# Integrating GIS and Semantic Web Technologies as a Next Step in the Evolution of Spatial Digital Humanities

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## Abstract

With the advent of information technology, numerous initiatives have been launched by cultural heritage, academic and commercial institutions aiming at digitization, organization, visualization and analysis of historical information of a given place. These projects usually utilize GIS (Geographic Information Systems) to represent and analyze a restricted range of spatial data, such as archaeological findings or landmarks from a single information source. To take the emerging field of spatial history to the next level—the spatial digital humanities—the traditional spatial data should be enriched with cultural and social data from heterogeneous resources, such as historical books, administrative documents, images, and multimedia objects, and allow for deeper analysis of the historical places' cultural and social context. To this end, ontologies and modern semantic web technologies should be combined with GIS technology to enable easy data standardization and integration, uniform data modeling, open-access and cross-project data sharing and analysis. In this paper, we review this combined approach and its utilization attempts in recent spatial digital humanities projects for cities from all over the globe while discussing the field's main common challenges and their possible solutions.

**Keywords:** deep mapping; semantic deep mapping; GIS; spatial history; archaeological data; spatial data; spatial digital humanities; semantic web; ontologies; linked data

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# 1. Introduction

Since the launch of the Memory of the World program by UNESCO in 1992, many memory projects have begun for cities worldwide, mostly led by GLAM institutions (Galleries, Libraries, Archives, and Museums). These institutions possess significant cultural memory resources and extensive archive materials such as books, historical documents, photographs, and audio and video recordings. All of these are valuable elements of a city's cultural heritage, which is studied by various fields, such as history, geography, archaeology, architecture, ethnography, art, and cultural studies. In 1994, the Library of Congress launched the American Memory project. This started the large-scale human memory digitization and preservation project in the field of library and information services and was followed by an open-access publication of these resources (Cuijuan, Lihua, and Wei 2021). Such comprehensive initiatives require heterogeneous data integration, visualization, and large-scale analyses. Usually, these projects are built on the foundations of geographic information system (GIS) technology: computer software for designing maps and performing spatial analyses of geospatial data (geodata), that is data that include a location (Gieseking 2018). In the next sections, we review the development, benefits, and challenges of modern GIS technology and its applications in the emerging field of spatial digital humanities. We further argue that the next step in the field's evolution involves integrating semantic web technologies in GIS and leading to the novel semantic deep-mapping approach, the benefits of which we illustrate with several case studies.

# 2. Geographic Information System (GIS) Technology for Spatial Historical Data Representation

GIS technology was developed by the Canadian government during the 1960s for cataloging and assessing land uses across the country. The United States Census Bureau developed a similar database for the 1970 census to manage the statistical analysis of census tracts. These early systems were databases specifically designed to manage data according to spatial parameters but without data visualization in map form. Modern GIS systems' cartographic component was developed independently by the UK, France, and US governments in the early 1970s. In the 1980s, GIS software packages became affordable and user-friendly and entered widespread use by universities and scholars (Yales 2015).

GIS provides a user interface for the visualization and analysis of geodata. The term *geodata* refers to two major spatial dataset types: The first is vector-based data, represented by points, lines, or polygons and accompanied by an attribute table, and the second is raster data, based on a mathematical matrix that represents a continuous surface where each matrix item expresses a grid cell (Zohar 2020).

Archaeologists were among the earliest adopters of GIS (Earley-Spadoni 2017), extensively drawing on it since the mid-1980s. Initially, scholars employed GIS for recording and storing data (Eiteljorg 2004) and, subsequently, for navigation and computer-assisted statistical analyses, thus allowing the transformation of geodata into knowledge (Zohar 2020). Later, numerous scholars began employing GIS technology to generate digital urban and regional historical maps (Zohar 2020) to determine early land uses and trace changes to the landscape (Tsorlini, Iosifescu, and Hurni 2013; Tsorlini et al. 2014). These scholars have been engaging in various projects, such as studying cartographic materials and analyzing maps and sketches. They use different types of available maps, including paintings, illustrations, and photographs. These are geo-rectified, converting the map image into a modern digitized map and rendering it zoomable and searchable. Additionally, historical maps undergo georeferencing, which associates digital image files with specific locations in physical space and compares them to modern maps.

As argued by da Silveira (2014), while combining spatial and temporal information constitutes a promising field of historical research, the conceptual framework for representing the relations among space, individuals, and societies across time is still underdeveloped. Such broad frameworks link spatial dataset-based research with other data-driven humanities research projects, developing the field of spatial digital humanities.

