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Context-driven reconciliation in ontology integration

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Abstract: In order to solve the semantic irreconcilable problems caused by contextual differences during the process of ontology integration, a context-driven reconciliation mechanism is proposed. The mechanism is based on the previous work about a context-based formalism—Context-SHOIQ (D +) DL, which is used for explicitly representing context of ontology by adopting the description logic and the category theory. The formalism is extended by adding four migration rules (InclusionRule, SelectionRule, PreferenceRule, and MappingRule), that are used to specify what should be imported into the IntegrativeContext, and three related contextual integration operations of increasing interoperability (import, partial reconciliation, and full reconciliation). While not exhaustive, the mechanism is sufficient for solving the five types of semantic irreconcilable problems that are discussed, and favors integration of ontologies from one context to another.

Key words: semantic web; context; reconciliation; ontology integration; migration rules

As the semantic web gains attention as the next generation of the web, the issue of reconciling different views of independently developed and exposed data sources becomes increasingly important. Ontology integration serves as a basis for solving this problem. Ref. [1] identified three different meanings of ontology integration. One of the meanings refers to building an ontology by merging several different ontologies about the same subject into a single one that unifies all of them. However, during the process of ontology integration, there are a great number of independently developed ontologies that reflect different views of their developers and the different needs and interests of their owners. Therefore, these ontologies hold with respect to their specific contexts, that is to say, the meanings of the ontological elements (concepts and relations) are different in different contexts. The contextual differences cause semantic irreconcilable phenomena that pose challenges for ontology integration. Unfortunately, there is not an explicit representation of contexts for ontologies in the semantic web so far. Hence, we need to develop a mechanism that allows us to explicitly represent and operate contexts to handle some of these semantically irreconcilable problems in ontology integration.

In the past, artificial intelligence (AI) researchers have encountered similar issues when integrating structured knowledge from different people or even the same person at different times. To handle these issues, mechanisms such as contexts[2–3] and micro-theories have been proposed and implemented in projects such as Cyc[4]. Nowadays, context has also become an important consideration in the semantic web[5–7]. However, the differences between AI systems and the semantic web also mean that a context mechanism for the semantic web will have substantial differences from the AI context mechanisms[8].

In this paper, we present a completely different context-driven reconciliation mechanism for the semantic web ontology integration. The mechanism is based on our previous work about a context-based formalism—— Context-SHOIQ (D +) DL[9] that is used for explicitly representing context. We extend the formalism in order to take into account four migration rules and three related contextual integration operations which favor integrating ontologies from one context to another.

1 Contextual Differences and Semantic Irreconcilable Phenomena

In this section we discuss some of the semantic irreconcilable phenomena caused by contextual differences that we observed in the process of building a travel ontology by merging several ontologies from multiple different contexts. These phenomena show the need to provide a context mechanism for the semantic web ontology integration.

Phenomenon 1 (synonym and homonym) The designer of each ontology uses one' s own lexical labels to identify concepts and relations which results in the phenomena of synonyms and homonyms.

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Phenomenon 2 (class differences and property differences) Different ontologies often use some particular classes and properties in different ways in different contexts.

Phenomenon 3 (attitude differences) A related phenomenon is that of an ontology having an implicit attitude.

Phenomenon 4 (points of view) More contextual differences occur when there are conflicting points of view.

Phenomenon 5 (approximation and accuracy) Approximation and accuracy is another contextual difference between ontologies.

2 Context-Driven Reconciliation Mechanism for Ontology Integration

We present the context mechanism based on our previous work about a context-based formalism—Context-SHOIQ (D+) DL[9] that is used for explicitly representing context.

2.1 Context-based formalism

The context of an ontology refers to the source it comes from. It can be any information used to characterize the situation of ontological elements (concepts and relations). The ontological source information is abstracted as a context.

There is not an explicit formalism definition of context for an ontology in the semantic web so far. In Ref. [9], we first defined a context-based formalism—Context-SHOIQ (D+) DL which is under the frame of SHOIQ (D+) DL, a kind of description logic underlying OWL DL, from the category theory point of view.

