Journal Subline
LNCS 3534

Journal on Data Semantics III

Stefano Spaccapietra
Editor-in-Chief

Springer

Stefano Spaccapietra Esteban Zimányi (Eds.)

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Library of Congress Control Number: 2004117338

CR Subject Classification (1998): H.2, H.3, I.2, H.4, C.2

ISSN 0302-9743
ISBN-10 3-540-26225-3 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-26225-1 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media

springeronline.com

Printed in Germany

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India
Printed on acid-free paper SPIN: 11496168 06/3142 5 4 3 2 1 0

Lecture Notes in Computer Science 3534

The LNCS Journal on Data Semantics

Computerized information handling has changed its focus from centralized data management systems to decentralized data exchange facilities. Modern distribution channels, such as high-speed Internet networks and wireless communication infrastructures, provide reliable technical support for data distribution and data access, materializing the new, popular idea that data may be available to anybody, anywhere, anytime. However, providing huge amounts of data on request often turns into a counterproductive service, making the data useless because of poor relevance or inappropriate level of detail. Semantic knowledge is the essential missing piece that allows the delivery of information that matches user requirements. Semantic agreement, in particular, is essential to meaningful data exchange.

Semantic issues have long been open issues in data and knowledge management. However, the boom in semantically poor technologies, such as the Web and XML, has boosted renewed interest in semantics. Conferences on the Semantic Web, for instance, attract crowds of participants, while ontologies on their own have become a hot and popular topic in the database and artificial intelligence communities.

Springer's LNCS Journal on Data Semantics aims at providing a highly visible dissemination channel for most remarkable work that in one way or another addresses research and development on issues related to the semantics of data. The target domain ranges from theories supporting the formal definition of semantic content to innovative domain-specific application of semantic knowledge. This publication channel should be of highest interest to researchers and advanced practitioners working on the Semantic Web, interoperability, mobile information services, data warehousing, knowledge representation and reasoning, conceptual database modeling, ontologies, and artificial intelligence.

Topics of relevance to this journal include:

- semantic interoperability, semantic mediators
- ontologies
- ontology, schema and data integration, reconciliation and alignment
- multiple representations, alternative representations
- knowledge representation and reasoning
- conceptualization and representation
- multimodel and multiparadigm approaches
- mappings, transformations, reverse engineering
- metadata
- conceptual data modeling
- integrity description and handling
- evolution and change
- web semantics and semistructured data

- semantic caching
- data warehousing and semantic data mining
- spatial, temporal, multimedia and multimodal semantics
- semantics in data visualization
- semantic services for mobile users
- supporting tools
- applications of semantic-driven approaches

These topics are to be understood as specifically related to semantic issues. Contributions submitted to the journal and dealing with semantics of data will be considered even if they are not within the topics in the list.

While the physical appearance of the journal issues looks like the books from the well-known Springer LNCS series, the mode of operation is that of a journal. Contributions can be freely submitted by authors and are reviewed by the Editorial Board. Contributions may also be invited, and nevertheless carefully reviewed, as in the case for issues that contain extended versions of best papers from major conferences addressing data semantics issues. Special issues, focusing on a specific topic, are coordinated by guest editors once the proposal for a special issue is accepted by the Editorial Board. Finally, it is also possible that a journal issue be devoted to a single text.

The journal published its first volume in 2003 and its second volume at the beginning of 2005. This is the third volume; the first one to be a special issue devoted to a specific theme. We are very grateful to Prof. Esteban Zimányi, from the Université Libre de Bruxelles, for accepting the load of organizing this special issue. Two other volumes are due to appear in 2005, and will be followed in 2006 by a special issue on Emergent Semantics.

The Editorial Board comprises one Editor-in-Chief (with overall responsibility) and several members. The Editor-in-Chief has a four-years mandate to run the journal. Members of the board have a three-years mandate. Mandates are renewable. More members may be added to the board as appropriate.

We are happy to welcome you to our readership and authorship, and hope we will share this privileged contact for a long time.

Stefano Spaccapietra
Editor-in-Chief
`http://lbdwww.epfl.ch/e/Springer/`

JoDS Volume 3 — Special Issue on Semantic-Based Geographical Information Systems

Geographical information has been established as a fundamental and strategic component of today's decision-support systems. Geographical information systems (GISs) have been successfully used in many diverse application domains, from land management to atmospheric and spatial observation, from history preservation and archaeology to biodiversity. However, new applications ask for enriching the semantics associated with geographical information in order to support a wide variety of tasks including data integration, interoperability, knowledge reuse, knowledge acquisition, knowledge management, spatial reasoning and many others. Examples of such semantic issues are temporal and spatiotemporal data management, 3D manipulation, spatial granularity, multiple resolutions, multiple representations, fuzzy and ambiguous geographic information, the relationship between geographic and physical concepts, and identity of geographic objects through time.

