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Guest Editorial

Modularity in ontologies

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1. The landscape of modular ontologies

In the past 10 years, modularity has been established as a central research topic in ontology engineering. Several approaches and techniques have been investigated and developed in detail to characterise and deal with modularity (Stuckenschmidt et al., 2009). Theoretical as well as practical aspects of modularity have become essential to the design of ontologies. They aim at reducing complexity, improving maintenance, and support reasoning over modules (Kutz et al., 2010). However, the field is still highly active and widely accepted solutions are yet to be determined. The 4 articles in this Special Issue present thoroughly investigated approaches that contribute to modularity in ontologies on quite distinct, but equally important layers, which we will sketch below in more detail.

The number of ontologies available nowadays, as well as their size, is steadily increasing. There is a large variation in subject matter, level of specification and detail, intended purpose and application. Ontologies covering several domains at once are often developed in a distributed manner addressing the various aspects, but also such that contributions from distinct sources may be relevant for different parts of a single domain. Not only is it difficult to determine and define interrelations between such distributed ontologies, it is also challenging to reconcile ontologies that might be consistent on their own but jointly inconsistent. Further challenges include extracting the relevant parts of an ontology, re-combining independently developed ontologies in order to form new ones, determining the modular structure of an ontology for comprehension, and the use of ontology modules to facilitate incremental reasoning and version control.

Still catching up with 40 years of related research in software engineering (cf., e.g., Parnas, 1972; DeRemer & Kron, 1975), modularity in ontologies is envisaged to allow mechanisms for easy and flexible reuse, generalisation, structuring, maintenance, collaboration, design patterns and comprehension (Baldwin & Clark, 2000). Applied to ontology engineering, modularity is central not only to reducing the complexity of understanding ontologies, but also to maintaining, querying and reasoning over modules. Distinctions between modules can be drawn on the basis of structural, semantic, or functional aspects, which can also be applied to compositions of ontologies or to indicate links between ontologies.

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In particular, reuse and sharing of information and resources across ontologies depend on purpose-specific, logically versatile criteria. Such purposes include ‘tight’ logical integration of different ontologies (wholly or in part), ‘loose’ association and information exchange, the detection of overlapping parts, traversing through different ontologies, alignment of vocabularies, as well as module extraction possibly respecting privacy concerns and hiding of information, etc. Another important aspect of modularity in ontologies is the problem of evaluating the quality of single modules or of the achieved overall modularisation of an ontology. Again, such evaluations can be based on various (semantic or syntactic) criteria and employ a variety of statistical/heuristic or logical methods.

Recent research on ontology modularity has produced substantial results and approaches towards foundations of modularity, techniques of modularisation and modular developments, distributed and incremental reasoning, as well as the use of modules in different application scenarios, providing a foundation for further research and development.

2. WoMO: The Workshops on Modular Ontologies

This Special Issue began to take shape during the planning of the *4th International Workshop on Modular Ontologies (WoMO 2010)*. Since the beginning of the WoMO workshop series in 2006, there has been steadily growing interest and awareness in modularisation problems related to ontologies, in particular concerning modular development of ontologies and information exchange across different modular ontologies. In real life, however, integration problems are still often tackled in an ad-hoc manner, with no clear notion of what to expect from the resulting ontological structure. Such unprincipled approaches often lead to unintended consequences, even if the individual ontologies to be integrated are widely tested and understood. Therefore, the progress that has been made concerning several technical aspects of modularity has yet to be matched by a similar sophistication in the actual practice of employing modular approaches in ontology engineering.

