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Real-time Space-time Integration in GIScience and Geography

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Abstract

Space-time integration has long been the topic of study and speculation in geography. However, in recent years an entirely new form of space-time integration has become possible in GIS and GIScience: *real-time space-time* integration and interaction. While real-time spatiotemporal data is now being generated almost ubiquitously, and its applications in research and commerce are widespread and rapidly accelerating, the ability to continuously create and interact with fused space-time data in geography and GIScience is a recent phenomenon, made possible by the invention and development of real-time interactive (RTI) GPS/GIS technology and functionality in the late 1980s and early 1990s. This innovation has since functioned as a core change agent in geography, cartography, GIScience and many related fields, profoundly realigning traditional relationships and structures, expanding research horizons, and transforming the ways geographic data is now collected, mapped, modeled, and used, both in geography and in science and society more broadly. 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 geospatial applications in governments, businesses, and society. This essay addresses briefly the development of these real-time space-time functions and capabilities; their impact on geography, cartography, and GIScience; and some implications for how discovery and change can occur in geography and GIScience, and how we might foster continued innovation in these fields.

Keywords

GIScience; GPS/GIS; Real-time Space-time; Spatiotemporal; Philosophy of Science; Geographic Management Systems

> "Have you also learned that secret from the river…that the river is everywhere at the same time, at the source and at the mouth, at the waterfall, at the ferry, at the current, in the ocean and in the mountains, everywhere, and that the present only exists for it, not the shadow of the past, not the shadow of the future?"
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> *Hermann Hesse*, Siddhartha *(1951)*

Real-time Space-time Integration

Time is a multi-faceted concept, with deeply personal and subjective meanings and as well as formally constructed but still arbitrary meanings, and ontologies for time in GIScience can be as complex as they are for space in Geography. However, at its simplest and in the practice of Geographic Information Science research, it is still useful to think about space-time research challenges in three basic temporal domains: (1) *past time* – documenting and interpreting historical events, places, and processes; (2) *future time* – modeling, simulating, or projecting future spatial scenarios; and (3) *real-time* –understanding and interacting with

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events, people, places, and spatial processes as they are emerging and mutually evolving in a dynamic and mobile world.

While of course interrelated, each of these simple categories has its own special set of challenges in gathering, understanding, and representing space-time integrated data. Historical time and geographic data, especially from the more distant past, is highly constrained by pre-existing and frequently indefinite or inconsistent time and space categories of bygone eras. Historical GIS cannot ignore and must struggle to work within and reconcile the profusion of its received categories of time and space (Richardson 2011). Future time GIScience work is less restricted, in the sense that its temporal and spatial constructs are not necessarily constrained by past categories or practices and can more freely be structured as the researcher or modeler wishes; its delineations of space or time need not be confined to those of a world or a time that is, or already has, occurred.

The possibility of autonomous and continuous *real-time space-time* geographic data creation, integration, and use as one encounters and travels through space is a relatively new and thoroughly transformative development for geography, GIS, and GIScience, as well as for science and society more broadly. The real-time interactive GPS/GIS functionality at the core of this transformation is largely responsible for the explosion of spatiotemporal[1] data being generated today, and is the underlying breakthrough enabling many new geographic research initiatives and myriad real-time space-time integrated geospatial applications in governments, businesses, and society. As others in this forum on space-time integration will discuss past time in the context of historical GIS, and the construction of future time for spatial modeling and so forth, I will limit my observations in this essay to the concept of *real-time space-time* integration in GIScience and geography.

Origins of Real-Time Space-Time Integration in GIS and GIScience

By the mid 1980s, geographic information systems (GIS) had developed into very useful cartographic tools for the computerized storage, manipulation, and graphic display of multiple thematic layers of locational data and attribute information, as well as some analytical functions. It greatly improved the efficiency of making and updating maps, compared with non-digital processes. However, GIS alone was a *post facto* system: its locational, feature, and attribute data were laboriously gathered and then integrated within the system well after it was collected. GIS was not fused with or interactive in real-time with the dynamic real world around it.

