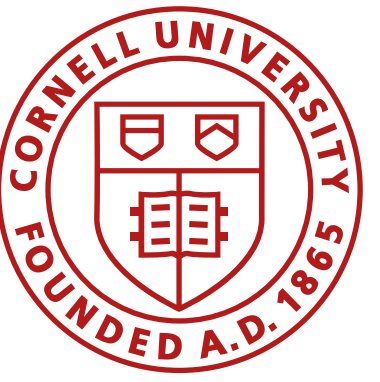


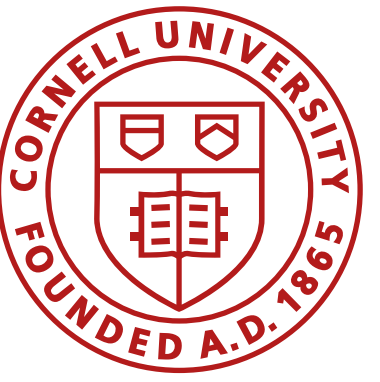


Introduction

Fast Robots, ECE4160/5160, MAE 4190/5190

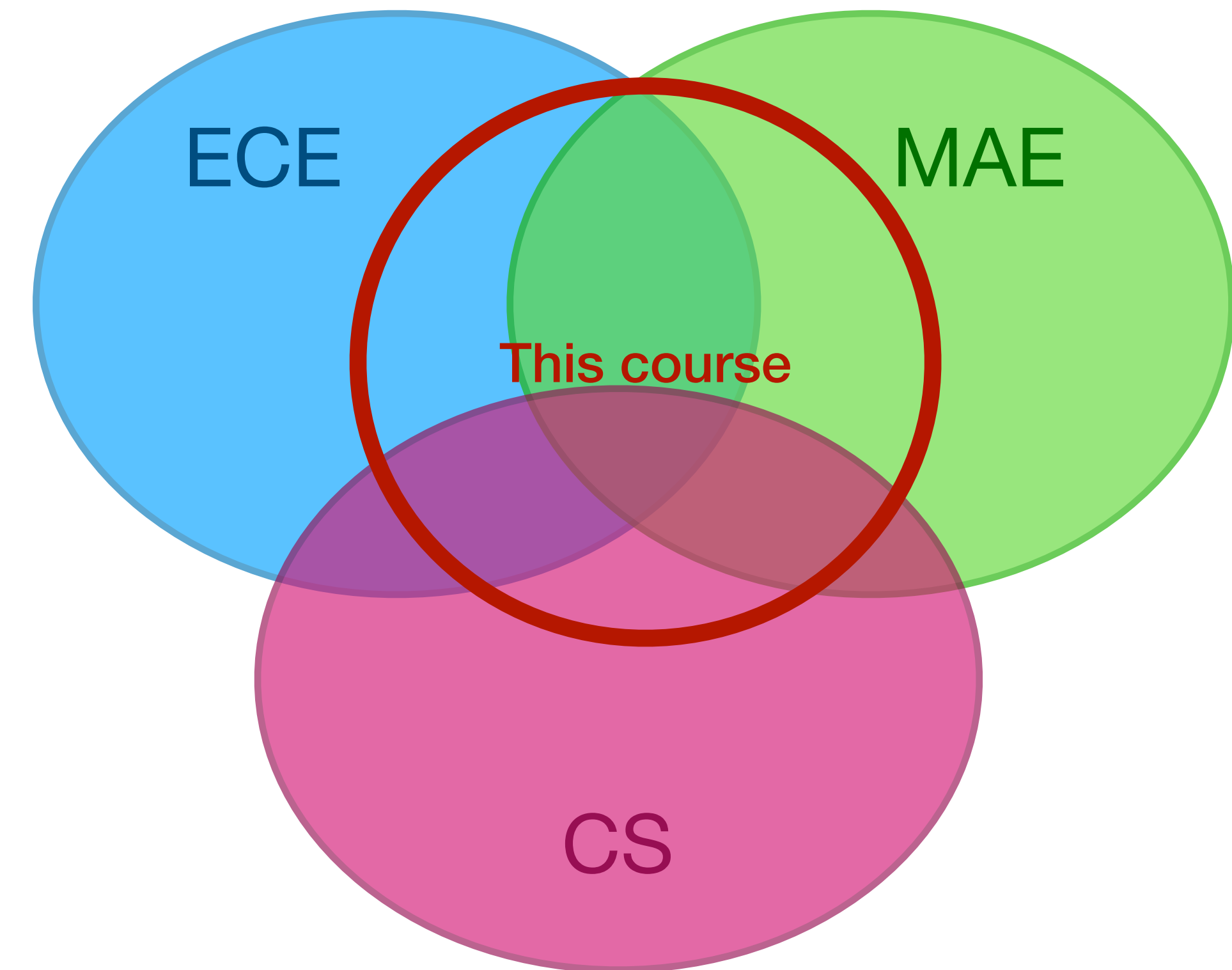
E. Farrell Helbling, 1/20/25

Slides adapted from Prof. Kirstin Petersen



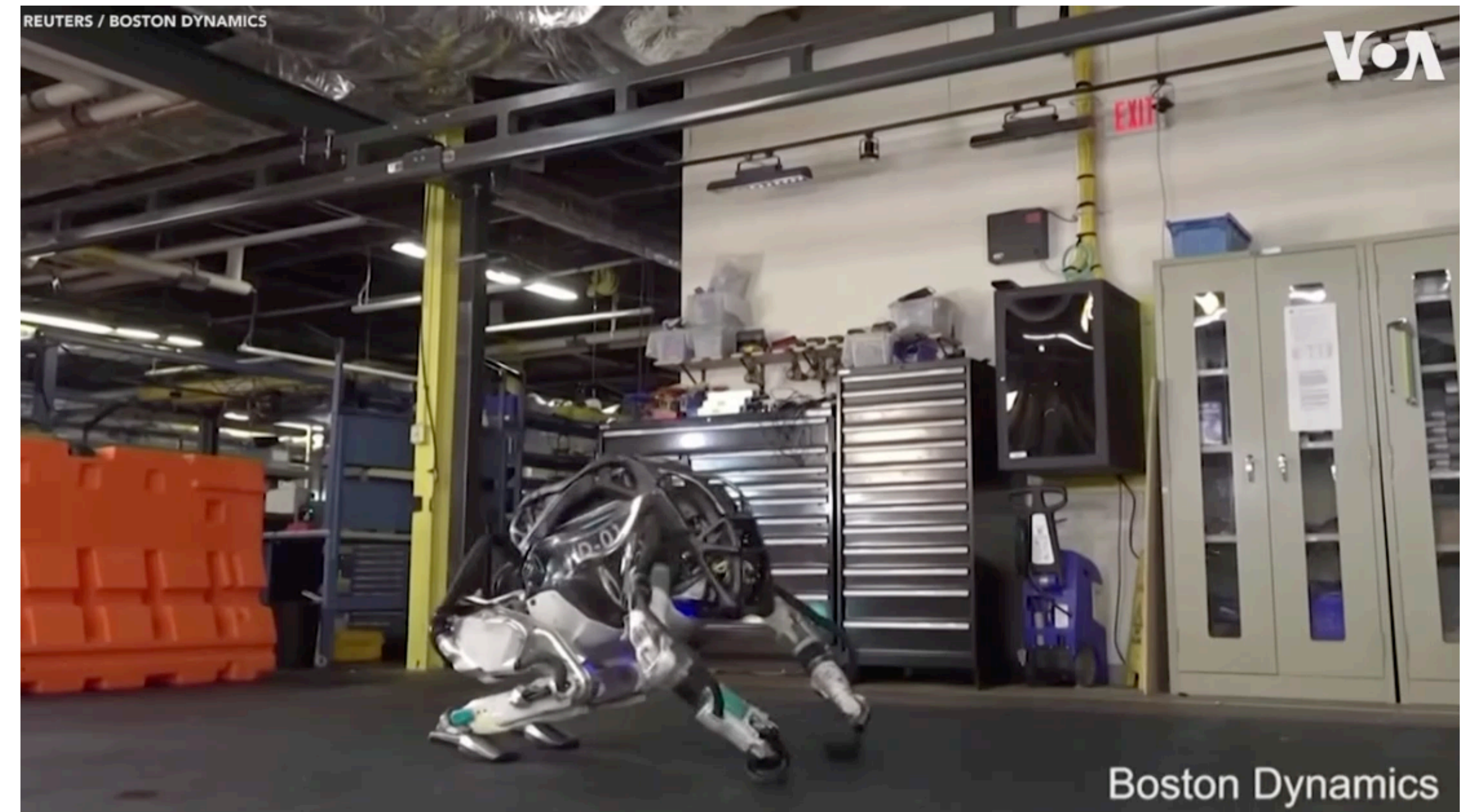
Why do you want to take this class?

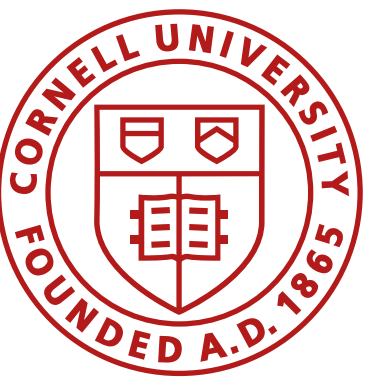
- Exists somewhere between a CDE (learn through implementation)
- ... and a foundations course
- Overlap with Autonomous Mobile Robots, Foundations of Robotics, and Feedback Control Systems



Fast Robots are fundamentally different

Kinematics — Dynamics





Fast Robots are fundamentally different

Stable — Unstable

Deep Drone Acrobatics

Elia Kaufmann*, Antonio Loquercio*, René Ranftl,
Matthias Müller, Vladlen Koltun, Davide Scaramuzza



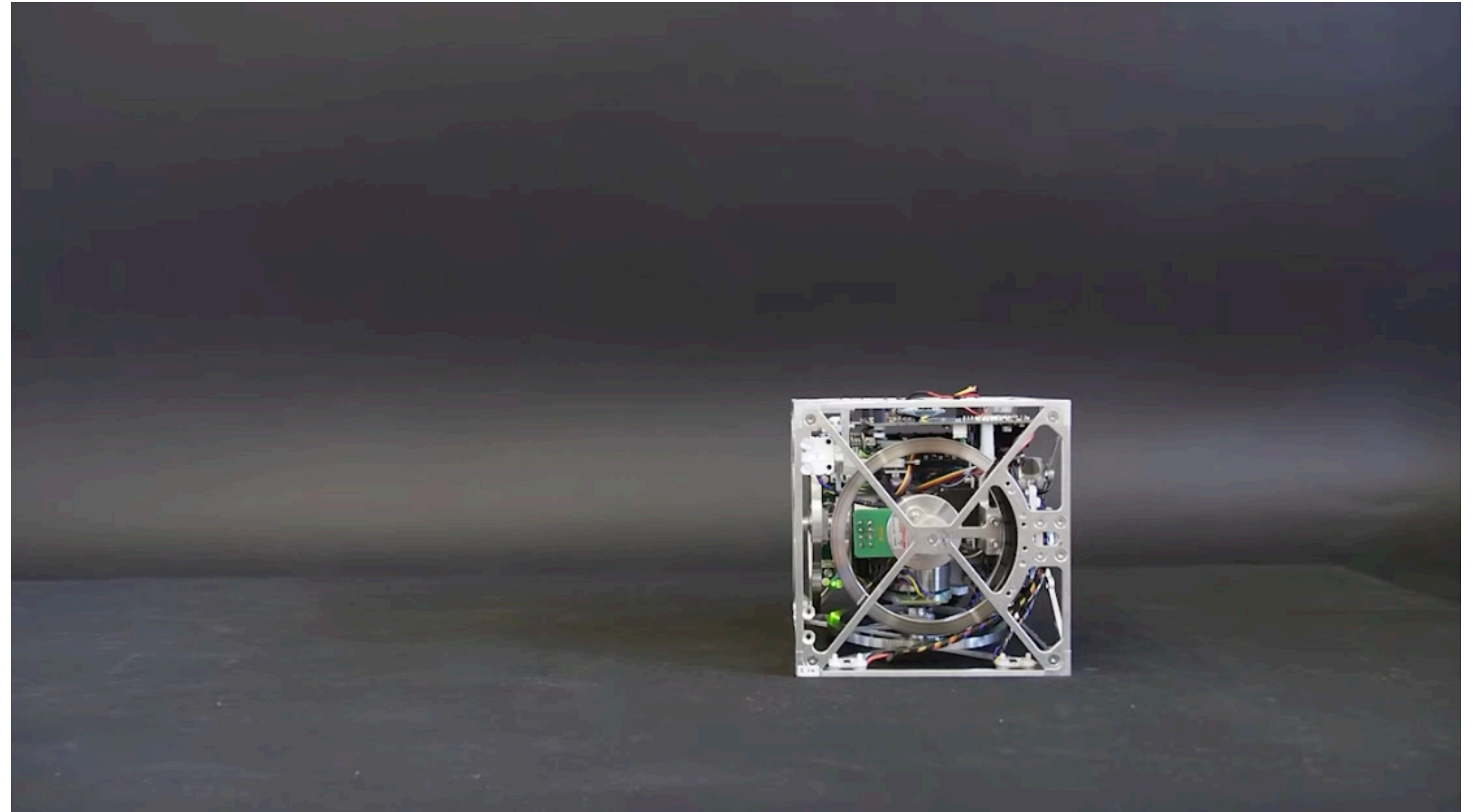
University of
Zurich^{UZH}



Pause (k)

