EMERGING TECHNOLOGIES AND THE GEOSPATIAL LANDSCAPE

A Report of the National Geospatial Advisory Committee

December 2016

Introduction

The National Geospatial Advisory Committee (NGAC) received guidance from the Federal Geographic Data Committee (FGDC) in 2016 to provide perspectives and advice on how new technologies will impact the geospatial community. This report examines new and emerging technologies that will be of importance to Federal Government agencies using geospatial data, in the near- and medium-term future (~5 year horizon). The report identifies five overarching technology trends driving geospatial technologies, and then examines within this context the impacts on federal agencies in the core geospatial activity areas of data collection and generation, data analytics, infrastructure, access, and workforce.

Overarching Trends Driving Emerging Geospatial Technologies

We identify five overarching technology trends that are enabling, shaping and driving emerging geospatial technologies. These include:

- **Real-time spatiotemporal data creation and interaction**
  Although real-time spatiotemporal data are now being generated by almost ubiquitously and their applications in research and commerce are widespread and rapidly accelerating, the ability to continuously create and interact in real time with this data is a recent phenomenon. This innovation is functioning as a core change agent in geography, cartography, GIScience, and many related geospatial fields, profoundly realigning traditional relationships and structures, expanding research horizons, and transforming the ways in which geographic data are now collected, mapped, modeled, and used, in geography and science and society more broadly. This real-time space–time interactive functionality remains today the underlying process generating the current explosion of fused spatiotemporal data, new geographic research initiatives, and myriad mobile geospatial applications in governments, businesses, and society.
- **Miniaturization of technologies**
  Miniaturization to create small, and often inexpensive, devices, sensors, and wireless connectivity is driving an explosion of the Internet of Things (IoT). Miniaturized and lower cost sensors lead to an increase in what, when, where, and how much data is collected and, more importantly, the ability to tailor the sensor to the specific data collection need.
- **Proliferation of new mobile geospatial sensor platforms**
  The rapid miniaturization of technologies has made it feasible to explore new modalities for sensor distribution, such as small satellites (smallsats) and unmanned aircraft systems (UAS, or ‘drones’) that can be rapidly designed and deployed with orbits or flight paths tailored to the mission. These mobile geospatial sensor platforms greatly expand the capability of individuals, businesses, and governments to collect volumes of remotely sensed data for diverse and mission critical purposes, including disaster response, environmental monitoring, and public safety.
- **Expanding wireless and web networks**
  The expansion of data collection methods, and the resulting volumes of real-time spatiotemporal data, demand improved methods for data transmission and distribution. Emerging new wireless and web networks are laying this groundwork.

- **Advances in computing speed and capacity for geospatial research and applications**
  High performance computing networks (including CyberGIS) and cloud computing services (including CloudGIS) provide governments and others with conduits with which they can more easily access and contribute to repositories of geospatial data, tools, and services.

Emerging Technologies in the Federal Agency Geospatial Landscape

Below we examine impacts of the above overarching technology trends in five broad areas of the federal agency geospatial landscape. These categories are:

1. ***Data collection and generation*** – technologies that enable collecting or processing spatial and spatiotemporal data, introduce new data types, or have other significant implications for data delivery and use. This includes impact on existing or de facto standards, real-time data generation and use, data confidentiality and privacy, and big datasets generated using these new technologies.
2. ***Data analytics*** – new technologies or methods to support analysis of big and small data, multi-dimensional, spatiotemporal, etc. These technologies include human-guided and autonomous, AI or machine learning type systems.
3. ***Infrastructure*** – infrastructure needed to support collection, processing, storage, sharing, and protection of data and systems.
4. ***Access*** **(technology and data)** – diffusion of technologies and data have been facilitated by improvements in access (e.g., changes in wireless systems and internet access). These changes impact who has access to the technologies and data, how we interact with them (e.g., types of device), and how we protect sensitive information.
5. ***Workforce*** – changes to the technology landscape require awareness of critical spatial thinking and technology skills needed for the next generation of spatial analysts, as well as consideration for how we broaden and diversify the geospatial workforce.

This report is not intended to be a comprehensive and exhaustive discussion of all areas of geospatial technology; however, it covers selected topics and trends that we feel are of particular importance to federal agencies.

