Note: This syllabus is for an old version of the course (Fall 2023)

**Hybrid Systems (CSE 510) Syllabus**
**Fall 2023**
**Stony Brook University**
**Prof. Stanley Bak**

**Course Description**
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.

**Explicit Learning Objectives**
- Develop an understanding of numerical simulation algorithms for hybrid systems, including their trade-offs. Be able to write code for simulating a given hybrid system model.
- Acquire the ability to verify hybrid systems using reachability analysis algorithms.
- Gain proficiency in verification approaches for neural networks and neural network control systems, and implement simple versions of these algorithms.
- Read research papers on advances in hybrid systems and demonstrate understanding through write-ups.

**Prerequisites**
No courses are listed as prerequisites although as a graduate CS course it will be assumed you are proficient in Python programming and basic linear algebra (knowledge of vectors and matrices). Background in differential equations, control theory, more advanced linear algebra and neural networks will help in the course, but is not required.

**Credits Allocated**
3 credits, Letter graded (A, A-, B+, etc.)

Clarification: Grading uses the standard percentage ranges. If the final score is 93 or above, it's an "A", if it's between 90 and 92, it's an "A-", and so on down the scale, with scores below 60 receiving an "F".

**Instructor Contact Information and Office Hours**
Professor: Stanley Bak
Website: http://stanleybak.com
Email: stanley.bak@stonybrook.edu

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Office hours are Thursdays 3:00-4:00 PM, New CS Building Room 247
If you are planning to come to office hours please let me know ahead of time and include the topic.

TA: Ertai Luo (erluo@cs.stonybrook.edu). Office hours are Fridays 3:00PM-4:30PM, New CS Building Room 256 (small room at the end of the floor). Please email the TA if you're planning to go and include the topic.

**Tentative schedule of required assignments**
Daily mini-assignments are due before each class period starts (when assigned)
HW 1: Sept 19
HW 2: ~~Oct 5~~ **Oct 17**
Midterm Exam: ~~Oct 19~~ **Oct 24**
HW 3: ~~Nov 7~~ **Nov 17**
HW 4: Dec 5
Final Exam: Thurs Dec 14, 11:30-12:50PM (finals week)

**Basis of Grade Determination**
Course work includes daily mini-assignments, homeworks, a mid-term, and a cumulative final. Each of these is weighted for final grades:

1. Daily Mini-Assignments (20%)
2. Homework (30%)
3. Mid-term (20%)
4. Cumulative Final (30%)

**Policy on make-up exams**
Make-up exams are generally not permitted. Exceptions will be given consistent university policy on Student Participation in University Sponsored Events, the policy on Final Exams and the New York State Education Law regarding Equivalent Opportunity and Religious Absences.

Students are responsible for presenting a printed copy of semester obligations to the professor at the beginning of the semester to alert them to activities that may present conflicts.

For unforeseen conflicts, please notify the professor as soon as possible. For serious health issues, please provide a doctor's note. This note should be from the Student Health Service at Stony Brook University, if possible.

**Other Course Policies Related to Integrity of Credit**
Daily Mini-Assignments should be written up and submitted using Brightspace. 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

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and for discussion. Some mini-assignments may include assigned reading. The lowest three grades on mini-assignments will be dropped.

Homework will generally include a combination of questions and coding assignments in Python, and may include bonus questions. Parts may also involve reading and summarizing literature on topics related to hybrid systems. The course will include 4 homework assignments. Late homework will lose 25% credit each day.

The midterm exam will cover the first half of the course, and the final exam will be comprehensive.

**Bibliographic and Other Resources**
There is no required textbook as all information needed will be provided on the slides and in class. However, the following may be useful for extra details:

- *Introduction to Embedded Systems*, Lee and Seshia (website with pdf link)
- *Principles of Cyber-Physical Systems*, Alur (website)
- *Verifying Cyber-Physical Systems*, Sayan Mitra (website)
- *Numerical Methods for Scientific Computing,* Novak (reddit post with pdf link)
- *Logic in Computer Science: Modelling and Reasoning about Systems*, Huth and Ryan
- *Model Checking*, Edmund M. Clarke Jr., Orna Grumberg, Daniel Kroening, Doron Peled and Helmut Veith

**Author of Syllabus**
Stanley Bak

**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.

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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 Statement**

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.