0:01 / 2:31

*these authors contributed equally

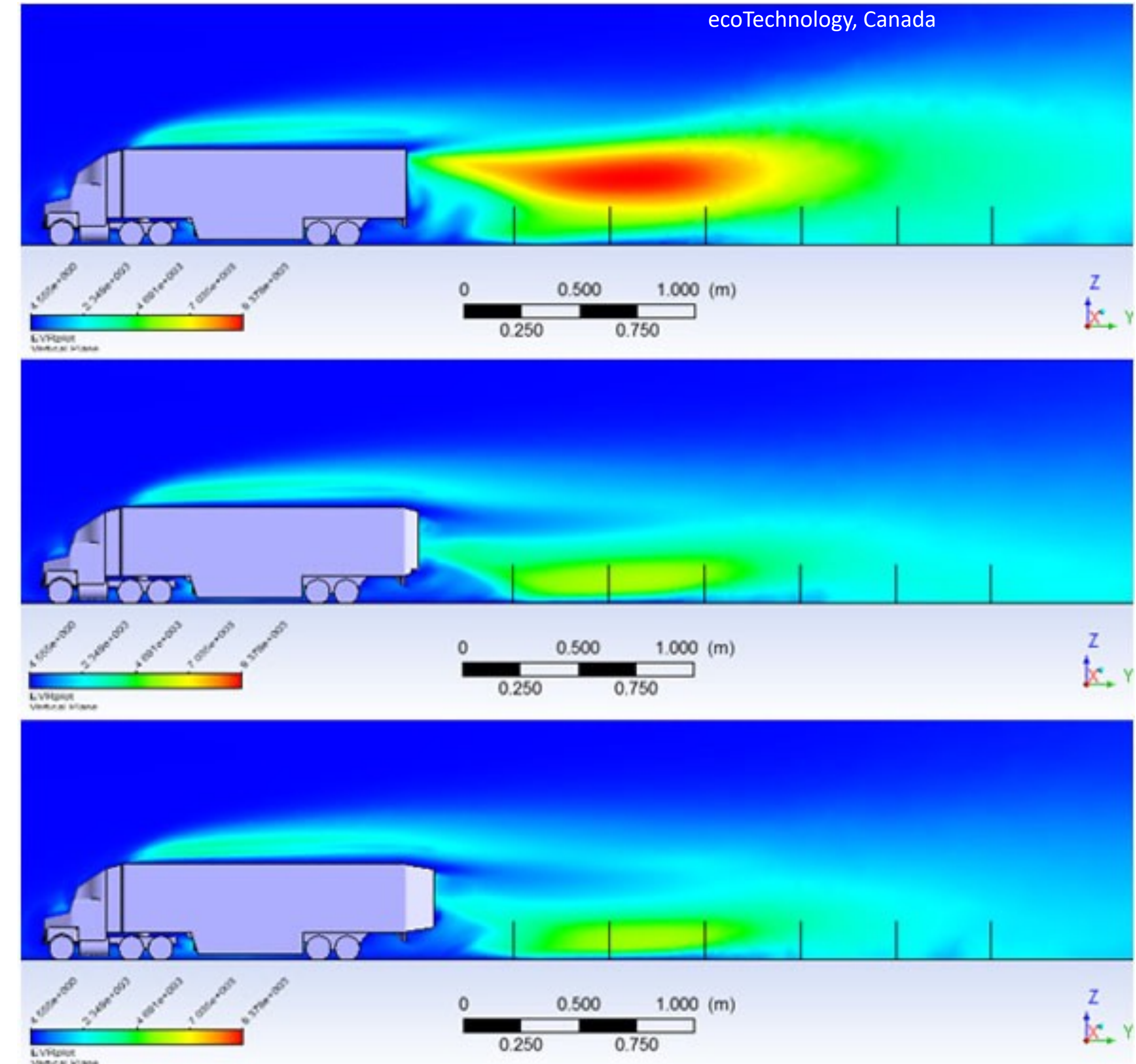
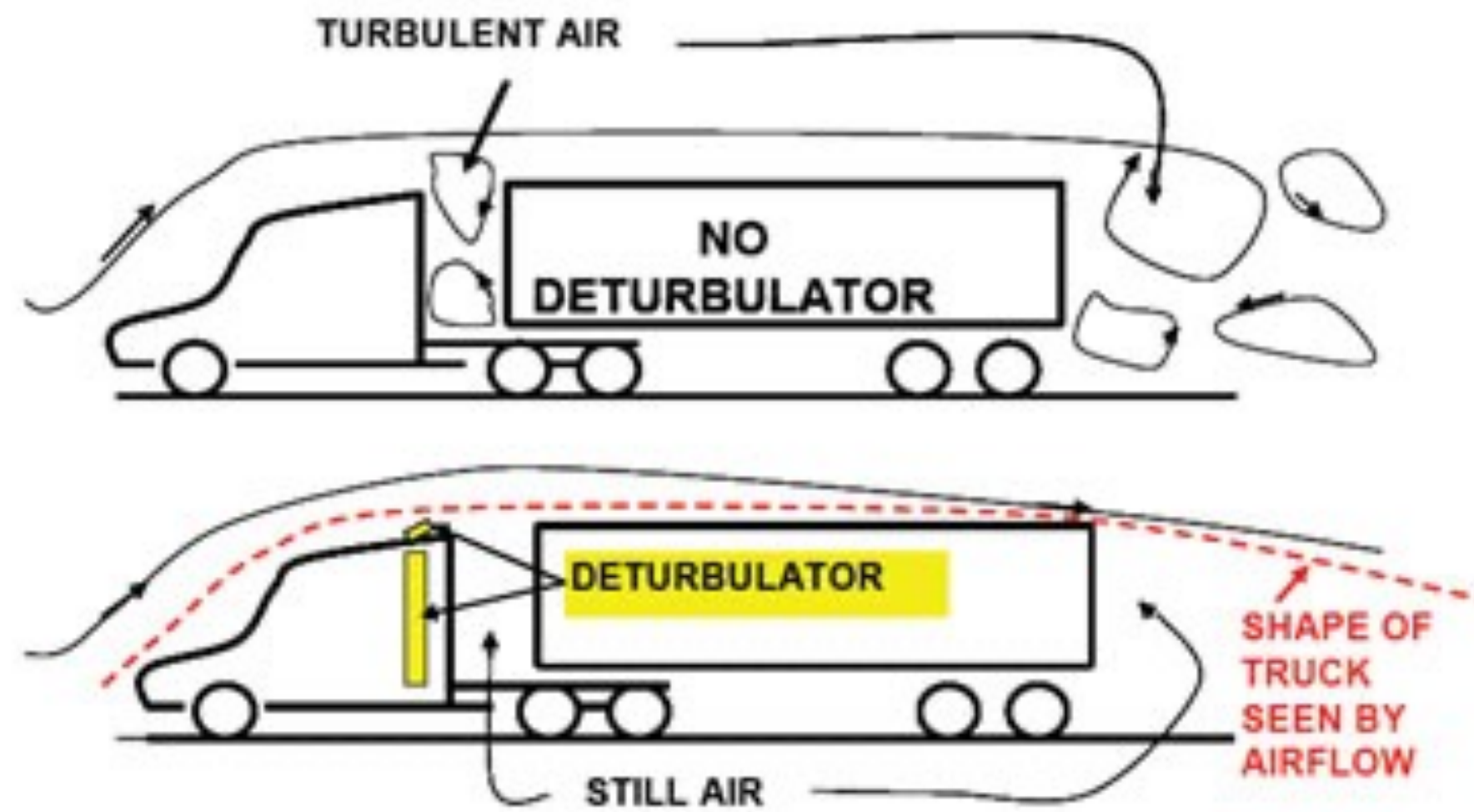
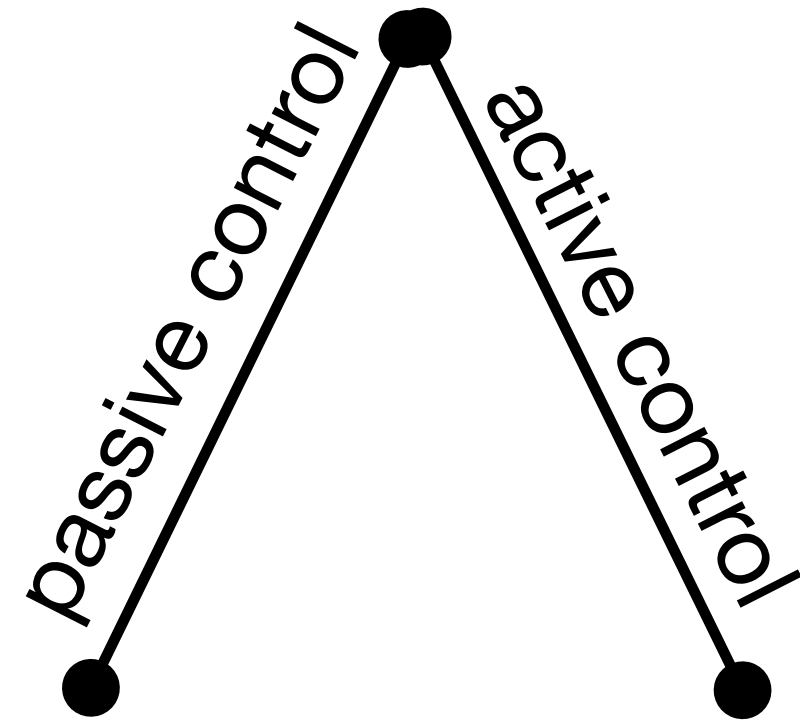


