Ontology Transformation in Multiple Domains

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Abstract. We have proposed a new approach called *ontology services-driven integration of business intelligence* (BI) to designing an integrated BI platform. In such a BI platform, multiple ontological domains may get involved, such as domains for business, reporting, data warehouse, and multiple underlying enterprise information systems. In general, ontologies in the above multiple domains are heterogeneous. So, a key issue emerges in the process of building an integrated BI platform, that is, how to support ontology transformation and mapping between multiple ontological domains. In this paper, we present semantic aggregations of semantic relationships and ontologies in one or multiple domains, and the ontological transformation from one domain to another. Rules for the above semantic aggregation and transformation are described. This work is the foundation for supporting BI analyses crossing multiple domains.

1 Introduction

Business Intelligence (BI) [1] is getting more and more popular for scientific decision making with comprehensive analyses on top of practical Business/Operation Support Systems (BSS/OSS). The usual approach to building a BI platform is to combine all BI packages such as reporting, Data Warehouse (DW) and Data Mining (DM) engines together on top of the above mentioned Enterprise Information Systems (EIS). We have analyzed [2] that this approach cannot make its business users satisfied with some key challenges. Two main problems are (i) it can only support technology-centered but not business-oriented personalization and localization, (ii) it cannot adapt to dynamic and emergent requests on both analytical model and underlying operational systems. To figure out the above problems, we have further proposed a new approach called *ontology* [4] *services-driven integration of business intelligence* [2, 3] to building an integrated BI platform.

The basic idea for *ontology services-driven integration of business intelligence* is as follows [2, 3]. Since it is regarded as unfriendly for business persons to interact with the current technology-centered BI packages, we re-build a logic link and communication channel which links reporting, DW and DM together. This channel is isolated from the existing linkage among reporting engine, DW engine and EIS; the objective of it is to handle business-oriented rather than technology-centered interaction and integration of BI. This channel actually links the following ontological

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domains together [2]: a Business Ontology domain (BO) for business profiles, a DW Ontology domain (DWO) for the DW, and multiple EIS Ontology domains (EISO) for different BSS/OSS systems. Obviously, ontologies in these ontological domains are heterogeneous in an integrated BI platform.

In the above integration of BI, a key issue for its successful operations is that flexible and efficient transformation, mapping [5] and discovery of ontologies can be dealt with between the above heterogeneous ontological domains. In this paper, we discuss a foundation work about semantic aggregation and ontological transformation. The rules for the aggregation and transformation are discussed. Semantic aggregation gets involved in aggregation of semantic relationships or of ontologies in one or multiple domains. Transformation supports ontological mapping from one ontological item to another in multiple ontological domains.

The sequel of this paper is organized as follows. In Section 2, ontology semantic relationships are introduced. Section 3 presents semantic aggregation and ontological transformation in the BI platform. We conclude this study and discuss about the future work in Section 4.

2 Ontology Semantic Relationships

Before undertaking ontological mapping, two steps must be performed: (i) extraction and collection of ontological elements from the above-mentioned ontological domains, and (ii) organization and management of these ontological elements in a structured manner. With regard to (ii), the analysis of semantic relationships is quite important. Semantic relationships [6] refer to semantic dependencies between ontological elements (or called ontological items or concepts) in the same domain and between different domains.

The following summarizes seven types of semantic relationships for managing ontological items in a BI system. They are Instantiation, Aggregation, Generalization, Substitution, Disjoin, Overlap and Association, respectively. Informal definitions of them are given below; the symbol *O* or *o* refers to an ontological element.

- ***Instance_of* (*O, o*):** two ontological elements *O* and *o*, *o* is an instance of the ontological class *O*.
- ***Part_of* (O_1, O_2):** two ontological elements O_1 and O_2, where O_2 *is part/member of* O_1, *or* O_1 *is made of* O_2.
- ***Is_a*(O_1, O_2):** the relationship between *O2* and *O1* is subtype/supertype or assubsumption, i.e. O_2 is-a O_1, or O_2 is a kind of O_1. The *is_a* sometimes is also called as *subclass_of.*
- ***Similar_to*(O_1, O_2):** it stands for that O_1 and O_2 are identical or to a large degree similar; in this case O_2 can be substituted by O_1.
- ***Disjoin_with*(O_1, O_2):** it stands for that O_2 is independent of O_1.
- ***Overlap_to*(O_1, O_2):** it represents that there is something shared by both O_1 and O_2; but the share percentage is not high enough for one to be substituted by another.
- ***Relate_to*(O_1,O_2):** it is the predicate over the ontology O_1 and O_2; it represents a relationship between O_1 and O_2 which cannot be specified by any of the above six; in this case, O_1 and O_2 are associated with each other by some linkage defined by users.

