# Chapter 5
# Geospatial Information Infrastructures

**Sven Schade, Carlos Granell, Glenn Vancauwenberghe, Carsten Keßler, Danny Vandenbroucke, Ian Masser and Michael Gould**

**Abstract** Geospatial information infrastructures (GIIs) provide the technological, semantic, organizational and legal structure that allow for the discovery, sharing, and use of geospatial information (GI). In this chapter, we introduce the overall concept and surrounding notions such as geographic information systems (GIS) and spatial data infrastructures (SDI). We outline the history of GIIs in terms of the organizational and technological developments as well as the current state-of-art, and reflect on some of the central challenges and possible future trajectories. We focus on the tension between increased needs for standardization and the ever-accelerating technological changes. We conclude that GIIs evolved as a strong underpinning contribution to implementation of the Digital Earth vision. In the future, these infrastructures are challenged to become flexible and robust enough to absorb and embrace technological transformations and the accompanying societal and organizational implications. With this contribution, we present the reader a comprehensive overview of the field and a solid basis for reflections about future developments.

**Keywords** Geospatial information · Infrastructure · Spatial data · Public sector · Government

S. Schade (✉)
European Commission—Joint Research Centre, Ispra, Italy
e-mail: s.schade@ec.europa.eu

C. Granell · M. Gould
Universitat Jaume I, Castellón, Spain

G. Vancauwenberghe · D. Vandenbroucke · I. Masser
Katholieke Universiteit Leuven, Louvain, Belgium

C. Keßler
Aalborg University, Copenhagen, Denmark

M. Gould
ESRI, Redlands, USA

161

## 5.1  Introduction

Geospatial information (GI), i.e., information including a relationship to the Earth (Worboys and Duckham 2004), is a foundational ingredient for any Digital Earth application. Examples include information about land parcels, transport networks and administrative boundaries, vehicles, microplastics, fine particles, mobile devices and people. With GI, we can build digital replicas of our planet and use them to exchange knowledge, monitor the state of the Earth, simulate possible future scenarios or assess possible impacts of decision making. Although also other terms (such as 'geographic' or 'spatial') are used in scientific and other literature to refer to the same or similar concepts, we use 'geospatial' in this chapter. Furthermore, we speak of 'information' as (possibly processed) data in a context that allows for interpretation and meaningful use.

The technological, semantic, organizational and legal structure that allows for the discovery, sharing, and use of GI is called geospatial information infrastructure (GII) (Yang et al. 2010; Granell et al. 2014). With its core functionalities, a GII can be considered the backbone for Digital Earth. GIIs are essential to facilitate the information flow that is required to implement any past, present and future version of the Digital Earth vision—the knowledge sharing platform as initially envisaged by Gore (1998), a global tool for multidisciplinary research as outlined by Goodchild and colleagues (2012), or the world laboratory to support codesign, cocreation and codelivery that was suggested by Schade and Granell (2014).

Emerging from an initially highly technical concept, GIIs have a relatively long history and are well researched, including their close relationships with geographic information systems (GIS) (Worboys and Duckham 2004) and spatial data infrastructure (SDI) as enabling technologies (Masser 2005; Yang et al. 2010). Prominent examples of these enabling technologies include the spatial data infrastructure for Australia and New Zealand (ANZLIC 2019), the United States of America-US National Spatial Data Infrastructure (NSDI 2019), the Infrastructure for Spatial Information in the European Community [(INSPIRE 2019), see also Chap. 20], OpenStreetMap [(OSM 2019a), see also Chap. 18], and Google Maps (Google 2019).

By nature, GIIs undergo a continuous evolution that is primarily driven by the increasing pace of technological advancements and the inherent digital transformation of our societies (Castells and Cardoso 2005; Gimpel and Röglinger 2015). Similar to other information handling tools, GIIs face continuous challenges caused by the speed of technological progress that sometimes conflicts with the heaviness inhering in most governance structures. For example, the implementation of heavily governed GIIs bears a risk to continually run behind technological solutions (Schade and Smits 2012; Tsinaraki and Schade 2016). We have witnessed a shift from public sector (alone) to more collaborative approaches to the provision and operation of GI and related services, which increasingly involve the private sector (smeSpire 2014; Sjoukema et al. 2017). Whereas public sector information (e.g., about cadastral parcels or protected sites) continues to play an important role, increasing amounts of spatial data are produced, owned and provided by the private sector. Examples

include street (navigation) data and satellite imagery, and 'standard' products such as Google Earth, Google Maps, Bing, and spatial data from GPS providers such as Here and TomTom.

In this situation, we face two opposing forces: traditional standardization processes and frequent technological disruption. Heavily standardized large infrastructures and platforms to support Digital Earth may have been a necessity a few years ago (Granell et al. 2016), when large amounts of GI were not easily accessible and data transformation used to be a process that was run on large computing machines for a long time before harmonized information could be provided to users. During that time, it was affordable to invest in traditional standard-based infrastructures and in educational programs that provided specialized training to develop, maintain and use such infrastructures (Masser 2005; Vandenbroucke and Vancauwenberghe 2016). However, is this still affordable today—in an era of fast digital transformation when disruptive technologies are about to become a new norm? Or will microservice-based architectures (Dragoni et al. 2017) to build smaller, more manageable platforms beat monolithic, big, layered architectures? How must the development of standards change to fit these new dynamics? What roles will the private sector play in this new set-up?

The question of whether Digital Earth will follow the traditional standardization approach, an alternative approach that completely embraces vivid digital transformation or anything in between has strong implications on the definition of the conceptual architecture of the GII with Digital Earth. Hence, we are at a controversial point in GII and Digital Earth history. This chapter outlines how we arrived at this point, explains the current situation in more detail, provides a critical reflection, and outlines a few future trajectories. We hope that this contribution to the Manual of Digital Earth aids in understanding the importance and evolution of GIIs and provides food for thought for those that will develop and use GIIs to implement the Digital Earth vision.

The remainder of this chapter is structured as follows. The next section introduces the history of GIIs during the different phases of organizational and technological development (Sect. 5.2). Next, we outline the current situation in respect to GII development, education and use (Sect. 5.3). We focus on the evolving relationship between GIIs and Digital Earth and important recent movements such as Open Science. In Sect. 5.4, we discuss changes and the challenges that GIIs face today. The most important implications for the Digital Earth vision are highlighted. In Sect. 5.5, we close the chapter with a brief conclusion and an outlook on the future of GIIs in support of Digital Earth. For details about GI analysis and processing, we refer the reader to Chap. 6. Matters of GI visualization are discussed in Chap. 7.

## 5.2  A Brief History of Geospatial Information Infrastructures

GIIs are not a new concept, and have evolved over a series of generations, each characterized by changing purposes, available technologies, and the main stakeholders involved in their design, implementation and use. Instead of describing these generations in detail, which has been done elsewhere (Rajabifard et al. 2002; Yang et al. 2010), we highlight fundamental milestones in the history of GII. We also highlight evolutions of the technical architectures used to implement GIIs over the past few decades.

### 5.2.1  Geospatial Information Infrastructure Milestones

In the history of GIIs worldwide, a series of milestones have been essential for the evolution of GIIs into their current form—most of which relate to actions of government, i.e., policy updates. Notably, these milestones differ in nature, for example, by administrative dimension, research purpose or geographic extent. However, they give a sensible impression of aspects that have framed the evolution of GIIs up to today.

As a first milestone, the EU initiated the CORINE program in 1985 with the aim of describing the status of the environment in Europe. This program was the first large-scale effort in Europe to collect spatial data covering the European territory according to agreed specifications in view of supporting different policies. It delivered its first pan-European land cover data set in 1990, with updates in 2000, 2006 and 2012. The second milestone dates back more than thirty years to the establishment of the Australian Land Information Council (ALIC) in January 1986. ALIC was the result of an agreement between the Australian Prime Minister and the heads of the state governments to coordinate the collection and transfer of land-related information between the different levels of government and to promote the use of that information in decision making (ANZLIC 1992). One year later, a third milestone occurred in May 1987 with the publication of the Report of the British Government Committee of Enquiry on Handling Geographic Information chaired by Lord Chorley (Coppock 1987). This report, also known as the Chorley report, set the scene for much of the subsequent discussion about GIIs in the UK and in other parts of the world. While the report reflected the committee's enthusiasm for the new technology: "the biggest step forward in the handling of geographic information since the invention of the map" (para 1.7), it also expressed their concern that information technology must be regarded as "a necessary, though not sufficient condition for the take up of geographic information systems to increase rapidly" (para 1.22). A fourth important milestone in the late 1980s was the release of the first issue of the International Journal of Geographic Information Systems, also in 1987. The journal, renamed

the International Journal of Geographic Information Science in 1997, was the first scholarly journal devoted to GI.

The fifth milestone occurred in 1990 when the United States Office of Management and Budget (OMB) established an interagency Federal Geographic Data Committee (FGDC) to coordinate the "development, use, sharing, and dissemination of surveying, mapping, and related spatial data." The main objectives of a national GII were "encouraging the development and implementation of standards, exchange formats, specifications, procedures, and guidelines, promoting technology development, transfer, and exchange; and promoting interaction with other existing Federal coordinating mechanisms that have an interest in the generation, collection, use and transfer of spatial data…" (OMB 1990, pp. 6–7). These ideas were subsequently developed and extended by the United States National Research Council's Mapping Science Committee in their report 'Toward a coordinated spatial data infrastructure for the nation' (National Research Council et al. 1993). This report, which can be seen as a sixth milestone in the history of GIIs, recommended that effective national policies, strategies, and organizational structures be established at the federal level for integration of national geospatial data collection, use and distribution. A seventh milestone is the outcome of an enquiry by the Directorate-General XIII (now DG Connect) of the European Commission (EC), which found that there was a strong Europe-wide demand for an organization that would further the interests of the European GI community. As a result, the first regional level multidisciplinary SDI organization in the world was set up in 1993. The vision of the European Umbrella Organisation for Geographic Information (EUROGI) was not to "replace existing organisations but catalyse effective cooperation between existing national, international, and discipline-oriented bodies to bring added value in the areas of Strategy, Coordination, and Services" (Burrough et al. 1993).

