Interconnection of Heterogeneous CPS Models Through Architectural Views

Designing cyber-physical systems involves decomposing them into heterogeneous models to represent different parts of the system. These models are created with different formalisms: signal flow diagrams, continuous equations, UML models, and so on. For example, one could represent physical parts of a system in MapleSim, its control structure in Simulink, and its source code in SysML. Differences in element vocabularies, levels of abstraction, and fundamental premises of these models pose a number of challenges to the engineering process of cyber-physical systems. How should heterogeneous models be composed? What is a consistent, correct composition of these models? How do changes in one model affect the other models? Answering these questions "correctly" is crucial to avoid implicit and costly errors late in the project.

The field of software architecture offers an approach to answering these questions. It suggests representing a system with a set of high-level structural representations – views [1]. Each view highlights cohesive concerns about system-level organization. For example, a dataflow view would show the system in terms of filters and streams of data. A hardware deployment view would describe computing nodes and physical connections between them. Views can be formally represented and analyzed with architecture description languages [2].

We believe that the view-based approach can answer the questions above about the consistency of multiple heterogeneous models. In the past, we used this approach to express and verify the structural consistency of multiple views [3]. Heterogeneous models of a system were abstracted to views and mapped to a base architecture, which ensured that they are structurally consistent. We plan to enrich the notion of consistency by adding semantic information to views. One example of important semantics is timing information. Schedulability of the whole system may depend on parts of system, modeled in different formal notations, meeting real-time constraints. In another case, one model's correctness may depend on another model's timing profile. Since different models may not agree on the notions of time, deadlines, and execution times, this information could be stored in architectural views.

Architectural views also provide a framework for integrating our group's work on modeling and verifying cyber-physical systems under this grant. Incorporating the theoretical findings into an architectural toolchain will help consolidate results into an integrated approach to CPS design and analysis. Our current vision is that views can contain rich information about the system and feed it to simulations and verification tools as needed.

Over previous projects we developed a set of architectural tools for style-based formal analysis [2, 4] and for structural consistency specification and checking [5] of cyber-physical systems. These tools proved useful in finding consistency violations in the design of a quadrotor helicopter [3, 6] and Toyota's X-in-the-loop simulations [3]. We are currently working with Toyota on an engine controller model to understand how to express and check semantic consistency in architectural views.

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