Similarly, Global Positioning System (GPS) alone, while a significant development of the early 1980s, provided location but not surrounding context. As Abler (1993) noted, “GPS equipment will tell me where I am with great precision… But knowing precisely where I am may not be very helpful. Location, no matter how precisely specified, is sterile in and of itself. Context determines whether knowledge of location is invaluable…Contextual knowledge immensely enriches the value of locational information” (133–34).

The pivotal enabling development in real-time space-time GIScience and geography was the invention and development of Real-Time Interactive (RTI) GPS/GIS software and systems in the late 1980s and early 1990s. This innovation enabled the continuous and mobile

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[1] In what follows, spatial and spatiotemporal should be taken as including references to location and also to time where appropriate. GPS refers also to new similar positioning systems providing equivalent autonomous and accurate location and time. GIS refers to a broad range of geographic database systems, including but not limited to commercial GIS products. GIScience refers to research on the scientific and technological challenges associated with working with spatial or spatiotemporal data, including philosophical, ethical and social considerations integral to its practice. “Real-time” refers, as always when dealing with the electronic transmission and processing of measurements, to “near real-time.”

creation of highly accurate real-time and tightly-fused geospatial location, attribute, and temporal data, and its simultaneous integration with the GIS for interactive real-time use as one moved through and encountered ones environment. This transformative development has since functioned in geography, GIScience, cartography, and related fields as a core change agent, profoundly realigning basic traditional relationships and changing the ways geographic data is collected, mapped, and used, as well as how people encounter and experience their world.[2] RTI GPS/GIS also has greatly expanded research frontiers in geography and other disciplines, including the social sciences, transportation, health, natural resources, genetics, ecology, logistics, and the environmental sciences, among many others.

The early conceptual and technical challenges to achieving the real-time space-time interactive functionality of RTI GPS/GIS were formidable, and years of intensive research were required to overcome the multiple scientific and ontological challenges and to develop the complex technical procedures and methods to achieve fully functional automated RTI GPS/GIS mapping systems. These early efforts are well documented in US Patent 5,214,757 (Mauney et al. 1990, 1993) and the reader is referred to this document for a thorough summary of the scope and technical details of the original invention and its range of new methods. Additional archival materials addressing the early development, functionality, and use of RTI GPS/GIS technologies are available online.[3]

With the fundamental conceptual, ontological, scientific, and technological research necessary for the development of the first RTI GPS/GIS systems largely accomplished during the mid and late 1980s, proven technologies embodying RTI GPS/GIS functionality for real-time space-time geographies were firmly demonstrated by the late 1980s, and initial commercial systems came into increasingly widespread use for research and a wide array of governmental, business, and educational applications by the early 1990s (Richardson 1990). Figure 1 summarizes the already mature functionality of an early RTI GPS/GIS system of this period (in green), and also illustrates two of many research and application domains, typical of subsequent outcomes of these innovations.

At this early stage, RTI GPS/GIS provided mobile real-time generation of high accuracy three-dimensional location (x, y, z coordinates), precise time, data on features and attributes via manual or automated electronic instrumentation input, and the real-time integration and interaction of these data within GIS or other spatial databases. While GPS was the preferred source of location, other supplemental methods such as dead reckoning, cellular signal, and laser rangefinders were also included in the invention and its early embodiments. Data from the GIS could be accessed in the field, and interactively created, updated, used, or acted upon in real-time. GIS vector maps, raster maps, and remotely sensed imagery could be manipulated and displayed as active or passive maps, and as foreground or background maps. Complex interactive data management, user interface, and QA/QC functions were developed to create tightly fused spatiotemporal data in real time and to interact and integrate that data continuously and in real time with GISs and other spatial databases. Special external data source (XDS) software modules also were developed to enable the automated input of data from multiple electronic sensors (such as laser range finders, digital photo and video, radiation detectors, air quality and other environmental monitoring instruments, etc.) directly into the RTI GPS/GIS system (Richardson 1993).

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[2] One could argue that RTI GPS/GIS has functioned within the disciplines of Geography, GIScience, Cartography, and related fields, as what is termed in computer science and related industries as a “Disruptive Technology,” impacting past processes and procedures broadly throughout these disciplines and industries (Bower and Christensen 1995).