## 3. The Spatial Digital Humanities

The digital humanities is a multi-disciplinary research field that uses information technology to illuminate the human record and brings its understanding of this record to bear on the development and use of information technology (Schreibman, Siemens, and Unsworth 2004). The digital humanities' purpose is the massive digitization of humanities archives, as well as their critical analysis and visualization (Gieseking 2018: 641). In the early 2000s, the term *digital humanities* replaced the former terms *computing in humanities* and *humanities computing*. This change of terminology marks a paradigm shift from a field that is "instrumental, methodological and text-based in focus and rarely engages with the digital as an object of study … [to a field that is] much broader and more generally aligned with the wide-ranging concerns and content of the traditional Humanities" (Vanhoutte 2016: 1).

The spatial digital humanities is a sub-field of digital humanities that emerged in the early 2000s (Knowles 2008) as a result of the *spatial turn* (Warf and Arias 2008; Warf 2015), a shift from environmental to socio-historical conceptions of the landscape that expanded the applicability of geospatial approaches beyond geography and archaeology into fields such as history, literature, sociology, and anthropology (Gregory and Geddes 2014; Juvan 2015; Earley-Spadoni 2017). It uses computer technology to enrich, enhance, and integrate geodata with other types of data from various humanist resources. One of the major enhancements is incorporating texts in the datasets, thus allowing for GIS-based analyses of literary and historical sources (Moretti 1999). Warf and Arias (2008: 1) argue that "a geographic dimension is an essential aspect of the production of culture," and the spatial turn is "a reworking of the very notion and significance of spatiality to offer a perspective in which space is every bit as important as time in the unfolding of human affairs, a view in which geography is … intimately involved in [social relations] construction. Geography matters … because where things happen is critical to knowing how and why they happen."

The latest emerging trends in the spatial digital humanities and spatial history, more specifically, are deep mapping, digital storytelling, and complex data visualization (Bodenhamer, Corrigan, and Harris 2015; Warf 2015; Roberts 2016). A deep map is a multi-layered, digital, cartographic representation that allows the assimilation of temporal, social, and cultural contexts into the spatial data presented on maps. Deep mapping also enables (1) incorporating images and multimedia objects into maps (e.g., the animation of archaeological settlement systems to illustrate how they changed over time; Gregory et al. 2015), (2) reconstructing historical cities by virtually displaying landmarks and residents' cultural and social life (in 2D or 3D), and (3) examining narratives using map stories (Zohar 2020) based on advanced GIS analyses, such as Cost-Surface Analysis (CSA) and Least-Cost-Path Analysis (LCP) of historical travel writings and topographical literature (Murrieta-Flores, Donaldson, and Gregory 2017).

## 4. Challenges and Criticism of GIS in Historical Research

Despite the clear benefits of GIS and deep mapping for managing, analyzing, and visualizing large spatial datasets, multiple weaknesses of this technology have been indicated, especially for historical research.

### 4.1. Inconsistency, heterogeneity, and lack of standard

A region's historical data are often scattered across various cultural institutions that lack consistent content integration standards (Zhao and Zhu 2014).

Inconsistencies include different names for certain places and people, various dating systems employed in different historical sources, discrepant scales, resolutions (specification level), and coordinate systems. Moreover, different research projects employ various cartographic layouts and levels of geometric accuracy for recording purposes while expressing their data in different formats: geographical coordinates or codes, geometrical shapes in geomatical files, or iconographic or textual non-vectored characterizations. For example, in a recent project that aimed to construct the digital atlas of Limousin, France, the locations of the World War 2 resistance camps in Corrèze were only available at the municipality scale (Morel, Crouzevialle, and Massoni 2020). In order to enrich the camps' data with highly detailed information from archaeological reports, one needed to adjust the parameters of the camps' locations to the archaeological reports' high-precision geometries and format. Furthermore, each project designs and uses a different data model and user interface. Also, not all data contributors agree to provide the same access permissions. Some might grant full access, while others may restrict the downloading option or allow it only in certain cases and under specific conditions (Morel, Crouzevialle, and Massoni 2020).

## 4.2. Low-quality and incomplete data

Location data may be incomplete and missing, which makes it difficult to produce continuous and consistent geographic coverage. In many projects, most of the available data is non-vectored (images or texts) and thus lacks any shape and coordinates (Morel, Crouzevialle, and Massoni 2020). These problems amplify, and map quality deteriorates as one goes farther back in history (da Silveira 2014). Often, cartographic production and data visualization created by humanities scholars must be published in iterative sets with remarks about the nature of the map instead of showing change through time on one platform and on different websites (Yales 2015).

