NOTE: THIS IS AN OLD VERSION OF THE COURSE (FALL 2021)

Hybrid Systems Syllabus
CSE510 – Fall 2021
Stony Brook University

COVID Note

If you are sick, starting to feel sick, or might be sick, please do not come in person to the class. Zoom links for the lectures will be provided on Blackboard. Please follow the latest SBU guidance on COVID measures, located here. At the time of this writing, this means wearing masks indoors in classrooms at all times.

Overview

Hybrid systems combine **discrete** state-machines and **continuous** differential equations and have been used as models of a large number of applications such as real-time software, embedded systems, robotics, mechatronics, aerospace systems, process control and biological systems. The course will cover modeling, design, analysis, and verification methods for hybrid systems. Topics may include SAT/SMT solvers, timed automata, formal logics for system specification, verification algorithms and closed-loop neural network control systems.

Course Objectives

- Learn verification methods for software, discrete, continuous, and mixed (hybrid) systems as well as neural network control systems
- Learn verification tools such as SMT solvers for verification problems
- Learn and apply generic research skills (Latex, paper writing, reviews)
- Apply some of the techniques and tools that were learned to a virtual course workshop

Background

The course is intended for students interested in hybrid systems, where systems have both discrete and continuous aspects. This is useful to design and build cyber-physical systems, where computer systems interact with the physical world. The course will include programming, mostly in Python. Background in theory of computation, formal logic, basic control theory, differential equations and linear algebra may be helpful, but is not required.

Course Website

https://sites.google.com/stonybrook.edu/cse510fall2021

Professor

Stanley Bak
Website (with contact email): http://stanleybak.com

Time and Place

Monday and Wednesday from 10:00am to 11:20am
Aug 23, 2021 - Dec 6, 2021 (See SBU Academic Calendar for holiday list)

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Old CS Building 2120
Lecture zoom link will be provided on Blackboard

Office Hours
Professor Bak office hours are Mondays 11:30am to 12:30pm (after class). Office hours will be on zoom. TA Abhinav Chawla's office hours are Wed 2pm to 3pm. The office hours link will be placed in an announcement on Blackboard.

Teaching Assistant
Abhinav Chawla (email: Abhinav.Chawla [at] stonybrook.edu)

Text
There is no required textbook, although the following may be useful:

Numerical Methods for Scientific Computing
Novak

Logic in Computer Science: Modelling and Reasoning about Systems
Huth and Ryan

The Craft of Scientific Writing
Alley

Grading
Course work includes in-class assignments, homework assignments, and a virtual course workshop / paper. Each of these is weighted for final grades.

1. In-Class Assignments (20%)
2. Homework (40%)
3. Course Project and Virtual Course Workshop (40%)

In-Class Assignments
In-class questions should be written up and submitted using Blackboard. They are due before the next class starts. Most lectures will contain 2-3 short questions to be answered covering material from the lecture, with a few minutes provided during class to create answers and for discussion. The lowest three grades on in-class assignments will be dropped.

Homework
Homework will generally include a combination of questions and coding assignments in Python, and may include bonus questions. The course will include 4 homework assignments.

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Each student will be given a total of **4 late days** to use throughout the semester, where they can submit homework after the deadline without a penalty. Please save these in case some event comes up during the semester that prevents you from submitting homework on this. If you plan to use your late days, please send the professor an email before the deadline. These cannot be used for project deadlines, only homework assignments.

After your homework is returned, you may make corrections within the next week and receive back up to half of the points you missed.

Course Project and Virtual Course Workshop
Students will participate in a virtual workshop organized for the course, with each student completing an individual course project and an approximately 10-page conference-style report. The project will be related to some of the techniques and tools learned during the course, and will involve research on your own outside of the classroom.

Projects ideally would develop original research related to hybrid systems and the project report would be similar to a conference submission. A second project and report option includes an experience report replicating research on hybrid systems recently published at top hybrid systems conferences such as HSCC, CAV, TACAS, EMSOFT, or ICCPS. A third option is to create a survey of the work of a researcher in the field, ideally a program committee member from one of the mentioned hybrid systems conferences. The topic for the project will be arranged with the instructor, with intermediate deadlines during the semester.

