USC Viterbi
School of Engineering

CSCI 699
Formal Methods for Robotics
Units: 4
Term—Day—Time: Spring Monday 2:00-5:20pm

Instructor: Jyo Deshmukh
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Office Hours: 11-12am Monday
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Teaching Assistant:
Office:
Office Hours:
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IT Help: Group to contact for technological services, if applicable.
Hours of Service:
Contact Info: Email, phone number (office, cell), Skype, Zoom etc.

Course Description

Formal methods is an area of computer science that uses formal logic and automata to reason about various aspects of a software system using rigorous mathematical techniques. Formal methods offer a number of techniques for problems such as: verification methods, techniques to build correct-by-construction software, formal specifications, and creating logical abstractions of complex systems. Autonomous mobile robots are complex software systems, and are increasingly becoming ubiquituous in human contexts. While core research in robotics has made fantastic advances in various aspects such as perception, planning, decision-making, and navigation, approaches based on formal methods have a lot to offer the field of robotics. Some examples include: synthesis of low-level control policies from high-level logical specifications, formal specifications for robots, real-time monitoring for robots, debugging and verification. In this seminar course, we will explore state-of-the-art in this area including the latest research results.

Learning Objectives

1. Gain broad understanding of formal methods in the field of robotics.
2. Understand verification approaches based on automatic techniques like model checking and testing as well as less automated deductive methods.
3. Learn how robotic specifications are expressed using real-time temporal logics.
4. Learn techniques for debugging and fault localization in robots.
5. Learn about formal techniques for multi-agent robotic systems.
6. Learn how to critically read a technical research paper in this topic.

Prerequisite(s): CSCI 170, 270 (preferred), 445

Co-Requisite(s): none

Concurrent Enrollment: none

Recommended Preparation: Basic introduction to automata theory, formal verification

Course Notes

Course Structure: The course will explore the topics indicated in the course description through a series of assigned readings in the form of papers and book chapters. For each reading assignment, the instructor or course participants will present the basic background material where needed. Each student will have to present a number of papers (est. 2-3) through the semester. Each student is also required to write a review of each paper read (at least 500 words of content). The course will have a final project where the goal will be to prepare a 15-page paper containing an original idea in the broad field of formal methods for robotics. For the final papers, we will explore a novel peer review system. The final paper will have 3 milestones: (a) initial draft due 6 weeks after start of the course, which will be peer-reviewed by the class (b) first revision based on peer review due 10 weeks after start of the course, and (c) a final version incorporating further suggestions from your peer reviewers. The final version will be graded by the instructor with inputs from peer reviewers.

Technological Proficiency and Hardware/Software Required

No specific hardware/software proficiency required. Ability to read advanced mathematical and research papers required.

Required Readings and Supplementary Materials

All reading material will be posted on the course web-page at the beginning of the course. The list of papers to be used are posted in the course schedule.

Grading Breakdown

	Category	Weight	
Paper Reviews	Paper Reviews (25 papers)	45%	45%
Peer Review	Instructor assessment of the peer review for the initial draft	10%	20%
	Instructor assessment of the peer review for the first revision	5%	
	Instructor assessment of the peer review for the final revision	5%	
Final Paper	Initial Draft	10%	35%
	First Revision	10%	
	Final Version	15%	

Assignment Rubrics

1. Reviews: Students will get credit for every review submitted. Reviews are expected to be turned in **at the beginning** of the class in which the paper will be discussed. Late reviews will receive a 10% penalty if turned within 2 days, and will not be graded otherwise.
2. Participation: Students will be expected to participate in the class discussion. To ensure a minimum level of participation, we will have each student talk about their impression of the paper for up to five minutes. Once each student has had a chance to talk about the paper, the discussion leader will have the responsibility to sustain a discussion. The instructor will provide feedback to students about their participation as necessary.
3. Peer Reviews: Reviewers will give useful suggestions to the student author for their paper. Each student will grade the review they receive on a scale of 1-5. These scores will be used as feedback to the instructor to assess and grade the quality of the peer-reviews.
4. Paper: Papers will be graded based on the depth of the research endeavor, the novelty and technical results.