Fast Robots are fundamentally different Design

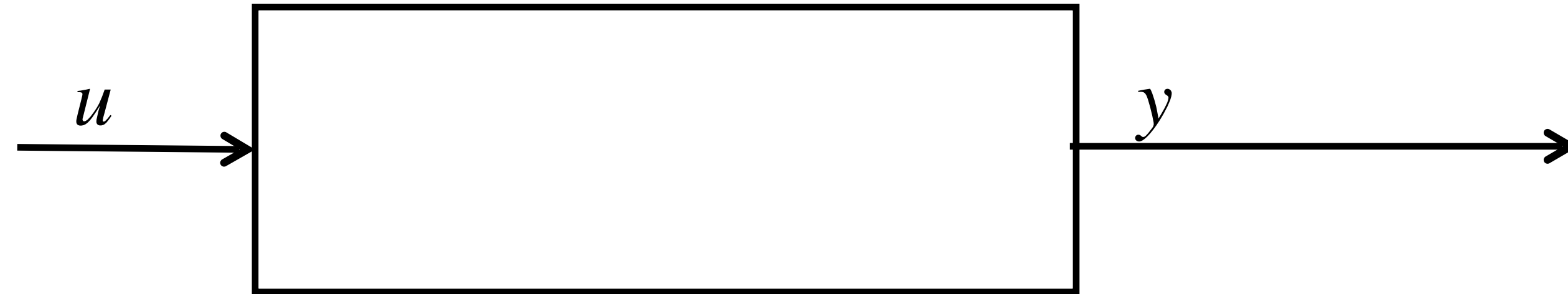
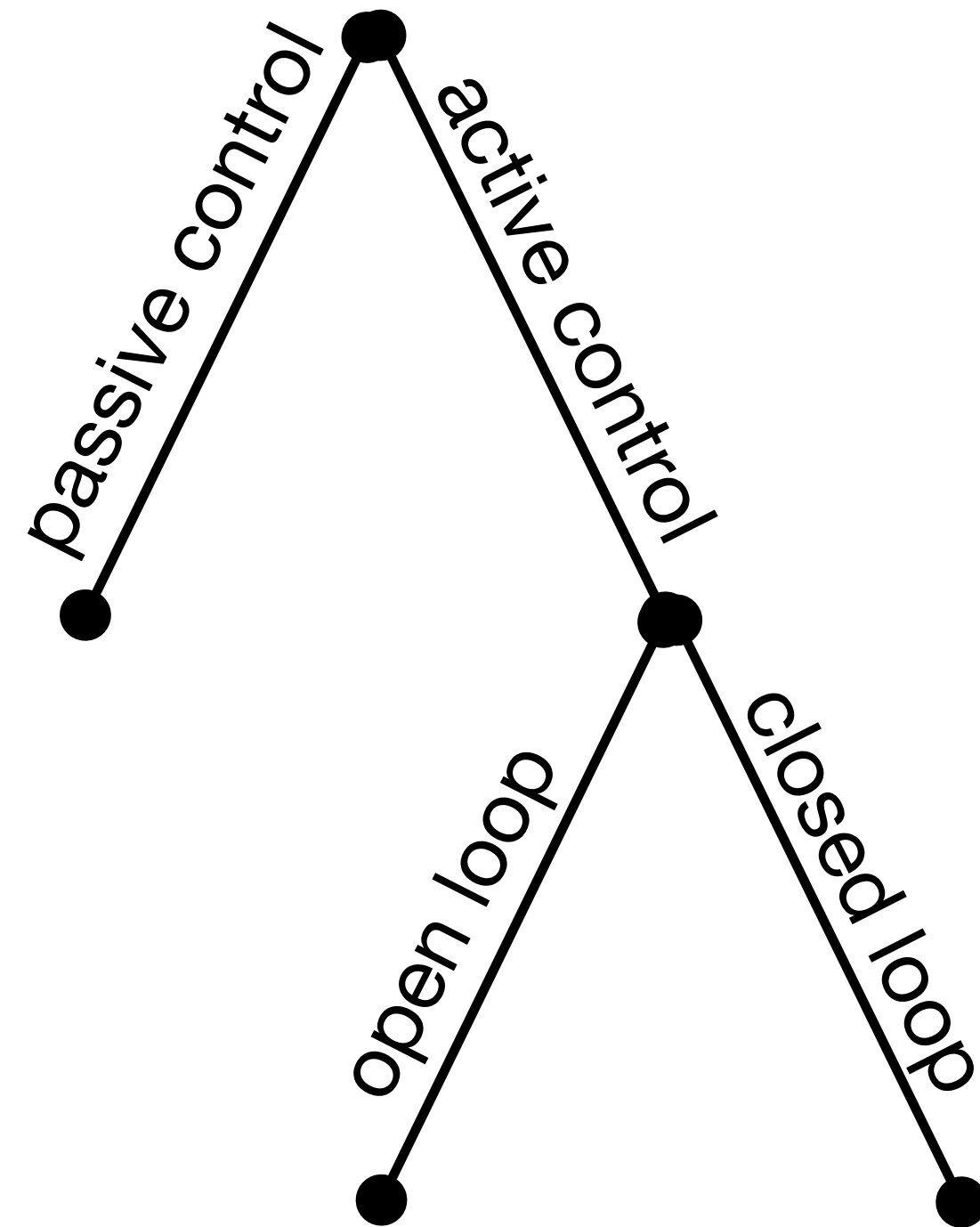
- Requires more than good control theory and dynamic models
 - Practical implementation: mechanics, sensors, processing, estimation, etc.



Control



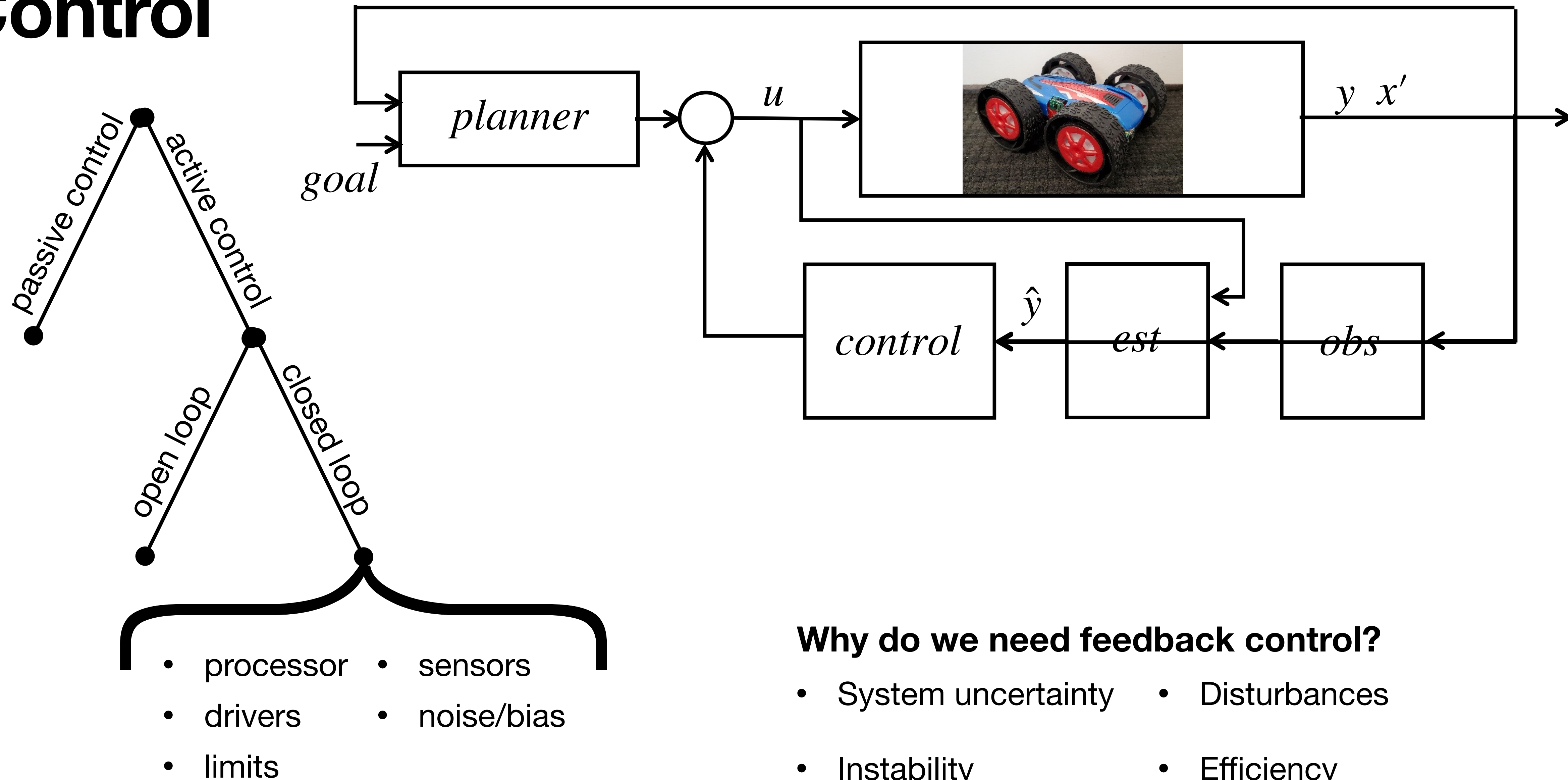
Control

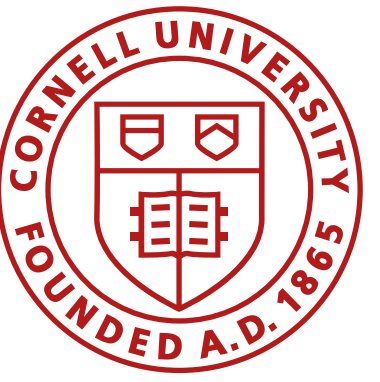


So why do we care about feedback?



