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Toward the tools selection in model based system engineering for embedded systems—A systematic literature review

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ABSTRACT

Model based system engineering (MBSE) is a systematic approach of modeling which is frequently used to support requirement specification, design, verification and validation activities of system development. However, it is difficult to customize MBSE approach for the development of embedded systems due to their diverse behavioral aspects. Furthermore, appropriate tools selection to perform particular MBSE activities is always challenging. This paper focuses on the identification and classification of recent research practices pertaining to embedded systems development through MBSE approach. Consequently, a comprehensive analysis of various MBSE tools has been presented. Systematic literature review (SLR) has been used to identify 61 research practices published during 2008–2014. The identified researches have been classified into six different categories to analyze various aspects of MBSE approach for embedded systems. Consequently, 39 preliminary tools are identified that have been used in recent researches. Furthermore, classification and evaluation of tools have been presented. This research highlights important trends and approaches of MBSE to support development of embedded systems. A comprehensive investigation of tools in this article facilitates researchers, practitioners and developers to select appropriate tools according to their requirements.

1. Introduction

Model based system engineering (MBSE) is a well-known approach for the development of complex systems. It has features to reduce development complexity, enhanced productivity, efficient change management and improved time-to-market. Therefore, it has been frequently researched and customized for the development of embedded systems (Andrade et al., 2009; Quadri et al., 2012; Moreira et al., 2010; Vidal et al., 2009; Herrera et al., 2014; Lecomte et al., 2011; Rafiq Quadri et al., 2012). The major MBSE activities for the development of embedded systems are shown in Fig. 1.

Modeling structural and temporal aspects of embedded systems is foremost activity. All other MBSE tasks (i.e. model transformation, verification and validation) are based on the models development methodology. Therefore, models are developed by taking into consideration the model transformation, verification and simulation requirements. For example, one of the major challenge is to model behavioral/temporal aspects of complex embedded systems for further verification and validation (Quadri et al., 2012; Rota Sena Marques et al., 2014).

UML (unified modeling language) and its SYSML (systems modeling language)/MARTE (modeling and analysis of real-time embedded systems) profiles are frequently used in contemporary research practices (Giuseppe Di et al., 2013; George-Dimitrios et al., 2014; Berrani et al., 2013; Sakairi et al., 2012; Stancescu et al., 2010; Anargyros et al., 2014; Ouchani et al., 2013; Bouquet et al., 2012; DeTommasi et al., 2013; Gomez et al., 2012; Andrade et al., 2009; Quadri et al., 2012; Bazydlo et al., 2014; Doligalski and Adamski, 2013; Mueller et al., 2010; Durand and Bonato, 2012; Wood et al., 2008; Moreira et al., 2010; Vidal et al., 2009; Linehan and Clarke, 2012) to specify embedded systems requirements. Furthermore, different properties specification techniques/languages have been proposed by researchers (Yin et al., 2013; Mallet, 2012; Knorreck and Apvrille, 2011; Ge et al., 2012; Behjati et al., 2011) to model behavioral/temporal aspects. Once requirements are modeled, different model transformation techniques have been applied to develop platform specific model and/or source code generation. Two types of transformations are commonly used i.e. model-to-model (M2M) transformation (George-Dimitrios et al., 2014; Berrani et al., 2013) and model-to-text (M2T) transformation (Wood et al., 2008; Moreira et al., 2010).

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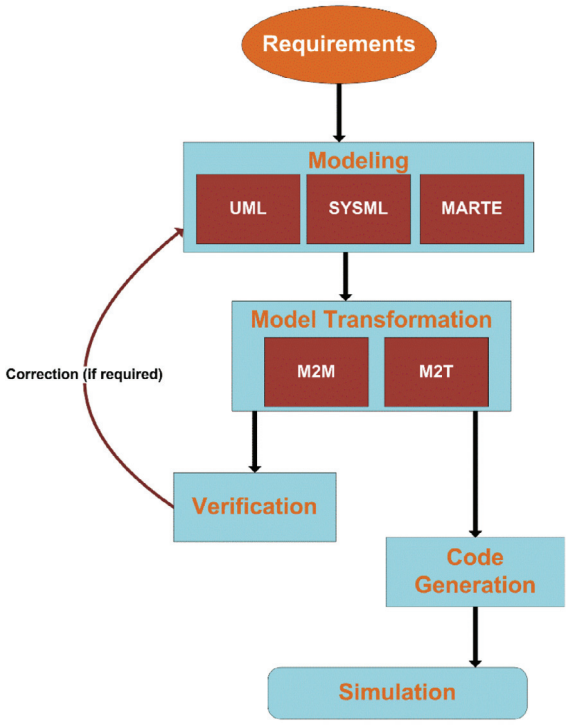

Fig. 1. Major MBSE activities for embedded systems.

