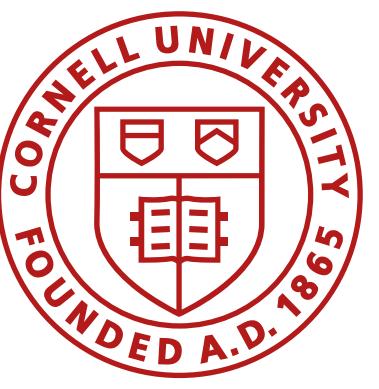


# Introduction

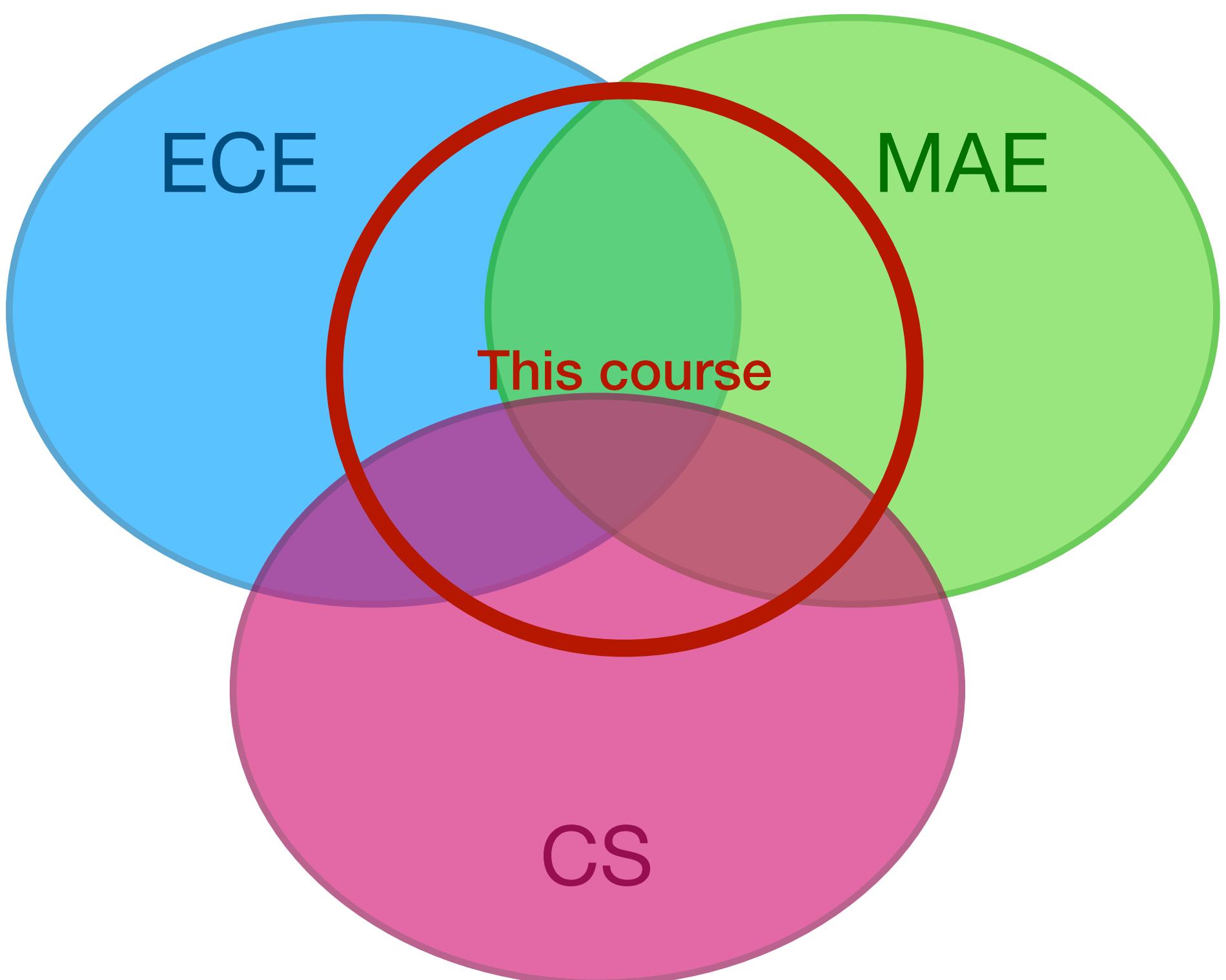
**Fast Robots, ECE4160/5160, MAE 4190/5190**

