Adaptive Step Size Control for Hybrid CT Simulation without Rollback

Rebeka Farkas[1,2,3] Gábor Bergmann[1,2,3] Ákos Horváth[1,3]

[1]Department of Measurement and Information Systems, Budapest University of Technology and Economics, Hungary, {farkasr,ahorvath,bergmann}@mit.bme.hu
[2]MTA-BME Lendület Cyber-Physical Systems Research Group
[3]IncQuery Labs Ltd, Hungary

Hybrid systems demonstrate both discrete and continuous behaviour which makes their simulation challenging. A possible approach is *Hybrid CT* that uses *continuous time* simulation and provides wrappers for discrete event components (as opposed to *Hybrid DE* simulation where continuous time components are adjusted so discrete event simulation can be used). The modular architecture of FMI-based simulation makes it appropriate for hybrid co-simulation.Additionally, components can be co-simulated without revealing the Intellectual Property that went into their design, which makes FMI-based co-simulation industrially applicable.

Challenges Despite the fact that there are proper approaches to create FMUs from discrete event components, the co-simulation of continuous-time and discrete-event blocks is still in its early phases. From a simulation point of view, one of the main differences between the two types of components is the simulation step size: continuous systems are simulated by periodically calculating the value of the variables with relatively large step sizes but discrete event-based systems operate irregularly and their simulation requires smaller steps (often measured in nanoseconds) since discrete events can trigger other discrete events (almost) instantly. It is possible to simulate continuous time models with smaller step sizes (in fact, it yields more accurate results), but it is inefficient (often preventing industrial application) and mostly unnecessary. The sporadic occurrence of discrete events raises the need for *adaptive step size control*.

Contribution In this paper we propose an adaptive step size control approach to overcome the difficulties of hybrid CT simulation. The core idea is to adjust the step size when an event is expected in order to decrease the detection latency. Event prediction relies on identifying the causes that might trigger an event, based on high-level information about the model provided as configuration parameters. The proposed component calculates the step size based on global minimal and maximal values and the events predicted by the following types of triggers:

- Events may trigger other events (reactions/responses). In order to detect discrete event responses with low latency, a set of *event indicators* – i.e. variables where the change of the value represent an event – have to be declared.
- Discrete events may be triggered by the elapse of time. For accurate simulation, special variables, called *time indicators* can be declared that each indicate when an event will be fired.
- Discrete events may be triggered by continuous variables crossing a given threshold. In order to facilitate the detection of such scenarios auxiliary intervals should be described, representing when the value is considered *close* to the threshold.

Experimental findings We have integrated the proposed adaptive step size controller component in the OMSimulator - an FMI-based simulator for cyber-physical systems, developed by the Open Source Modelica Consortium - and run measurements on case studies with constant steps of different step sizes as well as using adaptive step size control. In order to find out how the step size controller affects performance we measured the runtime and then analysed the differences between the efficiency and the results of corresponding simulations.

The results show, that in case of constant step sizes an order of magnitude difference in the step sizes yields an order of magnitude difference in event detection latency. However, in case of adaptive step size control, the latency is almost as small as in case of fixed step size simulation with the minimal possible step size, while the runtime is almost as small as in case of fixed step size simulation with the maximal step size.

Advantages The proposed approach facilitates co-simulation of discrete and continuous components without relying on step rejection that discrete components often fail to support. The step size controller requires only high-level information (types of variables, expected events, critical thresholds) for simulation, thereby respecting Intellectual Property. Measurements show that using adaptive step sizes can be a beneficial compromise between performance and accuracy. We believe that the step size controller can bridge the gap between continuous time simulation and discrete event components.