Modeling UML sequence diagrams using extended Petri nets

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Abstract Unified modeling language (UML) sequence diagrams combined with the UML profile for modeling and analysis of real-time and embedded (MARTE) systems are used to represent systems’ requirements. To enhance formal analysis abilities, sequence diagrams annotated with MARTE stereotypes are mapped into timed colored Petri nets with inhibitor arcs (TCPNIA). The mapping rules for the fragments of sequence diagrams and MARTE stereotypes are proposed respectively. They are proposed both in graphical and formal forms. The soundness of mapping rules is analyzed. The data related issues are handled through colored properties in TCPNIA models, guard functions and operational functions. A mapping rule for state invariant is proposed based on data related information. Through state invariant, complicated control relations can be expressed. Formal definitions for morphing and substitution in TCPNIA models are given. They provide modular and hierarchical modeling methods for TCPINA models. To show the applicability and feasibility of our method, an application example in vehicular ad hoc networks (VANETs) domain is studied.

Keywords UML · Sequence diagram · MARTE · Mapping rule · Petri net

1 Introduction

In the recent years, real-time embedded (RTE) software development needs to meet the requirement of short time to market and constant evolution. Model driven architecture (MDA) [1] is an attractive approach to realizing this target. It separates the application description from the platform specific implementation. Thus the modeling complexity can be reduced. Furthermore, alternative solutions to the target system can be investigated and compared in the early phase. The development risks can also be minimized.

Models are the core elements during the development processes in MDA. Unified modeling language (UML) [2] is one of the core techniques in MDA. UML 2 is recommended by open management group (OMG) to describe the models in MDA. UML sequence diagrams are intended to describe behaviors’ interactions of the system. So they are usually adopted to model detailed requirements when dealing with RTE systems. And they are usually used to describe the platform independent models (PIMs) [3] in MDA.

But UML lacks the ability to describe quantitative non-functional properties, such as real-time, performance, dependability and resource. These properties are important in trustworthy RTE software systems. The violation to some non-functional properties may lead to catastrophic consequence, such as equipment damage, environment pollution, or even loss of human lives. Non-functional properties, such
as time constraints and reliability, are also import in vehicular ad-hoc network (VANET) [4] applications. A new OMG UML profile dedicated for modeling and analysis of real-time and embedded (MARTE) [5] systems is recently presented. It mainly addresses the schedulability and performance analysis [6].

The development cost can be reduced dramatically when the errors and conflicts are found in the early development phase. In order to verify the functional correctness and analyze the non-functional properties of the systems in the early phase, formal verification and analysis are necessary. Lacking of formal semantics, UML models can not be verified and analyzed formally. Petri nets [7] are formal models based on strict mathematical theories. They are powerful and appropriate for modeling and analyzing systems. Plenty of verification and analysis methods have been developed around Petri nets. A lot of mature analysis tools are available. Mapping UML models into Petri nets for verifying and analyzing system properties is a promising research topic.

Timed colored Petri nets with inhibitor arcs (TCPNIA) [8] is recently proposed to cope with modeling and analyzing complicated RTE systems. Its verification method has been proposed in [9]. In this paper, we propose the rules to map UML sequence diagrams annotated with MARTE stereotypes (SD/MARTE) into TCPNIA models for verification and time analysis. This paper concentrates on the time property annotated by MARTE stereotypes.

This paper proposes a hierarchical method to transform a sequence diagram annotated with MARTE stereotypes into a TCPNIA model. The mapping rules are given both in graphical and formal forms. The soundness of mapping rules is analyzed. The guard functions on transitions for the loop operator are given. The data related issues are handled through colored properties in TCPNIA models, guard functions and operational functions. A mapping rule for state invariant is proposed based on data related information. Through state invariant, complicated control relations can be expressed.

This paper is an extended version of [10], which articulates how to transform each sequence diagram fragment annotated with MARTE stereotypes into a TCPNIA model graphically. Extending to previous work, this paper proposes formal transformation methods and analyzes the soundness of the mapping rules. The goal is to provide foundations for developing automatic tools to transform UML diagrams annotated with MARTE stereotypes into analyzable Petri nets.

The rest of this paper is organized as follows. In the next section, we review the related works. Section 3 describes how to annotate MARTE stereotypes on a sequence diagram, and formally define syntaxes of a sequence diagram annotated with MARTE stereotypes. Section 4 introduces the definitions of TCPNIA. The rules for mapping UML sequence diagrams annotated with MARTE stereotypes into TCPNIA models and their soundness analyses are proposed in Sect. 5. Section 6 presents a case study to illustrate the feasibility of our method. Section 7 concludes this paper.

2 Related works

Query/View/Transformation (QVT) [11], proposed by OMG, is a standard for expressing model transformation rules in MDA. It just provides methods for model transformations between different design levels in MDA. It hasn’t provided any approach to transforming a UML model into a formal analyzable model.

To verify and analyze UML models on different levels in MDA, many attributes [12–23] are available to map UML diagrams into Petri net models. We only concern mapping rules for transforming UML sequence diagrams into Petri nets in this section.

Ameedeen et al. [20, 21] proposed rules to transform a sequence diagram into a free choice Petri net. The transformation is based on the message. It firstly decomposes the sequence diagrams into fragments. Each fragment is transformed into a block of Petri net. The Petri net blocks are composed into a complete Petri net. We adopt the similar approach in this paper. But mapping rules for some elements to describe the relations between messages are not proposed. Fernandes et al. [22] proposed a method to transform use cases and sequence diagrams into colored Petri nets. But it did not provide methods for some important elements, such as state invariant. Li et al. [23] proposed a method to transform sequence diagrams into object Petri nets. It only concerned on several operators for combined fragments. All these works did not concern time information on the sequence diagram and their target Petri nets did not support to describe time information.

Andrade et al. [15] proposed mapping rules to transform a sequence diagram annotated with MARTE stereotypes into a time Petri net with energy constraints (ETPN). But mapping rules for asynchronous messages and hierarchal transformation methods are not available.

Previous literatures just deal with the flowing of events within sequence diagrams, but data related issues are not considered, to the best of our knowledge. Furthermore, they only provide graphical mapping rules. Formal definitions for mapping rules and the soundness of them are not concerned.

3 Sequence diagrams annotated with MARTE stereotypes

3.1 Sequence diagrams

A UML sequence diagram is a form of interaction diagram. It focuses on identifying the behavior within the system and