Technologies Impacting Federal Agency Geospatial Activities

Following is a discussion of specific emerging technologies of importance to Federal governmental agencies in the areas of data collection, data analytics, infrastructure, access, and the geospatial workforce.

1. Data Collection and Generation

***Real-time spatiotemporal data**.* The past few decades have witnessed an explosion of new geospatial data, including most significantly, fused spatiotemporal data. The changes in geospatial data collection wrought by real-time interactive GPS/GIS and its creation of mobile real-time space–time capabilities and applications are extensive. It is largely responsible for the highly detailed, specific, and updated GIS feature and attribute spatiotemporal data now available for governmental applications and GIScience research. It also has enabled the integration of GIS with mobile electronic sensors, such as environmental pollutant monitors, digital cameras, bathymetric instruments, noise monitors, biometric health sensors, and so forth, resulting in vast amounts of new continuously georeferenced and timecoded sensor data.

Real-time interactive GPS/GIS has spawned whole new industries, such as location-based services (LBS), and is a primary technology employed to create the navigational databases and street maps now used so widely by major Internet-map providers. It increasingly is a core component of the management of day-to-day real-time operations at most governmental agencies and large business organizations. It has also, in many ways, changed how wars are waged and military operations are carried out.

Broadening of participation. Another transformation enabled by real-time space–time interactive functionality is the enormous broadening of participation in mapping and geographic knowledge production to include the subject matter experts themselves (e.g., the botanist, the environmental scientist, the lineman, the archeologist, etc.), as well as community activists (participatory GIS), human rights organizations, and ordinary citizens through volunteered geographic information (VGI) and crowd-sourced geographies.

The proliferation of GPS-enabled mobile devices and sensors has resulted in new streams of real-time spatiotemporal data that is contributing to what is now termed geospatial 'big data.' Moreover, technology miniaturization coupled with low-cost location-aware capabilities is driving the geospatial social media and big data revolution. Geospatial 'big data' allows for the development and use of powerful predictive analytic and visualization capabilities that are increasingly important to government decision processes.

Small satellites (smallsat). Changes in satellite technologies are influencing the remote sensing industry in a significant ways as both space and airborne imaging sensors proliferate. The smallsat revolution is being driven by cost reductions associated with a wide variety of new technologies and 'new space' business models. Sensor, launch, and insurance costs are all orders of magnitude lower than for the traditional, larger satellites.

More small satellites mean larger constellations and increased opportunity for meaningful monitoring. This creates new applications in many areas, including agriculture and forest management, environmental monitoring and impact assessment, natural disasters response and recovery, and national security concerns.

These trends generate new opportunities for mission specific sensors. If a specific spectral signature is required for a critical application, smallsats can be rapidly designed and deployed with orbits tailored to the mission. For instance, disaster response professionals often require specific spectral signatures to identify damage after a hurricanes, floods, and earthquakes. Sensors can also be 'tuned' to find crops like poppies or specific oil related geology. Cost reductions associated with mission specific sensors will lead to increased commercial application such as counting cars at shopping centers or shipping containers at ports and harbors, as well as monitoring oil reserves for commodities trading. These opportunities will only grow as hyper-spectral sensors mature and offer thousands of spectral band combinations.

Unmanned aircraft systems (UAS). Additionally, the runway has been opened for drones with the 2016 release of FAA rules on the use of Unmanned Aircraft Systems. UAS proliferation and applications share many of the attributes of smallsats, but at an even lower cost. This increases the possibility of personal and small business use, putting a near real-time aerial monitoring capability in the hands of farmers, builders, inspectors, first responders, and the public. As with the opportunities afforded by smallsats, an expanded user community will lead to new sensors tailored to specific missions. Currently pre-programmed flight plans allow farmers to monitor crop moisture and nutrient levels multiple times per day, or to monitor new construction or open pit mines at the frequency needed for project managers and oversight bodies. The opportunities will be limited only by the imagination of the user communities.

2. Data Analytics

While data analytics is not an emerging technology, spatial data analytics are evolving in sophistication. A growing market of open source and commercial data analytics tools combined with increasing volumes of spatially referenced data makes the topic of interest to federal agencies.

The miniaturization of sensors has increased our capability to produce small, inexpensive devices to collect real-time data and produce geotagged messages or images, leading to new analytical challenges with large spatial datasets, including big data. Big data is commonly defined as three Vs, which break down as: lots of data (volume), of different types (variety) that are collected/distributed at high speeds (velocity).

