A Knowledge Management Approach Supporting Model-Based Systems Engineering

Pengfei Yang[1], Jinzhi Lu[2(✉)], Lei Feng[3], Shouxuan Wu[4], Guoxin Wang[4], and Dimitris Kiritsis[2]

[1] Beijing Zhongke Fengchao Ltd., Beijing, China
[2] Swiss Federal Institute of Technology Lausanne, Lausanne, Switzerland
jinzhi.Lu@epfl.ch
[3] KTH-Royal Insititute of Technology, Stockholm, Sweden
[4] School of Mechnical Engineering, Beijing institute of Technology, Beijing, China

Abstract. Model-based Systems Engineering (MBSE) is a noval approach to support complex system development by formalizing system artifacts and development using models. Though MBSE models provide a completely structural formalisms about system development for system developers, such large of domain specific knowledge represented by models cannot be captured as what the developers expect. This leads to a big challenge when MBSE can be widely used for complex system development. In this paper, a knowledge management approach is proposed to support an intelligent question answering scenario when implementing MBSE in system lifecycle. We make use of the GOPPRR approach to support MBSE formalisms which are transformed to knowledge graph models. Then such models provide cues for intelligent question answers through reasoning. In the case study, we make use of an auto-braking system scenario to develop MBSE models and to implement the intelligent question answering. Finally, we find the availability of our approach is evaluated which the domain engineers enable to capture their domain knowledge more efficiently.

Keywords: Knowledge management · Model-based system engineering · Knowledge graph modeling · Knowledge reasoning

1 Introduction

Model-based systems engineering (MBSE) is a formalized modeling methodology to address the challenges of traditional document-based systems engineering in the development of complex systems [6]. It makes use of logically coherent and multi-perspective system models as a bridge to achieve traceable, verifiable, and dynamic life-cycle management of cross-domain knowledge. Thereby, similar as systems engineering, MBSE enables to be used throughout the entire lifecycle of complex system development, from conceptualization, development,

Á. Rocha et al. (Eds.): WorldCIST 2021, AISC 1366, pp. 581–590, 2021.
https://doi.org/10.1007/978-3-030-72651-5_55

implementation to maintenance during different system hierarchy such as system of systems (SoS), system and subsystem [4].

Though MBSE has been widely used by different domains, different language specifications, such as SysML [11], BPMN [2] and domain specific modeling languages (EAST-ADL [3]) always lead to heterogeneous data structures for these domains. This lead a big challenge to current MBSE techniques when system developers who make use of the MBSE models want to understand the models from other domains. Moreover, since Artificial Intelligent (AI) techniques are widely used for supporting decision-makings for complex system development, these heterogeneous MBSE models cannot be integrated leading such AI platform cannot be used for the entire lifecycle of complex systems. Furthermore, such AI techniques are implemented by IT managers which are difficult to be used by domain engineers. In summary, a new technique is required by the current industry which can formalize domain specific knowledge with unified model representations and enables to be used by AI techniques for decision-makings for domain engineers based on the large amount of domain-specific knowledge [17] and their topologies.

In order to formalize the domain specific knowledges using a unified specification, knowledge graph models with unified ontology is used to support model integration of complex systems during the entire lifecycle [16]. Moreover, they enables to be used by AI algorithms for capturing the explicit and detailed information and topologies of complex system. Then these AI models can be used by other knowledge management systems to support decision-makings for domain engineers. In order to make this practice more acceptable by domain engineers, a knowledge Q&A system is developed for connecting the reasoning of knowledge graph models with the really problems in the industrial scenarios.

The contribution is to propose an MBSE-based Q&A approach based on knowledge graph modeling. In this approach, a Graph-object-Point-Property-Role-Relationship (GOPPRR) [7] approach is used to support MBSE formalims. Then the GOPPRR models are transformed to the knowledge graph models based on GOPPRR ontology. Through the knowledge graph models, a Q&A system is developed for domain engineers to capture the knowledge they expect for decision-makings. The domain engineers can obtain the knowledge they want directly from MBSE models through the domain specific questions, leading to that the efficiency of system development promotes.

