need to advance spatial thinking in education on campus. It supports students who are learning to include spatial sciences in their research. More importantly, it points to the importance of interconnections between research and the classroom at a research university, such as assisting with data preparation and access to the ArcGIS Online mapping platform. U-Spatial offers one-day GIS courses that complement a wide array of standard, credit-bearing offerings. As a spatial hub that provides research support and GIS training, U-Spatial helps to create tailored educational experiences for thousands of students, staff, faculty, and community members.

4.4.2 GeoCommons

The GeoCommons is an interdisciplinary hub for geospatial research, teaching, and outreach on campus. Housed in the College of Liberal Arts, it is quite simply "a place to talk about space" at our spatial university. The GeoCommons is the most recent component of our spatial university and is still in active development. Its physical space is being created via a major renovation in Blegen Hall, a teaching-oriented building of classrooms and lab on campus. The GeoCommons will provide a mixed-use activity hub, geospatial technology play-space, and a collaborative work area for students, staff, and faculty exploring geospatial and mapping projects. Additionally, the GeoCommons promises to broaden outreach to various publics in the Twin Cities and greater Minnesota. The GeoCommons is designed to align with other spatial units across the university described in Chap. 5, including Research Computing (Minnesota Supercomputing Institute, U-Spatial, and the Informatics Institute), Institute for Social Research and Data Innovation, Institute on Environment, the Borchert Map Library, Polar Geospatial Center, and others.

The GeoCommons also serves to bridge education and research. Students in professional programs such as MGIS and Master of Data Science do not always have the opportunity to engage in research, but the GeoCommons is open to all students to explore and engage in research opportunities with a community of spatial learners. Cross-fertilization of ideas and individuals across disciplinary domains creates rich learning experiences for students and faculty alike. Undergraduate students will also have the opportunity to engage in cutting-edge projects. Courses can more easily engage topics and use technologies that are available in the GeoCommons compared to a traditional GIS computer lab, for example.

4.4.3 GISSO

Another on-campus resource for those interested in spatial science is the GIS Student Organization (GISSO). GISSO was founded by students of the MGIS program in 2001 and has continued to serve graduate and undergraduate students from across campus who have interest in GISc. GISSO is primarily composed of students from the geography and GIS programs at the university. However, GISSO also has members coming in from other parts of campus such as the School of Public Health and the Computer Science. GISSO provides all students interested in GIS with opportunities to participate in GIS-related conferences, field trips, and various social and professional events, including GIS Day activities and the University of Minnesota GIS Career and Networking Fair.

GISSO's biggest event is the GIS Career and Networking Fair. The first annual GIS Career and Networking Fair was held in 2002, and since then, it has grown into a large event that draws GIS students from all over the region to a forum to network with potential employers in the public, private, nonprofit, and academic sectors. The fair invites anyone with interest in pursuing a career in GIS and hosts a range of professional GIS speakers, a vendor hall, and a resume review with GIS professionals. The goal of this career fair is to build a bridge between students who utilize GIS, GIS enthusiasts, and employers around the region by providing students with opportunities to network and share research. GIS professionals also look forward to the fair to catch up with their colleagues. GISSO contributes to the spatial university by bringing students of all stripes together and connecting them with potential employers, internships, and other GISc opportunities that span a broad array of disciplines.

4.4.4 Esri Innovation Program

The University of Minnesota hosts the Esri Innovation Program (EIP). This program was built to enhance spatial learning by forming partnerships between Esri and higher educational institutions across the world, including the University of Minnesota. The EIP was designed to promote innovation in the GIS industry in a way that aligns with workforce needs. By building a partnership between industry and education, the EIP supports the goals of both Esri and higher education by promoting high-quality GISc research and teaching. This partnership connects students and staff at EIP universities directly with support from Esri and a community of peers. Students from EIP universities have access to the latest geospatial technologies supported by the ArcGIS platform which, in turn, supports the growth and direction of the industry while providing students with the technical expertise needed to contribute to the ever-growing domain of GIS.

The University of Minnesota became a member of the EIP in 2009 (at that time known as the Esri Development Center), operating out of the University's Cartography Lab until 2021, when the EIP was moved to U-Spatial. The EIP is primarily affiliated with the MGIS program, but it welcomes students from all across the campus. The only requirement for memberships is that a person has formal student status and that they are doing GIS development work with Esri technologies. EIP institutions, including the University of Minnesota, are all connected in one big community network that is continually growing and developing via inter-university collaborations. These kinds of connections and collaborations offer ways to push the industry to develop tools and technologies that help universities reach their goals of improving access to and implementation of GIS teaching resources in higher education. By promoting the sharing of ideas across institutions, the EIP hopes to advance the spatial sciences and better prepare the workforce of tomorrow.

4.5 Using GIS as a Tool for Teaching

In addition to using GIS for teaching spatial science and spatial information systems, GIS is also a useful tool for teaching a broad range of science and humanities courses in general. As mentioned in Chap. 2, GIS has been taken up by numerous departments across campus from the Department of History to the School of Dentistry, and these disparate domains are not only turning to GIS as a tool for research but also a tool for teaching. There are various ways in which GIS can be used to supplement teaching across campus, but the most notable instance seen within the University of Minnesota is by way of StoryMaps and ArcGIS Online.

4.5.1 StoryMaps + ArcGIS Online

The university has found that StoryMaps-based assignments provide opportunities to engage students from a variety of academic disciplines with spatial thinking. The ArcGIS StoryMaps platform pairs digital maps, text, images, video, and audio in a simple website format that can be used to create digital products for assignments, class projects, research studies, and more. Increasingly, faculty are using StoryMaps-based assignments to encourage their students to use a spatial lens to empower analysis of issues, problem solving, and exposing them to new areas of inquiry. Many faculty have little to no experience with digital or interactive maps and are not necessarily knowledgeable about what spatial technologies can offer. The StoryMaps platform affords ample opportunities for the novice, faculty and students alike, to engage with maps like never before.

U-Spatial has partnered with University of Minnesota academic technologists and librarians to provide support for faculty implementing these tools in the classroom. Over the past 2 years, this partnership has worked with over 50 classrooms that include subjects such as history, design, music, foreign languages, forestry, geography, sociology, architecture, and more. A resource website for faculty and students, storymaps.umn.edu, hosts example projects, assignment prompts, rubrics, and technical support materials. The site includes guides and instructions for faculty to build a StoryMaps assignment, or they may reach out for consultation on additional support to develop learning outcomes, find spatial data, or technical support for students.

The introduction of StoryMaps assignments supported by this partnership has made a significant impact by introducing spatial thinking to students who may not otherwise have had the opportunity to learn about GIS (Fig. 4.4). Through classroom surveys, we have found that 94 percent of students said that making a story map helped them to think about the importance of geography and place, and 90 percent of students had never used GIS or heard of GIS before the class. To quote one student, "Looking at maps in textbooks or lectures is a fundamentally different experience from creating a map yourself." Faculty have found that StoryMaps assignments successfully encourage students to look at content in novel ways, especially through a spatial lens. Faculty have observed that when students become the map makers with these assignments, students are analyzing and interpreting

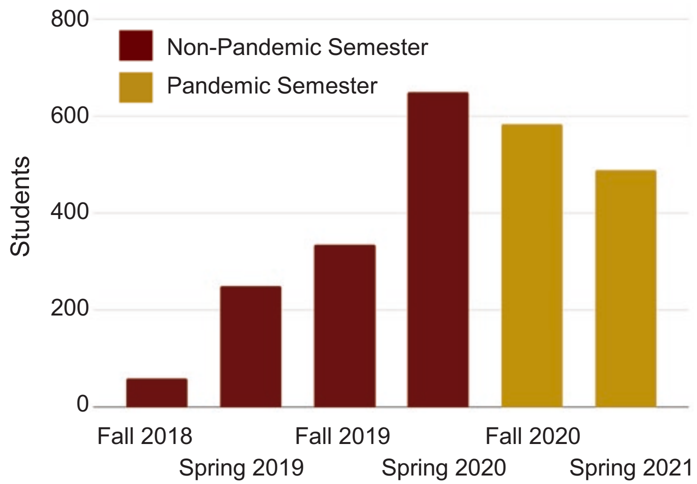

Fig. 4.4 Number of students making StoryMaps for a class assignment (2018 to 2021)

information in ways that were unexpected by both faculty and students. For example, students use StoryMaps to examine the history of Latin America before 1800. Their assignment is to make a map based on a secondary source describing the routes used in the silver trade in the 1700s, such as routes of the laborers or routes getting the silver from the mines to the ships. After the students did the mapping themselves, they found the maps in the secondary source were inaccurate and that the physical landscape (like mountains) would have interfered with the way the scholar said the routes went. Tools such as StoryMaps and ArcGIS Online allow students and faculty who are not GIS experts to become mapmakers. Faculty who use StoryMaps assignments often continue to use these types of assignments and geospatial approaches, finding other unique ways to use them in their teaching and research.

In addition to StoryMaps, classrooms all across campus have also turned to ArcGIS Online as a tool to facilitate learning. ArcGIS Online is an Esri cloud-based geospatial platform that enables users to create interactive maps and perform a wide array of spatial analyses. ArcGIS Online falls under the software as a service model, running on any device with an Internet connection, and is free to the public with limited functionality. As mentioned in Chap. 3, the University of Minnesota has an enterprise license agreement with Esri, which allows it to offer students, faculty, and staff more functionality than that provided by the free public account option, including the ability to create groups, publish hosted layers, and perform credit-based spatial analysis.

The university has over 18,000 ArcGIS Online users. Of these, 82 percent of accounts are owned by students, 13 percent by staff, 3 percent by faculty, and the remainder by departments and student organizations. The vast majority of these users are not GIS or geography students. In fact, ArcGIS Online users span a broad array of domains from Public Health and Medicine to Business and Law (Fig. 4.5).

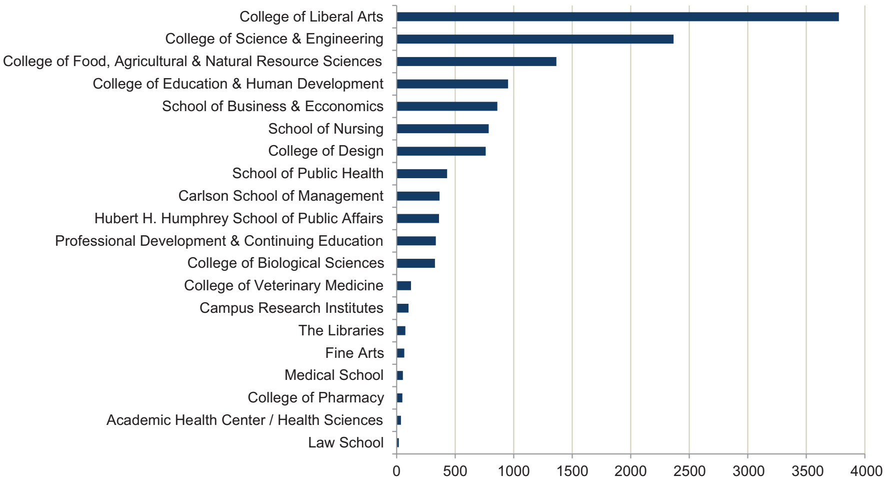

Fig. 4.5 ArcGIS Online users for the top 20 domains, which account for approximately 90 percent of all users at the University of Minnesota

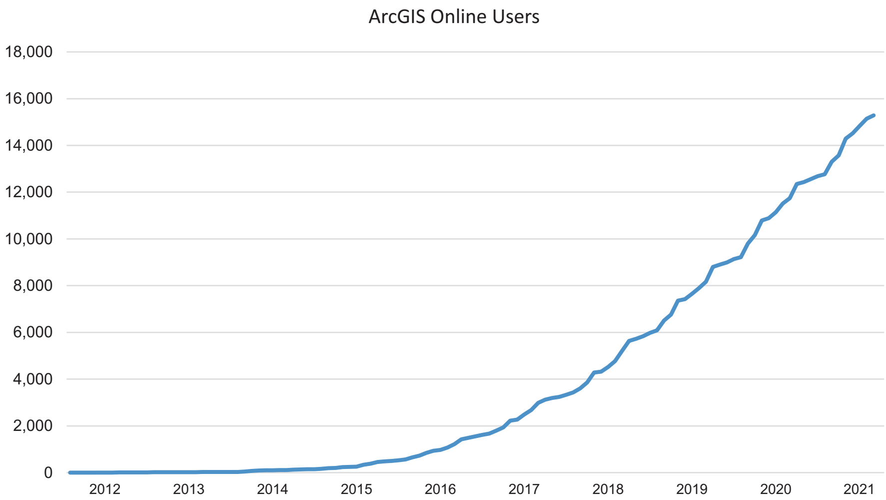

Fig. 4.6 Number of new ArcGIS Online users (2012 to 2021)

The largest proportion of ArcGIS Online users come from the College of Liberal Arts, which is the largest college at the University of Minnesota. The College of Liberal Arts consists of 31 different departments and encompasses a broad array of domains, ranging from Anthropology to Art History to Gender Studies to Geography. ArcGIS Online is used at all of the University of Minnesota's campuses, with the most users coming from the flagship campus (Twin Cities). The growth of ArcGIS Online users has been exponential since its introduction (Fig. 4.6), and the number of users continues to rise year after year. Having said that, we acknowledge that the COVID-19 pandemic seems to have had a negative impact on ArcGIS Online growth during the semesters in which courses were delivered completely online (Fig. 4.7). The pandemic has presented many challenges, but pivoting to online environments offers many potential advantages for flexible learning within the spatial university.