An eighth milestone that marks a turning point in the evolution of the SDI concept came in the following year with the publication of Executive Order 12906 signed by President Bill Clinton, entitled "Coordinating Geographic Data Acquisition and Access: the National Spatial Data Infrastructure" (Executive Office of the President 1994). This described the main tasks to be carried out and defined time limits for each of the initial stages of the national spatial data infrastructure. These included the establishment of a national geospatial data clearing house and the creation of a national digital geospatial data framework. (Here, we understand data clearing houses as "internet-based components that intend to facilitate access to spatial data, by establishing a centralized site from which data from several sources can be found, and by providing complementary services, including searching, viewing, transferring, and ordering spatial data" (Davis 2009). The Executive Order gave the FGDC the task of coordinating the Federal government's development of the National Spatial Data Infrastructure. As the Executive Order also required each member agency of that committee to hold a policy-level position in their organization, it significantly raised the political visibility of geospatial data collection, management and use among US institutions and internationally. The organization of the first Global Spatial Data Infrastructure (GSDI) Conference in Bonn, Germany, in September 1996 was another—ninth—milestone in the 90s. The conference brought together

representatives from the public and private sectors and academia for the first time to discuss matters relating to NSDIs at the global level. Shortly after, in 1998, the Baveno Manifesto set a fundamental milestone for European space policy. It led to the establishment of the Global Monitoring for Environmental Security (GMES) program, which was formally established in 2010 (Regulation (EU) No 911/2010), and followed by the Copernicus program in 2014 (Regulation (EU) No 377/2014).

After 2000, the evolution of GIIs worldwide continued, and several milestones can be highlighted. One was the establishment of the intergovernmental Group on Earth Observations in February 2005 to implement a global Earth observation system of systems (GEOSS) to integrate observing systems and share data by connecting existing infrastructures using common standards. In 2018, there were more than 400 million open data resources in GEOSS from more than 150 national and regional providers such as NASA and ESA, international organizations such as the World Meteorological Organization (WMO) and commercial sector groups such as Digital Globe (Nativi et al. 2013). Another—eleventh—milestone was the launch of the first scholarly journal in the GII field in 2006. The International Journal of SDI Research is a peer-reviewed journal that is operated by the Joint Research Centre of the European Commission, which aims to further the scientific endeavor underpinning the development, implementation and use of Spatial Data Infrastructures. Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 established an Infrastructure for Spatial Information in the European Community (INSPIRE, see Chap. 20 for more details) can be seen as a twelfth milestone in the evolution of GIIs. The INSPIRE Directive aimed to establish a spatial data infrastructure to improve the sharing and interoperability of geospatial data in support of environmental policies and policies that might have an impact on the environment (Directive 2007/2/EC of the European Parliament and the EU Council) and was the second multinational GII initiative that sought to make harmonized high-quality GI readily available. INSPIRE stresses the principles of data sharing and cross-border usage of the data. The year 2011 marked a key event that initiated the deep involvement of the private sector: the first Geospatial World Forum "Technology for people and Earth" (Geospatial World 2011). This global conference gathers diverse stakeholders to present and discuss the pathways of the geospatial industry. In addition, the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) was established in July 2011 (ECOSOC Resolution 2011/24) as the official United Nations consultative mechanism on global GI management. Its primary objectives are to provide a forum for coordination and dialogue among Member States of the United Nations (UN) and between member states and relevant international organizations and to propose work plans that promote global frameworks, common principles, policies, guidelines and standards for the interoperability and interchangeability of geospatial data and services. Not long ago, (23 June 2015) the first Sentinel (satellite developed for the Copernicus program delivering open Earth Observation) was launched. This milestone initiated the launch of a set of sister satellites that deliver high-resolution images and contribute strongly to a new era of GI provision worldwide.

Table 5.1 provides an overview of the fifteen milestones discussed in this section. They are mostly institutional, legal and policy-related. Notably, the milestones cover different regions (e.g., Europe, North America and Australia), administrative levels (e.g., national, regional and global) and sectors (e.g., academic and cross-sectoral initiatives). They reflect the breadth and diversity of GII initiatives since the 1980s. This demonstrates how GIIs took a leading role in promoting and enabling open data publishing, possibly as the most common theme across the globe. These developments took place in support of the Open Movement, Open Science, Open GIScience, and citizen science, which we explore in more detail later in this chapter (in Sect. 5.3).

**Table 5.1**  Geographical information infrastructure milestones

| Year | Milestone |
|------|-----------|
| 1985 | The European Union (EU) launched the CORINE land cover program as the first large-scale effort to collect spatial data covering the European territory |
| 1986 | The Australian Land Information Council began coordinating the collection and transfer of land-related information between the different levels of government |
| 1987 | Report of the Committee of Enquiry into Handling Geographic Information, chaired by Lord Chorley |
| 1987 | Launch of the International Journal of Geographic Information Systems |
| 1990 | The US Federal Geographic Data Committee was created to coordinate the development, use, sharing and dissemination of surveying mapping and related geospatial data |
| 1993 | US Mapping Science Committee report on 'Toward a coordinated spatial data infrastructure for the nation' |
| 1993 | Establishment of the European Umbrella Organisation for Geographic Information (EUROGI) as the first regional-level multidisciplinary SDI organization |
| 1994 | Executive Order 12906 'Coordinating geographic data acquisition and access: the National Spatial Data Infrastructure' |
| 1996 | First Global Spatial Data Infrastructure conference in Bonn, Germany |
| 2005 | Establishment of the intergovernmental Group on Earth Observations in February 2005 to implement a Global Earth Observation System of Systems (GEOSS) |
| 2006 | Launch of the International Journal of Spatial Data Infrastructure Research |
| 2007 | Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) |
| 2011 | The first Geospatial World Forum 'Technology for people and Earth' took place |
| 2011 | The United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) was established |
| 2015 | Launch of Sentinel-2, the first of a series of Copernicus satellites delivering open and high-resolution GI |

### 5.2.2 Architectural Evolutions in Geospatial Information Infrastructure Development

Alongside these milestones, we have witnessed an evolution of GII architectures and technological solutions, following the increased sophistication of technology and growth in user requirements. We summarize the central developments, concentrating primarily on GII. Another chapter of this manual addresses the irruption of sensors, sensor networks and the Internet of Things (IoT, see also Chap. 11). For developments and implications of machine learning, deep learning, and artificial intelligence, we refer the interested reader to Chap. 10.

GI has been used for many decades in different application fields (Longley et al. 2011). In the eighties, GIS technology started to spread globally. Prior to the development of SDIs, which only expanded at a broader scale in the nineties, geospatial data assets were created, managed and used by individual organizations using standalone GIS. In 1987, Specialized software companies such as ESRI brought GIS software to the market that could run on personal computers. Others, such as Intergraph, did the same, and academic and even public sector parties developed software for using geospatial data for particular purposes. Examples include ILWIS (2019) and GRASS (2019).

However, in this period, most efforts were focused on the collection and maintenance of data, as well as its use within the organization. Big data collection efforts started taking place. For example, in Europe the need for data that are standardized, well-documented, high-quality and available for the broader community became apparent. Therefore, the Coordination of Information on the Environment—CORINE program was initiated by the EU. This and similar initiatives elsewhere in the world, e.g., in the US through the FGDC, revealed the need to work more systematically in several technical aspects: documentation (metadata), data harmonization, access mechanisms and standards (Nebert 2004). These technological developments occurred in parallel with the organizational and institutional developments described in the previous section.

Originally, the focus was on exchange formats and particularly on the transformation—where required—from one format to another. In practice, for a long time de facto standards were used a lot. One good example is the shapefile format developed by ESRI that was (and still is) used to transfer geospatial data from one organization to the other (ESRI 1998). In the nineties, data exchange between organizations, although often on an ad hoc basis, became more and more important to avoid duplication of data sets and to share resources more efficiently. With this increased exchange, good documentation became paramount (Danko 2005). From the early nineties, organizations explored ways of documenting data in a standard manner. The first standard used by many was the FGDC metadata standard, which was initiated by President Clinton by executive order 12906 (1994) and became official in 1998 (FGDC 1998). This standard was used a lot, even in Europe. Work on an international metadata standard also began in the nineties but saw only light in 2003 with the adoption and publication of the International Organization for Standardization (ISO) standard

19115 in 2003 (ISO 2003). Since then, thousands of organizations have documented their geospatial data sets according to this standard.

To make potential interested parties aware of the existence of geospatial data resources, the publish-find-bind paradigm was defined as a key concept for SDIs (van Oosterom 2005). The idea is to 'publish' geospatial data resources by documenting and putting them in a catalogue, then make them 'discoverable' by a search mechanism and 'accessible' through a binding mechanism, which means that they can be integrated in a user application (e.g., a web-viewer, a desktop GIS or other application). In addition to the metadata, access mechanisms were designed and developed and became a key component of the technical parts of an SDI (Zhao and Di 2011). The Open Geospatial Consortium (OGC), which was established in 1994, brought together different academic, private and public sector parties and soon focused on the standardization of interfaces for accessing geospatial data resources (OGC 2019). They developed several web service interfaces to perform basic jobs such as 'discovery' (CSW—Catalogue Services for the Web), 'viewing' (WMS—Web Mapping Services—a first version of the standard was released in 2000), and 'downloading' (WFS—Web Feature Services). These OGC standards were meant to adhere to Service-Oriented architecture (SOA), an architectural style aimed at designing applications based on a collection of best practices, principles, interfaces, and patterns related to the central concept of a service (Papazoglou and van den Heuvel 2007). In SOA, services are the basic computing unit to support development and composition of larger, more complex services, which can be used to create flexible, ad hoc, dynamic applications. The main design principle behind SOA is that a service is a standards-based, loosely coupled unit composed of a service interface and a service implementation. Previous examples of OGC service specifications were designed to comply with these SOA principles to publish, find and use geospatial data. Most of the commercial software companies, as well as the Free and Open Source Software for Geospatial (FOSS4G) community—with a major push in 2006 with the establishment of the Open Source Geospatial Foundation (OSGeo)—developed tools and platforms to create such services and build portals for users to find and access data (Tait 2005; Maguire and Longley 2005).