[3] Archival documentation of early real-time space-time integration systems is available at www.aag.org/RTIGPSGIS.

The real-time fusion, analysis, visualization and interaction with dynamic geographic information and processes made possible by these early RTI GPS/GIS systems quickly engendered new research directions in geography and GIScience research as well as other scientific domains (Richardson et al. 2013). As Figure 1 illustrates, transportation, health, environmental change, and modeling are just some of the examples. RTI GPS/GIS functionality also stimulated and produced dynamic new real-time operations management possibilities for businesses and governments, generating what I have termed “geographic management systems” (Richardson 2006). For example, these systems were developed early on for the real-time management of vehicle fleets to optimize package delivery operations or taxicab dispatch; electrical utility energy demand monitoring, distributed asset inventory and maintenance, and mobile work force work management; public safety activities by government agencies; United Nations international relief operations; automated supply chain and logistics operations for retail and manufacturing; and for tracking and responding to contagious disease outbreaks. For a more detailed discussion of the transformations generated in geography and GIS by the introduction of real-time geographic management systems, see Richardson and Solis (2004) and Abler and Richardson (2003).

In recent years, further diffusion and widespread adoption of RTI GPS/GIS has been facilitated by improvements in supporting technology infrastructure such as smaller and faster computers, better wireless systems, easier access to the internet and developments in web communications, increased resolution of remote sensing, and continued development of smaller and more portable environmental sensors. However, nearly all of the RTI GPS/GIS functionality now in use today was embodied in these early systems and their related patents.

Miniaturized RTI GPS/GIS functionality is now also embedded in consumer technologies such as cell phones, automobiles, and personal navigation devices and is spawning new geographic research and applications involving volunteered geographic information (VGI), crowd sourcing, and citizen science. The compelling experiential immediacy of these technologies is also increasingly mediating and changing how individuals interact with and experience the world, and each other (Monaghan 2013).

Real-time Space-time Fault Lines in Geography and GIScience

RTI GPS/GIS has created completely new possibilities within the realms of GIScience and GIS for interacting with, representing, making decisions about, and negotiating the world around us *as it is encountered and experienced in real time.*[4] At the individual level, this allows GIS to better approximate how individuals actually interact with their environment in daily life (Kwan 2009; McQuoid and Dijst 2012). Within larger GPS/GIS systems it also enables researchers to better understand and monitor complex real-time population dynamics at a larger scale, for example natural disaster evacuations during Hurricane Katrina or refugee migrations occurring from conflict zones in Africa or the Middle East.

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[4] As David Lowenthal (1961) pointed out, the focus of geographic enquiry is fundamentally congruous with the objects and structures and immediacy of common experience. More than any other field, he argues, “the subject matter of geography approximates the world of general discourse; the palpable present, the everyday life of man on earth, is seldom far from our professional concerns…geography observes and analyzes aspects of the milieu on the scale and in the categories that they are usually apprehended in everyday life” (241). Along similar lines, when referring to the experience of RTI GPS/GIS mapping, Ron Abler (1993) noted that, “Few geographers will be able to resist the seduction of creating new maps interactively, in real time, amid the real phenomena the maps represent, while at the same time referring to and revising the background maps for the area contained in portable geographic information systems carried into the field. The capability for displaying to a person in the field background maps, the map being created, and the individuals changing position on both background and new maps will arouse the dormant field work virus lurking in even the most ardent armchair geographer” (135). The immediacy and somewhat exhilarating experience of direct encounter and interaction with the real world in real time while using RTI GPS/GIS has been remarked on by many users of these technologies.

The changes wrought by RTI GPS/GIS and its creation of new "real-time space-time" capabilities in GIScience and geography are extensive. One can discern its "fault lines," or discontinuities in multiple methods and practices in the disciplines of geography, cartography, and GIScience. Such fault lines signal discontinuities between what was possible prior to the introduction of transformative technologies, in this case RTI GPS/GIS functionality, and what then became possible following its development and introduction.

