Supporting model-based simulation of embedded systems by coupling tools
Hooman, J.J.M.; Mulyar, N.A.; Posta, L.

Published in:

Published: 01/01/2004

Document Version
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the author’s version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

Citation for published version (APA):
Supporting Model-Based Simulation of Embedded Systems by Coupling Tools

Jozef Hooman¹, Nataliya Mulyar², Ladislau Posta²

¹Embedded Systems Institute, Eindhoven & University of Nijmegen, the Netherlands
²Eindhoven University of Technology, the Netherlands

Abstract—The aim of this work is to support the multi-disciplinary development of real-time embedded systems by combining tools of different disciplines. As a concrete example, we have coupled a UML-based CASE tool (Rose RealTime) and Simulink to allow simultaneous simulation. Since Rose RealTime does not have a well-defined notion of timed simulation, we have used the simulation time of Simulink also for Rose RealTime. An intermediate component has been implemented, which realizes time synchronization and data exchange between the tools.

Keywords—Embedded systems; model-based development; simulation; real-time; UML; Simulink

I. INTRODUCTION

This research has been carried out in the context of the Boderc project. The main aim of this project is to improve multi-disciplinary system design, that is, combining mechanics, electronics and informatics, such that e.g. system-level decisions can be analyzed and consequences of design decisions can be predicted as early as possible. To achieve this goal, strong emphasis is put on high-level models and the combination of models from different disciplines.

There are several formal approaches that allow checking properties of hybrid systems (modeling both discrete and continuous aspects), such as HyTech [4] and Checkmate [2]. Exhaustive checking, however, is limited to relatively small models, and it often requires separate re-modeling and abstraction, which are rather time-consuming. Hence, there is a need for verification and validation methods that can be applied to the models the engineers are used to work with, such as Matlab/Simulink models and, for instance, software

Since tools are very important in the everyday practice of engineers, we have investigated the possibilities for coupling concrete modeling tools, namely Mathworks’ Matlab/Simulink (which is used heavily in many areas, including transportation) and a UML-based CASE tool for real-time systems. Because of pragmatic reasons (industrial contacts, licenses), we have chosen the UML-tool Rose RealTime (Rose-RT for short) of IBM/Rational. This tool supports the ROOM methodology [5] for the development of software for real-time reactive systems. Note that Rose-RT allows code generation for particular target platforms, so there is a direct connection between a model and generated code. However, we could have chosen other UML-tools in the embedded domain, such as Telelogic Tau, Rhapsody of I-Logix, or Real-Time Studio of Artisan.

Our aim is to establish a tool coupling, which allows the combination of a model of a physical dynamical system in Simulink, e.g. representing one or more motors, with a discrete control algorithm in Rose-RT, as depicted in Figure 1.

Figure 1 Combined Models
By establishing a proper notion of simultaneous simulation of these models, one can quickly investigate the effect of changes in the control strategy, software execution times, or concerning the characteristics of the motors. Also note that this allows a comparison with a model where part of the control (e.g. low-level motor control) is modeled in the Matlab environment (e.g. using TrueTime [6]) and a supervisory control part in Rose-RT.

Realizing the desired tool coupling is far from trivial. The two main challenges are:

- Conceptual correctness. The coupling should be such that the simultaneous simulation of models in both tools should give meaningful results. In particular, this means that there should be a common notion of time in combination with a proper exchange of data and messages.

- Technical implementation. Suitable ways should be found to allow the tools to communicate and to run a simulation mode simultaneously. Moreover, the coupling software should be properly designed to allow, for instance, a change to another UML tool.

Note that also TrueTime could have been used to represent discrete real-time control, but we have chosen a UML-based CASE tool, since UML is becoming an ad hoc standard in software engineering and it allows a coupling with large object-oriented software architectures which includes not only control but also other aspects such as error handling and diagnosis. Moreover, such a tool enables code generation for different platforms.

As far as we know, such a coupling between Rose-RT (or similar real-time UML tools) and Simulink models has not been realized before. Related is the work on the High Level Architecture (HLA) [3], a general-purpose architecture for the coupling of simulation tools. However, HLA could not be used for our purpose, because UML-case tools, such as Rational Rose RealTime do not fit into this framework; they do not have the required simulation mode with a well-defined notion of simulation time.

In the rest of this paper, we very briefly present the tools used (Rose-RT and Simulink), in Sections II and III respectively, describing them only as far as needed to understand the coupling. The main concepts of the coupling are described in Section IV. Concluding remarks can be found in Section V.
continuous part of the state to time and the current values of the inputs and the state.