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**Class Time**
TuTh 11:30AM - 12:50PM
Aug 28, 2023-Dec 21, 2023 (See SBU Academic Calendar for holiday list)
Old CS Building 2311

**ChatGPT / Generative AI Policy**
Please do not use ChatGPT or other generative AI on any assignments, unless indicated. Github Copilot is allowed for coding assignments.

**Submission Format**
All assignments should be submitted in a format you cannot edit after the fact. Do not submit links to google drive or overleaf documents. Pdf is safe, for example. Link submissions will be graded as zeros. Submissions I cannot open, for example a zip with a password or a corrupted document, also will receive a zero.

**Course Website**
https://sites.google.com/stonybrook.edu/cse510fall2023

**Course Resources Folder**
link

**Tentative Topic Schedule**

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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 a previous year's slides and syllabus.

| Class # | Date | Planned Topic | Notes |
|---|---|---|---|
| 1 | Aug 29 | Course Overview | |
| 2 | Aug 31 | Simulation | |
| 3 | Sept 5 | Simulation Accuracy | HW1 Released |
| 4 | Sept 7 | Runge Kutta Simulation | |
| 5 | Sept 12 | Zero-crossing | |
| 6 | Sept 14 | Model-Based Design | |
| 7 | Sept 19 | Discrete Dynamics / UPPAAL | HW1 Due - Simulation |
| 8 | Sept 21 | Extended and Timed Automata / UPPAAL | |
| 9 | Sept 26 | Dynamical Systems and Control 1 | |
| 10 | Sept 28 | Dynamical Systems and Control 2 | |
| 11 | Oct 3 | Linear Temporal Logic (LTL) | HW2 Released |
| 12 | Oct 5 | Computation Tree Logic (CTL) and Model Checking | |
| | Oct 10 | Fall Break | |
| 13 | Oct 12 | Decidable and Undecidable Classes of Hybrid Automata | |
| 14 | Oct 17 | Hybrid Automata and Reachability analysis overview | HW2 Due - Discrete and Continuous Systems |
| 15 | Oct 19 | Midterm Review | |
| 16 | Oct 24 | Midterm in normal classroom, 11:30AM to 12:50PM | |
| 17 | Oct 26 | Linear Systems Solutions | |
| 18 | Oct 31 | Reachability Analysis H-Polytopes, V-Polytopes, Zonotopes and Star Sets | |
| 19 | Nov 2 | Coding Reachability Analysis with Zonotopes | HW3 Released (Nov 4) |
| 20 | Nov 7 | Coding Reachability Analysis with Star Sets | |
| 21 | Nov 9 | Neural Network Verification Intro - NN Reachability with H-Polytopes | |

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| 22 | Nov 14 | Neural Network Reachability with Star Sets - Exact / Overapproximatation / Nonlinear activation functions | |
| 23 | Nov 16 | Nonlinear Reachability Analysis - Polynomial Zonotopes - Guest Lecture Ertai Luo | HW3 Due (Nov 17) - Reachability Analysis |
| 24 | Nov 21 | Advanced Topics in Neural Network Reachability Analysis | HW4 Released |
| | Nov 23 | Thanksgiving Break | |
| 25 | Nov 28 | Signal Temporal Logic and Falsification | |
| 26 | Nov 30 | Advanced Topics on Falsification | |
| 27 | Dec 5 | Industry Guest Speaker on Zoom - Bardh Hoxha (Senior Principal Scientist at Toyota Research Institute North America), “Simulation-Based Testing of autonomous CPS” | Class on Zoom<br><br>HW4 Due - Neural Network Verification |
| 28 | Dec 7 | Final Review | HW Bonus Due (Dec 6) |
| | Dec 14 | Final Exam in Frey Hall Room 109, 11:30AM to 12:50PM | Different Room |



**Disruptive Behaviors**
Disruptive behaviors will not be tolerated and be handled according to university policy.