3 Ontological Semantic Aggregation and Transformation

The process of a BI analysis in the integrated BI platform looks as follows. A business analyst first selects an analytical subject and relevant method according to her/his interestingness and the business requirements of the analytical problem. Then s/he specifies analytical dimensions and measures in the forms of her/his favorite business words. These arbitrary keywords are transformed to business ontologies first, and then mapped to target ontological elements in the target domain to extract/aggregate relevant data. The resulting query reports are fed back to the analyst in the predefined business terms.

Semantic aggregation and ontological transformation must be performed in the above analytical process, so that the analysis can be undertaken. There are three aspects which must be followed in order to do the semantic aggregation and ontological transformation from user-defined keywords to ontological elements in the DWO or any domain of the EISO. They are (i) semantic aggregation between semantic relationships, (ii) semantic aggregation of ontological items, and (iii) transformation of an ontology item to another one. All the above three types of transformations can be involved in either one ontological domain or multiple domains. The following three sections discuss them in details, respectively.

3.1 Semantic Aggregation of Semantic Relationships

The semantic aggregation of semantic relationships is to study whether there are transitivity, additivity and antisymmetry that can be performed between ontological semantic relationships. The aggregation of multiple semantic relationships can simplify the combination of semantic relationships, and supports to find the final reduced semantic relationship.

Let $A(a)$, $B(b)$ and $C(c)$ be arbitrary ontological items, where $A(a)$ means A or a. s, s_1, s_2 are Similarity Value defined by users. The following defines some basic specifications.

DEFINITION 1. 'AND' or 'OR' are logic connectors used to connect two ontological items which have the same grammatical function in a construction;

DEFINITION 2. The resulting output of '(A AND B)' includes both A and B, while the output of '(A OR B)' is either A or B.

DEFINITION 3. '(A AND B)' is equal to '(B AND A)'; similarly, '(A OR B)' is equal to '(B OR A)'.

DEFINITION 4. Boolean logic operators '$\wedge$' and '$\vee$' represent "and" and "or" relationships between semantic relationships or between logic formulas.

DEFINITION 5. Similarity value s measures to what degree that two ontological items are related in a semantic relationship.

This metric s usually is used with relationships *similar_to*(), *overlap_to*(), and user-defined relationship *relate_to*(). For instance, *similar_to* (A, B, s_1) means that B is similar to A in a degree of s_1.

For all the seven semantic relationships discussed in Section 2, rules will hold for semantic aggregation of combinations of the above semantic relationships. The following shows an excerpt for some cases.

Rule 1. Let $A(a)$, $B(b)$ and $C(c)$ be associated by the Instantiation relationship, then

- $\forall$ (*instance_of* $(A, a) \wedge$ *instance_of* $(B, A)) \Rightarrow$ *instance_of* (B, a)
- $\forall$ (*instance_of* $(A, a) \wedge$ *instance_of* $(B, a)) \Rightarrow$ *instance_of* $((A$ AND $B), a)$, which means a is an instance of both A and B

Rule 2. Let A, B and C be associated by the Aggregation relationship, then

- $\forall$ (*part_of* $(A, B) \wedge$ *part_of* $(B, C)) \Rightarrow$ *part_of* (A, C)
- $\forall$ (*part_of* $(A, B) \wedge$ *part_of* $(B, A)) \Rightarrow$ *similar_to*(A, B)
- $\forall$ (*part_of* $(A, B) \wedge$ *part_of* $(C, B)) \Rightarrow$ *overlap_to*$(A, C) \vee$ *similar_to*(A, C) depend on the intersection between A and C.

Rule 3. A, B and C be associated by the Generalization relationship, then

- $\forall$ (*is_a*$(A, B) \wedge$ *is_a* $(B, C)) \Rightarrow$ *is_a*(A, C)
- $\forall$ (*is_a*$(A, B) \wedge$ *is_a*$(A, C)) \Rightarrow$ *is_a*$(A, (B$ AND $C))$
- $\forall$ (*is_a*$(A, B) \wedge$ *is_a*$(B, A)) \Rightarrow$ *similar_to*(A, B)

Rule 4. A, B and C be associated by the Substitution relationship, then

- $\forall$ (*similar_to* $(A, B) \wedge$ *similar_to* $(B, C)) \Rightarrow$ *similar_to* (A, C)
- $\forall$ (*similar_to* $(A, B) \wedge$ *similar_to* $(A, C)) \Rightarrow$ *similar_to* (B, C)

Rule 5. A, B and C be associated by the Overlap relationship, then

- $\forall$ (*overlap_to* $(A, B) \wedge$ *overlap_to* $(B, C)) \Rightarrow$ *overlap_to* $(B, (A$ AND $C))$

Accordingly, we can list many other aggregation rules for reducing the combinations of the seven semantic relationships.