The rest of the paper is organized as follows. We discuss the related work in Sect. 2. Then we introduce our approach including GOPPRR approach for MBSE, knowledge graph modeling with GOPPRR ontology and the developed Q&A system in Sect. 3. Then, in Sect. 4, an auto-braking system case study is proposed to explain how the proposed approach supports really industrial practices. Finally, we offer our conclusion in Sect. 5.

2 Related Work

In this section, we first introduce MBSE, then ontology and knowledge graph modelings. Finally, we capture the gaps for the existing MBSE approaches and identify the motivations in this paper.

MBSE is the formalized modeling approach to support system lifecycle including requirements, design, analysis, verification and validation activities from the conceptual design phase and continuing throughout development and finally to the later life cycle phases [8]. Compared with traditional systems engineering approach, MBSE adopts models to improve the consistency of knowledge representations throughout the system's life cycle, and enhances the ability to verify the system's functional performances and to optimise the design of multidisciplinary development. However, differnt language specifications such as SysML [11], BPMN [2] and domain specific modeling languages (EAST-ADL [3]) make engineers from different domains difficult to understand each other because of heterogeneous data structure and discrepancies of domain knowledge.

In order to support data integration of MBSE, previous researchers provide ontology and knowledge graph models as the unified representation of model formalisms. Ontology is actually "formal expressions of a set of domain-specific concepts and their interrelationships" [5]. The ontology defines the 'basic terms' that make up the glossary of 'subject areas' and their 'relationships', as well as the 'rules' that combine these terms and relationships to define the extension of the glossary. Ontology is generally used to support domain knowledge definitions and reasoning for domain properties through knowledge graph models [1].

The 'ontology languages' are proposed for knowledge graph modeling including: XML, RDF, OWL [13]. Some researchers make use of such knowledge gragh modeling approaches to support MBSE formalisms. A GOPPRR ontology is proposed for knowledge graph modeling of MBSE [18]. It can provide one unified formalisms for different MBSE languages. Moreover, a service orchestration ontology is proposed in the MBSE tool-chains [10]. Based on the ontology, knowledge graph models are developed to support decision-makings during tool-chain implementations.

From the literature review, we identify some gaps for current MBSE and provide our motivations.

1. Heterogeneous model specifications and data structure makes it difficult to integrate domain knowledge by one unified format.
2. AI technique integrating with MBSE is the future trend [12]. However, it is a big challenge when implementing AI techniques for decision-makings based on MBSE.
3. It is not practical for domain engineers to make use of AI techniques directly for decision-makings without any technical support.

Thus, we proposed an MBSE Q&A approach to overcome the previous challenges.

3 A Knowledge Management Approach Supporting Model-Based Systems Engineering by Q&A Techniques

In this section, we first introduce an overview of our proposed approach, then we detail the GOPPRR approach for MBSE formalisms, knowledge graph modeling based on GOPPRR approach and the workflow in the Q&A system.

3.1 Overview

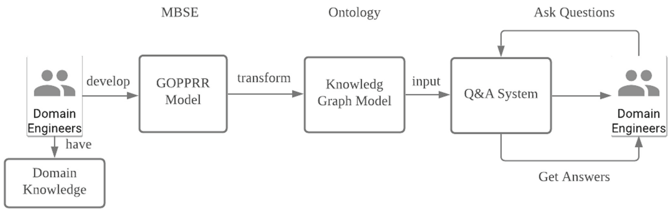

Fig. 1. Overview of the knowledge management approach supporting model-based systems

As shown in Fig. 1, the overview of the knowledge management approach is demonstrated. First, domain engineers make use of the GOPPRR approach to formalize their systems and products by using MBSE methodology. Then such MBSE models are transformed to knowledge graph models based on the GOPPRR ontology [19]. The knowledge graph models are used as the basis to the Q&A system. The domain specific questions for domain engineers are proposed for which the knowledge graph models are reasoned. Finally, in the Q&A system, the answers are demonstrated for the domain engineers.