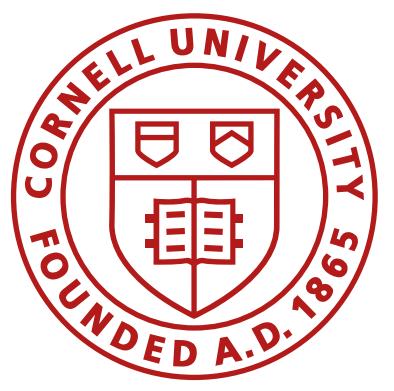
**E. Farrell Helbling, 1/21/25**



# 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



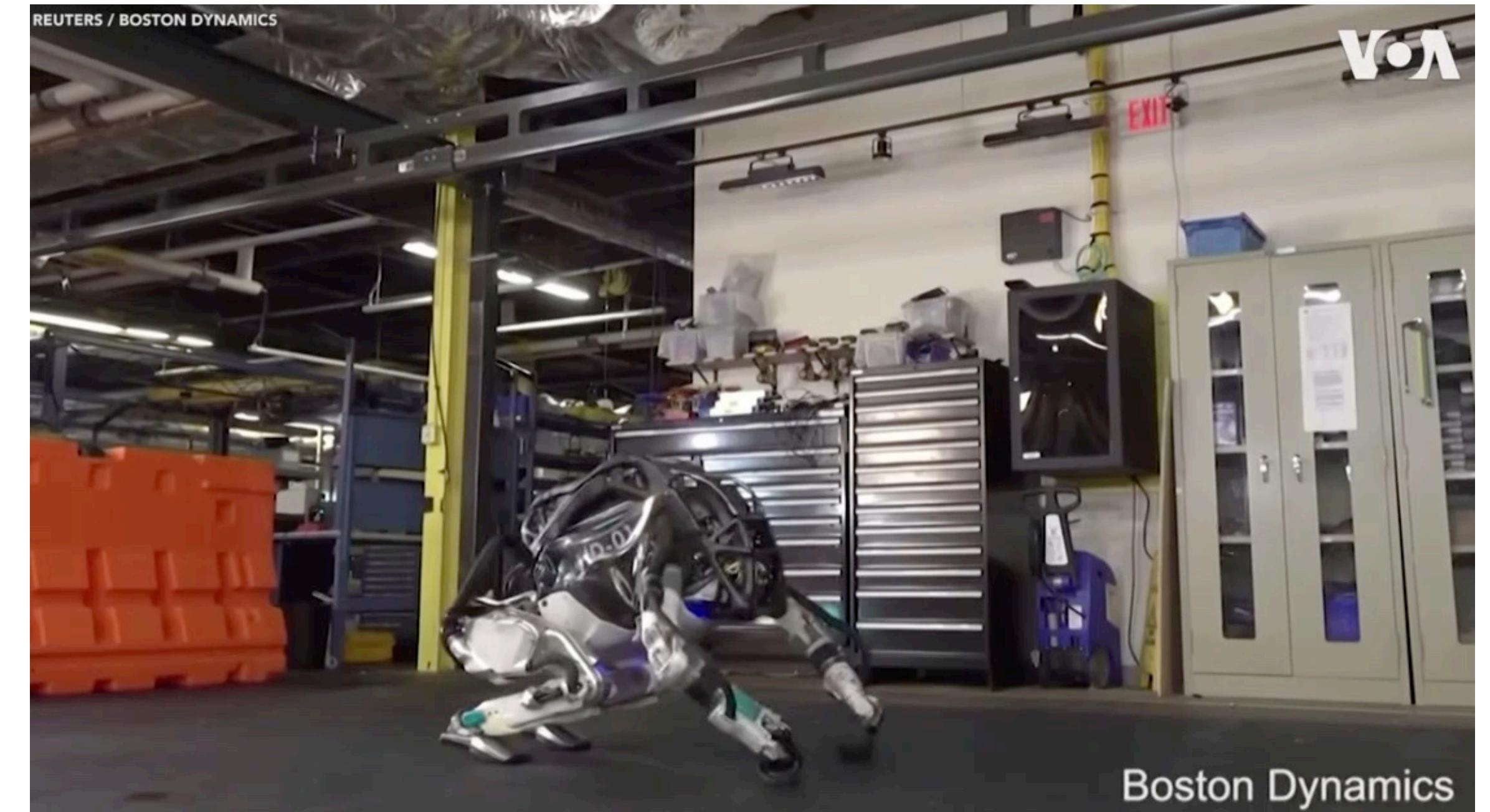


# Fast Robots are fundamentally different

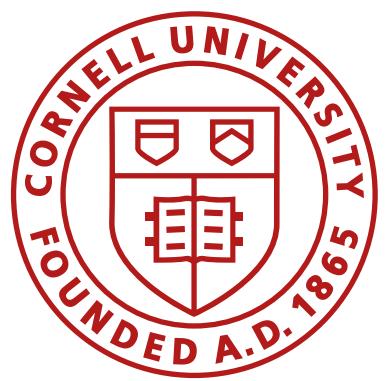
## Kinematics – Dynamics



Hajime Robot



Boston Dynamics

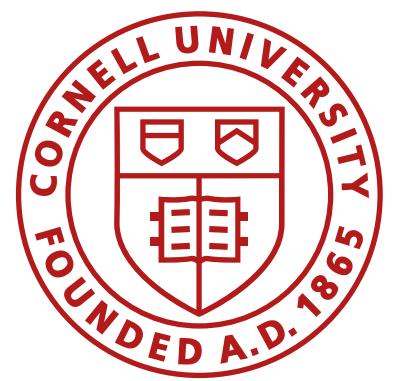


# Fast Robots are fundamentally different

## Stable – Unstable

The image shows a presentation slide with a black background. At the top, the title "Deep Drone Acrobatics" is displayed in large white font. Below the title, the