EECS 598-002

Hybrid Systems: Specification, Verification and Control

Fall 2015 [1]

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Schedule: MW, 3:30pm-5:00pm, COOL 1940

Office Hours: TBD

Prerequisites: EECS 562 (or equivalent), or EECS 560 (or equivalent) and consent of the instructor. Students are expected to be comfortable with state-space methods and should have a basic understanding of Lyapunov theory and Lyapunov functions. Some programming experience with MATLAB or Python will be useful.

Grading and evaluation: Class work consists of a few homework assignments, critiquing research papers and in-class discussions, and a (team) term project (see pages 3-4 for details).

- 30% Homework (3-4 assignments)
- 25% Paper presentation and critiques
- 5% Class participation
- 40% Term project

Summary

Hybrid systems, dynamical systems where continuous dynamics and discrete events interact, are ubiquitous and can be found in many different contexts. Examples are as diverse as manufacturing processes, biological systems, energy systems, medical devices, robotics systems, automobiles and aircrafts. Advances in computing and communication technologies have enabled engineering such systems with a high degree of complexity. Most of these systems are safety-critical, hence their correctness must be verified before they can be deployed. This course will provide a working knowledge of several analysis and design techniques that can guarantee the satisfaction of certain safety and performance specifications for such systems.

[1]This is a tentative syllabus. Date: 04/03/2015.

The course will introduce a combination of tools from computer science (automata theory, ω-regular languages, temporal logics) and control theory (Lyapunov functions, optimization based control) for modeling, formally specifying, verifying and controlling hybrid systems. We will cover both theoretical and computational aspects. Recent research progress in control of networked cyber-physical systems will be discussed. We will present methods for synthesizing hierarchical control architectures with low-level continuous controllers and high-level protocols for decision making. Finally, we apply the theory and algorithms in case studies to complex problems such as automated highway systems, vehicle management systems, motion planning and smart camera networks. Various software tools will be used in the course.

Topics

- Specifications: Automata theory, temporal logics, discrete transition systems
- Model checking for discrete systems
- Hybrid systems modeling: hybrid automata, switched systems, piecewise-affine systems
- Verification of hybrid systems: direct methods (barrier certificates, reachable set computations), abstraction-based methods (simulation, bisimulation relations)
- Correct-by-construction controller synthesis: reactive control synthesis, two-player discrete games, hierarchical control protocols, switching protocols
- Model-predictive control of hybrid systems
- Advanced topics (depending on time and interest): distributed protocols, stochastic systems and probabilistic model checking, quantitative objectives, system identification for hybrid systems

Apart from the above mentioned topics, we will spend two-three lectures on advanced optimization methods (e.g., sum-of-squares) used in control and verification.

References

There is no textbook for the course. There will be some lecture notes supplemented by reading assignments, mostly from recent research articles. The following books and manuscripts can be used as reference.

1. Principles of Model Checking, C. Baier and J.-P. Katoen, The MIT Press, 2008.

2. Model Checking, E. M. Clarke, O. Grumberg, D. A. Peled, The MIT Press, 1999.

3. An Introduction to Hybrid Dynamical Systems, A. J. van der Schaft, J. M. Schumacher, Springer, 2000.

4. Switching in Systems and Control, D. Liberzon, Birkhauser, 2003.

5. Verification and Control of Hybrid Systems: A Symbolic Approach, P. Tabuada, Springer, 2009.

6. Automata, Logics, and Infinite Games: A Guide to Current Research, E. Grädel, W. Thomas, T. Wilke, eds., Vol. 2500. Springer, 2003.

7. Predictive Control for linear and hybrid systems, F. Borrelli, A. Bemporad, M. Morari, 2013 (manuscript).

8. Hybrid Systems: Foundations, advanced topics and applications, J. Lygeros, S. Sastry, and C. Tomlin, 2012 (manuscript).

Grading Policy

Homework (30%): Collaboration on homework assignments is encouraged. You may consult outside reference materials, other students, or the instructor. You must properly cite any outside reference that you use and list the students you discussed the solutions with. All solutions that are handed should reflect your understanding of the subject matter at the time of writing/implementation. No late homework will be accepted.

Paper presentation and critiques (25%): Critically reading a research article is a crucial skill for a graduate student. It is also important for engineers who want to keep up with the state-of-the-art in their field. We will devote approximately ten lectures for understanding and discussing relatively recent, high-impact research papers in the area of hybrid systems. These papers will be chosen mostly from control and robotics journals (IEEE TAC, Automatica, IJRR, IEEE T-RO, etc.) and conferences (HSCC, CDC, ACC, ICRA, etc.). A team of two will be responsible for each paper. They will prepare a two part presentation:

- summarize the preliminaries and definitions required to understand the paper (on the board),
- present the paper (slides).

It can be a tag-team presentation or each student can be responsible for one of the above parts. They will also lead the discussion after the presentation. Each student will present once through the term. This presentation will constitute 15% of the grade. The rest of the class will also read the paper and prepare a 1-2 page(s) review including a summary of the paper contributions, paper strengths, paper weaknesses, and extensions/applications you can think of. The reviews are due at the beginning of the class the paper will be discussed. If you are part of the presenting team that week, you do not need to write a review. You might find it useful to read "How to read a research paper" by Michael Mitzenmacher before writing your reviews. The reviews will constitute 10% of your final grade.

Term project (40%): The projects can either be in the form of a review of an area of the literature or, preferably, involve the exploration of original applications or research ideas. The length of the project can be inversely proportional to its originality. Joint project proposals (with groups of 2 or 3) are encouraged. The project should be chosen in consultation with the instructor. The schedule is as follows:

- Project proposal (2 page summary) due before term break
- Project report (10-12 pages) due final exams week

An initial suggestion on project ideas are:

Investigation of a class of hybrid systems: evaluation and benchmarking of synthesis or verification tools/techniques for a subclass of hybrid systems.

Applications: robotics, (semi)autonomous driving, aircraft electric power systems, aircraft environmental control systems, car engine cooling.

Software development: parallel implementations of abstraction algorithms for hybrid systems, code generation for low level constrained reachability controllers.

Open problems: hierarchical (nested) abstractions of dynamical systems, distributed control protocols and cooperation in multi-player games, synthesis with partial information, temporal logic fragments for human-machine interaction, temporal logic based reactive synthesis for security and privacy.