Revisiting cartography: towards identifying and developing a modern and comprehensive framework

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Developments in production, sharing and use of spatial data and information involve revisiting the role and scope of cartography. Cartography is a core discipline for spatially modelling, investigating and mapping natural and cultural environments, developing location-aware applications, establishing spatial data infrastructures and forming spatially enabled societies. In this context, spatial data handling provides key tools for creating spatial databases, integrating spatial data, producing geographic information and maps and so on. Although cartography plays a key role in many phases of such activities, it tends to be introduced only as visualization phase of spatial data handling. On the other hand, it is sometimes regarded to encompass entire phases of spatial data handling. So this article investigates the relationships between cartography and spatial data handling, management and use, and on this basis, proposes a modern and comprehensive framework for cartography to contribute to restoring the full conceptual breadth of the discipline.

Keywords: cartography; spatial data handling; management and use; spatial data infrastructure; spatially enabled society; GIScience

1. Introduction

The public awareness of the value of geographic information and maps for solving real world challenges and problems has dramatically increased over the past decade in conjunction with the advances in spatial data collection, spatial information and communication technologies (ICTs) and their extensive involvement in our daily lives.

Technological revolutions are not new in the over 2000-year written history of cartography. The revolution caused by a pervasive use of electronics and, in particular, computers in mapping eventually led to the emergence of digital cartography, and subsequently geographic information systems (GISs) (Robinson et al. 1995; M. Wood 2003). Having been developed by substantially inspiring and benefiting from cartographic theory and practice, GISs have had a revolutionary impact on spatial data handling, management and use. One of the earliest goals of geospatial community after the development of digital cartography, GIS and the Internet was to develop some sort of basis spatial data infrastructure (SDI). The possibility of reusing and combining spatial data from various sources created the need to constitute a framework called SDI, where people can communicate, access and use data without specific efforts of humans and machines (Cammack 2007; Toth 2007). Although maps are very useful

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spatial models of real world, geographic database creation has largely substituted for traditional map-oriented data acquisition from real world along with GIS paradigm. As a result of worldwide spread of the GISs, single-purpose spatial data production concept has changed. Geographic information and maps at different scales and/or themes can now be produced from multi-representation spatial databases and widely disseminated via modern ICTs such as web and mobile services as outputs of SDI. Furthermore, social media and location-aware technologies have created opportunities for volunteered geographic information and collaborative mapping.

During the digital transition phase in spatial data handling, management and use, no uniform consensus was established for the role and the scope of cartographic discipline in spatial arena. In other words, the attempts of cartographers to redefine or reposition their discipline were scarce and incoherent. Some very contrasting arguments were even asserted in this dynamic era concerning the future of cartography, for example, by D. Wood (2003) and Carter (2004). In the context of GIS, as a technology predicated on geographic data, cartography as a term is now used more to cover the visualization and reproduction aspects, starting from processed data and excluding the earlier stages of building databases and carrying out analysis (Hardy & Field 2012). On the other hand, cartography has also been regarded as the organization and communication of spatial information, including the whole stages from data acquisition to presentation and use (Taylor 1991). Taylor (1994) emphasizes that seeing cartography as a mere display technique is a very limited view of the scope of modern cartography and the abilities of cartographers, and moreover, maps are not only for display but knowledge, action and development. M. Wood (2003) expresses that,

...cartography is not just about ‘map-making’. Map creation should be seen more correctly as part of the spatial problem-solving process which also involves the manipulation and use of maps. With appropriate content and design, maps can improve the comprehension and support the analysis of environmental problems and, when appropriate, help communicate this information to others.

Moellering (2012, p. 66) points out that ‘The University Consortium for Geographic Information Science (UCGIS) Body of Knowledge for Geographic Information Science & Technology (GIS&T) in the USA defines Cartography rather narrowly and conventionally, and subsumes several cartographic concepts into other areas’. Similarly, Fairbairn (2014) states that majority of knowledge areas in UCGIS Body of Knowledge for GIS&T apart from ‘Cartography and Visualization’ had some further themes and topics which might be regarded as cartographic in nature. As a result, this ambiguity on the concept and scope of cartography negatively affects the theoretical and practical progress of the discipline.

In a response to this situation, the International Cartographic Association (ICA) has published a research agenda on cartography and geographic information science (GIScience) (Virrantaus et al. 2009) and has been striving for advancing the discipline (Cartwright 2011; Buchroithner & Gartner 2013) as a continuation of the previous efforts (see, e.g. Moellering 1980, 2000; Rhind & Taylor 1989; Taylor 1991; MacEachren & Taylor 1994; Taylor 1994; Robinson et al. 1995; M. Wood 2003). However, Cauvin et al. (2010), Moellering (2012) and Fairbairn (2014) stress the importance and the necessity for developing a body of knowledge for cartography.