authors are listed: "Elia Kaufmann\*, Antonio Loquercio\*, René Ranftl, Matthias Müller, Vladlen Koltun, Davide Scaramuzza". On the left side, there is a circular logo of the University of Zurich and the text "University of Zurich UZH". To the right of the text is the Intel logo. At the bottom of the slide, there is a navigation bar with icons for back, forward, and search, and the text "Pause (k)" and "0:01 / 2:31".





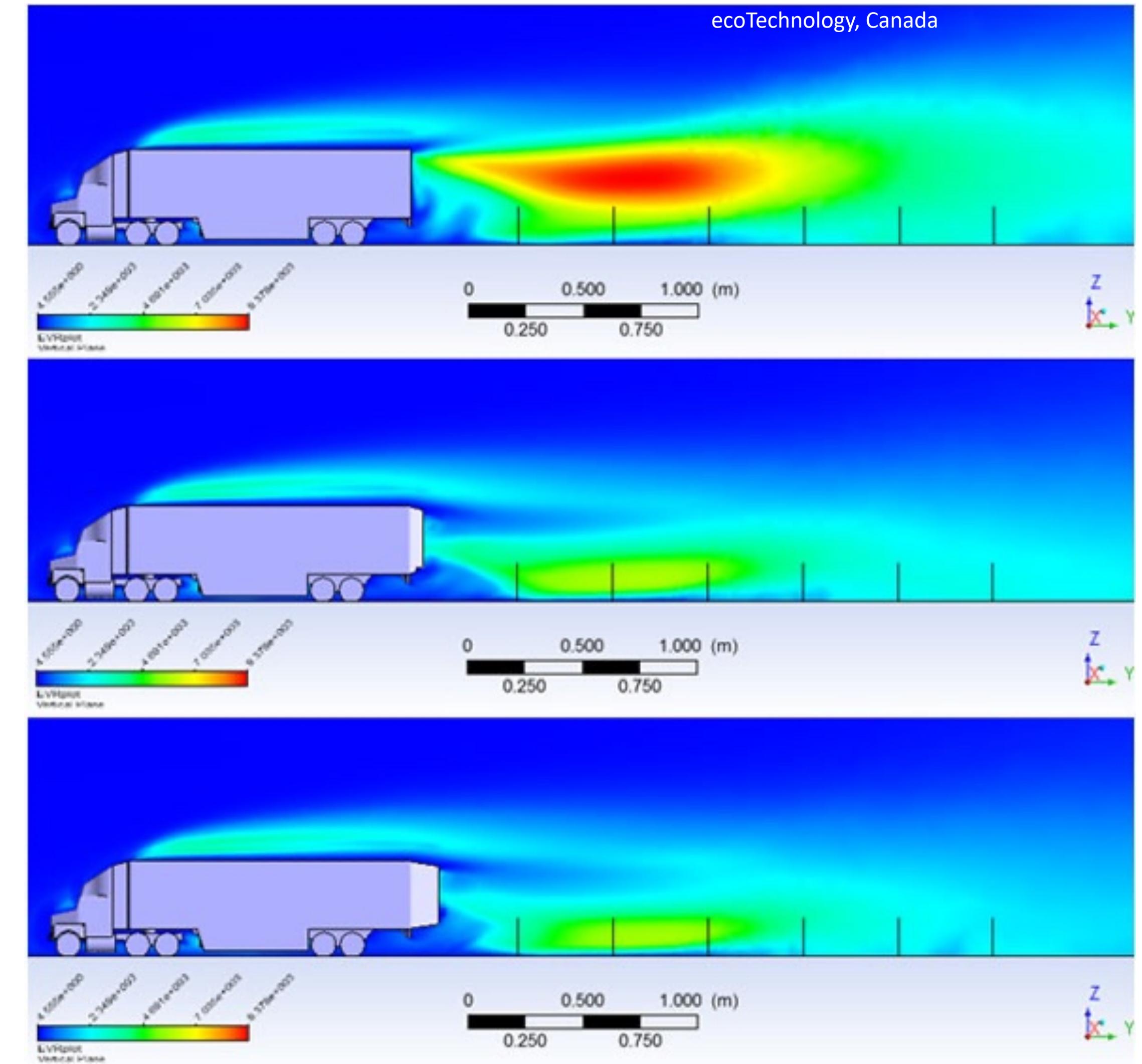
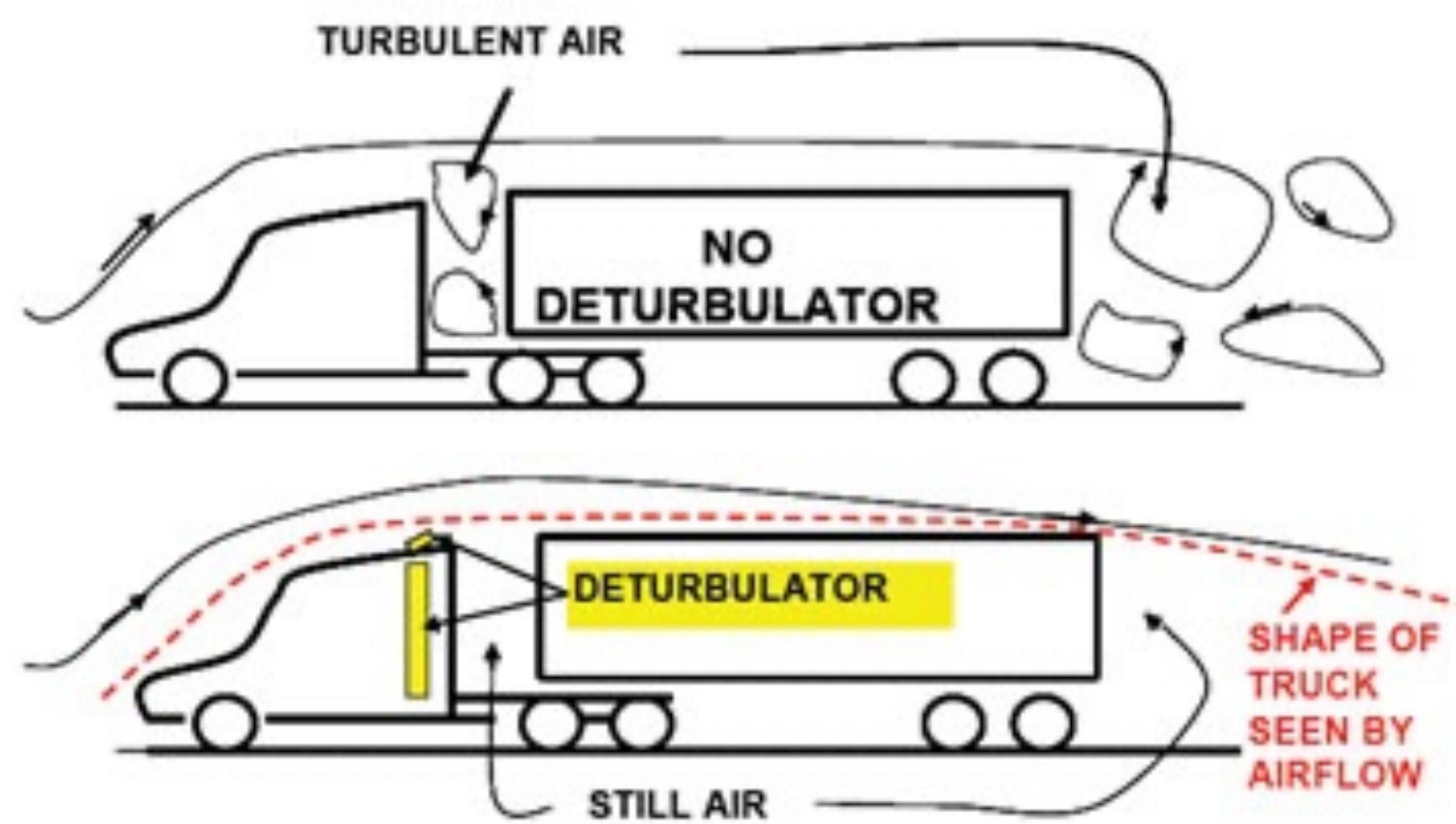
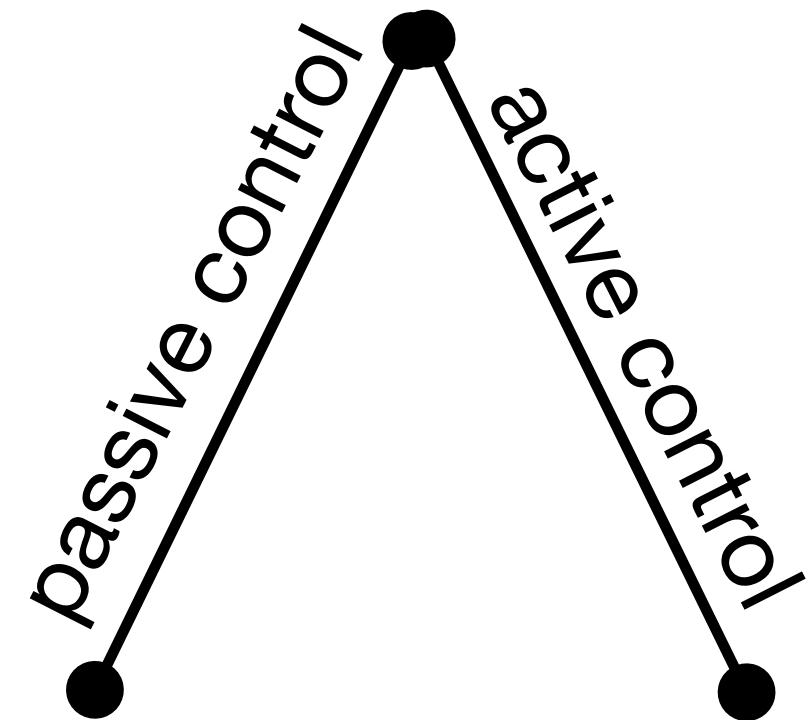
# Fast Robots are fundamentally different