4.5.2 Pivoting to Online Learning During the COVID-19 Pandemic

Like many institutions, the University of Minnesota had many courses move online in response to the COVID-19 pandemic. The Department of Geography, Environment, and Society moved several of its methods courses online, including its Health Geography and four core quantitative methods courses. These courses are foundational to hundreds of majors and serve students in the department and beyond. Moving these courses online helped address multiple roadblocks to students taking

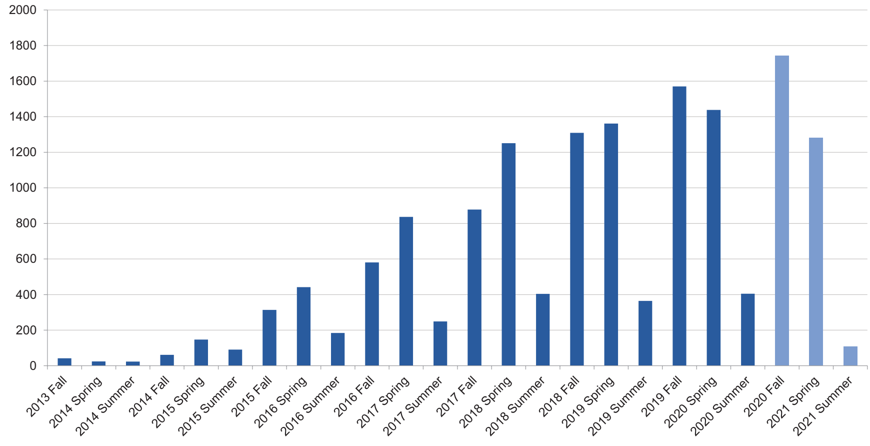

Fig. 4.7 The number of students using ArcGIS Online by semester (2013 to 2021). Use is lower in summer semesters when enrollment is lower. During the pandemic, ArcGIS Online use dropped in the summer and spring semesters when classes were completely taught online

these courses, and it raises an opportunity to rethink how students learn foundational geographic methods and develop geospatial data literacy in online environments. The department created a best-practices template and developed a suite of online materials for these core quantitative methods courses.

Core courses are essential to students who want to learn geospatial data literacy and geospatial technologies such as global positioning systems, Geographic Information Systems, and satellite remote sensing. The key roadblocks to students taking these courses are having a single in-person lecture and/or having physical labs that have strict limits to seating and timing. Moving these courses online lifted these roadblocks and benefited many students. Moving these courses online involved developing innovative ways to use universal design and experience practices to create courses with asynchronous delivery that suits the needs of a wide array of learners; modifying existing material and creating new material for online instruction; developing a shared computational ecosystem, using Canvas, Jupyter Notebooks, and Virtual Machines (VMs) that support core methods courses in the Department of Geography, Environment, and Society (GES); and revising the GIScience curriculum based on the latest advances and topics.

Importantly, the online effort was largely possible because it built on a strong foundation of preliminary work that ensured the success of this project. We collected material from a dozen other institutions in summer 2019. We had sample labs, data, and learning materials (e.g., lecture slides, videos) from online courses. We had materials for our current courses, including labs already written for Esri ArcGIS Pro, that we could adapt for online use. ArcGIS Pro is the most popular GISc package in the world and essential to dozens of courses on campus. We also had labs using Esri ArcGIS Online that have been delivered in a physical lab setting. The college supported development of a Virtual Machine (VM, a simulated desktop computer hosted in the cloud) pilot that will serve as a foundation for making geospatial software available to all students via VMs. The effort to move courses online could also build off the fact that the U of M has a major presence on ArcGIS Online with the ability to manage thousands of users. Finally, we could draw on a pedagogical framework called Cyber Literacy for GIScience and an online platform for interactive lessons called the Hour of CI project (Shook et al., 2019).

While this process of moving core courses online is only in its first year, it is already offering benefits. The department increased the size of the lab sections for its courses, which is useful because collegiate advisors echo student feedback that caps on lab sections are the primary roadblock to much larger enrollments. The broader hope is to increase majors given that a focus in Geographic Information Science (GISc) is one of great interests to students, but demand for core courses is too great because labs are currently limited to in-person settings. A broader hope is that we can expand the use of mapping into other courses because many courses across the university could be significantly enhanced by integrating more GIS and mapping capability. This work helps integrate spatial technologies and spatial thinking into our curriculum at all levels in addition to meeting the immediate needs of moving some courses online. Online environments offer a unique opportunity to potentially improve accessibility and reduce barriers to learning. Finally, this effort advances existing nationwide collaborations to reenvision foundational GIScience education based on the tremendous shifts in methodologies and technologies in the past decade and sudden shift to online environments as part of the pandemic.

4.6 Conclusion

The University of Minnesota has long offered spatial science teaching in ways that matched the needs of the spatial science worker by ensuring curriculum evolves in line with the dynamic nature of GIScience. Spatial thinking has been intricately woven into a broader learning experience at the University of Minnesota through an array of GISc course offerings and several interrelated programs and degrees, as well as through the use of mapping tools for teaching by departments outside of the spatial sciences. Looking forward, we expect the spatial university will continue to build its existing online learning capabilities in ways that support the perpetual reenvisioning of GIScience education into the future.

References

Adaktylou, N. E., Landenberger, R. E., Czajkowski, K. P., Liu, P., Hedley, M. L., & Struble, J. (2018). Using geospatial technology to enhance science teaching and learning: A case study for 'SATELLITES' Geo-science Program. *International Journal of Environmental and Science Education, 13*(7), 605–621.

Battersby, S. E., Finn, M. P., Usery, E. L., & Yamamoto, K. H. (2014). Implications of web Mercator and its use in online mapping. *Cartographica: The International Journal for Geographic Information and Geovisualization, 49*(2), 85–101.

Bolstad, P. (2002). *GIS fundamentals: A first text on geographic information systems*. Eider Press.

Dahlberg, R. E. (1977). Cartographic education in US colleges and universities. *The American Cartographer, 4*(2), 145–156.

DiBiase, D., DeMers, M., Johnson, A. B., Kemp, K. K., Plewe, B. P., & Wentz, E. A. (2006). *The geographic information science and technology body of knowledge*. Association of American Geographers.

National Research Council. (2006). *Learning to think spatially*. The National Academies Press.

Porter, P. W. (1991). Geographic cartography—A Minnesota tradition. *Cartography and Geographic Information Systems, 18*(3), 208–216.

Shook, E., Bowlick, F. J., Kemp, K. K., Ahlqvist, O., Carbajeles-Dale, P., DiBiase, D., & Wang, S. (2019). Cyber literacy for GIScience: Toward formalizing geospatial computing education. *The Professional Geographer, 71*(2), 221–238.

Slotterback, C. S., Runck, B., Pitt, D. G., Kne, L., Jordan, N. R., Mulla, D. J., Zerger, C., & Reichenbach, M. (2016). Collaborative Geodesign to advance multifunctional landscapes. *Landscape and Urban Planning, 156*, 71–80.

Spielman, S. E., Folch, D., & Nagle, N. (2014). Patterns and causes of uncertainty in the American community survey. *Applied Geography, 46*, 147–157.

Turner, A. (2006). *Introduction to Neogeography*. O'Reilly Media.

Chapter 5
Spatial Sciences and Research

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Abstract Spatiality—using concepts of space and place to understand patterns and processes—is found across many academic disciplines at the spatial university. This chapter outlines how spatial sciences both enhance and are furthered by work in an array of fields. It first offers an overview of the breadth of work going on at the spatial university, from arts and humanities to the social, natural, policy, and health sciences. It then provides specific examples of the spatial sciences at the university as advanced by researchers in natural resources, remote sensing, computer sciences, polar research, supercomputing, and geography and CyberGIS. The chapter then examines how a range of centers and groups are using spatial approaches to deal with topics in geology, population, urban affairs, informatics, environment, food protection, and health. We also showcase how the advancement in spatial sciences at the University of Minnesota benefits various domain knowledge areas. In sum, while this chapter can only scratch the surface in describing the range of research at the spatial university, it handily demonstrates how spatiality is central to range of important scholarship.

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5.1 Introduction

Spatial science, or, more broadly, the spatial sciences, has emerged as a vital locus of research and scholarship across many disciplines. If we broaden this focus beyond the sciences to spatiality in general—in terms of using the lens of space and place to understand patterns and processes—there are few scholarly fields that fail to engage with spatial thinking. Because nothing is "nowhere" and almost everything has a spatial component, many disciplines have developed interests in spatial reasoning and spatial analysis related to the earth, physical objects, and the built environment (Baerwald, 2010). Spatial sciences contribute to the "toolboxes" of a broad range of scholarly work and creative activity at the spatial university, regardless of the underlying focus on theoretical development or empirical research.

New analytical tools, geographic information systems (GIS), and new modes of visualization have transformed the way that scientists in numerous fields conduct research. In a statement that holds true for the spatial sciences in general, the National Research Council's, 2010 report, "Understanding the Changing Planet: Strategic Directions for the Geographical Sciences," underscores the widespread and urgent need for these tools: "Many of the central challenges of the 21st century are tied to changes to the spatial organization and character of the landscapes and environments of Earth's surface as populations move, natural resources are depleted, and climate shifts. Research in the geographical sciences has the potential to contribute greatly to efforts to monitor, analyze, and prepare for these changes" (NRC, 2010).

Spatial science enables the advancement of research in multiple ways. In terms of theory building, the spatial sciences promote a special perspective and various forms of spatial thinking by incorporating place and space into a range of inquiry across many scholarly fields. Data-wise, spatial sciences enable data integration

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between nonspatial data and spatial data, as well as the conversion of data collected at one spatial scale to other scales. Methodologically, spatial science provides analytical tools to discover patterns, suggest associations, test spatial effects, and generate knowledge about a range of phenomena.

Perhaps more importantly, the interaction between spatial sciences and the array of fields—from arts and humanities to the social, natural, policy, and health sciences—is not unidirectional. Indeed, the development of spatial sciences over time can trace their origins to natural, social, information, and health sciences. Furthermore, recent theoretical developments across the sciences have created new fields that highlight the interaction between human and environmental contexts, including ecology, social epidemiology, health geography, urban geography, and economic geography. These developments have played a significant role in motivating and promoting spatial research. The growth of spatial science has been fueled by the growing conceptual and societal recognition that space matters in understanding human and physical perspectives, alongside the emergence of new geotechnologies including GIS, global positioning system (GPS), remote sensing, surveying, and cartography that made spatial research easier.

In this chapter, we outline the increasing significance of spatial sciences and offer an overview of research fields that have contributed to the advancement of spatial sciences. We provide specific examples at the University of Minnesota, where a broad array of work has advanced many core facets of spatial sciences. We also showcase how the advancement in spatial sciences at the University of Minnesota benefits various domain knowledge areas. Note that this chapter cites to references relatively sparingly, in keeping with the broader ethos of this book to provide a broad overview. Much of the research described here is the basis for dozens upon dozens of compelling and important publications, presentations, and other forms of scholarship attached to them.

