Advances in networked embedded computing and communication devices have fueled the need for design techniques that can guarantee safety and performance specifications of embedded systems, or systems that involve the integration of discrete logic with the analog physical environment. Hybrid dynamical systems are continuous time, continuous variable systems with a phased operation. The phases of operation capture the system’s discrete event or linguistic behavior, while the continuous variable dynamics capture the system’s detailed or “lower-level” behavior. The two behaviors influence each other. 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 applications in real-time software, robotics and automation, 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 artificial intelligence communities. In the past several years, methodologies have been developed to model hybrid systems, to analyze their behavior, and to synthesize controllers that guarantee closed-loop safety and performance specifications. This class presents recent advances in the theory for analysis, control, verification, and simulation of hybrid dynamical systems, and shows the application of the theory to the design of the control architecture for complex, large scale systems.

We will present hybrid automaton models and related modeling approaches. We present emerging approaches for hybrid system simulation. 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 treat different control system setups such as game theoretic and optimal control, switched systems, and other recent techniques. Finally, we will apply the theory to case studies of complex problems such as automated highway systems, air traffic management systems, networks of unmanned vehicles, closing the loop around sensor networks, and systems biology.

**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.

**Office Hours:**
721 Sutardja Dai Hall, Tu W 11-12, tomlin@eecs.berkeley.edu
Grading and Evaluation:
Class work consists of some homework exercises and a substantial individual project.

- Homework 50%
- Class Project 50%

Class Project:
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. The project should be chosen in consultation with the instructors. The schedule is as follows:

- Project Proposal (two page summary) due before term break
- Project Report (10-12 pages) and poster due final week of classes

Joint project proposals (with groups of 2 or 3 per group) are encouraged.

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.
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.
Applications: 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 a set of lecture notes and articles which will be made available throughout the term.

Course email list:
Please sign in on the first day of lectures to ensure that you are on the class email list.