Co-Simulation of Hybrid Systems with SpaceEx and Uppaal

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Despite advances in model checking and other formal verification techniques, simulation remains the workhorse for system analysis. A plethora of simulation tools are available today, from academia as well as from industry. These tools support a large variety of modeling languages, targeted at different types of systems from various disciplines, e.g., mechanical, electrical, digital, continuous or discrete, or mixes thereof. Unfortunately, these tools can rarely interoperate. This is a problem because modern cyber-physical systems are highly complex and multidisciplinary, requiring specialized modeling languages and tools from several domains.

The Functional Mock-up Interface (FMI) is a standard developed to address this problem. In particular, FMI enables co-simulation of complex heterogeneous systems using multiple simulation engines. In this paper, we show how to use FMI in order to co-simulate two state-of-the-art modeling and verification tools for cyber-physical systems: SPACEEX (Frehse et al., 2011) and UPPAAL (Larsen et al., 1997). SPACEEX is a tool for modeling and verifying *hybrid systems*. UPPAAL is primarily a model-checker for *timed automata*, however, it also supports statistical model-checking of hybrid systems. We also show how FMI components can be automatically generated from SPACEEX and UPPAAL models.

We validate the co-simulation approach by comparing the results of our case study in two settings: (a) when the benchmark is modeled and simulated in a single tool, and (b) when the various components of the benchmark are modeled in two tools and co-simulated using our framework. We show that the simulation trajectories induced by our co-simulation framework can be made arbitrary close to the trajectories in the setting (a) provided that the maximum simulation step size of co-simulation is sufficiently small. Finally, we perform a measurement experiment on a composite model to show a potential for statistical model checking using stochastic co-simulations.

References

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