5.2 Research Advancing Spatial Science

This section will offer a general overview of the rapid growth in spatial research at the research university, with a focus on research at the University of Minnesota that has furthered the data, methods, and theories of spatial science and practice. We examine the broad range of work being funded and published on campus. We then highlight five areas of work that are directly related to the advancement of spatial sciences. They include natural resources and remote sensing, computer science and engineering, spatial research at the Polar Geospatial Center, spatial computing resources at the Minnesota Supercomputing Institute, and geography and CyberGIS work at the Department of Geography, Environment, and Society.

The University of Minnesota consistently ranks in the top ten public research institutions in the United States and had research expenditures of over 1 billion dollars in 2020. Every year, the University of Minnesota garners millions of dollars in grants with a spatial emphasis and publishes across an extraordinary range of fields

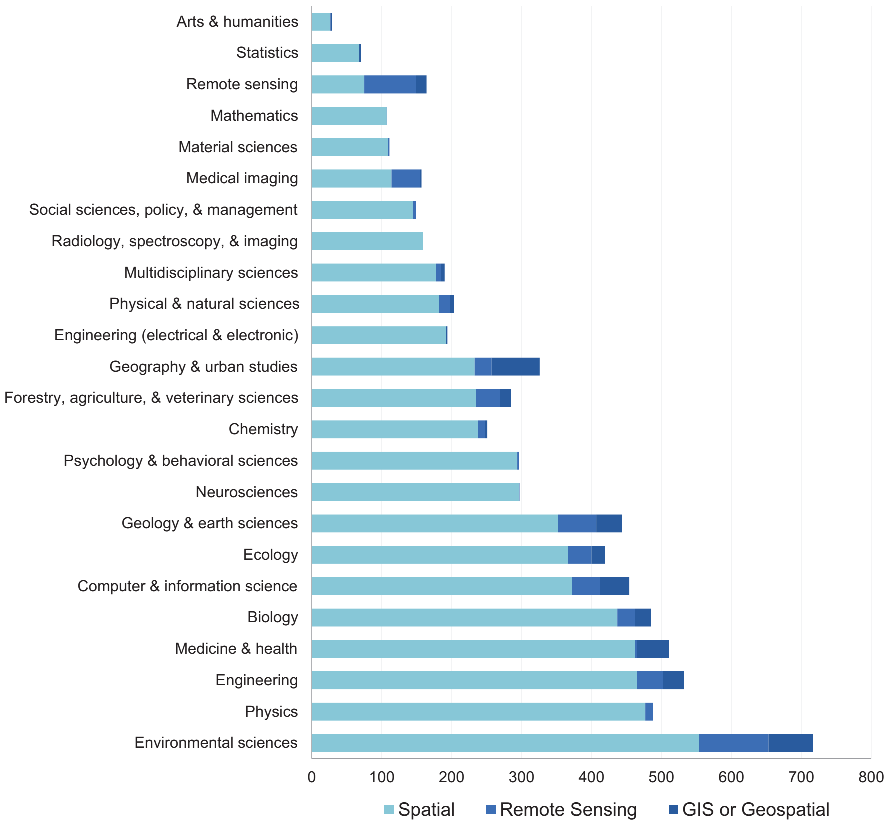


Fig. 5.1 Publications by field (2010–2020) in SCOPUS database for search terms "spatial," "remote sensing," and "GIS" or "geospatial"

(Fig. 5.1). Centers such as the Minnesota Population Center and Polar Geospatial Center host influential global spatial datasets funded in part by a range of external grants. The Institute for Social Research and Data Innovation uses a range of spatial science approaches to develop the world's largest freely available population and environment datasets. The University of Minnesota computer scientists are on the leading edge of developing new spatial science to better understand a range of social and environmental issues, such as climate change, desertification, and population growth. The Polar Geospatial Center has some of the largest holdings of remotely sensed data for researchers in the world. These and other projects highlight how the University of Minnesota hosts influential global spatial datasets that are used by thousands of students, scholars, policy makers, and other stakeholders around the world.

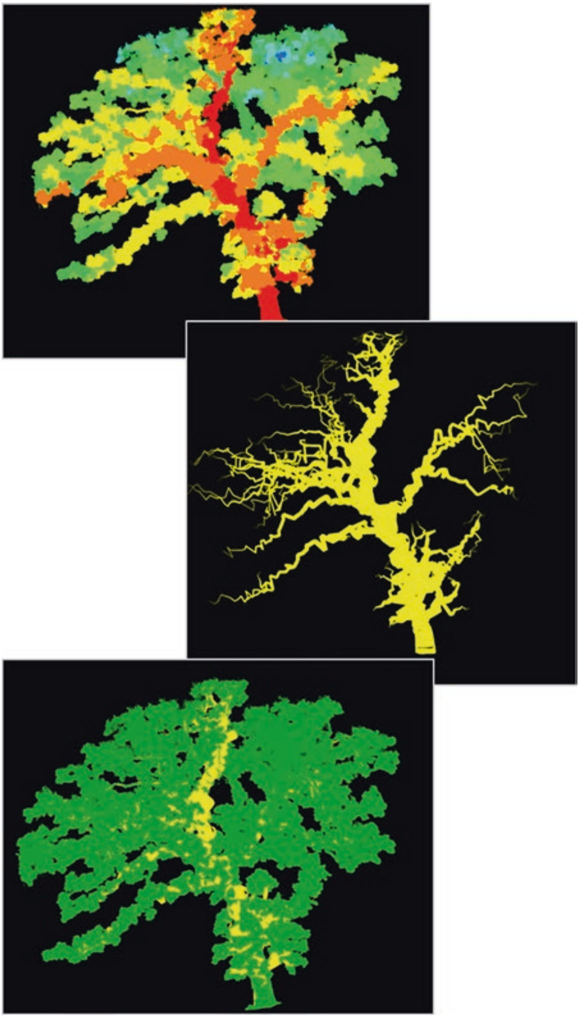
Beyond research dollars, the students, staff, and faculty of the university contribute to a wide array of spatial research areas. Over 2000 faculty, students, and staff engage in spatial research at the University of Minnesota. They combine spatial approaches with spatiotemporal data gleaned from maps, satellites, smartphones, sensor networks, UAV-based cameras, and social media. They help commuters to minimize travel time; farmers to best plant and protect crops; epidemiologists to identify emerging disease hotspots; emergency planners to develop smarter evacuation routes; policy makers to visualize spatiotemporal climate change scenarios; and first responders to use high-resolution imagery to map areas of need. Our faculty members have developed crucial public domain spatial software (e.g., UMN MapServer, SpatialHadoop) and have served in leadership roles for national and international societies; for example, Robert McMaster and Shashi Shekar have served as president of the University Consortium on Geographic Information Science, Harvey Thorleifson was a member of the National Geospatial Advisory Committee, Mohamed Mokbel was president of ACM SIG-Spatial, and Shashi Shekhar led a national academy workshop on spatial computing. Many other faculty members and staff have served on spatially oriented national academy committees (e.g., Mapping Sciences Committee) and boards (e.g., Board on Earth Resources and Sciences). What follows are some examples of the many high-impact and relevant spatial topics being pursued on campus.

5.2.1 Natural Resources and Remote Sensing

Research focused on the changing forests of Minnesota benefits from the rapid expansion in recent years of spatial capabilities centered on the use of remotely sensed imagery to understand many human and environmental systems. Throughout the university and the state, spatial data and methods are now ubiquitous. This broadening scope comes largely as a result of spatial research, education, and outreach done by the university. Agency partners now have skilled spatial experts on staff who are interested in expanding the use of imagery, lidar, and other spatial data in their work. Among these are resource managers and scientists at the Minnesota Department of Natural Resources' Division of Forestry and the USDA Forest Service. Some of this work can be traced back decades, as examined in Chap. 3, and in the late 1990s via Environmental Resources Spatial Analysis Center (ERSAC), which had about 20 faculty members and dozens of graduate students from multiple departments and across colleges focusing on spatial analysis of the environment (McMaster et al., 2011).

In partnership with these state and federal agencies, researchers in the Remote Sensing and Geospatial Analysis Laboratory (RSGAL), a university-wide center for remote sensing, are developing novel methods for forest health assessment and inventory. Forests are changing rapidly due to natural and anthropogenic influences. Robust methods are needed to monitor forest ecosystems, which are vital for a wide range of functions including wildlife habitat, timber production, recreation, and carbon sequestration (Knight et al., 2017). RSGAL scientists are using high-resolution lidar and infrared aerial imagery in an object-based image analysis (OBIA) context

Fig. 5.2 Terrestrial Laser Scanning (TLS) image of an oak tree. From left to right, the images are the cylindrical model of the tree trunk and branches, the additional leaves and other minor branch points, and finally the reconstructed tree with stem (red) and the other colors representing branch order



to derive unprecedented detail about the structure, function, and health of our forests (Fig. 5.2).

Unlike per-pixel image analysis approaches that focus on classification of individual pixels in an image, OBIA methods delineate and classify homogeneous groups of pixels or objects using spectra, shape, size, texture, and spatial context, producing land cover classes that better approximate real-world features. These efforts integrate geospatial data from different sensors with varying resolutions and vector data. The ability to incorporate disparate data (e.g., multiple resolutions and GIS layers) into OBIA often results in higher mapping accuracy compared to traditional pixel-based classification techniques (Blaschke, 2010), which in turn makes these data better for a mix of uses.

5.2.2 Computer Science and Engineering

The University of Minnesota is a world leader in spatial computing, the term applied to a range of technologies that have transformed our lives via pervasive services such as navigation and ride-sharing apps, ubiquitous systems like the Global Positioning System, and rich scientific methods including spatial data mining (Shekhar & Vold, 2020). The Department of Computer Science and Engineering (CSE) is central to the spatial computing enterprise at the university.

CSE has made notable contributions to spatial infrastructure at the spatial university and beyond. CSE researchers also helped scale up the UMN MapServer, which was initially developed by Steve Lime when working at the University of Minnesota and in partnership with the state Department of Natural Resources as part of the NASA ForNet Project (Lime, 2008). Map Server was the first public domain software for developing spatial Web servers for analyzing satellite imagery and maps. This founding project for the Open Source Geospatial Foundation has been used to create 30,000 spatial Web servers including the NASA World Wind (a counterpart of Google Earth), which is used extensively by the scientific community. More recently, Mohammed Mokbel spearheaded development of the SpatialHadoop software system, which speeds up spatial queries on modern cloud computing platforms. It has been downloaded over a hundred thousand times by software developers around the world and influenced the design of ESRI GIS Tools for Hadoop among other projects (Eldawy & Mokbel, 2016).

In addition to advancing general spatial infrastructure, CSE scholars have developed novel approaches to a range of problems with a spatial component. These researchers have done work on responding to hurricanes and nuclear plant emergencies, including developing capacity-constrained routing planning (CCRP) algorithms, which allow policy makers and disaster response teams to develop evacuation plans. The Minnesota Department of Transportation used this work to craft evacuation plans to quickly move vulnerable populations to safety (Shekhar et al., 2012), and the Hajj Research Center (Mecca, Saudi Arabia) leveraged CCRP for emergency planning during Hajj, one of the largest global gatherings. Another standout example is the use of data-driven approaches to understanding climate and global fine-scale land cover change (Faghmous & Kumar, 2014). Finally, CSE faculty have served the spatial research community in many ways that help build the spatial capacity of other institutions. Mokbel helped Umm Al-Qura University (Saudi Arabia) and Qatar Computing Research Institute (Qatar). Shekhar served as a president of the University Consortium for Geographic Information Science and led a call for including a geospatial perspective in data science degrees and curricula. He coauthored a popular textbook on spatial databases that is used worldwide and has been translated in Chinese and Russian (Shekhar and Chawla, 2003). He also coedited the Encyclopedia of GIS, a widely used resource.

5.2.3 Polar Geospatial Center

The Polar Geospatial Center (PGC) is a federally funded center that provides geospatial support and spatial data products to the polar science community. Founded in 2007, the center's mission is to solve geospatial problems in the Arctic and Antarctic by working with researchers on mapping and remote sensing projects. Its staff works with scientists, operations staff, and military personnel, just to name a few constituencies. More broadly, it purses three broad missions: providing knowledge and expertise to address a broad range of polar geospatial problems; providing access to spatial data on the Antarctic and Arctic alongside the expertise necessary to task, manage, process, and deliver a range of products; and providing educational material and programming to transfer center knowledge and experience to the community.