We use γ to denote a context. All the ontological elements (concepts and relations) are always defined within a context. For example, $\gamma.C$ indicates that the concept C is defined according to the context γ to restrict C within context γ.

In Ref. [9], Context-SHOIQ (D+) DL syntax and semantics are defined in detail, such as the definitions of context, subcontext, context sequence and context migration. Having the context-based formalism, we can explicitly represent context as a basis for the contextual ontology integration.

2.2 Migration rules and contextual integration operations

The context-based formalism provides us a metatheory to solve the semantically irreconcilable problems arising in the integration of ontologies from different contexts. Based on the formalism definitions of context above, we can extend the formalism in order to take into account the migration rules and the related contextual integration operations to assist in the integration of ontologies from one context to another.

For the sake of convenience in rendering descriptions in the remainder of this paper, we assume that in the process of ontology integration, we have a set of ontologies ($O_1, O_2, \ldots, O_n$; we call them source ontologies) that are going to be integrated into ontology O (we call it the target ontology).

First, we declare a new definition about the IntegrativeContext as follows:

Definition 1 (IntegrativeContext) Provided that several source ontologies ($O_1, O_2, \ldots, O_n$) from multiple different contexts are integrated into the target ontology O, these source ontologies correspond to their contexts $\gamma_1, \gamma_2, \ldots, \gamma_n$ which are called sourceContexts. The target ontology corresponds to its context γ which is called targetContext. We call the collection of targetContexts IntegrativeContext.

Here, these sourceContexts $\gamma_1, \gamma_2, \ldots, \gamma_n$ are also called the context sequence $\gamma_1, \gamma_2, \ldots, \gamma_n$.

An ontology is always in some context. The ontology can migrate between contexts, that is to say, it can immigrate to or emigrate from some contexts. Therefore, the process of ontology integration can be abstracted as context migration, and it can be denoted as $\gamma_1, \gamma_2, \ldots, \gamma_n \sim \gamma$.

We now introduce four migration rules that can be used to specify what should be imported into the IntegrativeContext. The migration rules are not exhaustive, but are adequate to cover the most common types of contextual differences that we discussed in section 1.

Definition 2 (InclusionRule) The rule constrains the IntegrativeContext to contain the full facts of what it imports. That is to say, for example, if InclusionRule ($\gamma_1 \sim \gamma$) (where γ_1 is a sourceContext, γ is a targetContext), then facts that are true in γ_1 are also true in γ. The defining axiom for it is as follows:

$$\gamma_1.\phi(x) \wedge \text{InclusionRule}(\gamma_1 \sim \gamma) \rightarrow \gamma.\phi(x) \quad (1)$$

where a free variable x is a formal ontological element (concept or relation); ϕ is an axiom or a fact[10]. The rule is the simplest form of migration.

Hereafter, we introduce some properties (sourceFilter, targetFilter, propFilter, propMapTo, propMapFrom) proposed in Ref. [8].

Definition 3 (SelectionRule) The rule explicitly specifies the ontological elements that should be directly imported from the sourceContext(s) to the targetContext. The defining axiom for it is as follows:

$\gamma.(\text{SelectionRule}(\gamma_i \sim \gamma) \wedge \text{sourceFilter}(\gamma_i) \wedge$

$$targetFilter(\gamma) \wedge propFilter(\phi)) \wedge \gamma_i.\phi(\gamma_i.x, \gamma.y) \rightarrow \gamma.\phi(x, y) \quad (2)$$

where $\gamma_i (i = 1, 2, \ldots, n)$ as sourceContext(s), and γ is a targetContext.

Sometimes, we might have a preference for one context over another. A preference rule serves for this situation which can either specify a total preference ordering on a list of sourceContexts or simply that one particular sourceContext is preferred over another. As with SelectionRule, a preference rule can be constrained to apply to only a particular context. For example, the ontology O_1 from γ_1 has more detailed information about more tourist attractions than O_2 from γ_2, but γ_2's data is more accurate. This preference rule allows us to combine γ_1 with γ_2, preferring γ_2 over γ_1 if both have values for a particular property for the same individual.

