# Formal Methods for Robotics and AI
## EEL 5934
***Class Periods:*** M/W/F Period 5 (11:45 AM - 12:35 PM)
***Location:*** MAEA0327
***Academic Term:*** Fall 2023

***Instructor:***
Jie Fu
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Office hours: TBD,
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***Teaching Assistant/Peer Mentor/Supervised Teaching Student:***
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***Course Description***
The course introduces formal specification, planning and game-theoretic control algorithms for developing reactive and provably correct autonomous robots and other safety- and mission-critical cyber-physical systems. Credits: 3.

***Course Pre-Requisites / Co-Requisites***
EEL 3850 Data Science for ECE (or equivalent courses on linear algebra, probability theory)
Other: Students need basic computer programming skills and familiar with C language and Python.

***Course Objectives***
The course is an introduction to formal logic specification, probabilistic model checking, Markov decision processes with Temporal logic constraints, and game-theoretic methods in formal synthesis. The theory and algorithms will be taught in class and demonstrated through applications in robotic motion planning, control design of cyber-physical systems, and strategic decision making.

***Materials and Supply Fees***
N/A

***Required Textbooks and Software***
- A computer with the following software installed:
    o Python 3.4.3 or later.
- Textbooks: None

***Recommended Materials***
Title: Principles of model checking
Authors: Baier Christel, Joost-Pieter Katoen, and Kim Guldstrand Larsen.
Publication date: 2008. Available online.
Link: https://ufl-flvc.primo.exlibrisgroup.com/permalink/01FALSC_UFL/6ad6fc/alma990332125790306597

Title: Reinforcement Learning: An Introduction

Authors: Sutton, Richard S., and Andrew G. Barto.

MIT press, 2018.

Link (online PDF): http://incompleteideas.net/book/the-book-2nd.html

Title: Automata, logics, and infinite games: a guide to current research.
Authors: Thomas, Wolfgang, and Thomas Wilke.
Publication date: 2002.
Link: https://link.springer.com/book/10.1007/3-540-36387-4
Other reading materials (research papers, lecture nodes) will be provided.

*Course Schedule*

| Week | Topic | Content | HW |
|------|-------|---------|-----|
| 1 | Introduction: Correct-by-construction autonomous systems | • Class objectives, expectations, and syllabus.<br>• Understanding the role of formal methods in constructing provably correct autonomous systems. | |
| 2 | Specification: Automata and formal languages | • Definition of automata on finite words, on infinite words.<br>• Basic operations with automata; | |
| 3 | Specification: Temporal Logic and its automata representation | • Syntax and semantics.<br>• Translating Temporal logic to Automata and toolbox.<br>• Applications to robotic motion specifications.<br>• (HW+ programming exercise): Spot and other tools. | HW1 |
| 4 | AI Planning with temporal logic: Framework and algorithms | • Hierarchical motion planning framework.<br>• Planning with temporal logic specifications.<br>(HW+ programming exercise): sensor-based robot motion planning, manipulation planning | HW2 |
| 5 | Probabilistic Planning In Markov decision process with temporal logic objectives | • Qualitative planning in MDP given TL formulas.<br>• Quantitative planning in MDP.<br>(hw+ programming excise): temporal logic planning in stochastic gridworld. | HW3 |
| 6 | Reinforcement learning with temporal reward machine | • Model-based RL and model-free RL for planning with unknown MDP and temporal objective.<br>• Construction of reward machine from logical specification | HW4 |
| 7 | Midterm; | | |
| 8-9 | Two-player games on graphs: Theory and application | • Safety and reachability games.<br>• Attractor computation for solving games on graphs. | HW5 |

| | | (programming exercise): robot motion planning in adversarial environments. | |
|---|---|---|---|
| 9/10 | Project group reading and research paper presentations. | • Each reading group include 2-3 students.<br>• Each group will present one research paper related to the course, with a focus on the applications of formal methods to autonomous robotics, decision-making, and control of cyber-physical systems.<br>• Each group will propose a small project related to their reading (implementing the algorithm, extensions, other applications, etc.) | |
| 11-12 | Concurrent stochastic games: Qualitative analysis and planning algorithms | • Almost-sure winning for concurrent deterministic/stochastic games.<br>• (programming exercise): robot motion planning in adversarial environments with liveness and recurrent missions. | HW6 |
| 13 | Timed automaton and planning for time-sensitive temporal logic | • Metric interval temporal logic.<br>• Timed automaton<br>• Planning with clocks | HW7 |
| 14-15 | Advanced topic and summary | • Multi-agent cooperative games<br>• Preference-aware planning and reinforcement learning | Reading and review papers |
| 15 | Project group presentations | | |

***Attendance Policy, Class Expectations, and Make-Up Policy***
Excused absences must be consistent with university policies in the Graduate Catalog (https://catalog.ufl.edu/graduate/regulations) and require appropriate documentation. Additional information can be found here: https://catalog.ufl.edu/graduate/regulations/

***Evaluation of Grades***

**Assignments (40%):** Written assignments as well as programming assignments.

**A midterm exam (20% for graduates and 35% for undergraduates):** This will include questions that requires a basic understanding of the fundamental concepts and algorithms taught in the class.