In addition, recent years have witnessed many technological developments that have radically changed how we understand information processing. Data warehouses and OLAP systems have evolved as a fundamental approach for developing advanced decision-support systems. This led to improved data mining techniques allowing us to extract semantics from raw data. Furthermore, the success of the Internet generated a paradigm shift in distributed information processing leading to the area of the Semantic Web, in which semantics is the fundamental component for achieving communication both for humans and applications. At the same time, mobile and wireless computing have entered everyone's life through dedicated devices leading to location-based services. Finally, Grid computing, a paradigm enabling applications to integrate computational and information resources managed by diverse organizations in widespread locations, pushes the frontier of global interoperability. The fact that all these recent developments are entering the geographic domain increases the importance of the elicitation of the semantics of geographical information.

The papers in this special issue address many of the topics mentioned above. They all provide different insights about the multiple benefits that can be obtained by envisioning GISs from a new semantic perspective. As this is a relatively new domain, these papers open many new research directions that need to be addressed in future work. This research will definitely have a huge impact on the next generation of GIS applications and tools.

March 2005

Esteban Zimányi
Special Issue Editor

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I would like to thank all the reviewers for their excellent work evaluating the papers. Without their commitment the publication of this special issue of the JoDS journal would never have been possible.

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Geospatial Semantics: Why, of What, and How?

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Abstract. Why are notions like semantics and ontologies suddenly getting so much attention, within and outside geospatial information communities? The main reason lies in the componentization of Geographic Information Systems (GIS) into services, which are supposed to interoperate within and across these communities. Consequently, I look at geospatial semantics in the context of semantic interoperability. The paper clarifies the relevant notion of semantics and shows what parts of geospatial information need to receive semantic specifications in order to achieve interoperability. No attempt at a survey of approaches to provide semantics is made, but a framework for solving interoperability problems is proposed in the form of semantic reference systems. Particular emphasis is put on the need and possible ways to ground geospatial semantics in physical processes and measurements.

1 Introduction: Why Semantics?

In some sense, Geographic Information Systems (GIS) have always been based on semantics, sometimes even on explicitly defined semantics. For example, a GIS user in an environmental planning agency in Germany is likely to keep a heavy binder on her shelf. It is called the ATKIS Object Catalogue[1] and its role is to define the object classes and attributes occurring in topographic data, both syntactically and semantically. Similarly, land use and land cover databases have always been built according to some semantic classifications, such as the European CORINE standard [1]. So, what has changed, and what would it mean today for a GIS to be based on semantics?

The answer is that access to and use of geospatial information have radically changed in the past decade. Previously, the data processed by a GIS as well as its methods had resided locally and contained information that was sufficiently unambiguous in the respective information community [2]. Now, both data and methods may be retrieved and combined in an ad hoc way from anywhere in the world, escaping their local contexts. They contain attributes, data types, and operations with meanings that differ from those implied by locally-held catalogues and manuals. Since the semantics specified by these local resources is not machine-readable, it cannot be shared with other systems. Coping with this situation defines the challenges of *semantic interoperability* [3].

The notion of semantic interoperability is hard to pin down, for several reasons: it is somewhat redundant, there is no accepted formal definition, there are no bench-

[1] http://www.atkis.de/dstinfo/dstinfo2.dst_gliederung2?dst_ver=dst

S. Spaccapietra and E. Zimányi (Eds.): Journal on Data Semantics III, LNCS 3534, pp. 1 – 24, 2005.

marks or commonly agreed challenges, the role of humans in the process is unclear, and the acronym inflation around the semantic web obscures rather than highlights the deeper research issues. Clearly, semantic interoperability is the only useful form of interoperability. In the real world, it is hard to imagine two agents interoperating successfully without a shared understanding of the messages they exchange. Therefore, it seems appropriate to define interoperability in a way that involves shared conceptualizations.

The following definition of interoperability that emerged from a geospatial context is often quoted (ISO TC204, document N271):

> *"The ability of systems to provide services to and accept services from other systems and to use the services so exchanged to enable them to operate effectively together."*

This definition is almost identical to the one in Wikipedia[2]. Such definitions are technical enough to be useful in systems engineering and testing. They also make clear that interoperability rests on services. But they fall short of establishing verifiable criteria. What does it mean for systems to operate together? And when can they be said to do this effectively?

