Toward semantic interoperability with linked foundational ontologies in ROMULUS

Zubeida Casmod Khan
School of Mathematics, Statistics, and Computer Science, University of KwaZulu-Natal, and UKZN/CSIR-Meraka Centre for Artificial Intelligence Research, South Africa
zkhan@csir.co.za

C. Maria Keet
School of Mathematics, Statistics, and Computer Science, University of KwaZulu-Natal, and UKZN/CSIR-Meraka Centre for Artificial Intelligence Research, South Africa
keet@ukzn.ac.za

ABSTRACT

A purpose of a foundational ontology is to solve interoperability issues among ontologies. Many foundational ontologies have been developed, re-introducing the ontology interoperability problem. We address this with the new online foundational ontology repository ROMULUS, in which DOLCE, BFO and GFO have been aligned. We summarise the alignments, mappings, and logical inconsistencies of the foundational ontologies, and ROMULUS's features.

Categories and Subject Descriptors

M.8 [**Knowledge Reuse**]: Miscellaneous; I.2.4 [**Knowledge Representation Formalisms and Methods**]: Knowledge base management

Keywords

Ontology engineering, Ontology Repository, Ontology Matching

1. INTRODUCTION

A foundational ontology (FO) provides the developer with guidance on how to model entities in a domain ontology, which speeds up ontology development [4], and it can be used for networked ontologies and integration of domain ontologies. Over the years, several FOs have been developed, such as DOLCE [6], GFO [2], and BFO (`http://www.ifomis.org/bfo`), which have been used to improve domain ontology development (e.g., [3, 7]). However, ontology developers use their preferred FOs yet may need to link to another ontology that is aligned to a different FO. Thus, the semantic interoperability problem has been re-introduced at a more abstract level. A solution was envisioned as the "WonderWeb Foundational Ontologies Library" (WFOL), to allow different ontologies to commit to different but systematically related FOs [6]. However, this library was not implemented due to theoretical and usage gaps at the time. We propose to solve those theoretical and practical shortcomings through the creation of the first such online library of machine-processable, aligned and merged, FOs: the Repository of Ontologies for MULtiple USes ROMULUS, which can be accessed at `http://www.thezfiles.co.za/ROMULUS`.

K-CAP '13, June 23-26, 2013, Banff, Canada.

2. FO MEDIATION

Ontology mediation is made up of three processes: alignment, mapping and merging [1]. Alignment deals with identifying correspondences between entities in isolation, whereas correspondences are created and ontologies integrated during mapping and merging.

2.1 Alignment

We performed ontology alignments on BFO, DOCLE, and GFO with seven matching tools and manually; the tools' accuracy results are included in Table 1. In total, there are 35 manual alignments for DOLCE↔GFO, 17 for DOLCE↔BFORO, and 23 for GFO↔BFORO, which we used as a gold standard for comparison with the output of the tools. Many inaccurate alignments were generated by H-Match and PROMPT, such as dolce:state to bfo:Site and bfo:Role to gfo:Set, some due clearly to string matching issues. The ontology alignment initiative (OAEI) tools performed better, although common incorrect alignments include dolce:part to gfo:has_part and bfo:IndependentContinuant to gfo:Independent.

Table 1: Number of accurate over total alignments found; D = DOLCE, B = BFO, G = GFO.

Matching tool	D↔B	D↔G	B↔G
H-Match	4/16	4/25	5/31
PROMPT	3/8	8/12	7/12
LogMap	2/2	3/3	11/12
YAM++	4/4	13/25	6/7
HotMatch	3/3	10/12	7/7
Hertuda	3/3	11/13	7/7
Optima	4/13	7/39	9/17

2.2 Mapping and resolving inconsistencies

Alignment does not take the entity in context with other axioms in the respective ontologies. When two entities in isolation may appear to be the same based on their descriptions, they may not be due to their position in the hierarchy or some other axiom (e.g., class complement), such as a disjointness constraint. Attempting to map ontologies

Table 2: Logically consistent mappings between DOLCE, GFO, and BFO 'classes' in their OWL files.

	DOLCE	GFO
1.	particular	Individual
2.	endurant	Presential
3.	physical-object	Material_object
4.	amount-of-matter	Amount_of_substrate
5.	perdurant	Occurrent
6.	process	Process
7.	state	State
8.	abstract	Abstract
9.	quality	Property

	DOLCE	BFO
1.	endurant	IndependentContinuant
2.	physical-endurant	MaterialEntity
3.	physical-object	Object
4.	perdurant	Occurrent
5.	process	Process
6.	quality	Quality
7.	space-region	SpatialRegion

	BFO	GFO
1.	Entity	Entity
2.	IndependentContinuant	Presential
3.	Object	Material_object
4.	ObjectBoundary	Material_boundary
5.	Function	Function
6.	Occurrent	Occurrent
7.	Process	Process
8.	Quality	Property
9.	SpatialRegion	Spatial_region

based on the alignments reveals such incompatibilities. For the mappings, we take a logic-based approach, and map each alignment from higher to lower in the hierarchy as long as the combined ontology remains consistent. There are only 13 successful mappings for DOLCE↔GFO, 11 for DOLCE↔BFORO, and 16 for GFO↔BFORO. Table 2 shows the list of entity ('OWL class') mappings of the ontology pairs of the three base FOs; all alignments and mappings (including those between other modules and relational properties) can be accessed at the ROMULUS repository.