RTI GPS/GIS functionality has transformed mapping and cartographic methods worldwide, by enabling the collection and use of geographic information that is far more detailed, timely, accurate, immediate, and specific to a particular application than was possible before. It is largely responsible for the explosion in the amount of highly detailed, specific, and updated feature and attribute spatiotemporal data now available for GIS applications and for GIScience research. It has also enabled the integration into GIS of *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 time coded sensor data.

RTI 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 Google, Apple, MapQuest and other internet mapping providers. It is a core component of the management of day-to-day real-time operations at most governmental agencies and large business organizations. It has, for better or worse, changed the ways wars are waged and military operations are carried out.

Another fault line created by the introduction of real-time space-time geographies is evident in the enormous broadening of participation in mapping and geographic knowledge production to include directly in the mapping process the actual subject matter experts themselves (e.g., the botanist, the environmental scientist, the lineman, the archeologist, etc.), or community activists (participatory GIS), human rights organizations, and most recently by ordinary citizens through volunteered geographic information (VGI) and crowd-sourced geographies.

Trends and Research Challenges

The pace of real-time geographic data creation and it usage in consumer and business applications is expected to accelerate in future years, resulting from three interrelated trends that together constitute a convergence of opportunities for new research: (1) the explosion of realtime, spatiotemporal data from real-time interactive GPS/GIS enabled devices, often integrated with distributed environmental sensor systems, satellite remote sensing, and crowd sourcing; (2) continuous advances in computing and mobile wireless technologies, Web service-oriented architectures, and geospatial cyberinfrastructure; and (3) the development of more sophisticated tools and methods for *analyzing, modeling, and visualizing* spatiotemporal data at scales ranging temporally from the everyday to the life course and spatially from the microscale to the global (Richardson 2011).

As spatiotemporal data and applications have become ubiquitously available, and as the adoption of RTI GPS/GIS as a "geographic management system" has become more pervasive in society in recent years, research agendas for real-time space-time integration in geography and GIScience are also proliferating.[5] What follows below is a brief summary of key real-time space-time research and development agenda items that I believe warrant special attention and focus.

Temporal scale

We should address temporal scale with the same degree of attention paid to spatial scale. Metadata frameworks for spatial-temporal data need to be developed to accommodate varying time systems. Efficient methods for integrating important legacy temporal databases that are at widely varying temporal scales (temporal data conversion) are needed.

Space-time models

We should inventory and assess existing space/time data structures and analysis models as found in different application domains, identify commonalities across those domains and models, and seek integration across domains. We should also identify the exceptions and outliers, and seek separate but linked solutions for these. Substantial funding from the National Science Foundation should be directed to the development of more sophisticated "now-casting" capabilities, as well as predictive and forecasting models which incorporate the growing wealth of RTI GPS/GIS spatiotemporal data.

Ontology-based frameworks

Ontological frameworks (or data dictionaries) to guide the development of real-time space-time research should link the properties of data and task characteristics to functional capabilities of visualization and analytical techniques to indicate fruitful chains/workflows of real-time spatial-temporal analysis operations. These frameworks will likely become key contributions to knowledge about the practice of spatial-temporal analysis. Workshops, interactive forums, and publications should be organized to develop shared frameworks.

Transforming geographic data into meaningful information

This is a central research challenge for all of GIScience. The key research question, fundamentally, is how do increasing quantities of geographic data become fused into meaningful information? Information is the rich relational context that dynamically binds data together, provides much of its utility, and allows people to choose among several otherwise indistinguishable courses of action (Abler and Richardson 2003). The integrated GIS component of RTI GPS/GIS offers some potential pathways forward, as the robust integrated data collected by these systems can be directly integrated in real time in the field into previously structured GIS databases, designed for specific tasks or for answering focused research questions. Essentially, the extended GIS itself can provide much of the necessary external relational context, not only about ones immediate surroundings, but also key related information necessary to answer specified questions in real time in the field based on the new real-time interactive GPS/GIS data being generated about events, places, and processes as they are emerging, evolving and interacting in real-time across space.