When the recent developments in spatial arena, and various issues and perspectives mentioned above are taken into consideration, it is clear that cartography should be revisited to establish its contemporary and coherent understanding and scope. In other
words, it has remained an open question whether there is something more to cartography and cartographers than ‘visualization’ and ‘map-making’? Thus, this article aims to contribute to restoring the full conceptual breadth of cartography by seeking an answer to this question and proposing a modern and comprehensive framework along with new definitions of ‘cartography’ and ‘map’.

2. An overview on the evolution of cartographic concepts and paradigms, and spatial data handling, management and use

Various concepts and paradigms have emerged in cartography so far (Dodge 2011; Dodge et al. 2011; Fernandez & Buchroithner 2013). Among them, the most relevant ones are map communication model (MCM), graphic semiology, analytical cartography, geovisualization, cybercartography, geovisual analytics and ICT-oriented cartography (web cartography, mobile cartography, ubiquitous cartography and neocartography) from the perspective of the article.

American cartographer Arthur H. Robinson laid the foundations of the MCM in the 1950s. According to the MCM, a map is a communication channel that conveys a message about geographical reality from map maker to map user by taking into account the user’s cognitive and psychophysical abilities. The most sophisticated version of the MCM was introduced by the Czech cartographer Kolacny in 1969 (Crampton 2001; Morrison 2011).

French cartographer Bertin introduced graphic semiology (or semiotics) in 1967 that showed cartographers how to make design choices based on the ideas about consonance between data characteristics and map symbol characteristics by analysing the elements of map graphics to develop a language of cartography (Montello 2002; Bertin 2010). Integrated cognitive-semiotic theoretical perspective on cartographic representation was introduced by MacEachren (1995). In this context, cognitive cartography is a relatively new term that encompasses the application of cognitive theories and methods to understanding maps and mapping and the application of maps to understanding cognition (Montello 2002).

Analytical cartography has grown in the 1960s from Tobler’s concept of ‘solving cartographic problems’ into a broader and deeper scientific specialization that includes the development and expansion of analytical/mathematical spatial theory and model building. Analytical cartography has a considerable overlap with GIScience and its principles contribute to the core of GIScience. The fundamental body of analytical theory begins with Tobler’s concept of cartographic transformations, Nyerges’ deep and surface structure and data levels, Moellering’s real and virtual maps, the sampling theorem and concepts of spatial primitives and objects. These fundamental analytical concepts can also be expanded to include other pertinent analytical concepts such as spatial frequencies, spatial surface neighbourhood operators, information theory, fractals, Fourier theory, topological network theory and analytical visualization, to name a few (Moellering 2000, 2002; Mu 2008).

Geovisualization was developed based on the works of DiBiase (1990), MacEachren et al. (1992) and MacEachren and Taylor (1994). Geovisualization integrates approaches from visualization in scientific computing, cartography, image analysis, information visualization, exploratory data analysis and geographic information systems (GISs) to provide theory, methods and tools for visual exploration, analysis, synthesis and presentation of geospatial data (MacEachren & Kraak 2001).

Cybercartography, first introduced by Taylor (1997), is defined as the organization, presentation, analysis and communication of spatially referenced information on a wide
variety of topics of interest and use to society in an interactive, dynamic, multimedia, multi-sensory format with the use of multimedia and multimodal interfaces in order to increase our understanding of the complex world (Taylor 2005; Taylor & Pyne 2010).

Geovisual analytics describes efforts integrating analytical reasoning process with visualization through visual interactive interfaces, especially towards very large and complex data such as geospatial big data. It is a multidisciplinary research field bringing together scientists in information visualization, scientific visualization and geographic visualization with researchers from analytical disciplines, such as statistical analysis and modelling, machine learning and data mining, and geospatial modelling and analysis for developing new methods and techniques to find solutions to complex problems of the earth and the society, involving geographic space and various objects, events, phenomena and processes populating it (Andrienko et al. 2011; Schiewe 2013).

Developments in ICTs have opened up new horizons to produce and deliver maps and geographic information, and hence have brought innovative, ICT-oriented concepts into cartography (Cartwright et al. 2007; Buchroithner & Gartner 2013). Among these concepts, web cartography is concerned with theoretical and practical issues that the web offers for the design, production, distribution and use of maps and geographic information (Kraak & Brown 2001; Peterson 2010). Mobile cartography deals with the issues related to mapping for small location-aware devices to provide contextualized and personalized location intelligence to the users (Meng et al. 2005). Ubiquitous cartography focuses on how maps can be created and employed anywhere and at any time with the assumption that there is something special about real-time, in situ map production or use (Gartner et al. 2007). Neocartography facilitates spatial data capture, processing and publishing using social software, available via Web 2.0. It empowers volunteers to map their community, contribute to national and international mapping activities, to build and make freely available spatial datasets and publish their maps in a collaborative manner (Cartwright 2012).