The verification is performed to ensure the correctness of the model/system and it is tightly coupled with the modeling technique used to specify behavioral/temporal aspects. Various formal verification techniques (Launiainen et al., 2010; Zhang et al., 2009; Uchevler and Svarstad, 2013) have been used to verify the behavioral/temporal aspects of the system. If the model does not satisfy the verification requirements, then corrections have been made in the model as shown in Fig. 1. The validation of the model/system has been performed through simulation.

Although, researchers put a lot of efforts in the field of MBSE for embedded systems, it is still a challenging area due to the diversity of behavioral/temporal characteristics of embedded systems. It is always difficult to select appropriate modeling techniques and UML profiles to model embedded systems requirements. Moreover, there is a considerable dependency among different MBSE activities (i.e. modeling, model transformation, verification and simulation) that require sufficient knowledge of all the phases for the development of embedded systems. Similarly, there are separate toolsets for each MBSE activity and selection of appropriate tools for embedded system development is always problematic for researchers and practitioners.

Keeping in view the current state of affair, the objective of this systematic literature review (SLR) is to identify the latest research practices where MBSE approach has been used for the development of embedded systems. The identified researches are classified into six categories depending upon their relevance with corresponding MBSE activity. Furthermore, various tools have also been identified to perform modeling, model transformation, verification and validation activities for embedded systems development. Consequently, following research questions have been developed for this SLR:

Research question 1: What important researches have been reported from 2008 to 2014 where MBSE approach has been utilized to support the development of embedded systems?

Research question 2: Which of the UML and its SYSML/MARTE profiles are more frequently utilized to model embedded system requirements during 2008–2014 researches?

Research question 3: Which of the model-to-model and model-to-text transformation approaches are more frequently utilized during 2008–2014 researches?

Research question 4: What are the significant tools for requirement specifications, model transformation, verification and simulation (validation) activities in the context of MBSE for embedded systems?

The answers of all research questions are given in Section 5. Review protocol, that incorporates selection and rejection criterion, has been developed to perform this SLR. We have defined six categories (Section 2.1) for the selected researches in order to get the answers of our research questions. Complete overview of this research work is presented in Fig. 2.

A review protocol is developed (Section 2.2) that contains the selection and rejection criterion (Section 2.2.1). As shown in Fig. 2, four scientific databases are selected for search process (Section 2.2.2) and six categories are defined (Section 2.1) to classify the 61 selected researches. Similarly, data extraction elements (Section 2.2.4) are defined to perform comprehensive analysis and synthesis of the selected researches. Consequently, the major findings of SLR have been summarized in Section 3. On the basis of SLR, we preliminary identified 39 tools (Section 3.3), those have been used in the selected researches, to perform particular MBSE activities. In Section 4, various tools characteristics (Section 4.2) are defined for further evaluation. The characteristics-based evaluation eliminated few preliminary MBSE tools lacking certain common characteristics and included some additional tools those have been missed during the SLR. Consequently, 28 MBSE tools in five different categories (Section 4.3) are presented as shown in Fig. 2. Results in Sections 3 and 4 provided the answers of research questions and are discussed in Section 5. Further important aspects and certain limitations of the research are discussed in Section 6. Finally, Section 7 concludes the article.

2. Research methodology

Systematic literature review (Kitchenham, 2004) has been used to carry out this research. It is a proper and replicate process to document pertinent details on precise research area for reviewing and investigating all existing research related to research questions. Consequently, this research incorporates five stages: 1) categories definition, 2) review protocol development, 3) selection and rejection criterion, 4) search process, 4) quality assessment, 5) data extraction and synthesis.

2.1. Categories definition

We have defined six categories in order to organize the selected researches. This categorization significantly improves the accuracy of the answers of our research questions. The details of categories are given below:

2.1.1. General category

There might be a number of researches where complete solution covering all MBSE activities (i.e. modeling, model transformation, verification and simulation) is proposed for embedded systems. Moreover, there might be a number of researches covering all MBSE activities but do not particularly intended for embedded systems, however, these researches have great potential to be used for embedded systems. Furthermore, some researches might cover more than one MBSE activities simultaneously (e.g. modeling, model transformation or model transformation, verification etc.). All aforesaid researches will be included in the general category.

2.1.2. Modeling category

Requirements specification is the foremost activity. Therefore, all proposed categories may contain some information about the model