## 4.3. Biases and uncertainty

The selective inclusion of place names and varying mapping resolutions, which cause certain places to be described in great detail and others to be neglected, reflect explorers' and scholars' biases and preferences. Yales (2015) provided literary evidence that some explorers deliberately eliminated indigenous place names because they were thought to deter Europeans. For digital humanists, the awareness of this bias is important for understanding the period. The cultural and social biases in the data are amplified by the GIS technology, which leads to the biased, and even unfair and unethical, representation of historical data at scale (Zhitomirsky-Geffet and Hajibayova 2020), proving maps' potential for violence (Harley 1989).

In addition, GIS relies on a base program of spatial analysis that requires precision. It was not designed to cope with multiple alternatives or uncertainty (Yales 2015). However, historical spatial data is rarely precise and univocal. This is a major pitfall for scholars dealing with ambiguous historical places which moved or changed their names through time or whose location and date are disputed.

In summary, GIS does not solve theoretical challenges or data problems but allows improved and more efficient storage, processing, management, and analysis of large spatial datasets. Even recent advancements, such as deep maps, do not provide a comprehensive solution to most of the abovementioned pitfalls.

## 5. Semantic Web Technologies and Linked Data

Databases held by different cultural institutions contain interrelated information. However, because they do not use the same terminology, do not conform to the same standards, and their data are not interlinked, their information cannot be easily and accurately cross-referenced and analyzed. As a result, these datasets constitute closed and isolated islands that can only be analyzed locally and separately.

One of the main solutions proposed by information and computer scientists for the lack of semantic connectivity across datasets is the creation of formal lexicons. Each term (entity) in the lexicon constitutes one concept with a single meaning; these terms are interlinked by semantic relationships, which are also unambiguously defined. Such lexicons are referred to as *ontologies* and defined as formal vocabularies, rich semantic models of a domain's common knowledge for human experts and computer algorithms, which contain concepts, their definitions, their properties, and semantic relationships among them (Uschold and Gruninger 1996). Ontologies have been recognized as a very promising approach to solving heterogeneity problems (Sun et al. 2019).

Since the late 1990s, the W3C International Web Standards Organization has developed several standards and technologies for the formal definition of ontologies. The main ones are RDF (Resource Description Framework) and RDF/S (Resource Description Framework Schema) (Brickley and Guha 2014), both of which are based on the XML (Extended Markup Language) technology. The RDF's building blocks constitute the following triple structure: *subject—predicate—object*. *Subject* and *object* denote the concepts or entities being linked, while *predicate* indicates the particular semantic relationship connecting them. These triples represent structured statements, and a collection (an ontology) of such triples formally establish a domain's knowledge base in a machineinterpretable manner. Every entity in RDF is assigned a unique identifier (URI, Uniform Resource Identifier). RDF allows the dynamic addition of new entity types and triples, linking data from various resources based on common concepts, even if they have different names. When such RDF ontologies for different knowledge domains are published on the web with unique URIsand interlinked, they form a web of "linked data," also referred to as a *semantic web* and *web 3.0*. The term was coined by the web's inventor, Sir Tim Berners-Lee (Berners-Lee, Hendler, and Lassila 2001; Bizer, Heath, and Berners-Lee 2009). The web of linked data is machine-readable, as opposed to the web of linked documents (pages) that is understood only by humans.

In order to retrieve and analyze local RDF ontologies and online linked data, the SPARQL query language was developed. The power of SPARQL lies in its ability to simultaneously retrieve information from multiple RDF ontologies simultaneously through one detailed and focused query. The more linked data from various resources and institutions is available on the web, the more complete and reliable results will be.

Ontologies and semantic web standards have been utilized in the geospatial domain. In 2003, a basic geospatial ontology was developed by the W3C (https://www.w3.org/2003/01/geo/). Recently, Sun et al. (2019) proposed a more comprehensive ontological model for the semantic representation of geospatial data, widening its coverage to include data dimensions such as morphology, temporality, provenance, and thematic characteristics. GeoNames and LinkedGeoData are examples of global geospatial RDF datasets, which allow the integration of large data repositories such as OpenStreetMap. Recently, GeoSPARQL, an RDF SQL-based query language for manipulating geospatial RDF data and supporting geometrical literals and topological relations, was defined as a standard.

Nevertheless, the construction of a rich geospatial ontology, which is generalizable across many fields and applications, remains a major challenge (Claramunt 2020). This challenge is even greater for spatial history and the spatial digital humanities since they necessitate that the ontology will convey not only geospatial and temporal semantics but also cultural, historical, archaeological, social, and anthropological semantics. In such an ontology, any spatial object will be endowed with a unique identifier and meaning and linked to related historical, social, and cultural entities (e.g., periods, locations, activities, people, events, archaeological findings), using various semantic relationships.