The virtual workshop will go through the steps of a real workshop / conference. Papers will be written in latex, submitted and students will perform peer review and provide feedback about each other's papers. Authors will make changes based on the feedback and create a 20 minute conference-style presentation for the project.

Due dates:

- September 29 (10% of grade): Idea / Paper Type description
- October 13 (10% of grade): Literature Review
- Nov 3 (10% of grade): Draft #1 (paper at least 50% done)
- Nov 22 (20% of grade): Paper Submission Due
- Dec 6 (20% of grade): Peer Review Due
- Finals Week (15% of grade): Final Presentations
- Finals Week (15% of grade): Final Paper

Please ask questions in office hours if there are questions on any aspects of the project.

Deadline 1 - Idea / Paper Type Description (Due September 29):
Decide on your project type and topic, discuss it with me (for example, during office hours). On Blackboard, hand in a description of which papers you read to research the project and want to

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accomplish (what results you hope for in the final paper). Please write this in latex and hand in the pdf (10 points). An overleaf project you can copy the contents of for the submission is here: https://www.overleaf.com/read/wpysmgprgrgv . You can create your own overleaf account or install latex locally.

Example papers that could be starting points for interesting replicability studies:

1. **Abstraction-Refinement:** Clarke, Edmund, et al. "Verification of hybrid systems based on counterexample-guided abstraction refinement." International Conference on Tools and Algorithms for the Construction and Analysis of Systems. Springer, Berlin, Heidelberg, 2003.
2. **Simulation:** Julius, A. Agung, et al. "Robust test generation and coverage for hybrid systems." International Workshop on Hybrid Systems: Computation and Control. Springer, Berlin, Heidelberg, 2007.
3. **Linear Reachability:** Han, Zhi, and Bruce H. Krogh. "Reachability analysis of large-scale affine systems using low-dimensional polytopes." International Workshop on Hybrid Systems: Computation and Control. Springer, Berlin, Heidelberg, 2006.
4. **Non-linear Reachability**: Chen, Xin, Erika Abraham, and Sriram Sankaranarayanan. "Taylor model flowpipe construction for non-linear hybrid systems." 2012 IEEE 33rd Real-Time Systems Symposium. IEEE, 2012.
5. **Neural Network Verification:** Wang, Shiqi, et al. "Formal security analysis of neural networks using symbolic intervals." 27th USENIX Security Symposium (USENIX Security 18). 2018.
6. **Zeno Behaviors:** ZKonečný, Michal, et al. "Enclosing the behavior of a hybrid automaton up to and beyond a Zeno point." Nonlinear Analysis: Hybrid Systems 20 (2016): 1-20.
7. **Abstract Interpretation:** Miné, Antoine. "The octagon abstract domain." Higher-order and symbolic computation 19.1 (2006): 31-100.
8. **Abstract Interpretation**: Ghorbal, Khalil, Eric Goubault, and Sylvie Putot. "The zonotope abstract domain Taylor1+." International Conference on Computer Aided Verification. Springer, Berlin, Heidelberg, 2009.
9. **Abstract Interpretation:** Goubault, Eric, and Sylvie Putot. "Static analysis of numerical algorithms." International Static Analysis Symposium. Springer, Berlin, Heidelberg, 2006.
10. **Star Sets:** Duggirala, Parasara Sridhar, and Mahesh Viswanathan. "Parsimonious, simulation based verification of linear systems." International Conference on Computer Aided Verification. Springer, Cham, 2016.
11. **Traffic Management**: Karimi, Abolfazl, and Parasara Sridhar Duggirala. "Formalizing traffic rules for uncontrolled intersections." 2020 ACM/IEEE 11th International Conference on Cyber-Physical Systems (ICCPS). IEEE, 2020. (Available on Stony Brook IEEE Library: http://proxy.library.stonybrook.edu/login?url=http://www.ieee.org/ieeexplore/)