PGC's primary services include a range of geospatial expertise, processing and analysis of remotely sensed imagery, bespoke mapping applications and products, and on-site support at McMurdo Station during the United States Antarctic Program Antarctic field season. The PGC User Services support team is staffed with specialists in geographic information systems, cartography, Web development, and remote sensing of various kinds. This team works with scholars from myriad fields, including astronomy, geography, glaciology, ornithology, oceanography, and operations management. Of note, in addition to the center's explicit focus on polar research, it processes other forms of remotely sensed imagery as needed. User Services have expertise in a range of geospatial fields spanning GIS, remote sensing, databases, and cartography. These staff members assist and educate the PGC users in an array of geospatial techniques and solutions. Among these are the following:

- Satellite image delivery and processing. PGC provides to the polar community access to data collected and dissemination by Maxar (formally DigitalGlobe), which offers high-resolution satellite imagery. The PGC collaborates with DigitalGlobe and the National Geospatial-Intelligence Agency (NGA) and to coordinate imagery acquisition and processing these data for delivery to PGC users.
- GIS data and maps. The PGC curates and disseminates a variety of other geospatial data beyond just remotely sensed imagery, including historic and current maps, aerial photography, digital elevation models such as ArcticDEM, and lidar collections of the McMurdo Dry Valleys.
- GIS analysis and mapping. The center offers assistance in spatial analysis and modeling to researchers, including custom mapping based on its extensive archive of maps and spatial data on the Arctic and Antarctic.
- Seasonal on-site support at McMurdo Station. During the United States Antarctic Program (USAP) Antarctic field season, PGC staffs an office at McMurdo Station to provide on-site support to science and operations personnel. Because research resources and Internet bandwidth are limited in McMurdo, PGC will often perform work in support of users in advance of the field season in addition to in situ support.

The center is housed in the Department of Earth and Environmental Sciences in the College of Science and Engineering. It receives most of its funding from the National Science Foundation (NSF), National Geospatial-Intelligence Agency (NGA), and National Aeronautics and Space Administration (NASA), although the University of Minnesota also provides support in various forms. Over its near two-decade history, the center has provided geospatial support to hundreds of research groups and their academic activities along with engaging with a wide range of constituencies outside of the academy, ranging from K–12 groups to policy makers.

5.2.4 Minnesota Supercomputing Institute (MSI)

Minnesota Supercomputing Institute (MSI) is one of the oldest supercomputing institutes in the United States. It has advanced research at the University of Minnesota for over 30 years and continues to provide computational and data-intensive resources and expertise to advance research across the university. Operating as part of Research Computing in the Office of the Vice President for Research provides MSI broad reach across the university as well as tight integration with other units in Research Computing, including the University of Minnesota Informatics Institute (UMII) and U-Spatial.

Spatial research has been a growing area for MSI in recent years with active research in remote sensing, satellite imagery, data science, and deep learning. MSI provides unique resources for spatial research, including interactive computing, a visualization studio for massive display of geospatial information, and several compute- and data-intensive resources for processing, analyzing, and visualizing spatial data. To help interface with the growing need in spatial research, MSI has a dedicated HPC Geospatial Analyst as part of their Research Informatics Solutions group. Through combining computational resources and expertise, MSI is an important component of any spatial university, providing the computational backbone to support advances in geospatial technology development and creating advanced geospatial infrastructure including spatial databases, spatial data science, and geospatial computing.

5.2.5 Geography and CyberGIS

Geography is a dynamic and growing field, with intellectual connections that ramify across the liberal arts and the natural and applied sciences. Established in 1925, the Department of Geography, Environment, and Society (GES) is one of the oldest and most respected geography programs in the United States and consistently ranks among the top geography programs nationally. In recent years, GES faculty have received multiple major research grants in the spatial sciences from the NSF and NIH. GES has always been well known as an innovative place for GIS and spatial analysis more generally, much of which inherits from the work of Borchert and others who built the department.

The department has several areas of focus. As outlined in Chap. 3, the department has long been a leader in cartography and visualization. Mark Lindberg, Susanna McMaster, Robert McMaster, Ying Song, and Di Zhu all work on solving research challenges in cartography and visualization, ranging from advancing the state of art in generalizing maps to work that identifies how to best represent complex spatiotemporal patterns and processes in contexts ranging from human transportation to animal movement. For example, Lindberg studies cartography with a strong psychological element—in the sense of drawing on decision-making research on how people perceive maps—that adapts to vagaries of real-world map production.

The department also does much work with global data and challenges. Steven Manson, Eric Shook, and Kathryn Grace collaborate with the Minnesota Population Center, Institute on the Environment, and Libraries to conduct scholarship that integrates the social science of population and environmental science of global change. This work is related to that in health and population, where a number of scholars work in topics around health and population, from how rainfall affects human well-being in Mali and Ethiopia to using big data to map and predict the spread of disease in the global south. Grace's work, for example, examines the role of context in maternal and child health via a quantitative, mixed disciplinary approach to the examination of the way that individual and household outcomes are conditioned by culture and the natural environment.

The department has a history of scholarship on how society interacts with GIS, with former colleagues including Eric Sheppard, Helga Leitner, Howard Veregin, and Francis Harvey joining current faculty in advancing understanding of how maps contribute to, and are conditioned by, social dynamics. In this vein, Susanna McMaster researches professional GIS education alongside the history of academic cartography. Finally, the department does much work in big data and data science, with Manson, Shook, and Zhu all working to address the challenges of advancing the data, method, and theory of using large datasets to tackle a range of human-environment topics including agriculture, deforestation, and global pandemics.

5.3 Spatial Science in Service of Discovery

In addition to a broad array of work on advancing the data, methods, and theory of spatial science as such, the university is home to a vast array of work that uses spatial science approaches in service of domain knowledge. We highlight seven domain areas in which the advancement of spatial sciences has benefited the knowledge discovery process. They include geological mapping in the Minnesota Geological Survey, spatial research at the Natural Resources Research Institute, urban research at the Center for Urban and Regional Affairs, data-driven agriculture innovation at the GEMS Informatics Center, demographic research at the Minnesota Population Center, ecological research at the Institute on the Environment, food system research at the Food Protection and Defense Institute, and health and medical research across the university.

5.3.1 *Minnesota Geological Survey*

Throughout the world, geological survey agencies mandated by government maintain the systematic, jurisdiction-wide subsurface mapping, monitoring, and research that is needed for government and society to function optimally in fields such as water, energy, minerals, hazards, and engineering. As with other federal systems, the United States has a federal survey—the United States Geological Survey (USGS), which has a budget of greater than $1B and approximately 9000 employees—and state geological surveys that presently receive total annual funding of $241 M and have over 1840 employees. About a third of the state geological surveys are based in universities. The Minnesota Geological Survey (MGS), established by the Legislature as part of the University of Minnesota in 1872, has been located off campus in St. Paul since 1970. It has an annual budget of $3.3 M and a staff of 38 that has grown by 30 percent over the past decade. MGS priorities have been specified by a series of broadly consultative state resource planning exercises. For example, in 2011, the Minnesota Water Sustainability Framework advocated that a measure of progress in obtaining a picture of groundwater resources—our principal source of drinking water—should be the rate of completion of county geological atlases. The framework advocated for geological atlases, which are prepared by MGS and the Department of Natural Resources (DNR), to be completed at a much faster pace.

County Geologic Atlases (CGA) provide information essential to sustainable management of groundwater resources for applications such as aquifer management, groundwater modeling, monitoring, permitting, remediation, water allocation, well construction, and wellhead protection. The atlases define aquifer properties and boundaries, as well as the connection of aquifers to the land surface and to surface water resources. They also provide a broad range of information on county geology, mineral resources such as construction materials, and natural history. The atlases thus are also useful to consultants, exploration efforts, educators, and the public. A complete atlas consists of two parts: Part A prepared by MGS that includes the water well database and 1:100,000 scale geological maps showing properties and distribution of sediments and rocks in the subsurface, and Part B, constructed by the DNR, which includes maps of water levels in aquifers, direction of groundwater flow, water chemistry, and sensitivity to pollution. Atlases in most cases are initiated by a request from a county and an offer to provide in-kind service. A User's Guide to Geologic Atlases helps non-geologists understand the information products and their uses. Atlases are available in print or in digital formats, including PDFs and GIS files. Atlases are complete for 41 counties, and of these, 5 have been revised and 2 revisions are underway. There are 23 new atlases underway; 21 counties have not yet been started. At the current pace and a completion rate of approximately 5 per year, statewide coverage will be achieved in less than a decade from now.

The County Geologic Atlas program is the key to the broader MGS plan to fulfill a range of user needs. It does so primarily through mapping of geology, bedrock topography, and sediment thickness. This geological mapping is first published as authored and peer-reviewed geological maps but is also being assembled as a two-resolution (1:100,000 and 1:500,000) layered set of databases that includes the off-shore region that underlies bathymetric and soil mapping, and that is as compatible as possible with neighbors. MGS is producing progressively more seamless geological areas that increasingly show properties, heterogeneity, and uncertainty. A layered 1:500,000 state bedrock geological map is now complete, with mapping of thickness and underlying geology for Precambrian layers completed in 2020, along with a new state Quaternary geology map in 2019. This geological mapping is accompanied by associated spatial databases. The publication database, which is spatial through publication footprints, includes over 50,000 pages and 700 scanned maps, both searchable and Web accessible. These geological databases include a range of field observations and geological collections. MGS coordinates with the DNR drill core library and mineral exploration document archive, the Bell Museum fossil collection now stored in Ohio, and the DNR aquifer properties database. In sum, the MGS has long offered a range of data collection and mapping services as a core part of the spatial university in terms of data and workflows as well as to meet the needs of many individuals and groups in the state across the private and public sectors.

5.3.2 GEMS Informatics Center

Agriculture is a spatially sensitive production process. Productivity performance of the sector depends heavily on precisely where, and when, on the planet agriculture takes place. And it is deeply intertwined with spatially variable environmental attributes such as soil, water, and sunlight. The University of Minnesota's GEMS (named for Genetics, Environment, Management, Socioeconomic) informatics initiative, launched in 2015, is a novel, joint venture between the College of Food, Agricultural, and Natural Resource Sciences (CFANS) and the Minnesota Supercomputing Institute (MSI) designed to catalyze a data-driven revolution in food and agriculture. To do so, GEMS developed and operates the GEMS informatics platform, a standards-based analytics and data sharing system. The platform is built using open-source tools, is geospatial by design, is respectful of intellectual property, and expedites the analysis of big (and little), disparate, and sometimes messy data. GEMS services encompass four main program areas: secure data storage, sharing, and analytics platform; Internet of Things (IoT) data collection systems; Application Programmer Interfaces (APIs) for on-demand GxExMxS (genetics x environment x management x socioeconomic) data, modeling, and analytic products; and GEMS external consulting and advising services.

- GEMS secure data storage, sharing, and analytics platform. GEMS services include a secure data sharing and analysis platform that enables interoperability across data holdings by fostering the usage of international metadata and ontology standards. Additional data processing features include metadata management, auto-versioning of data files, and the associated workflow approach that is taken to ensure information products are replicable. During data ingest, platform users can tap an array of data outlier detection and cleaning tools, including those specifically designed to identify and rectify spatial data. An important attribute of the GEMS platform is its secure storage and smart sharing capabilities that support the ethical use of data subject to data privacy or security concerns (drawing on the work of James Wilgenbusch and others in the University of Minnesota's Research Computing). Users of the platform can choose to make their data openly available, keep their data private, or share with any combination of teams or individuals. Importantly, metadata can be shared separately from the data itself, allowing users to make their data discoverable or share the data itself via their own click-through licenses. The platform also includes a range of anonymization tools that enable sensitive data (including, e.g., georeferenced farm level data) to be kept private while an internally linked, anonymized version of that same data can be shared more widely at the data provider's discretion. The GEMS platform can be federated, with an on-site instance of the platform now operating at Stellenbosch University, South Africa, in addition to its core hub at MSI's supercomputing facilities in Minneapolis.
- GEMS-IoT data collection systems. GEMS has a continually evolving Internet of Things (IoT) offering that provides affordable, multi-sensor deployments that stream data directly to the platform. These sensing systems (and their associated back-end data pipelines) have been deployed on four continents, including across Minnesota and Malawi. Part of the configuration in Minnesota is being implemented in an explicitly spatially aware fashion across the University of Minnesota's Research and Outreach Centers (ROCs), thus providing an integrated network of electronic infrastructure that enables digital agricultural discoveries across highly diverse agroecologies and agricultural production systems.
- GEMS APIs for on-demand GxExMxS modeling and analytics. In parallel with the analytic and data collection capabilities on the GEMS platform, users also have the option to subscribe to a range of Application Programming Interfaces (APIs), which allow them to query complimentary streams of data that have been predesigned to be spatially and temporally interoperable. The API infrastructure allows other platforms to exchange data with the GEMS platform, empowering remote scientific workflows. Thus, GEMS makes an ideal back end to widely flexible visualization front ends.
- GEMS external consulting and advising services. Even with the many offerings that GEMS provides, collaborators and clients find it useful to create custom projects. GEMS personnel consult with numerous companies, private nonprofit corporations, and government agencies. These professionals include experts in systems administration, software development, network security, machine learning, data science, plus domain science expertise in genetics and agronomy,

Geographic Information Science (GISc), spatial econometrics, environmental modeling, and other areas. GEMS staff work with organizations including private companies such as PepsiCo; a range of private foundations and nonprofits including the Rockefeller Foundation, Soil Health Partnership (SHP), One Acre Fund, and Land O′ Lakes Venture37; and government agencies such as the USDA's Foundation for Food and Agriculture Research (FFAR). Further, GEMS has designed data and software systems specifically for other consortia including Genomes2Fields (G2F, funded by Iowa Corn), which includes collaborators from more than 20 states throughout the nation.

