Modeling the External Quality of Context to Fine-tune Context Reasoning in Geo-spatial Interoperability

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Abstract

Context reasoning is the process of drawing conclusions from existing context information, and is considered crucial to geospatial interoperability. However, such reasoning still remains a challenge because context may be incomplete or not appropriate for a specific use. Thus, evaluating and modeling the external quality (fitness-for-use) of context information is important for reasoning about context. In this paper, we propose an ontology-based approach to model the external quality of context information. This approach aims at fine-tuning context reasoning and hence enhancing geospatial interoperability.

1 Introduction

Over the last decades, there has been an exponential increase in the amount of geospatial data available from multiple sources. Reusing this data can significantly decrease the cost of geospatial application. In order to develop ways to enhance the reuse of available geospatial data, significant research efforts have been carried out. Among these efforts, semantic interoperability of geospatial data has been extensively investigated [Bishr, 1998; Harvey *et al.*, 1999; Brodeur, 2004], but it still remains a challenge in spite of all these efforts [Staub *et al.*, 2008]. A key issue in such interoperability is reasoning about context information of geospatial data. Context information may be used in several ways to capture data semantics. We distinguish between two kinds of context: *production context* and *use context*. Production context is any information that can be specified explicitly or implicitly by a data producer (e.g., the method of data collection). On the other hand, characteristics that surround user's application (e.g., reference system, scale) are considered as use context. Context can be thematic (e.g., data acquisition method), spatial (e.g., spatial reference system used) or temporal (e.g., the time of data acquisition).
Context may be incomplete or not appropriate for a specific use. This may affect the context reasoning process [Henricksen and Indulska, 2004; Bikakis *et al.*, 2007]. The degree of completeness and appropriateness of context information can be indicated by the quality of this context. We distinguish two parts of context quality: internal quality and external quality. The internal quality of a context refers to the extent to which a producer meets specifications, that is, the extent to which the required context information is free from errors and inconsistency. The external quality of a context refers the appropriateness of context information for a given application (i.e. its fitness-for-use).
In geospatial interoperability, context reasoning needs to verify and compare the degree of appropriateness of the contexts associated with different sources of information. Consequently, evaluating and modeling the external quality of context is important for context reasoning in geospatial interoperability.
In previous work we proposed a framework to overcome the conflicts related to the semantic interoperability of geospatial data. The framework is based on bidirectional communication and reasoning about context information [Sboui *et al.*, 2007]. In another work, we proposed a set of indicators for the external quality of context and a method to evaluate those indicators [Sboui *et al.*, 2009]. In this paper, we propose an ontology-based approach to model the external quality of a context with respect to the application for which the interoperability is carried out. This approach aims at fine-tuning context reasoning and hence enhancing geospatial interoperability.
In the next section, we briefly present the existing approaches to reason about context. In Section 3, we present a set of indicators that have a major role in indicating the quality of context; and we propose a model to represent and reason about the external quality of context. We conclude and present further works in Section 4.

2 Approaches for context modeling and reasoning

Several approaches have been proposed for context reasoning (e.g., ontology-based reasoning, rule-based reasoning, and probabilistic reasoning). Ontology-based and rule-based reasoning are the two major approaches [Gu *et al.*, 2004; Bikakis *et al.*, 2007].

Ontology-based reasoning

Ontology, as a formal and explicit specification of a shared conceptualization, is considered as an efficient technique for modeling context enabling software agents to interpret and reason about context information [Gu *et al.*, 2004; Souza *et al.*, 2006; Frank, 2007]. Ontology-based approaches use Semantic Web technologies (e.g., RDF(S) and OWL) to model and reason about context information. These approaches are the most commonly used thanks to their formal structure and high expressiveness.

Rule-based reasoning

These approaches are based on predefined sets of rules that aim at verifying the consistency of context information [Bikakis *et al.*, 2007]. They typically provide a formal model for context reasoning and can be integrated with the ontology-based reasoning approaches.

Both approaches focus on verifying the internal quality (e.g. consistency) of the context information. They pay less or no attention to the external quality of context information (i.e., fitness-for-use). However, in semantic interoperability, context reasoning needs to take into account the quality of context with regard to the application for which the interoperability is carried out. Consequently, evaluating and modeling such quality is important to enhance context reasoning.

3 Evaluating and Modeling the external quality of context

3.1. Evaluating the external quality of context

In previous work [Sboui *et al.*, 2009], we proposed a restricted set of indicators and a method for evaluating the external quality of context with regard to a specific use. These indicators are: *convenience of language*, *completeness*, *trust*, and *freshness*. Each indicator is evaluated according to a function. The resulting quality value is within the interval [0, 1]. The value 1 indicates perfect quality while the value 0 indicates completely poor quality. Based on this value, a qualitative value (i.e., "good", "medium" or "poor") may be assigned to the external quality.

1- Convenience of language. It indicates the convenience of using a given language to represent the context of geospatial data. For example, the convenience of a free natural language for a novice user is "medium".

2- Completeness. It shows the quantity of the provided context (i.e., metadata) with regards to user's requirements. We recognize thematic, spatial, and temporal completeness. For example, the spatial completeness of a context that does not contain information about reference system is "poor".

3- Trust. It describes the degree of faith that we have about the context provided and transmitted in a chain of interveners in semantic interoperability of geospatial data. For example, the faith we have about data precision is "medium".