However, the power of big data has more to do with a fourth 'v', its *value.* To get to the value of big data one must understand the ecosystem of technologies feeding and supporting big data. Advancement in web technologies has driven our connected world to the proliferation of data services, cloud software and hosting, platform integration, smart devices, and the Internet of Things (IoT). These advancements yield massive amounts of varied and continuous data – big data. While big data itself does not necessarily translate to knowledge, however, GIS and geospatial data provide the context, analytic capabilities, and understanding to the big data to better inform decisions.

Summarizing and visualizing aggregated spatial big data on a map allows users to immediately begin the analytic process of asking and answering questions about the data. For instance, where are disease outbreaks occurring based on sales at pharmacies? Or, where is insurance risk greatest given recently updated population shifts and storm patterns?

Big data, whether transactional business or government data or sensor data collected in the IoT ecosystem, requires context to understand and make it valuable. Geolocation and GIS feature and attribute data provides that context, by transforming the raw data into useful information and ultimately actionable intelligence. Advances in spatial data visualization and analytics are transforming the way governments and businesses operate, plan and deliver their services.

A recent Gartner, Inc. report forecasted 6.4 billion connected things will be in use worldwide in 2016, up 30 percent from 2015, and will reach 20.8 billion by 2020. Our hyperconnected world and evolving spatial data analytics enable better understanding of objects, environmental conditions, people and their interactions in real-time. These new capabilities raise technical challenges and policy questions related to privacy, human rights, data standards, confidentiality and security, and the management and dissemination of these data.

As the spatial-temporal data ecosystem expands, it will create opportunities for integrating data from billions of multipurpose devices through evolving communication technologies, which will support numerous GIS applications including geocoding, routing, geofencing, and spatial analysis, along with a full complement of geoenriched data. Geospatial analytics and GIS modeling will become more predictive and also potentially prescriptive during the next five years.

3. Infrastructure

Since the Web became ubiquitous in early 2000's, the core development of geospatial information science and technology has shifted from "top-down authoritative" to also include "bottom-up contributive" approaches. This shift takes advantages of cyberinfrastructure and manifests itself in new geospatial methods of data acquisition, space-time analytics, spatial big data, geovisualization, and interface design. Cyberinfrastructure, on the broadest sense, delivers information computing and sharing facility over digital wired or wireless networks. From high performance computing networks (including CyberGIS) to cloud computing services (including CloudGIS), cyberinfrastructure provides governments and others with access to conduits with which they can contribute to repositories of geospatial data, tools, and services. Over the years, "bottom-up contributive approaches" have been developed and popularized, for example, volunteered geographic information (VGI), ambient geographic information from web crawling and crowd sourcing, location-based services, mobile geosensor networks, personalized navigation systems, social GIS coding, and geospatial UAS applications. New frontiers on mobile health (mHealth), Internet of Things, smart cities, and self driving cars pose new demands on geospatial cyberinfrastructure for communication, storage, access, and analysis.

Self-driving cars, for example, will rely heavily on mobile creation of and access to real-time information among people, machines, and our environment. While the unit of data in transmission may be small, the boundless number of transmissions at one time with geo-enabled applications can crowd the internet bandwidth and stagnate progress. Cyberinfrastructure, such as national broadband, is crucial to mobile access and the development of geospatial applications. New cyber infrastructure, such as programmable optical networks, holds promise for decreasing network delays, enhancing scalability, and offering rapid and efficient deployment of geospatial services. Federal policies also play a key role. The US DOT Federal Automated Vehicles Policy of 2016, for example, is helping to pave the way for the emerging geospatial infrastructure required for self-driving vehicles.

Data storage in the cyberGIS infrastructure is demanding but critical to deep learning of spatial patterns and associations. Cloud-based data storage and dissemination are creating more cost effective and flexible computing platforms. In 2012, the White House directed a cloud-first strategy to migrate 25% (or $20 billion) of federal IT spending to cloud-computing solutions. As government agencies and organizations expand commercial cloud storage, cyberGIS infrastructure needs should be considered.

In 2015, the Congressional Research Service identified challenges in federal implementation of cloud services. These include security requirements, organizational culture, acquisition processes, and funding for implementation. While technological advances have addressed some security requirements, policy and standard solutions will also be key to addressing these challenges.

