CSCI-699: Theory and Algorithms for Formal Verification

Units: 4

Spring 2024 – Mondays – 3:00-6:20PM

Location: TBD

Instructor: Jyotirmoy (Jyo) V. Deshmukh
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Office Hours: 11am to 12pm on Mondays
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[Response within 24 hours]

Course Description
Complex software systems are everywhere. How do we reason about the correctness of software programs, from distributed message-passing programs to shared-memory concurrent programs to autonomous cyber-physical systems? The area of formal verification provides you with tools that allow you to express the correctness of software programs in a mathematically precise fashion and algorithms that can check for correctness, often with minimal human intervention or input.

This course will provide you with the necessary background to reason about topics such as correctness of sequential and concurrent programs, safety of autonomous cyber-physical systems including those that use AI, and core ideas from requirement formalisms based on temporal logic and automata theory. We will examine the theory and algorithms for formal verification in discrete software programs as well as hybrid and nonlinear continuous dynamical systems. This course is meant to be a depth course that focuses on the theoretical considerations for concurrent/distributed programs, timed and probabilistic systems, and hybrid and nonlinear dynamical systems.

Learning Objectives and Outcomes
- Gain familiarity with formal verification
- Get acquainted with automata over infinite length words and trees, timed automata and hybrid automata
- Learn how to analyze the complexity of verification algorithms
- Learn about temporal logic
- Understand the theoretical and practical challenges of applying formal verification techniques in practice

Recommended Preparation:
a) knowledge at the level of CSCI 270 or CSCI 570
b) knowledge at the level of CSCI 610

Course Notes:
Course Structure. In this course, most of the teaching will be accomplished through lectures. In addition, we will have 4 written homework assignments through the semester, and a final exam.

Technological Proficiency and Hardware/Software Required
None required.

Required Readings and Supplementary Materials
The course will cover material from the following textbooks:
1) Principles of Model Checking by Christel Baier and Joost Pieter Katoen, MIT Press
2) Verifying Cyber-Physical Systems by Sayan Mitra, MIT Press
3) Principles of Cyber-Physical Systems by Rajeev Alur, MIT Press

Some lectures will cover material from expository survey papers, and will be made available on the course website.

Description and Assessment of Assignments
There will be 4 written assignments that will test the theoretical understanding of the techniques and algorithms introduced.

Grading Breakdown

Category		Points	% of Grade	
Homeworks/ Mini-Projects	HW1	100	20	80
	HW2	100	20	
	HW3	100	20	
	HW4	100	20	
Final Exam		100	20	20
TOTAL				100

Assignment Rubrics
1. Homework assignments and exams will be graded for correctness of answers and provided explanation/proofs. Partial credit will be given wherever applicable.
2. The class will use Slack for online discussions related to the concepts covered in the class. Students will be expected to ask and answer questions during in-class lectures and participate in discussions on Slack.

Assignment Submission Policy
Assignments are expected to be turned in to the instructor/TA by 11:59.59pm Pacific Time on the deadline. There will be a 5% penalty for every late day for 7 days. Assignments submitted 7 days after the deadline will be returned with a zero grade.

Grading Timeline
Graded assignments will be returned to students in a time period not exceeding 2 weeks from the submission of the assignment.

Use of Generative AI in this Course
All the homework assignments in this course will require providing proofs of mathematical theorems, logical arguments, or algorithms. Arguments that are logically invalid will not receive points irrespective of whether they are generated by humans or generative AI tools. The students are permitted to try generative AI models to answer homework questions (with the acknowledgment that they have used it). However, we warn that generative AI does not do well at logical reasoning, and is likely to give garbage answers. If you do use generative AI, please explain in detail why you think the output of the generative AI models is correct/incorrect, and if incorrect, suggest a correction.

- You should also be aware that AI text generation tools may present incorrect information, biased responses, and incomplete analyses; thus, their answers may not meet the standards of this course.
- To adhere to our university values, *you must cite any AI-generated material (e.g., text, images, and other content) included or referenced in your work and provide the prompts used to generate the content*. Using an AI tool to generate content

without proper attribution will be treated as plagiarism and reported to the Office of Academic Integrity. Please use the guidance from: USC Libraries AI Generators Citation Guidance to cite the use of Generative AI tools.

- Students will be held accountable for AI's tendency toward hallucination if the text generated has illogical/unsound mathematical arguments, and if the student answers do not point these instances out to the instructor/TA.
- AI is a tool, but one that you need to acknowledge using. Please *include a paragraph at the end of any assignment explaining if, how, and why you used AI and indicate/specify the prompts you used to obtain the results*. Failure to do so is a violation of academic integrity policies.