## Design

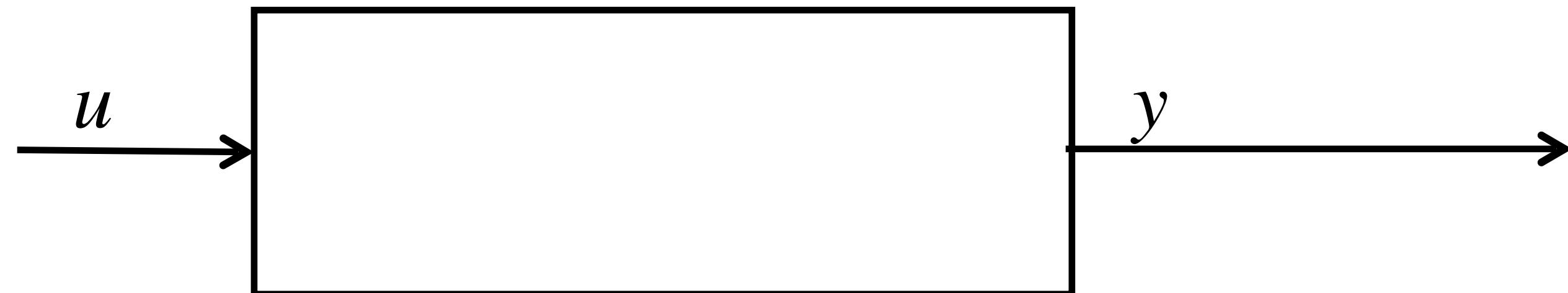
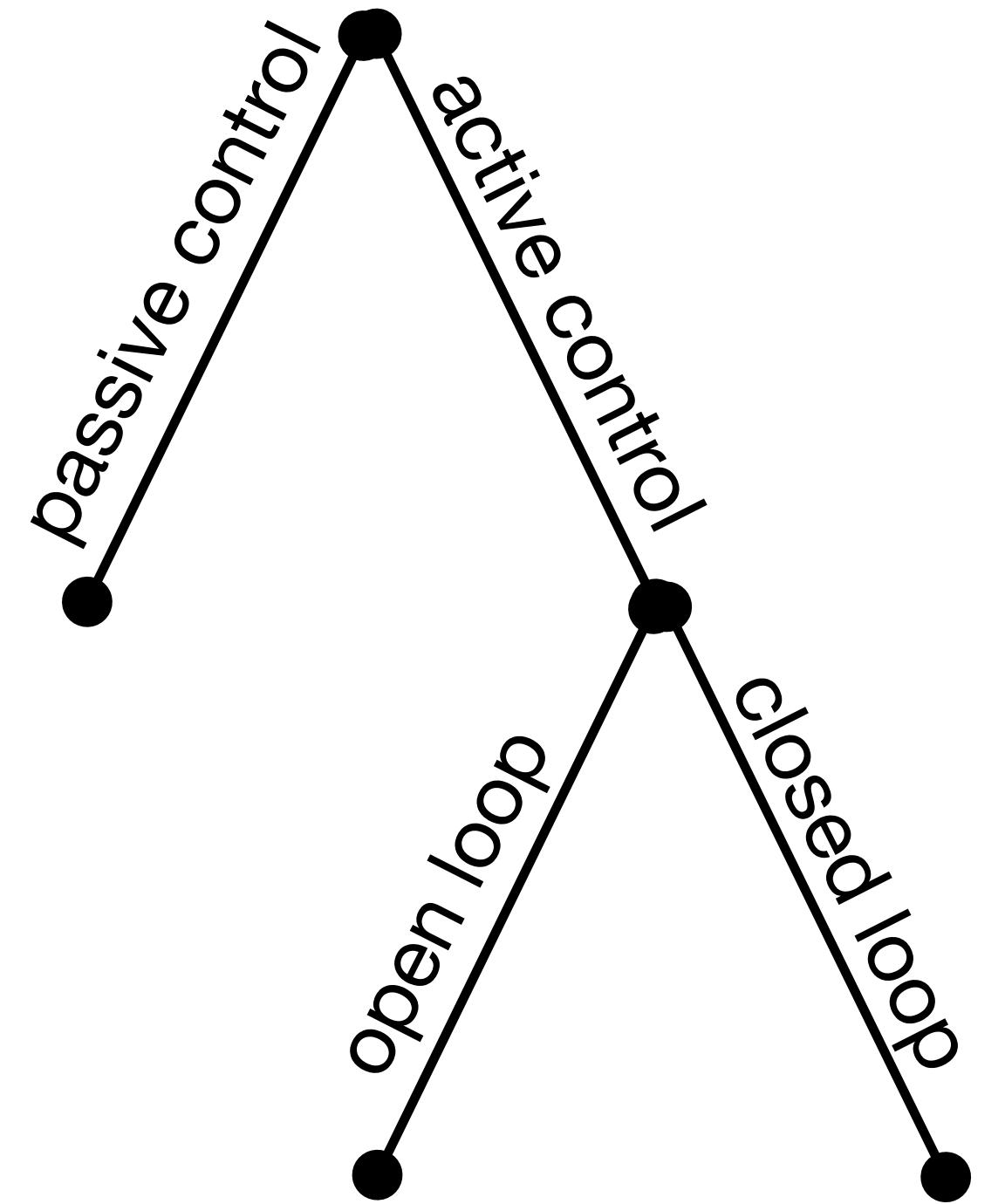
- Requires more than good control theory and dynamic models
  - Practical implementation: mechanics, sensors, processing, estimation, etc.