Such an ontology can be based on CIDOC-CRM (International Committee for Documentation Conceptual Reference Model), an ISO-standard generic ontology for the semantic representation and integration of cultural knowledge that facilitates the exchange of information by defining cultural heritage information entities and the relationships between them (https://www.cidoc-crm.org/; Doerr 2003; Doerr, Kritsotaki, and Boursika 2011). CIDOC-CRM has several extensions for different domains, such as CRMgeo (an ontology for integration of geospatial information), CRMba (a model for semantic representation of archaeological buildings), and CRMtex (a semantic model for the study of ancient texts).

Recently, the incorporation of such rich semantic modeling into GIS with deep mapping, which allows the advanced visualization and interactive functionality described above, resulted in the emergence of the *semantic deep-mapping* approach (Noordegraaf et al. 2021). The latest attempts to define a generic research framework and toolkit for semantic deep mapping include Seshat: Global History Databank (http://seshatdatabank.info/; François et al. 2016), which employs linked data/RDF technology to analyze large historical and archaeological datasets, and Pelagios (https://pelagios.org), which provides the infrastructure for linked open geodata in the humanities, connecting data from historical texts with dynamic maps and periods.

## 6. Several Case Studies of the Semantic Deep-Mapping Approach for Historical Cities

Below, we present three case studies for the application of the semantic deep-mapping approach from across the globe. They offer examples of virtual reconstructions of historical cities by integrating historical evidence of their landscapes, memories, and cultural heritage into a unified data model and geospatial information system.

### 6.1. Venice

In 2012, the Ecole Polytechnique Fédérale de Lausanne (EPFL) and the University Ca' Foscari launched the Venice Time Machine project (https://www.epfl.ch/research/domains/venice-time-machine/). It aimed to convert Venice's heritage into "Big Data of the Past" and build a "Google map of the Past," presenting a virtual multidimensional reconstruction of the city and its evolution over the centuries (Kaplan 2015; Kaplan and di Lenardo 2015; di Lenardo and Kaplan 2020). To this end, about 80 km of shelves of primary and secondary sources (in Venetian libraries and city archives) spanning 1000 years of Venetian history have been scanned and digitized using advanced digitization and artificial intelligence technologies. These sources are of various languages and include register pages, photographs, personal diaries, bank records, ship logs, administrative documents, birth registrations, death certificates, tax statements, maps, and urban planning designs. The data extracted from these sources were organized as linked data (an ontology) and displayed in a historical geographical information system. This is a new type of historical information system organized around the city's digital twin, which allows one to "travel in time" across reconstructed models of the city. Combining and cross-referencing this mass of information enables biographies, political and economic dynamics, buildings, and neighborhoods to be comprehensively reconstructed. Since its launch, the project has expanded to a European scale. Founded in 2018, the Time Machine Organization (TMO) is constantly growing and presently includes more than 500 institutions and 20 cities.

## 6.2. Shanghai

The Shanghai Memory Project (http://wkl.library.sh.cn; Cuijuan, Lihua, and Wei 2021) has been carried out by the Shanghai Library since 2006, aiming to develop a digital humanities platform to present the city's history from 1843 to the present. At the basis of the platform lies a dedicated ontology—the Shangai Memory generic ontology (Fig. 1)—that allows the integration of information from a dozen independent databases built during the past two decades. This ontology (encoded in RDF and queried by SPARQL) links persons (from the Name Authority Control Database), events (from the Shanghai historical events knowledgebase), buildings (from the Shanghai architecture knowledgebase), roads (from the Shanghai historical geonames knowledgebase), and literary and multimedia sources (from the Shanghai library).

To illustrate, let us consider the project *a Journey from Wukang Road*, which was launched in 2018. Built in 1907, Wukang Road has been recognized as one of China's National Historic and Cultural Streets. There are 37 historical buildings on this road and over 200 historical personae associated with it. The project aims to reproduce Wukang Road's history at different periods. A fragment of the project's populated ontology is provided in Figure 2. On top of this ontology, a GIS-based platform was built, enabling, in addition to standard visualizations on maps, panoramic navigation, change-over-time data exploration using a timeline (including the emergence of new roads, completion of new buildings, the coming and going of famous people), and the investigation of relevant persons and events via photos, music, video materials, and other cultural heritage data. A user selects a site on the map and reads or listens to information about it; then, they can delve deeper into a specific person or event by selecting them on the site description page, thus receiving additional information, including photos, historical documents, and other resources.