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[5] A special three-day Symposium focused on the research status, recent advances, and research needs of space-time integration, modeling and analysis in geography and GIScience was organized by the Association of American Geographers (AAG) for its Annual Meeting in Seattle, April 12-16, 2011. This major research Symposium built on momentum from an earlier space-time analysis workshop co-sponsored by the AAG, Esri, the University of Redlands, and the University of Southern California in February of 2010. Research agendas presented here draw in part on collaborative activities undertaken by the author during these symposia and workshops. The space-time integration research presented at the AAG Symposium has generated, as intended, many ongoing outcomes. These include books, workshops, journal special issues, NSF and NIH research proposals, and this space-time forum in the *Annals of the Association of American Geographers*, which provides perspectives from each of the plenary speakers at the AAG Space-Time Symposium.

Space-time integration has of course long been the topic of study and speculation in geography and beyond. A great deal of productive research has been undertaken generally on space-time relationships in GIS and GIScience, with a few leading examples including Worboys (2005), Kwan (2004), Cressie (2011), Miller (2004), Peuquet (2002) and Yuan (1996), and with broader treatments by Hawking (1988), Hägerstrand (1970), and Kennedy (2002).

Ethics, human rights and human subject protection

GIScience is an international and interdisciplinary enterprise. Examining the impacts of our research on others is a necessary component of research in our field. Concepts of human subject protection vary greatly from country to country, and also among academic disciplines. Examining fundamental human rights as a broader foundation for examining human subject protection in a transdisciplinary and transboundary field such as GIScience is a promising direction which demands our attention and further research (Albro and Richardson 2012).

User interfaces and communications

We should integrate new wireless communications bandwidth, high speed Internet options, and existing real-time GPS/GIS linkages to optimize dynamic background map displays and database use on the fly, in order to enable current real-time “real world” interactive systems and methods to better incorporate change over very short time periods into GIS databases. We should enhance real-time user interfaces to match those available for computer games.

Analytical tools

Existing real-time space-time interactive functions should be expanded to support additional visualization, query, and analysis specific to multiple application domains. Time-constrained decision making imposes less time for analytical processing. Broader utilization of current analytical tools such as interpolation, derived geometry, and dead reckoning to supplement GPS will develop better real-time decision support systems. Extensions of RTI GPS/GIS into indoor mapping and navigation also need additional research. Prior work from the 1990’s on indoor extensions of GPS/GIS mapping using laser rangefinders and radio frequency ID (RFID) needs to be complemented by additional instrumentation to create seamless interfaces. We also should build on existing error budget assessment and QA/QC tools for identifying and measuring spatial-temporal uncertainty, and explore RTI GPS/GIS data intensive solutions to address the uncertain geographic context problem (Kwan 2012a, b).

Computing and large datasets

Although the explosion of real-time spatiotemporal data from RTI GPS/GIS functionality embedded in consumer devices and in vehicles (including piloted and unmanned aerial vehicles,[6] or UAVs) creates many new possibilities and opportunities, it also poses new challenges regarding data handling, analysis, and storage and raises new questions regarding data privacy and confidentiality. Ongoing research in distributed and cloud computing, CyberGIS (Wang 2010), and data mining of so-called big data (Li et al. 2010) represent current attempts to manage and find meaning and “caution” in large diffuse data sets. These research efforts, especially those which employ critical approaches, should be encouraged and funded. Related research also is needed to address the formidable challenges of archiving spatiotemporal data.

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[6] RTI GPS/GIS technologies have long been used from helicopters and fixed-wing aircraft for rapid response to disasters such as earthquakes, forest fires, and floods (Mauney and Bottorff, 1993). Continuous environmental sensor input to mobile RTI GPS/GIS systems was well developed by the early 1990’s. Early automated sensor inputs included laser range finders, Geiger counters, air quality monitors, bathemetric sensors, radio frequency signal strength instruments, etc. Subsequent extensions of early RTI GPS/GIS laser range finder integration include the addition of multiple lasers and other features for current LIDAR (Light Detection and Ranging) systems. UAVs and other vehicles now integrate RTI GPS/GIS functionality with multiple sensor systems, including most of those available in the early 1990’s.

