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Towards a MARTE extension to address adaptation mechanisms

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Abstract—The profile for Modeling and Analysis of Real-Time and Embedded systems (MARTE) defines a framework for annotating non-functional properties of embedded systems. In particular, the SAM (Schedulability Analysis Model) sub-profile offers stereotypes for annotating UML models with the needed information which will be extracted to fulfill a scheduling phase. However, SAM does not allow designers to specify data to be used in the context of adaptive systems development. In this position paper, we present the related works around the development of adaptive real-time and embedded systems and discuss why we seek to improve the meta-models of MARTE.

Keywords—Adaptive Systems; Real-time & Embedded Systems; Model-Driven Engineering; MARTE

I. INTRODUCTION

The modeling of Real-Time & Embedded Systems (RTES) is not an easy task in the software engineering domain. RTES are subject to a multitude of constraints (e.g., battery, temperature, ...) and real-time requirements, and have to execute in a highly variable environment (e.g., update available, hardware crash, position change, ...). In order to retain reliability and preserve the system non-functional properties (NFPs) (e.g., deadlines), RTES must be able to adapt themselves to the changes of their operating environment and context. Hence, a reconfiguration scenario is required for the automatic improvement of the system performance or for the system protection at run-time when hardware faults occur [1]. Lightening the task of adaptive systems designers and reducing the development cost and time to market represent a major challenge in the field. In this context we propose to explore the use of the MARTE profile in a Model-Driven Engineering (MDE) context.

MDE [2] aims to reduce the complexity of the design task by using abstraction and automated analysis with transformation of the models. In particular, Unified Modeling Language (UML) profiles promote an adequate solution to

support the whole lifecycle co-design of complex systems. In the RTES domain, its adoption is seen promising for several purposes: requirements specification, behavioral and architectural modeling with their real time constraints and performance issues. In this context, the profile for Modeling and Analysis of Real-Time and Embedded systems (MARTE) [3] is a promising extension for general-purpose embedded system modeling with real-time constraints that facilitate interoperability between designers and tools. Unfortunately, MARTE does not define a clear semantics for modeling and analysis of the adaptation in RTES.

We aim in this position paper at studying the proposed adaptation extensions for this profile in the literature and we provide some ideas for what we believe would be the adequate extension in order to support the adaptability concept. We will present and classify contributions around the modeling and analyzing of the adaptation with MARTE profile in RTES. We will also identify the needs in adaptability and propose our research fundamentals and road-map to a new extension for MARTE to support this reconfiguration in RTES development.

The remainder of this paper is organized as follows. Section 2 introduces the concept of the adaptation. Section 3 surveys relevant related works in the adaptive RTES field. After the research objective is described in Section 4, we present in Section 5 the actual status of our work. Finally, in section 6 we conclude and give an outlook of future work.

II. THE ADAPTABILITY CONCEPT

A. Definition

There are several definitions of adaptation in the literature. In [4], a *software adaptation* is defined as any software modification that changes the reliability or timeliness of the software without affecting other aspects of its functionality.

In [5] and [6], adaptation means change in the system to accommodate change in its environment. More specifically, the adaptation of a software system (S) is caused by a change (Che) from an old environment (E) to a new environment (E'), and results in a new system (S') that ideally meets the needs of its new environment (E'). Formally, adaptation can be viewed as a function:

Adaptation: $E \times E' \times S \rightarrow S'$, where meet (S, need (E')).

A system is adaptable if an adaptation function exists.

In [7], adaptive system is defined as a system that is able to change its structure or behavior at run-time in response to the execution context variations and according to adaptation engine decisions.

In our view, adaptation is defined as any modification in the structure, behavior or architecture of the system to accommodate external or internal change of their operating environment or context and according to predefined adaptation plan and rules.

B. Axes of adaptation

Several adaptation techniques are defined to manage reconfiguration in the software development lifecycle. In model-based approaches for RTES, these adaptation techniques can affect: (i) the functional model in the case of a change in the behavior of the system, (ii) the platform model if there is an adjustment in performance of material resources or unavailability of a resource for a certain period at run-time, and (iii) the implementation model when a task migration between resources is required.

Possible changes in the system can be caused by external variation, such as change in the operational environment (e.g., airplane mode in smart phone) or internal variation (e.g., new requirement). The adaptation can be either static or dynamic. Static adaptation requires that the system is inactive, while dynamic adaptation is carried out to a running system without having to stop it completely. The change undergone by the system can be qualified as partial or full adaptation. Full adaptation completely changes the initial configuration of the system, while partial adaptation concerns only one level of the system configuration while the remaining portions continue their normal execution. Thus any software system could be adaptable in one or more axes of adaptation.

