

HYBRID SYSTEMS: COMPUTATION AND CONTROL

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TUTh 2:00-3:30, Place: 540 Cory

This class presents recent advances in the theory for 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.

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.

Control systems design based on hybrid models consist of three parts:

1. Controller synthesis,
2. Formal verification, and
3. Simulation.

Given hybrid models of a plant and the behavior desired of it, a controller is designed so that the closed-loop system yields only desired behavior. In the design of the controller one exploits or imposes a hierarchical organization of the system to propose layered control architectures—planning or supervisory control at the discrete event level, and "traditional" control at the continuous level. The formal verification step is used to guarantee that the controlled system produces no undesired behavior. For this one must construct hybrid abstractions of the closed-loop system, represent them in a suitable formalism, and use the inference mechanisms of the formalism to deduce that the closed-loop system is satisfactory. Formal verification—checking that no undesired behavior is produced—is a minimal requirement on proposed controllers. It does not provide a sense of the qualitative behavior of the closed-loop system. Other techniques, such as game theory and optimal control need to be used for this and finally simulation is employed for this purpose, especially in the case of large, complex systems. The simulation and verification steps yield additional insight into the system, and this insight can be used to refine the controller synthesis.

In this course we will present the hybrid automaton model and related modeling approaches. In hybrid controller synthesis, we will treat different control system setups such as game theoretic and optimal control, switched systems, and other recent advances. For hybrid verification we treat decidability of timed automata, rectangular automata, and some approximation properties, and introduce software tools such as HYTECH, CHECKMATE, REQUIEM. We present emerging approaches for hybrid system simulation and illustrate them using software tools such as PTOLEMY, HYVISUAL, CHARON, MATLAB. Finally, we apply the theory in case studies to complex, real-life problems such as Automated Highway Systems, Air Traffic Management Systems, Networks on Unmanned Vehicles and Systems Biology.

Prerequisites and Requirements:

Consent of instructors. Background in systems and control and in finite automata is desirable. Class work consists of a few homework exercises and a substantial individual project. 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.

Office Hours:

Sastry, 514 Cory Hall MW 3:00 to 4:00 pm. or by appointment, sastry@eecs.berkeley.edu

Outline

1. **Introduction**
2. **Overview of Dynamical Systems**
3. **Review of Continuous Systems**
4. **Hybrid Automata and Executions**
5. **Existence of Executions and Zeno Phenomena**
6. **Analysis and Synthesis**
7. **Model Checking and Timed Automata**
8. **Simulation Tools**
9. **Review of Optimal Control and Game Theory**
 - (a) Two Person Zero Sum games: saddle solutions
 - (b) Hamilton Jacobi Isaacs equations
 - (c) Pursuit games
 - (d) Multi Person games: Nash, Stackelberg solutions
 - (e) Incomplete Information
10. **Synthesis Techniques for Hybrid Systems and Hamilton Jacobi Theory**
11. **Approximation Techniques for Controller Synthesis**
12. **O-Minimal Systems and Safety Properties of Hybrid Systems**
13. **Case Study 1: Hybrid Systems in Intelligent Vehicle Highway Systems**
 - (a) Introduction to IVHS: Smart Cars on Smart Roads
 - (b) Lead Vehicle Control: Switched Controllers
 - (c) Protocol verification using CoSpan
 - (d) Interface Design and difficulties in verification
 - (e) Game Theoretic Formulation of Hybrid systems design
 - (f) Safety Theorems for IVHS
 - (g) Degraded Modes of Operation
 - (h) Micro and Macro Simulation
14. **Case Study 2: Hybrid Systems in Air Traffic Management**
 - (a) Free flight and air traffic management
 - (b) Conflict Resolution