Assignment Submission Policy

1. Reviews are expected to be turned in at the beginning of every class on blackboard.
2. Paper drafts at each milestone are expected to be turned in by the deadline. There will be a 10% late penalty.

Grading Timeline

Weekly.

Additional Policies

None.

Course Schedule: A Weekly Breakdown

	Topic	**Presenter**
Week 1	Admin, General Introduction	Deshmukh
Week 2	1.1 & 1.2	
Week 3	1.3 & 1.4	
Week 4	2.1 & 2.2	

Week 5	2.3 & 2.4	
Week 6	2.5 & 2.6	
Week 7	2.7 & 2.8	
Week 8	Proposal Presentation	
Week 9	3.1 & 3.2	
Week 10	3.3 & 3.4	
Week 11	3.5 & 3.6	
Week 12	4.1 & 4.2	
Week 13	4.3 & 4.4	
Week 14	4.5 & 4.6	
Week 15	4.7 & 4.8	
FINAL	**Final Presentations** (due on university-scheduled date of the final exam)	

Module 1: Specifications & Survey

Specifications

1) Bartocci, Ezio, Jyotirmoy Deshmukh, Alexandre Donzé, Georgios Fainekos, Oded Maler, Dejan Ničković, and Sriram Sankaranarayanan. "Specification-based monitoring of cyber-physical systems: a survey on theory, tools and applications." In Lectures on Runtime Verification, pp. 135-175. Springer, Cham, 2018.
2) Menghi, C., Tsigkanos, C., Pelliccione, P., Ghezzi, C. and Berger, T., 2019. Specification patterns for robotic missions. IEEE Transactions on Software Engineering.
3) Kress-Gazit, H., Fainekos, G. E., & Pappas, G. J. (2008). Translating structured english to robot controllers. Advanced Robotics, 22(12), 1343-1359.

Robotics + Formal Verification

3) Farrell, M., Luckcuck, M., & Fisher, M. (2018, September). Robotics and integrated formal methods: Necessity meets opportunity. In International Conference on Integrated Formal Methods (pp. 161-171). Springer, Cham.
4) Luckcuck, Matt, Marie Farrell, Louise A. Dennis, Clare Dixon, and Michael Fisher. "Formal specification and verification of autonomous robotic systems: A survey." ACM Computing Surveys (CSUR) 52, no. 5 (2019): 1-41.

Module 2: Verification Algorithms

Statistical & Probabilistic Model Checking

1) Agha, Gul, and Karl Palmskog. "A survey of statistical model checking." ACM Transactions on Modeling and Computer Simulation (TOMACS) 28.1 (2018): 1-39.
2) Katoen, Joost-Pieter. "The probabilistic model checking landscape." In Proceedings of the 31st Annual ACM/IEEE Symposium on Logic in Computer Science, pp. 31-45. 2016.
3) Norman, Gethin, David Parker, and Jeremy Sproston. "Model checking for probabilistic timed automata." Formal Methods in System Design 43.2 (2013): 164-190.
4) Baier, C., Hermanns, H., & Katoen, J. P. (2019). The 10,000 facets of MDP model checking. In Computing and Software Science (pp. 420-451). Springer, Cham.

Control Theory-inspired methods

5) L. Wang, A. D. Ames, and M. Egerstedt, M., 2017. Safety barrier certificates for collisions-free multirobot systems. *IEEE Transactions on Robotics*, *33*(3), pp.661-674.
6) Wang, Li. "Multi-robot coordination and safe learning using barrier certificates." PhD diss., Georgia Institute of Technology, 2018. [Chapters 3-7]

Runtime Verification

7) Desai, A., Dreossi, T. and Seshia, S.A., 2017, September. Combining model checking and runtime verification for safe robotics. In International Conference on Runtime Verification (pp. 172-189). Springer, Cham.
8) Huang, Jeff, Cansu Erdogan, Yi Zhang, Brandon Moore, Qingzhou Luo, Aravind Sundaresan, and Grigore Rosu. "ROSRV: Runtime verification for robots." In International Conference on Runtime Verification, pp. 247-254. Springer, Cham, 2014.