In addition to the efforts to document GI and make it more discoverable and accessible, many efforts were made to better harmonize them for use in cross-border and cross-sector settings. The ISO Technical Committee 211 (ISO/TC211) was created in 1994 to look into the standards for Geographic Information and Geomatics. There was a large effort to develop the so-called ISO 19100 series of standards that, in addition to the already mentioned metadata standard, comprise a series of standards describing how to model our world (ISO 2002). The series includes a reference model, the definition of spatial and temporal schema, rules for application schema, and a methodology for cataloguing spatial features. In 2001, preparations began to design and implement INSPIRE, the Infrastructure for Spatial Information in Europe (INSPIRE 2019). In addition to the key idea of improving GI sharing (policy challenge), another objective was to improve spatial data interoperability through the design of data specifications for 34 themes (technical and organizational challenges). The ISO 19100 series of standards served as a basis for this huge effort. The

resulting portfolio of standardized data sets serves cross-border applications in the context of environmental policy making/monitoring and other sectors. The process of harmonization is still ongoing at the time of writing.

In parallel with these more formal developments, stimulated by the public sector, developments in the private sector soon influenced SDIs and were ultimately (at least partially) integrated. In 1998, US Vice President Al Gore coined the term Digital Earth in view of global challenges such as climate change (Gore 1998). In 2001, a small software company called Keyhole Inc. launched and developed the Keyhole Earth viewer for looking at our globe from a global, bird's-eye view. The technical solution, aimed primarily at the defense sector, looked at geospatial data from a 3D perspective. A few years later, in 2004, Google acquired the small company and launched the still very popular product Google Earth based on the KML standard. More SDI developments embraced these new developments and aimed to integrate data from these commercial products into SDIs and applications. This whole process ended with the adoption of KML (originally keyhole markup language) by the OGC as a community standard.

In support of the development of SDIs, specific software developments emerged. Traditional GIS desktop software such as ArcGIS from ESRI was extended with server and mobile software, and the FOSS4G communities developed specific products that became very popular, such as GeoNetwork (to create geoportals and catalogue services), GeoServer, Degree and others (to set up all kinds of web services), and open source systems for data management such as POSTGIS (Steiniger and Bocher 2009; Brovelli et al. 2017). In addition to open standards and open software, open data became a new paradigm with important initiatives that are still very popular. In 2004, there was a global effort from the geospatial community to develop and maintain a network of streets (OSM), which was a joint effort of thousands of volunteers to provide and include data into an open data product (Haklay and Weber 2008). These volunteered geographic information (VGI) efforts became also part of the maintenance procedures of commercial products such as those from TomTom (formerly Tele Atlas) and Here (formerly NavTeq). The idea of citizens contributing to data and information gathering has now become widespread and is termed crowdsourcing [(Capineri et al. 2016), see also Chap. 18 for more details]. From the SDI perspective, which often focuses on authoritative data coming from government, these initiatives and the resulting geospatial data resources are considered complementary. The concept of GIS-based (open) data portals for smart city projects has also taken hold in recent years (ESRI 2019a).

These developments (see Table 5.2) led to a vibrant geospatial community and many GIIs that are interconnected (Vandenbroucke et al. 2009) and rich in content and quality, and new developments started to influence the way of working and the methods of providing data to user communities. Although the geospatial world has always worked somewhat in isolation, the developments in the general ICT world led to increased interest in joining forces. In 2006, Tim Berners-Lee coined the concept of Linked Data to combine the huge amounts of data available on the web (Berners-Lee 2006). In the geospatial world, this led to the idea of the geosemantic web. In 2014, the OGC and W3C started several joint initiatives including the Spatial Data

**Table 5.2**  Timeline of relevant technological developments

| Year | Technological development |
|------|---------------------------|
| 1982 | First release of GRASS as open source software, managed by the US Army Corps of Engineers |
| 1985 | First release of ILWIS as closed, proprietary software developed by a university, ITC in the context of a land use zoning and watershed management project in Sumatra; the release as open source software followed in 2002 |
| 1987 | First release of pcARC/INFO (ESRI), available on personal computers |
| 1992 | Introduction of the shapefile format by ESRI, which became a de facto standard format for exchanging geospatial data |
| 1994 | The Open Geospatial Consortium (OGC) is established and starts work with 8 members (currently more than 500) |
| 1994 | ISO/TC 211 is created as one of the technical committees of the International Organisation for Standardisation (ISO) responsible for the field of Geographic Information |
| 1998 | The FGDC metadata standard (US) becomes official |
| 1998 | The term Digital Earth is coined by former US Vice President Al Gore, describing a virtual georeferenced representation of the Earth |
| 1998 | Publication of the specifications of the shapefile format, which became open at that stage |
| 2000 | First version of the Web Mapping Service (WMS) interface standard released by OGC |
| 2001 | Keyhole Inc., the developers of Google Earth (originally called Keyhole Earth Viewer) and the KML format, is established |
| 2002 | The development of quantum GIS (QGIS) began, released as open source in 2009 |
| 2003 | ISO 19115 Geographic Information—Metadata standard is adopted by the participating countries |
| 2004 | Publication of the SDI Cookbook by the Global Spatial Data Infrastructure Association (GSDI) |
| 2004 | Keyhole Inc. is acquired by Google |
| 2004 | OSM launched |
| 2006 | Linked Data as a concept, method and technique was coined by Tim Berners-Lee within the W3C as part of the semantic web project |
| 2006 | Founding of the open source geospatial foundation OSGeo, with currently more than 30000 volunteers, and the first FOSS4G International Conference in Lausanne, Switzerland |
| 2007 | The term volunteered geographic information (VGI) was coined by Michael Goodchild |
| 2008 | INSPIRE metadata regulation adopted as Implementing Rule 2007/2/EC |
| 2010 | INSPIRE regulation regarding interoperability of spatial data sets and services adopted as Implementing Rule 1089/2010 |
| 2014 | The DCAT metadata standard for data resources of W3C is released |
| 2014 | Establishment of the Spatial Data on the Web Working Group focused specifically on the intersection of issues facing OGC and W3C members |
| 2015 | OGC adopts KML as a community standard |
| 2015 | GeoDCAT-AP, an implementation allowing for data exchange between geoportals and open data portals, was adopted by the EU ISA program |

on Web Working Group to examine and test new ways of publishing and linking data (W3C 2015). One of the tangible results of this closer collaboration was the effort to exchange metadata between geoportals and (open) data portals through a more generic and broadly used DCAT standard (W3C 2014). More of these developments are expected to take place—and will continue to emerge faster and faster. This poses particular challenges to standardization processes, which should keep pace with these evolutions. In the next sections, we describe ongoing and new developments, for example, the changing power relationship from the public to the private sector and challenges posed by the trending platformization of society (van Dijck et al. 2018).

## 5.3 Geospatial Information Infrastructures Today

Leaving the past behind, several important developments and aspects of the current situation of GIIs are important to mention. We consider the following items worth highlighting in the context of Digital Earth: the mainstreaming of GI and the proliferation of GIIs, especially on the web; the contribution of GII developments to the opening of data and science as a whole; and the growth of knowledge exchange and learning networks across the globe.

### 5.3.1 The Evolution of Geospatial Information on the Web

In parallel to the organizational milestones described in Sect. 5.2, the technical foundations of GIIs were developed and standardized, mostly through bodies such as the OGC and ISO (see Sect. 5.2.2). Along with this development, the proliferation of slippy web maps and map-based mobile applications has led to the establishment of a separate branch of GII that primarily addresses end-user needs by, for example, providing directions to get from one place to another or offering extensive geocoding capabilities ("where is the closest coffee shop?"). The widespread adoption of these new services that were no longer just providing GI for a group of professional users was driven by the introduction of Google Maps in 2005 as well as the introduction of touch-screen smart phones with built-in GPS through the first iPhone in 2007.

Shortly after the introduction of Google Maps, the first reverse-engineered map mashups appeared and demonstrated how Google's JavaScript-based maps could be combined with GIs from other sources (such as crime data on ChicagoCrime.org or real estate offerings on housingmaps.com). The subsequent release of a public Application Programming Interface (API) for Google Maps that allowed for any web developer to embed a map in their web pages triggered the development of open source alternatives such as OpenLayers (OpenLayers 2019), which is still under active development today as an OSGeo project. OpenLayers is notable in this context because it bridges the worlds of consumer-oriented GI and GIIs targeted at

professional use cases by allowing the combination of data from OGC-based web services with tiles and file formats such as KML. Esri released its JavaScript API to facilitate the creation of web apps from traditional GIS datasets (ESRI 2019b). Together with other, more recent examples such as Leaflet (Leaflet 2019), a 'grass-roots' standard emerged for the URL scheme of map tiles for slippy maps (OSM 2019b). This URL scheme enabled any web mapping framework to consume and display the tiles from any of the increasing number of servers that can produce them (GeoServer, MapServer and TileStache are a few examples)—a de facto standardization process that was successfully completed without the involvement of any of the abovementioned standardization bodies.