Control





Class Layout

Lab 1-4: HW / Embedded SW

Lab 5-8: Feedback Control

Lab 9-12: Localization
and Planning

Lab 1-4: HW / Embedded SW

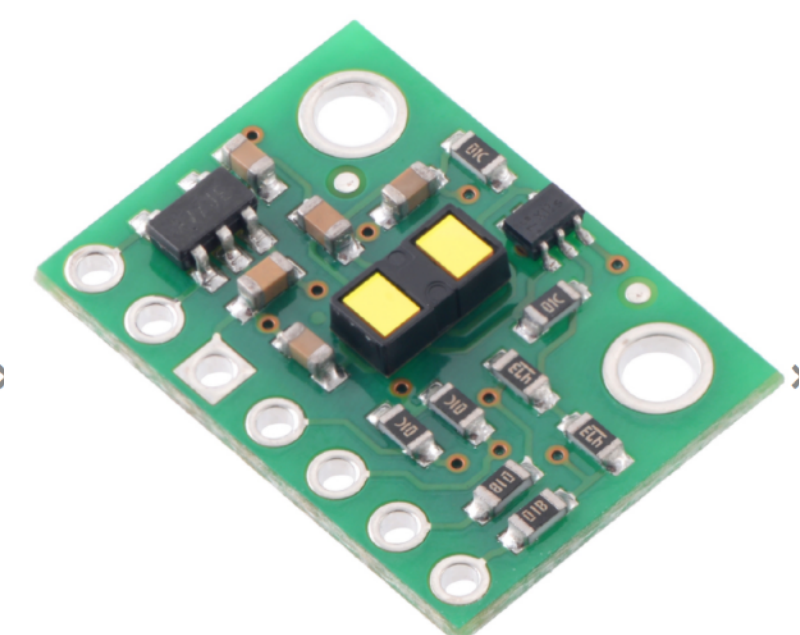
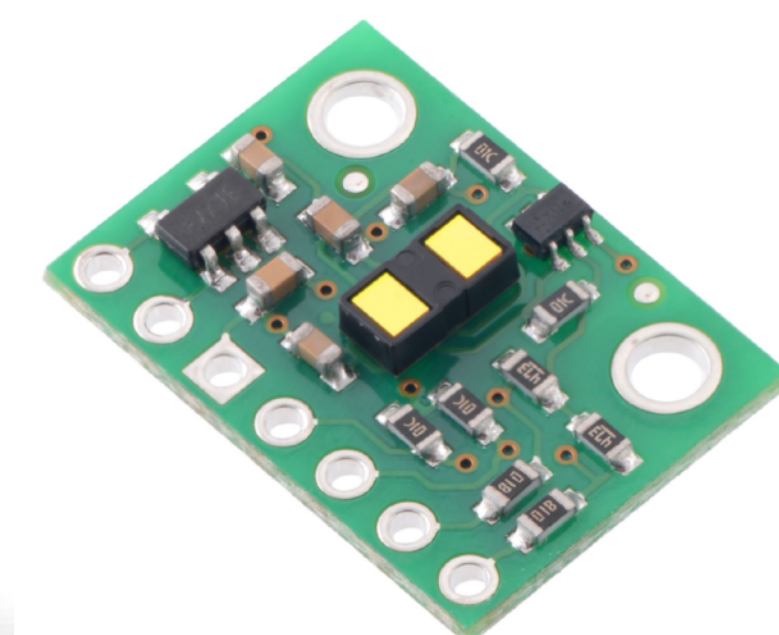
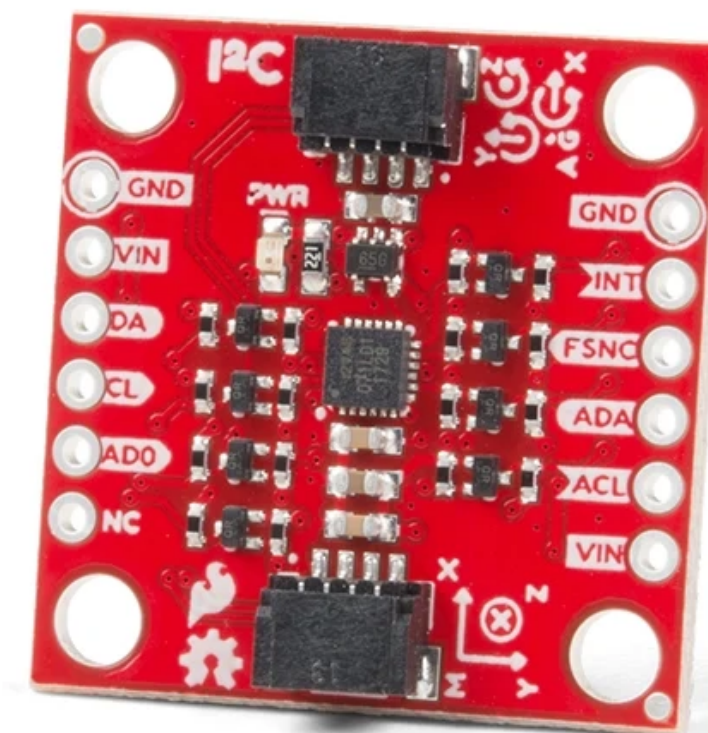
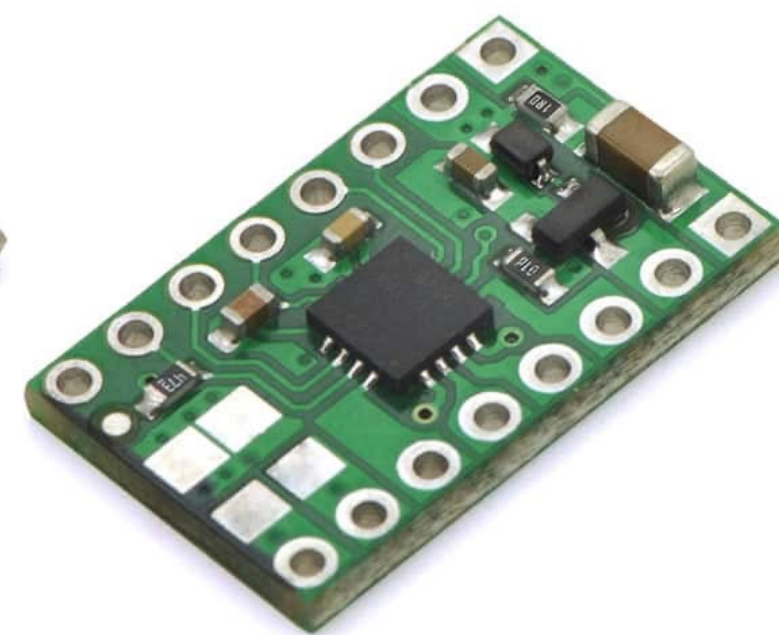
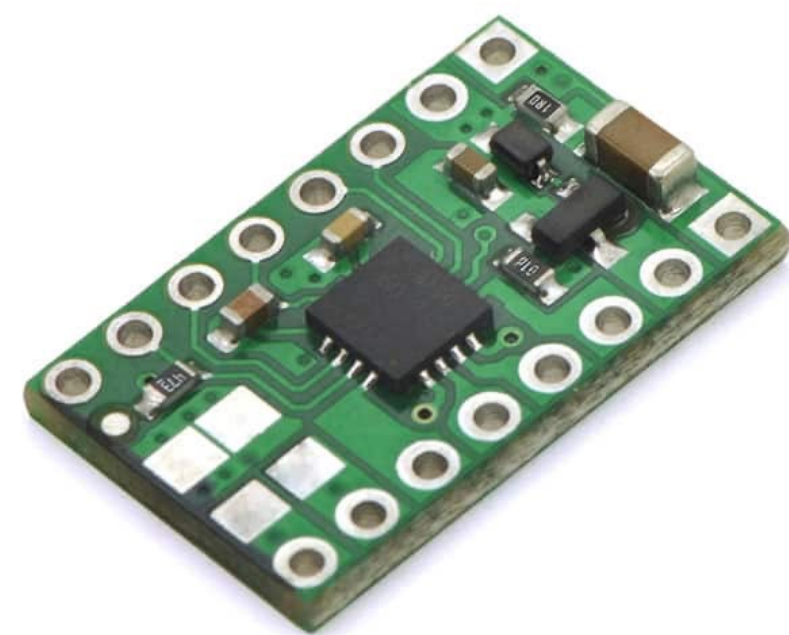
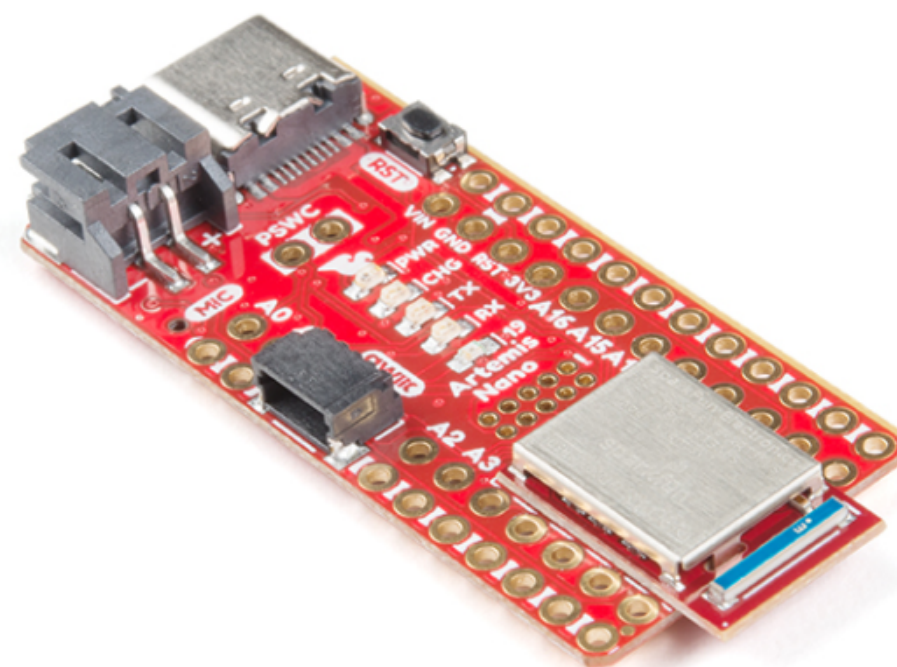
Lab 5-8: Feedback Control

Lab 9-12: Localization and Planning

- Take the RC car base and combine with processor, sensors, and motor drivers
- Refresh on linear algebra and T-matrices
- Sensor modalities and types of sensors
- Actuators, drivers, circuits and routing, and EMI



\$125 lab kit! It's yours!

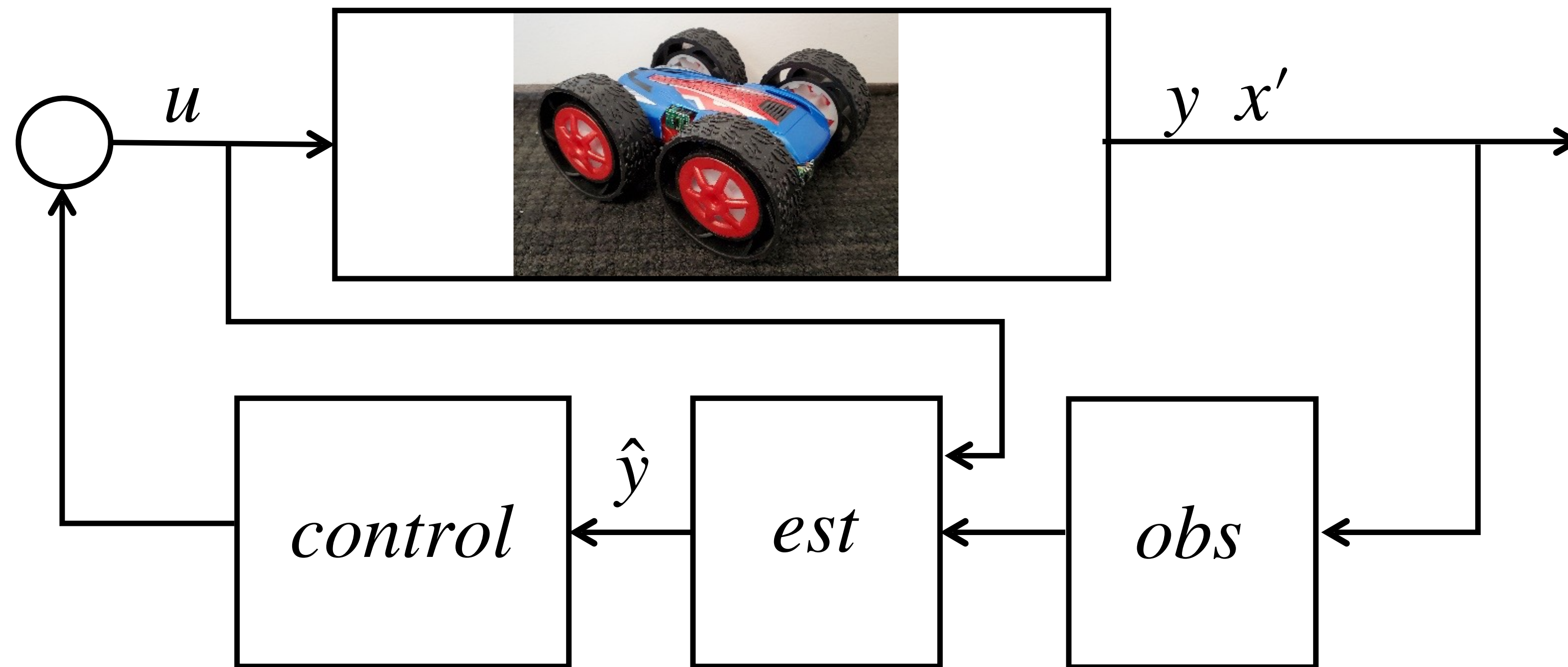


Lab 1-4: HW / Embedded SW

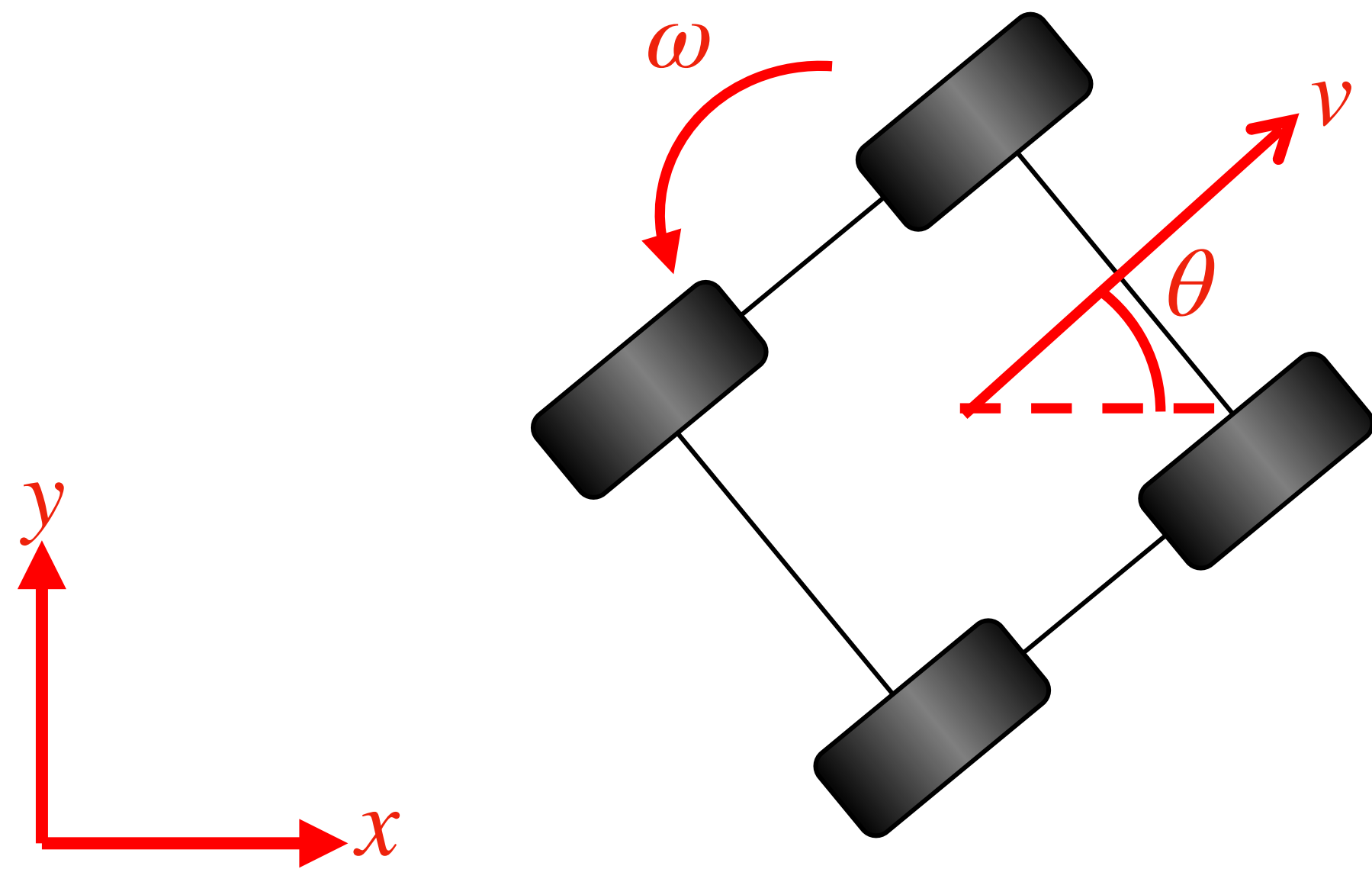
Lab 5-8: Feedback Control

Lab 9-12: Localization
and Planning

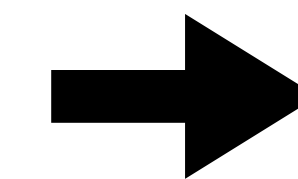
- Linear systems, model-free and model-based control