GEMS operates with innovation partners across campus and throughout the world to integrate spatial data, thinking, and analytical tools. For example, GEMS has developed and operates a flexible spatial tile indexing system to streamline access to and analytical use of geospatial remote-sensed data from various remote sensing platforms. In partnership with the university's InSTePP (International Science and Technology Practice and Policy center), GEMS has a multifaceted program of spatially explicit, bio-economic modeling, including, for example, workstreams to measure and assess the spatial movement of agricultural production. GEMS has developed and implemented workflows that assess, in a probabilistic, spatially explicit fashion, the bio-economic implications of crop pests and diseases (Pardey et al., 2013). Partnering with the Minnesota Invasive Terrestrial Plants and Pests Center (MITPPC) at the university, GEMS is drawing on MSI's supercomputing capabilities to also stand up a flexible pest dispersal simulation system that models climate and human-mediated crop pest dispersal at multiple spatial scales. MSI's resources have also been used to train locally developed models that use historic weather and soil conditions to predict with high-accuracy yield and high-quality traits for arbitrarily selected crop variety genotypes in desired planting locations. A significant workstream is also being developed to power real-time, distance-to-market analytic pipelines that inform myriad decisions by multiple public and private parties. These in turn affect the cost-effective access to outputs produced on farm and production inputs used by farmers. Spatially aware market access information is a particular challenge for those farms and agribusiness seeking to innovate in developing countries with fragile rural infrastructure systems. In sum, GEMS leads the way in integrating spatial data and methods into a broad array of research and policy.

5.3.3 MPC and Spatial Analysis Core

The Minnesota Population Center (MPC) hosts the Spatial Analysis Core and plays a key role supporting spatial research across the university. The MPC was established in 2000 with a grant from the National Institutes of Health (NIH) to, among other tasks, curate and disseminate large-scale population datasets (Sobek et al., 2011). Development of a major spatial data infrastructure project and recognition that numerous groups at the University of Minnesota required spatial research support precipitated development of the Spatial Analysis Core in 2006. In 2018, the MPC served as the foundation for the Institute for Social Research and Data Innovation, an interdisciplinary research institute within the university that provides the infrastructure and services to four centers within the institute: IPUMS, the Minnesota Population Center, the Life Course Center, and the Minnesota Research Data Center.

The MPC received a $5 million grant in 2001 from the NSF to create the National Historical Geographic Information System (NHGIS). The initial vision of NHGIS was a Web-based data access platform providing aggregate census data and GIS-compatible mapping files from 1790 to the present (Fitch & Ruggles, 2003). While a large portion of the historical aggregate census data was in digital form by that time, relatively little GIS data existed that depicted historical states/territories, counties, or census tracts. Many people, including a large number of undergraduate and graduate students working alongside full-time staff, created these mapping files and incidentally built a critical mass of people with strong spatial skills that would serve as the nucleus for the core.

Recognizing the importance of the spatial capacity developed through work on NHGIS, the MPC established the Spatial Analysis Core in 2006 when it received renewed NIH center funding. The core, directed by Pétra Noble from 2006 to 2010 and David Van Riper from 2010 onward, provided support for spatial analysis to students, staff, and faculty who were MPC members. This support ranged from the acquisition or creation of spatial data to the development and execution of complex spatial analysis tasks to training in basic GIS skills. For example, the core provided support for numerous research projects in the School of Public Health exploring the relationship between obesity, the built environment, and the food environment. Core staff geocoded participant addresses and constructed egocentric measures of the built or food environment surrounding the addresses. These personnel also worked with faculty and staff to enrich participant data with information describing the demographic and socioeconomic characteristics of their neighborhoods.

When U-Spatial was established in 2011, it took over a number of the services from the Spatial Analysis Core, but the core continues to support the spatial analysis needs of MPC members. The core also plays a key role in a number of data infrastructure products, including IPUMS NHGIS, IPUMS USA, and IPUMS International, developed and maintained by the Minnesota Population Center. IPUMS NHGIS offers harmonized US Census data for 1790 onward and is the largest publicly accessible population database in the world, while IPUMS International is the largest international population database in the world, covering much of the world and over half a billion individuals described by hundreds of billions of data points. Both projects require a good deal of spatial science support through the data collocation, collation, curation, and dissemination. In particular, core staff create GIS files delineating the administrative and statistical units represented in the data, and they create customized geographic variables that increase data utility. For several years, U-Spatial and the Spatial Analysis Core shared the same space, which helped both units grow—so much so that they needed their own bigger spaces—but the two groups still communicate and work together regularly to advance the mission of the spatial university.

5.3.4 Institute on the Environment

As noted throughout this volume, there is an extraordinary amount of spatially informed research happening in ecology and cognate environmental fields. In addition to stand-out examples noted above, work at the University of Minnesota's Institute on the Environment exemplifies spatial research with an ecological focus. Several projects stand out in particular: the Global Landscapes Initiative, the Global Water Initiative, and the Natural Capital Project. While all three see themselves primarily as human-environment projects, all are built in part on a foundation of spatial science approaches.

The Global Landscapes Initiative researches, develops, and applies approaches to characterize global land use, although it touches on land cover as well. The overriding goal of the initiative is to understand human land-change, particularly trends in global agricultural supply and demand and underlying facets of the land use, including cropping and its many inputs (fertilizer, water, labor) and outputs (food, fiber, fuel). This work is also designed to improve how people balance human needs met by land use with environmental impacts. Much of this work is inherently spatial but happens outside of what many people consider standard workflows for GIS, using a mix of programming and mathematics in approaches closer to physics and other natural sciences. In addition to supporting publications in high-profile venues, GLI is focused on making available public-facing publications including Environment Reports hosted at the Institute on the Environment and data via the EarthStat (EarthStat.org) for other researchers and policy makers around the globe at a range of institutions including National Geographic, ESRI, CGIAR (formerly the Consultative Group for International Agricultural Research), the Inter-American Development Bank, the American Museum of Natural History, and others. Figure 5.3 shows one of the project's most popular products, the 2000 cropland layer, which shows croplands and pastures for around the turn of the century derived from agricultural inventories and satellite-based land cover data at a spatial resolution of about 10 km.

The Global Water Initiative uses spatial science approaches in combination with other methods to evaluate water sustainability and help develop tools that help water managers. Some of this work centers on mapping water use, availability, and scarcity at various scales around the world and exploring potential effects shifts in water use and supply. Lead researcher Dr. Kate Brauman worked with staff at the Institute on the Environment and partners with the Global Water Policy Project, the Nature Conservancy, and the Center for Environmental Systems Research at the University of Kassel in Germany to create a water scarcity map. This product set a new bar for understanding water availability (especially where there is insufficient water to meet demand) around the globe at a much finer resolution than previously available.

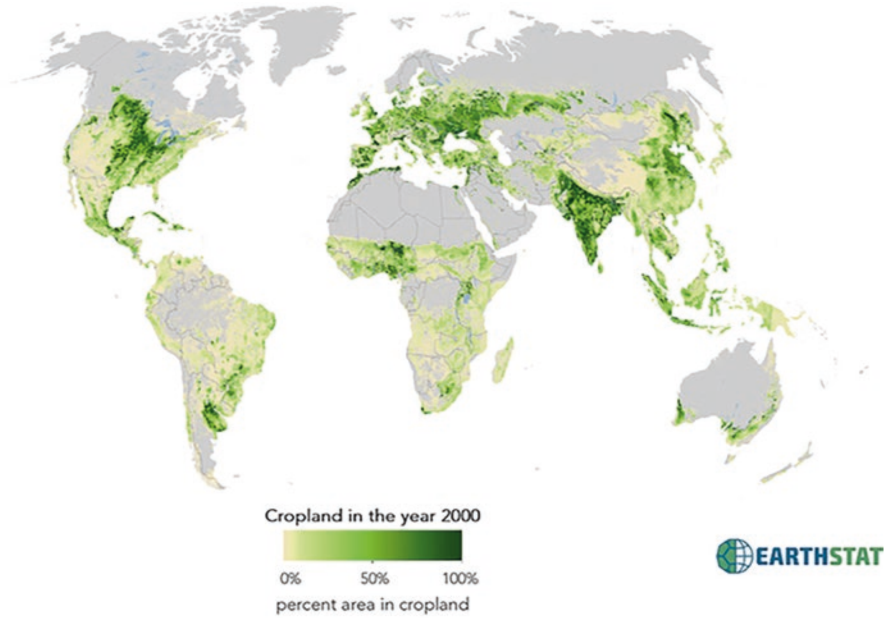


Fig. 5.3 Global Landscapes Initiative global cropland layer

In addition to better spatial resolution, this product also recognized the impacts of seasonal and annual shifts in the water availability.

The Natural Capital Project is a decade-long partnership among the University of Minnesota, Stanford University, the Nature Conservancy, and the World Wildlife Fund. This project is interested in better understanding and modeling ecosystem services or the many ways in which nature provides humankind with a range of goods and services including clean air, fresh water, and food. The project has several focal areas within its broader remit: human well-being and valuation, land use change, livable cities, visualizing trade-offs, and advancing the case for sustainability standards. Many of these areas are addressed through the lens of spatially and temporally assessing ecosystem services. Much of its work focuses on assessing and projecting the ecosystem impact of land use change such as agriculture and forestry on water and soil provision. These models can drive sophisticated visualization that a range of stakeholders better understand how a mix of human actions can bear on a range of ecosystem services. While the project has a global reach, it has been integral to advancing local projects, including providing tools to model the impacts of conservation easements (such as placing crop land into long-term forestry projects) and to assess the threats to water quality in the state from future climate change.

5.3.5 Food Protection and Defense Institute

The Food Protection and Defense Institute (FPDI) at the University of Minnesota is an Emeritus DHS Center of Excellence founded in 2004. FPDI was established to provide research, education, and technology development to enhance the ability to protect the food supply from disruption to include an intentional attack. The knowledge and tools generated from FPDI's work have been used by numerous agencies and organizations around the world—including US agencies (DHS, USDA, FDA, FBI, and CDC), foreign governments, and the United Nations—in their regulation, public health, trade, law enforcement, and homeland security and missions. In addition, numerous companies in the food industry have also benefited from using FPDI's expertise and tools to better understand their food protection-related risks, threats, and mitigation needs and to implement food defense practices.

FPDI uses spatial science approaches to enable collaboration with myriad stakeholders to tackle complex issues. Protecting the food supply from intentionally caused harm is a uniquely challenging endeavor for several reasons. First, almost all of this critical infrastructure is owned by the private sector where information is not widely shared. Second, in the United States, 14 federal agencies have food safety responsibilities, and several more have responsibilities for responding to intentional contamination events. Finally, all state and territorial governments and many local ones have significant food-related public health jurisdiction. Negotiating the overlapping, sometimes poorly defined, and/or conflicting food, trade, and critical infrastructure rules and regulations among these stakeholders is a highly complex and challenging responsibility requiring significant collaboration among many partners to illuminate and mitigate food system challenges (e.g., food safety issues, intentional adulteration).