According to Moellering (2012), all the theory and concepts serve to three major paradigms of the field of Cartography: the Production Paradigm, the Analytical Paradigm and the Communication (Cognitive) Paradigm (see Section 3 for details).

On the other hand, spatial data handling, management and use have also evolved in either common or parallel with cartography. Before digital technology, spatial data were collected and processed, and paper maps were produced with analogue methods. Maps were only medium for spatial information storage, analysis and portrayal. Along with the introduction of computers, early efforts concentrated on digital representation of maps and the automation of mapping process, also known as digital cartography. Advances in surveying and mapping techniques in parallel to the developments in electronic and computer technology have resulted in the increased uses of digital data and computerized methods in all aspects of spatial data handling, management and use. The software technology employed in this domain is centred around GIS (Robinson et al. 1995; Huisman & de By 2009). GIS has provided vast opportunities to storage, integration, manipulation, analysis, display and management of a wide variety of spatial data. In conjunction with the emergence of Internet technology, the World Wide Web has brought about major changes in GIS use and implementation (Jones & Purves 2008; Sun & Fu 2011). SDIs have followed these developments, providing an efficient and coherent framework for spatial data/information production, sharing and use (Groot & McLaughlin 2000; Onsrud 2007). The pervasiveness of powerful mobile phones along with the advances in software development platforms, databases, positioning technology, GIS and communication networks have led to the creation of location-based
services (LBSs). LBSs are the delivery of data and information services where the content of those services is tailored to the current or some projected location and context of a mobile user. Global demand for LBSs continues to rise very fast (Brimicombe & Li 2009; Labrador et al. 2011) so interaction, usability, mobility and portability issues have increasingly gained importance for GIS applications. Such developments provide opportunities to enhance and change the ways people access and utilize spatial information, and lead to ubiquitous GIS (Davies et al. 2010).

3. Methodology
The methodology of this article is based on an investigation into the relationships of basic cartographic theory and practice with spatial data handling, SDIs and spatially enabled society. For this purpose, their relationships are clarified in association with the evolution of spatial data handling, management and use.

3.1. The relationship of cartography with spatial data handling
Spatial data handling comprises the phases of acquisition, modelling, processing, analysis, visualization and dissemination of spatial data. This section summarizes the relationships of cartography with these phases.

Spatial data acquisition is the starting point of building a primary spatial database or producing a base map. Remote sensing, global navigation satellite systems and sensor technologies can be listed as main sources of spatial data (Nittel 2009; Lemmens 2011; Yang et al. 2011; UN-GGIM 2013; Yang & Li 2013). The core disciplines in this domain are geodesy, surveying, photogrammetry and remote sensing. Cartography does not have a direct role in this phase since the work of a cartographer usually starts with compiling existent spatial data. Nevertheless, spatial data should be acquired according to the specifications that domain experts and cartographers prepare for task-oriented products. Besides, developments in spatial data acquisition such as LiDAR, unmanned aerial vehicles, very high-resolution imagery and sensor networks provide broad opportunities to cartographers for designing new kinds of maps and geographic information such as real-time (4D) maps and indoor maps.

Spatial data modelling provides a conceptual foundation from semantic, geometric and/or graphic aspects to represent spatial phenomena in a specific product. As commonly known, maps are classical but still incredible and essential models of real world. When designing a particular map, cartographers determine and classify both the real world phenomena that constitute the content of the map as well as their graphic representation (i.e. symbology) according to its scale and its purpose (i.e. theme). In other words, scale and theme help to define the conceptual model of a spatial database on which maps rely. Moellering (1980, 2012) differentiated spatial models as virtual and real maps. In addition, Nyerges (1991) defined deep and surface structures. The deep structure information is the basic meaning of geographic phenomena, the relationships among phenomena (often providing part of the meaning), and the meanings of the relationships among phenomena while surface structure is in the form of individual symbols or collections of symbols representing meaningful concepts on a map. In this context, two main kinds of spatial models about real world can be distinguished (after Moellering 1980; Nyerges 1991; Grunreich 1995): geographic model, i.e. semantic and geometric spatial model, and cartographic model, i.e. graphic spatial model. A geographic model or database (GeoDB) is primarily employed for spatial data analysis
while a cartographic model or database (CartoDB) is mainly designed for spatial data visualization. They can further be categorized as topographic and thematic models. Shortly, today’s modern spatial data modelling methods were developed to a great extent through integrating cartographic theory and practice with database systems.