- Linear systems, model-free and model-based control
 - PID controllers, theory, LQG control, Kalman Filters



$$\begin{aligned}\dot{x} &= \cos(\theta)v \\ \dot{y} &= \sin(\theta)v \\ \dot{\theta} &= \omega\end{aligned}$$



$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & 0 \\ \sin(\theta) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix}$$

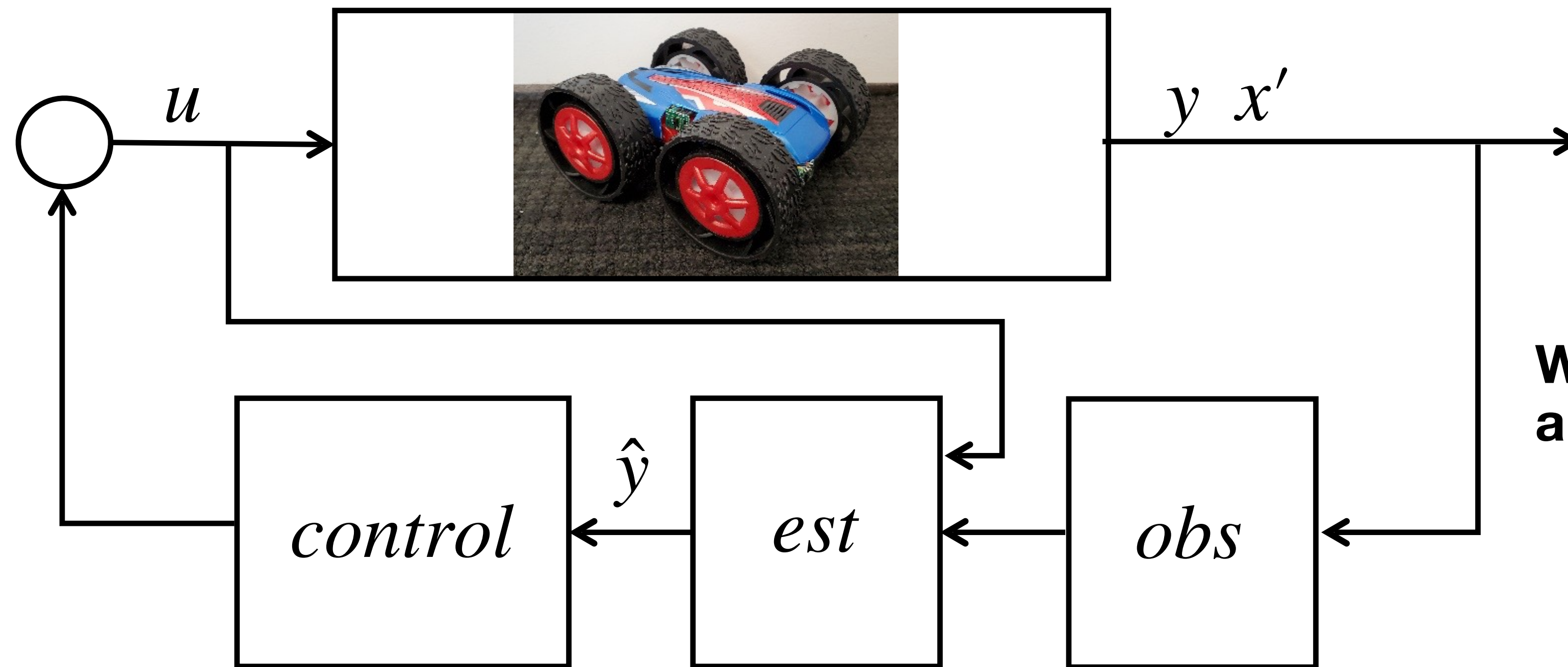


Lab 1-4: HW / Embedded SW

Lab 5-8: Feedback Control

Lab 9-12: Localization
and Planning

- Linear systems, model-free and model-based control
 - PID controllers, LQG control, Kalman Filtering



Why do we need feedback control and observers?

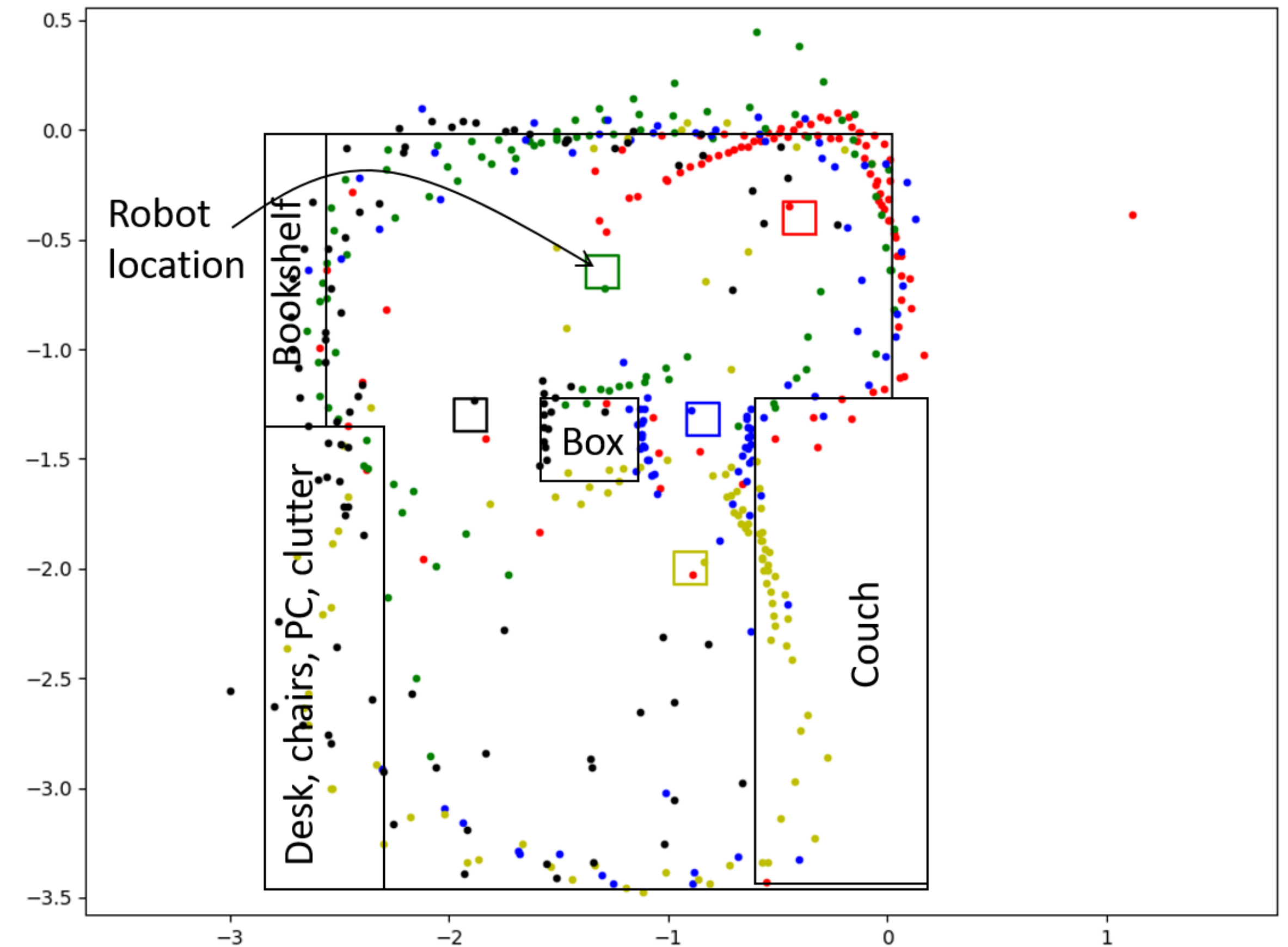
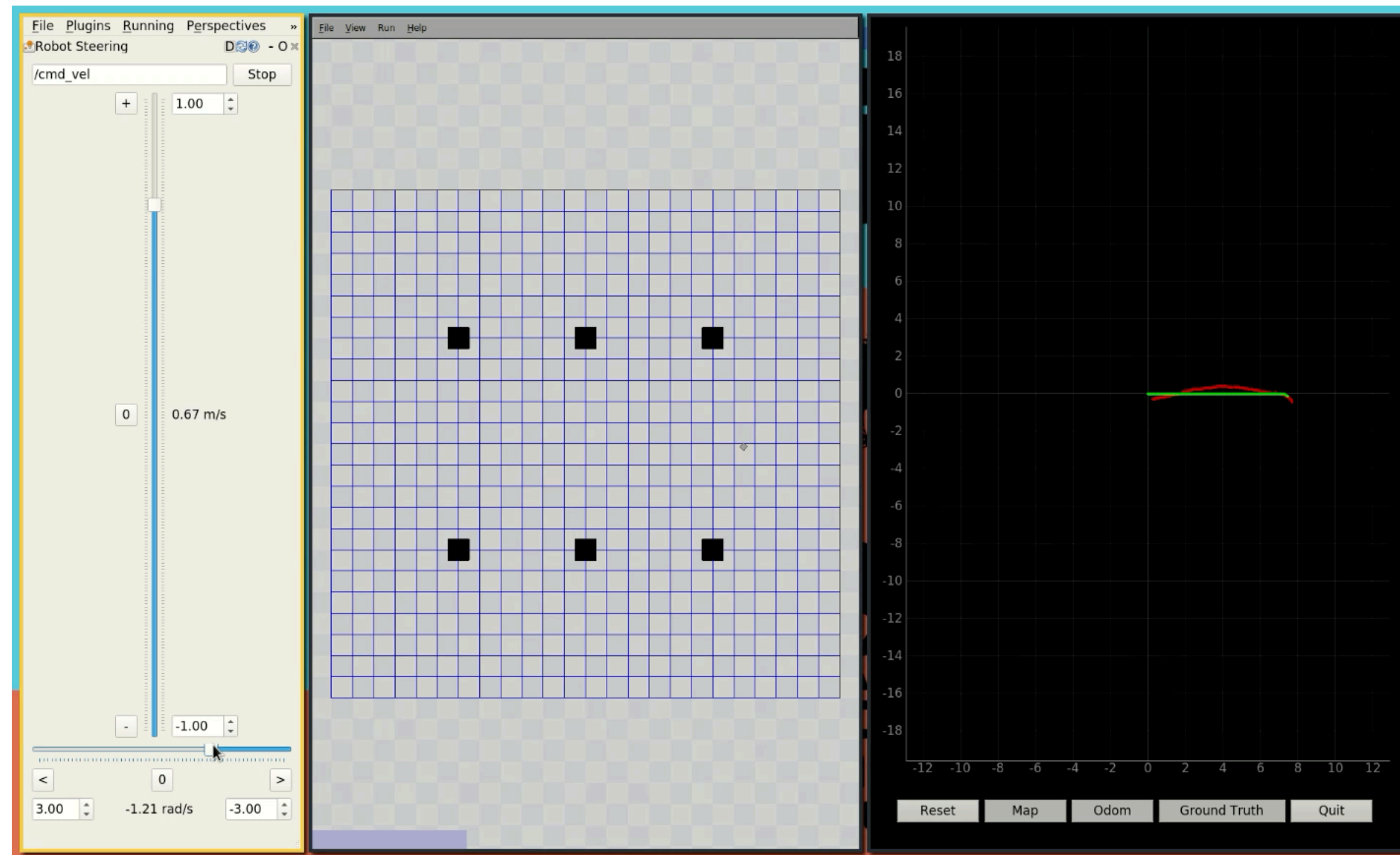
- Performance depends on the battery
- Sensing is slow (relatively)