Policy and institutional considerations

We must confront and address locational privacy and data confidentiality issues related to real-time space-time data.[7] Promising directions include the development of interactive Virtual Data Enclaves (VDE) for sharing confidential space-time data within the GIScience research community and beyond. Improved methods for spatiotemporal data access and sharing for sustainable development and environmental protection is also needed, especially in developing regions, and on terms as desired by those in the region. We should continue to foster cross-border coordination and international standards, and develop stronger public, private, and university research coordination. Finally, we must support existing and develop new advanced higher education programs to address the complex next generation research needs of real-time space-time interaction in GIScience and geography.

Transformational Research in Geography: Science, Technology, Innovation, and Discovery

Scientific and technological innovations in real-time space-time interactions have transformed geography, cartography and GIScience, and continue to drive research and applications within and well beyond these fields. Inherent within such transformative changes are interesting implications, and perhaps lessons, regarding how innovation in geography can occur and how it might be understood, nurtured and fostered in the future. In addition to the more specific research agenda suggestions related to real-time space-time integration above, I would like to close with some thoughts on the practice of GIScience itself and more broadly the practice of science in geography, and to pose a few provocative questions for consideration and discussion as we think about future directions of space-time integration research.

I believe we need to examine more closely how the actual processes, practices, and cultures of science in GIScience and geography currently function, and how they might function in the future. The process of innovation in our intertwined disciplines needs to be better understood, and documented. What is the actual role of theory and its interaction with practice and applications in GIScience? How is theory generated in GIScience? Are we over-privileging borrowed and brittle notions of theory from other disciplines in GIScience? And, more simply, what are our key theories, and in what ways do they serve or hinder innovation and discovery?

I would argue that the tendency to de-couple technologies and applications from theory in GIScience has not served us well. Research which takes a closer look at the ways in which science, technology, and applications-driven research interact in the actual practice of GIScience, as has been done in many other sciences (Pickering 1995, Kuhn 1996) is long overdue.

We also need to examine past and potential future linkages and synergies among public, private, and university real-time space time integration research. One can argue that research and innovation in the private sector in this area is as advanced as in the university, and has at times, especially earlier, outstripped research in GIScience in the universities. After all, the

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[7] Issues of privacy and dual use of RTI GPS/GIS technologies are also significant. I have addressed these questions in multiple venues (see for example, Richardson 2008), and as chair of the American Association for the Advancement of Science (AAAS) Science and Human Rights Coalition Steering Committee (Albro, Richardson, et. al., 2012). The dilemma posed by the prospect of any scientific or technological innovation being used or abused for the wrong ends is a real and inevitable cause for concern. Norbert Weiner famously stated that, "I have seriously considered the possibility of giving up my scientific productive effort because I know of no way to publish without letting my inventions go into the wrong hands." (Roszak 1994, 202). These issues have been the focus of a substantial body of scholarship during the past half century (see, for example, Pickles [1995]. Harris and Weiner [1998], Onsrud [2003], and Chomsky [1969]).

term GIScience was not coined until 1992 (Goodchild 1992, 2010), and a major focus of its early practice was to describe and attempt to understand what had already happened in the development of core GIS and geospatial technology functionality, and to begin to assemble it as a science. This is and has been a worthwhile and necessary undertaking, and those who engaged in this debate early on are to be commended. But it does raise the question of how all of this early development actually happened, prior to a formal GIScience that now aspires to guide it, and further, what drives what: the GIScience or the GITechnology? How did the unnamed science work then, and how does GIScience work now? What is its dynamic? What flows from what? Or is the reciprocal interaction between the technology and the science actually the real dynamic?

It is perhaps also time to examine current interactions and boundaries between GIScience and geography in more detail. In what ways are these boundaries fixed and rigid, or permeable and mobile? What does the intellectual trade across these boundaries look like? Is the flow balanced or dependent, and in which direction? Are the two fields diverging or converging?