Running a simulation of a Simulink model means that outputs, inputs and states are computed at certain intervals, from the simulation start time to the simulation end time. All time-related tasks are performed by a so-called solver, a Simulink-specific program. In fact, there are several types of solvers, depending on, e.g., whether the step size is fixed or variable, and the integration method used.

IV. MAIN CONCEPTS OF THE COUPLING
In this section we describe the main decisions taken to establish a correct coupling and the conceptual architecture, which realizes this coupling.

The most important decision concerns the notion of time to be used for the simulation. First we observed that the timing of Rose-RT is strongly coupled to the timing service of the operating system of the target system on which the model is running. Moreover, timing is not respected in the step-by-step simulation. Hence, we concluded that the timing of Rose-RT is not suitable for our purpose and decided to use the notion of simulated time of Simulink instead. The alternative is to use a separate, independent, notion of time, but this would also require new implementations of solvers, redoing a lot of things already available in Simulink.

To be able to establish a proper global notion of time, which faithfully reflects the execution of both models, somehow the execution time of the transitions in the Rose-RT model has to be taken into account. We assume that this information is available, representing an assumption on the underlying platform.

Another decision to be taken is the global architecture of the coupling. A possible approach, depicted in Figure 2, is to extend each tool with a specific component, which communicates directly with the other tool.

Instead of such a tight coupling, we decided to use a more loosely coupled architecture by introducing a third component called Multidisciplinary Coupling Tool (MCT), as shown in Figure 3. Observe that each tool contains an add-in, which is responsible for the communication with the MCT component.

By introducing such an MCT interface the modeling tools do not need to know about each other and it becomes much easier to change, for instance, switching to another UML-based CASE tool.

To obtain proper timing of the UML models, we have redefined the timing service of Rose-RT such that it gets the current notion of time from the MCT component. Moreover, the UML model has to be extended by specifying the assumptions on the execution times of all transitions. The Simulink model is extended with blocks that obtain data and timing info from the Rose-RT model via the MCT and ensure that the data is used at the appropriate moment of time. Also the setting of a timer in the UML model is communicated to these added Simulink blocks, which then generate the timeout.

To run a simulation, we have to initialize the simulation environment as follows:
1. Start Rose-RT and open a UML model which has been prepared for coupling
2. Start Matlab/Simulink and open a Simulink model which has been prepared for coupling
3. Start the simulation in the Simulink model, which:
   a. Starts the Simulink timer
   b. Sets the time of MCT to the current Simulink simulation time
   c. Starts the Rose-RT Target Run-Time System; the Rose-RT environment then requests the system clock, which by our modifications means that it gets the time of the MCT, next the Rose-RT model waits for external triggers
Next we describe an example of typical steps performed during a part of the simulation, depicted in the sequence diagram of Figure 4.

**Figure 4 Interactions During Simulation**

The numbered interactions represent the following actions:

1. The Simulink MCT add-in sets the time of the MCT to the current Simulink time. The Simulink model is frozen from this moment.
2. The Simulink MCT add-in sends an external event to the Rose-RT model; there this message is put to the queue.
3. The Simulink MCT add-in gives a command to perform one step in Rose-RT.
4. Rose-RT updates its clock with the value taken from the MCT.
5. Rose-RT processes a message from the queue; and executes a transition triggered by this message (if any).
6. Rose-RT sends the calculated data together with the transition duration to the MCT.
7. The Simulink MCT add-in reads the data and the execution delay set by Rose-RT in the MCT.
8. Simulink ensures that Simulink simulation time advances with the value of the received delay. The Simulink model is resumed from this moment.
9. The Simulink MCT add-in passes the data to the Simulink model and the simulation loop continues.

Figure 5 show a more detailed architectural view of the implementation, showing for instance in more detail how the timing of a UML model is obtained from the MCT.

**Figure 5 Module Architecture View**

V. CONCLUDING REMARKS

The current version of the coupling has been applied to a few small examples, showing the feasibility and usefulness of such a simultaneous simulation on a small scale. Clearly, much more experiments with larger industrial examples are needed to investigate the performance for complex systems. Future work also includes the removal of a few simplifications that have been made to obtain a first prototype quickly. For instance, at the moment only one timer is allowed in the UML model. Currently, the models are simulated on a single PC, but we also intend to investigate a distributed implementation, which couples models on different PCs.

REFERENCES