Lab 1-4: HW / Embedded SW

Lab 5-8: Feedback Control

Lab 9-12: Localization and Planning

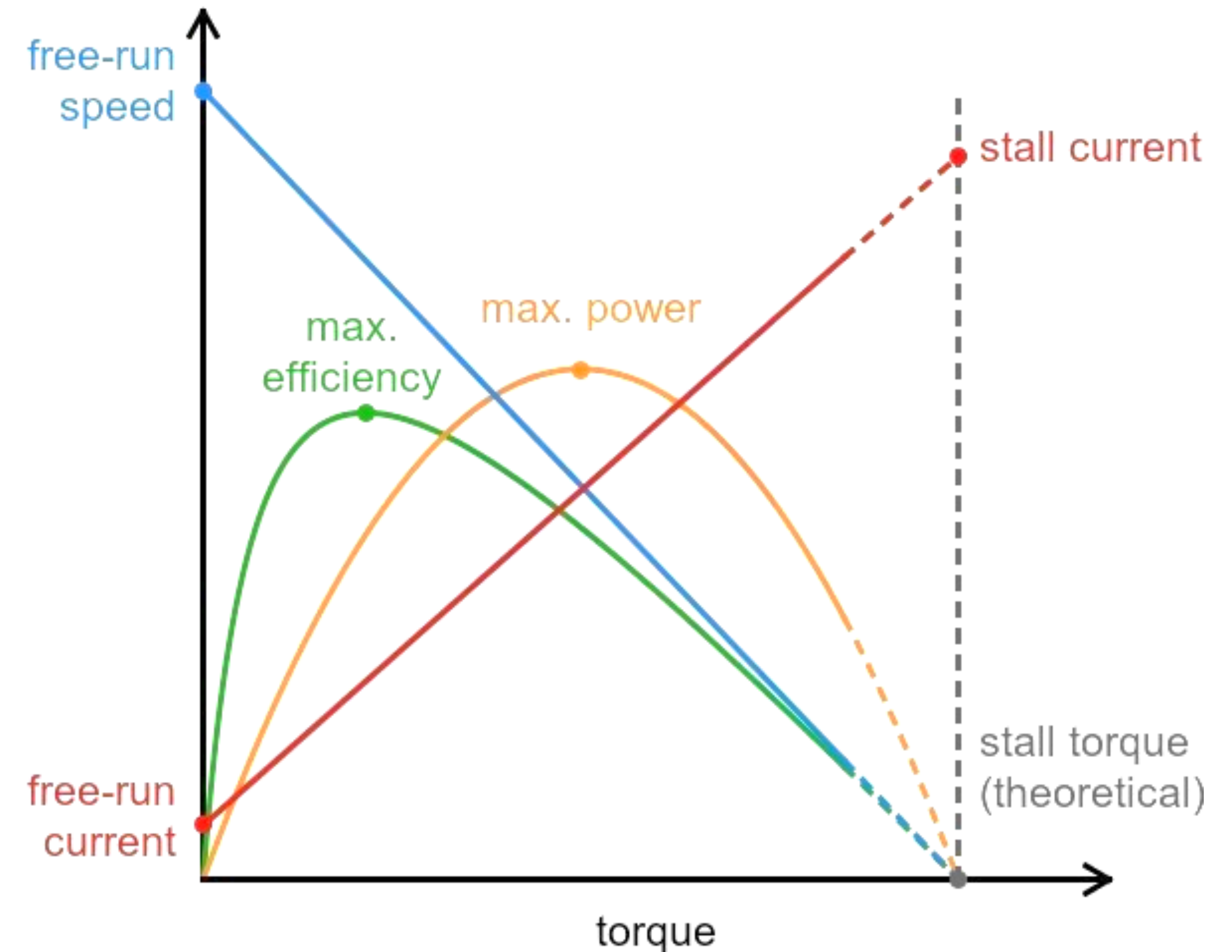
- Map representations
- Search and planning



- Map representations
- Search and planning
- Noise, discrete probability
- Motion and sensor models

What are sources of error?

- Sensor noise, resolution
- Momentum and slippage
- Weak motors



Lab 1-4: HW / Embedded SW

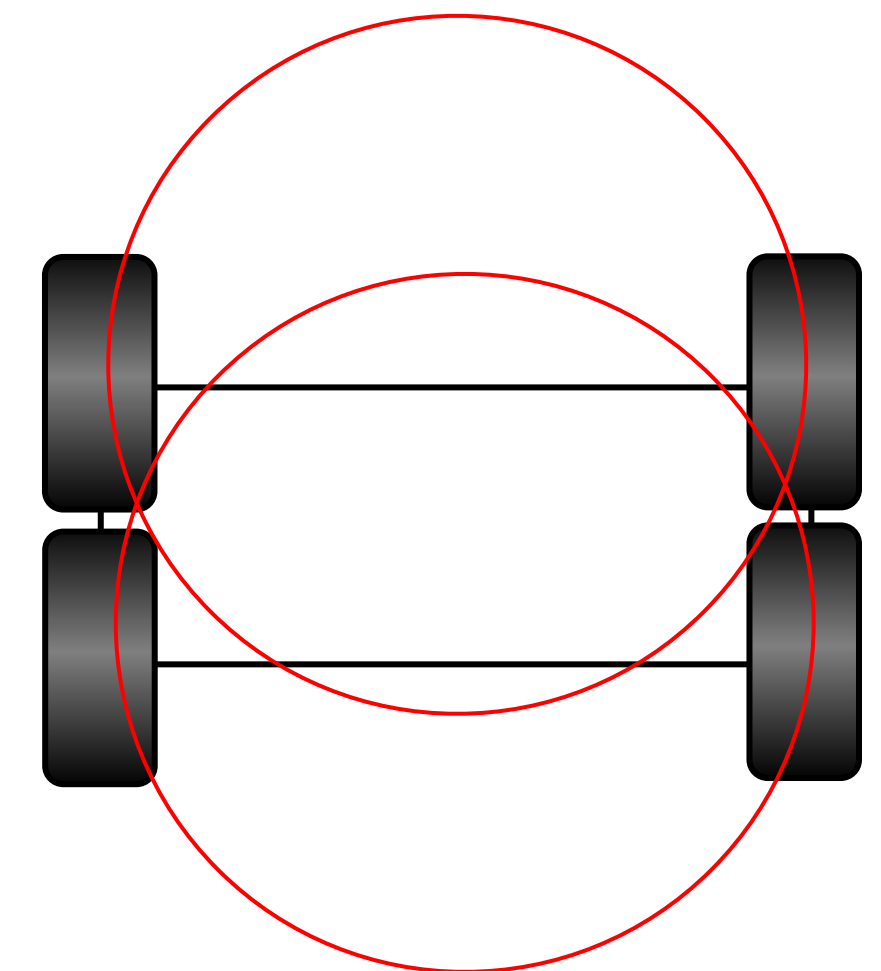
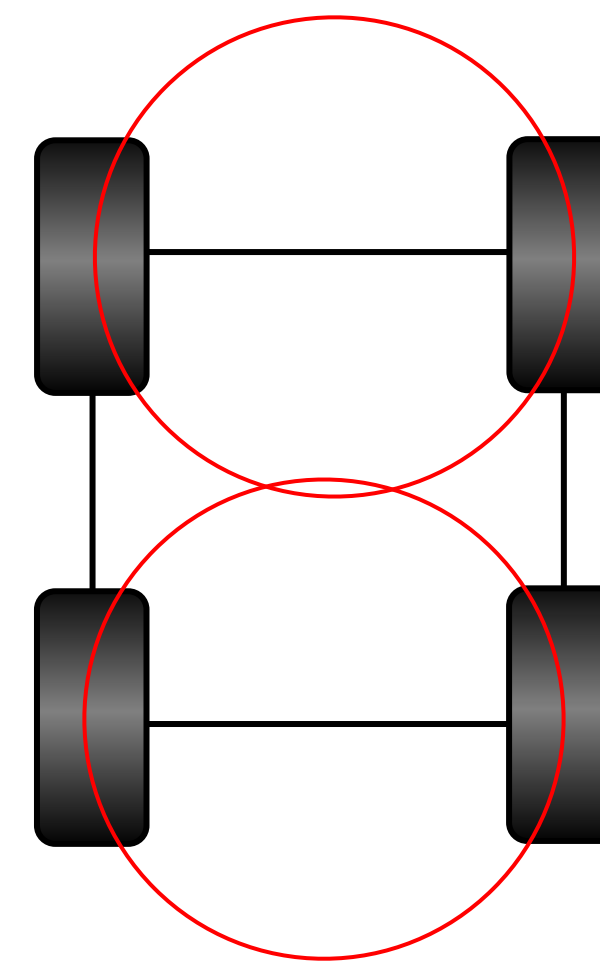
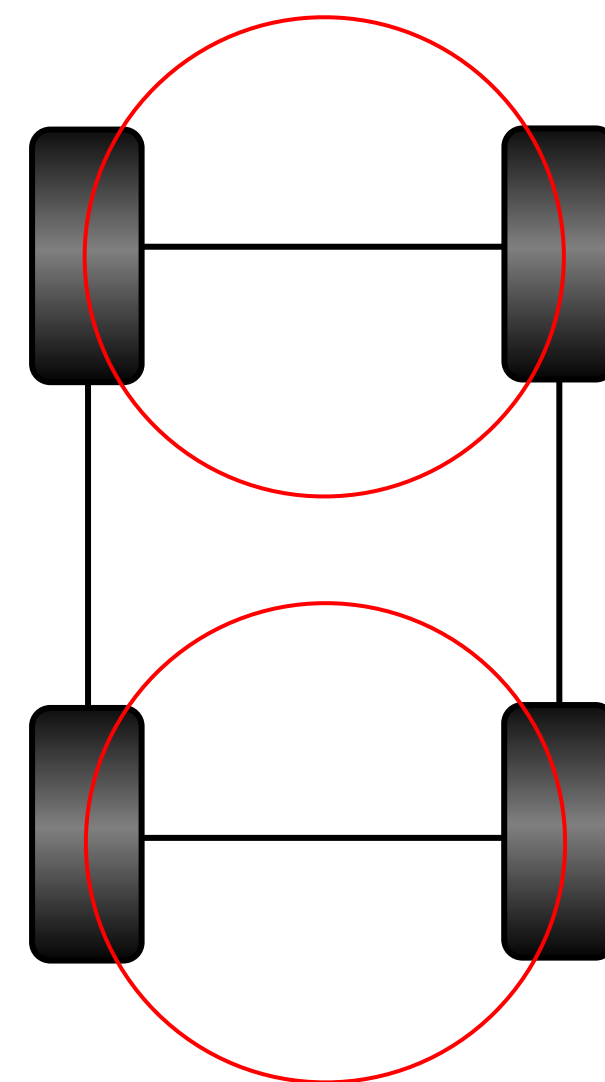
Lab 5-8: Feedback Control

Lab 9-12: Localization and Planning

- Map representations
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What are sources of error?

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- Skid steering



Lab 1-4: HW / Embedded SW

Lab 5-8: Feedback Control

Lab 9-12: Localization and Planning

- Map representations
- Search and planning
- Noise, discrete probability
- Motion and sensor models

What are sources of error?