Further, how does conceptual thinking as part of the iterative processes of overcoming research obstacles generate innovation in GIScience? What social structures of GIScience will best enable the next conceptual breakthroughs and the new methods, and what social values will shape the future of our coupled scientific and technological research program? And how do curiosity-driven research and applications-aware research actually differ in practice and intersect as drivers of GIScience, and how mutually exclusive are these categories? Current work in the philosophy and history of science has much to offer our examination of these questions. I suggest as a starting point the work of Andrew Pickering, (e.g., *The Mangle of Practice*), Helen Longino (e.g., *The Fate of Knowledge*), and Peter Galison (e.g., *Einstein's Clocks, Poincaré's Maps*). In closing, I would like to thank all of my colleagues within the geography and GIScience communities who have contributed so constructively and critically to research at the intersection of these fields, and in advance for our continued discussions on these and related ideas in the future.

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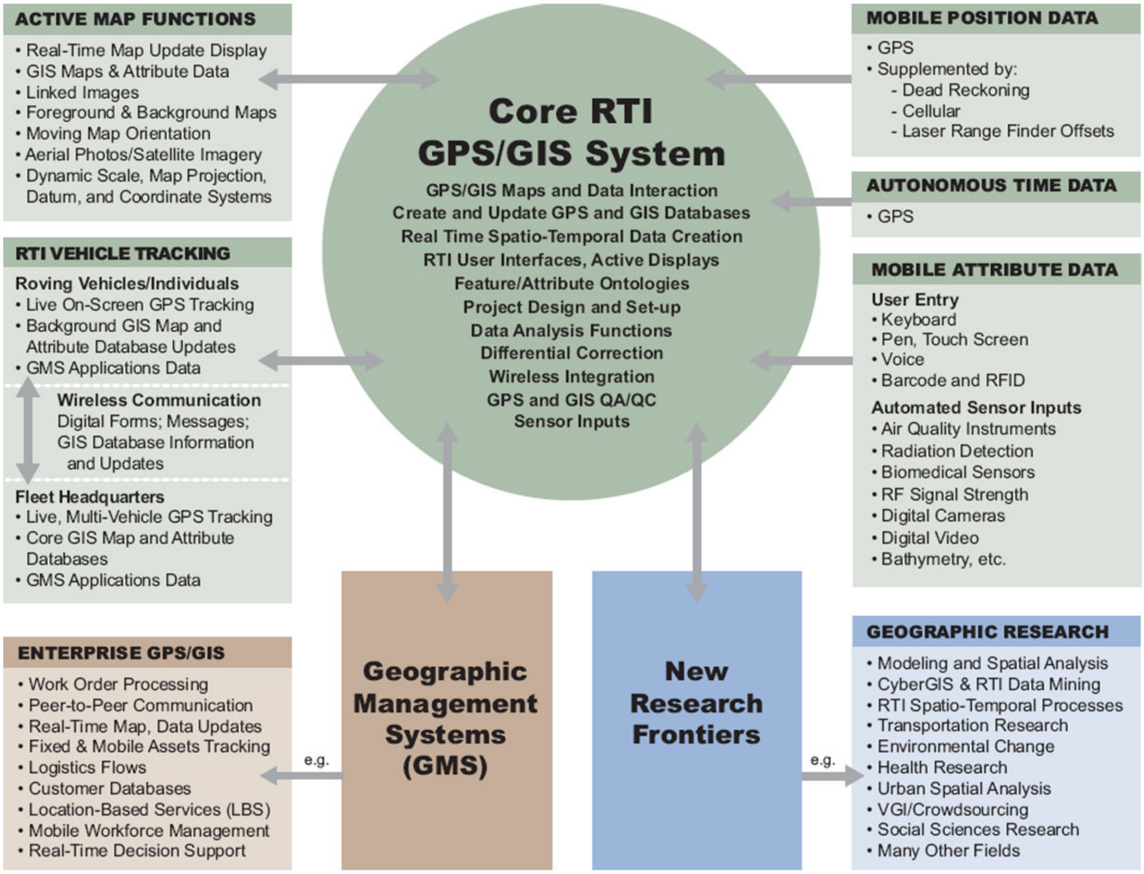

Figure 1.

Real-Time Interactive GPS/GIS system functionality (in green) developed by the early 1990s, and two examples of the many subsequent outcomes of these technologies: (1) the generation of new research frontiers and capabilities in geography and many related fields (in blue), and (2) the development and widespread implementation of "Geographic Management Systems" for real-time operations management by many governmental, business, and nongovernmental organizations (in brown).