Automatic Construction of OWL Ontologies From Petri Nets

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ABSTRACT

Ontology, as a formal representation method of domain knowledge, plays a particular important key role in semantic web. How to construct ontologies has become a key technology in the semantic web, especially constructing ontologies from existing domain knowledge. Currently, Petri nets have been a mathematical modeling tool, and have been widely studied and successfully applied in modeling of software engineering, database and artificial intelligence. In particular, PNML (Petri Net Markup Language) language has been a part of ISO/IEC Petri nets standard for representing and exchanging data on Petri nets. Therefore, how to construct ontologies from PNML model of Petri nets needs to be investigated. In this article, the authors investigate a method for automatic construction of web ontology language (OWL) ontologies from PNML of Petri nets. Firstly, this paper gives a formal definition and the semantics of PNML models of Petri nets. On this basis, a formal approach for constructing OWL ontologies from PNML model of Petri nets is proposed, i.e., this paper transforms Petri nets (including PNML model and PNML document of the Petri nets) into OWL ontologies at both structure and instance levels. Furthermore, the correctness of the transformation is proved. Finally, a prototype construction tool called PN2OWL is developed to transform Petri nets models into OWL ontologies automatically.

KEYWORDS

Construction, OWL ontologies, Petri nets, PNML, Semantic Web

1. INTRODUCTION

The semantic web is an extension of the WWW, which goal is to create machine-processing information on the Web (Antoniou & van Harmelen, 2004). Ontology, which is a World Wide Web Consortium (W3C) standard knowledge representation model for the Semantic Web, allows the semantics of a domain to be expressed in a language understood by computers, enabling automatic processing of the meaning of shared information (Berners-Lee, Hendler, & Lassila, 2001). Full implementation of the Semantic Web requires widespread availability of ontologies and ontology construction has become a key problem to enable the Semantic Web (Maedche & Steffen, 2001). However, constructing ontologies is a difficult and time-consuming process. Automatic construction of ontologies is hereby an effective way to overcome ontology developing bottleneck. In recent years, a lot of studies has been dedicated to the construction of ontologies from diverse existing domains (Zhou, 2007).

As we have known, many domains are modeled by various data models, including relational data model, object-oriented data model, XML data model, ER/EER (entity-relationship/extended entity-
relationship) data model, and UML (Unified Modeling Language) data model. Correspondingly, different approaches for constructing ontologies from various data models have been developed. Ontologies are automatically constructed, for example, by transforming relational databases (Lubyte and Tessaris, 2009), object-oriented databases (Zhang, Ma and Yan, 2011) and XML (Zhang and Ma, 2014). In addition, some conceptual data models are applied to automatically construct ontologies by transforming ER/EER data models (Han and Elmasri, 2003; Upadhyaya and Kumar, 2005; An, Mylopoulos and Borgida; 2006) and UML data models (Falkovych, Sabou and Stuckenschmidt, 2003; Xu et al., 2012).

In addition to various data models for domain modeling, Petri nets (Murata, 1989) have been proposed as a more precise way of modeling processes, which provide an abundance of analysis techniques to evaluate process modeling languages. Nowadays Petri nets have been widely investigated and successfully applied in many applications (e.g., mobile computing (Kahloul, Chaoui, & Djouani, 2015), smart homes (Nabih, Gomaa, Osman, & Aly, 2011), manufacturing systems (Chen, Li, Al-Ahmari, Wu, & Qu, 2017), business processes (Clempner, 2014; Kheldoun, Barkaoui, & Ioualalen, 2017), biology (Koch, 2015; Gogolinska, Jakubowski, & Nowak, 2016), and Web services (Cheng, Liu, Zhou, Zeng, & Ylä-Jääski, 2015)). Given the information resources of Petri nets in application domains, some efforts have been done to reuse/share Petri nets through the Semantic Web (Gašević & Devedžić, 2004). The approach in (Gašević & Devedžić, 2006) defined a Petri net ontology, which focuses on full semantic interoperability of Petri net models. In addition, Vidal, Lama, and Bugarin (2006) defined a high-level Petri net ontology. These two approaches above do not discuss the formal definition of Petri net and the correct proof of transformation rules, and do not implement a prototype construction tool. The mappings from Petri nets to OWL (Web Ontology Language) ontologies were established in (Zhang, Ma, and Ribaric, 2011), where the formal descriptions of Petri net models and OWL ontologies were presented but the comprehensive transformation rules and a prototype transformation tool were missing. A recent review of knowledge sharing between Petri nets and ontologies was presented in (Cheng & Ma, 2016).

With the ontologies from Petri nets, Petri nets can be easily reused and shared on the Semantic Web. More important, the constructed ontologies represent semantically and declaratively both the static structure and the dynamic behavior of Petri nets, and this can improve the applications of Petri nets (Brockmans et al., 2006; Liu, 2006; Lu, Sun & Ma, 2007; Recker & Indulska, 2007; Soffer, Kaner & Wand, 2008). Axioms in the constructed ontologies, for example, constrain creating the instances of the taxonomy, restricting the range and domain of the relations, and the values of the attributes. Then these axioms can ensure that a HLPN is correctly constructed, and restricts how it should be executed (Vidal, Lama & Bugarin, 2010). In the context of money changing service environment represented with High-level Petri Net, it is demonstrated in (Lu, Sun & Ma, 2007) that it is more efficient to analyze High-level Petri Net with the ontologies and the effect of using the ontologies is better than that of using PNML. Typically, in the workflow-oriented applications such as business process modeling and management, where Petri nets are extensively applied as the modeling technique, a comprehensive evaluation of this standard notation (e.g., sound analysis of the representational capabilities of Petri nets) is essential and the ontologies can play an important role at this point (Recker & Indulska, 2007).

In this paper, we focus on developing a formal approach to construct OWL ontologies from PNML (Petri Net Markup Language) of Petri nets. Here PNML (Billington et al., 2003) is a part of ISO/IEC Petri nets standard for representing and exchanging data on Petri nets. We establish a complete correspondence between Petri nets and OWL ontologies. In more detail, this paper makes the following main contributions:

### 1.1. Constructing OWL Ontologies From Petri Nets

In Section 4, we propose an approach for constructing OWL ontologies from Petri nets using a PNML transformation step. Firstly, in order to establish the relationships between PNML models and OWL
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