3.2 Semantic Aggregation of Ontological Items

Another situation for semantic aggregation is to aggregate ontological items that are linked by logic connectors associated with some semantic relationship. The objective for semantic aggregation of ontological items is to reduce items, and to generate the resulting ontological items.

To the above end, rules for aggregating ontological items can be found. The following rules hold for semantic aggregation in some cases. These rules define what the resulting logical output is for each given input logical combination with some semantic relationship inside.

Rule 6

- $\forall$ $(A$ AND $b)$, $\exists$ b ::= *instance_of*(B, b)
  $\Rightarrow A$ AND B, the logical resulting output is A and B
- $\forall$ $(A$ OR $b)$, $\exists$ b ::= *instance_of*(B, b)
  $\Rightarrow A$ OR B, the logical resulting output is A or B

Rule 7

- $\forall$ $(A$ AND $B)$, $\exists$ B ::= *part_of*(A, B)
  $\Rightarrow B$, the resulting output is B

Rule 8

- $\forall$ $(A$ AND $B)$, $\exists$ B ::= *is_a*(A, B)
  $\Rightarrow B$, the resulting output is B

Rule 9

- ∀ (A AND B), ∃ B ::= *similar_to*(A, B)
  ⇒ A OR B, the resulting output is A or B

Rule 10

- ∀ (A AND B), ∃ B ::= *disjoin_to*(A, B)
  ⇒ A AND B, the resulting output is A and B

Rule 11

- ∀ (A AND B), ∃ B ::= *overlap_to*(A, B)
  ⇒ A AND B, the resulting output is A and B

Rule 12

- ∀ (A AND B), ∃ B ::= *relate_to*(A, B)
  ⇒ (A AND B) ∨ (A OR B), the resulting output is A and B, or either A or B, one of the three output will hold depending on user-defined relationship

3.3 Transformation Between Ontological Items

This section discusses about the transformation of an ontological item to another one. This could be a mapping from an arbitrary keyword to its relevant items in BO domain, or from BO to another domain such as DWO or one of EISO domain. The basic idea for transformation of ontological items is as follows: given an input item, checking candidate ontological items by semantic relationships, and finding the suitable candidate as the output item.

Rules for this transformation must be built, so that the matched ontological item can be generated as output. The following lists some rules for the transformation, where C_i is an input item, O, O_1 and O_2 are candidate items in the target domain.

Rule 13

- $\forall C_i$, ∃: (*similar_to*(O, C_i) ∨ *is_a*(O, C_i) ∨ *instance_of*(O, C_i) ∨ *part_of*(O, C_i) ∨ *relate_to*(O, C_i)) ⇒ O, the O is the output item

Rule 14

- $\forall C_i$, ∃: (*is_a*(O_1, C_i) ∧ *is_a*(O_2, C_i)) ⇒ O_1 AND O_2

Rule 15

- $\forall C_i$, ∃: (*part_of*(O_1, C_i) ∧ *part_of*(O_2, C_i)) ⇒ O_1 OR O_2

Rule 16

- $\forall C_i$, ∃: (*is_a*(O_1, C_i) ∧ *part_of*(O_2, C_i)) ⇒ O_1 AND O_2

Rule 17

- $\forall C_i$, ∃: (*similar_to*(O_1, C_i) ∧ *similar_to*(O_2, C_i)) ⇒ O_1 OR O_2

Rule 18

- $\forall C_i$, C_j, ($i \neq j$), ∃: (*part_of*(O, C_i) ∧ *part_of*(O, C_j)) ⇒ O

Rule 19

- $\forall C_i$, C_j, ($i \neq j$), ∃: (*is_a*(O, C_i) ∧ *is_a*(O, C_j)) ⇒ O

Rule 20

- $\forall C_i$, C_j, ($i \neq j$), ∃: (*relate_to*(O, C_i) ∧ *relate_to*(O, C_j)) ⇒ O

4 Conclusions and Future Work

There are multiple heterogeneous ontological domains existing in our proposed ontology-based integrated BI platform. In this paper, we have discussed about