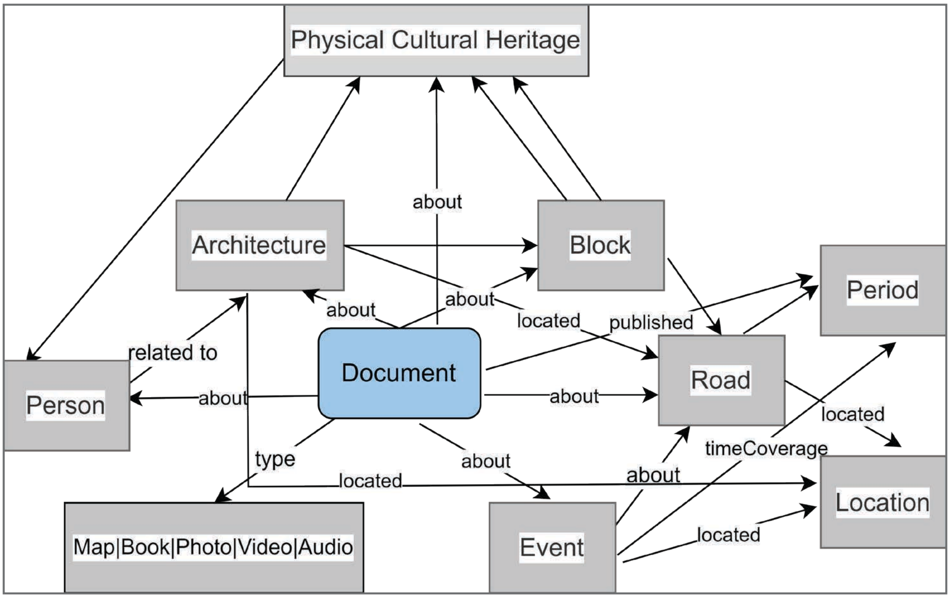


**Fig 1.** The Shanghai memory ontology model (after Cuijuan, Lihua, and Wei 2021: Fig. 2).

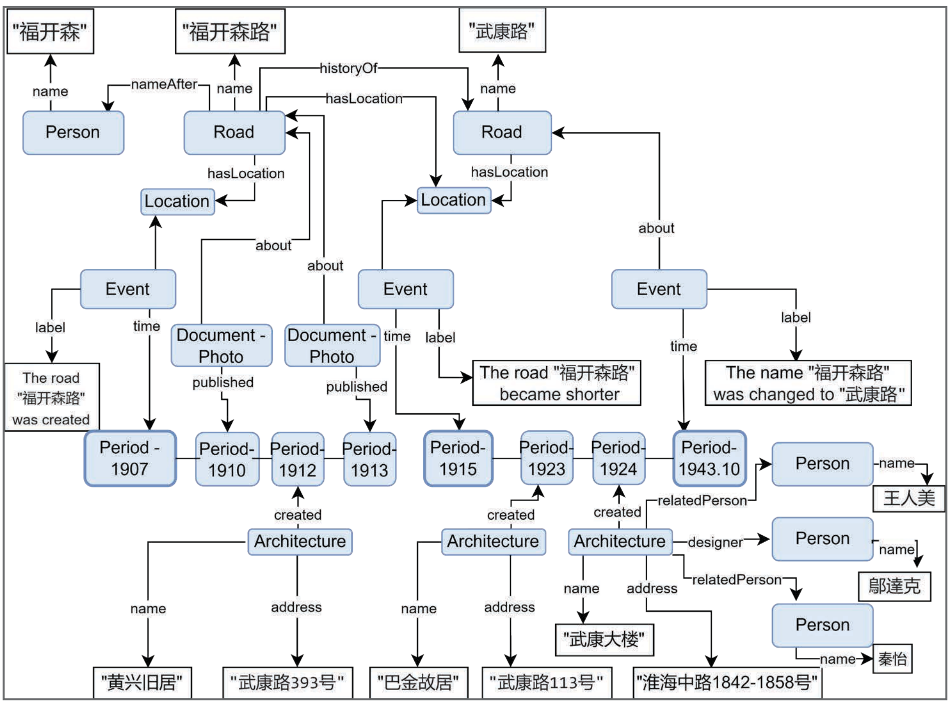


**Fig. 2.** A data-populated fragment of the Wukang road memory ontology (after Cuijuan, Lihua, and Wei 2021: Fig. 4).

### 6.3. Los Angeles

Another example of the semantic deep-mapping approach is the Historic Places LA project (http://www.historicplacesla.org/). This project emerged from the Los Angeles Historic Resources Survey conducted by the city and the Getty Trust in 2010–2017. Encompassing the entire area of the city from 1542 to the present, it is the first and largest all-digital citywide historic resource survey in the US, serving as a model for other cities in the country (Enriquez, Myers, and Dalgity 2018). Historic Places LA also incorporates data from other sources, such as the National Register of Historic Places, the California Register of Historic Resources, City Historic-Cultural Monuments (HCMs), and Historic Preservation Overlay Zones.

