EECS C291E/ME C290S: An Invitation to Hybrid and Intelligent Systems Design

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TTh 9:30-11:00 Place: 540 Cory or 240 Bechtel
http://inst.eecs.berkeley.edu/∼ee291e/

Advances in networked embedded and cloud computing, IoT, and machine learning have fueled the need for design techniques that come with certificates of guarantee and safety. They also need to be designed to provide high confidence assurances of performance specifications. This course has two parts. Some lectures will be given by Professor Claire Tomlin.

1. **Hybrid Systems: Modeling, Analysis and Design**.
   Hybrid dynamical systems are continuous time, continuous variable systems with *a phased operation*. Hierarchical organization is implicit in hybrid systems, since the discrete event dynamics represent planning, which is based on an abstraction of the continuous dynamics. Hybrid systems are important in new and emerging applications in robotics and intelligent machines, mechatronics, aeronautics, air and ground transportation systems, systems biology, process control, and have recently been at the center of intense research activity in the control theory, computer-aided verification, and intelligent systems communities. We will present modeiing and simulation techniques for hybrid systems, to analyze their behavior, and to synthesize controllers that guarantee closed-loop safety and performance specifications. We will then discuss specifications for performance, verification and design of controllers for hybrid systems. For hybrid verification we treat decidability of timed automata, rectangular automata, general nonlinear systems with some approximation properties and some software verification tools. For hybrid controller synthesis, we will develop useful tools from game theory and optimal control.

2. **Safe Learning Systems**.
   There is a great deal of concern about whether systems which incorporate on-line learning can maintain safety properties as they enhance their performance. For example can you make sure that autonomous cars do not crash into obstacles while they are learning about their environment or unmanned aerial vehicles not run into the ground. There is a great deal of learning literature which focuses on learning on simulation models (off-line). We will discuss how to provide guarantees of safety in learning systems. This is sometimes referred to Safe AI.

Prerequisites:
Background in systems and control, such as EECS 221A or ME 232 is desirable. EECS 222 is offered concurrently and is a useful class to take with this one.

Grading and Evaluation:
Class work consists of 4-5 homework problem sets and two substantial group projects.

- Homework 35 %
- Mini-Project (middle of term) 25 %
- Final Project 40%

Class Projects:
The projects can either be in the form of a review of an area of the literature or, preferably, involve the exploration of original research ideas. The length of the project can be inversely proportional to its originality. If the project is a review of the literature, it needs to be thoroughly digested and homogenized. There are two projects for the class: a Mini-Project (due around Week 9 of the class) and the Final Project. It is recommended that the Mini-Project be of the literature review variety and the Final Project have some originality or be a review of a broad area. The project should be chosen in consultation with the instructor(s). Joint project proposals (with groups of 2-4 per group) are encouraged. You can keep your group for both the Mini Pbroect as well as the Final Project.

An initial suggestion of some project ideas are:

- *Investigation of a subclass of hybrid systems:* linear hybrid systems (ellipsoidal calculus, switched Lyapunov functions); discrete-time hybrid systems; stochastic hybrid systems.
- *Hybrid System topics:* multiple objective systems; topics from game theory (n-player pursuit evasion games, cooperative games, collective intelligence); hybrid system simulation; control and optimization of hybrid systems; observability of hybrid systems; model identification.
- *Cyber Security of Network Embedded Systems:* attacks on network embedded systems can be modeled as games between the adversary and the controller. With the ubiquitous use of network embedded systems in physical infrastructure in so-called SCADA (Supervisory Control And Data Acquisition) systems, it is important to derive provably correct defenses to certain classes of attacks.
- *Autonomous Systems: driving, flying, etc.* Design control schemes for safe learning for autonomous systems.
- *New Perception Action Loops incorporating Learning.* Provide guaranteed behavior for systems which involve active vision, that is closing the loop around the vision sensor for application such as autonomous driving, Augmented Reality, etc.
- *Multi-Agent Societal Systems:* groups of coordinating vehicles; identification of modes in ATC observed data; gait modeling, stability and control; engine control; guidance of a UAV; biological modeling and control; embedded control and real time scheduling.
- *Open Problems.* Examples include: Observers and State Estimation for Hybrid Systems, approaches such as Generalized Principal Component Analysis or Markov Chain Monte Carlo methods have been proposed; Model Predictive Control or Finite Horizon Control and its relationship to controller design.

Course References: The course is based on lecture notes and articles which will be made available throughout the term. We have a draft monograph on Hybrid Systems by Lygeros, Sastry and Tomlin, "Hybrid Systems: Foundations, Advanced Topics, and Applications", and a draft manuscript by Ratliff and Sastry, "Societal Scale Cyber Physical Systems: The Science of Digital Transformation" which will be made available. We will also extensively use the recent doctoral disseration of Dr. Jaime Fernandez Fisac, "Game Theoretic Safety Assurance for Human Centered Robot Systems", UC Berkeley, Fall 2019.

Course Road Map

1. Week of Jan. 20th Introduction to Hybrid Systems. Examples of Hybrid Systems
2. Week of Jan. 27th. Models of Hybrid Automata, Solution Concepts **Problem Set I** to be issued January 29th.
3. Week of February 3rd Existence and Uniqueness of Solutions
4. Week of February 10rh Specification and Verification of Properties, Bisimulation **Problem Set 2** to be issued February 12th.
5. Week of February 17th, Timed Automata, Rectangular Automata
6. Week of February 24th, Stability of Hybrid Systems **Problem Set 3** to be issued February 28th.
7. Week of March 2nd Introduction to Game Theory and Solution Ccncepts for games
8. Week of March 9th, Nash Solutions to Games, Differential Games **Mini Project Proposals Due**
9. Week of March 16th, Controller Synthesis for Discrete and Continuous Systems, Hamilton Jacobi Isaacs (HJI) equation
10. Week of March 23rd Term break
11. Week if March 30th Mini Project Presentations, both in-class and during the week.
12. Week of April 6th Controller Synthesis for Hybrid Systems (some lectures by Claire Tomlin) **Problem Set 4 issued April 7th**
13. week of April 13th. Time Varying HJI and Reach-Avoid Games **Final Project Proposals Due**
14. Week of April 20th. Multi-Robot Trajectory Planning
15. Week of April 27th. Safe Learning Under Uncertainty.(incuding possible guest lectures by Jaime Fernandez Fisac)
16. Week of May 4th Final Presentations.