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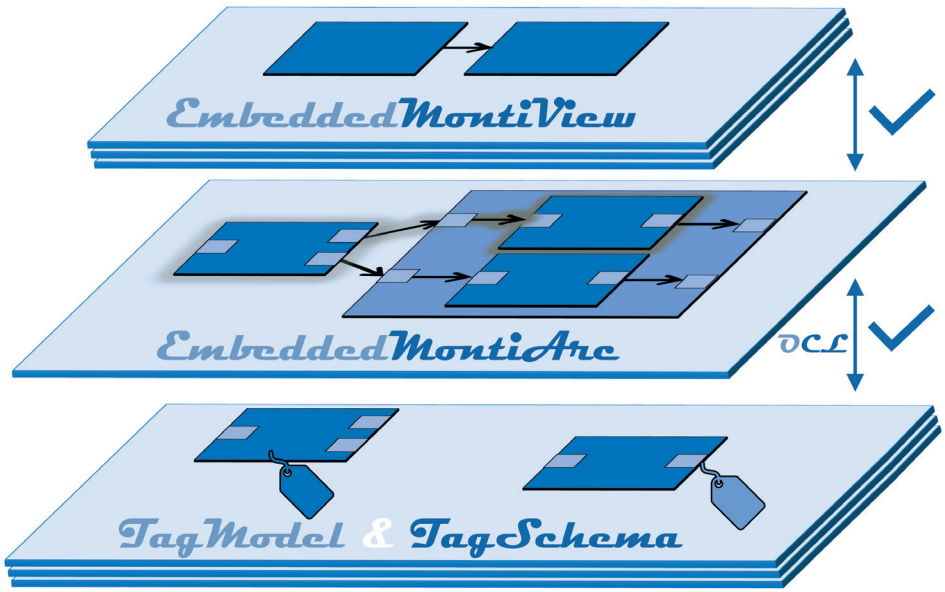
Michael von Wenckstern

Verification of Structural and Extra-Functional Properties in Component and Connector Models for Embedded and Cyber-Physical Systems



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Hrsg: Prof. Dr. rer. nat. Bernhard Rumpe

Verification of Structural and Extra-Functional Properties in Component and Connector Models for Embedded and Cyber-Physical Systems

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Abstract

The industry area of embedded and cyber-physical systems is one of the largest and it influences our daily life. The global embedded systems marked was valued at about 160 billion US dollar in 2015 and it is getting up to 225 billion US dollar by end of 2021 [Zio17]. Example domains of embedded and cyber-physical systems are: automotive [DHJ+08], avionics [FLV03], robotics [WICE03], railway [DNCH10], production industry [EWSG94], telecommunication [ZSM11], healthcare [ERA09], defense [BNP+04], and consumer electronics [VOVDLKM00].

Model-based engineering, esp. component and connector (C&C) models to describe logical architectures, are one common approach to handle the large complexity of embedded and cyber-physical systems [FR07, MBNJ09, OMG15, EJL+03]. Components encapsulate software features; the hierarchical decomposition of components enables formulating logical architectures in a top-down approach. Connectors in C&C models describe the information exchange via typed ports; they model black-box communication between software features.

The current development of complex C&C-based embedded systems in industry mostly involves the following steps [BMR+17a, DGH+19]: (1) formulating functional and extra-functional requirements as text in *IBM Rational DOORS*; (2) creating a design model of the software architecture including its environment interactions in *SysML*; (3) developing a complete functional/logical model to simulate the embedded system in *Simulink*; and (4) system implementation based on available hardware in C/C++ satisfying all extra-functional properties.

This current development process has the following disadvantages [KBFS12, HKK+18, BMR+17a]: (a) *SysML* models do not follow a formalized approach; i.e., engineers may interpret these models differently due to missing semantics; (b) the check between the informal *SysML* architecture design against the *Simulink* model is done manually, and thus, error-prone and very time-consuming; (c) refactoring of *Simulink* models (e.g., dividing a subsystem) needs manual effort in updating the design model, and therefore, due to timing constraints this step is often skipped resulting in inconsistencies; and (d) most tools do not support a generic approach for different extra-functional property kinds, and thus, extra-functional properties are mostly modeled as comments or stereotypes and consistencies between these properties are checked manually.

This thesis aims to improve the software development process of large and complex C&C models for embedded and cyber-physical systems by providing model-based methodologies to develop, understand, validate and maintain these C&C models. Concrete, this thesis presents concepts to support the embedded software engineer with: (i) automatic consistency checks of C&C models; (ii) automatic verification of logical C&C models against their design decisions; (iii) automatic addition of traceability links between design and implementation models; (iv) finding structural inconsistencies during model evolution; (v) providing a flexible framework to define different extra-functional property types; (vi) presenting an *OCL* framework to specify (company-specific) constraints about structural or extra-functional properties for C&C models; and (vii) generation of positive or negative witnesses to explain why a C&C model satisfies or violates its extra-functional or structural constraints or its design decisions.

Prototype implementations of above mentioned concepts and an industrial case study in cooperation with Daimler AG show promising results in improving the model-based development process of embedded and cyber-physical systems in industry.

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