Historic Places LA builds on the Arches platform, which was developed by the Getty Conservation Institute to integrate and organize data in the Los Angeles Historic Resources Inventory. Arches incorporates the CIDOC-CRM ontology, which allows it to automatically encode data in a machine-readable and portable manner, and supports six types of information: (1) historic sources, such as buildings, structures, monuments, archaeological sites, and landscapes; (2) historic resource groups, which comprise districts of historic resources; (3) people and organizations, including individuals, cultural communities, and institutions; (4) historical events, such as battles, natural disasters, and cultural movements; (5) preservation activities and surveys; and (6) Multimedia data, like photos, reports, videos, audio files, and 3D models. All these data types constitute ontological entities interlinked by semantic relationships predefined by the CIDOC-CRM ontology. Based on this ontology, the platform's functionality integrates GIS with several types of interactive maps (e.g., street view, satellite view) and a search function that allows users to seek various data (e.g., location, period, or subject).

## 7. Discussion and Conclusion

Over the years, GIS technology has been widely adopted by scholars of various domains for spatial data visualization and analysis. However, the high data heterogeneity is one of the greatest challenges in the spatial digital humanities (Chen et al. 2018; Suissa, Elmalech, and Zhitomirsky-Geffet 2021). Related datasets obtained from various resources and institutions may differ in the types of information they contain, as well as their formats, vocabulary, and structure, complicating their analysis and interpretation and limiting research possibilities. Ontologies and semantic web standards (RDF, SPARQL) offer comprehensive models for heterogeneous data integration and harmonization, as well as formal and machine-readable representations of domain knowledge (Zhitomirsky-Geffet and Prebor 2016).

Therefore, this paper suggests that the optimal approach for spatial digital humanities research is to establish semantic deep mapping by leveraging the widely practiced GIS-based data investigation with rich ontologies and linked data technologies. This approach helps handle various common challenges in digital humanities research (e.g., data heterogeneity and incompleteness), in general, and historical urban data analytics, in particular. The advantages of using semantic technologies include,

- The ability to share, integrate, reuse, and cross-reference information from diverse resources;
- Improved clarity of the data semantics and information model, leading to a common understanding of the domain's information structure by humans and software agents;
- A unified and comprehensive information model that reduces data conflicts, inconsistencies, and duplications;
- Improved data analysis, retrieval, and visual representation in an automatic and user-friendly manner;
- The correction and completion of missing or flawed data by cross-referencing information from different datasets encoded in an RDF standard.

Future work will confront the last challenge mentioned in Section 4—bias elimination and multi-vocal data representation. Ibekwe-SanJuan and Geoffrey (2017: 5) state that "scientific theories which are the result of scientific discoveries are not immutable facts that are true at all times, but can be overturned by the competing theories." Towards the facilitation of multi-vocal data representation, multi-viewpoint and multi-theory ontological models can be adapted and extended so as to place an ontological statement within its epistemological context and appropriate validity scope. This approach allows the inclusion and harmonious representation of uncertain, negotiable, incommensurable, and even contradictory data and statements (Zhitomirsky-Geffet 2019; Zhitomirsky-Geffet and Hajibayova 2020). Thus, in a prospective multi-viewpoint ontology for historical cities, a given historical building whose location is uncertain or disputed will feature several possible sites, each under a different validity scope. Accordingly, based on such ontological data, several alternative maps of a region may be generated and comparatively analyzed using GIS technology. Finally, the multi-viewpoint data research approach will allow us to explore more balanced and inclusive scientific evidence, which will improve the digital humanities research results' quality and ethical value.

## References


Berners-Lee, T., Hendler, J., and Lassila, O. 2001. The Semantic Web. *Scientific American* 284/5: 28–37.

Bizer, C., Heath, T., and Berners-Lee, T. 2009. Linked Data — The Story So Far. *International Journal on Semantic Web and Information Systems* 5/3: 1–22. http://dx.doi.org/10.4018/jswis.2009081901.

Bodenhamer, D. J., Corrigan, J., and Harris T. M., eds. 2015. *Deep Maps and Spatial Narratives*. Bloomington: Indiana University Press.

Brickley, D. and Guha, R., eds. 2014. Resource Description Framework (RDF) Schema 1.1, W3C Recommendation. *The World Wide Wed Consortium (W3C)*. https://www.w3.org/TR/rdf-schema.

Chen, Y., Sabri, S., Rajabifard, A., and Agunbiade, M. E. 2018. An Ontology-Based Spatial Sata Harmonisation for Urban Analytics. *Computers, Environment and Urban Systems* 72: 177–190.