As a consequence, these topics have been discussed throughout the WoMO workshop series, starting in 2006 when the workshop was co-located with ISWC (Athens, GA, USA). Back then, the idea of heterogeneous specifications and the need for logical modules was discussed (Haase et al., 2006), and a special focus was on so-called modular ontology languages such as distributed description logics DDL (Borgida & Serafini, 2003), packaged-based description logics (Bao et al., 2006) and $\mathcal{E}$-connections (Kutz et al., 2004). In 2007, the WoMO workshop was organised as part of the conference K-CAP (Whistler, BC, Canada). Contributions to this workshop concentrated on the variety of transformations and layers as well as different types of modularity and modularisation (Cuenca Grau et al., 2007). The following workshop in 2008, co-located with ESWC 2008 (Tenerife, Spain), had an emphasis on reasoning with and querying over modular ontologies, showing applications and tools (Sattler & Tamilin, 2008). WoMO 2010 took place in co-location with the FOIS conference (Toronto, Canada), where large-scale ontology modularisation and metrics were presented as well as applications and empirical studies (Kutz et al., 2010). The fifth workshop of the WoMO series took place as part of the ESSLLI summer school in 2011 (Ljubljana, Slovenia). Among other topics, contributions presented algorithms for the design and maintenance of modular ontologies (Kutz & Schneider, 2011).

The *6th International Workshop on Modular Ontologies* is co-located with FOIS 2012 (Graz, Austria). The continuity of this workshop series confirms its relevance and significance, and the events have been an excellent venue for practitioners and researchers to discuss latest work and current problems. They are intended to consolidate cutting-edge approaches that tackle problems associated with modularity in formal ontology, broadly understood, and bring together researchers from different disciplines who study the problem of modularity in ontologies at a fundamental level, develop design tools for distributed ontology engineering, and apply modularity in different use cases and application scenarios.

The interdisciplinarity of the WoMO workshops is very much in the spirit of the International Association for Ontology and its Applications (IAOA), and WoMO has accordingly been a supported event of IAOA since 2011.[1] Starting in 2012, the WoMO workshop series finds a new permanent home as an event organised under the auspices of IAOA (WoMO, 2012).

3. Contributions to this Special Issue

After a thorough reviewing process, we accepted 4 papers for publication covering a wide range of topics associated with modularity in ontologies, from studying the OWL imports mechanism to support modular design, to ABox modularisation in description logics, modularity in repositories, as well as a study of the module concept in Common Logic. In more detail:

Techniques for the modular development of large ontologies covering several subdomains are the focus of "Engineering use cases for modular development of ontologies in OWL" by Alan Rector, Matthew Horridge, Nick Drummond, Colin Pulestin, Sebastian Brandt and Robert Stevens. Inspired by software engineering, the article distinguishes different types of use cases for modularity in ontologies, namely organization/factoring, interfaces/bindings, localization and extension/encapsulation. The approach is focused on OWL ontologies and thus discusses in detail its import mechanism, its advantages and disadvantages, with examples drawn from the biomedical domain.

The article "Towards ABox modularisation of semi-expressive description logics" by Sebastian Wandelt and Ralf Möller is concerned with the problem of querying very large sets of assertional statements associated with an ontology. Modularisation techniques are introduced that particularly aim at the reduction of instance checking cost by considering smaller subsets of relevant axioms and increasing the granularity of modules. The contribution focuses on the logic $\mathcal{SHI}$, which is stronger than typical lightweight DLs such as $\mathcal{EL}$. It defines 'individual islands' that can be used for sound and complete instance checking. Their experimental results and benchmarks show that reasoning performance can be improved by using modularisation techniques.

Michael Gruninger, Torsten Hahmann, Ali Hashemi, Darren Ong and Atalay Ozgovde present how the research topics of ontology modularity and ontology repositories can be combined in their article "Modular first-order ontologies via repositories". Their focus is on first-order ontologies and specific types of modularity, namely non-conservative extension and relative interpretation. They discuss semi-automated procedures to decompose ontologies into irreducible ontology modules, for which the authors introduce the definition of core hierarchies. As a result, the proposed method allows the definition of modules that can be shared and reused among different ontologies.

In "Common Logic and the Horatio problem", Fabian Neuhaus and Pat Hayes introduce a refinement of the semantics of modules in Common Logic, a framework for a family of languages based on first-order logic. Modules are a syntactic category in the Common Logic standard ISO/IEC 24707. In this article, the 'incongruent' definition of the semantics of modules given in the standard is adapted to deal with the so-called 'Horatio problem': the problem to reuse an ontology module within an ontology with a different, larger domain. The authors introduce a module operator based on quantifier restriction, discuss its most important logical properties, and show that the operator can be eliminated from the language, thus not extending the logic itself.

[1] See http://iaoa.org/.

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