A more precise definition of interoperability would require at least two steps: (1) identifying the vocabulary and syntax of service interfaces, and (2) defining interoperability mathematically. In this paper, I address the first requirement. Preliminary results of an ongoing debate[3] suggest that the theory of institutions [4, 5], building on category theory, supplies the necessary formal foundations for the second requirement.

Semantic interoperability is the technical analogue to human communication and cooperation. It hardly constitutes a research topic per se for Geographic Information Science, but serves as a technical goal justifying the formalization of semantics in GIS and providing measurable criteria of success for this undertaking. The research questions it raises range from those of ethnophysiography , which studies how people conceptualize landscape features, to questions about human cognition of geospatial information in general [6, 7], through formalization methods for geospatial concepts [8] and architectures for ontology-based GIS [9], to socio-economic aspects of spatial data infrastructures [10].

The notion of interoperability needs to be understood broadly enough, encompassing the interoperation between human beings and systems. But it should also remain precise enough, allowing for a common syntactic basis. While it is essential to consider the organizational and societal issues involved in information sharing [11], it is detrimental to overload the definition of technical interoperability with these aspects. Levels of interoperability should be defined incrementally, starting at the purely technical and proceeding through the organizational and social levels. Sooner rather than later, however, environments for semantic interoperability will have to include means for meaning negotiation and other ways of dealing with organizational and social contexts [12].

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[2] http://en.wikipedia.org/wiki/Interoperability

[3] http://www.dagstuhl.de/04391/Materials/

The Muenster Semantic Interoperability Lab (MUSIL[4]), as well as other research groups (see, for example, [13]), have found that a *focus on actual interoperability problems* helps to sharpen the research questions around the broad theme of semantics of geospatial information. Investigating interoperability scenarios based on actual cases of using geospatial information for decision making provides measures of success to test specific semantic and technological hypotheses: a certain choice of concepts specified in an ontology, or certain elements in a service architecture should produce a difference in the degree of interoperability between some components. With a formal definition of interoperability, the difference could even be measured.

This paper shows what syntactic parts of geospatial information need to be specified semantically to support interoperability (Section 2); it classifies semantic interoperability problems and illustrates them through scenarios (Section 3); it postulates a solution framework inspired by spatial reference systems (Section 4), and concludes with a summary and an outlook on longer term research challenges (Section 5).

2 Semantics of What?

This section defines the bases for semantic interoperability research by asking "what needs to be semantically specified in order to support semantic interoperability?" It clarifies the notion of semantics and the syntax of the expressions which require semantics to achieve interoperability. The fundamental construct of a service interface is highlighted and analyzed. Since the perspective taken on semantic interoperability includes human beings as parts of interoperating systems, user interfaces are subsumed under service interfaces. Finally, the question "what is special about spatial" is revisited in the context of geospatial semantics.

2.1 Semantics

The only sensible use of the term "semantics" refers to the meaning of *expressions* in a language. Such expressions can be single symbols (the "words" of a language) or symbol combinations. As the term implies, they are used to express something, i.e., to communicate meaning. Neither concepts nor entities nor properties nor processes have semantics, but expressions in languages describing them do.

The relevant languages in an information system context express how human beings conceptualize something for the purpose of representing and manipulating it in machines. Many such languages exist and need semantics: programming languages, schema languages, query languages, interface specification languages, workflow modeling languages, user interface languages, sensor modeling languages, and others. Many of these languages allow users to define new symbols (for individuals, types, properties, relationships etc.). Additionally, application standards introduce all sorts of more or less controlled vocabularies (such as those in feature-attribute catalogues or metadata standards). Furthermore, free-form text entries in data and metadata collections open the gate to almost unlimited uses of natural language expressions. Coping with the semantics of all expressions in such languages is beyond current means.

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[4] http://musil.uni-muenster.de

Restricting the expressions to those affecting interoperability will make the task more manageable.

