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Editorial

Addressing Semantic Geographic Information Systems

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Abstract: The progressive consolidation of information technologies on a large scale has been facilitating and progressively increasing the production, collection, and diffusion of geographic data, as well as facilitating the integration of a large amount of external information into geographic information systems (GIS). Traditional GIS is transforming into a consolidated information infrastructure. This consolidated infrastructure is affecting more and more aspects of internet computing and services. Most popular systems (such as social networks, GPS, and decision support systems) involve complex GIS and significant amounts of information. As a web service, GIS is affected by exactly the same problems that affect the web as a whole. Therefore, next generation GIS solutions have to address further methodological and data engineering challenges in order to accommodate new applications' extended requirements (in terms of scale, interoperability, and complexity). The conceptual and semantic modeling of GIS, as well as the integration of semantics into current GIS, provide highly expressive environments that are capable of meeting the needs and requirements of a wide range of applications.

Keywords: semantic technologies; semantic web; geographic information system (GIS); ontology development; geographic space modeling; spatial data infrastructure (SDI)

1. Towards Semantic GIS

A geographic information system (GIS) is a functional and data infrastructure designed to perform complex tasks involving geographical data, e.g., to capture, store, manipulate, analyze, manage, and represent geographically-based data.

When applied to geographically-oriented computer technology and integrated systems, GIS have been generating massive interest worldwide in the context of different domains and applications [1]. Their intrinsic flexibility and diversity, their multi-disciplinary features combined with their commercial focus, have not assisted in producing a clear and unambiguous definition of GIS [1]. A satisfactory and generic set of domain or application-independent fundamental principles, as well as an exhaustive description and evolution of applications, are hard to convey [1].

Today GIS appears as a core concept in a wide domain of applications involving any kind of classic geographic data (e.g., sensors [2]), rich contents (e.g., multimedia-contents [3]) as well as complex dynamics (e.g., social content [4,5]). Expectations around GIS's capabilities and performance are quickly growing. Consequently, GIS technology is constantly evolving and is evidencing a progressive and unrelenting convergence with web technologies (*Web GIS* [6]).

Such convergence is much more than a simple technological trend: the current generation of GIS is intrinsically designed and developed to work at a global level on the web using web-scale data resources (*Big Data* [7]).

The scale and the complexity of the information on the internet have led researchers to design the next version of the internet (known as *Web 3.0* or the *Semantic Web* [8]): the model assumes that published data will be integrated with its "meaning" (*i.e.*, semantic description) through a machine-processable specification. Such integration would potentially allow for the processing of contextual information by machines in a context of interoperability and with a lack of ambiguity. Semantic processes on the internet are not limited to data, but can also involve web services. Indeed, *Semantic Web Services* [9] extend the common web service concept by using semantic descriptors (e.g., those regarding modeling, service behavior, and capacity) to perform dynamic tasks. These involve the discovery, matchmaking, and execution of services that are supplied by different providers scattered throughout the global network.

The next generation GIS is expected to address an extended set of issues that reflect a new understanding of requirements in terms of scale, interoperability [10] and complexity. Those requirements could propose further relevant tradeoffs and challenges if GISs are understood as integrated systems in the context of upper frameworks (e.g., *Spatial Data Infrastructure* (SDI) [11]).

More than one technologic aspect is evidently involved in the GIS evolution but, in practice, if the current development of GIS are naturally suited to the consolidated technological and conceptual environment of the second version of the web (*Social Web* [12]), then the next generation GIS should be reasonably designed according to the semantic web model (*Semantic GIS* ([13,14]). Here is the core of the problem: regardless of the current availability of *semantic technologies* [15], semantics is a debatable open research issue, and the understanding of the third generation web is a continuously evolving concept [16]. Therefore, semantic GIS has to be designed and developed in the context of a not-yet-mature and consolidated technological framework.

The next subsections deal with the possible impact of semantics on GIS and the main challenges of next generation GIS. Anticipated improvements will also be defined for the most important features of next generation applications and services of GIS.

1.1. Understanding Semantics of GIS

Emerging applications involving GIS introduce strong demands in terms of performance, capabilities and interoperability affecting most aspects of the GIS's functional and data infrastructure. Most existing GIS are being re-designed and re-packaged to address extended requirements, as well as in an attempt to exploit or explore market opportunities as much as possible.