The institute also applies geospatial capabilities to protect the food system. A wide range of natural or man-made events, including natural disasters, political instability, and market fluctuations, may disrupt supply and incentivize intentional adulteration. While data exists to monitor these risk factors, optimal use of this information by government and private industry is hindered by sheer amount of data that must be reviewed. To address finding signals within vast quantities of data sources and systems, FPDI developed the Focused Integration of Data for Early Signals (FIDES) platform to curate and make sense of this data to support "horizon scanning" of potential food system disruptions. The FIDES Web application fuses multiple streams of data from disparate sources and displays information in the form of an online geospatial dashboard where users browse, search, and layer dynamic and reference datasets related to disruption events. Visualizing fused data geospatially highlights food disruption patterns, cascading effects of natural disasters (e.g., typhoons, infectious disease), and illuminates supply chain challenges that create food system issues as a result of natural (e.g., weather) or man-made (e.g., piracy) events. FIDES has been employed in support of intergovernmental organizations, government agencies, and private industry to rapidly identify and mitigate the impact of catastrophic or intentional contamination events. Examples of data currently included in FIDES are import refusals, global disasters, animal health alerts, food defense incidents, historical food safety incidents, import data, price alerts, and reference data on food production worldwide.

5.3.6 Spatial Science and Health Research

We turn to the health sciences for a final example of how spatial sciences are helping advance domain knowledge, specifically our understanding of public health, nursing, medicine, health informatics, and veterinary science. Epidemiology has been incorporating spatiality into its study since the nineteenth century and continues to advance spatial science more generally today. Anesthesiologist John Snow's 1854 investigation of a cholera outbreak in London is popularly referenced in almost every introductory-level epidemiology course given its relevance to communal and environmental health. By mapping cholera deaths in the area, Snow (often considered the founder of epidemiology) was able to determine the cause of the cholera outbreak to be a contaminated water pump. Several versions of the story exist, and its historical significance has been called into question, but Snow's work remains a popular way to bring together social and geographical concepts into the conversation of population health. Modern social epidemiology considers the interplay between individual-level genetic vulnerabilities and population-level social determinants of health while also underscoring the role of place. Where we live; the conditions in which we work and go to school; place-based differences in climate, environment, policy, and discrimination; and the impact of history and culture at each and every level all paint a clearer picture of how health and disease encapsulate the human experience.

Scholarship at the University of Minnesota leads the way in exploring how space can be integrated into models of health and disease. In the School of Public Health, researchers look at a wide range of topics spanning from heart disease to depression to substance abuse, all of which greatly benefit from spatial perspectives. There are many examples of public health research groups on campus taking advantage of existing spatial technologies to explore topics of health. For instance, public health researchers Austin Rau, Jesse Berman, Jonathan Oliver, and Claudia Muñoz-Zanzi used mapping tools to examine the spread of tick-borne diseases in the neighboring state of Wisconsin. Another public health research team working with U-Spatial investigated population health in Lorain County, Ohio, by using multi-resolution land cover imagery to derive heat vulnerability to assess the impact of climate change on cause-specific mortality. More broadly, Michael Oakes in the Division of Epidemiology and Community Health coedited *Methods in Social Epidemiology* (Oakes & Kaufman, 2017) and uses spatial approaches that capture the interplay of individual, household, and neighborhood health dynamics. Scholars in the Division of Biostatistics focus on developing statistical methods, including spatially aware approaches, for biomedical research related to topics including communicable disease, cardiovascular and pulmonary disorders, cancer, and neuroimaging. Finally, scholars across the university used spatial approaches to address the COVID-19 pandemic, including developing disease maps and planning responses such as optimal spacing of classrooms and other spaces to enable social distancing.

In the School of Nursing, researchers have been integrating spatial analysis into their work as well. Madeleine Kerr, Associate Professor Emerita, led and coled several projects that relied on GIS and spatial analysis to examine various aspects related to the discipline of nursing. For example, Kerr first collaborated with U-Spatial to create a mapping project so that students could collect and map data using the World Health Organization's age-friendly cities checklist (Kerr et al., 2016b). Next, Kerr and nursing students organized the creation of a crowdsourced Web map to assist nursing colleagues working on the ground in Liberia during the Ebola crisis. Later, Kerr collaborated with U-Spatial, Karen Monsen, University of Minnesota professor and coordinator of the DNP Nursing Informatics specialty, and Carol Flaten, University of Minnesota clinical associate professor, to create a windshield survey mapping project as a follow-up to their international study using windshield survey methods and the Omaha System standardized terminology to describe community observations (for an example, see Kerr et al., 2016a). In a follow-up project, students at the University of Minnesota and the University of Auckland New Zealand mapped their observations of community strengths and challenges using ArcGIS online. More recently, in order to further encourage spatial research within nursing, Kerr and Monsen led intensive workshops to provide nursing informatics students with research training in GIS methods.

The School of Medicine has also taken advantage of the abundance of spatial analytical resources and research support on campus. For example, U-Spatial RAs assisted the Minnesota Heart Health Program with the Ask About Aspirin community intervention trial by using mapping software to build custom control and treatment sites that were exchangeable in population demographics (Krzyzanowski et al., 2019). Related research in the University of Minnesota's Variety Club Research Center (VCRC) investigated the geographic distribution of peripheral arterial disease (PAD) and major adverse cardiovascular and limb events among Medicare beneficiaries. Within the Pediatrics Department, Pui-Ying Iroh Tam collaborated with U-Spatial and the Geography Department to conduct the geographical analysis for a retrospective cohort study that examined the role of social and environmental determinants on pneumonia hospitalization risk (Tam et al., 2017).

The Institute for Health Informatics has also grown to integrate the application of spatial methods and geographic concepts to health data. For example, David Haynes led a team to explore ways in which they could address the lack of spatial computation, exploratory data analysis, and spatial data exploration tools available within public platforms by creating a Spatial Online Analytical Platform (SOLAP). SOLAP uses a user-interface and user experience design approach to integrate spatial analysis tools that allow users to explore and learn more about spatial patterns of COVID-19. On a separate project, the Institute for Health Informatics collaborated with the Minnesota Department of Health to explore small area mapping techniques to understand disease prevalence for sparsely populated areas and small geographies (i.e., a city block). The team used novel methods to estimate breast cancer screening rates for the state of Minnesota at fine spatial scales (Hughes et al., 2021). This approach offered policy-relevant insights necessary for better planning of testing locations and dealing with the vagaries of how administrative boundaries are drawn. Another project out of the institute explored use of a mobile app, Smart Community Health (SCH), that connects people with social care needs to local community resources via health screening, self-referrals, real-time registration and modification of services, and real-time visualization and analytics. This platform improves the ability for patients and health-care providers to improve a patient's well-being and exemplifies, with the other projects noted, how health informatics can drive forward the spatial university.

The School of Veterinary Medicine also integrates widely available campus spatial analytical resources within their work. For instance, a research team associated with the Minnesota One Health Antibiotic Stewardship Collaborative (MOHASC) examined the role of the natural environment in the emergence and dissemination of antimicrobial resistance (AMR). The project was designed to predict environmental "hotspots" of antibiotics and antibiotic-resistant genes (ARG) by combining field data with geospatial modeling. Spatial tools and methods were key to identifying the spatial distribution of antibiotic and AMR sources in the natural environment of Minnesota; designing the study at two different spatial scales (macroscale and microscale); capturing the field data in an easy, coordinated fashion with the Collector app; and analyzing spatial patterns to predict areas with higher antibiotic concentrations and ARG abundance (Bueno Padilla et al., 2017). In addition to research on AMR and ARGs, researchers with the Center for Animal Health and Food Safety in the School of Veterinary Medicine collaborated with multiple stakeholders in Minnesota to explore the application of spatiotemporal tools when informing decisions related to health. This work explores the process of cocreating knowledge where researchers and stakeholders could work together to improve data quality, surveillance, and preventive measures in epidemiological studies addressing a range of health issues.

More importantly, interdisciplinary health teams have formed on campus, and these groups are well suited for the uptake of spatial methods in their research. One particular interdisciplinary health research team working together for the University of Minnesota's Global One Health Initiative created a One Health Mapping and Analysis Resource Toolkit (OH-SMART) for community infectious disease preparedness. The OH-SMART Toolkit is best seen as an interactive process that helps guide research across organizations responding to disease outbreaks or responding to other complex health challenges by assisting with coordination, response planning, and team development. Another related example is the broader team-building aspects of One Health. Pelican and others (2020) describe a number of case studies of building One Health leadership and team building in locations around the globe, including Indonesia, Vietnam, Minnesota, and over a dozen countries in Africa. In all of this work, the research mission of the spatial university is advanced by building teams that can enact values of trust, innovation and adaptability, systems base problems solving, support mobilization, and modeling helpful behaviors.

Some of the University of Minnesota scholarship at the intersection of spatial science and health have led to patents and technology commercialization. For example, Yingling Fan and her collaborators have patented and commercialized an app-assisted day reconstruction tool that combines mobile sensing with human input to accurately and comprehensively measure human behavior and well-being with minimal respondent burden. The novelty of the app is twofold: (1) the use of spatio-temporal machine learning algorithms to reconstruct daily time use (activity) and spatial movement (trip) episodes from mobile sensing data in real time and (2) the use of a well-designed user interface to acquire additional self-reported data on the auto-constructed daily activity and trip episodes such as emotional well-being. The technology, initially called SmarTrAC and later named Daynamica, was granted a US patent titled "Travel and Activity Capturing." A year later, Fan and her collaborators founded Daynamica, Inc. with the help from the University of Minnesota Venture Center. Figure 5.4 illustrates the main user interface of the Daynamica app, which is currently available as both an Android and IOS application.

The Daynamica app has been deployed in a wide range of research studies across the United States to collect spatial movement, time use, and well-being data (e.g., Fan et al., 2019; Le et al., 2020). Recently, Daynamica, Inc. has expanded the capabilities of the application by integrating physical activity and biometric data from wearable devices and developing the capability to deliver context-sensitive behavior interventions within the application. The Daynamica team has also developed a HIPAA-compliant version of the app that is currently being trialed in two medical research studies at the University of Minnesota.

5.4 Conclusion

The above review of the spatial science-related work at the University of Minnesota shows that the interaction between spatial sciences and natural/social sciences is not one-directional: the development of spatial sciences traces its origins to natural and social sciences and at the same time contributes to the advancement of natural and social sciences. It is not surprising that employment opportunities relating to spatial science have grown explosively over the past few decades. Spatial science is a useful lens with which to study many research topics that concern the earth and its people. Across many disciplines, the importance of spatial thinking skills—the ability to place problems and objects within the space dimension and reflect on the spatial relationships between problems and objects—has been widely acknowledged. For modern research universities such as the University of Minnesota, it is increasingly important to strengthen investments in spatial science-related infrastructure that could not only serve but also drive a fast-growing need for expertise in GIS, locational sensing, and spatial computing across a diverse range of natural and social science disciplines.

