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Editorial: Formal Ontologies meet Industry

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The Formal Ontologies meet Industry (FOMI) workshop series is a scientific initiative supported by the International Association for Ontology and its Applications (IAOA)[†] aimed at bringing together academics and practitioners interested in ontologies for industry. FOMI addresses research and application topics concerning, e.g., the design of domain-specific ontologies, the development of ontology-based information systems, or the investigation of the theoretical underpinnings of formal ontology when tuned to engineering applications.

As documented in the literature (see, e.g., [5][7]), some of the key motivations for using ontology in engineering are:

- To enable knowledge sharing across multiple human or software agents.
- To tackle semantic interoperability among computer-based systems and data sources.
- To capitalize experts' knowledge using formal axioms that are accessible to machines.
- To support knowledge and data visualization.
- To maintain a cut-off distinction between (reusable) domain knowledge and application-dependent, sometimes even proprietary, knowledge.

In short, from an engineering perspective, ontologies are interesting tools because they represent reference knowledge models that can be shared by various systems and communities to guarantee a smooth interaction in tasks related to data sharing or knowledge management.

The importance of ontologies in industry is demonstrated by European and national research programmes but also by past and ongoing international initiatives such as the Ontology Based Engineering (OBE) Group [1], the Industrial Ontologies Foundry (IOF)[‡], and the W3C Linked Building Data Community Group[§]. However, several research priorities related to technological and methodological gaps between academic studies and industrial practices remain to be addressed to fully exploit the potential of ontology engineering approaches and technologies.

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Examples of such priorities concern:

- The development and (re-)use of standard and inter-connected ontologies, both upper- and domain-level ontologies.
- A library of modelling alternatives, e.g., in the form of ontology design patterns, tuned to engineering representational needs. The purpose is to avoid the proliferation of modelling mistakes and, therefore, to foster the development of well-defined ontologies.
- The need of more efficient and effective software environments to support the various phases in the lifecycle of an ontology-based software tool.
- The development of high performing reasoners, as well as mature case studies concerning the use of reasoning inferencing mechanisms to tackle real-world problems.

In order to foster the adoption of ontology-based technologies in industrial application contexts, it is also needed the willingness of stakeholders to collaborate with universities and research centres with an open-minded aptitude. Ontology development is challenging because it requires a collaborative interaction between ontology engineers, domain experts, software engineers, database managers, and data analysts. If industrial practitioners are not willing to share their knowledge, ideas, and problems, then researchers can hardly support any advancement in the technologies and methodologies they adopt.

For the 10th edition, FOMI was hosted by the Changeable, Agile, Reconfigurable and Virtual Production (CARV) conference. For this reason, the workshop was explicitly focused on ontologies for manufacturing, including product design, process planning, manufacturing system design, layout planning, production planning, and maintenance. The call for paper stressed the need of ontology-based applications for factories of the future [12] adopting *Industry 4.0 enabling technologies* like digital factory, cloud computing, Internet of Things, Cyber-Physical Systems, robotics, virtual and augmented reality, among others. Also, call explicitly asked companies working with ontology-based systems to share their experiences in developing or using ontologies.

A total of six papers have been presented at FOMI 2018. In both the academic and industrial community, we note an interest for foundational ontologies to clarify the semantic of the represented notions, and develop domain or application ontologies on the basis of rigorous modelling principles. Three different foundational ontologies are used in three papers, i.e., the *Descriptive Ontology for Cognitive and Linguistic Engineering* (DOLCE) [9] (see [2]), the *Unified Foundational Ontology* (UFO) [6] (see [3]), and the *Basic Formal Ontology* (BFO) [1] (see [4]).

Benavent et al. [2] present a preliminary restructuring of the ontologies *Product and Processes Development Resource Capability* (PPDRC) and *Manufacturing and Inspection Resource Capability* (MIRC) on the basis of DOLCE. According to the authors, the restructuring is due to the need of spelling out clearly the basic modelling assumptions behind both PPDRC and MIRC. An example is the distinction between roles and their bearers, which is useful in manufacturing to model physical objects like drillers and the *resource role* they possibly play.

Cao et al. [3] present a core ontology, called *CM-core*, for condition monitoring. This work is contextualized within the Industry 4.0 vision with the idea of using the ontology to facilitate the exchange of condition monitoring data. Differently from existing works, *CM-core* is developed independently from specific application settings in such a way to facilitate its reuse, hence to foster the interoperability of condition monitoring data and applications. The ontology has been designed by relying on industrial standards and previously developed ontologies. Also, from an upper-level perspective, it relies on UFO.

Mas et al. [8] discuss a preliminary ontology developed at Airbus for applications in the aerospace domain. The presented work is framed within a model-based approach in design and manufacturing aimed at enabling the homogeneous handling of data across multiple applications. The ontology is meant to be applied in a Product Lifecycle Management (PLM) system to handle aerospace data through the entire product lifecycle.

Negri et al. [10] present an ontology-based approach for supporting the generation and integration of simulation tools aimed at evaluating the performance of manufacturing systems via Discrete Event Simulation (DES). A semantic data model is used to develop a digital twin of evolving manufacturing systems, thus enhancing the exploitation of other digital technologies such as cloud computing and Cyber Physical Systems (CPS). The approach is tested on lab-scale pilot plant dedicated to the assembly of mobile phones.

Schneider et al. [11] address how a domain ontology for Finite State Machine (FSM) can be exploited to formalize knowledge about automation and control systems. Such formalization can help to support interoperability for industrial applications, in particular in the scope of Industry 4.0. The paper shows how a domain ontology enables a smooth conversion among different FSM formalisms while taking as a reference an industrial use case.

Cheong [4] proposes a method to validate JSON by exploiting state-of-the-art ontology-based tools. The need of such validation stems from the ever growing use of JSON format to exchange among software applications in Industry 4.0 scenarios, particularly in the case of cloud platforms. However, this requires a challenging conversion from JSON schemas and data to the Web Ontology Language (OWL).

Finally, Table 1 presents the FOMI 2018 papers by mapping their contents against motivations to use formal ontologies, addressed ontology research priorities, and specific FOMI 2018 topics.

Table 1: Mapping of the FOMI 2018 papers

Paper	Motivations for ontology use	Ontology research priority	FOMI @CARV Focus
Benavent et al. [2]	Formal representation of engineering knowledge; alignment with foundational ontology	Development and use of domain ontologies	Product design, process planning, production planning
Cao et al. [3]	Semantic interoperability; formal representation of engineering knowledge; alignment with foundational ontology; Industry 4.0	Development and use of domain ontologies	Maintenance of manufacturing systems
Cheong [4]	Semantic interoperability; ontology-based software development; alignment with foundational ontology	Management of large amount of data	Ontology integration with Industry 4.0 technologies
Mas et al. [8]	Semantic interoperability; formal representation of engineering knowledge; ontology-based software development	Development and use of domain ontologies	Manufacturing system design; manufacturing use case
Negri et al. [10]	Semantic interoperability; Industry 4.0	Development and use of ontology-based applications	Ontology integration with Industry 4.0 technologies; manufacturing use case
Schneider et al. [11]	Semantic interoperability; separation of domain knowledge from proprietary systems	Use of domain ontologies	Ontology integration with Industry 4.0 technologies; manufacturing use case

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