- Sensor noise, resolution
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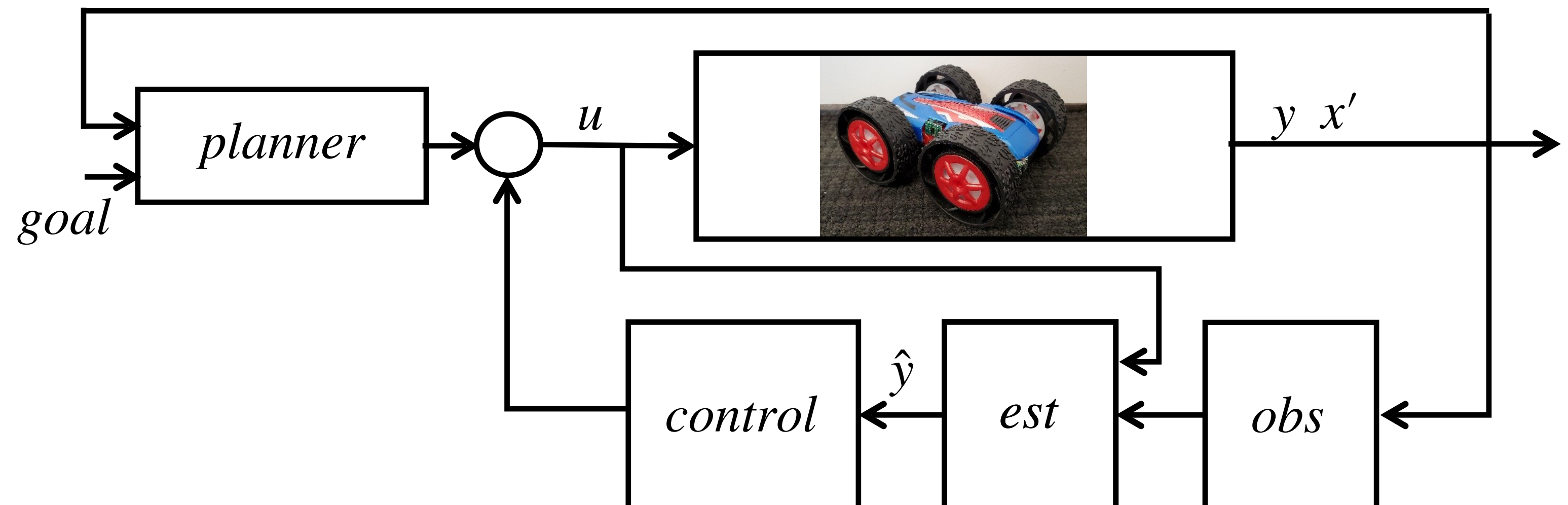
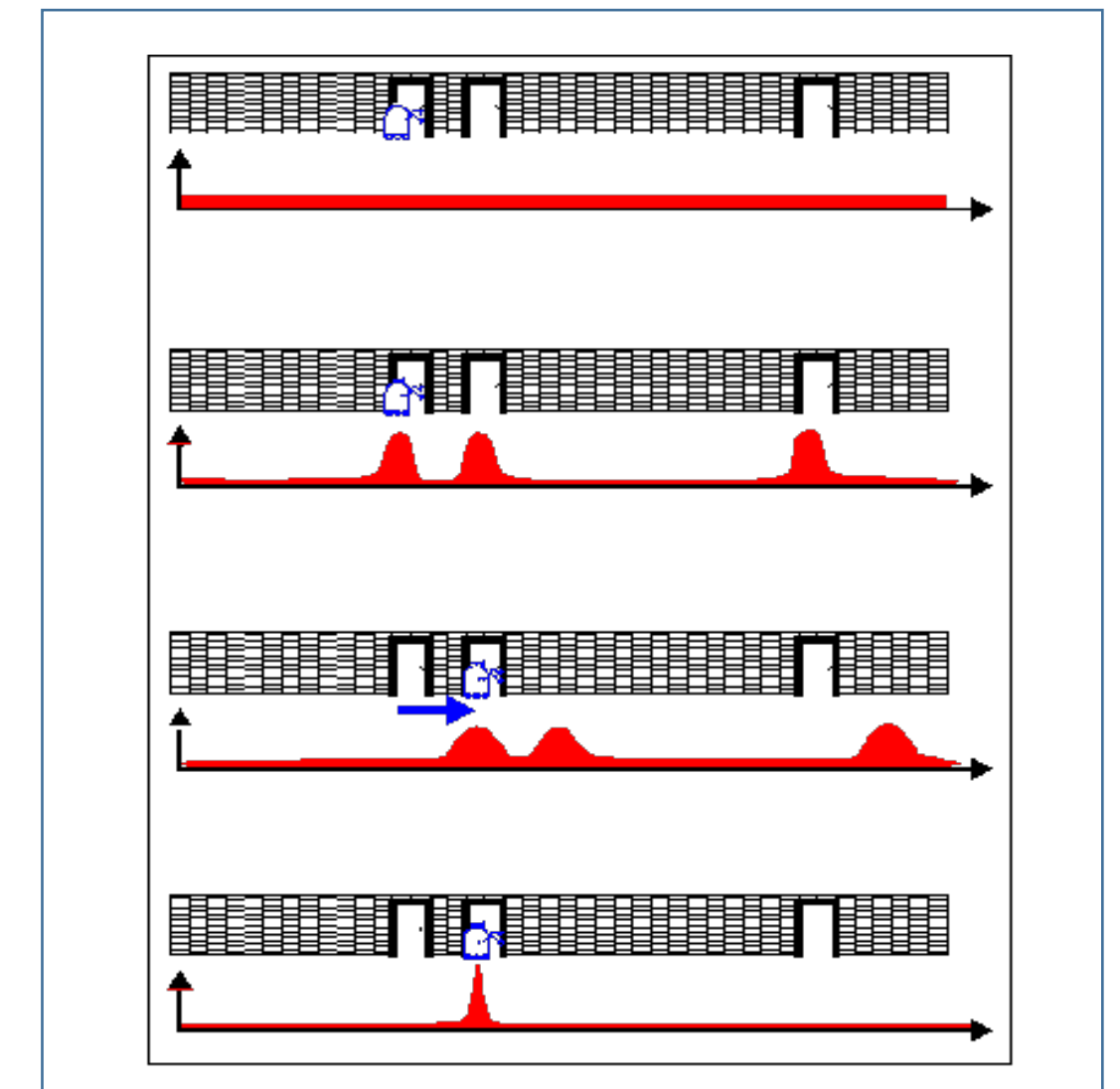


Lab 1-4: HW / Embedded SW

Lab 5-8: Feedback Control

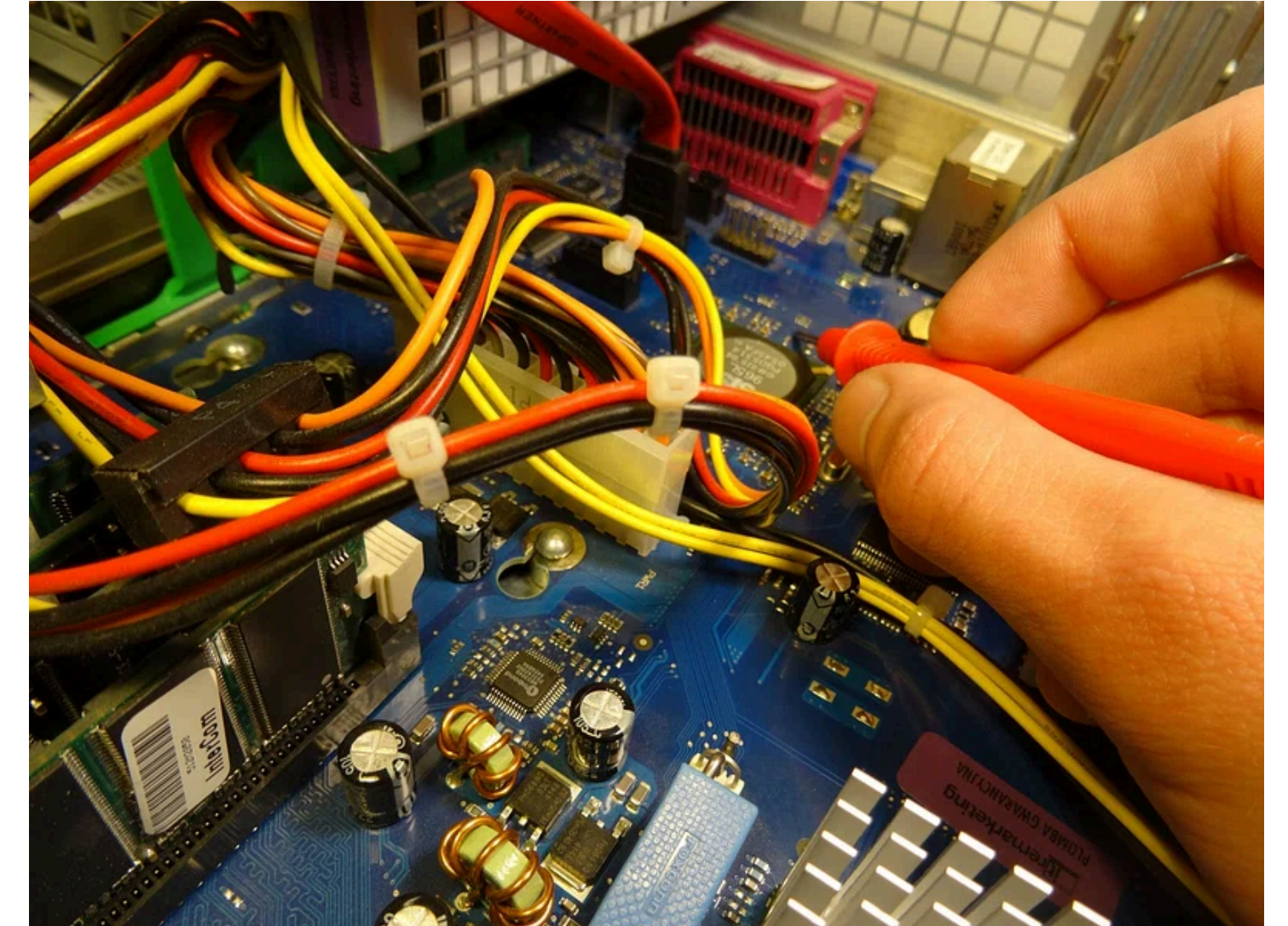
Lab 9-12: Localization and Planning

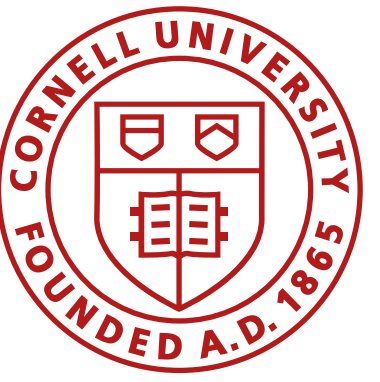
- Map representations
- Search and planning
- Noise, discrete probability
- Motion and sensor models
- Bayes theorem/ filters
- Localization, planning



Disclaimer

- We work with real hardware.
 - Everyone must build and operate a robot
 - We **break** things!
- Take this course if you want a highly interactive teaching team, fun and advanced challenges, experience with real robots, and an opportunity to build up an online portfolio
- **Do not take this class** if you prefer a deep dive into fundamentals, simulation-heavy work, or if you have a very busy schedule





Logistics

Logistics

Online resources

- Github page (<https://fastrobotscornell.github.io/FastRobots-2026/>)
 - Schedule, lecture slides, lab documents, tutorials, code examples, etc.
- Canvas
 - Deadlines, grades
- EdDiscussion
 - Post general questions to benefit all of your classmates, private messages to communicate with the course staff about extensions

FastRobots-2025

ECE4160/5160-MAE 4190/5190: Fast Robots course, offered at Cornell University in Spring 2025

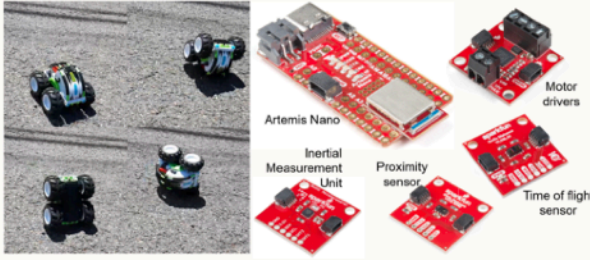
View On GitHub

This project is maintained by [FastRobotsCornell](#)

ECE 4160/5160, MAE 4190/5190: Fast Robots

Cornell University, Spring 2025

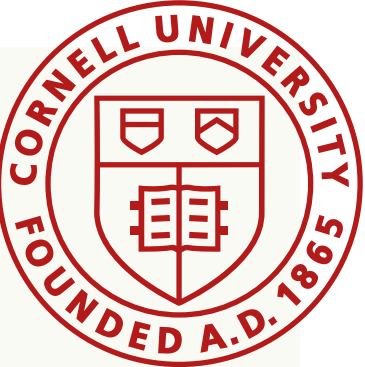
This course focuses on systems level design and implementation of dynamic autonomous robots. We will design a fast autonomous car and explore dynamic behaviors, acting forces, sensors, and reactive control on an embedded processor, as well as the benefit of partial off-board computation, low-latency software, and noise-tolerant implementation.



Instead of traditional hand-ins, we leverage peer-to-peer mentoring where students, under guidance, upload their progress and ideas to create a sustainable and continuously evolving database for future students to rely on.