III. RELATED WORK

The design of adaptive RTES presents many challenges due to the complexity of the problem it handles [8]. In the present paper, we limit our study to research works particularly tackling adaptive RTES using the MARTE profile.

Many researchers have benefited from the MARTE profile for the design and verification of adaptive RTES from high-level models. In [9] authors have benefited from MARTE to model reconfigurable architectures such as FPGAs based Systems-on-Chip (SOC). They extended the MARTE profile with some semantics and Xilinx specific concepts, which limits their applicability for diverse systems, to support Dynamic and

Partial Reconfiguration (DPR) of FPGA. Unlike this contribution, we aim to propose a new extension to support adaptation which is independent from any specific platform.

In [10] the authors give a classification of 13 publications that have dealt with the subject of adaptation in the design approach. Following this classification, the authors illustrate using an avionic example the need for the validation of adaptation rules at design-time according to the real-time features of the system. In this context of verification approaches, they have proposed in [11] an MDE approach for modeling and offline validation of application timing constraints. In fact, this article uses state machine to represent the application configurations and transitions between them to represent adaptation rules. This work is based on the generation of all possible configurations of a system before running, in order to validate timing constraints. The number of configurations varies from one system to another and it can be very large, this combinatorial explosion makes the timing analysis inapplicable. Furthermore the proposed approach considers only periodic tasks and cannot be applicable to aperiodic and sporadic tasks.

Two major scheduling approaches are available in the literature: the partitioned and the global approaches. Originally, MARTE supports only the modeling of the systems to be scheduled according to the partitioned approach. In [12] the authors have proposed various updates for MARTE meta-models of specialization and generalization stereotype in order to support global scheduling approaches, allowing task migrations. Those changes allow a schedulable resource to be executed on different computing resources in the same period [13]. Unfortunately, extensions proposed in MARTE profile do not allow assessing the gain in time of an adaptation operation (task migration in this case).

In [8], five patterns have been proposed to model and evaluate adaptation. These design patterns are presented in a static form through class diagrams and stereotyped MARTE profile. In this work, adaptation is considered as a dynamic and partial change of the operating mode, without taking into account the platform adaptation which is essential in the verification of time constraints.

All the previously mentioned works are beneficial since they facilitate the design of adaptive real-time systems. However, they present some weaknesses. These research studies [8] are not sufficiently generic since they tackle a specific adaptation problem, which consequently compromises their reusability as well as their ability to adapt to new system requirements and constraints. Additionally, most of them only focus on the software side adaptation while ignoring the hardware and implementation adaptation which are essential in the design and analysis of complex systems.

Table 1 presents a classification of works around modeling and verification of adaptive real-time systems according to the level of adaptability considered and timing verification supported. As we can see in this classification, to the best of our knowledge, there is no work that deals with all axes of adaptability.

TABLE I. STATE OF THE ART CLASSIFICATION

Criteria	Related Work			
	[9]	[11]	[12]	[8]
MDE approach	+	+	+	+
Modeling software adaptability	-	+	-	+
Modeling hardware adaptability	+	-	-	-
Modeling implementation adaptability	-	-	+	-
Scheduling Analysis supported	-	+	-	-
Adaptation Type	Internal	Internal	Internal	External
	Dynamic	Static	Static	Dynamic
	Partial	Full	Partial	Full

IV. RESEARCH OBJECTIVE

Our research scope concerns mainly the usability of MARTE profile for supporting the adaptive systems design. This research scope is the result of investigations on relevant existing adaptation-related works. Thus, a need to new extension of MARTE, to support adaptability in system design, is what this work aim to prove. To achieve this goal, we will discuss this need on the three levels of modeling identified in section II.B: functional model, platform model and implementation model.

A. Adaptability of functional model

To model the functional model of the systems, we use MARTE/SAM (Schedulability Analysis Model) capabilities which offer a variety of stereotypes for annotating models with real-time features. This profile has the capacity to model tasks, dependencies between them and events under shape a Workload Behavior of system. Subsequently, it promotes the validation of the system temporal accuracy by the construction of the end-to-end computation. The end-to-end computation represents the processing load of the system. It represents the different steps executed in the system and triggered by one or more external stimulus. «*saStep*» is a stereotype annotating an action/operation. A set of steps specify the so-called *Schedulable Resources*. These are units of execution taken into account by the scheduler of the system, called tasks in scheduling literature [14].