# Control

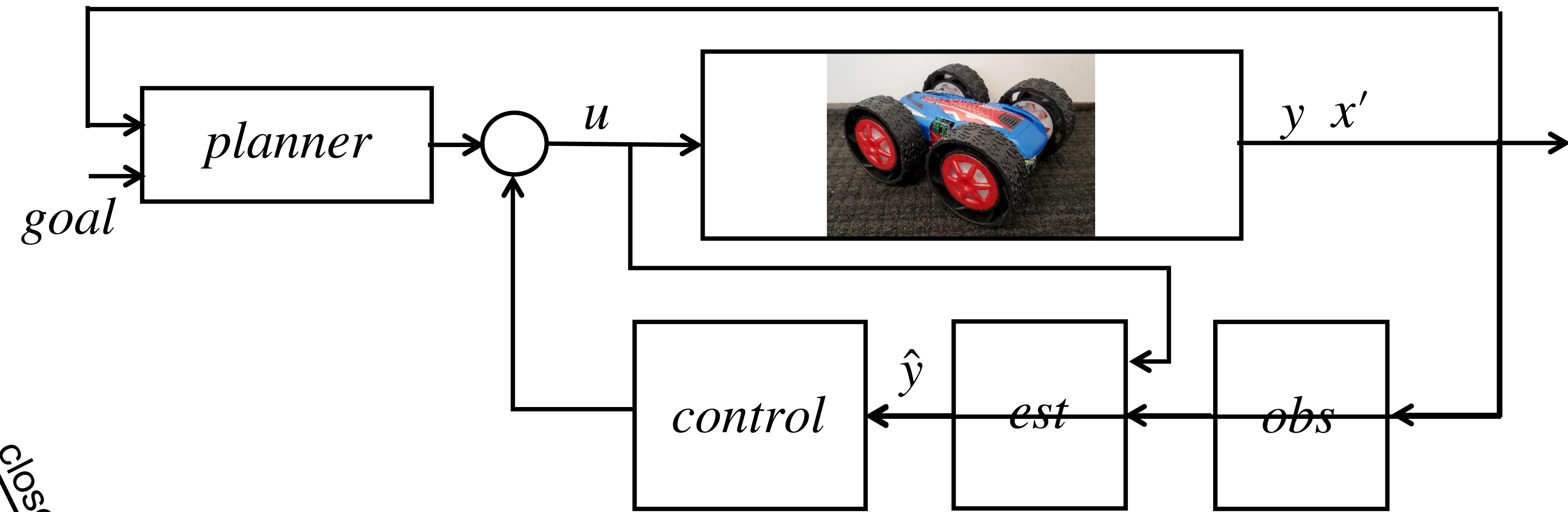
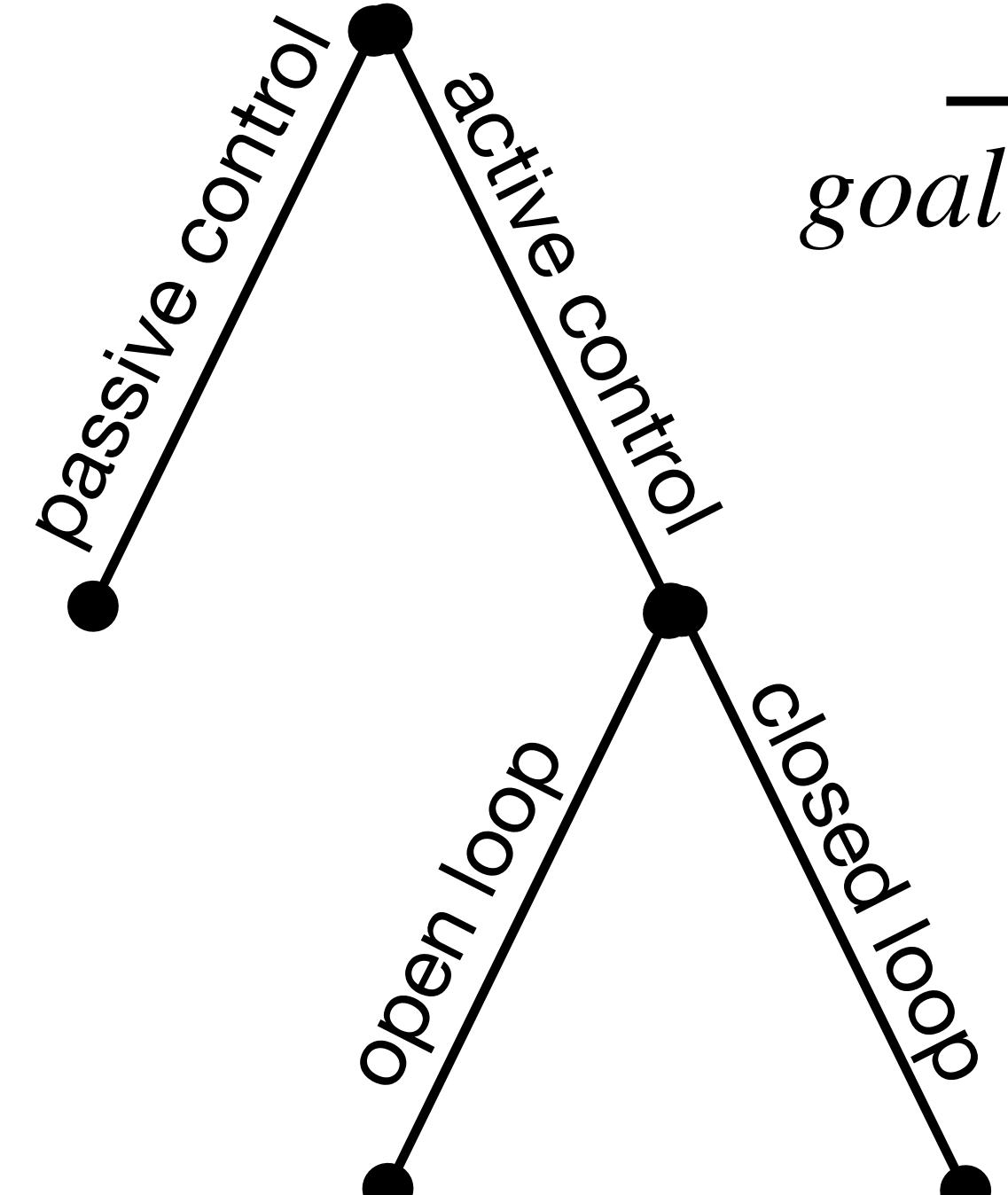


# Control



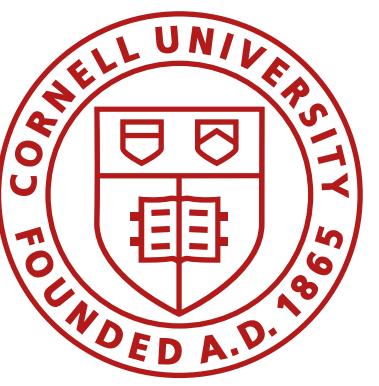
So why do we care about feedback?