3.2 GOPPRR Approach Supporting MBSE

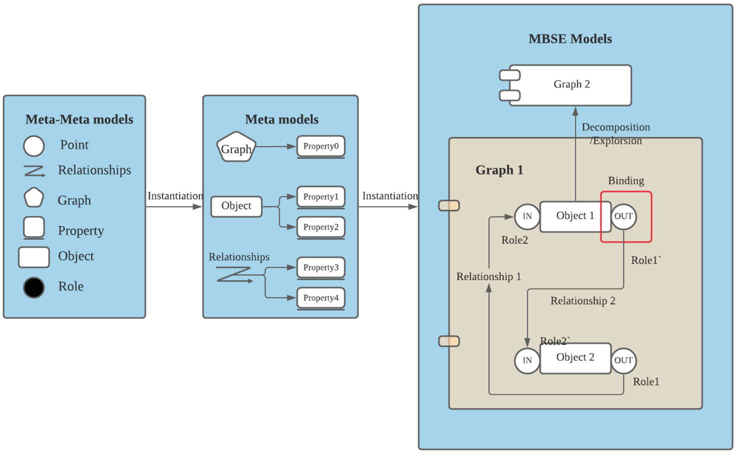

Fig. 2. GOPPRR Approach and Graph, object, point, property, role

Figure 2 illustrates a GOPPRR approach to support MBSE formalisms of entire lifecycle for complex system. In the approach, meta-meta models are used to construct meta-models which are the basic components in MBSE models.

1. Meta–meta models include six concepts including Graph, Object, Property, Point, Relationship, Role. which are introduced in Table 1.

Table 1. Meta–meta models and meta models in GOPPRR

GOPPRR Key meta-meta models	
Graph	The collection of Objects and their Relationships is considered as a single window (an integrated concept of a class diagram). The Graph is a visual diagram on the top level or lower level decomposed or explored by one Object
Object	One component in Graphs (for example, one class concept in SysML)
Property	One attribute of the other five meta–meta models
Point	One port in Objects
Relationship	Link between the different Points or Objects
Role	Used to define the connection rules pertaining to the relevant Relationship. Each Relationship may have two Roles as its ends. Each one is connected with one Point or one Object
Dependencies between GOPPRR concepts	
Binding	Referring to a connection rule between Objects, Points, and Relationships which are defined in the Graph. In each binding, one Relationship is defined to have one Role. Each Role is assigned to connect with one or more Objects or Points in Objects
Have Property	GOPPRR concepts excluding property have their own property
Property link type	Each property having only one data type, such as String
Explosion	One or more graphs related to one Object, Role, and Relationship
Decomposition	The dependency that an object is decomposed into a new graph

2. Meta-models are defined based on meta–meta models as the model compositions.
3. MBSE models are created based on meta-models aiming to formalize system artifacts and the development for complex systems.

3.3 Knowledge Graph Modeling Based on GOPPRR Ontology

In order to generate the knowledge graph models from the MBSE models, a GOPPPRR ontology is developed [18]. We use an OWL-based ontology [20] approach to support knowledge graph modeling for the MBSE models throughout the lifecycle. The transformation process requires the strong dependencies between the syntax of MBSE models and knowledge graph models, thus a transformation rule is defined for generating the knowledge graph models. (1) key meta-meta models including GOPPRR concepts are transformed to class concepts in OWL; (2) the interrelationships between GOPPRR meta-meta models are transformed to Object-property concepts in OWL; (3) Meta-models are defined as sub-class in OWL; (4) Models for describing systems are defined as individuals. Through this approach, a large number of MBSE models throughout the product lifecycle in different domains are generated to unified representation based on OWL: (1) This expression includes a complete representation of the meta-model, the meta-model and the model knowledge including concrete syntax (what do the meta-model and models look like) and abstract syntax in the language (how the model components connect with each other). (2) The expression is represented based on OWL specification, which enables to be used as middle-ware.