Spatial data processing basically consists of various manipulations applied to spatial data from semantic, geometric and graphic aspects. To give some examples, map projection and coordinate system transformations change planar coordinates, and even geographic coordinates in case of datum shift (Yang et al. 2000; Iliffe & Lott 2008). Generalization is employed to derive a new dataset at a coarser level of detail (i.e. smaller scale/lower resolution) and/or with a different theme by means of some modifications to class, attributes, location, shape, size and/or symbols of spatial objects with respect to the specification of a target product (Brassel & Weibel 1988; Buttenfield & McMaster 1991; McMaster & Shea 1992; Li 2007). Interpolation methods are used to produce continuous grids from discrete data. Map algebra developed by Tomlin (1990) provides methods for the manipulation of raster-based spatial data. Grid-to-TIN or raster-to-vector conversions require recreating spatial data in different geometric data structures. Foundations of such methods and techniques principally come from analytical cartography (Monmonier 1982; Cromley 1992; Clarke 1995; Jones 1997; Chrisman 2001).

Spatial data analysis denotes the manipulation of spatial data into different forms in order to extract additional meaning. The major concerns are to investigate the patterns in spatial data and to discover possible relationships between such patterns and other attributes within the study region (Lo & Yeung 2007). Map use and analysis techniques have conventionally been developed for obtaining metric, topological and semantic information from maps (Campbell 2001; Kimerling et al. 2011). In this sense, cartometry is a relatively old term that refers to the measurements from maps (Maling 1989). Generalization operations heavily rely on structure and shape recognition techniques because generalization aims at portraying geographic information as accurately as possible according to target scale and theme. Terrain analysis is performed based on TIN or grid DEMs for deriving terrain characteristics such as slope, aspect, curvature, visibility and volume as well as hydromorphometric characteristics of drainage networks and catchments (Mark 1984; Li et al. 2005). All these entail comprehensive spatial analysis techniques and advanced spatial data structures. Again, analytical cartography has contributed considerably on the development of those techniques and structures.

Spatial data visualization has unarguably been one of the top research topics of cartography, with the objective of effective and impressive communication of spatial information to the users (Slocum et al. 2008; Kraak & Ormeling 2010). Spatial data visualization techniques enable the portrayal and discovery of spatial patterns, relationships and trends. Topographic maps visualize natural and man-made phenomena on the earth’s surface and the elevation of terrain’s surface. Besides, they serve as a spatial reference to thematic cartography applications. Thematic maps visualize spatial distribution of qualitative and quantitative characteristics of spatial phenomena in various subjects pertaining to natural and cultural environment with different techniques. If data has a temporal dimension, dynamic maps can also be created. In recent years, three-dimensional (3D) visualization has become widespread together with the progress in softwares and standards. In this context, terrain representation and visualization has a long history in cartography (Buckley et al. 2004; Li et al. 2005; Imhof 2007; Buchroithner & Knust 2013). Besides, virtual geographic environments (VGEs) are
proposed as a new generation of spatial analysis and visualization tool to contribute to human understanding of the geographic world and assist in solving spatial problems at a deeper level. VGE refers to a form of reconstruction of a landscape, either real or imaginary, that gives the impression of a 3D environment that allows varying types and degrees of interaction with geographic information and other human beings, often from a ‘first person’ perspective. The development of VGEs is focused on the cooperation and integration of multi-dimensional visualization, dynamic phenomenon simulation and public participation (Priestnall et al. 2012; Lin et al. 2013).

Spatial data dissemination comprises the production and distribution of spatial products (i.e. geographic information and maps). It is an essential procedure for cartography since cartographers have always aimed at effectively conveying spatial information to users via quality spatial products on various media. Correspondingly, the vision of the ICA is ‘… to ensure that geospatial information is employed to maximum effect for the benefit of science and society’ (ICA 2014). Traditional map production systems involving hard copy output and managed by professional organizations are still important particularly in sectors such as national mapping, atlas production and tourist cartography (De Maeyer 2011); however, the growth of ICTs such as Web 2.0, cloud computing and cyberinfrastructure, actually, transformed the way geographic information and maps are produced and distributed (Sui et al. 2013) The reach of Web GIS is growing towards the GeoWeb, a large, distributed collaboration of knowledge and discovery that promotes and sustains worldwide sharing and interoperability. Instead of providing wide access to a single source of data, the GeoWeb can bring together vast stores of dynamic and disparate data, scattered across different agencies or served from the commercial or government cloud. The general idea coalesces around the use of the Internet to create, analyse, display and share geographic information and maps via multiple computing devices/platforms that allow people to benefit from spatial tools and information. These interactions facilitate geocollaboration across multiple stakeholders (Pratt & Fu 2011; Sui et al. 2013). Service-oriented cartography can be seen as a most modern framework in the realm of SDIs and modern web mapping, allowing modern cartography a tailored and enormous map production based on services, thus backing the enormous distribution of maps (Gartner 2015). This approach may prevent the collection of spatial data by others than the data manufacturers, supports a distributed network of data and functions that should be directly accessed for map production and integrated in the production lane (Jobst 2012). In a mobile context, communicating spatial information usually involves cartographic form of representation (Gartner 2013). Map-based LBSs represent one of the fundamental and most common types of LBSs that entail regarding, on the one hand, the technical restrictions of mobile devices and the dynamic usage contexts as design constraints. On the other hand, the availability of additional situative information within the mobile environment offers new ways for data integration and individualization of mobile maps (Meng 2008).