# Control



- processor
- drivers
- limits
- sensors
- noise/bias

- Why do we need feedback control?**
- System uncertainty
  - Instability
  - Disturbances
  - Efficiency



# Class Layout

Lab 1-4: HW / Embedded SW

Lab 6-9: Feedback Control

Lab 10-12: Localization  
and Planning

## Lab 1-4: HW / Embedded SW

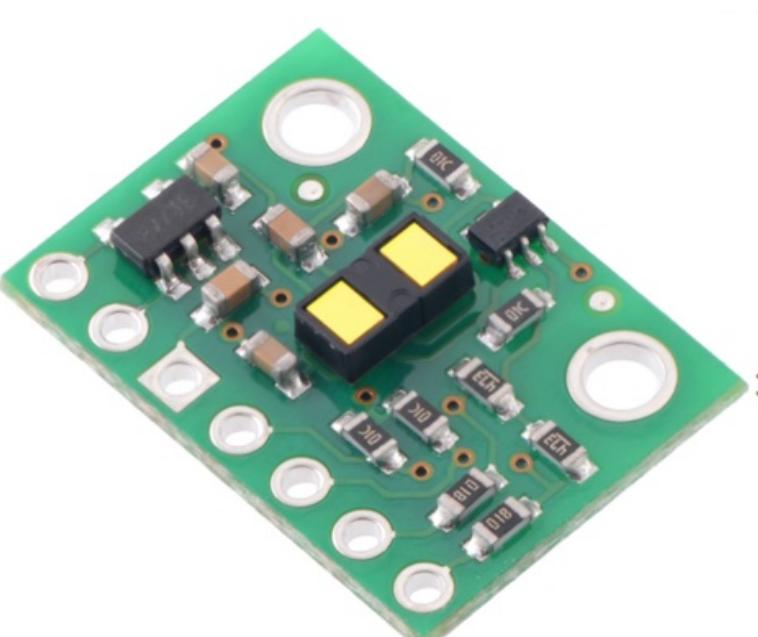
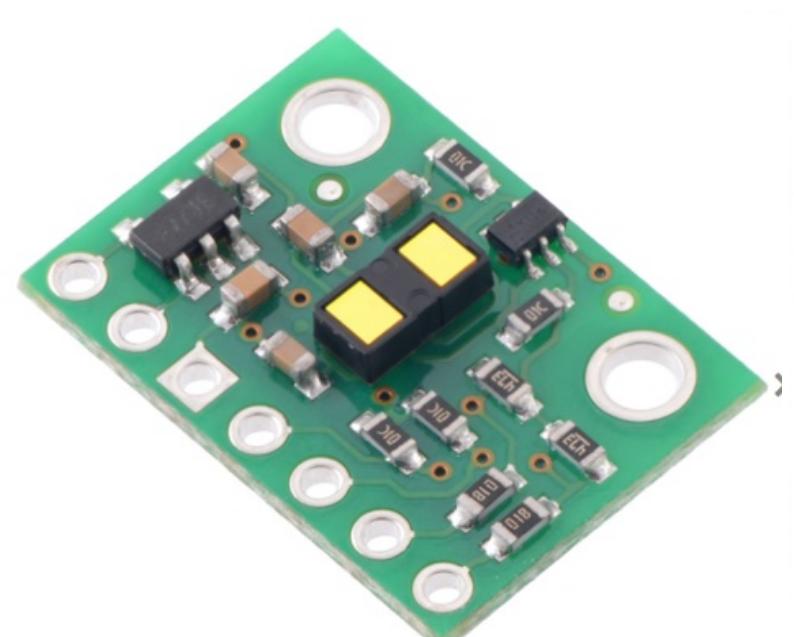
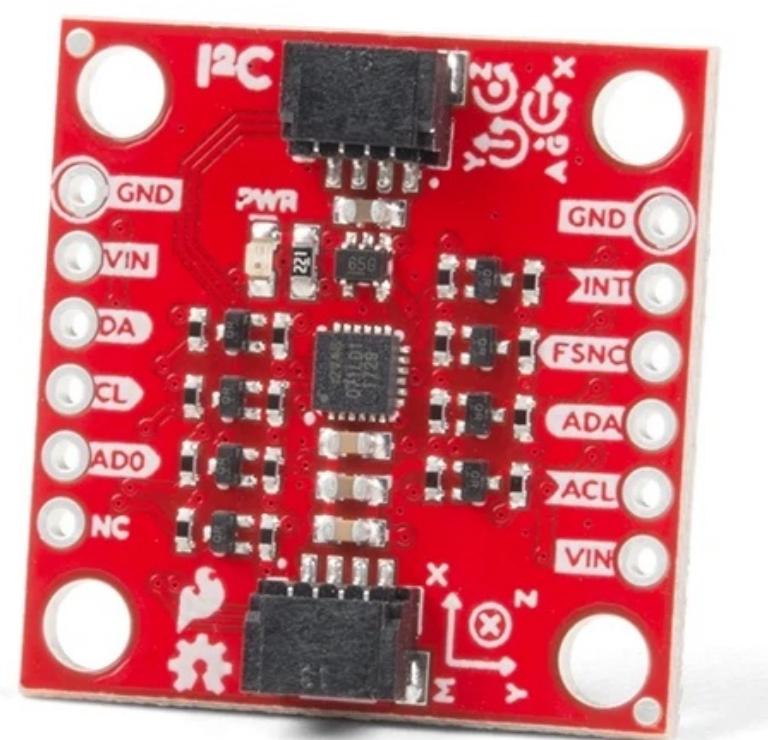
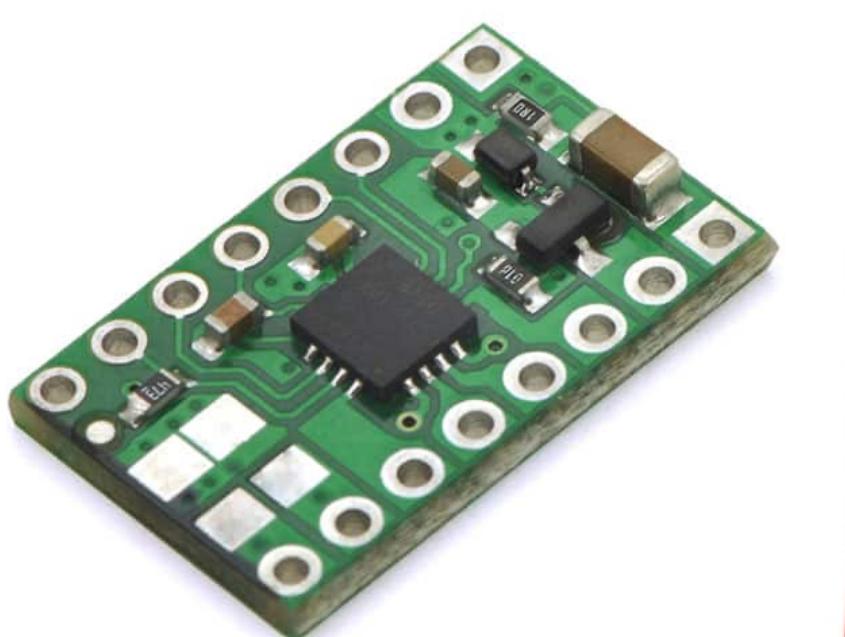
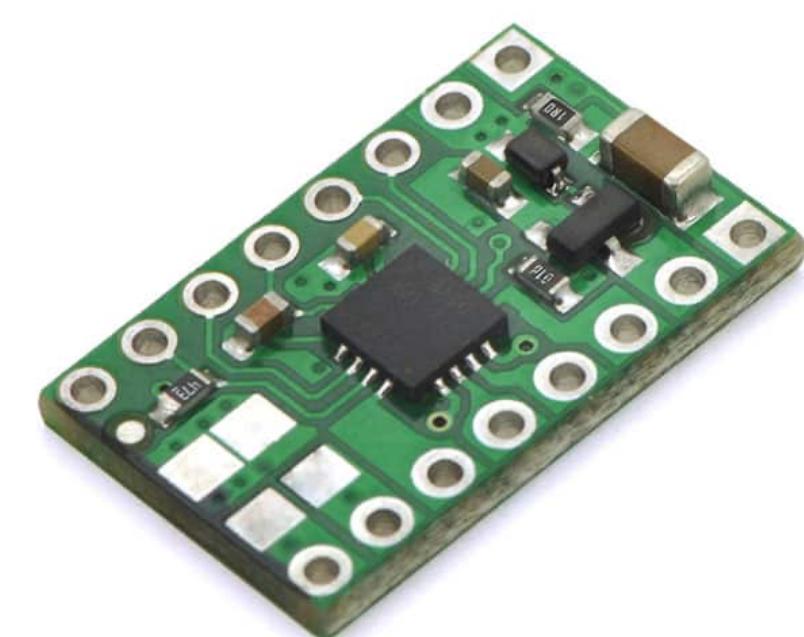
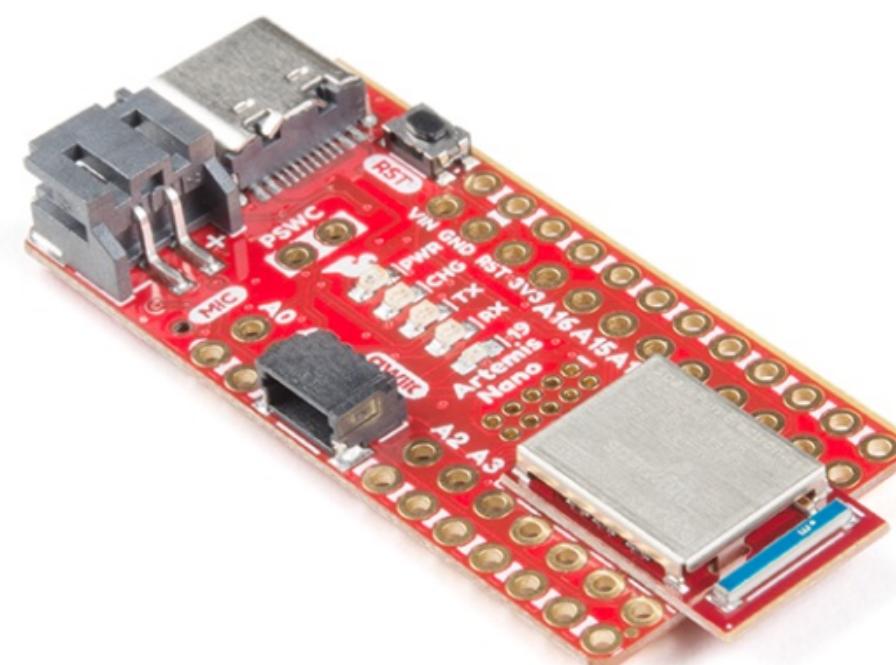
## Lab 6-9: Feedback Control