Claramunt, C. 2020. Ontologies for Geospatial Information: Progress and Challenges Ahead. *Journal of Spatial Information Science* 20: 35–41. doi:10.5311/JOSIS.2020.20.666.

Cuijuan, X., Lihua, W., and Wei, L. 2021. Shanghai Memory as a Digital Humanities Platform to Rebuild the History of the City. *Digital Scholarship in the Humanities* 36: 841–857. doi:10.1093/llc/fqab023.

Doerr, M. 2003. The CIDOC Conceptual Reference Module: An Ontological Approach to Semantic Interoperability of Metadata. *AI Magazine* 24/3: 75–92.

Doerr, M., Kritsotaki, A., and Boutsika, A. 2011. Factual Argumentation—a Core Model for Assertions Making. *Journal on Computing and Cultural Heritage*, 3/3: 8.

Earley-Spadoni, T. 2017. Spatial History, Deep Mapping and Digital Storytelling: Archaeology's Future Imagined Through an Engagement with the Digital Humanities. *Journal of Archaeological Science* 84: 95–102. doi:10.1016/j.jas.2017.05.003.

Eiteljorg, H. II. 2004. Computing for Archaeologists. Pp. 39–51 in *A Companion to Digital Humanities*, ed. S. Schreibman, R. Siemens, and J. Unsworth. Malden, MA: Blackwell Publishing.

Enriquez, A. L., Myers, D., and Dalgity, A. 2018. The Arches Heritage Inventory and Management System for the Protection of Cultural Resources. *Forum Journal* 32/1: 30–38.

François, P., Manning, J. G., Whitehouse, H., Brennan, R., Currie, T. E., Feeney, K., and Turchin. P. 2016. A Macroscope for Global History: Seshat Global History Databank: A Methodological Overview. *Digital Humanities Quarterly* 10/4. http://www.digitalhumanities.org/dhq/vol/10/4/000272/000272.html.

Gieseking, J. 2018. Where Are We? The Method of Mapping with GIS. *American Quarterly* 70: 641–648. doi:10.1353/aq.2018.0047.

Gregory, I. N., Geddes, A. eds. 2014. *Toward Spatial Humanities: Historical GIS and Spatial History*. Bloomington: Indiana University Press.

Gregory, I., Donaldson, C., Murrieta-flores, P. and Rayson, P. 2015. Geoparsing, GIS, and Textual Analysis: Current Developments in Spatial Humanities Research. *International Journal of Humanities and Arts Computing* 9: 1–14. doi:10.3366/ijhac.2015.0135.

Harley, J. B. 1989. Historical Geography and the Cartographic Illusion. *Journal of Historical Geography* 15: 80–91.

Juvan, M. 2015. From Spatial Turn to GIS-Mapping of Literary Cultures. *European Review* 23: 81–96.

Ibekwe-SanJuan, F. and Geoffrey, B. 2017. Implications of Big Data for Knowledge Organization. *Knowledge organization* 44: 187–198.

Kaplan F. 2015. The Venice Time Machine. In *DocEng '15: Proceedings of the 2015 ACM Symposium on Document Engineering*, 73. New York, NY: Association for Computing Machinery. doi:10.1145/2682571.2797071.

Kaplan, F. and di Lenardo, I. 2020. Building a Mirror World for Venice. Pp. 197–201 in *The Aura in the Age of Digital Materiality: Rethinking Preservation in the Shadow of an Uncertain Future*. Milan: Silvana Editoriale.

Knowles, A. K. ed. 2008. *Placing History: How Maps, Spatial Data and GIS are Changing Historical Scholarship*. Redlands, CA: ESRI Press.

Lenardo, I. di and Kaplan, F. 2015. Venice Time Machine: Recreating the Density of the Past. A paper presented at DH2015: Global Digital Humanities, Sydney, Australia, June 29–July 3.

Morel, J., Crouzevialle, R., and Massoni, A. 2020. Construction and Management of a Geo-Historical Information System for an Interdisciplinary and Contributory Atlas: The Historical Atlas of Limousin. *International Journal of Humanities and Arts Computing* 14: 27–45.

Moretti, F. 1999. *Atlas of the European Novel: 1800–1900*. New York, NY: Verso.

Murrieta-Flores, P., Donaldson C., and Gregory I. 2017. GIS and Literary History: Advancing Digital Humanities Research through the Spatial Analysis of Historical Travel Writing and Topographical Literature. *Digital Humanities Quaterly* 11/1. http://www.digitalhumanities.org/dhq/vol/11/1/000283/000283.html.

