Specification and analysis of timing requirements for real-time systems in the CBD approach

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Abstract In real-time software, not only computation errors but also timing errors can cause system failures, which eventually result in significant physical damages or threats to human life. To efficiently guarantee the timely execution of expected functions, it is necessary to clearly specify and formally verify timing requirements before performing detailed system design. With the expected benefit of reusability and extensibility, component technology has been gradually applied to developing industrial applications including real-time systems. However, most of component-based approaches applied to real-time systems lack in a systematic and rigorous approach to specifying and verifying timing requirements at an earlier development stage.

This paper proposes a component-based approach to specifying and verifying timing requirements for real-time systems in a systematic and compositional manner. We first describe behaviors of the constituent components including timing requirements in UML diagrams, and then translate the UML diagrams into MTER nets, an extension of TER nets, to perform timing analysis in a compositional way. The merit of

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the proposed approach is that the specification and analysis results can be reused and independently maintained.

**Keywords** Component · CBD · Real-time system · Timing constraints · Petri nets · Compositional analysis · Timing analysis

### 1 Introduction

Real-time systems are rapidly gaining influence in the contemporary world; cars, mobile phones, transport systems, air-conditioning systems, military weapon systems, and medical devices are prime examples (Selic and Motus 2003). In addition the next ten years will see distributed real-time computer systems replacing many mechanical and hydraulic control systems in high-dependability applications. In these applications a failure in the temporal domain can be as critical as a failure in the value domain (Kopetz 2000). In real-time systems, correctness depends not only on the results produced by computations, but also on the time at which such results are produced. The system may enter an incorrect state if the right result is produced too early or too late with respect to certain time bounds (Wirth 1977). Therefore, for developing real-time systems, it is essential to clearly specify the timing requirements in addition to the functional ones and to apply some systematic development and analysis methods to guarantee the required timing constraints.

Component technology has become a central focus of software engineering in research and development due to its great success in market. Reusability and extensibility are key factors that contribute to this success. Component-based development aims at decreasing development time and costs by creating applications from reusable, easily connectible and exchangeable building blocks—the components. In other words, component technology enables software systems to be built by assembling components that have already been developed earlier. Component-based development (CBD) of a system is a promising technique, due to its inherent adequacy to distribution (a component is an independent entity) and easy maintainability (components can be easily replaced).

To make such advantages from component-based development, there has been much work to apply the object-oriented or component technology to real-time systems development. That is, the use of component technology in real-time systems development has been the main object of recent research. Since UML has been a basis for modeling component-based systems and UML lacks formality for supporting automatic analysis, many works have focused on transforming UML diagrams into more formal analyzable notations. McUmber and Cheng (2001) proposed transformation of UML diagrams into Promela for supporting model checking. The transformation is defined on the mapping between the meta models of UML diagrams and Promela. Petri nets formalism has been considered for transformation. Bernardi et al. (2002) proposed translation of Statecharts and Sequence diagrams into Generalized Stochastic Petri Nets. Petri nets-based transformation approaches have also been applied for modeling and analyzing manufacturing systems (Jeng and Lu 2002; Lin et al. 2004). Trowitzsch et al. (2005) proposed derivation of Stochastic Petri nets from UML diagrams aimed at performance evaluation of real-time systems. In addition,