USC Viterbi
School of Engineering

EE 599 Spring 2018

Mathematical Foundations for System Design: Modeling, Analysis, and Synthesis

Schedule
Tuesday and Thursday, 9:30am-10:50am (Lecture), WPH 101
Tuesday, 2pm-3:20pm (Lab & Discussion Section), HED 103

Instructor
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EEB 346

Office Hours
Tuesday, 3:30-4:30pm EEB 346

Course Summary
The modeling, analysis, and optimization of complex systems requires a suite of algorithms and design software. This course introduces students in our School to the fundamental techniques underlying the design methodologies for complex systems. Integrated circuit design will be used as a central example, augmented by examples from cyber-physical systems, biological systems, and software design. Topics include design flows, fundamental classes of systems and models (discrete, timed, continuous, dataflow, hybrid, probabilistic), and fundamental analysis, verification, and synthesis techniques and algorithms for each class (e.g., state-space exploration, discrete-event simulation, numerical simulation, throughput analysis, steady-state analysis). Lab assignments and a class project will expose students to state-of-the-art tools.

Course Goals
- Provide students with the mathematical foundations and fundamental algorithms that are the basis of model-based design (MBD) and computer-aided design (CAD) techniques used in research and by industry;
- Provide insights into the benefits and limitations of state-of-the-art MBD and CAD tools and the techniques they employ;
- Provide students with valuable knowledge regarding a suite of mathematical tools they can use in their research on problems in the areas of CAD, VLSI design, architecture, networks, and CPS design.

Grading

The grading will be based on different components. A tentative partitioning would be as follows: homework (15%), discussion (5%), lab (10%), final exam (20%), and class project (50%).

Prerequisites

No formal prerequisites. We recommend some exposure to the fundamentals of calculus or discrete mathematics, some background in programming, and an inclination to formal reasoning.

Course Outline

- Week 1. **Introduction:** Introduction to Design Flows (for VLSI circuits, cyber-physical systems, biological systems, etc.); Model-Based Design and Design Methodologies; Platform-Based Design and Contract-Based Design; Design Automation Problems: Modeling, Analysis (Verification, Simulation, Validation), and Synthesis; Design Automation Challenges.
- Week 2. **Discrete Models:** Boolean Functions and Relations; Finite State Machines; Synchronous/Reactive Model; Discrete-Events (DE) Model.
- Week 3. **Discrete Models**: Dataflow and Process Networks; Petri Nets; Primer on Logic: Propositional/First Order Logic; Temporal Logic. Overview of timed discrete models.
- Week 4. **Analysis and Verification of Discrete Models**: Overview of Complexity and Computability; Primer on Graph Algorithms: Shortest/Longest Paths; Graph Covering/Coloring/Cliques; Timing Analysis.
- Week 5. **Analysis and Verification of Discrete Models**: Reachability Analysis (State Exploration) and Model Checking. Fixed Points. Implicit Techniques for State Exploration; Implicit Representations; Binary Decision Diagrams (BDDs). **Project Proposal Presentation.**
- Week 6. **Analysis and Verification of Discrete Models**: Satisfiability (SAT) Solving; Satisfiability Modulo Theories (SMT) Solving.
- Week 7. **Synthesis for Discrete Models:** Introduction to Logic Synthesis: Two-Level Circuits; Elements of Multi-Level Logic Optimization; Technology Mapping; Dynamic Programming.
- Week 8. **Synthesis for Discrete Models:** Controller and Program Verification; Synthesis of Controllers.
- Week 9. **Interfaces for System Engineering**: Types; Ontologies; Assume-Guarantee Reasoning; Contracts.
- Week 10. **Continuous and Hybrid Models**: Continuous-Time Model; Acausal Model; Hybrid Systems; Signal Temporal Logic. **Project Midterm Review.**
- Week 11. **Analysis and Synthesis for Hybrid and Cyber-Physical Systems:** Cyber-Physical System (CPS) Requirements (Functional, Extra-functional, Safety, Liveness, Reliability, Real-Time); Requirement Analysis and Validation Techniques; CPS Simulation; CPS Architecture Exploration; Mapping and Synthesis for CPSs.
- Week 12. **System Optimization:** Mathematical Programming; Linear Programming; Convex Programming; Related software and applications.
- Week 13. **System Optimization:** Mixed-Integer Linear Programs; Branch and Bound; Simulated Annealing; Related software and applications.
- Week 14. **Advanced Topics (based on available time and student interest)**: 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;
- Hachtel GD, Somenzi F. Logic synthesis and verification algorithms. Springer Science & Business Media; 2006;
- S. Devadas, A. Ghosh, and K. Keutzer, "Logic Synthesis," McGraw-Hill, 1994;
- Stephen Boyd, Lieven Vandenberghe, Convex Optimization, Cambridge University Press;
- Edmund M. Clarke, Jr., Orna Grumberg, and Doron A. Peled, Model Checking, MIT Press, January 2000;
- Michael Huth and Mark Ryan, Logic in Computer Science: Modelling and Reasoning about Systems, Cambridge Univ. Press, June 2004 (2nd edition).

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.