From a research point of view, the alignments that lead to an inconsistency are the most interesting. We illustrate two such unresolvable cases; the full list of inconsistencies is available in ROMULUS. *I. Nonmappable Set.* dolce:Set is a subclass of dolce:Abstract, which is declared to be aligned with gfo:Abstract, but gfo:Abstract $\sqsubseteq$ gfo:Item and gfo:Item $\sqsubseteq \neg$gfo:Set. *II. Incompatible temporal regions.* The issue with incompatible temporal regions between BFO, GFO, and DOLCE is a result of the DisjointClasses class axiom between gfo:Concrete, gfo:Space_Time and gfo:Abstract, and between dolce:Abstract and dolce:Perdurant, or: because BFO made TemporalRegion an Occurrent, DOLCE made it Abstract, and GFO neither. Some incompatibilities can be resolved by using subsumption instead of equivalence axioms. One such case is that of BFO's and GFO's aligned Role, which results in an inconsistency due to one of GFO's subclasses of Role: i) GFO's Processual_role is a subclass of both Role and Process, Process $\sqsubseteq$ Occurrent, and both Role and Occurrent are subclasses of Concrete, however, ii) gfo:Occurrent $\equiv$ bfo:Occurrent, and bfo:Occurrent $\sqsubseteq \neg$bfo:Continuant but bfo:Role $\sqsubseteq$ bfo:Continuant, so that an assertion gfo:Role $\equiv$ bfo:Role will make Processual_role unsatisfiable. Instead of changing any axioms in either of the ontologies, one can assert subsumption alignments and mappings for the other two subclasses of Role in GFO: i.e., gfo:Relational_role $\sqsubseteq$ bfo:Role and gfo:Social_role $\sqsubseteq$ bfo:Role.

3. THE REPOSITORY OF ONTOLOGIES FOR MULTIPLE USES

We have created the web-based FO repository ROMULUS that contains modularised, aligned, and logic-based merged foundational ontologies. ROMULUS' features include, among others, online ontology browsing with WebProtégé, the use of Ontology Metadata Vocabulary elements for the ontologies' metadata, FO comparison and selection with ONSET [5], all alignments and mappings, and a catalogue of the logical inconsistencies with their explanations.

4. CONCLUSIONS

The alignment of the DOLCE, BFO and GFO foundational ontologies resulted in 35 manual equivalence alignments for DOLCE↔GFO, 17 for DOLCE↔BFORO, and 23 for GFO↔BFORO, with substantially fewer alignments found by the tested matching tools. Mapping the alignments in the context of the whole ontology revealed a considerable amount of logical inconsistencies, therewith decreasing the successful mappings to 13, 11, and 16, respectively. The ontologies, carefully crafted modules thereof, and the pairwise mapped ontologies have been made available in the new online library of machine-processable foundational ontologies, ROMULUS.

5. REFERENCES

[1] J. de Bruijn et al. Ontology mediation, merging, and aligning. In *Semantic Web Technologies*, pages 1–20. Wiley Online Library, 2006.

[2] H. Herre. General Formal Ontology (GFO): A foundational ontology for conceptual modelling. In *Theory and Applications of Ontology: Computer Applications*, chapter 14, pages 297–345. Springer, 2010.

[3] I. J. Jureta, J. Mylopoulos, and S. Faulkner. A core ontology for requirements. *Applied Ontology*, 4(3-4):169–244, Aug. 2009.

[4] C. M. Keet. The use of foundational ontologies in ontology development: an empirical assessment. In *Proc. of ESWC'11*, volume 6643 of *LNCS*, pages 321–335. Springer, 2011.

[5] Z. Khan and C. M. Keet. ONSET: Automated foundational ontology selection and explanation. In *Proc. of EKAW'12*, volume 7603 of *LNAI*, pages 237–251. Springer, 2012.

[6] C. Masolo, S. Borgo, A. Gangemi, N. Guarino, and A. Oltramari. Ontology library. WonderWeb Deliverable D18 (ver. 1.0, 31-12-2003)., 2003. http://wonderweb.semanticweb.org.

[7] B. Smith et al. The OBO Foundry: Coordinated evolution of ontologies to support biomedical data integration. *Nature Biotech.*, 25(11):1251–1255, 2007.