In view of three major cartographic paradigms (Figure 1), spatial data compilation, modelling, processing and dissemination phases are largely pertinent to the production paradigm. The production paradigm encompasses the abstraction (a.k.a. object generalization) from real world during spatial data capture according to the spatial data specifications, prepared by domain experts and cartographers, that describe semantic, geometric and graphic modelling procedures for designing and creating different spatial databases with multiple representations of spatial phenomena, as well as producing and delivering multiple spatial products on multiple media. Spatial data analysis phase
along with the some parts of the spatial data processing phase corresponds to the analytical paradigm. The analytical paradigm includes various computation, manipulation, analysis, mathematical and statistical techniques applied to spatial datasets (Moellering 2000, 2002). Spatial data visualization and some of parts of dissemination phases are connected to the communication (cognitive) paradigm. The communication
(cognitive) paradigm is concerned about how geographic information and maps can be
designed, visualized and used for providing more effective spatial thinking, involving a
continuum from spatial awareness, through spatial perception and spatial reasoning, and
finally to spatial judgement via cognitive (mental) maps, internalized images of
geographic space, that play a critical role in spatial problem solving (Wentz 2006).

3.2. The relationships of cartography with SDIs and spatially enabled society

It is increasingly becoming an important everyday life activity for people to seek
answers to what, where, how many and when inquiries about real world via geographic
information and maps. Ubiquitous creation, integration, sharing and use of spatial
information by governments, industry and citizens through modern technologies
enhance people’s spatial reasoning and intelligence and contribute to individual and col-
laborative spatial decision-making processes, leading to spatially enabled society. Spa-
tially enabled society is ‘an evolving concept where location, place and other spatial
information are available to society including governments, the business sector, and
citizens as a means of organizing their activities and information’. In this sense, it is
critical the role played by SDI, ‘a dynamic, hierarchic and multi-disciplinary concept
that includes people, data, access networks, institutional policy, technical standards and
human resource dimensions’. SDIs were initially developed as a mechanism to facilitate
access and sharing of spatial data for use within a GIS environment. However, the role
of SDI within society is now changing together with the user’s pervasive access to
spatial information in order to enhance cross-jurisdictional collaboration and decision-
making (Rajabifard 2009; Enemark & Rajabifard 2011; Williamson et al. 2011).

The core of an SDI is a set of networked, and potentially interlocked, spatial data-
bases: digital collections of data that represent features and their characteristics as they
exist in the real or an imaginary world. Such a spatial database can be considered a
complex form of a virtual map, as defined by Moellering (1980, 2000). In order to get
an overview of the issues concerning modelling an SDI, a first task is to review the dif-
ferent reference models applicable to the SDI. In this context, the architectural reference
model provided by the Reference Model for Open Distributed Processing consists of
five different viewpoints (Hjelmager et al. 2008): enterprise viewpoint, information
viewpoint, computation viewpoint, engineering viewpoint and technology viewpoint.
The Commission on Geoinformation Infrastructures and Standards of the ICA has been
working on defining models of SDIs. SDI models from the enterprise and information
as well as computational viewpoints have been presented in Hjelmager et al. (2008)
and Cooper et al. (2013) respectively.

Cartography offers multiple (i.e. multi-scale, multi-theme and multi-dimensional)
spatial products on multiple media in the different forms of geographic information
and maps through multiple representations of real world phenomena for satisfying
various application-oriented requirements as well as user-centric preferences. These
spatial products are used to discover the physical and human environments mainly
via analytical cartographic tools. In this respect, they are designed appropriately,
using cartographic techniques to enhance people’s perceptions and decisions about
real world.