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12. **Traffic Management**: Aoki, Shunsuke, and Ragunathan Rajkumar. "Dynamic intersections and self-driving vehicles." 2018 ACM/IEEE 9th International Conference on Cyber-Physical Systems (ICCPS). IEEE, 2018. (see related work section for more)
13. **Neural Network Verification Survey**: Liu, Changliu, et al. "Algorithms for verifying deep neural networks." arXiv preprint arXiv:1903.06758 (2019). https://arxiv.org/abs/1903.06758
14. **Neural Network Competition Examples & Results**: See report here: https://www.overleaf.com/project/5f0c85e8d15dc10001749fa9
15. **Closed-Loop Neural Network Verification Examples:** https://easychair.org/publications/paper/Jvwg
16. **Path and Motion Planning for Robots:** Dantam, Neil T., et al. "An incremental constraint-based framework for task and motion planning." The International Journal of Robotics Research 37.10 (2018): 1134-1151.
17. **Falsification competition**: pdf
18. **Neural Network Verification Survey**: Liu, Changliu, et al. "Algorithms for verifying deep neural networks." arXiv preprint arXiv:1903.06758 (2019). Pdf
19. **Neural Network Tool Competition (2021)**: Bak, Stanley, Changliu Liu, and Taylor Johnson. "The Second International Verification of Neural Networks Competition (VNN-COMP 2021): Summary and Results." arXiv preprint arXiv:2109.00498 (2021). (pdf)

Deadline 2 - Literature Review (Due Oct 13)
Use the IEEE conference template to start writing your paper. Also include a brief paragraph of what you're doing in the abstract and a paragraph in the introduction. Read at least 8 papers and write about them in the Related Work section. Use complete sentences and paragraphs, not just a bulleted list (like something you would see in a conference paper). Should be 1-2 pages.

An overleaf project with the requirements that you can copy is here.

Final Exam
There is no final exam, although the final exam period time may be used for aspects of the course project / workshop.

Illness Policy
If you are sick or starting to feel sick, please do not come in person to the classroom. All classes will be streamed on zoom and cloud recorded (link and videos on blackboard). For in-class assignments, you will hand them in on blackboard so in-person attendance is not needed. For homework, since you are given four late days, missing the deadline by a day is not a large issue. Extended absences or other circumstances will be handled according to university policy (contact the professor).

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Tentative Schedule

Note the planned schedule and topics are subject to change based on course interests and progress.

If you want to preview material before the lecture, you can look at last semester's slides and syllabus.

#	Date	Planned Topic	Actual Topic	Notes
1	Aug 23	Course Overview	Course Overview	slides
2	Aug 25	Numerical Simulation	Simulation	slides notes
3	Aug 30	Numerical Simulation	Simulation Accuracy	slides notes Euler sim code
4	Sep 1	Numerical Simulation	Runge Kutta Simulation	slides notes RK45 sim code
	Sep 6	No Class. Labor Day		No Class; Labor Day
5	Sep 8	Numerical Simulation	zero-crossing	Course Materials Folder
6	Sep 13	Numerical Simulation	Hybrid Automata overview	Course Materials Folder
7	Sep 15	Reachability Analysis	Linear Systems Solutions	HW1 (Simulation) Due
8	Sep 20	Reachability Analysis	Sets - V-Polytopes, Zonotopes	Course Materials Folder
9	Sep 22	Reachability Analysis	Zonotopes and Star Sets	Course Materials Folder
10	Sep 27	Reachability Analysis	Coding Reachability Analysis	Course Materials Folder
11	Sep 29	Reachability Analysis	Coding star sets	Course Materials Folder Project Idea Writeup Due
12	Oct 4	Reachability Analysis	Neural network verification intro, ReLU	Course Materials Folder
13	Oct 6	Neural Network Verification	Neural network reachability with polytopes	Course Materials Folder HW2 (Reachability) Due
	Oct 11	No Class. Fall Break.		
14	Oct 13	Neural Network Verification	Neural network reachability with stars (exact)	Course Materials Folder Project Literature Review Due
15	Oct 18	Neural Network Verification	Neural network reachability with stars (overapproximatation), handling sigmoid and other activation functions	Course Materials Folder
16	Oct 20	Neural Network Verification	CEGAR for NN verification and optimizations	Course Materials Folder
17	Oct 25	SAT / SMT Solving	Propositional logic	Course Materials Folder
18	Oct 27	SAT / SMT Solving	Predicate logic intro	Course Materials Folder

