

ASEN 6519 SPECIAL TOPICS – SECTIONS 2/2B

HYBRID SYSTEMS: THEORY, COMPUTATION, AND APPLICATIONS

SPRING 2022

LECTURE INFORMATION

Tuesday and Thursday 4:00-5:15pm

Room: AERO 111

Video recording will be made available after each lecture on the course canvas page

INSTRUCTOR

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Office hour: Wednesday TBD and by appointment

COURSE DESCRIPTION

In many modern engineering applications -- robotics, automation, real-time software, aeronautics, air and ground transportation systems, systems biology, and process control, to name a few -- the states of the system undergo a mixture of real-time (continuous) and instantaneous event (discrete) transitions. This mixture can be dictated by the fundamentally non-smooth or discontinuous nature of some physical phenomena (e.g., mechanical impact, network rerouting, and cell differentiation) or intentional by design (e.g., integration of discrete logic or digital computers with continuous physical processes). The result of such a coupling of discrete and continuous dynamics is a hybrid system. More specifically, hybrid systems are continuous variable systems with a phased operation, capturing both discrete event (linguistic behavior) and “lower-level” continuous behavior of the system. For this very reason, hybrid systems have recently been at the center of intense research activity in the control theory, computer-aided verification, and artificial intelligence communities.

This course provides an introduction to hybrid systems. We start by presenting a modeling framework for hybrid systems that combines elements from automata theory and differential

equations. We then introduce a set of techniques that can be used for design and analysis of hybrid systems. We also present recent advances in the theory for formal verification and control of these systems and show the applications of the theory to the design of the control architecture for complex and uncertain systems.

This course is designed to be aligned with the objectives of the CEAS's Autonomous Systems Interdisciplinary Research Theme and is open to AES, CS, ME, and ECEE students.

PREREQUISITES

Hybrid systems contain both continuous and discrete dynamics. This implies that this course builds on both continuous and discrete mathematics. Prerequisites includes linear algebra, differential equations, linear control systems, and some scientific programming language (e.g., MATLAB).

GRADING AND EVALUATION

Classwork consists of some homework exercises worth 40%, a paper presentation and participation in the class discussion 15%, and a substantive project worth 45% of the grade.

COURSE TEXTBOOKS

The course is essentially self-contained, and no textbook is required.

Recommended readings:

- Formal methods for discrete-time dynamical systems
C. Belta, B. Yordanov, and E. Gol
Springer
2017
- Verification and control of hybrid systems: a symbolic approach
P. Tabuada
Springer Science & Business Media
2009

COURSE OUTLINE

- Introduction, motivation, and examples

- Mathematical background
- Trajectories of hybrid systems
- Existence of Executions
- Stability of hybrid systems
- Formal analysis and control of dynamical systems
 - Transition systems, simulations, and bisimulations
 - Temporal logics
 - Model checking and verification
 - Analysis and control for finite systems
 - Analysis and control for continuous-time dynamical systems
 - Analysis and control for discrete-time dynamical systems
- Stochastic Hybrid Systems
- Applications
 - Symbolic motion planning and control
 - Sampling-base motion planning

CLASSROOM BEHAVIOR

Both students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote or online. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. For more information, see the policies on [classroom behavior](#) and the [Student Conduct & Conflict Resolution policies](#).

REQUIREMENTS FOR COVID-19

As a matter of public health and safety, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements and all public health orders in place to reduce the risk of spreading infectious disease. Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to [Student Conduct and Conflict Resolution](#). For more information, see the policy on [classroom behavior](#) and the [Student Code of Conduct](#). If you require accommodation because a disability prevents you from fulfilling these safety measures, please follow the steps in the “Accommodation for Disabilities” statement on this syllabus.

CU Boulder currently requires masks in classrooms and laboratories regardless of vaccination status. This requirement is a precaution to supplement CU Boulder’s COVID-19 vaccine requirement. Exemptions include individuals who cannot medically tolerate a face covering, as well as those who are hearing-impaired or otherwise disabled or who are communicating with

someone who is hearing-impaired or otherwise disabled and where the ability to see the mouth is essential to communication. If you qualify for a mask-related accommodation, please follow the steps in the “Accommodation for Disabilities” statement on this syllabus. In addition, vaccinated instructional faculty who are engaged in an indoor instructional activity and are separated by at least 6 feet from the nearest person are exempt from wearing masks if they so choose.

If you feel ill and think you might have COVID-19, if you have tested positive for COVID-19, or if you are unvaccinated or partially vaccinated and have been in close contact with someone who has COVID-19, you should stay home and follow the further guidance of the [Public Health Office](mailto:contacttracing@colorado.edu) (contacttracing@colorado.edu). If you are fully vaccinated and have been in close contact with someone who has COVID-19, you do not need to stay home; rather, you should self-monitor for symptoms and follow the further guidance of the [Public Health Office](mailto:contacttracing@colorado.edu) (contacttracing@colorado.edu). In this class, if you are sick or quarantined, inform the instructor that you are not able to attend the lectures immediately; lecture recordings will be made available.

ACCOMMODATION FOR DISABILITIES

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the [Disability Services website](#). Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition, see [Temporary Medical Conditions](#) on the Disability Services website.

PREFERRED STUDENT NAMES AND PRONOUNS

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

HONOR CODE

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code academic integrity policy. Violations of the Honor Code may include, but are not limited to: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course

without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu; 303-492-5550). Students found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found on the [Honor Code website](#).

SEXUAL MISCONDUCT, DISCRIMINATION, HARASSMENT AND/OR RELATED RETALIATION

CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. The university will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by or against members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or email cureport@colorado.edu. Information about university policies, [reporting options](#), and the support resources can be found on the [OIEC website](#).

Please know that faculty and graduate instructors have a responsibility to inform OIEC when they are made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about their rights, support resources, and reporting options. To learn more about reporting and support options for a variety of concerns, visit [Don't Ignore It](#).

RELIGIOUS HOLIDAYS

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, inform the instructor of such conflicts at least three weeks in advance.

See the [campus policy regarding religious observances](#) for full details.