Course Schedule: A rough weekly Breakdown
Please see up-to-date schedule at:
https://jdeshmukh.github.io/teaching/cs699-theory-of-fv-spring-2024/schedule.html

	Topics/Daily Activities	**Deliverable/ Due Dates**
Week 1	Course overview, Pre-history of verification (Floyd, Hoare, and Dijkstra)	
Week 2	Modeling concurrent/distributed systems as labelled transition systemsords	
Week 3	Linear Temporal Logic and Automata on Inifite Words	HW1 posted
Week 4	Computation Tree Logic and Tree Automata	
Week 5	Mu-calculus and Model checking	
Week 6	Trace Equivalences, Counterexamples, Abstraction-Refinement	HW2 posted
Week 7	Ameliorating State Explosion	
Week 8	Timed Automata and Verification	
Week 9	Metric Temporal Logic and Signal Temporal Logic	HW3 posted
Week 10	Probabilistc Systems: Markov chains, Markov Decision Processes, Probabilistic Timed Automata, Continuous-Time Markov Chains	
Week 11	Probabilistic CTL, Probabilistic/Stochastic Bisimulations, and Prob. Model Checking	
Week 12	Nonlinear Dynamical Systems	HW4 posted
Week 13	Verification for Hybrid and Continuous Dynamical Systems: Reachability analysis	

Week 14	Simulation-guided Reachability Analysis and Deductive Methods	
Week 15	Verifying neural network-based systems, Data-driven verification	
FINAL		Final Exam (take-home) due on university-scheduled date of the final exam

Statement on Academic Conduct and Support Systems

Academic Integrity:
The University of Southern California is a learning community committed to developing successful scholars and researchers dedicated to the pursuit of knowledge and the dissemination of ideas. Academic misconduct, which includes any act of dishonesty in the production or submission of academic work, comprises the integrity of the person who commits the act and can impugn the perceived integrity of the entire university community. It stands in opposition to the university's mission to research, educate, and contribute productively to our community and the world.

All students are expected to submit assignments that represent their own original work, and that have been prepared specifically for the course or section for which they have been submitted. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s).

Other violations of academic integrity include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), collusion, knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage.

The impact of academic dishonesty is far-reaching and is considered a serious offense against the university. All incidences of academic misconduct will be reported to the Office of Academic Integrity and could result in outcomes such as failure on the assignment, failure in the course, suspension, or even expulsion from the university.

For more information about academic integrity see the student handbook or the Office of Academic Integrity's website, and university policies on Research and Scholarship Misconduct.

Please ask your instructor if you are unsure what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

Course Content Distribution and Synchronous Session Recordings Policies
USC has policies that prohibit recording and distribution of any synchronous and asynchronous course content outside of the learning environment.

Recording a university class without the express permission of the instructor and announcement to the class, or unless conducted pursuant to an Office of Student Accessibility Services (OSAS) accommodation. Recording can inhibit free discussion in the future, and thus infringe on the academic freedom of other students as well as the instructor. (Living our Unifying Values: The USC Student Handbook, page 13).

Distribution or use of notes, recordings, exams, or other intellectual property, based on university classes or lectures without the express permission of the instructor for purposes other than individual or group study. This includes but is not limited to providing materials for distribution by services publishing course materials. This restriction on unauthorized use also applies to all information, which had been distributed to students or in any way had been displayed for use in relationship to the class, whether obtained in class, via email, on the internet, or via any other media. (Living our Unifying Values: The USC Student Handbook, page 13).

Students and Disability Accommodations:
USC welcomes students with disabilities into all of the University's educational programs. The Office of Student Accessibility Services (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at osas.usc.edu. You may contact OSAS at (213) 740-0776 or via email at osasfrontdesk@usc.edu.

Support Systems:

Counseling and Mental Health - *(213) 740-9355 – 24/7 on call*
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

988 Suicide and Crisis Lifeline - *988 for both calls and text messages – 24/7 on call*
The 988 Suicide and Crisis Lifeline (formerly known as the National Suicide Prevention Lifeline) provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week, across the United States. The Lifeline is comprised of a national network of over 200 local crisis centers, combining custom local care and resources with national standards and best practices. The new, shorter phone number makes it easier for people to remember and access mental health crisis services (though the previous 1 (800) 273-8255 number will continue to function indefinitely) and represents a continued commitment to those in crisis.

Relationship and Sexual Violence Prevention Services (RSVP) - *(213) 740-9355(WELL) – 24/7 on call*
Free and confidential therapy services, workshops, and training for situations related to gender- and power-based harm (including sexual assault, intimate partner violence, and stalking).

Office for Equity, Equal Opportunity, and Title IX (EEO-TIX) - *(213) 740-5086*
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - *(213) 740-5086 or (213) 821-8298*
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

The Office of Student Accessibility Services (OSAS) - *(213) 740-0776*
OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.

USC Campus Support and Intervention - *(213) 740-0411*
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity, Equity and Inclusion - *(213) 740-2101*
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - *UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call*
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - *UPC: (213) 740-6000, HSC: (323) 442-1200 – 24/7 on call*
Non-emergency assistance or information.

Office of the Ombuds - *(213) 821-9556 (UPC) / (323-442-0382 (HSC)*
A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.

Occupational Therapy Faculty Practice - *(323) 442-2850 or* otfp@med.usc.edu
Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.