Hosted on [GitHub Pages](#) using the [Dinky](#) theme

Info



ECE4160/ECE5160/MAE4190/MAE5190 > Modules

63 View as Student

Spring 2025

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Rubrics

People

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Expand All View Progress Publish All + Module

Resources

Quick recap: Linear Algebra and Transformation Matrices

Robot Hardware -- Sensing, Actuation, Connections

Control and Estimation

Course Status

Published

Import Existing Content

Import from Commons

Choose Home Page

View Course Stream

New Announcement

New Analytics

View Course Notifications

Coming Up

View Calendar

Nothing for the next week

ed Fast Robots – Ed Discussion

New Thread

Search

Staff

COURSES

CS 0000 286

ECE 0000 781

ENGRD 2300

Fast Robots

ME-UG-Program 967

CATEGORIES

General

Lectures

Labs

Welcome! #1

Farrell Helbling 8 hours ago in General

UNPIN STAR WATCHING 54 VIEWS

Hi everyone!

3 Welcome to Fast Robots! We will be using Ed Discussion throughout the semester for general course announcements, to answer questions about the lab assignments or lecture materials, and to get in touch privately with the course staff.

Looking forward to seeing everyone tomorrow in lecture, and our first lab!

Farrell

Comment Edit Delete

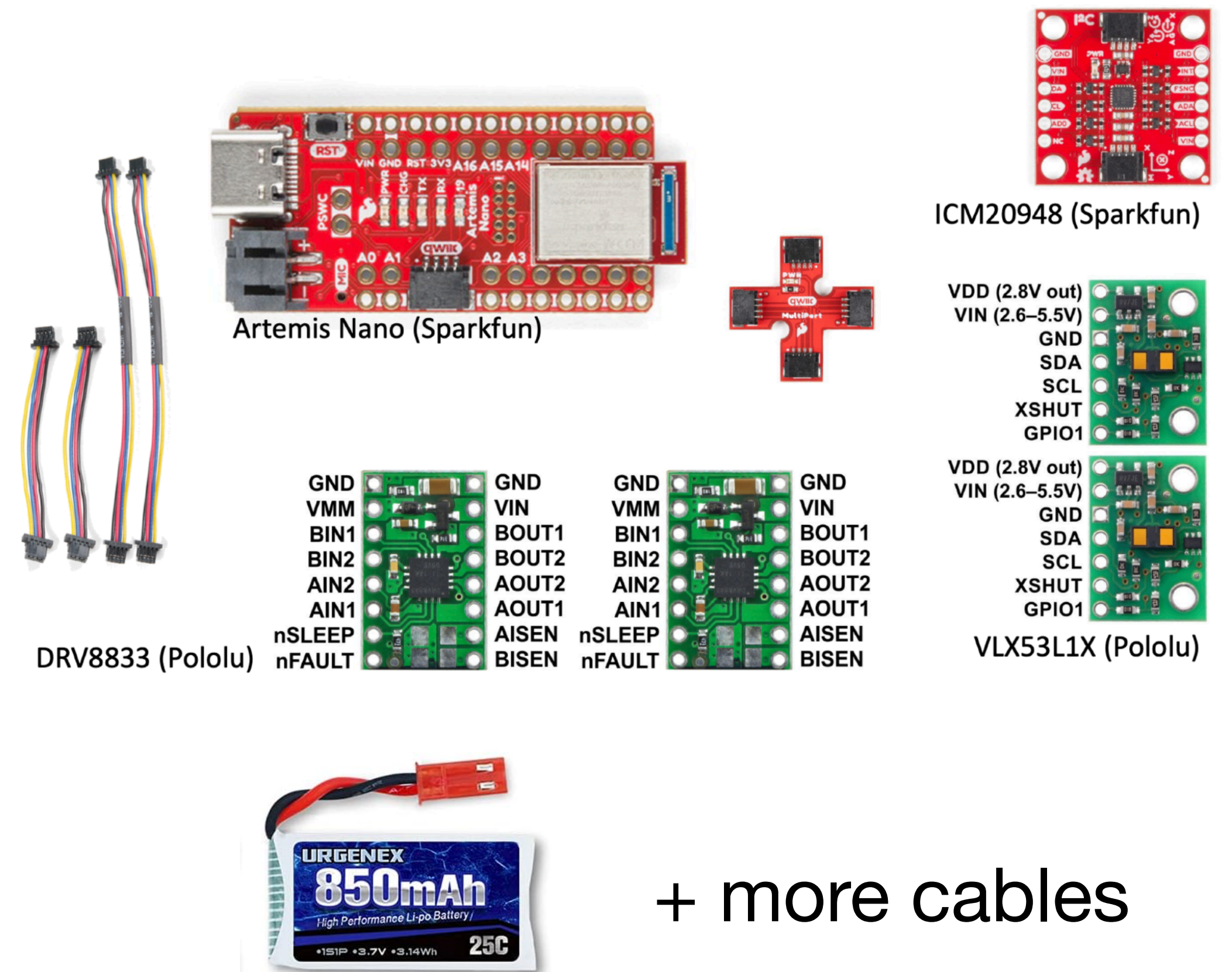
Add comment

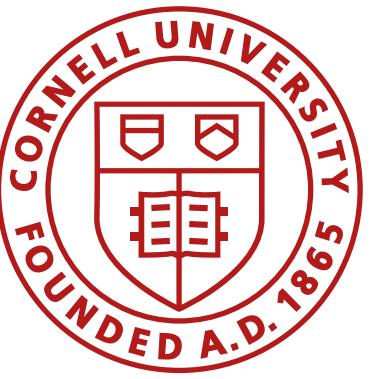
27 others online

Logistics

Lab Kit

- Things will break, we have a small set of extra components, but please be careful. If you have never handled hardware before or are worried about breaking something, please ask the teaching staff for assistance.
- We will hand out all of the electronic components this week, and the RC cars we will hand out for Lab 2
- If you drop the class, we want these items back!

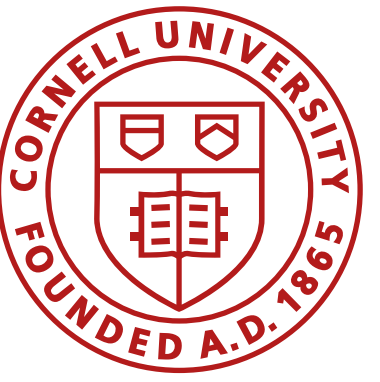




Logistics

Lab Software

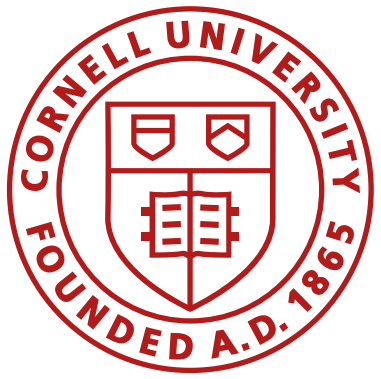
- Guaranteed support on the 12 lab computers in Tang 291 (Windows 11)
- The teaching team has tested these labs on their personal machines (Mac Intel/M1/M1Pro and Windows 11) with minimal issues
- Minimum requirements:
 - Windows 10, MacOS 12, and Linux (bluez>4.58, kernel=4.15)
 - Processor: Core i3-8100 3.6GHz/AMD Risen 5 1400 or equivalent
 - Memory: 4GB RAM, Free Space: 8GB (Windows)/ 1GB (else)
- We are aware of an issue with the lab codebase and Python 3.14 and Bleak. **Please do not update to Python 3.14**, it's a huge pain to modify all of the functions.



Logistics

Labs

- Official lab times: T 2-4:30pm, W 8:30-11am, W 2-4:30pm. **Lab attendance is mandatory.** I will attend every lab as my official “office hours.” I will get to know each of you, please feel comfortable emailing me if you need to meet privately.
- Open lab times: TBD, will update the google calendar to the website later this week
- Time Commitment: 10 hrs/week
 - Spread this out over multiple days (batteries last 10-15mins).
 - These labs build on top of each other, start early and use each other/ the teaching staff/ past examples as resources.
 - If you run low on time, you have two one-week extensions to apply to any two labs throughout the semester (except lab 12).
 - You **must** let the teaching team know before the lab deadline through a private message on Ed.

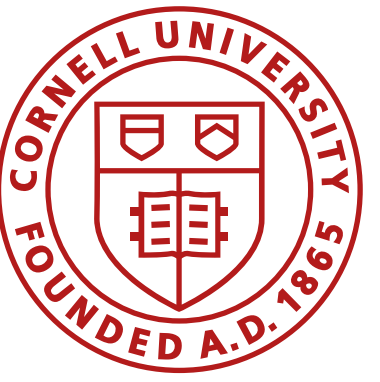


Logistics

Grading

- All assignments and the respective deadlines are already outlined on Canvas.
- Lab write-ups are due one week after the lab session at 8am. Lab section 401 write-ups are due Tuesday at 8am, 402 and 403 due Wednesday at 8am.
- Specific grading policies can be found on the course website: <https://fastrobotscornell.github.io/FastRobots-2026/Grading.html>
 - 67% of the grade goes to technical solution, 33% goes to the write-up.
 - Many labs are graded on a curve, students that have more significant results score higher, even if all tasks are completed

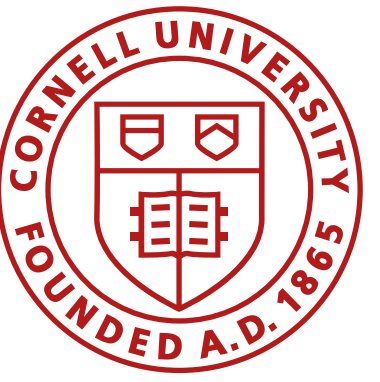
Task	pts
Lab 1 Artemis + Bluetooth	5
Lab 2 ToF Sensors	7.5
Lab 3 IMU Sensors	7.5
Lab 4 Motor driver, Open Loop Control	7.5
Lab 5 PID Linear Control	7.5
Lab 6 PID Orientation Control	7.5
Lab 7 KF	7.5
Lab 8 Stunts	10
Lab 9 Mapping	7.5
Lab 10 Localization (sim)	U/S
Lab 11 Localization (real)	10
Lab 12 Planning and Execution	12.5
Participation	10
Bonus points for midterm and final course evals	2
Total:	102



Logistics

Collaborations

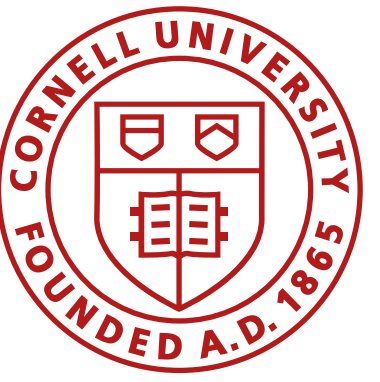
- You are welcome to check the write-ups from last year (links to the previous years student pages are clearly visible on our front page).
- You are welcome to work together, teams of 2-3 usually function best in this class. **Everyone is still responsible to implement the electronics/ software/mechanics and complete the write-ups on their own!**
 - Work/strategize
 - Complete prefabs
 - Debug
 - Compare results
 - Borrow teammates robot if yours fails (implement your own code).
- Include a collaboration/ resources statement in your write up. State who you worked with, resources you used, and **how you used them**. If (when) you use genAI, tell us how you use the resource.



Teaching Team

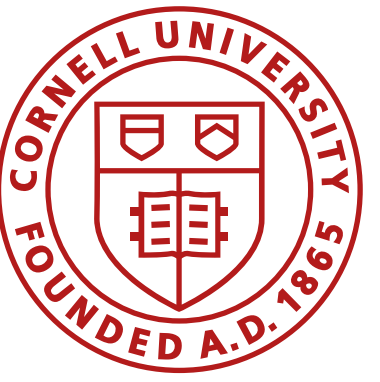
Course Staff

- **Julie Villamil**, ECE PhD student building autonomous insect-scale crawling robots
- **Jack Long**, MAE Senior UG, took Fast Robots last year!
- **Trevor Dales**, MAE Senior UG, took Fast Robots last year!
- Open Hours assistance:
 - **Selena Yao**: MAE Senior UG, took Fast Robots last year!
 - **Lucca Correia**: Systems MEng, took Fast Robots last year!
- **Cheney Zhang**, MAE MS student, TA'd Fast Robots last year!



Class Action Items

- Please if you have decided not to take the course, let me know ASAP. **Email farrell@cornell.edu.** We have 20+ people on the waitlist.
- **January 30th, midnight:** Make a GitHub repository and build your Github page
 - Include: name, photo, a small introduction, and the class number
 - Share **the page link** in the canvas assignment
- Labs start **TODAY**. You will pick up your electronics kit and start Lab1A. See some of you in Tang 291 later today! The rest I will see tomorrow!



See you later today (or tomorrow)