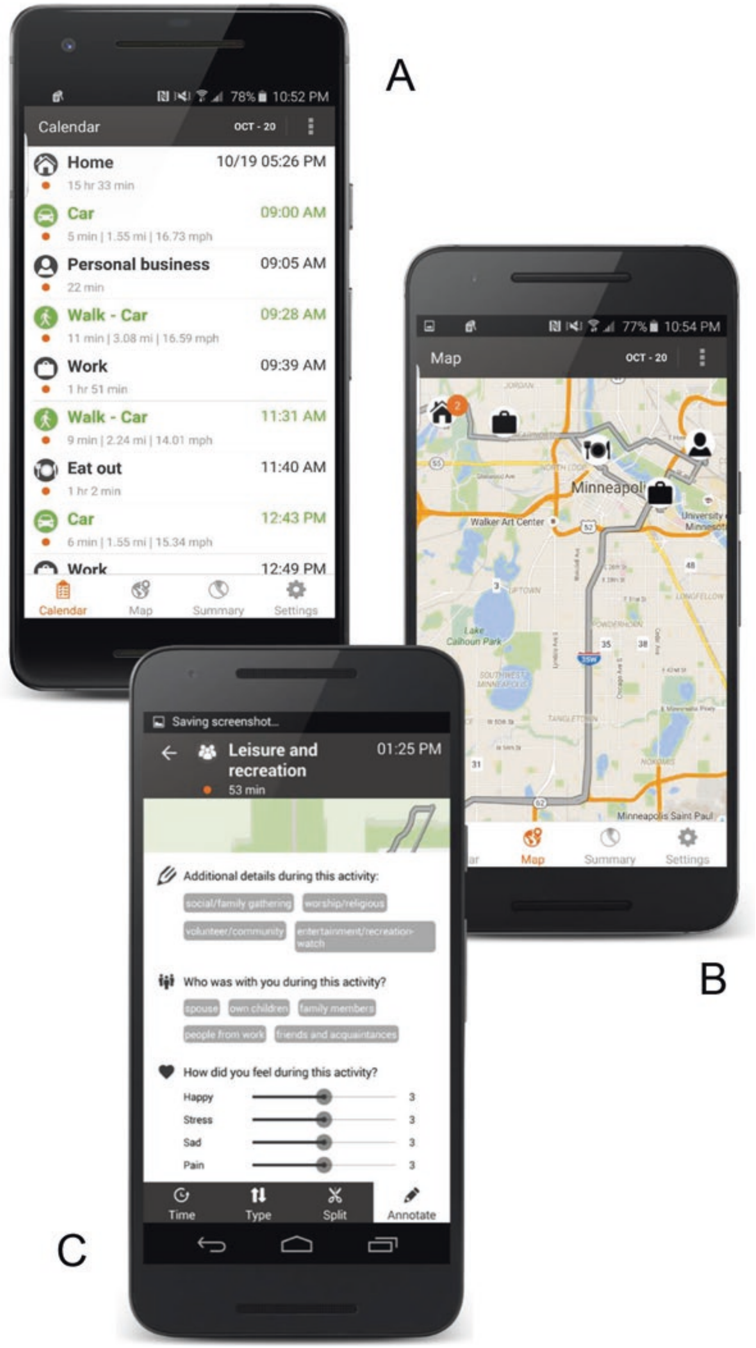


Fig. 5.4 Daynamica main interface. Daynamica constructs the activity-trip sequence in real time from mobile sensing data, inferring activity/trip start/end time, activity type, and trip mode (**a**). It captures and displays detailed spatial information (**b**). Users can confirm or correct the activity/trip information and provide additional details (**c**)

References

Baerwald, T. J. (2010). Prospects for geography as an interdisciplinary discipline. *Annals of the Association of American Geographers, 100*(3), 493–501.

Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing, 65*(1), 2–16.

Bueno Padilla, I., Williams-Nguyen, J., Hwang, H., Sargeant, J. M., Nault, A. J., & Singer, R. S. (2017). Impact of point sources on antibiotic resistance genes in the natural environment: A systematic review of the evidence. *Animal Health Research Reviews, 18*(2), 112–127.

Eldawy, A., & Mokbel, M. F. (2016). The era of big spatial data: A survey. *Foundations and Trends in Databases, 6*(3–4), 163–273.

Faghmous, J. H., & Kumar, V. (2014). A big data guide to understanding climate change: The case for theory-guided data science. *Big Data, 2*(3), 155–163.

Fan, Y., Brown, R., Das, K., & Wolfson, J. (2019, February). Understanding trip happiness using smartphone-based data: The effects of trip-and person-level characteristics. *Findings*, 7124.

Fitch, C. A., & Ruggles, S. (2003). Building the national historical geographic information system. *Historical Methods: A Journal of Quantitative and Interdisciplinary History, 36*(1), 41–51.

Hughes, K. D., Haynes, D., & Joseph, A. M. (2021). Novel mapping methods to describe utilization of free breast cancer screening from a state program. *Preventive Medicine Reports*, 101415.

Kerr, M. J., Flaten, C., Honey, M. L., Gargantua-Aguila, S. D. R., Nahcivan, N. O., Martin, K. S., & Monsen, K. A. (2016a). Feasibility of using the Omaha System for community-level observations. *Public Health Nursing, 33*(3), 256–263.

Kerr, M. J., Honey, M. L., & Krzyzanowski, B. (2016b). Geo-spatial informatics in international public health nursing education. *Studies in Health Technology and Informatics, 225*, 983–984. Amsterdam, The Netherlands: IOS Press.

Knight, J. F., Pelletier, K. C., & Rampi, L. P. (2017). Change detection. In R. A. Marston (Ed.), *The international encyclopedia of geography* (Vol. 8, pp. 520–529). Wiley-Blackwell.

Krzyzanowski, B., Manson, S. M., Eder, M. M., Kne, L., Oldenburg, N., Peterson, K., et al. (2019). Use of a Geographic Information System to create treatment groups for group-randomized community trials: The Minnesota Heart Health Program. *Trials, 20*(1), 1–7.

Le, H. T., Buehler, R., Fan, Y., & Hankey, S. (2020). Expanding the positive utility of travel through weeklong tracking: Within-person and multi-environment variability of ideal travel time. *Journal of Transport Geography, 84*, 102679.

Lime, S. (2008). MapServer. In *Open source approaches in spatial data handling* (pp. 65–85). Springer.

McMaster, S., Edsall, R., & Manson, S. (2011). Geospatial research, education and outreach efforts at the University of Minnesota. *Cartography and Geographic Information Science, 38*(3), 335–337.

National Research Council. (2010). *Understanding the changing planet: Strategic directions for the geographical sciences*. National Academies Press.

Oakes, J. M., & Kaufman, J. S. (Eds.). (2017). *Methods in social epidemiology*. Wiley.

Pardey, P. G., Beddow, J. M., Kriticos, D. J., Hurley, T. M., Park, R. F., Duveiller, E., & Hodson, D. (2013). Right-sizing stem-rust research. *Science, 340*(6129), 147–148.

Pelican, K., Blair, B., Adisasmito, W., Allen, I., & Wanzala, S. (2020). One health leadership and team building training. In J. Zinsstag, E. Schelling, L. Crump, M. Whittaker, & M. Tanner (Eds.), *One health: The theory and practice of integrated health approaches* (pp. 184–196). Centre for Agriculture and Bioscience International.

Shekhar, S., & Chawla, S. (2003). *Spatial databases: A tour*. Pearson Education.

Shekhar, S., & Vold, P. (2020). *Spatial computing*. MIT Press.

Shekhar, S., Yang, K., Gunturi, V. M., Manikonda, L., Oliver, D., Zhou, X., et al. (2012). Experiences with evacuation route planning algorithms. *International Journal of Geographical Information Science, 26*(12), 2253–2265.

Sobek, M., Cleveland, L., Flood, S., Kelly Hall, P., King, M. L., Ruggles, S., & Schroeder, M. (2011). Big data: Large-scale historical infrastructure from the Minnesota Population Center. *Historical Methods, 44*(2), 61–68.

Tam, P. I., Krzyzanowski, B., Oakes, J. M., Kne, L., & Manson, S. (2017). Spatial variation of pneumonia hospitalization risk in Twin Cities metro area, Minnesota. *Epidemiology & Infection, 145*(15), 3274–3283.

Chapter 6
Future of the Spatial University

Thomas Fisher

Abstract Spatiality has become a key factor in the economy, in pedagogy, and in the future of higher education. The idea of a "spatial university" has implications not only for how we teach, learn, and conduct research but also for how we organize knowledge, create new disciplines, and conceive of the world around us. Having, for centuries, expanded our knowledge through the printed word, we now have spatial computing and Geographic Information Science to help us visualize information and create new knowledge through often-unrecognized spatial relationships.

Keywords Spatial university · Design thinking · Spatial economy · Spatiality

6.1 Introduction

What does it mean to call an institution like the University of Minnesota a "spatial university"? While this book has tried to answer that question in various ways and from different perspectives, this conclusion attempts to lay out some of the complexities of spatiality in higher education today. To some, spatiality may not seem like a complex subject – after all, universities have long occupied particular campus spaces, with buildings housing the institutions' core activities. In that sense, universities are inherently and perhaps inevitably spatial, with diverse groups of people coming together in physical places in order to teach, learn, and research.

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6.2 The Need for Spatial Critique

Universities, of course, have some unique spatial qualities. Unlike many other institutions, universities often have campus plans that determine the spaces in and among buildings over long periods of time. And contrary to corporate campuses, universities remain largely open to the public, at least during the day and evening hours, with few of the security measures and identification required by other public or private facilities. Universities are more like cities, with a diversity of spaces – offices and classrooms, libraries and living quarters, dining halls, sports and recreational facilities – and with a range of city-like operations: their own police force, transportation system, and infrastructure (i.e., heating and cooling plants, underground utilities, communications, etc.). At one level, talking about a “spatial university” sounds like a tautology; universities have always been spatial, defined by what sets them apart geographically and organizationally from almost every other institution.

But that obvious fact can obscure the underlying complexity of the university as a spatial phenomenon. For example, the way universities use space and locate people has reinforced certain behaviors while inhibiting others. While most universities claim to support interdisciplinary teaching and research, for example, most also spatially separate disciplines in different buildings or places on campus, making it hard for colleagues in various fields to connect. That has become so common that we see it as normal, without thinking about the assumption behind it: that colleagues in the same discipline need to be located in the same place even though they may be doing research more related to that of colleagues in other departments. I office in the architecture department, for instance, but my mapping-based work has more in common with colleagues in planning and geography, who are located at the other end of campus. While colocating faculty in a department may make it easier to assign and budget for space, it makes it harder to carry out one of the most important missions of the university: to discover new knowledge, which almost always happens at the edges or intersections of disciplines.

What might happen if universities, instead, clustered all the historians, software developers, or data analysts in the same location, regardless of the discipline they were from? Might we see temporal, digital, or analytical connections among fields that we miss now because of their spatial segregation on campus? And might new insights emerge and even new disciplines arise more readily if faculty from a variety of disciplines with the same focus or method shared the same space?

A now-demolished building – Building 20 – at MIT offers an example of how physically mixing disciplines can prompt innovations that might not otherwise occur. Built as a temporary structure during World War II, Building 20 became “swing space” for departments having their permanent facilities upgraded. As a result, it brought together a diversity of disciplines – linguistics, acoustics, computer science, biology, engineering – from which whole new fields evolved: generative linguistics, bioengineering, computational acoustics. Such conceptual ferment depends, at least in part, on physical proximity and spatial adjacency, which raises the following questions: What if every building on a campus became temporary swing space, with a continual mix of seemingly unrelated fields in adjacent locations? Inconvenient, perhaps in some ways, but what creative new combinations might arise from it?

The mixing of disciplines can occur not just in physical quarters but institutionally as well. The Institute on the Environment at the University of Minnesota (Chap. 5) offers one example of that, constituting what we might call a “virtual Building 20.” It convenes faculty and staff from all parts of the university working on environmental issues, with myriad lectures, salons, seminars, and conversations aimed at attracting as diverse a set of perspectives and audiences as possible. The university’s U-Spatial provides an infrastructural example of cross-disciplinary knowledge creation by supporting Geographic Information Science (GISc), remote sensing, and spatial computing across all campuses. U-Spatial not only provides training and technical support but also serves as a clearinghouse of ideas related to the “spatial” aspects of the university as well as information about much of the spatially related teaching and research underway in the institution (more in Chap. 2).

Such examples highlight a couple of key points. First, spatiality matters. How we locate ourselves reflects what we value and reveals what we don’t while also enabling certain kinds of behaviors and inhibiting others. Mapping spatial relationships on university campuses thus becomes not just a bureaucratic task for facility managers, but also an ongoing opportunity to reexamine our assumptions and beliefs and to make unexpected connections in hopes of generating new knowledge and perhaps new disciplines. Second, spatiality requires critique. Universities have long provided space – and protection in the form of tenure – for faculty willing to speak truth to power and who might be vulnerable outside the academy’s walls. But inside those walls, faculty rarely apply the same critical attention to the space in which they work. Some may grumble about the location of their parking space or the size of their office, but few speak truth to the power of space within the institution itself, arrangements that reflect centuries-old and often out-of-date assumptions.