Noordegraaf, J., van Erp, M., Zijdeman, R., Raat, M., van Oort, T., Zandhuis, I., Vermaut, T., Mol, H., van der Sijs, N., Doreleijers, K., Baptist, V., Vrielink, C., Assendelft, B., Rasterhoff, C., and Kisjes, I. 2021. Semantic Mapping in the Amsterdam Time Machine: Viewing Late 19th- and Early 20th-Century Theatre and Cinema Culture through the Lens of Language Use and Socio-Economic Status. Pp. 191–212 in *Research and Education in Urban History in the Age of Digital Libraries,* ed. F. Niebling, S. Münster, and H. Messemer. Cham: Springer. doi:10.1007/978-3-030-93186-5_9.

Roberts, L. 2016. Deep Mapping and Spatial Anthropology. *Humanities* 5/1. doi:10.3390/h5010005.

Schreibman, S., Siemens, R., and Unsworth, J. 2004. The Digital Humanities and Humanities Computing: An Introduction. Pp. 16–19 in *A Companion to Digital Humanities*, ed. S. Schreibman, R. Siemens, and J. Unsworth. Malden, MA: Blackwell Publishing.

Silveira, L. E. da. 2014. Geographic Information Systems and Historical Research: An Appraisal. *International Journal of Humanities and Arts Computing* 8: 28–45.

Suissa, O., Elmalech, A., and Zhitomirsky-Geffet, M. 2021. Text Analysis Using Deep Neural Networks in Digital Humanities and Information Science. *Journal of the Association for Information Science and Technology* 73: 268–287.

Sun, K., Zhu, Y., Pan, P., Hou, Z., Wang, D., Li, W., and Song, J. 2019. Geospatial Data Ontology: The Semantic Foundation of Geospatial Data Integration and Sharing. *Big Earth Data* 3: 269–296.

Tsorlini, A., Iosifescu, I., and Hurni L. 2013. Comparative Analysis of Historical Maps of the Canton of Zurich—Switzerland in an Interactive Online Platform. In *Proceedings of the 26th International Cartographic Conference, Dresden, Germany, August 25–30, 2013.* http://icaci.org/files/documents/ICC_proceedings/ICC2013/_extendedAbstract/147_proceeding.pdf (accessed January 18, 2023).

Tsorlini, A., Iosifescu, I., Iosifescu, C., and Hurni. L. 2014. A Methodological Framework for Analyzing Digitally Historical Maps Using Data from Different Sources through an Online Interactive Platform. *e-Perimetron* 9: 153–165.

Uschold, M. and Gruninger, M. 1996. Ontologies: Principles, Methods and Applications. *The Knowledge Engineering Review* 11: 93–136.

Vanhoutte, E. 2016. The Gates of Hell: History and Definition of Digital Humanities Computing. Pp. 135–172 in *Defining Digital Humanities: A Reader*, ed. M. Terras, J. Nyhan, and E. Vanhoutte. Farnham, Surrey, England: Ashgate.

Warf, B. 2015. Deep Mapping and Neogeography. Pp. 134–149 in *Deep Maps and Spatial Narratives*, ed. D. J. Bodenhamer, J. Corrigan, and T. M. Harris. Bloomington: Indiana University Press.

Warf, B. and Arias, S. 2008. Introduction: The Reinsertion of Space in the Humanities and Social Sciences. Pp. 1–10 in *The Spatial Turn: Interdisciplinary Perspectives*, ed. B. Warf and S. Arias. London:Routledge. doi:10.4324/9780203891308.

Yales, R. 2015. Hoisting Anchor: Exploring the Interaction between Time, Place, Space and Text in Early Modern American Travel Narratives Using Digital Technologies. MSc dissertation, University College London.

Zhao, Sh. H. and Zhu, X. F. 2014. The Theory and Practice of Urban Memory Project 2. 0 in China. *Documentation, Information & Knowledge* 2014/5: 30–38.

Zhitomirsky-Geffet M. 2019. Towards a Diversified Knowledge Organization System: An Open Network of Inter-Linked Subsystems with Multiple Validity Scopes. *Journal of Documentation* 75/5: 1124–1138.

Zhitomirsky-Geffet, M. and Hajibayova, L. 2020. A New Framework for Ethical Creation and Evaluation of Multi-Perspective Knowledge Organization Systems. *Journal of Documentation* 76/6: 1459–1471.

Zhitomirsky-Geffet, M., and Prebor, G. 2016. Toward an Ontopedia for Historical Hebrew Manuscripts. *Frontiers in Digital Humanities* 3. doi:10.3389/fdigh.2016.00003.

Zohar, M. 2020. Advancing the Historical Geography of Late Ottoman and British Mandate Palestine Using GIScience: A review. *Transactions in GIS* 24: 1464–1481.