H-SPEX: Exploiting Model-Driven Engineering and Aspect-Oriented Design Concepts to Improve High-level Design Space Exploration of Embedded Systems

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Abstract

Modern embedded systems have increased their functionality by using a large amount and diversity of hardware and software components. Realizing the expected system functionality is a complex task. Such complexity must be managed in order to decrease time-to-market and increase overall system quality. This work presents a method for high-level Design Space Exploration (DSE) of embedded systems that uses the Model-Driven Engineering (MDE) and Aspect-Oriented Design (AOD) approaches. The modelling style and the abstraction level open new design automation and optimization opportunities, thus improving the overall results. Furthermore, the proposed method achieves better reusability, complexity management, and design automation by exploiting both MDE and AOD approaches at higher abstraction levels.

1. Introduction

A growing number of hardware and software components is being incorporated into single embedded systems, enhancing their functionality and also increasing design complexity, which must be managed properly. In addition, stringent requirements regarding power, performance, cost, and time-to-market also hinder embedded systems design. The designers’ expertise is not enough to deal with this ever growing challenge, where a very wide range of design alternatives must be evaluated in order to find the best trade-off among conflicting requirements. Therefore, new development methods are imperative, including efficient Design Space Exploration (DSE) approaches, which are used to quickly find an adequate design solution while coping with a wide design space and conflicting requirements.

This work proposes a DSE method to be used in the context of Platform-Based Design (PBD). This DSE method takes advantage of the development process and modelling style to open new optimization opportunities and improve the overall result of system design, by applying both the Model-Driven Engineering (MDE) and Aspect-Oriented Design (AOD) approaches. MDE and AOD allow performing DSE much earlier, during the high-level design model specification, than other approaches that postpone it to a later and more expensive design step, after code generation and/or hardware synthesis. Moreover, MDE and AOD also provide mechanisms to represent system concerns in a consistent and orthogonal way. To cope with the lack of methods to support requirements specification and improve the separation of concerns, as argued by PBD, the proposed method exploits the AOD approach during the development phase, by which system functional (FR) and non-functional requirements (NFR) can be specified separately. Furthermore, using MDE combined with AOD increases the abstraction level of system models, achieving better system customization and design automation.

2. Design method

As DSE is essentially a requirements-driven activity, FR and NFR, which are the inputs to the DSE process, must be specified in an adequate fashion. Therefore, in order to provide a suitable requirement specification, a development process based on AOD was tailored for DSE and applied to the development of embedded systems. The RT-FRIDA (Real Time – From Requirements to Design using Aspects) [1] method provides a set of templates and specification guidelines, in order to assist designers in identifying and specifying system requirements.

Through AOD, we improve simultaneously the abstraction and the separation of concerns, by separating the handling of NFRs through aspects and hence opening new design automation and optimization opportunities. The development process provides guidelines to specify analysis and design models using UML and AOD concepts. The DERAF framework (Distributed Embedded Real-time Aspects Framework) [1], containing high-level aspect models, is used. DERAF aspects specify pre-defined handling elements for common NFRs found in embedded, real-time, and distributed systems domains.

The MDE/AOD approach is supported by the MDE framework MODES (Model-Driven Embedded System design) [2], which provides an efficient meta-modelling infrastructure to capture system structure and behaviour. It represents system concerns in distinct dimensions that correspond to the Y-chart approach: application, platform, mapping, and implementation. Moreover, MODES provides a transformation engine, which interacts with the exploration tools to allow both requirements verification and generation of the final model after the DSE step.

The H-SPEX (High-level design SPace Exploration) [3] tool has been developed to exploit MDE and AOD approaches in the requirements, analysis, and design phases of the development process. Early and fast evaluation is achieved by using a model-based estimation tool called SPEU (System Properties Estimation with UML) [4].

Figure 1 illustrates the proposed design methodology, highlighting the main activities and support tools. On the left column the basic activities are shown, following the...
RT-FRIDA development method. The development method has three main phases: (i) requirements identification and specification; (ii) mapping requirements onto system elements; and (iii) system design. The schema in the middle column illustrates the PBD approach: the abstraction levels and the mapping of elements from application to architecture, which is performed during the refinement from the analysis to the design phase. The right column indicates which support tools and methods are used during each development phase.

The focus of this work is on the design space exploration of embedded systems. However, the research effort in progress at the Embedded System Lab of UFRGS (www.inf.ufrgs.br/~lse) considers the complete development process, which includes different tools to support all phases, from the requirements specification until the lower level of implementation activities, such as code generators (GeneRTiCA), estimation/simulation (CACO-PS), and synthesis (SASHIMI).

3. Tool support

The tool chain, which supports the design methodology, is integrated with the Magic Draw UML tool editor. Using this editor, designers specify the intended system functionality by following the RT-FRIDA design steps. Figure 2 shows the tool interactions during the automated DSE process in the design phase, after the system specification. The process starts by (1) loading the UML models from UML editor’s repository into the MODES meta-modelling infrastructure. Afterwards, (2) H-SPEX reads Application, Platform, and Mapping Models to search for alternative designs in the design space. For the selected alternative designs, H-SPEX (3) writes, in the Mapping Model, conditions and design choices to set up the Implementation Model according to the selected alternative design. After that, SPEU (4) is used to perform the model-based estimation; (5) it reads the resulting Implementation Model from the MODES framework and (6) performs the estimations, writing the results back to the MODES infrastructure. By using the estimated values in the Implementation Model, H-SPEX (7) evaluates the design alternative and, if the selected set does not meet design constraints, iterates again from step (2) to generate another alternative design.

The H-Spex DSE tool employs the Crowding Population-based Ant Colony Optimization for Multi-objective (CPACO-MO) algorithm. In each iteration, this algorithm generates a set of candidate solutions, from where the best candidates are selected to compose a population. This population is a set of non-dominated design points (Pareto-optimal), with which the designer can take its decision by considering design trade-offs and system requirements. Currently, the activities performed by the H-Spex tool in the context of an MPSoC design are: i) selecting the number and types of processors; ii) mapping tasks into processors; iii) allocating processors into a communication structure, and; iv) selecting processor voltage operation. In the MPSoC design context, the DSE tool can be used to optimize the system in terms of energy or power consumption, communication bandwidth, memory footprint, performance (execution time or cycles), or any combination of the above. The candidate designs found by the H-Spex tool are transformed by means of model transformations back into the MDE framework infrastructure and can be refined or used as input to code generation and synthesis tools.

4. Conclusion

This work has presented a high-level method for DSE, which takes advantage from the AOD and MDE approaches, in order to provide an efficient development framework focusing on automated DSE. Through the proposed approach, DSE can be performed at earlier development phases using higher abstraction levels, hence leading to substantially superior improvements.

References


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