6.3 Spatializing Knowledge

That critical eye needs to extend beyond the physical location of faculty to how we organize knowledge itself within the institution. Academic libraries in the United States, for example, organize their collections and shelve books according to the disciplinary categories of the Library of Congress catalog system, which makes it less likely that an expert in one field will serendipitously come upon a provocative book in another. While that disciplinary organization of knowledge reflects the intellectual monocultures that have come to define higher education, that organization can also lead us to misunderstand and even do damage to the world, whose human and natural ecosystems exist in particular places, in multiple layers, and as complex webs (Fisher, 2016). What if, in addition to the alphabetical and numerical categorization of the Dewey Decimal and Library of Congress systems, we also organized knowledge as the world itself is organized, spatially, with Geographic Information Systems (GIS)-based catalogs that map the relationships among different fields as they apply to each place? Subjects now thought of as separate and distinct, like hydrology and sociology, for example, might begin to see connections between them: how human behavior can alter the water cycle or how changing levels of precipitation can affect communities. This could move us from a monocultural to an ecological way of thinking about disciplinary knowledge.

Imagining the university in such spatial terms is not just a thought experiment; it might hold the key to the institution's survival. In the digital age, as information becomes easily accessible and online degrees become increasingly common, the university as traditionally conceived faces possible obsolescence. In order to avoid that fate, higher-education institutions will need to focus on what the online world cannot do as well: the unexpected conversations, serendipitous interactions, and in-person collaborations, both on campus and off, that happen informally now and that may need to be more consciously curated and facilitated in the future. Those activities will, in turn, require different kinds of learning environments: more flexible, adaptable, and varied spaces than those that typically occur on campuses today. Lecture halls may largely disappear, and so too might dedicated offices. In their place may arise spaces that accommodate a greater mix of activities over the day and across the year, with students accessing, through their mobile digital devices, immersive learning opportunities wherever they occur.

In one of my seminars, I asked my students to take responsibility for finding the spaces in which the class would meet and communicating the reasoning for each spatial decision. Significantly, my students never once chose a classroom in which to meet; instead, they chose coffee shops, lobbies, lounges, and other similar spaces in which they could find comfortable seating, daylight, and views, often in places with other activities going on or with people passing by. Space mattered but not in the way universities often understand it. I discovered that, with digital support, I could teach in every space they selected, as the campus – and some off-campus locations – became my classroom. I also discovered how much space can serve as a memory device (Yates, 1966). My students reported remembering the content of our conversations by recalling where we had the discussion, reinforcing the role of spatiality in the digital age and raising the paradoxical idea that the twenty-first-century spatial university may have as much in common with the medieval university as with that of the last century.

In the digital age, the spatiality of the university will continue to undergo dramatic transformation. Students, staff, and faculty will increasingly interact with others at various spatial scales, from those who occupy the same classrooms and office corridors to those who work across campus – or across the world. And with that, our idea of the "spatial university" will evolve. When we use the term "spatial," we need to define which space – and whose space – we mean. The rarefied space of the campus for those who work or pay tuition there represents one sort of space, while the expansive space of the Internet, open to all who have a digital device and a Wi-Fi connection, represents another. That has made twenty-first-century academic life at once nonspatial, in the sense that academic work can occur almost anywhere, and also intensely spatial, in the sense that we now move constantly from one space to another, from the analog to the digital and the physical to the virtual, over the course of the day.

6.4 The University's Spatial Challenges

Universities have only begun to face the implications of this challenge to the historic face-to-face transmission of knowledge and conduct of research. A few universities have embraced the challenge and gone mainly online – from Southern New Hampshire University in Manchester to Capella University in Minneapolis – and many more will be offering courses entirely or partly online in the wake of the COVID-19 pandemic. The widespread use of platforms like Zoom to deliver coursework during the pandemic has forced universities to ask fundamental questions such as the following: Who are our students now that people can log on to courses from anywhere in the world? Who are our faculty now that professors can teach from wherever they have access to the Internet? And what is a class when it can happen asynchronously as well as synchronously, remotely as well as in person?

Such questions will also force universities to reimagine campuses as places that complement the digital delivery of knowledge and that facilitate the serendipitous encounters and unplanned conversations that can only happen in physical space. And the complementarity of the digital and physical worlds in higher education may lead to a greater engagement with the local communities in which universities sit, something that can only happen in physical space, and a greater focus on the diverse interactions and immersive experiences that students can have when doing community work that the digital environment can support but cannot replicate. The most promising place for universities in the future may well be the places in which they stand and where they have deep and long-term commitments. Mapping those relationships and the interactions of faculty, students, and community members may one day even replace the traditional course catalog, if place-based learning off campus becomes as common as lecture-based education on campus and if interdisciplinary project-based pedagogy becomes more of the norm rather than the exception it is now.

That pedagogical shift may also send universities back to their original role and meaning. The Latin word for these institutions – universus – means whole or entire, and with that in mind, universities may need to rethink their organization around grand challenges, the big problems we face on this planet that can only be addressed by seeing them in their entirety, as a whole. The University of Minnesota has a grand challenge curriculum and research program in which faculty from at least two different disciplines engage students from across the institution in some of the major dilemmas of our time, from developing social entrepreneurial businesses in partnership with community members to exploring the meaning of the good life in the epoch of the Anthropocene. In the grand challenge course I co-taught for several years, with colleagues from the Institute on the Environment and the Humphrey School of Public Affairs, students from several disciplines worked together in teams to develop new ventures related to everything from rural air pollution stemming from the burning of agricultural plastics to the childcare crisis in small, remote communities to the food insecurity of underserved urban neighborhoods.

One of the grand challenges of our time is the digital divide, in which large numbers of people lack access to digital technology and to the global economy dependent upon it. The Council of Economic Advisors (2015) mapped the gap between urban and rural access to the Internet, with "red" America having at least 15 percent less access than "blue" America. And a Pew Research Center study (2020) showed that over one in five households do not have computers at home or access to the Internet. Here, the spatial university, with its commitment to learning wherever it occurs, might serve as a model for the spatial city, county, and state, especially in places that have low levels of participation in the digital economy. The economist Jeremy Rifkin has called for a "collaborative commons" in which providing more services, offering more information, and adding more people to existing digital networks can happen at a "zero marginal cost," making them essentially free to those who cannot otherwise afford them (Rifkin, 2014). One of the primary tasks of the spatial university may be to prepare students to be a part of a more collaborative and equitable economy.

Anyone with access to Esri's ArcGIS Online site has access to the "Living Atlas of the World," which represents one form of the collaborative commons Rifkin writes about. The hundreds of thousands of maps in the Living Atlas allow people to become informed about almost any topic and see its relevance to where they live and work. The marginal cost of adding maps is near zero, while the volunteered geographical information of people using the site continually enhances its value as well as its breadth and depth. The U-Spatial website offers another example of the collaborative commons, providing research highlights that anyone can access and understand, which suggests that the spatial university of the future can help make the investigations of its researchers as spatially distributed and readily accessible to the widest readership as possible.

6.5 The Centrality of GIS

In a multilingual, digitally networked world, the ability of GISc to help people visualize information and map data will make spatial computing a common language of the twenty-first century. According to U-Spatial Director Len Kne, his staff has worked with every department at the university, with GISc offering a way in which disciplines can see themselves spatially and understand how their subject matter plays out in particular places, revealing connections over time and across space in ways not possible before.

Given the potential for spatial thinking across disciplines, it seems inevitable that GISc will affect the pedagogy and perhaps even the processes of universities. In addition to the traditional core skills of language ability, critical thinking, and mathematical reasoning, every university may need to ensure that students have basic knowledge of GISc and spatial computing, considering the increasingly central role it will play in our lives. While knowledge of coding helps, every college graduate should at least be able to assess what GIS-based analysis tells us and what relationships and connections it reveals.

All higher-education institutions have a number of spatially oriented fields, ranging from social sciences like sociology and anthropology to hard sciences like geology and hydrology to applied sciences like engineering and public health to the arts and humanities like dance or design. Despite this, many disciplines in universities do not have a geographical conception of themselves. Every specialty, in other words, has scholars who research and teach the history of the field, but even those disciplines that deal with spatial phenomena rarely engage in scholarship or have coursework related to their own disciplinary geography: to the physical movements and proximate locations of people whose work and ideas underpin the domain. Most faculty have at least a rough timeline of their discipline, but not many can map it, which suggests the need for a rethinking of the role of geography in higher education. In the spatial university of the future, geography might provide a spatial understanding of every field, as history does a temporal one. Hegel (1975) argued in the nineteenth century that we cannot understand anything without knowing its history; in the twenty-first-century – and beyond – we won't be able to understand anything without also knowing its geography, how it relates to everything else spatially as well as temporally.

GIS can greatly aid the spread of that geographical understanding. The widespread use of GIS to map data, visualize information, and spatialize knowledge can transform disciplines and connect fields that hadn't seemed related before. In the Minnesota Design Center, GIS has enabled my staff and our students to understand and communicate the relationships among seemingly disparate fields: the impact of urban design on public health, of natural resources on economic development, and of transportation on equity. The center also operates as an open platform in which anyone – faculty, students, practitioners, and community members – interested in our GIS-based work can participate. This offers another model of the "spatial university" as a gathering place for diverse participants across their careers and over their lifetimes, open to diverse perspectives and welcoming of varied contributions. The "science of where," as Esri calls GIS, provides a "platform of where" as well.

6.6 The Spatial Economy

GISc has also helped create an "economy of where." Research into the future of work suggests that nearly half of the job categories that currently exist remain vulnerable to automation within the coming decade: work that is either predictable or dangerous and readily replaced by software or robotics (Frey & Osborne, 2017). When we look at the job categories that resist automation, they have several characteristics, typically requiring a high degree of human interaction (caring, communications, and community jobs, for instance) or a great deal of unpredictability (creative, craft, and construction jobs), all of it work that involves some degree of spatial proximity.

While the digital environment allows people to care for each other remotely, communicate over long distances, and create things in teams distributed around the world, the jobs that resist automation ultimately demand some spatial activity as well: caring for and communicating with other people and making, building, and crafting things in physical space. In many ways, the economy, like universities, has always been spatial in the sense that interactions among buyers and sellers have long occurred in particular places. And like universities, the economy has also become at once placeless and also place-bound in the sense of an increasing percentage of economic activity now happening through digital transactions of various kinds, almost everywhere, with the provision of goods and services to very particular locations, almost anytime. We now live in a world where we can Venmo our payment to a restaurant that will deliver food to our door by Uber Eats.

That ability reflects not just a new form of delivery but a new kind of economy. GISc not only allows traditional businesses to locate their bricks-and-mortar operations; it also enables the providers of goods and services to deliver their products to people wherever they are and allows consumers to pay only for what they access and use, without having to own things. This would not be possible without the use of mobile, digital, and spatial tools, which allow people to find each other and the goods and services they seek in a much more dynamic and fluid way. The responsibility of universities to prepare students for this way of living and working shows why an understanding of GISc and spatial computing will need to become a core skill of those who hope to thrive in the emerging economy.

6.7 The Spatial University

In sum, GISc represents the "Gutenberg" revolution of our time, where a new medium – in this case, digital mapping – has begun to transform our lives. GISc provides a medium that allows us to understand information and see the connections among phenomena in ways that no printed book or text-based computer file ever could. We evolved as a visual, spatial species, and long before we created written languages and packaged them in book form, we assessed our environments and understood the world around us through what we experienced in space, in particular places. GISc links all the data and information that resides in print and in computer files across the world to how we, as a species, process data and information most effectively: visually and spatially. In that sense, we might see the "spatial university" as the next phase of higher education itself, as the integration of all that we know with how we know best.

References

Council of Economic Advisors. (2015). Mapping the digital divide (issue brief). https://obamawhitehouse.archives.gov/sites/default/files/wh_digital_divide_issue_brief.pdf. Accessed 1 June 2021.

Fisher, T. (2016). *Designing our way to a better world*. University of Minnesota Press.

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change, 114*, 254–280.

Hegel, G. W. F. (1975). *Lectures on the philosophy of world history. Introduction, reason in history*. Translated from the German edition of Johannes Hoffmeister from Hegel papers assembled by H. B. Nisbet. New York: Cambridge University Press.

Pew Research Center. (2020). 53% of Americans say the Internet has been essential during the COVID-19 outbreak. https://www.pewresearch.org/internet/2020/04/30/53-of-americans-say-the-internet-has-been-essential-during-the-covid-19-outbreak/. Accessed 1 June 2021.

Rifkin, J. (2014). *The zero marginal cost society, the Internet of Things, the collaborative commons, and the eclipse of capitalism*. Palgrave Macmillan.

Yates, F. A. (1966). *The art of memory*. University of Chicago Press.

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