Lecture Schedule
Logical Foundations of Cyber-Physical Systems
Instructors: André Platzer, Sarah Loos, and João Martins
{aplatzer | sloos | jmartins}@cs.cmu.edu

*** Before the course begins, students should install Mathematica and KeYmaera and complete lab0. ***

Monday 24th March, 2014

Lecture 1
10:00–11:45

Basics of Hybrid Programs: Choice, Control & Domains

In the first lecture, we will cover the syntax and semantics of hybrid programs (HPs) and differential dynamic logic (dℒ). Most importantly, we will cover how to model the effects of discrete control choices on continuous physical dynamics.

Lecture 2
12:00–13:30

Safety & contracts

After covering the basics of how to model and design hybrid programs, we quickly move on to investigating the properties we want to verify. What does it mean to verify a hybrid system? How can we represent safety in dℒ? In this lecture we delve deeper into the subtleties and advantages of nondeterministic models which can cover the behavior of a class of controllers rather than a single system. Then we discuss how to represent the properties we want our HPs to satisfy.

Lunch
13:30–14:30

Lecture 3
14:30–15:30

Dynamical systems & dynamic axioms

Lecture 2 demonstrated how useful and crucial contracts are for CPS. However, in this lecture we introduce the axioms of dℒ to go beyond understanding contracts in the light of dynamic testing.

Lab 1
15:30–18:00

Charging Station

Students will practice writing contracts as formulas in dℒ. Then they will use the formal verification tool KeYmaera to prove safety and liveness properties about a robot reaching a charging station.

Tuesday 25th March, 2014

Lecture 4
10:00–11:45

Truth & proof & arithmetic

In this lecture, we present the proof calculus for dℒ, which allows us to prove that the HPs we've created satisfy given safety contracts under all admissible behavior of the system. This lecture will also discuss the basics of proofs and frequently used techniques for proving.

Lecture 5
12:00–13:30

Control loops & invariants

Lecture 1 on Choice & Control demonstrated how important control is in CPS and that control loops are a very important feature for making this control happen. Without loops, CPS controllers are limited to short finite sequences of control actions, which are rarely sufficient. In this lectures, we'll explore iterative repetition and how to prove properties about systems which can iteratively repeat arbitrarily often. TD (Theory): Students will practice working with the proof rules related to loop invariants. They will also create a proof of safety by hand using the proof rules they have learned.

Lunch
13:30–14:30

Lecture 6
14:30–16:30

Events & delays, part 1 (event-triggered)

This lecture will focus on how loops interface with differential equations in HPs. There are two important paradigms for handling this interaction between cyber and physical. The first paradigm is that of event-driven architecture, where reactions to events dominate the behavior of the system. The other paradigm is time-triggered control, which may only control the system at periodic intervals.

Lab 2
16:30–18:00

Event-triggered car following
Students will design a hybrid controller to follow a lead robot along a straight line without colliding. Students get to assume continuous sensing.

Wednesday 26th March, 2014

Lecture 7
10:00–11:30

Events & delays, part 2 (time-triggered)
This lecture will focus on the time-triggered control paradigm.

Lab 3
11:45–13:30

Time-triggered car following
Students will modify their hybrid controller for following a lead robot so that it no longer requires continuous sensing.

Thursday 27th March, 2014

Lecture 8
10:00–11:45

Differential equations & differential invariants, part 1
In previous lectures and materials we have examined how to prove properties about hybrid programs with simple solutions. In this lecture we will introduce differential invariants for analyzing systems with differential equations which are not solvable or for which the solution may be computationally intractable.

Lecture 9
12:00–13:00

Logical foundations of CPS
In this lecture, we will take a cursory look at extensions of $\mathsf{d}\mathcal{L}$ and other topics related to the logical foundations of CPS.

Lunch
13:00–14:30

Lecture 10
14:30–15:30

Differential equations & differential invariants, part 2

Lecture 11
15:45–17:00

Differential equations & proofs
This lecture will discuss how to find and use differential invariants in proofs.

Lab 4
17:00–19:00

Curved motion
Students will prove safety properties about systems with curved dynamics using KeYmaera and have the opportunity to catch up on unfinished practical assignments.

Friday 28th March, 2014

Lecture 12
10:00–11:00

Ghosts & differential ghosts
Differential ghosts, also called differential auxiliaries, can also be used where differential invariants fall short for proving properties about differential equations without solutions in first-order arithmetic.

Lab Session
11:00–13:00

Review
Students will have the chance to complete any unfinished work from previous practical assignments. They will also be given directions for optional advanced hybrid systems verification tasks.

Lunch
13:00–14:30

Q&A Session
14:30–15:30

Exam Review and Question & Answer Session
Students have the opportunity to ask questions in preparation for the exam and about related or future work.

Exam
15:30–17:00

Final Exam