**Research paper presentations (15% - Graduate Students only):** Each student will choose a research paper, preferably related to their term project, in the field of automated verification and present it in class. The

presentations will be graded based on 1) the presenter's ability to clearly describe the problem, explain the solution, and evaluate the (experimental) results, 2) the quality of answers provided to the questions, and 3) the content of the slides.

**Term Project (20%):** A semester long project that will involve the design and implementation of planning algorithms for autonomous systems. Students will choose from a list of project topics from research papers or topics provided by the instructor. Each project team includes 2-3 students. The project and the report will be evaluated based on the problem formulation, the rationale and correctness of proposed solutions, algorithm implementation, experimental validation and analysis result, the presentation quality and the technical writing. Each team member will explicitly state their work in this team project and will be expected to answer relevant questions about his/her work in the team projects.

For graduate students' teams, the lecturer will help to select projects that explore some interesting and open research problems.

| Assignment | Total Points | Percentage of Final Grade |
|---|---|---|
| Class attendance | | 5% |
| Homework sets | | 40% |
| Research paper presentation | | 15% |
| Midterm exam | | 20% |
| Term Project | | 20% |
| | | 100% |

*Grading Policy*
The following is given as an example only.

| Percent | Grade | Grade Points |
|---|---|---|
| 93.4 - 100 | A | 4.00 |
| 90.0 - 93.3 | A- | 3.67 |
| 86.7 - 89.9 | B+ | 3.33 |
| 83.4 - 86.6 | B | 3.00 |
| 80.0 - 83.3 | B- | 2.67 |
| 76.7 - 79.9 | C+ | 2.33 |
| 73.4 - 76.6 | C | 2.00 |
| 70.0 - 73.3 | C- | 1.67 |
| 66.7 - 69.9 | D+ | 1.33 |
| 63.4 - 66.6 | D | 1.00 |
| 60.0 - 63.3 | D- | 0.67 |
| 0 - 59.9 | E | 0.00 |

More information on UF grading policy may be found at:
http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#grades

*Students Requiring Accommodations*
Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting https://disability.ufl.edu/students/get-started/. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

*Course Evaluation*
Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

**In-Class Recording**
Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A "class lecture" is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To "publish" means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

*University Honesty Policy*
UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Conduct Code (https://sccr.dso.ufl.edu/process/student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions.  If you have any questions or concerns, please consult with the instructor or TAs in this class.

*Commitment to a Safe and Inclusive Learning Environment*
The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination.  It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

• Your academic advisor or Graduate Program Coordinator
• Jennifer Nappo, Director of Human Resources, 352-392-0904, jpennacc@ufl.edu
• Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
• Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

## *Software Use*

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

## *Student Privacy*

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

## *Campus Resources:*
### *Health and Wellness*

**Covid-19 Protocols:**
• You are expected to wear approved face coverings at all times during class and within buildings even if you are vaccinated.
• If you are sick, stay home and self-quarantine. Please visit the UF Health Screen, Test & Protect website about next steps, retake the questionnaire and schedule your test for no sooner than 24 hours after your symptoms began. Please call your primary care provider if you are ill and need immediate care or the UF Student Health Care Center at 352-392-1161 (or email covid@shcc.ufl.edu) to be evaluated for testing and to receive further instructions about returning to campus.
• If you are withheld from campus by the Department of Health through Screen, Test & Protect, you are not permitted to use any on campus facilities. Students attempting to attend campus activities when withheld from campus will be referred to the Dean of Students Office.
• UF Health Screen, Test & Protect offers guidance when you are sick, have been exposed to someone who has tested positive or have tested positive yourself. Visit the UF Health Screen, Test & Protect website for more information.
• Please continue to follow healthy habits, including best practices like frequent hand washing. Following these practices is our responsibility as Gators.

**U Matter, We Care:**
Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

**Counseling and Wellness Center:** https://counseling.ufl.edu, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

**Sexual Discrimination, Harassment, Assault, or Violence**

If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

**Sexual Assault Recovery Services (SARS)**
Student Health Care Center, 392-1161.

**University Police Department** at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

*Academic Resources*

**E-learning technical suppor**t, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.

**Career Connections Center**, Reitz Union, 392-1601.  Career assistance and counseling; https://career.ufl.edu.

**Library Support**, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.

**Teaching Center**, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

**Writing Studio, 302 Tigert Hall**, 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

**Student Complaints Campus**: https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/;https://care.dso.ufl.edu.

**On-Line Students Complaints**: http://www.distance.ufl.edu/student-complaint-process.