Module 3: Path Planning

1) A. Bhatia, L. E. Kavraki, and M. Y. Vardi. Sampling-based motion planning with temporal goals. ICRA 2010
2) Fainekos, G.E., Girard, A., Kress-Gazit, H. and Pappas, G.J., 2009. Temporal logic motion planning for dynamic robots. Automatica, 45(2), pp.343-352.
3) Plaku, Erion, and Sertac Karaman. "Motion planning with temporal-logic specifications: Progress and challenges." AI communications 29, no. 1 (2016): 151-162.
4) Saha, I., Ramaithitima, R., Kumar, V., Pappas, G.J. and Seshia, S.A., 2014, September. Automated composition of motion primitives for multi-robot systems from safe LTL specifications. In 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems (pp. 1525-1532). IEEE.
5) Hubmann, Constantin, Jens Schulz, Marvin Becker, Daniel Althoff, and Christoph Stiller. "Automated driving in uncertain environments: Planning with interaction and uncertain maneuver prediction." IEEE Transactions on Intelligent Vehicles 3, no. 1 (2018): 5-17.
6) Zhou, Z., Ding, J., Huang, H., Takei, R. and Tomlin, C., 2018. Efficient path planning algorithms in reach-avoid problems. Automatica, 89, pp.28-36.

Module 4: Reinforcement Learning & Learning from Demonstrations

1) Anderson G, Verma A, Dillig I, Chaudhuri S. Neurosymbolic Reinforcement Learning with Formally Verified Exploration. Advances in Neural Information Processing Systems. 2020;33.
2) Fulton, Nathan, and André Platzer. "Verifiably safe off-model reinforcement learning." International Conference on Tools and Algorithms for the Construction and Analysis of Systems. Springer, Cham, 2019.
3) Lütjens, B., Everett, M. and How, J.P., 2020, May. Certified adversarial robustness for deep reinforcement learning. In Conference on Robot Learning (pp. 1328-1337). PMLR.
4) Könighofer, Bettina, et al. "Safe Reinforcement Learning Using Probabilistic Shields." International Conference on Concurrency Theory: 31st CONCUR 2020: Vienna, Austria (Virtual Conference). Schloss Dagstuhl-Leibniz-Zentrum fur Informatik GmbH, Dagstuhl Publishing, 2020.Li X, Serlin Z, Yang G, Belta C. A formal methods approach to interpretable reinforcement learning for robotic planning. Science Robotics. 2019 Dec 18;4(37).
5) Lavaei A, Somenzi F, Soudjani S, Trivedi A, Zamani M. Formal controller synthesis for continuous-space MDPs via model-free reinforcement learning. In2020 ACM/IEEE 11th International Conference on Cyber-Physical Systems (ICCPS) 2020 Apr 21 (pp. 98-107). IEEE.
6) Neary C, Xu Z, Wu B, Topcu U. Reward Machines for Cooperative Multi-Agent Reinforcement Learning. arXiv preprint arXiv:2007.01962. 2020 Jul 3.

7) Vazquez-Chanlatte M, Jha S, Tiwari A, Ho MK, Seshia S. Learning task specifications from demonstrations. InAdvances in Neural Information Processing Systems 2018 (pp. 5367-5377).
8) Kasenberg, Daniel, and Matthias Scheutz. "Interpretable apprenticeship learning with temporal logic specifications." In 2017 IEEE 56th Annual Conference on Decision and Control (CDC), pp. 4914-4921. IEEE, 2017.

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

Support Systems:

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

National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL), press "0" after hours – 24/7 on call
studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED) - (213) 740-5086 | Title IX – (213) 821-8298
equity.usc.edu, titleix.usc.edu
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
usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity |Title IX for appropriate investigation, supportive measures, and response.

The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.