New developments in fog computing, which facilitates the operation and management of computing, storage, and networking services between end devices and cloud computing data centers, will likely become more widespread. Because of neighborhood effects, spatial uncertainty and spatial autocorrelation, fog computing appears well suited as an infrastructure for local analyses that are essential to geospatial applications.

***Threats to spatial cyberinfrastructure*.** Spatial cyberinfrastructure also is vulnerable to potential threats common to Internet, wireless network and power grid vulnerabilities. It is clear that this infrastructure for cyberGIS, cloudGIS, and GPS must be protected to ensure continued growth and use of the nation's spatial infrastructure.

Key elements of spatial infrastructure such as GPS are exposed to disruption. On September 9, 2016, H.R. 5978 was reintroduced to create a ground-based back up to GPS, however, this was subject to the availability of funding. Past legislative efforts for this have not been funded. Geospatial services from navigation and routing to marketing and defense applications, are dependent on and intertwined with GPS in just about every aspect of the geospatial infrastructure.

Given needs for modernization of air traffic control, automated vehicles and autonomous drones, GPS protection should be addressed as a critical part of the nation's geospatial infrastructure. A cursory review of many federal agency plans reveals little mention of GPS or the National Spatial Data Infrastructure (NSDI). Federal agencies may wish to include the NSDI and GPS in their critical infrastructure protection policies.

4. Access

A fundamental goal of democracy is to expand the engagement and active participation of citizens. Historically that has meant engaging in one's community in an active, generally in-person way. However, the nature of technology today, with a plethora of devices and wider internet access, now provides a platform for immediate and global access to information and ways for people to engage and collaborate virtually. A majority of US citizens carry a web integrated, sensor laden, geo-located mobile computer in their pocket that makes this access ubiquitous and pervasive. Whether merely reading websites, getting directions, engaging with apps, or actively publishing information like reporting potholes, requesting help after a disaster, or collecting data as a citizen scientist, we have an unprecedented ability to interact with both our physical and digital worlds in coordination with one another, essentially integrating our work and our home life with real-time and historical data on just about anything.

A role of government historically has been to gather resources in order to build physical infrastructure such as roads, parks, and buildings, so that communities and commerce can grow and flourish. Increasingly, a new role for government is to provide a digital public infrastructure to support access to information, improve the efficiency of government operations, spur innovation and economic growth, and create a more informed citizenry and government. This digital ecosystem is more than just websites; new digital services are more responsive, spatially scalable, and mobile.

A noticeable shift in access and use of geospatial technologies is occurring. Innovation in geographic technologies originally occurred primarily in universities and within some governmental agencies. Increasingly, however, innovation in these fields now also includes the private sector, which has developed numerous commercial applications that depend on geospatial technologies. Consideration should be given to strategic alignment of public and private sector geospatial data requirements, funding, and public access. Opportunities for large public and private coordinated investments are particularly attractive in the emerging technologies addressed in this report, including earth observations such as aerial photography, satellite imaging, and high resolution lidar elevation data programs, which benefit broadly both public and commercial entities.

The democratization of geographic data can enhance transparency and foster productive dialogue. These capabilities present opportunities to increase the ability of governments to work smarter and simultaneously empower citizens to have an active and integrated role with their government. Data-driven government and citizenship fosters collaborative decision making, issue advocacy, and community planning. The NSDI and the Geospatial Platform play a key role in enabling these trends.

Geospatial data and tools play a significant role in this new paradigm as the online mapping revolution is well underway, and the implications of this are far-reaching. Today consumer maps are common place on smartphones and the web. Map-based applications are among the most-used programs on smartphones and mobile devices. Online maps have helped millions of people to interact with their communities and governments. Quality, up-to-date geospatial data and tools are central to citizen access to governmental programs and conversely, are an important means for federal agencies to interact and communicate with local communities and citizens.