4- Freshness. This quality indicator shows the degree of rationalism related to the use of context information at a given time. The value of freshness is determined by the age and lifetime of the context information. For example, a context defined in 2008 is fresh (i.e., the freshness is "good").

We should notice that these indicators do not aim at being complete or precise but rather at making agents globally aware of the external quality of a context information.

3.2. Modeling the external quality of context

We propose a formal model based on ontology using Web Ontology Language (OWL) to represent the previously defined indicators of external quality and facilitate context reasoning. The model embeds both a context and the information about its external quality using OWL classes and properties. The choice of ontology technique is motivated by the fact that ontology provides: (1) a flexible structure with explicit vocabulary to represent concepts and relations of both a context and its external quality, (2) logic reasoning mechanisms which are necessary to verify the context external quality, and (3) a common structure to exchange data between interveners in the geospatial interoperability.

Figure 1 shows a simplified view of the model that includes a set of OWL classes such as *ContextElement*, *ExternalQuality*, *Indicator* and *Value*. *ContextElement* class allows representing any context element (spatial, thematic or temporal). *ExternalQuality* class allows specifying various qualities with different external quality indicators. *Indicator* class defines the indicators of the external quality of context in a specific use. *LanguageConvenience*, *Completeness*, *Trust* and *Freshness* are subclasses of *Indicator*. Each indicator has a *Value* that can be *Good*, *Medium* or *Poor*.

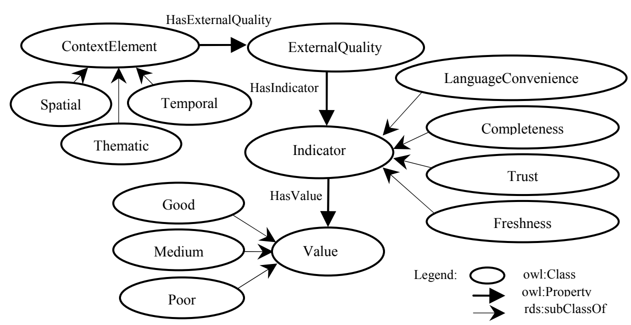

Figure 1. OWL-based context external quality model

The semantics of OWL ontology are derived from Description Logics (DL) which are a family of formalisms for representing knowledge [Baader, 2003]. DL consists of four parts: constructors which represent concepts and relations (or roles), terminological axioms, assertions about individuals, and a set of rules which allow to infer new knowledge from existing one. We use the description logics ALC as an example. The descriptions expressible by ALC are: bottom-concept ($\bot$), top-concept ($\top$), A ($A \in N_C$), conjunction ($C \sqcap D$), disjunction ($C \sqcup D$), negation ($\neg C$), existential restriction ($\exists R.C$), and value restriction ($\forall R.C$). Where N_C is the set of primitive concept names, A is a concept name, C and D are concept descriptions, and R is a role description. The expression of the form $A \equiv C$ assigns A to C, and is called *concept definition*.

In the proposed model, we defined the following sets of primitive concepts and primitive roles:

Primitive concepts: N_C = {ContextElement, ExternalQuality, Indicator, LanguageConvenience, Completeness, Trust, Freshness, Value, Good, Medium, Poor, SpatialContextElement, TemporalContextElement, ThematicContextElement}

Primitive roles: N_R = {HasQuality, HasInternalQuality, HasExternalQuality, HasIndicator, HasValue}

Using the above sets, we can define additional concepts and roles. For example the concepts GoodExternalQuality and BadExternalQuality can be defined as follows:

GoodExternalQuality ≡ ExternalQuality ⊓ ∀HasIndicator.(Indicator ⊓ ∃HasValue.Good)

That is, a good external quality is an external quality that has Good value for all its indicators.

BadExternalQuality ≡ ExternalQuality ⊓ ∀HasIndicator.(Indicator ⊓ ∃HasValue.Poor)

Also, in order to facilitate the comparison of heterogeneous context elements, we define the following additional concepts: ExcellentContextElement and BadContextElement. These two concepts indicate, respectively, that a context element has a good and bad quality for all indicators. They can be represented as follows:

ExcellentContextElement ≡ ContextElement ⊓ ∀HasExternalQuality.GoodExternalQuality

BadContextElement ≡ ContextElement ⊓ ∀HasExternalQuality.BadExternalQuality

The above examples show that the proposed model allows inferring conclusions not only from existing context information, but also from information about the external quality of context. Based on such conclusions, interveners in the interoperability process (i.e., agent systems or humans) will be able to appropriately reason about the context of geospatial data and make appropriate decisions. For example, if interveners have to choose between two heterogeneous context elements, they will be invited to choose the element with a better external quality (i.e. the element fitting better for the current use).

4 Conclusion

Modeling and reasoning about context information still remains a major issue in geospatial interoperability. Although many approaches have examined this issue, they focus solely on the internal quality of context. In this paper, we propose an approach based on ontology to model and reason about context taking into account the external quality (fitness-for-use) of context. Such model aims at helping interveners in the geospatial interoperability to appropriately reason about context information. In addition, the proposed model provides relevant information that can be used in making appropriate decisions (e.g., comparing two heterogeneous context elements and considering one of them, or ignoring a context that has a poor external quality).

Further research is undergoing to define additional indicators of context external quality such as relevancy and granularity of context information. Then, a prototype will be implemented to validate the importance of the proposed model in enhancing the geospatial interoperability.

Acknowledgments

We wish to acknowledge the contribution of the NSERC Industrial Research Chair in Geospatial Databases for Decision Support.

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