A third aspect that explains today's GII landscape is the development and widespread adoption of open data (Open Data Barometer 2015; Gurstein 2011; Kitchin 2014). This includes thematic open data sets available for direct download via web portals (ESRI 2019c) and the free provisioning of governmental data, which was previously made available for a (sometimes substantial) fee—if at all. The proliferation of open government data (OGD) has been complemented by the development of user-generated data sources, dubbed volunteered geographic information (VGI, Goodchild 2007) in the context of GI. OGD aims to make data originally produced for professional users available to a broader public, and VGI can be seen as a grass-roots movement producing its own collection of non-authoritative datasets. The VGI project with the most profound impact is OSM. OSM started as a free, bottom-up alternative to the then-prohibitively expensive data produced by the UK's Ordnance Survey, and has since become the largest collection of freely available GI. At the time of writing of this chapter, the OSM database consisted of close to 5 billion mapped nodes (points), collected by almost 5 million registered users (OSM 2019c). Its significance for development in the field today lies in the provisioning of a free, global, and in many areas extremely detailed collection of GI and in the number of innovative companies that have entered the market with products based on OSM. They continuously contribute to the OSM dataset and have developed open source tools around it for mapping, quality checking, and the use and processing of OSM data.

A notable recent development that emerged from this OSM ecosystem is the trend towards using vector tiles instead of prerendered image tiles. The improved support for rendering vector data in modern web browsers has enabled this switch. Vector tiles have several advantages over image tiles, such as adaptable styling, maps that look sharp independent of screen resolution, and opportunities for interaction with the actual individual map features (interactive labels or clickable features, for example), with smaller data volumes to transfer between the server and client.

As these examples show, the collection, distribution, and analysis of GI has evolved from a field that used to require expensive equipment and extensive professional training to activities that are carried out by users (and contributors) with highly diverse backgrounds and different levels of education. The ubiquity of devices capable of both producing and consuming GI, in combination with an ever-growing amount of free-to-use GI and powerful free and open source software solutions has led to a somewhat chaotic landscape of practices, standards and conventions for the

data and processes involved. The involvement of a broader public in these processes also means that organizations such as OGC or ISO that primarily focus on the professional use of GI are addressing a decreasing share of the actual GI user base. An increasing number of users and producers of GI do not work for government agencies, conduct commercial mapping efforts, or develop software for GI web services. Instead, they may be working in data science or data visualization (Bostock et al. 2011), may be open data advocates or citizen scientists, or may do research in areas such as economics, ecology, or the humanities.

New companies that deal with GI at the core of their business that do not consider themselves GIS companies have established new ways of dealing with GI, without taking the time to go through time-consuming standardization processes. The long list of prominent examples of these companies includes Mapbox, Carto, Uber, booking.com, Trip Advisor, Google and Facebook. Many of the relatively new internet platforms contain GI and thereby initiated a shift to the traditional organizational structures (van Dijck et al. 2018).

Arguably, with this industrial production and use of GI, large companies set the de facto standards—as far as standards are relevant for their internal workings. To some extent, these developments have been acknowledged by the World Wide Web Consortium (W3C) in some efforts that have traditionally been exclusive to the OGC, most notably the Spatial Data on the Web Working (W3C 2015) and Interest Groups (W3C 2017) and the best practices documents produced in this context (W3C 2019). The formation of these groups leverages the opportunity to involve a much broader group of users in the discussion around how GI should be shared on the web, and their discussions and outputs clearly show that the integration of GI from different sources is a semantic issue at its core (Kuhn 2005). This semantic interoperability and its role for the future of GII in the context of Digital Earth is discussed in detail in Sect. 5.4.2. The following section describes how GII is a prime example of the openness that has become the new normal in many fields of science, technology, and business.

### 5.3.2 Geospatial Information Infrastructures Champion Openness

As presented earlier, today's GII landscape is shaped by the influence, development and widespread adoption of open data (see also above). The notion of 'openness' has long been part of GIIs, especially due to the long-term leading role of the public sector (Schade et al. 2015). A foundational role of GIIs has been, and still is, to enable the discovery and sharing of spatially referenced data. As described in Sect. 5.2, SDIs were essentially designed and developed to support the generation, management and processing of GI, as key vehicles to make data openly accessible to a broader community. However, as a social construction, the understanding and

interpretation of openness is far from static; it is dynamic and changes as the tandem technology-society evolves. Thus, the interpretation of 'open' (data, tools, etc.) reflects the changes in society and necessarily adapts to the new uses and needs of people. In addition, the value of open data is under scrutiny (Craglia and Shanley 2015) and an increasing number of commercial companies produce and host GI.

To better understand how the current discussion about openness affects GIIs and to better speculate future scenarios, we provide two brief stories, paraphrasing the way Arribas-Bel and Reades (2018) examine the evolution between geography and computers. First, we take a brief historical perspective to determine what openness meant in the origins of (governmental) GIIs. Next, we look at the new 'open' trends and growing forces that are currently emerging, mostly outside of GIIs, which we argue are important for GIIs (and Digital Earth) to pay close attention to. Both stories allow for us to reflect and speculate on the need for a convergent point in the future, where GIIs can embrace and continuously adapt to evolving notions of openness and to the resulting societal changes and economic implications.

The first story goes back to the reasons that motivated the need to establish GIIs. Since the outset, GIIs in the form of hierarchical visions on SDI (Rajabifard et al. 2003) or networked visions (Tulloch and Harvey 2008; Vandenbroucke et al. 2009) contained relatively restricted themes and types of resources owned by the public sector. The underlying motto was "collected once, shared multiple times", so each GII node was managed homogeneously its own spatially referenced data. Data sharing was feasible through these infrastructure nodes because data discovery, access, and delivery were affordable through well-known standardization practices (see Sects. 5.2.2 and 5.3.1). Standardized data models and service interfaces characterized the data sharing capabilities of these government-led GIIs, although only a small group of specialized, tech-savvy users benefitted from them. At that time, the concept of openness was tightly coupled to the idea of sharing. The democratization of data sharing through GIIs was a great leap to facilitate transnational and multidisciplinary projects because the problems of discovery, access and redundancy of GI were significantly alleviated by standardized and unified mechanisms. Most recently, this led to the offerings of location enabled e-Services using web-based application programming interfaces (APIs) built upon SDIs. One example of this is the development of an application for citizens called Spotbooking to apply for, process and maintain uses of public spaces within a town or city (Spotbooking 2019).

In addition to past studies to find synergies bridging geospatial research data with public sector information and open data initiatives, other relevant open trends/movements enable knowledge/data collection, creation and dissemination and mostly operate outside GIIs (Schade et al. 2015). We do not list the multitude of open trends and their technological infrastructure here but highlight a few examples to underline the evolving meaning of openness from data sharing to dynamic processes for knowledge production and dissemination. One example is the European Open Science Cloud (EOSC 2019), a cloud for research data in Europe that supports the ongoing transitions in how research is performed and how knowledge is shared. As a second example, the IoT infrastructure generates a vast amount of spatiotemporal data streams at a finer granularity, which undoubtedly represent valuable sources of

data (i.e., 'things' observe the environment by collecting data) and analytical computation (i.e., 'things' act by processing gathered data) for Digital Earth and GIIs. Granell et al. feature the promising bridges and synergies between the IoT and Digital Earth application scenarios in Chap. 11, but a true convergence of the two infrastructures is still in its infancy. As a third example, the relationship between Digital Earth and citizen science is outlined in detail in this book by Brovelli and others (Chap. 18).

Fast-forwarding to the present, openness has become a more prominent concept than ever. It has been transformed and extended to all aspects of people's daily lives (Price 2013). Contrary to the common perception of openness in the first example, which was practically restricted to 'sharing' data, today's vision of openness takes multiple and varied forms (Sui 2014). Openness permeates many facets of today's culture, society, government, science and education, leading to a series of (old and new) 'open terms' such as open culture, open cities (Domingo et al. 2013; Degbelo et al. 2016), open movement (Lee et al. 2015), open government (Lathrop and Ruma 2010; Goldsmith and Kleiman 2017), open software (Aksulu and Wade 2010), open hardware (Powell 2012), open science, open research, open laboratories (Nosek et al. 2015), open innovation (Schade and Granell 2014; Mathieu and Aubrecht 2018), and open education (Bonk et al. 2015). In contrast, as analyzed below, daily (geospatial) information still flows to platforms that are not defined as open and are owned by the above-mentioned companies. Offering services free of charge but in exchange for personal (user-generated) data has become a popular business model.

We argue that peoples' perception of openness is dramatically influenced by the irruption, rapid adoption, and new uses and appropriations of technology. Digital transformations brought changes in the proliferation of new data sources, the consolidation of novel ways of producing and consuming data, and in the demography of users. The cost of creating GI anywhere, at any time, from anyone, about anything (aka 4-A technology) drastically decreased. However, the cost for current GIIs to consume, integrate and make sense of 4A-generated data is still considerable—especially when considering the direct and indirect costs for the provision and application of 4-A-generated data for a rich portfolio of use cases and stakeholders (Johnson et al. 2017). The scale, frequency, and granularity of the data being generated and gathered today were simply unimaginable when the foundations of GIIs were designed many years ago. The motto "collected once, shared multiple times" is no longer a fundamental truth that drives GIIs because anyone can collect data on the same phenomenon, in the same place, from multiple perspectives, which was previously technically infeasible. In fact, we unconsciously create such GIs all the time. As a result, more and more data sources are available for a single phenomenon, requiring additional analytical approaches and interoperability arrangements to integrate these data sources and offer a comprehensive picture about the phenomenon in question (Huang et al. 2018). Thus, data in traditional (governmental) GIIs provide one perspective of a phenomenon (mobility, pollution, demography, etc.). Other perspectives of that phenomenon are provided by data that are collected via other infrastructures. This does not fully address the concept of openness. Openness means sharing data about a phenomenon for small groups of experts, enabling and promoting comprehensible

views of phenomena taken from disparate sources, and making them accessible and understandable to various user groups. What characteristics do modern GIIs need to fully exploit 4A-generated data? What does this imply in terms of interoperability? And how does this impact current approaches to openness?