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19	Nov 1	SAT / SMT Solving	Predicate logic rules	Course Materials Folder
20	Nov 3	SAT / SMT Solving	SAT Solving	Course Materials Folder Project Draft #1 Due (11/7) HW3 (NN Verification) Due HW4 Released
21	Nov 8	SAT / SMT Solving	SMT Solving	Course Materials Folder
22	Nov 10	Select Topics (TBD)	Nelson Oppen	Course Materials Folder
23	Nov 15	Select Topics (TBD)	Temporal Logic Intro / LTL	Course Materials Folder
24	Nov 17	Select Topics (TBD)	CTL and Model Checking Algorithm / Signal Temporal Logic	Course Materials Folder HW4 (SMT) Due
25	Nov 22	Select Topics (TBD)	Guest Speaker (Niklas Kochdumper)	Project Paper Submission Due
	Nov 24	No Class. Thanksgiving Break.		
26	Nov 29	Select Topics (TBD)	Guest Speaker (Gagandeep Singh)	
29	Dec 1	Select Topics (TBD)	Guest Speaker (Andrew Mata)	
28	Dec 6	Select Topics (TBD)	Guest Speaker (Aditya Zutshi)	HW 4 Corrections Due Project Peer Review Due
29	Dec 13 (Finals Week)	Final: Project Presentations		Project Presentation. Final Paper Due on Thursday (12/16)

Class Material Copyright Notice

Religious Holiday Policy

SBU's religious holiday policy is here. If possible, please let me know in advance if you plan to miss classes so we can make appropriate arrangements.

Required Syllabus Statements

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The University Senate Undergraduate and Graduate Councils have authorized that the following required statements appear in all teaching syllabi (graduate and undergraduate courses) on the Stony Brook Campus.

Student Accessibility Support Center Statement
If you have a physical, psychological, medical, or learning disability that may impact your course work, please contact the Student Accessibility Support Center, Stony Brook Union Suite 107, (631) 632-6748, or at sasc@stonybrook.edu. They will determine with you what accommodations are necessary and appropriate. All information and documentation is confidential.

Students who require assistance during emergency evacuation are encouraged to discuss their needs with their professors and the Student Accessibility Support Center. For procedures and information go to the following website: https://ehs.stonybrook.edu//programs/fire-safety/emergency-evacuation/evacuation-guide-disabilities and search Fire Safety and Evacuation and Disabilities.

Academic Integrity Statement
Each student must pursue his or her academic goals honestly and be personally accountable for all submitted work. Representing another person's work as your own is always wrong. Faculty is required to report any suspected instances of academic dishonesty to the Academic Judiciary. Faculty in the Health Sciences Center (School of Health Professions, Nursing, Social Welfare, Dental Medicine) and School of Medicine are required to follow their school-specific procedures. For more comprehensive information on academic integrity, including categories of academic dishonesty please refer to the academic judiciary website at http://www.stonybrook.edu/commcms/academic_integrity/index.html

Critical Incident Management
Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of Student Conduct and Community Standards any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn. Faculty in the HSC Schools and the School of Medicine are required to follow their school-specific procedures. Further information about most academic matters can be found in the Undergraduate Bulletin, the Undergraduate Class Schedule, and the Faculty-Employee Handbook.

Attendance Statement
Students are expected to attend every class, report for examinations and submit major graded coursework as scheduled. If a student is unable to attend lecture(s), report for any exams or complete major graded coursework as scheduled due to extenuating circumstances, the student must contact the instructor as soon as possible. Students may be requested to provide documentation to support their absence and/or may be referred to the Student Support Team for assistance. Students will be provided reasonable accommodations for missed exams,

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assignments or projects due to significant illness, tragedy or other personal emergencies. In the instance of missed lectures or labs, the student is responsible for ***reviewing posted slides and reviewing recorded lectures***. Please note, all students must follow Stony Brook, local, state and Centers for Disease Control and Prevention (CDC) guidelines to reduce the risk of transmission of COVID. For questions or more information click here.