Definition 4 (PreferenceRule) The rule explicitly specifies a preference list of sourceContexts or one particular sourceContext that is preferred over another. The defining axiom for it is as follows:

$$\gamma\ (PreferenceRule(\gamma_i.\gamma_j \sim \gamma) \wedge sourceFilter(\gamma_i.\gamma_j) \wedge targetFilter(\gamma) \wedge propFilter(\phi)) \wedge \gamma_i.\phi(\gamma_i.x, \gamma.y) \wedge \gamma_j.\neg(\exists(\gamma.z)\ \phi(\gamma_j.x, \gamma.z) \wedge \gamma_j.x \neq \gamma.z) \rightarrow \gamma.\phi(x, y) \quad (3)$$

where $\gamma_i, \gamma_j (i, j = 1, 2, \ldots, n)$ are sourceContext(s), and γ is a targetContext.

One of the most common migrations required is to distinguish between different uses of the same term or to normalize the use of different terms for the same concept. These migration rules specify the source term and the target term. As with the SelectionRule, we can constrain the application of these mappings to specific phenomena such as synonyms and homonyms and class differences and property differences.

Definition 5 (MappingRule) The MappingRule can be used to distinguish synonyms and homonyms and class differences and property differences between contexts in the IntegrativeContext. The defining axiom for it is as follows:

$$\gamma.(MappingRule\ (\gamma_i \sim \gamma) \wedge sourceFilter(\gamma_i) \wedge targetFilter(\gamma) \wedge propMapTo(\phi_2) \wedge propMapFrom(\phi_1)) \wedge \gamma_i.\phi_1(\gamma_i.x, \gamma.y) \rightarrow \gamma.\phi_2(x, y) \quad (4)$$

where $\gamma_i (i = 1, 2, \ldots, n)$ are sourceContext(s), and γ is a targetContext.

The IntegrativeContext may have any number of migration rules defined above to be imported into it.

Having these definitions and the set of migration rules above, we can easily handle some semantic irreconcilable problems in the process of ontology integration. Depending on the number of migration rules necessary to be applied in the IntegrativeContext, three different levels of "integration operations" of increasing operational power can be distinguished. They are import, partial reconciliation, and full reconciliation.

Import is the weakest form of "integration operations". It can only support InclusionRule. It imports some ontological elements without any modifications, so it can only support limited kinds of interoperability.

Partial reconciliation has more integration operational power and it can support SelectionRule and PreferenceRule as well as InclusionRule. So it supports more extensive interoperability.

Full reconciliation provides a more complete integration operational power with all migration rules (InclusionRule, SelectionRule, PreferenceRule, and MappingRule). It requires more extensive changes or major reorganizations by selection, modification, transformation, adding or ignoring some ontological elements in the sourceContext(s). So, it can result in the most complete interoperability.

While not exhaustive, we believe these migration rules and related contextual integration operations are sufficient for solving many issues that arise in ontology integration on the semantic web. More importantly, this functionality can be incorporated into the semantic web with fairly small and simple additions to the existing standards.

3 Conclusion

The contextual differences cause semantic irreconcilable phenomena that pose challenges for ontology integration. In this paper we propose a context-driven reconciliation mechanism to handle some of these semantically irreconcilable problems. We avoid the generalist[3] construct in AI but provide a completely different context mechanism for the semantic web ontology integration. Our aim is to do some research for contextual ontology integration. This is only the beginning of exploring the contextual ontology integration for the semantic web, and many challenges such as how to apply migration rules and related integration operations need to be done by our future efforts.

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本体集成中上下文驱动协调

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摘要:为了解决本体集成中因上下文的不同所引起的语义不协调的问题,提出了一个上下文驱动的协调机制. 该机制基于先前的工作,即一种基于上下文的形式化 Context-SHOIQ(D+)DL,采用描述逻辑和范畴论显示表示本体的上下文信息. 为了扩展这个形式化,添加了 4 个迁移规则(包含、选择、优先和映射规则),用来规定输入到集成上下文中的内容;还添加了 3 个互操作能力依次递增的上下文集成操作(输入、部分协调和完全协调). 该机制不是完备的,但足以解决提出的 5 种语义不协调的问题,有助于本体从一个上下文集成到另一个上下文.

关键词:语义 web;上下文;协调;本体集成;迁移规则

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