While common sense tells us that the way to solve the growing complexity of today's social challenges and underlying research problems is through multidisciplinary collaboration at all levels including technical infrastructures, access to data, and participation in the creation and dissemination of knowledge, the reality is that the diversity of 'open' trends is understandable considering the diversity of actors that have different objectives and needs and are affected differently by a constantly changing technological landscape. It appears that each actor (citizens, NGOs, scientists, private companies, government, etc.) has a different understanding of the meaning and application of the notion of openness. All of them are entirely legitimate given the contexts in which each of the different stakeholders operate.

Regardless of any controversy about the future meaning of openness, it is clear that 'open' cannot be considered a static feature of data or of GII, but should be considered under the lens of recent trends and critiques as a dynamic process for the production, creation and dissemination of knowledge, which is subject to improvements and optimizations over time. The reconceptualization of openness as a dynamic process is vital to enable convergent points and bridges among emerging movements and GIIs—which still operate rather disconnectedly—to make sense of the vast amounts of collected data to solve the pressing issues facing the Earth today. We can rephrase the previous questions: What characteristics would define such dynamic processes in GIIs to exploit 4A-generated data?

Leading GIS scientists recently reflected on the current limitations of the field and called for an entirely new brand of geospatial algorithms and techniques to analyze and process these new forms of data (Jiang 2015; Miller and Goodchild 2015; Li et al. 2016). Lü et al. (2019) magnificently summarize this perception in one sentence: "a successful past [of GII] does not guarantee a bright future" (pp 347). The historical view of GII reported in this chapter is indisputably a story of success. Nevertheless, new driving forces and trends such as open movements and open information infrastructures—along with the datafication and platformization of society—have had and will have significant impacts on the future success of GIIs, so GIIs should carefully consider them to explore alliances and actively integrate and process new forms of information sources.

### 5.3.3 Capacity Building and Learning for Geospatial Information Infrastructures

Although appropriate technologies and policies to enable data access and data sharing are crucial in the development of GIIs, it also requires education and capacity building to ensure the necessary knowledge, skills and competencies are available

(Craglia et al. 2008). Complementing more general frameworks on the development of digital skills (van Deursen and van Dijk 2014), the need for collaboration between government, businesses and academics in the development of an appropriate knowledge infrastructure has been reflected in national and regional GII strategies and actions (Vancauwenberghe and Vandenbroucke 2016). In the past 20 years, various education and training initiatives on GII and related topics have been developed and implemented by higher education institutions, public administrations and businesses. Throughout the years, the focus has broadly shifted from raising awareness of the potential of GI, to capacity building for the implementation of different GII components to skills and knowledge related to the use and integration of GII data and services in decision making, service delivery and product development processes. GII education and training also must be dynamic and change in response to new technological and policy-related developments. The key challenge in successful GII education and training is to ensure that it addresses the needs of GII professional developers and users. Demand-driven GII education and training requires insight in and agreement on what professionals in the domain of GII should know and be able to do (Vandenbroucke and Vancauwenberghe 2016). Studies investigating the demand for GII capacity building have been undertaken at organizational, national and cross-national levels. A European-wide study on the workforce demand in the domain of GISandT showed that, despite differences in the tasks they perform, employees and representatives from the different sectors including public administration, private sector and academia have strongly similar views on the skills and knowledge areas they consider the most relevant (Wallentin et al. 2014). The European GI community identified a shift in focus from map making and local database handling towards online and mobile technologies based on SDIs with a massive amount of—open—data to be integrated. This is a clear indication that the importance of capacity building for GII will increase in the near future.

A valuable approach in the identification of the specific knowledge and skills that professionals need to master for career success in their field is the development of a comprehensive inventory of the knowledge domain. To provide such an inventory for the GISandT domain, in 2006 the University Consortium of Geographic Information Science (UCGIS) developed the Geographic Information Science and Technology Body of Knowledge (GISandT BoK) (DiBiase et al. 2006). The main intended use of the GISandT BoK was to support the development and assessment of GISandT curricula, but the document also serves other purposes such as for professional accreditation or screening of employees. The 2006 version of the Body of Knowledge included more than 330 topics organized into seventy-three units and ten knowledge areas. Notably, the concept of 'spatial data infrastructure' was included twice, in two different knowledge areas: once in the knowledge area of geospatial data (as a topic under the 'Metadata, standards and infrastructures' unit) and once in the organizational and institutional aspects knowledge area (as a topic under the Institutional and interinstitutional aspects unit). This reflects the need for training and education on the technological and organizational (or institutional) aspects of SDI. In addition to the concept of spatial data infrastructure, the Body of Knowledge contains other concepts that are linked or relevant to the development of SDIs and

GIIs, spread across different knowledge areas and units. This demonstrates the relevance and importance of GIIs as a field and the need for an ontology-based approach to the field, where different types of relationships between concepts can be identified (Vandenbroucke and Vancauwenberghe 2016).

To reflect and address recent trends, developments and challenges in the GISandT domain, continuous revision and updating of the Body of Knowledge are required. Initiatives to revise and update the Body of Knowledge have been undertaken and are ongoing in Europe and the United States (Vandenbroucke and Vancauwenberghe 2016). In addition to the topics covered and defined learning objectives, another key aspect in the design and implementation of GII training and education is the teaching and learning activities applied to help students achieve these objectives. GII education has evolved from traditional 'teacher-centric' teaching styles to more 'learner-centric' methods and approaches. With the availability of online—open—education resources by organizations and institutions such as the EuroSDR (EduServ program), the University of Salzburg (UNIGIS program), the Geographical Information System International Group (GISIG) and recently the European Commission (Geospatial Knowledge Base (GKB) Training Platform), the GI/GII community has a strong tradition of e-learning activities. Collaboration between higher education institutions and other stakeholders to design and deliver GI and GII education has taken place for many years. In many cases, this collaboration is often organized in a rather traditional manner, through internships at public or private organizations, the provision of data and tools for educational purposes, and the organization of study visits and excursions to private or public organizations in the GISandT domain (Vancauwenberghe and Vandenbroucke 2016). Recently, several universities started experimenting with more case-based approaches in which students and teachers closely collaborate with practitioners on real-life case studies. The concept of academic SDIs for research and for education can be viewed in the context of adopting more innovative teaching and learning methods (Coetzee et al. 2017). Students could actively contribute to the development and implementation of various SDI components and use the infrastructure to share the results of their efforts with other students, teachers and researchers. In addition, GIIs play a role in the cocreation of knowledge and thereby in lifelong learning (Foresman et al. 2014), and through their fundamental contribution to the Digital Earth vision, GIIs can enable living labs, i.e., user-driven approaches to innovation (Schade and Granell 2014).

## 5.4  Recent Challenges and Potential for Improvement

Given the situation today—as indicated in the introduction to this chapter—we face a series of challenges. These challenges primarily emerge from the pace of technological change, including more frequent technological disruptions than in the past, and the (to some extent heavy-headed) standardization applied to GIIs. We note the challenges caused by what we call the 'big data' phenomenon (Tsinaraki and Schade 2016) and by the mainstreaming of GI, which introduced new users with new needs

as well as new providers of GII. Given these current changes and challenges, we emphasize two implications for GIIs and their future evolution.

### 5.4.1 Strengthened Role of Semantics

The insight that semantic heterogeneity is a key factor that interferes with the effective use and analysis of GI from different sources is by no means new, nor are the solutions based on semantic web technologies to address the corresponding challenges (Kuhn 2005; Lutz and Klien 2007; Lutz et al. 2009). However, although academic research noted these issues quite early on in the establishment of SDIs, in practice, most efforts have been focused on achieving the underlying technical and syntactic interoperability. This focus is understandable, as semantic interoperability only becomes an issue when the technical and syntactical issues are largely solved. This stage in the development of GII appears to have been reached, since the role of geospatial semantics has been strengthened considerably and is now an issue that practitioners deal with in implementation of open data platforms and geospatial web services.

Arguably, this development was not solely driven by questions about the semantics of geospatial data at hand. Rather, the need for approaches that let us add information about the semantics of entities (geospatial features, in our case), particularly their types and properties, has been recognized in many other fields. These include generic examples such as the publication of structured data on the web (Schema.org is the most prominent example) or specialized application domains (such as biology or history), and closely related research fields such as the sensor web and the Internet of Things. The common need for structured data with clearly defined semantics across those domains has led to efforts in a number of different directions, including research on the theoretical underpinnings of semantic reasoning (Noy 2004; Wang et al. 2004), development of specifications [RDF(S) (Staab et al. 2002), OWL (McGuinness and Van Harmelen 2004), OWL2 (Hitzler et al. 2009; Motik et al. 2009), query languages [SPARQL (Harris et al. 2013), GeoSPARQL (Battle and Kolas 2012)]], implementation of the triple stores (Rohloff et al. 2007) and query engines (Broekstra et al. 2002; Carroll et al. 2004). In combination, these efforts have led to a more widespread adoption of approaches that focus on the semantics of geospatial data (Stock et al. 2011), and semantics is now front and center in best practice recommendations for publishing spatial data (W3C 2019).

The W3C's Spatial Data on the Web Best Practices discusses how to best semantically annotate geospatial data—, i.e., using shared vocabularies—and recommends full-fledged adoption of Linked Data principles. A more widespread adoption of these best practices will imply a paradigm shift (Kuhn et al. 2014) towards a radically distributed approach to the publication of GI. Linked Data are currently treated as a byproduct in the publication of GI, e.g., when government agencies such as the UK's Ordinance Survey are starting to offer their GI as Linked Data or when universities convert OSM data to Linked Data. These are valuable efforts—a little semantics goes

a long way (Hendler 2009)—but the data that is being published is still the output of an extract-transform-load (ETL) process on top of an original data source such as a relational spatial database. Furthermore, the provision of GI as Linked Data only adds another data offering with the potential use for data integration. Actual success cases remain rare.