## Lab 10-12: 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!

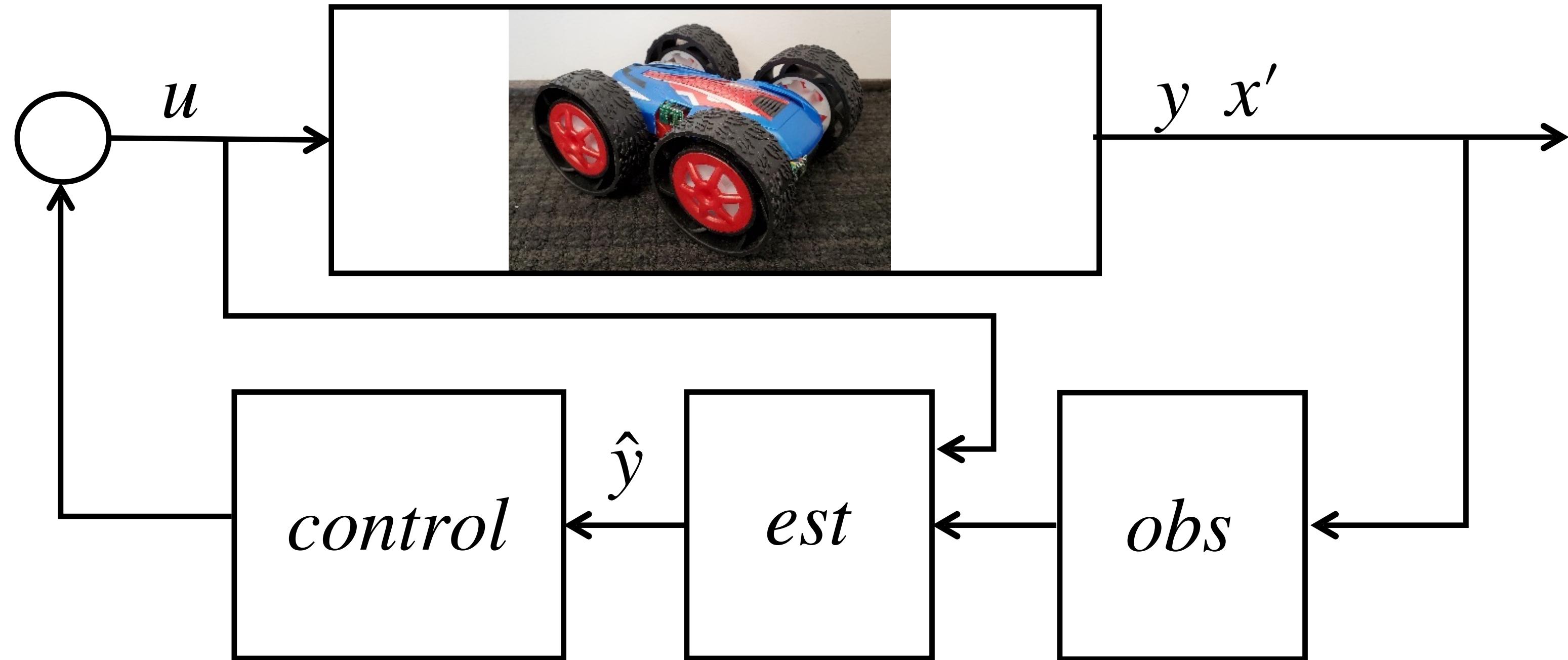


Lab 1-4: HW / Embedded SW

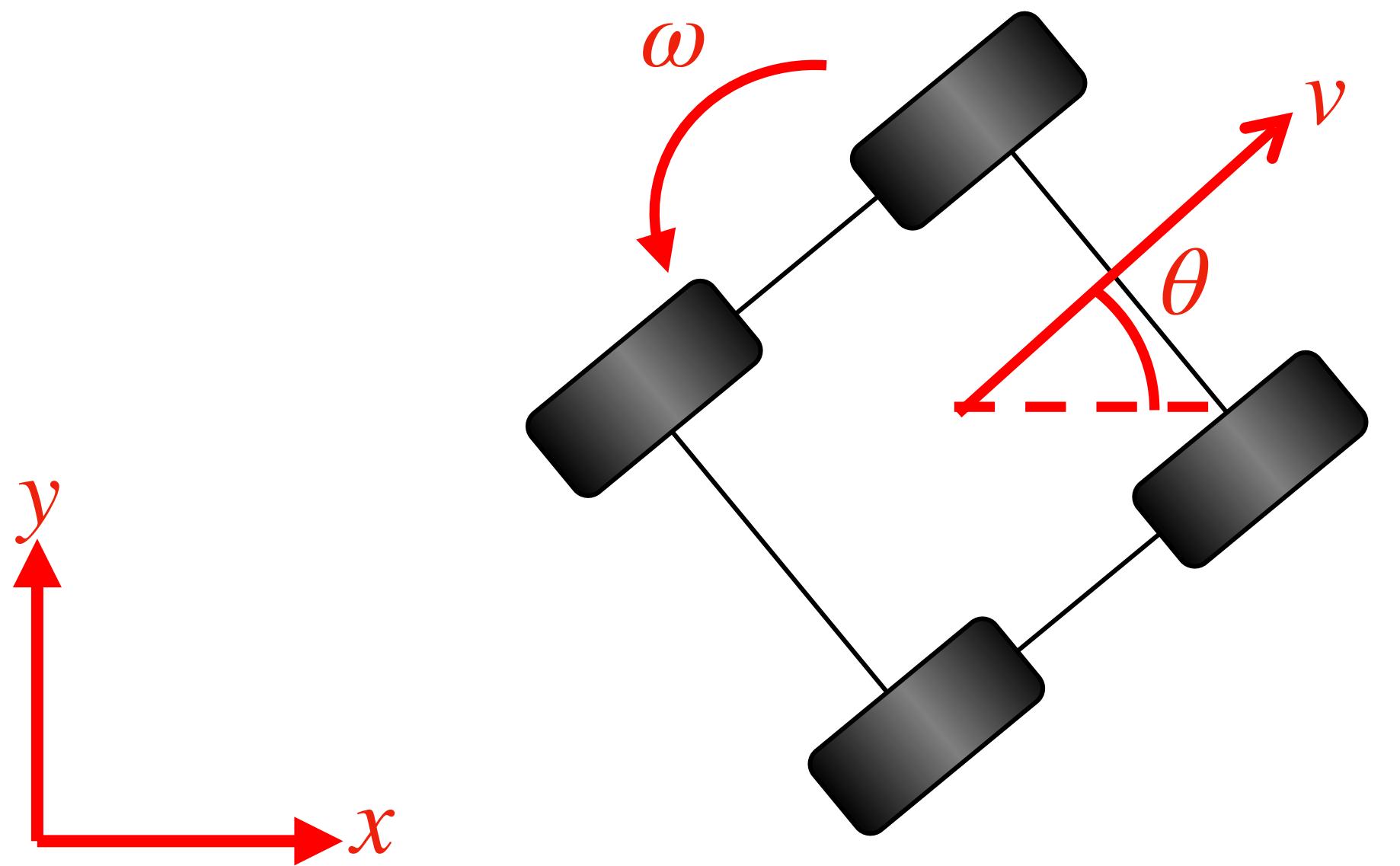
## Lab 6-9: Feedback Control

Lab 10-12: Localization  
and Planning

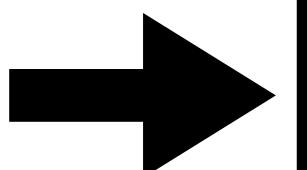
- Linear systems, model-free and model-based control



