



## EE 581 Fall 2021

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

#### Schedule

Monday and Wednesday, 10am-11:50am (Lecture & Discussion Section),  
Zoom Meeting URL: TBD

Monday, 2pm-3:50pm (Lab)  
Zoom Meeting URL: TBD

#### Instructor

Pierluigi Nuzzo (nuzzo@usc.edu)  
EEB 346  
*Office Hours:* Wednesday, 4-6pm  
Zoom Meeting URL: TBD

#### Teaching Assistant

Chanwook Oh (chanwooo@usc.edu)  
EEB 337  
*Office Hours:* TBD

#### 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, from integrated circuits to embedded and cyber-physical systems. 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 (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 research problems and tools. **In Fall 2021, discussions sections, labs, and class projects will be motivated by the design and verification of cyber-physical systems enabled by artificial intelligence and machine learning methods (e.g., neural network-based systems, intelligent autonomous systems).**

## Grading

The grading will be based on different components. A tentative partitioning would be as follows: homework (20%), discussion (10%), lab (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:** Design Methodologies: Model-Based Design, Platform-Based Design, and Contract-Based Design; Design Automation Problems and Challenges: Modeling, Analysis (Verification, Simulation, Validation), and Synthesis.
- 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; Timed discrete models; Primer on Logic: Propositional/First Order Logic, Temporal Logic.
- Week 4. **Analysis and Verification of Discrete Models:** Primer/Review on Graph Algorithms. Reachability Analysis (State Exploration) and Model Checking. Fixed Points.
- Week 5. **Analysis and Verification of Discrete Models:** 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:** Synthesis of Programs and Controllers.
- Week 8. **Interfaces for System Engineering:** Types; Ontologies; Assume-Guarantee Reasoning; Contracts.
- Weeks 9-10. **Continuous and Hybrid Models:** Continuous-Time Model; Acausal Model; Hybrid Systems; Signal Temporal Logic. **Project Midterm Review.**
- Weeks 11-12. **Analysis of 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.
- Weeks 13-14. **Synthesis and Optimization of Cyber-Physical Systems:** CPS Architecture Exploration; Mapping and Synthesis for CPSs; Primer/Review on Mathematical Programming: Linear Programming, Convex Programming, Mixed-Integer Linear Programming. Optimization software and applications.
- 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;
- 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>.

### Support Systems

*Counseling and Mental Health* - (213) 740-9355 – 24/7 on call  
[studenthealth.usc.edu/counseling](http://studenthealth.usc.edu/counseling)

Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

*National Suicide Prevention Lifeline* - 1 (800) 273-8255 – 24/7 on call  
[suicidepreventionlifeline.org](http://suicidepreventionlifeline.org)

Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

*Relationship and Sexual Violence Prevention Services (RSVP)* - (213) 740-9355(WELL), press “0” after hours – 24/7 on call  
[studenthealth.usc.edu/sexual-assault](http://studenthealth.usc.edu/sexual-assault)

Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

*Office of Equity and Diversity (OED)* - (213) 740-5086 | *Title IX* – (213) 821-8298  
[equity.usc.edu](http://equity.usc.edu), [titleix.usc.edu](http://titleix.usc.edu)

Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

*Reporting Incidents of Bias or Harassment* - (213) 740-5086 or (213) 821-8298  
[usc-advocate.symplicity.com/care\\_report](http://usc-advocate.symplicity.com/care_report)

Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity | Title IX for appropriate investigation, supportive measures, and response.

*The Office of Disability Services and Programs* - (213) 740-0776  
[dsp.usc.edu](http://dsp.usc.edu)

Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

*USC Campus Support and Intervention* - (213) 821-4710  
[campussupport.usc.edu](http://campussupport.usc.edu)

Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

*Diversity at USC* - (213) 740-2101  
[diversity.usc.edu](http://diversity.usc.edu)

Information on events, programs and training, the Provost’s Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

*USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call*

[dps.usc.edu](http://dps.usc.edu), [emergency.usc.edu](http://emergency.usc.edu)

Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

*USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call*

[dps.usc.edu](http://dps.usc.edu)

Non-emergency assistance or information.