The opportunities and challenges of making Linked Data the original data format based on which all changes are made and from which other formats can be derived can currently be observed in the Wikidata effort (Vrandečić and Krötzsch 2014). After the immense success of DBpedia (Auer et al. 2007)—a Linked Data product generated via ETL from the structured information in Wikipedia—the potential of turning this process around by making the produced structured data the actual data underlying all language editions of Wikipedia has been recognized. This approach now allows for an editor to update information in Wikidata—such as the population number for a country after a new census, or the publication of the latest book by a given author—and that information can automatically be reused across all Wikipedia.

GI still has a way to go in making a semantics-based approach its primary format for data management and publication, and thus become part of an ever-growing distributed knowledge graph. Conceived as part of the infrastructure driving Digital Earth, this goal appears attractive, particularly because of its potential to further normalize the use GI across a wider range of disciplines. However, a number of challenges must be addressed before this vision can be put into practice, including the development and implementation of standardized handling of GI in triple stores, interfaces to access geospatial Linked Data directly from GI 'front ends' such as traditional GIS, web-based and mobile mapping applications, as well as capacity building, particularly in the form of educating students in the underlying technology stack so that they can help with these developments after graduation. These challenges highlight the fact that geospatial semantics will remain an essential and dedicated research area for the foreseeable future, helping users make sensible use of GI and turn it into actionable knowledge. Finally, in the context of Linked Data, (geo)spatial information is definitely special because spatial (and particularly spatiotemporal) data can be used as an integrator to help build connections between originally disparate data sources.

### 5.4.2  Is Spatial Still Special?

There are several slogans related to GI, including "spatial is special". Although one might argue that GI is only more complex than many kinds of (nonspatial) information, at least in the past, geospatial informatics filled a niche role with comparably few specialists working on the topic. As far as mainstream computing was concerned, the spatial-temporal components of GI were restricted to a pair of coordinates (a point) and a date-time stamp. Today, the spatiotemporal characteristics of GI have made it popular for data integration tasks, where location is an obvious commonality between many separately collected data sources (Tsinaraki and Schade 2016). In

combination with the recent trend towards platformization of society and wider use of remotely sensed images, online maps, sensors (see also Chap. 11), as well as people's location and tracks, one might argue that the time when (geo)spatial has been special has come to an end. However, although the collection of GI has become much easier (and hence gone mainstream), pitfalls in analysis (spatial autocorrelation, projections, etc.) remain. Related special challenges surface, especially when standard approaches for handling big data are directly applied to GI. Many of the common "divide and conquer" approaches applied to big data analysis tasks fail because of the spatial relationships between chunks of data. As argued in Sect. 5.4.1, semantics is highly important. Using colocation as the only element for data integration can easily lead to the senseless combined processing of data from completely different and potentially conflicting contexts.

The mainstreaming of location information has direct implications for the evolution of GII, as with the future conceptualization of GIS and SDIs. In the past, these notions were a research and application field in their own right, and they now appear to be much more integrated into the wider fields of computer science and data science (Cadell 2018). With a narrow view, this could be seen as a thread to the communities and associations that formed around these concepts (the introduction to this chapter provided some examples of these). Conversely, the mainstreaming of GI provides immense opportunities such as the increasing market for companies specializing in GI and many new job opportunities for GI experts.

From a government perspective, GIIs became more relevant—and geospatial data less special—through the use of data in this infrastructure for the provision of spatially enabled e-government services to citizens, businesses and other societal actors (Vancauwenberghe and van Loenen 2018). Geospatial data that became increasingly available were used to improve existing e-services and provide novel services. Such spatially enabled e-services now exist in many policy areas (i.e., environment, agriculture, transport) and at different levels of government (i.e., local, regional, national). They evolved from more simple information and contact services to more advanced transaction services. These spatially enabled transaction services refer to the use of geospatial data in the electronic intake and handling of requests and applications of rights, benefits and obligations. Because these transaction services demand multiple two-way interactions between governments and citizens/businesses, they are more complex than information or contact services, which are mostly one-way services. This increased complexity applies to both technological and organizational aspects, since the delivery of these e-services requires a strong alignment and possible integration of GIIs with e-government developments. Initiatives to enable this integration have been taken at organizational, national and regional levels—especially in Europe (Vancauwenberghe and van Loenen 2018).

In the private sector, we have observed manifold developments. First, the traditional partnerships with the public sector evolved into collaborations in which governmental bodies such as mapping agencies still own and provide authoritative content (such as cadaster information, protected sites, and utilities), and the industry offers solutions for data hosting, access, and cost recovery. The data and information access services (DIAS) for the European Space program Copernicus is a particularly

impressive example (Copernicus 2019). In each of these five different implementations, the public-sector GII is coupled with data from commercial satellites to provide additional value. Second, there are an increasing number of companies building upon GIIs. Especially for technologies such as web-based APIs, as in the example of Spotbooking, GI has become more accessible and value-added services and applications have been created. Due to the abovementioned platformization, large internet firms create many GIs and host them in their infrastructures, and they are only occasionally linked to existing public-sector GIIs. GI has clearly moved into the mainstream information infrastructures. Lastly, many GI projects today rely on data provided by companies such as Google, DigitalGlobe, Waze, Here, and Esri. Examples include geospatial data about commercial demographics and personal mobility.

In the context of Digital Earth, these developments are all good news. In every conceptualization of the Digital Earth vision—and in any future evolution thereof—GI and GIIs will remain fundamental building blocks. As increasing related expertise becomes available and the mainstreaming trend of GI continues, GI can provide the capacity that is required for improving Digital Earth applications and enlarging implementations of the Digital Earth vision across the globe. The transition from mainstreamed GI to GIIs that are readily available to developers and implementers of the Digital Earth vision is the logical next step and an area for further research and organizational improvements. The interplay between and the changes in power relationships between society, research, industry and the public sector deserve dedicated attention.

## 5.5 Conclusion and Outlook

This chapter situated GIIs in the wider context of the Digital Earth vision and introduced GIIs as a major enabling element for Digital Earth implementation. The past and present of GIIs was outlined along with a subjective view of today's major challenges concerning the status of GII development and use, and possible future directions. Notably, this view might be biased towards academia and governments, but we have highlighted emerging developments from the private sector as a disruptive driving force that quickly emerged over the past decade.

This chapter demonstrates that GIIs have come a long way and evolved as a strong underpinning contribution for implementation of the Digital Earth vision. Whereas we witnessed a dispersion of efforts in the early days, we illustrated how GIIs evolved and coordinated efforts emerged in different national and international contexts. The increasing pace of technological changes poses new challenges to the continuation and further convergence of these efforts because new actors with different backgrounds and expectations enter the discussion. We see a particular need to continue and strengthen the role of semantics in GII development and implementation to ensure that the provided information can be used appropriately. We also recognize the changing power relationship from the public to the private sector, with a disrupting effect on traditional data owners (especially mapping agencies). These changes

will significantly affect the role of the public sector in geospatial data management and provision.

Lastly, we underlined the needs for further evolution of GIIs so that they become flexible and robust enough to absorb and embrace technological transformations and the accompanying societal and organizational implications. These required capacities for addressing technological and organizational issues, and training of present and future generations of GII developers and GII users. As a prominent example, we highlighted the relationships to movements to open up data and the access to knowledge. GIIs—which were in the forefront of open data sharing in the past—must react to changing conditions, provide bridges to other existing infrastructures to absorb new data sources, and contribute to the development of new standards for collaboration. The next generation of GIIs should provide management and processing capacities for classical GI, and must be able to input and handle novel information sources. In this way, they will continue to fuel innovation for the future of Digital Earth. Chapters 6, 9 and 10 provide additional insight into analytical aspects and issues related to big data. For details about the economic value of Digital Earth, we refer the reader to Chap. 19.

# References

Aksulu A, Wade MR (2010) A comprehensive review and synthesis of open source research. J Assoc Inf Syst 11(11):576–656

ANZLIC (1992) Land information management in Australasia 1990–1992. Australia Government Publishing Service, Canberra

ANZLIC (2019) ANZLIC home page. ANZLIC. https://anzlic.gov.au/. Accessed 6 May 2019

Arribas-Bel D, Reades J (2018) Geography and computers: past, present, and future. Geogr Compass 12(10):e12403

Auer S, Bizer C, Kobilarov G et al (2007) DBpedia: a nucleus for a web of open data. In: Aberer K, Choi K-S, Noy N et al (eds) The semantic web. ISWC 2007, ASWC 2007. Lecture notes in computer science, vol 4825. Springer, Heidelberg, pp 722–735

Battle R, Kolas D (2012) Enabling the geospatial semantic web with parliament and geoSPARQL. Semant Web 3(4):355–370

Berners-Lee T (2006) Linked data: design issues. W3C. https://www.w3.org/DesignIssues/LinkedData.html. Accessed 6 May 2019

Bonk CJ, Lee MM, Reeves TC et al (2015) MOOCs and open education around the world. Routledge, New York

Bostock M, Ogievetsky V, Heer J (2011) D3: data-driven documents. IEEE Trans. Visualization and Comp. Graphics (Proc. InfoVis). Stanford Vis Group, Stanford

Broekstra J, Kampman A, van Harmelen F (2002) Sesame: a generic architecture for storing and querying RDF and RDF schema. In: Horrocks I, Hendler J (eds) International semantic web conference, the semantic web — ISWC 2002. Springer, Heidelberg, pp 54–68

Brovelli MA, Minghini M, Moreno-Sanchez R et al (2017) Free and open source software for geospatial applications (FOSS4G) to support future earth. Int J Digital Earth 10(4):386–404

Burrough P, Brand M, Salge F et al (1993) The EUROGI vision. GIS Eur 2(3):30–31

Cadell W (2018) Geospatial analytics will eat the world, and you won't even know it. Forbes Technology Council. https://www.forbes.com/sites/forbestechcouncil/2018/07/16/geospatial-analytics-will-eat-the-world-and-you-wont-even-know-it/#40457209726a. Accessed 6 May 2019

Capineri C, Haklay M, Huang H et al (2016) European handbook of crowdsourced geographic information. Ubiquity Press, London