This tendency to re-engineering, apart from not always being effective, sometimes causes some confusion in a field already characterized by a great diversity of applications. Furthermore, the inability to accommodate emerging requirements into current models is quite evident in most cases (e.g. [17,18]). The feeling is that models should evolve in accordance with technological environments.

In fact, GIS are integrating systems which bring together knowledge and ideas developed in many different areas, as well as knowledge-intensive processes, complex data models and patterns. In this context, most solutions look for a heuristic response to specific problems rather than tangible advances. It is not always easy to evaluate the impact of *ad-hoc* solutions for a wider range of applications and to generalize application-oriented approaches.

Furthermore, there are many different ways to define and classify subjects, objects and relations between them. The target knowledge often exists with multiple perspectives of the information; rich data models [19] are required to represent complex information fully supporting further steps for business processes (e.g., analysis). Heterogeneous models from different domains are being produced, but it is difficult to achieve a convergence process.

Such considerations, and the constantly increasing systems' scale, are leading researchers to the progressive integration of semantic models and, consequently, to a design approach oriented to the semantic web. The benefits and current limitations of semantics are extensively discussed in the literature (e.g., in [8]) but are not the object of discussion in the context of this paper.

It is possible to identify a wide range of different approaches in order to apply semantic models to GIS. Such solutions would consistently vary in function of the context and the purpose(s). For example, current research solutions can be designed according to an overall approach (e.g., semantic geospatial web [13]) or could match a completely vertical approach. Hybrid approaches, based on interdependent semantic layers, are currently in development in the context of several research projects.

An analysis of semantic needs for GIS architectures identifies at least two different kinds of semantic support:

- *Horizontal or Base support* mostly refers to the geographic space itself. Current models fundamentally lack formalization which makes finding a high-level match, or definition of consistent relations among the different components, difficult. By providing a rich and formalized set of concepts, an ontological approach (e.g., [20,21]) could provide a revolutionary solution for problems of geographical information modeling, enabling semantically interoperable frameworks, spatial data reuse, data sharing and mining, as well as the development of intelligent networks.
- *Vertical support* is a natural complement to the previous one since it should basically define a formal interoperable meta-layer for the specification of data layers and relevant relations. Such data structures should overcome the barriers affecting the internal management of content inside the GIS, as well as enabling a consistent data sharing model [22].

1.2. Issues and Challenges

As previously mentioned, semantics could contribute to GIS progress by providing a wide range of formalizations and relations as an expression of complex conceptualizations involving space and data [23].

The formal definition of semantics targeting a complex data and functional infrastructure is a difficult challenge especially if, as for GIS, application domains can be quite different in structure, scale and scope. A mix of generic, domain-specific and application-specific concepts and relations have to work together, requiring strong efforts in terms of knowledge engineering in order to assure intelligible and usable models.

From a strictly product-oriented perspective, the minimal set of challenges to address can be summarized as:

- Most emerging applications require an innovative understanding of space, overcoming the strongly physical model currently in use. An extended specification of space, including logic views and relations in the context of interoperability and reducing ambiguity, could be extremely helpful for a large number of business processes and applications involving GIS. In recent years, several projects have been proposed in order to combine themes of space and time using an ontological approach (e.g., [24]). Semantics are being extensively used in order to define the contextualization of geospatial information (e.g. [25]).
- At the same time, an improved model for data management [26] and sharing [22] is sought. Next generation GIS should reflect data ecosystems and not simply federations of data. Rich data models are required to provide capabilities for effective data management and sharing. An additional effort is required to manage complex data on a large scale (e.g., *Open Data* [27] and *social objects* [16]) as well as to provide multi-dimensional perspectives of data (such as in semantic similarity measurement [28]).
- Semantics, able to formalize current models, would be an important (and in most cases also comprehensive) result. Looking at ICT architectures and the speed of their evolution, a more consistent role for semantics is expected in the near future, mostly in order to provide a consistent level of interoperability [23,29]. Big Data, mobility, social trends in information [30,31] and all the other phenomena potentially involving the web, should provide a deeper understanding of semantics as an effective *n*-th dimension of space, enabling creation of innovative models for representation and interaction.

Conflicts of Interest

The authors declare no conflict of interest.

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