USC Viterbi
School of Engineering

EE 599 Spring 2017

Cyber-Physical System Design: Modeling, Analysis, and Synthesis

Schedule
Tuesday and Thursday, 9:30am-10:50am (Lecture), KAP 163
Thursday, 2pm-3:50pm (Lab & Discussion Section), MRF 229

Instructor
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EEB 346

Office Hours
TBD, EEB 346

Course Summary
The emerging scenario of the *Internet-of-Things (IoT)* features *swarms* of devices that are immersed in all kinds of physical processes and can offer a variety of personal or societal services, from health monitoring to vehicle, building, and energy management. In these *cyber-physical systems,* computing, networking, and control are combined with mechanical, electrical, chemical, and biological processes in tight feedback loops where physics affects computation and vice versa. The increasing sophistication of these systems requires innovations in several technology domains as well as *design methodologies*. This course bridges theoretical aspects to applications to provide an understanding of the *fundamentals of system design* as well as a sense of the problems posed by complex applications. It presents theories, design methods, and tools that help handle the growing complexity and heterogeneity of embedded and cyber-physical systems, by offering a new vista on system design, where correct-by-construction abstraction, refinement, and composition techniques are pursued to substantially reduce design time and errors. Methodologies and tools will be illustrated on several *applications*, including robotic motion planning, car electronics, building automation, and electrical power systems control. During the lab sessions, the students will work on specific design cases using both industrial-strength and research-oriented software platforms. During the discussion sessions, recent results and papers will be presented to the class by the students.

Grading
The grading will be based on different components. A tentative partitioning would be as follows: homework (15%), discussion (10%), lab (15%), final exam (20%), and class project (40%).

Prerequisites

The course targets both Master and PhD students with interest in cyber-physical system and IoT system design. We recommend some exposure to the basics of real-time embedded systems, the fundamentals of calculus or discrete mathematics, some background in programming, and an inclination to formal reasoning.

Course Outline

- Week 1. **Introduction:** Cyber-Physical Systems (CPS); CPS Design Challenges; Model-Based Design and Design Methodologies; Simulation, Validation, Verification, and Synthesis; Platform-Based Design and Contract-Based Design.
- Week 2. **Modeling:** Introduction to Models of Computation; Languages and Tools for System Design; Mathematical Background; Notions of Complexity and Computability.
- Week 3. **Concurrent Models of Computation**: Finite State Machines; Synchronous/Reactive Model.
- Week 4. **Concurrent Models of Computation**: Process Networks; Dataflow; Petri Nets.
- Week 5. **Concurrent Models of Computation**: Timed Models; Discrete-Events (DE) Model. **Project Proposal Presentation.**
- Week 6. **Concurrent Models of Computation**: Continuous-Time Model; Acausal Model; Mixed Models; Hybrid Systems.
- Week 7. **Interfaces for System Design**: Types; Ontologies; Behavioral Types; Interfaces and System Specification; Interfaces and Compositional Methods; Assume-Guarantee Reasoning.
- Week 8. **Interfaces for System Design**: Contracts; Contract Operations and Relations; Compatibility, Consistency, Composition, Refinement.
- Week 9. **Analysis:** Cyber-Physical System Requirements (Functional, Extra-functional, Safety, Liveness, Reliability, Real-Time); Specification Languages; Temporal Logic; Overview of Requirement Analysis and Validation Techniques.
- Week 10. **Analysis:** Core Engines for Algorithmic System Verification; Satisfiability (SAT) Solving; Satisfiability Modulo Theories (SMT) Solving; Optimization; Reachability Analysis and Model Checking. **Project Midterm Review.**
- Week 11. **Design Space Exploration and Synthesis:** Cyber-Physical Systems Architectures; Mapping and Synthesis; Architecture Exploration; Optimization-Based and Simulation-Based Techniques for Mapping and Synthesis.
- Week 12. **Design Space Exploration and Synthesis:** Verification and Synthesis of Controllers; Algorithmic Synthesis Techniques; Optimization-Based Controller Design.
- Week 13. **Design Space Exploration and Synthesis:** Fundamentals of Real-Time Operating Systems and Scheduling.
- Week 14. **Applications**: Modeling and Design of Power Distribution Networks; Modeling and Design of Building Automation and Control Systems. **Advanced Topics (based on available time and student interest)**: Security and Privacy; Stochastic Systems; Machine Learning and System Design.
- Week 15. **Course Wrap Up. Class Project Presentations.**

Course Material:

The main source for this course will be lecture notes or handouts provided by the instructor. The following books are suggested for further reading: E. A. Lee and S. A. Seshia, "Introduction to Embedded Systems, A Cyber-Physical Systems Approach," Second Ed., http://LeeSeshia.org, 2015; R. Alur, "Principles of Cyber-Physical Systems," MIT Press, 2015.

Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Part B, Section 11, "Behavior Violating University Standards" https://policy.usc.edu/student/scampus/part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Discrimination, sexual assault, intimate partner violence, stalking, and harassment are prohibited by the university. You are encouraged to report all incidents to the *Office of Equity and Diversity/Title IX Office* http://equity.usc.edu and/or to the *Department of Public Safety* http://dps.usc.edu. This is important for the health and safety of the whole USC community. Faculty and staff must report any information regarding an incident to the Title IX Coordinator who will provide outreach and information to the affected party. The sexual assault resource center webpage http://sarc.usc.edu fully describes reporting options. Relationship and Sexual Violence Services https://engemannshc.usc.edu/rsvp provides 24/7 confidential support.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://ali.usc.edu, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://dsp.usc.edu provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* http://emergency.usc.edu will provide safety and other updates, including ways in which instruction will be continued by means of Blackboard, teleconferencing, and other technology.