Carroll JJ, Dickinson I, Dollin C et al (2004) Jena: implementing the semantic web recommendations. In: Feldman S, Uretsky M, Najork M et al (eds) Proceedings of the 13th international World Wide Web conference on alternate track papers and posters. ACM, New York, pp 74–83

Castells M, Cardoso G (2005) The network society: from knowledge to policy. Johns Hopkins Center for Transatlantic Relations, Washington DC

Coetzee S, Steiniger S, Köbben B et al (2017) The academic SDI—Towards understanding spatial data infrastructures for research and education. In: Peterson MP (ed) International cartographic conference. ICACI 2017: advances in cartography and GIScience. Springer International Publishing, Cham, pp 99–113

Copernicus (2019) DIAS EC. https://www.copernicus.eu/en/access-data/dias. Accessed 6 May 2019

Coppock JT (1987) Handling geographic information. Report of the committee of enquiry. Int J Geogr Inf Syst 1(2):191–192

Craglia M, Goodchild MF, Annoni A et al (2008) Next-generation digital earth: a position paper from the Vespucci initiative for the advancement of geographic information science. Int J Spat Data Infrastruct Res 3:146–167

Craglia M, Shanley L (2015) Data democracy – increased supply of geospatial information and expanded participatory processes in the production of data. Int J Digit Earth 8(9):679–693

Danko D (2005) ISO/TC 211 metadata. Geo-information standards in action. Nederlandse Commissie voor Geodesie (NCG), Delft

Davis Jr. CA (2009) Spatial data infrastructures. In: Khosrow-Pour M (ed) Encyclopedia of information science and technology, second edition. IGI Global, Hershey, pp 3548–3553

Degbelo A, Granell C, Trilles S et al (2016) Opening up smart cities: citizen-centric challenges and opportunities from GIScience. ISPRS Int J Geo-Inf 5(2):16

DiBiase D, DeMers M, Johnson A et al (2006) Geographic information science and technology body of knowledge. Association of American Geographers, Washington DC

Domingo A, Bellalta B, Palacin M et al (2013) Public open sensor data: revolutionizing smart cities. IEEE Technol Soc Mag 32(4):50–56

Dragoni N, Giallorenzo S, Lafuente AL et al (2017) Microservices: yesterday, today, and tomorrow. In: Mazzara M, Meyer B (eds) Present and ulterior software engineering. Springer International Publishing, Cham, pp 195–216

EOSC (2019) European open science cloud (EOSC). EC. http://ec.europa.eu/research/openscience/index.cfm?pg=open-science-cloud. Accessed 6 May 2019

ESRI (1998) ESRI shapefile technical description: an ESRI white paper. Environmental Systems Research Institute, Redlands

ESRI (2019a) ArcGIS hub examples. In: ArcGIS Hub. ESRI. Available via DIALOG. https://hubdemo-cityx.opendata.arcgis.com/. Accessed 6 May 2019

ESRI (2019b) ArcGIS API for JavaScript. In: JavaScript API, Version 4.12. ESRI. Available via DIALOG. https://developers.arcgis.com/javascript/. Accessed 6 May 2019

ESRI (2019c) ArcGIS open data charter. ESRI. https://www.esri.com/en-us/arcgis/open-vision/standards/open-data. Accessed 15 Apr 2019

Executive Office of the President (1994) Executive Order 12906: Coordinating Geographic Data Acquisition and Access: the National Spatial Data Infrastructure, signed by President Bill Clinton on April 11, 1994, launched the initiative to create the NSDI. https://www.fgdc.gov/policyandplanning/executive_order. Accessed 12 Aug 2019

FGDC (1998) Content standard for digital geospatial metadata, FGDC-STD-001-1998. Federal Geographic Data Committee, Metadata Ad Hoc Working Group, Washington DC

Foresman T, Schade S, Georgiadou Y et al (2014) Does DE need a C? A proposal for a DE curriculum. Int J Digit Earth 7(1):88–92

Geospatial World (2011) Geospatial world forum 2011: technology for people and earth, geospatial world. Geospatial World. https://www.geospatialworld.net/article/geospatial-world-forum-2011-technology-for-people-and-earth/. Accessed 6 May 2019

Gimpel H, Röglinger M (2015) Digital transformation: changes and chances – Insights based on an empirical study. Fraunhofer FIT, Sankt Augustin

Goldsmith S, Kleiman N (2017) A new city O/S: the power of open, collaborative, and distributed governance. Brookings Institution Press, Washington DC

Goodchild MF (2007) Citizens as voluntary sensors: spatial data infrastructure in the world of web 2.0. Int J Spat Data Infrastruct Res 2:24–32

Goodchild MF, Guo H, Annoni A et al (2012) Next-generation digital earth. Proc Nat Acad Sci USA 109(28):11088–11094

Google (2019) Google Maps home page. Google. https://www.google.com/maps. Accessed 6 May 2019

Gore A (1998) The digital earth: understanding our planet in the 21st century. Speech given at the California Science Center, Los Angeles, California, on January 31ESRI. http://portal.opengeospatial.org/files/?artifact_id = 6210. Accessed 6 May 2019

Granell C, Fernández ÓB, Díaz L (2014) Geospatial information infrastructures to address spatial needs in health: collaboration, challenges and opportunities. Future Gener Comput Syst 31:213–222

Granell C, Havlik D, Schade S et al (2016) Future internet technologies for environmental applications. Environ Model Softw 78:1–15

GRASS (2019) GRASS GIS home page. OSGeo. https://grass.osgeo.org/. Accessed 6 May 2019

Gurstein MB (2011) Open data: empowering the empowered or effective data use for everyone? First Monday 16(2). https://doi.org/10.5210/fm.v16i2.3316

Haklay M, Weber P (2008) OpenStreetMap: user-generated street maps. IEEE Pervasive Comput 7(4):12–18

Harris S, Seaborne A, Prud'hommeaux E (2013) SPARQL 1.1 query language. W3C Recomm 21(10):806

Hendler J (2009) A little semantics goes a long way. Rensselear School of Science. https://www.cs.rpi.edu/~hendler/LittleSemanticsWeb.html. Accessed 6 May 2019

Hitzler P, Krötzsch M, Parsia B et al (2009) OWL 2 web ontology language primer. W3C Recomm 27(1):123

Huang H, Gartner G, Krisp JM et al (2018) Location based services: ongoing evolution and research agenda. J Locat Based Serv 12(2):63–93

ILWIS (2019) Integrated land and water information system (ILWIS). ITC, University of Twente. https://www.itc.nl/ilwis/. Accessed 6 May 2019

INSPIRE (2019) INSPIRE home page. EC. https://inspire.ec.europa.eu/. Accessed 6 May 2019

ISO (2002) ISO 19101:2002 geographic information – Reference model. ISO. https://www.iso.org/standard/26002.html. Accessed 6 May 2019

ISO (2003) ISO 19115:2003 geographic information – Metadata. ISO. https://www.iso.org/standard/26020.html. Accessed 6 May 2019

Jiang B (2015) Geospatial analysis requires a different way of thinking: the problem of spatial heterogeneity. GeoJournal 80(1):1–13

Johnson PA, Sieber R, Scassa T et al (2017) The cost(s) of geospatial open data. Trans GIS 21(3):434–445

Kitchin R (2014) The data revolution: big data, open data, data infrastructures and their consequences. SAGE Publications Ltd, Maynooth

Kuhn W (2005) Geospatial semantics: why, of what, and how? In: Spaccapietra S, Zimányi E (eds) Journal on data semantics III. Springer, Heidelberg, pp 1–24

Kuhn W, Kauppinen T, Janowicz K (2014) Linked data - A paradigm shift for geographic information science. In: Duckham M, Pebesma E, Stewart K et al (eds) International conference on geographic information science. Springer International Publishing, Cham, pp 173–186

Lathrop D, Ruma L (2010) Open government: collaboration, transparency, and participation in practice. O'Reilly Media, Sebastopol

Leaflet (2019) Leaflet home page. Leaflet. Open Streat Map. http://leafletjs.com. Accessed 6 May 2019

Lee M, Almirall E, Wareham J (2015) Open data and civic apps: first-generation failures, second-generation improvements. Commun ACM 59(1):82–89

Li S, Dragicevic S, Castro FA et al (2016) Geospatial big data handling theory and methods: a review and research challenges. ISPRS J Photogramm Remote Sens 115:119–133

Longley PA, Goodchild MF, Maguire DJ et al (2011) Geographic information systems and science. John Wiley and Sons, Hoboken

Lü G, Batty M, Strobl J et al (2019) Reflections and speculations on the progress in geographic information systems (GIS): a geographic perspective. Int J Geogr Inf Sci 33(2):346–367

Lutz M, Klien E (2007) Ontology-based retrieval of geographic information. Int J Geogr Inf Sci 20(3):233–260

Lutz M, Sprado J, Klien E et al (2009) Overcoming semantic heterogeneity in spatial data infrastructures. Comput Geosci 35(4):739–752

Maguire DJ, Longley PA (2005) The emergence of geoportals and their role in spatial data infrastructures. Comput Environ Urban Syst 29(1):3–14

Masser I (2005) GIS worlds: creating spatial data infrastructures. ESRI Press, Redlands

Mathieu PP, Aubrecht C (2018) Earth observation open science and innovation. Springer Open, Cham

McGuinness DL, Van Harmelen F (2004) OWL web ontology language overview. W3C Recomm 10(10):2004

Miller HJ, Goodchild MF (2015) Data-driven geography. GeoJournal 80(4):449–461

Motik B, Grau BC, Horrocks I et al (2009) OWL 2 web ontology language profiles. W3C Recomm 27:61

National Research Council, Division on Earth and Life Studies, Commission on Geosciences et al (1993) Toward a coordinated spatial data infrastructure for the nation. National Academies Press, Washington DC

Nativi S, Craglia M, Pearlman J (2013) Earth science infrastructures interoperability: the brokering approach. IEEE J Sel Top Appl Earth Obs Remote Sens 6(3):1118–1129