When adaptation is required, an event triggers all the behavior scenarios of the system workload and a new step can appear. For example, let us imagine that for an adaptive event that denoted a low level of battery, a new step appears, such as no flash mode in camera. Thus, steps can be mapped into more than one schedulable resource to manage reconfiguration. The designer is not able to specify these properties considering that the MARTE/SAM does not

address the case that event and steps are involved in multiple schedulable resources.

B. Adaptability of platform model

SAM platform is a package providing sufficient concepts to model a general platform, at a high-level of abstraction, for executing the functional model. It is a specialization of the sub-profile Generic Resource Modeling (GRM), which provides mechanisms to manage access to different execution resource. Originally it does not support modeling of unavailability of resource for a certain period at run-time. This uncertainty is a main factor that can influence the effectiveness of the configuration and affecting its performance considerably.

Moreover in literature a popular alternative to static power management in RTES is to allow the speed factor to adjust dynamically to the number of requests in the system. Using the MARTE/SAM, the designer is able to specify these properties. But, for each adjustment, he must repeat the modeling of the same resource to specify the new features this is due to the multiplicity of the concerned attributes.

C. Adaptability of implementation model

In literature, three scheduling approaches are presented: the partitioned, the semi-partitioned and the global approaches [15]. Regarding the partitioned approach, it affects each task to be executed on one processor. Accordingly, tasks are not allowed to migrate between processors [16]. CPU utilization is therefore not optimal. As for the global approach and semi-partitioned, they enable a tasks migration such that schedulable resource may be allocated, not simultaneously, on different computing resources.

The task migration is considered as an adaptive technique that allows improving application performance and achieves optimality. Currently, MARTE support only the partitioned approach. Thus, task that can be across multiple processors for different periods of time is not permitted in MARTE.

V. RESEARCH ROAD-MAP

The scheduling analysis modeling is performed through the MARTE/SAM profile. The idea of performing scheduling analysis based on MARTE models assumes that all the information that is needed for the analysis is already part of the MARTE model [18]. In fact, SAM meta-model supports the modeling of different systems as it models all the temporal features needed in the scheduling step except those used to model adaptation constraints. Consequently, we seek to improve SAM meta-model in order to support modeling and early analysis of adaptation process. Since static adaptation requires stopping the system and restarting it with a new configuration, the modeling of the adaptation can be done through the modeling of different values for the same resource. This modeling technique requires amendments in the multiplicity of specific attributes of the MARTE model related to the adaptation context.

In our study, the dynamic adaptation is based on a set of predefined adaptation plan and context rules, statically designed and verified at design time. At runtime, the system can select an alternative from the available ones in accordance with adaptation rules.

The amendments to be done on the SAM sub-profile can be useful in the functional model, the platform model and the implementation model. These changes affect MARTE/SAM, but it also affects the use of the GRM sub-profile since some classes of the sub-profile SAM inherit from GRM sub-profile. Afterwards, these extensions can be used in only one pattern to incorporate adaptation features in the modeling view. The use of only one pattern, including all the scheduling criteria in adaptation context, makes simple the compliance test between the pattern and a model. In addition, a design pattern gives a higher abstraction view and eases the modeling of adaptive RTES by promoting reusability of the design. The implementation of the envisaged solution can be performed by the modeling tool Papyrus according to MARTE. Note that, we will prove that the new extension of MARTE profile have no bad influence on the modeling of static systems.

To better evaluate our approach, we depend on a dynamically reconfigurable system and a target architecture holding heterogeneous computing resources. We will conduct various experiments with different properties and desired requirements values to prove capabilities of MARTE extended model to support adaptability mechanisms, previously detailed. The validation of the proposed meta-model can be done through modeling different possible configuration of the application, which contains adaptive tasks, running on a target platform in the presence of resource availability constraints and applying adjustment in the platform resource capacity. The change in functional model, platform model and implementation model represents a different design focus in order to prove reusability of the proposed solution. The extended meta-model of MARTE must contain all needed information to perform schedulability analysis test, in the context of partitioned, the semi-partitioned and the global approaches. The schedulability analysis test can be carried out through a simulation tool, such as Cheddar tool [20].

VI. CONCLUSION

In this paper, we have presented the concept of adaptability. We have also discussed and classified several related work for the development of adaptive Real-Time & Embedded Systems (RTES). By the present classification we identified the need for a new extension of the MARTE profile to support modeling and analysis, at high level abstraction, of adaptive systems. Our research objective consists mainly in the improvement of MARTE/SAM sub-profile. This contribution makes MARTE able to stand adaptability at early design stages of RTES.

In the close future we will develop the extension meta-model of MARTE profile to establish scheduling analysis for adaptive systems.

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