Various applications in urban and regional planning, environmental monitoring,
disaster management, agriculture, forestry, tourism, defence and so on require spatial
information at varying levels of detail depending on the problem and the size of the
area to be treated. Therefore, mapping agencies and departments offer diverse ranges of spatial products at multiple scales. The larger the scale of a spatial dataset, the higher its level of detail but the smaller its extent in general. Likewise, SDIs are organized and implemented at hierarchical levels (i.e. global, supranational, national, regional and local) to be able to deal with a wide variety of issues and applications ranging from local to global in scope (Figure 2). According to INSPIRE (European SDI) common principles, ‘it should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes’ (Toth et al. 2012). Modern cartographic production strategy largely conforms to ‘collect once, use many times’ objective and hierarchic nature of SDIs (Rajabifard et al. 2006) and can almost perfectly serve this goal and perspective through multi-representation spatial databases (Bedard & Bernier 2002; Hampe et al. 2003).

SDI can be divided into three generations in connection to the evolution of the Web, i.e. data-centric SDI (SDI 1.0), process-centric SDI (SDI 2.0) and user-centric SDI (SDI 3.0) (Figure 3). Data-centric SDI (first generation) focused more on spatial data acquisition, modelling and compilation since spatial datasets meeting the national and international standards were substantially missing. The produced datasets were decentralized and controlled by individual government agencies. After the availability of various kinds of spatial datasets, their utilization has naturally gained more importance among government agencies and private companies. Hence process-centric SDI

Figure 2.  Hierarchic nature of SDI and cartographic production (after Rajabifard et al. 2006).
(second generation) has concentrated more on spatial data processing and analysis, and partly visualization, moving away from the centralized structures of most early SDIs to the decentralized and distributed networks. It has more attention to the user then data-centric SDI using new technologies such as Web 2.0, Wikipedia, web service, and so on. However, even process-centric SDIs have not developed beyond the view of the user as an active recipient and still do not fully consider the user’s interests for services/infrastructure designing. User-centric SDI (third generation) gives priority to end user’s preferences and interests so spatial data visualization, dissemination, access and utilization gain more importance. It also allows individuals to input and share spatial data voluntarily and collaboratively in a networked society (Rajabifard et al. 2006; Sadeghi-Niaraki et al. 2010). In this respect, the number of sensors and sensor applications is increasing rapidly. Cell phones transmit geocoded information, credit cards and wi-fi hotspots tell where we have been and internet-connected sensors of all kinds are being used in a wide variety of applications (Ramage & Reichardt 2010). There is sufficient capability for ubiquitous access to spatial data/information now but this potential faces many technological and organizational challenges. Achieving improved access through Semantic Web applications that can handle the semantic issues offers interesting means to support uses hitherto constrained by Web 1.0 and 2.0 technologies. As an important part of Web 3.0, Semantic Web technologies serve as integrators across different content, information applications and systems (Harvey et al. 2014). In conclusion, these three SDI generations well suit the major paradigms of cartography.
4. A modern and comprehensive framework for cartography

Cartography is classically defined as ‘the discipline dealing with the art, science and technology of making and using maps’ by the ICA (ICA 2014) or ‘the study and practice of making maps’. These definitions generally reflect more the era before the use of computers for creating digital maps and geographic databases. Guptil and Star (1984) describe cartography as ‘an information transfer process that is centred, about a spatial database which can be considered, in itself, a multifaceted model of geographic reality. Such a spatial database then serves as the central core of an entire sequence of cartographic processes, receiving various data inputs and dispensing various types of information products’. Taylor (1991) remarks that maps are central to cartography and defines cartography as ‘the organisation, presentation, communication and utilisation of geo-information in graphic, digital or tactile form. It can include all stages from data preparation to end use in the creation of maps and related spatial information products’. According to M. Wood (2003), when interpreted holistically, cartography should be defined as ‘a unique facility for the creation and manipulation of visual (or virtual) representations of geospace – broadly referred to as maps – to permit the exploration, analysis, comprehension and communication of information about that space’. In the context of this article, cartography is defined as ‘the art, science, engineering and technology of producing and using geographic information and maps through modelling, processing, analysis, visualisation and dissemination of spatial data for enhancing spatial cognition, creating spatial knowledge, supporting spatial decision-making and forming spatially enabled society’.

Geographic information and maps are essential tools of cartography. Both have similar characteristics; however, geographic information is a partly different way of representing geographic reality that focuses more on the semantic and geometric aspects (i.e. deep structure) rather than the graphic aspects (i.e. surface structure) of spatial data. Geographic information is more related to analysis while maps are visualisation. One of the classical but a rather narrow definition of a map is ‘the graphic representation of geographic reality’. On the other hand, Cassettari (1993) gives an exhaustive description of a map: ‘a medium for comprehension, recording and communication of spatial relationships and forms. It is an abstract model of reality which includes transformations of various kinds and conveys, directly or implicitly, various sorts of information, such as location, direction, distance, height, connectivity, contiguity, adjacency, hierarchy and spatial association’. In the context of this article, a map is defined as ‘a spatial knowledge providing medium designed and produced via mathematical, conceptual and graphic modelling of spatial reality at a particular scale for a general or special purpose’.