3.4 Workflow in the Developed Q&A Systems for MBSE Models

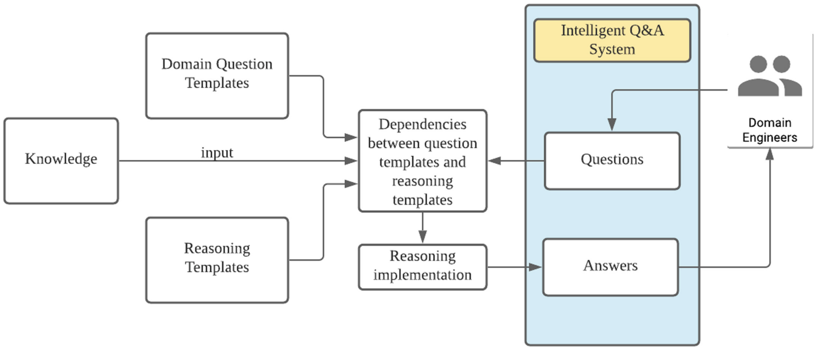

Fig. 3. GOPPRR approach workflow

Figure 3 illustrate the workflow in the Q&A system. First, based on the domain knowledge, domain question templates and reasoning script templates based on different reasoning techniques are developed. The domain question template refer to the practice questions about MBSE models from domain engineers, such as "how many components are included in the MBSE model?". The reasoning script templates refer to reasoning implementations based on different reasoning query languages, such as SPQWL [15] and SQWRL [14]. The Templates including the domain questions and reasoning are created by the domain engineers manually. Based on these templates, dependencies between domain questions and reasoning scripts are developed. Finally, when domain engineers provide some domain questions, the Q&A system enables to implement the reasoning based on the dependencies to identify the answers.

4 Cases Study

4.1 Problem Statement

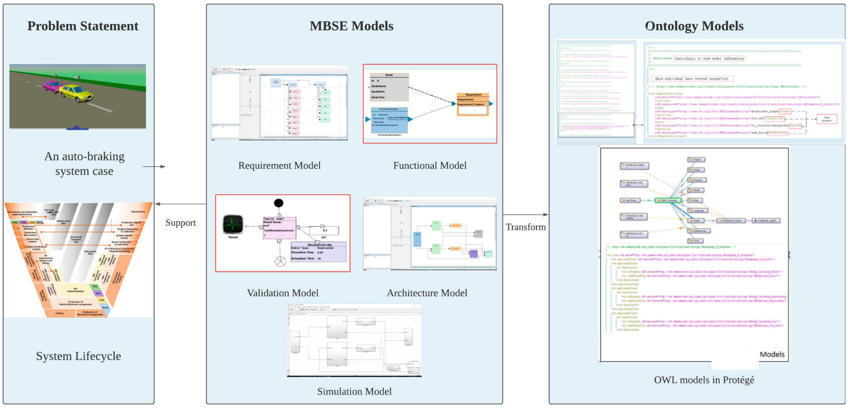

Fig. 4. A Q&A Scenario for MBSE models

Figure 4 shows a case of an auto-braking system with GOPPRR approach supporting MBSE formalisms during the entire lifecyle. In order to develop the auto-braking system using MBSE, the GOPPRR appraoch is used to support architecture modeling. All the architecture models are developed in MetaGraph (http://www.zkhoneycomb.com/) [10], which is an architecture modeling tool based on GOPPRR approach. Then the architecture models are transformed to the knowledge graph models through a developed plugin which is developed based on the GOPPRR ontology. It supports the MBSE models in MetaGraph transforming to OWL[1]. The knowledge graph models are used by the Q&A system. Then the domain engineers can propose their domain questions in the Q&A szystem and obtain their expected answers.

