ASEN 6519 Special Topics – Sections 1/1B
Verification and Control Synthesis for Stochastic Systems
Spring 2021

Lecture Information

Tuesday and Thursday 2:50-4:05pm on Zoom (remote/online)

Instructor

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Office hours: Wednesday 2-3pm and by appointment on Zoom

Course Description

Real-world phenomena and processes by and large include randomness in their nature. To mathematically describe them, stochastic models provide a fundamental tool with major applications in physics, biology, finance, and engineering. This course provides an introduction to formal verification and control synthesis for stochastic system with emphasis on safety-critical applications.

The course consists of two parts. In the first part, the focus is on systems with discrete state spaces. We start by introducing a modeling framework for such stochastic systems, e.g., discrete- and continuous-time Markov chains and Markov decision processes. We then introduce appropriate formal languages to specify behaviors of such systems. Next, we introduce a set of techniques that can be used for design and analysis of these stochastic models. In the second part of the course, we focus on continuous-space stochastic systems. We introduce verification and control synthesis techniques for these systems by means of discrete abstractions.

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

The course is essentially self-contained, and students are only expected to be familiar with linear algebra, basics of probabilities and difference equations, and graph theory.

Recommended preparation: students should be proficient in linear algebra, basic notions of probabilities and difference equations, and some discrete math (graphs and transition systems). Basic knowledge of controls concepts is helpful but not essential.

Grading and Evaluation

Classwork consists of:

- homework 20%
- tool exercises 10%
- mid-term exam 30%
- paper presentation 10%
- final project 30%

Course Textbooks

Required:

- *Principles of Model Checking*
  Christel Baier and Joost-Pieter Katoen
  MIT Press
  2008
  e-book through CU library: https://tinyurl.com/yxoxgjav

Additional Resources:

- *Stochastic Model Checking*
  M. Kwiatkowska, G. Norman, and D. Parker
  Springer
  2007
  Link: https://www.prismmodelchecker.org/papers/sfm07.pdf

- *Automated Verification Techniques for Probabilistic Systems*
  V. Forejt, M. Kwiatkowska, G. Norman and D. Parker
  Springer
  2011
  Link: https://www.prismmodelchecker.org/papers/sfm11.pdf

- *Temporal logic motion planning and control with probabilistic satisfaction guarantees*
  M. Lahijanian, S. B. Andersson, and C. Belta
  IEEE Transactions on Robotics
  2012
  Link: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6085615

- *Formal Verification and Synthesis for Discrete-Time Stochastic Systems*
  M. Lahijanian, S. B. Andersson, and C. Belta
  IEEE Transactions on Automatic Control
  2015
  Link: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7029024&isnumber=7166373

Course Outline

- Discrete-time Markov chains (DTMCs) and their properties
- Probabilistic temporal logics: PCTL, LTL, etc.
- PCTL model checking for DTMCs
- The PRISM model checker
- Costs & rewards
- Continuous-time Markov chains (CTMCs)
- Applications (CTMC)
- Markov decision processes (MDPs)
- Strategy synthesis
- Probabilistic LTL model checking
- Applications (MDP)
- Discrete-time, continuous stochastic difference equations
- MDP approximate abstraction
- Multi-objective analysis

Classroom/Zoom 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 Code of Conduct.

Students are required to keep their **camera** on during class on Zoom. The students are to present themselves as if each individual were actually in the classroom. Classes on Zoom, like all other classes, are governed by the campus policy on Student Classroom and Course-Related Behavior.

Recording Lectures

Each lecture will be recorded, and the video will be made available on the course website. Zoom automatically provides notice to students when recordings are started, paused, and stopped. Only the course instructor is authorized to record a class. Students are not authorized to record a class through any means. Access to a recording is limited to class participants through one's CU Boulder IdentiKey. Students are not authorized to distribute class recordings outside the class.

Requirements for COVID-19

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements, and public health orders in place to reduce the risk of spreading infectious disease. Required safety measures at CU Boulder relevant to the classroom setting include:

- maintain 6-foot distancing when possible,
- wear a face covering in public indoor spaces and outdoors while on campus consistent with state and county health orders,
- clean local work area,
- practice hand hygiene,
- follow public health orders, and
- if sick and you live off campus, do not come onto campus (unless instructed by a CU Healthcare professional), or if you live on-campus, please alert CU Boulder Medical Services.

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 policies on COVID-19 Health and Safety and classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please see the "Accommodation for Disabilities" statement on this syllabus.
Before returning to campus, all students must complete the COVID-19 Student Health and Expectations Course. Before coming on to campus each day, all students are required to complete a Daily Health Form.

Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home and complete the Health Questionnaire and Illness Reporting Form remotely. In this class, if you are sick or quarantined, inform the instructor that you are not able to attend the lectures immediately.

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. Violations of the policy may include: 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 at the Honor Code Office website.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation

The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder 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 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 cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.

Please know that faculty and instructors have a responsibility to inform OIEC when 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 options for reporting and support resources.

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.