Regarding these concepts and definitions, cartographic processes can be described in connection to spatial data handling, management and use.

The first phase of cartographic processes is to compile multi-source and multi-dimensional spatial data, depending on application and purpose. These spatial data often exhibit multi-scale and multi-theme nature. Following that spatial data needs to be modelled with respect to application characteristics and requirements.

Spatial data modelling phase is directly related to scale and theme since they affect the semantic, geometric and graphic aspects and resolution of a spatial database. Semantic resolution determines how fine a concept is defined with class hierarchies in a taxonomic or partonomic structure and how detailed the objects in those classes are defined via qualitative or quantitative attributes and their values. Geometric resolution
refers to minimum sizes that can be obtained from a geographic database. Graphic resolution denotes minimum symbol sizes and spacings discernible from a cartographic database according to scale. Thus, spatial data specifications describe the contents and the representations of spatial phenomena for different geographic or cartographic databases. Both databases can further be categorized as topographic and thematic databases. Domain experts contribute to the modelling phase, especially when a thematic database is designed. Spatial data is often processed in accordance with the specific requirements of spatial databases after the modelling phase.

Spatial data processing phase includes various transformations. Spatial data often come with heterogeneous coordinate systems. Bringing data into a common coordinate system requires an underlying set of transformations such as those caused by map projection and datum changes. GIS softwares offer adequate automation in this respect. Other kinds of transformations emerge from scale or theme changes when deriving a new database from existing higher detailed database. These comprise database schema transformations as well as semantic, geometric and graphic generalization operations. Another important operation is topology building for explicitly storing spatial relationships among features, reusing of common geometric elements when defining geometry of features, ensuring geometric data quality and performing more advanced spatial analysis. Raster-to-vector conversions or vice versa are also parts of this phase. After that, spatial databases become operational for spatial investigations through spatial analysis and visualization.

Spatial data analysis phase includes various operations that are applied to object-based (i.e. vector) and field-based (i.e. raster) models of spatial data. These operations are usually categorized based on geometry. Metric, topological and semantic characteristics are often analysed in combination. Spatial analysis operations enable both producing spatial information that is usually inherent in data and solving a range of spatial problems.

Spatial data visualization phase includes producing all types of static and dynamic spatial representations such as 3D perspective views, two-dimensional (2D) displays, and maps. This phase aims at portraying spatial information in geographic or cartographic forms. In this respect, geographic visualization refers to creating direct representations of spatial reality such as GIS displays or 3D VGEs while cartographic visualization refers to designing slightly modified but improved task-oriented representations such as maps or 3D cartographic models. In other words, the reality is represented as it is in the former, whereas important features are emphasized and unimportant ones are abstracted in the latter for the sake of effective spatial information communication and usability. Thereafter, spatial information is disseminated through various channels to stakeholders.

Spatial data dissemination phase includes the use of wide variety of digital and analogue models (i.e. virtual and real maps) to distribute spatial data/information among and across government agencies, private companies and citizens together with the production of these models in the various forms of geographic information and maps. In this respect, analogue environments such as solid landscape models and paper maps; desktop GIS/CAD/graphic design environments such as 3D city models and (animated) thematic maps; GeoWeb technologies such as geoportals, spatial (semantic) web services and geobrowsers as well as LBSs such as navigation assistance, geotracking and geocommerce applications are of primary importance in current spatial industry. Modern online mediums or channels, so-called new spatial media extend or enhance our ability to interact with and create geographic information and maps (Elwood &
Leszczynski 2013). In brief, geographic information and maps can be disseminated with multiple products on multiple media (e.g. analogue environments, desktop GIS/CAD/graphic design environments, GeoWeb and LBS) through multiple representations, and optionally with multi-modal and multi-sensory interfaces, depending on multiple application requirements and multiple user preferences.

SDI undertakes supporting, coordinating and guiding role in both the implementation of spatial data handling procedures and the management, maintenance, discovery, sharing and use of geographic information and maps effectively via relevant technologies, standards, policies, human resources and organizational framework.

The use of spatial products (i.e. geographic information and maps) has been the primary mechanism for people to conceptualize, define, and understand geographic space through generating cognitive (mental) maps in their minds. These products need to follow a series of key principles of cartographic design and visualization that will enhance their understanding, and thus improve spatial cognition. Spatial cognition deals with human perception, memory, reasoning, problem-solving and communication involving real world phenomena and their representation as spatial information (Montello & Freundschuh 2005; Wentz 2006; Jones 2010). People gain spatial knowledge through spatial cognition and this assists and enhances individual and collaborative spatial decision-making. Thus, using this spatial intelligence generation mechanism by governments, companies and citizens facilitates the realization of spatially enabled societies that can understand, monitor and manage the world and its resources more effectively.