5. Workforce

Geospatial technologies are an integral part of many industries, including those that are not considered traditionally 'geospatial' (e.g., emergency management, urban and regional planning, and oil, gas, and mining). While the emerging technologies discussed in this report by themselves present interesting challenges in the near-future of geospatial technology application, it is imperative that we also consider the impacts of these technological shifts with respect to the workforce that will be deploying them. Perhaps the most significant general impact is the Bureau of Labor Statistics projected increase in demand for workers in traditional geospatial fields (e.g., increase of 29% for cartographers and photogrammetrists) and non-geospatial fields that rely on geospatial technologies (e.g., 11% increase for environmental scientists and specialists, 6% for urban and regional planners, etc.). While these numbers are indicative of the need for rapid growth in the workforce development pipeline, the technological changes reported in the report emphasize that this workforce also be trained with the critical geospatial thinking and technology skills required to adapt to emerging new technologies. As part of this workforce development challenge, we must also consider how to broaden and diversify this spatial workforce.

Taken as a whole, the technologies facilitating the collection, processing, storage, analysis, and display of spatial data require a distinct set of professional skills involving both spatial cognitive skills and understanding of geographic perspectives in order to appropriately structure the problems, solution pathways, and to interpret the results. This combination of expertise is not widespread, though it underpins many activities. In 2012, the NGAC presented a white paper focused on advancing geospatial workforce development. The white paper addressed STEM education opportunities, reliance on the Department of Labor Geospatial Technology Competency Model, and a focus on updates to the Standard Occupational Classification codes. We feel the recommendations presented in the 2012 white paper are still relevant and valid, and here extend the discussion to address concerns specific to development of a broad and diverse workforce to enhance our capabilities using emerging geospatial technologies.

A workforce prepared for addressing the challenges of emerging geospatial technologies requires a core set of transferrable critical spatial thinking skills that will be relevant to any geospatial technology (e.g., fundamental understanding of spatial relationships, map projection, and spatial resolution). While there is some K-12 emphasis on geospatial thinking and reasoning, it is largely absent from the US curriculum, and in higher education is often only emphasized in geo-technology programs. Many of the users of the data and products generated from emerging geo-technologies will not have formal geospatial technology training (e.g., GIS, remote sensing, & cartography coursework); in the long-term, increased emphasis on K-12 spatial and geospatial thinking development will help produce a broader potential workforce to engage in direct or indirect work with emerging geospatial technologies. While there are technical skills specific to emerging geospatial technologies, it is the underlying, transferrable higher order cognitive processes that provide a means to adapt and manipulate, interpret, and problem solve with geospatial data – regardless of specific technology. For instance, spatial inaccuracies introduced by application of incorrect map projections can, if not fully understood, distort visual or analytical interpretations.

While spatial thinking and reasoning skills form the basis for an adaptable geospatial workforce, there is additional need for a workforce trained to thrive in novel situations for data collection, processing, and analysis. For instance, we need training which focuses on the ability to collect and quality control volunteered geographic information (VGI), to develop geospatial tools and technologies that are accessible to non-geospatial experts, and to partner with citizen scientists.

Emphasis is also needed in ensuring that the geospatial workforce represents the growing US diversity, to facilitate approach of geospatial problems with a variety of perspectives. Diversity should be considered with a broad lens, to include ethnic, racial, gender, generational, and socioeconomic factors, but also diversity in training and background (disciplinary diversity with varying application backgrounds). Geospatial decision-making teams should reflect the nation's growing multiculturalism, and should present a wide range of perspectives on national and international problems.

These broadened perspectives will improve the decision making process. There are also many ethical challenges in collecting, analyzing, and decision making with geospatial data. For instance, many emerging technologies have surveillance applications. The data they produce may be used – intentionally or unintentionally – to invade the privacy of private citizens. For more details, see the GIS Professional Ethics Project. We can minimize the impact of unconscious biases in decision making by ensuring we approach problem solving by building teams with diverse perspectives.

Conclusion

The National Geospatial Advisory Committee appreciates the opportunity to provide this analysis and information to the Federal Geographic Data Committee. We hope that it will be useful for federal government agencies as they establish plans for the future. The revolution in geographic science and technologies is transforming every aspect of our economy and government, providing benefits to our nation and to the world.

We look forward to your comments and input on this report and hope it will generate productive dialogue on these emerging technologies and their role in shaping the federal geospatial landscape of the future.

This paper was prepared by a subcommittee of the NGAC that included the following members: Douglas Richardson (chair), Sarah Battersby (vice-chair), Pat Cummens, Matt Gentile, Jack Hild, Jeff Lovin, Rebecca Moore, Carl Reed, Gary Thompson, Jason Warzinik, David Wyatt, and May Yuan.