Attaching meaning to language expressions is a *conceptual* phenomenon. Natural language symbols and expressions evoke concepts in human minds and are used to express those concepts. For example, the term "jaguar" can evoke a concept of an animal, car, or jet fighter in a human mind, with context usually picking out the intended interpretation and discarding the others. The concepts, in turn, are shaped by human experience with some real-world entities. Thereby, expressions come to refer to entities (as well as properties, relationships, and processes) in the world. This fundamental ternary meaning relationship between symbols, concepts, and entities is captured in the so-called semantic (or semiotic) triangle, going back at least to [14], but already implicit in Aristotle's work. The triangle exists in many versions; the one shown here considers the three relationships forming the edges as human activities (using a symbol to express a conceptualization of something in the real world, and to refer to that):

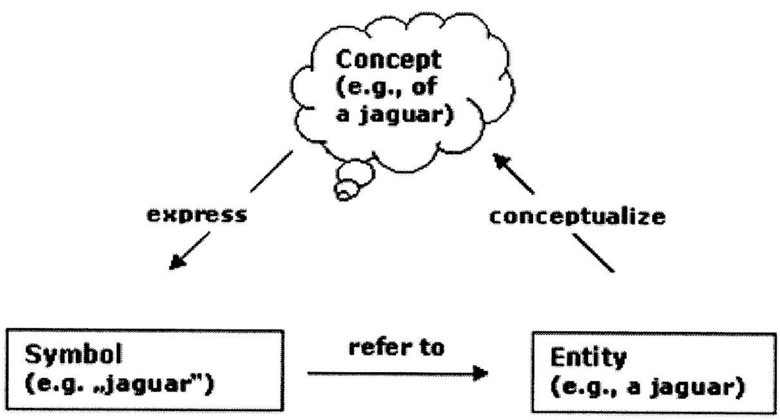

Fig. 1. The semantic triangle

The languages used in information systems are not natural languages, even if they use natural language terms. They are the results of social *agreements* in information communities on how to use certain terms; agreements which are typically more explicit than those underlying the use of natural languages. The agreements establish technical terms (say, `overlap` as a topological operator), which are recognized to have a relatively fixed meaning that is sometimes formally defined and often made explicit in the form of feature-attribute catalogues, interoperability standards, legal regulations, and other defining documents. For example, the navigation community has agreed on various forms of graph representations to model road networks for navigation purposes [15]. Codifying such agreements in ontologies is a useful first step toward semantic interoperability [16, 17].

The symbols and expressions of information system languages can be produced or consumed by machines, but acquire meaning by the same relationships as those of natural languages. The fundamental fact about meaning, that it is generated by humans and not defined by a state of the world, applies to all symbols, and independently of whether they stand for individuals (as names or constants do) or classes (as nouns or type labels do). This view of semantics avoids the pitfalls of simplistic associations between symbols and entities in the world, sometimes referred to as realist semantics [18].

Geospatial semantics, consequently, is *not* about the relationship between GIS contents and the world, and does not need to be: this relationship is already captured in the notion of *correctness* (and, more generally, integrity) of databases and information systems. Geospatial semantics is about *understanding* GIS contents, and capturing this understanding in formal theories. At the same time, one should not make simplistic assumptions about the nature of the concepts that define such understanding. They are not just individual notions, but constantly evolving and often elusive results of conceptualization processes in information communities.

Is the goal of research on geospatial semantics to fully specify the semantics of geospatial terms? Such an enterprise would be too daunting, but also unnecessary. Consider how well human communication works without precisely defined semantics. We all use one or more natural languages (such as English or Mandarin) to communicate, none of which has a formally defined semantics. Yet, we understand and cooperate with each other reasonably well, despite frequent semantic ambiguities. As human beings living in certain social contexts, we have devised means of resolving these ambiguities *as far as necessary* to make communication and cooperation successful. This fact should caution us against putting more emphasis on formalizing meaning than on the reasoning that uses these formalizations to make necessary distinctions. Nevertheless, a few words on formalization are in order before addressing the reasoning challenges posed by interoperability.

2.2 Formalizing Semantics

Since concepts (and meanings, as relationships between expressions, concepts, and the world) are not directly observable, theories of semantics have to introduce substitutes for them. They can choose to represent meaning as a relationship between symbols (symbols of a language and symbols representing concepts) or instead represent effects of meaning (for example, the actions in the world resulting from understanding an expression). The former option is taken by the field of formal semantics and constitutes the only practical approach today. The latter requires theories of action (and of the role of information in them) that are not available yet for geospatial applications. As it would compensate some shortcomings of formal semantics, I will discuss this option in some more detail in Section 4.

Formal semantics, as coming out of logic, linguistics, and computer science, establishes a mathematical basis to talk about meaning. Through model theory, it introduces the notion of possible models, formally defining the semantics of expressions [19]. These models are considered to *be* the meanings. From a conceptual point of view, they are just symbolic structures, albeit useful ones: They represent conceptualizations of entities, properties, and relationships in a domain and can therefore be tested against human intuitions about these [20]. Differences observed between the intuitions and the behavior of the models can then suggest possible changes to the models.