Nebert DD (ed) (2004) Developing spatial data infrastructures: the SDI cookbook. Global Spatial Data Infrastructures Association, Reston

Nosek BA, Alter G, Banks GC et al (2015) Promoting an open research culture. Science 348(6242):1422–1425

Noy NF (2004) Semantic integration: a survey of ontology-based approaches. ACM Sigmod Rec 33(4):65–70

NSDI (2019) Advancement of the national spatial data infrastructure. FGDC. https://www.fgdc.gov/nsdi. Accessed 6 May 2019

OGC (2019) Open geospatial consortium home page. OGC. http://www.opengeospatial.org/. Accessed 6 May 2019

OMB (1990) Coordination of surveying, mapping and related spatial data activities. Executive Office of the President, Circular A-16 Revise, Office of Management and Budget, Washington, DC

Open Data Barometer (2015) Open data barometer – Key findings open data barometer. https://opendatabarometer.org/2ndEdition/summary/. Accessed 6 May 2019

OpenLayers (2019) OpenLayers home page. OpenLayers. http://openlayers.org. Accessed 6 May 2019

OSM (2019a) Open Street Map home page. OSM. https://www.openstreetmap.org. Accessed 6 May 2019

OSM (2019b) Slippy map tilenames. OSM. https://wiki.openstreetmap.org/wiki/Slippy_map_tilenames. Accessed 6 May 2019

OSM (2019c) OpenStreetMap stats reports. OSM. https://www.openstreetmap.org/stats/data_stats.html. Accessed 6 May 2019

Papazoglou MP, van den Heuvel W-J (2007) Service oriented architectures: approaches, technologies and research issues. VLDB J 16(3):389–415

Powell A (2012) Democratizing production through open source knowledge: from open software to open hardware. Media Cult Soc 34(6):691–708

Price D (2013) Open: how we'll work, live and learn in the future. Crux Publishing, Great Britain

Rajabifard A, Feeney M-EF, Williamson IP (2002) Future directions for SDI development. Int J Appl Earth Obs Geoinf 4(1):11–22

Rajabifard A, Feeney MF, Williamson I (2003) Spatial data infrastructures: concept, nature and SDI hierarchy. In: Williamson I, Rajabifard A, Feeney MF (eds) Developing spatial data infrastructures: from concept to reality. CRC Press, Boca Raton, pp 17–40

Rohloff K, Dean M, Emmons I et al (2007) An evaluation of triple-store technologies for large data stores. In: Meersman R, Tari Z, Herrero P (eds) OTM confederated international conferences on the move to meaningful internet systems. Springer, Heidelberg, pp 1105–1114

Schade S, Granell C (2014) Shaping digital earth applications through open innovation – Setting the scene for a digital earth living lab. Int J Digit Earth 7(7):594–612

Schade S, Granell C, Perego A (2015) Coupling public sector information and public-funded research data in Europe: a vision of an open data ecosystem. In: Reddick C, Anthopoulos L (eds) Information and communication technologies in public administration: innovations from developed countries. CRC Press, London, pp 275–298

Schade S, Smits P (2012) Why linked data should not lead to next generation SDI. In: 2012 IEEE international geoscience and remote sensing symposium, IEEE, Munich, 22–27 July 2012

Sjoukema J-W, Bregt A, Crompvoets J (2017) Evolving spatial data infrastructures and the role of adaptive governance. ISPRS Int J Geo-Inf 6(8):254

smeSpire (2014) A European community of SMEs built on environmental digital content and languages. smeSpire. http://www.smespire.eu/wp-content/uploads/downloads/2014/03/D1.3_FinalReport_1.0.pdf. Accessed 6 May 2019

Spotbooking (2019) The smart way to reserve & manage the use of public domain. GEOSPARC. https://www.geosparc.com/en/spotbooking. Accessed 6 May 2019

Staab S, Erdmann M, Maedche A et al (2002) An extensible approach for modeling ontologies in RDF(S). In: Grütter R (ed) Knowledge media in healthcare: opportunities and challenges. IGI Global, Hershey, pp 234–253

Steiniger S, Bocher E (2009) An overview on current free and open source desktop GIS developments. Int J Geogr Inf Sci 23(10):1345–1370

Stock K, Hobona G, Granell C et al (2011) Ontology-based geospatial approaches for semantic awareness in earth observation systems. In: Ashish N, Sheth AP (eds) Geospatial semantics and the semantic web: foundations, algorithms, and applications. Springer US, Boston, pp 97–118

Sui D (2014) Opportunities and impediments for open GIS. Trans GIS 18(1):1–24

Tait MG (2005) Implementing geoportals: applications of distributed GIS. Comput Environ Urban Syst 29(1):33–47

Tsinaraki C, Schade S (2016) Big data—A step change for SDI. Int J Spat Data Infrast Res 11:9–19

Tulloch DL, Harvey F (2008) When data sharing becomes institutionalized: best practices in local government geographic information relationships. URISA J 19:51–59

van Deursen AJAM, van Dijk JAGM (2014) Digital skills: unlocking the information society. Palgrave Macmillan US, New York

van Dijck J, Poell T, de Waal M (2018) The platform society: public values in a connective world. Oxford University Press, New York

van Oosterom P (2005) Geo-information standards in action. Netherlands Geodetic Commission (NCG), Delft

Vancauwenberghe G, van Loenen B (2018) Exploring the emergence of open spatial data infrastructures: analysis of recent developments and trends in Europe. In: Saeed S, Ramayah T, Mahmood Z (eds) User centric E-government: challenges and opportunities. Springer International Publishing, Cham, pp 23–45

Vancauwenberghe G, Vandenbroucke D (2016) Collaborative learning: analysis of the needs of industry and academia. http://www.gicases.eu/download/d1-1-collaborative-learning-analysis-of-the-needs-of-industry-and-academia/. Accessed 6 May 2019

Vandenbroucke D, Crompvoets J, Vancauwenberghe G et al (2009) A network perspective on spatial data infrastructures: application to the sub-national SDI of Flanders (Belgium). Trans GIS 13(s1):105–122

Vandenbroucke D, Vancauwenberghe G (2016) Towards a new body of knowledge for geographic information science and technology. Micro Macro Mezzo Geoinf 2016(6):7–19

Vrandečić D, Krötzsch M (2014) Wikidata: a free collaborative knowledgebase. Commun ACM 57(10):78–85

W3C (2014) Data catalog vocabulary (DCAT) W3C. https://www.w3.org/TR/vocab-dcat/. Accessed 6 May 2019

W3C (2015) Spatial data on the web working group, main page. W3C. https://www.w3.org/2015/spatial/wiki/Main_Page. Accessed 6 May 2019

W3C (2017) Spatial data on the web, interest group page. W3C. https://www.w3.org/2017/sdwig/. Accessed 6 May 2019

W3C (2019) Spatial data on the web best practices. W3C. https://www.w3.org/TR/sdw-bp/. Accessed 6 May 2019

Wallentin G, Hofer B, Traun C (2014) Analysis of the demand for geospatial education and training. Results of the GI-N2K demand survey. Deliverable of the project GI-N2K – Geographic Information Need to Know. http://www.gi-n2k.eu/?wpdmdl=455. Accessed 12 Aug 2019

Wang XH, Zhang DQ, Gu T et al (2004) Ontology based context modeling and reasoning using OWL. In: Proceedings of the second IEEE annual conference on pervasive computing and communications workshops, 2004. IEEE, Orlando, 14–17 March 2004

Worboys MF, Duckham M (2004) GIS: a computing perspective, second edition. CRC Press, Boca Raton

Yang C, Raskin R, Goodchild M et al (2010) Geospatial cyberinfrastructure: past, present and future. Comput Environ Urban Syst 34(4):264–277

Zhao P, Di L (2011) Geospatial web services: advances in information interoperability. IGI Global, Hershey

**Sven Schade** is a scientific officer at the European Commission's scientific and knowledge management service, the Joint Research Centre (JRC), with a background in geospatial information science and knowledge engineering. His interests cover knowledge extraction from heterogeneous data sources, multi-disciplinary interoperability, and public participation in science for policy.

**Carlos Granell** currently holds a 5 year Ramón y Cajal post-doctoral fellowship at the Universitat Jaume I of Castellón, Spain. His interests lie in multi-disciplinary application of GIS (Science/Systems), spatial analysis & visualization of streams of sensor- and/or user-generated geographic content, reproducibility research practices, and finding synergies between citizen science projects, education and dissemination of science.

**Glenn Vancauwenberghe** is a senior researcher at the Spatial Applications Division Leuven (SADL) of KU Leuven, with a background in sociology and public administration. His main fields of research are the governance and performance of spatial data infrastructures and the role of geospatial data in open and digital government.

**Carsten Keßler** is an Associate Professor for Geoinformatics in the Department of Planning at Aalborg University Copenhagen, Denmark, and an adjunct faculty member at The Graduate Center, City University of New York, USA. He is interested in data interoperability, volunteered geographic information, and geo-simulation techniques for large-scale assessments of the impacts of global warming.

**Danny Vandenbroucke** is research manager at KU Leuven, Belgium. His research interest relates to organizational and technical interoperability aspects and the impact geospatial standards might have on the performance of business processes. He works on several Erasmus+ projects that address the educational challenges in the geospatial domain (defining an ontology-based Body of Knowledge for GI/EO, case-based learning …).

**Ian Masser** has held professorial positions at the Universities of Utrecht, Sheffield and Twente as well as visiting positions in University College London, Melbourne and Leuven. His publications include twenty books and more than 300 papers. In 2016 he received the Global Citizen Award from the GSDI Association for his exemplary service to the geospatial community.

**Michael Gould** is a professor of GIS at Universitat Jaume I of Castellón, Spain, and ESRI's Global Education Manager working mostly in Europe, Middle East and Africa. His research interests include distributed GIS, Smart Cities, and hybrid FOSS/proprietary interoperability.