4.2 Q&A Scenario for MBSE Models

In Fig. 5, the demo of the developed Q&A system is demonstrated which is developed based on HTML5 and Java reasoners. The *TAB1* in the system demonstrates all the domain questions expected by the domain engineers. The domain engineers can select the domain questions through *TAB1*. Then when they implement the reasoning, the java reasoners are implemented. The the reasoning reasons are demonstrated by the *TAB2* in the Q&A system.

[1] The details are proposed in [18].

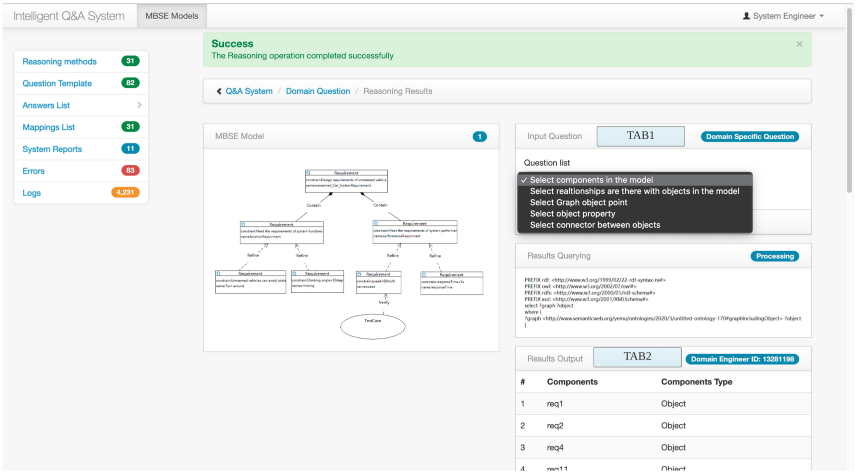

Fig. 5. The intelligent Q&A system

4.3 Discussion

From the case study, we find the MBSE models of the entire lifecycle can be developed based on the GOPPRRR approach because it is considered as one of the most powerful meta-meta modeling language [9]. Through this approach, the requirement models, functional models, behavior models and physical structure models are formalized. Then all these models are transformed to the knowledge graph models based on the GOPPRR ontology in OWL models. These OWL models can be generated from MetaGraph, but also from other modeling tools. This promotes the capabilities for heterogeneous data integration across modeling tools.

After the knowledge graph models are generated, reasoning script templates and domain question templates are used to construct the dependencies between domain knowledge and reasoning query implementations. Through the dependencies, the automatic reasoning process can be implemented in the developed Within the developed intelligent Q&A system.

When using the demo, the system developers and domain engineers enables to provide their domain questions about the MBSE models directly. Then the Java reasoning engine enables to reason the knowledge graph models and identify the answers. Through this process, the domain engineers without any MBSE skills can understand the domain knowledge represented by the MBSE models.

5 Conclusion and Future Work

This paper presents an MBSE Q&A approach supporting knowledge management for systems engineering. In the approach, a GOPPRR modeling method is used to support MBSE formalisms, then the related models are transformed to knowledge graph models based on the GOPPRR ontology. The knowledge graph models are used in the Q&A system to provide required answers for domain questions. Through this approach, the engineers enable to capture their required knowledge in the efficiency way. In order to make this approach more practical, a further research based on a natural language processing approach will be used to identify the domain questions and provide an automated implementation of Q&A process based knowledge graph reasoning.

Acknowledgement. The work presented in this paper is supported by the EU H2020 project (869951) FACTLOG-Energy-aware Factory Analytics for Process Industries, EU H2020 project (825030) QU4LITY Digital Reality in Zero Defect Manufacturing and the InnoSwiss IMPULSE project on Digital Twins.

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