Regarding the above-mentioned workflow of the cartographic processes, the schematic representation of the framework is given in Figure 4.

5. Discussion

Cartography is the oldest of mapping and geospatial sciences (Estaville 2010); however, there is a common trend for its marginalization by transferring the most of its theory, techniques and practice under GIScience or equivalent titles despite its long history of spatial information supply about the earth and the society in various forms for different purposes.

Narrowed role and scope of cartography naturally creates a barrier for its scientific and technical development as well as its independent identity. For this reason, the terms ‘cartography’ and ‘cartographer’ are not widely preferred in geospatial community. Furthermore, cartography is usually identified within a specific scope (i.e. maps and visualization) while closely related areas such as GIScience are assumed to have no limits in this context, absorbing nearly all new concepts with spatial nature. However, cartography and GIScience fields possess largely overlapping research themes and applications. Therefore, a judicious approach will be to increase the interaction and integration between these close fields and eliminate the somewhat artificial boundaries without ignoring any one of these two fields. Such attempts can be seen in the formation of research groups, laboratories and institutes worldwide (e.g. Institute of Cartography and Geoinformatics – University of Hannover; CartoGIS Research Group – University of Ghent; Institute of Cartography and Geoinformation – ETH Zurich; Department of Geoinformatics and Cartography, Finnish Geospatial Research Institute; Department of Cartography and GIS Engineering, Xi’an Research Institute of Surveying and Mapping; Cartography and Geoinformation Sciences Working Group, University of Vienna; Department of Geoinformatics and Cartography, University of Wroclaw; Geomatics and Cartographic Research Centre, Carleton University; COGIT
Figure 4. A modern and comprehensive framework for cartography.
Laboratory, IGN France; Laboratory of Geoinformatics and Cartography, Masaryk University; Department of Cartography and Geoinformatics, Eötvös Lorand University), scientific organizations (e.g. The Cartography and Geographic Information Society – USA, SSSI Spatial Information and Cartography Commission – Australia), academic publications (e.g. Cartography and Geographic Information Science, Casopis Kartografija i Geoinformacije/Journal of Cartography and Geoinformation) and graduate programmes (e.g. Cartography and GIS – MSc, University of Wisconsin-Madison; Geoinformation Technology and Cartography – MSc, University of Glasgow; Cartography and Geographical Information Engineering, University of Wuhan – MSc and PhD; Cartography and Geoinformation – MSc, University of Vienna).

Cartography has, in fact, a prominent place in many phases of spatial data handling including modelling, processing, analysis, visualization and dissemination. Cartography also significantly contributes to the implementation of SDIs while they guide cartographic processes with standards and specifications, prepared by the committees that include cartographers, as well as with the policies and legal arrangements. Moreover, the efforts of cartographic discipline are substantially directed to achieve the spatial enablement of governments, industry and citizens. Although geospatial community tends to identify cartographers solely as map makers or spatial data visualizers, indeed modern cartographers model real world at different scales and themes in multi-representation spatial databases, process spatial data for transforming them into demanded forms, analyse spatial data for obtaining various spatial information about natural and cultural environment, visualize them in an optimal way to convey the intended message both correctly and clearly, disseminate the task-oriented products through various channels at various modes to make people’s spatial information access, cognition and utilization easier, and thus contribute to constitute a spatially enabled society by providing spatial knowledge acquisition mechanism and supporting spatial decision-making activities.

6. Conclusion

This article presents an attempt to identify and develop a modern and comprehensive framework for cartography by revisiting its concepts, techniques and paradigms as well as investigating its relationships with spatial data handling, management and use. One of the main reasons of the marginalization of cartography is that it is narrowed down to spatial data visualization and map-making. This point of view is not consistent with the past and even current scientific status and scope of cartography if its role is considered that it plays for spatial data handling, SDIs and spatially enabled society. Significant contribution of cartography to all these areas proves that cartography is an essential spatial discipline for the earth and the society. Cartography needs and deserves to be identified in a broader context without ignoring the role that it plays in spatial data handling, management and use. From this point of view, modern and comprehensive definitions of cartography and map are proposed along with a basic framework. In this context, the research agenda and a body of knowledge are of great importance for shaping the future of cartography. Particularly, overlapping topics of cartography and GIScience should be investigated carefully and joint frameworks should ideally be developed instead of transferring cartographic theory and practice into related popular areas. The framework presented here has not been elaborated too much not to lose main idea so it is flexible enough to be extended. Such general frameworks will likely support the efforts to advance the discipline of cartography.
Disclosure statement

No potential conflict of interest was reported by the author.

Supplementary material

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Note

1. The production of virtual and real maps (i.e. all kinds of digital and analogue models of spatial reality).

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