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



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



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

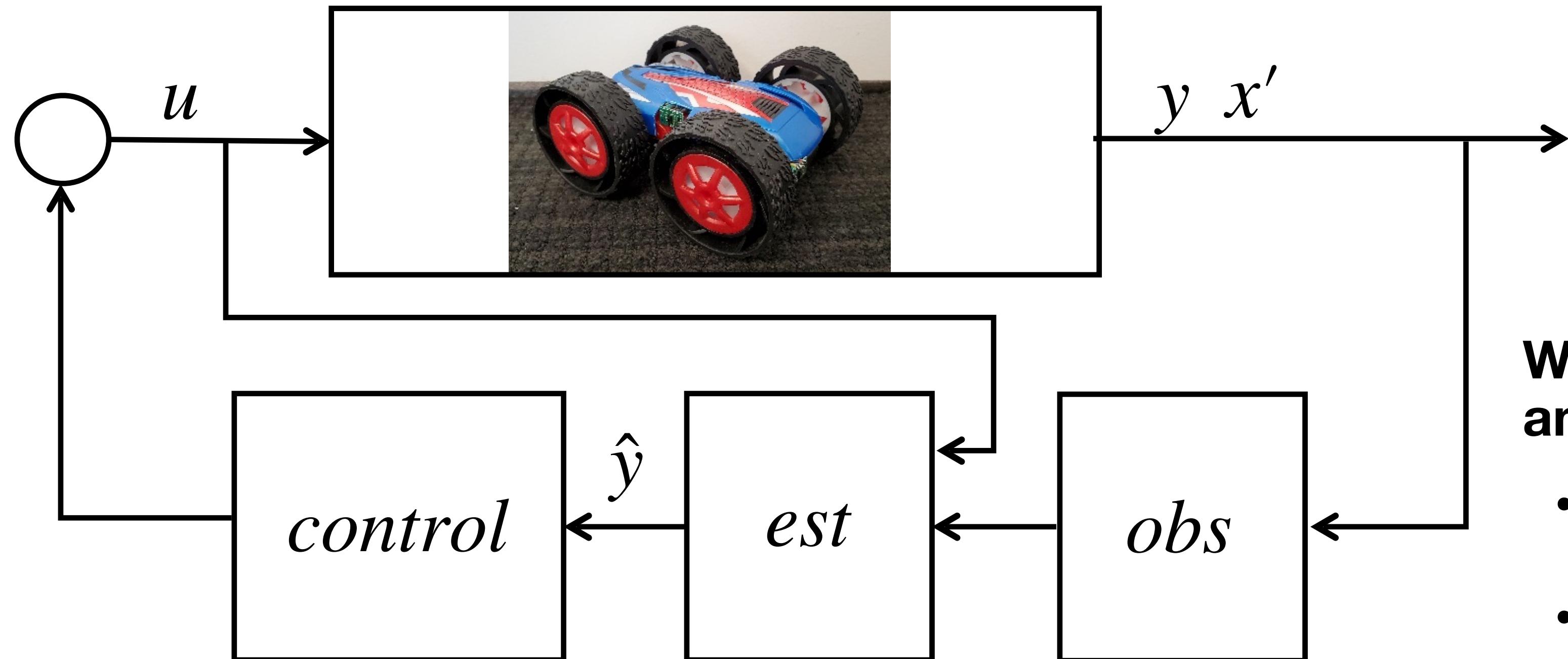


Lab 1-4: HW / Embedded SW

## Lab 6-9: Feedback Control

Lab 10-12: 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?**

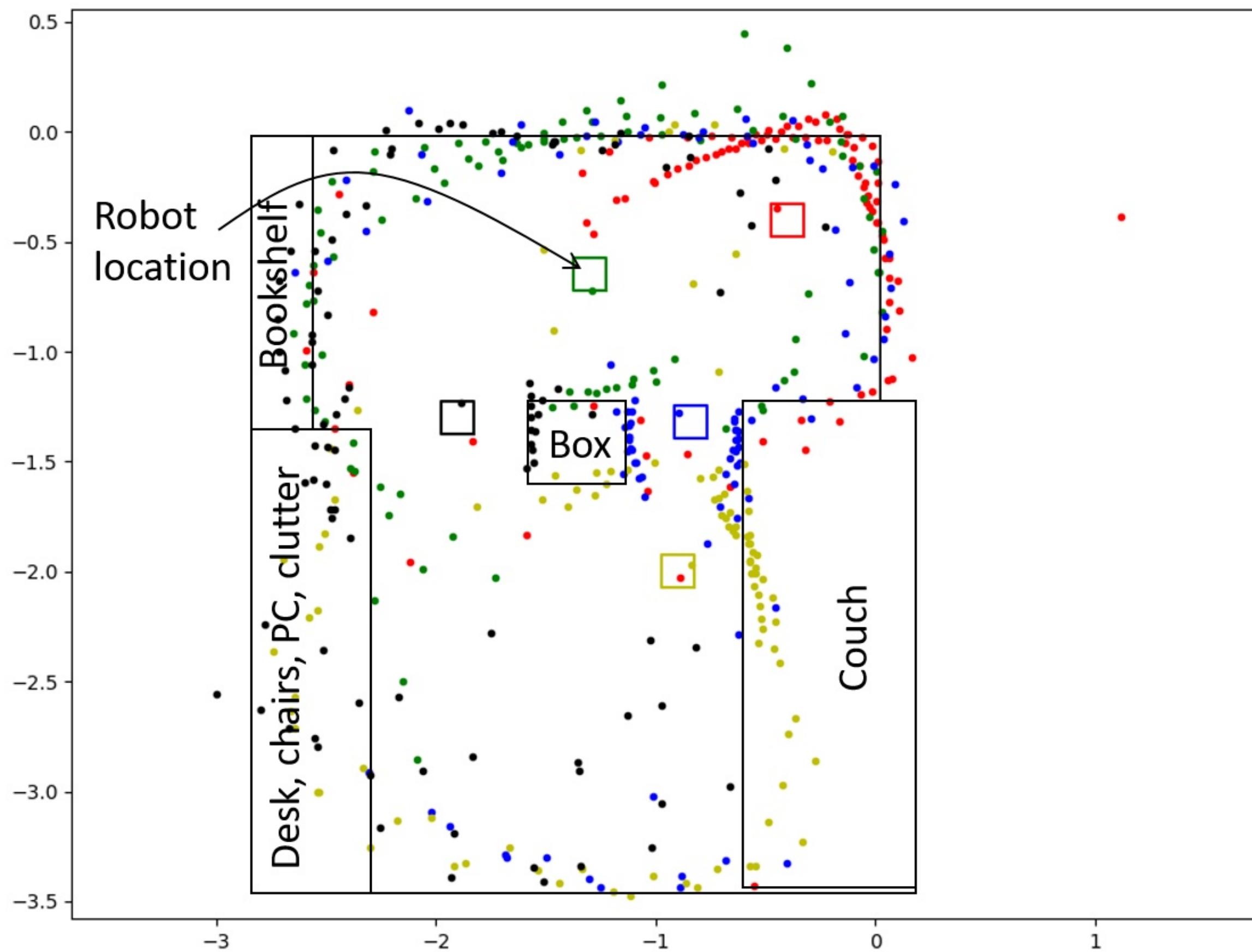
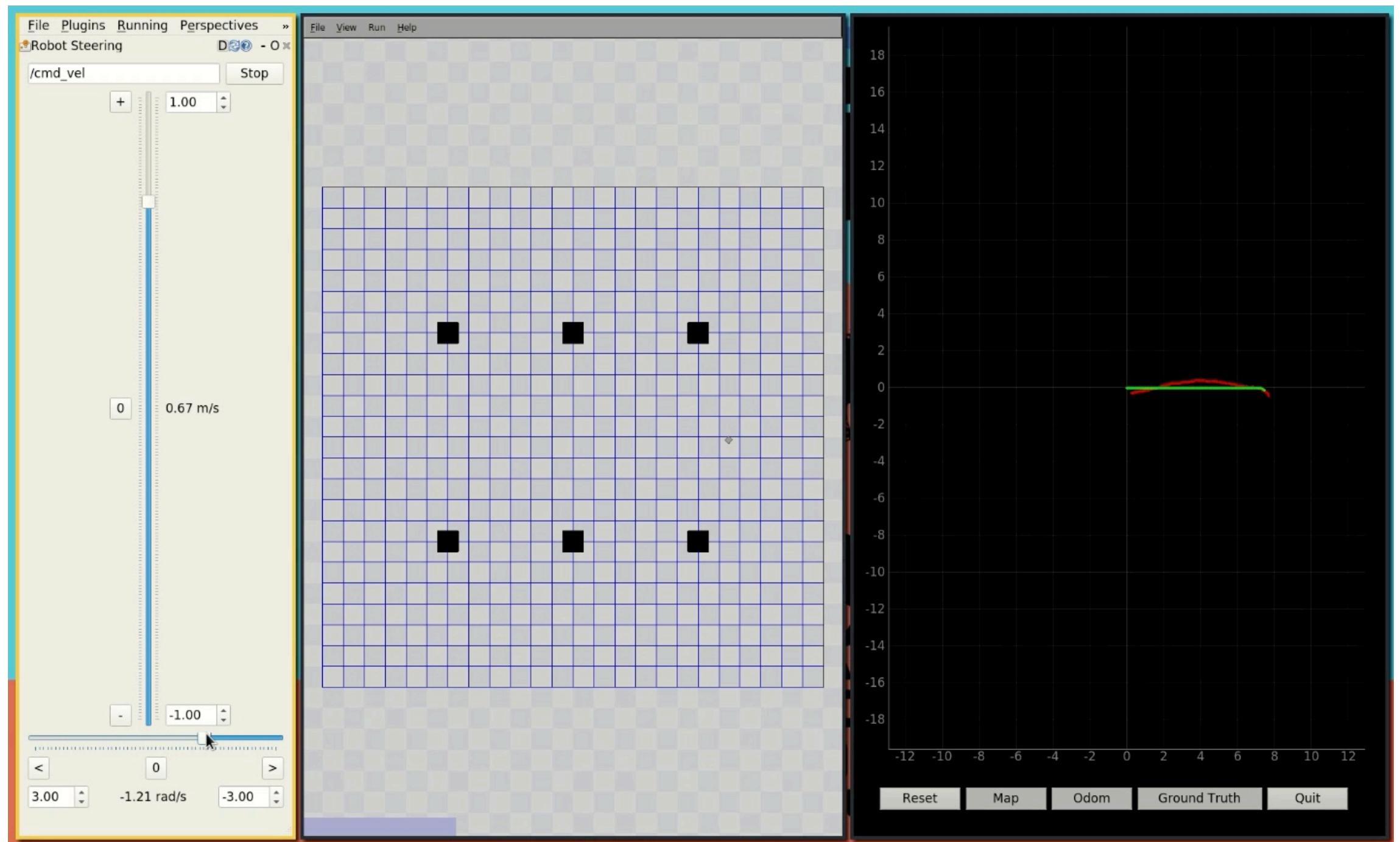
- Performance depends on the battery
- Sensing is slow (relatively)

## Lab 1-4: HW / Embedded SW

## Lab 6-9: Feedback Control

## Lab 10-12: Localization and Planning

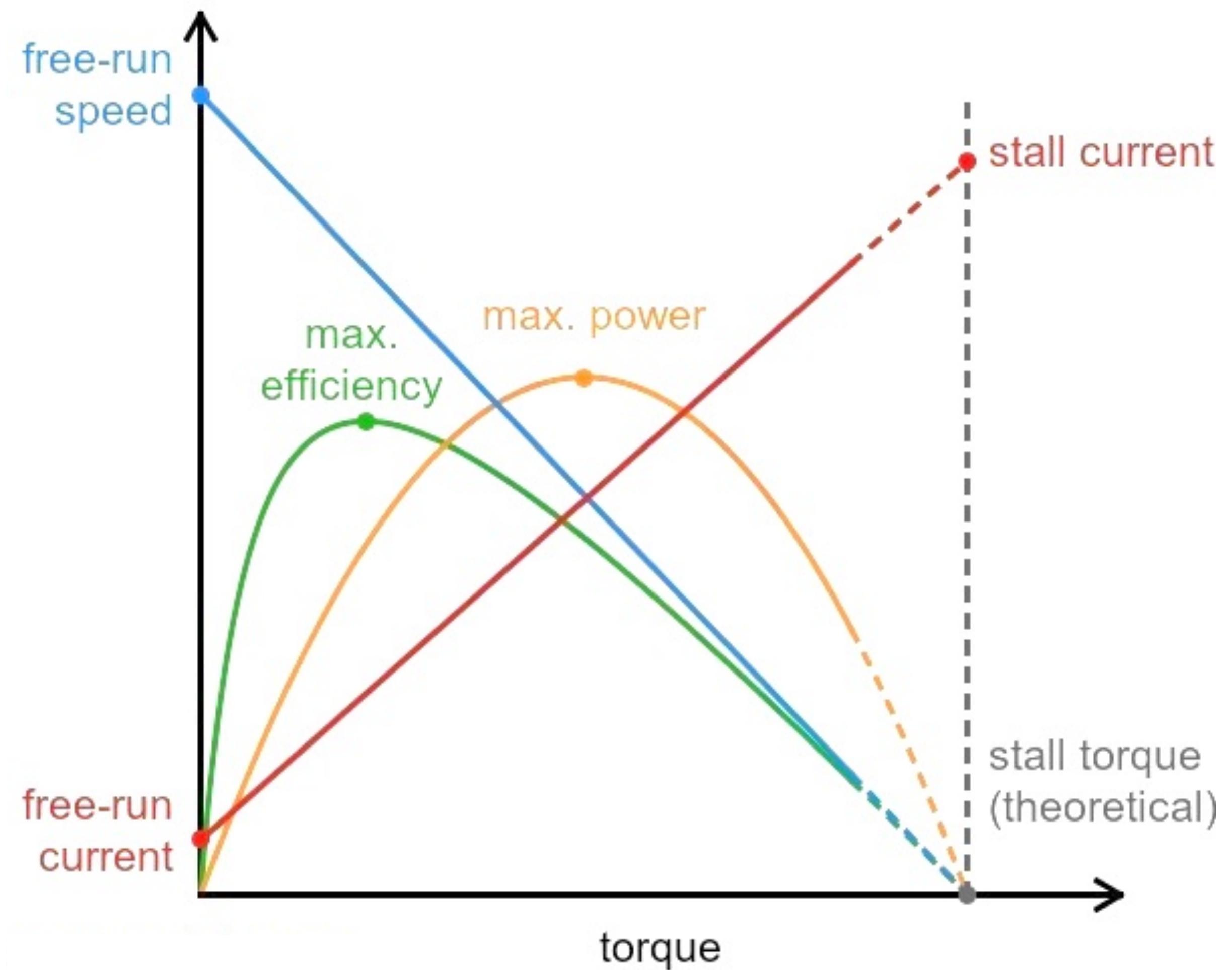
- Map representations
- Search and planning



- 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

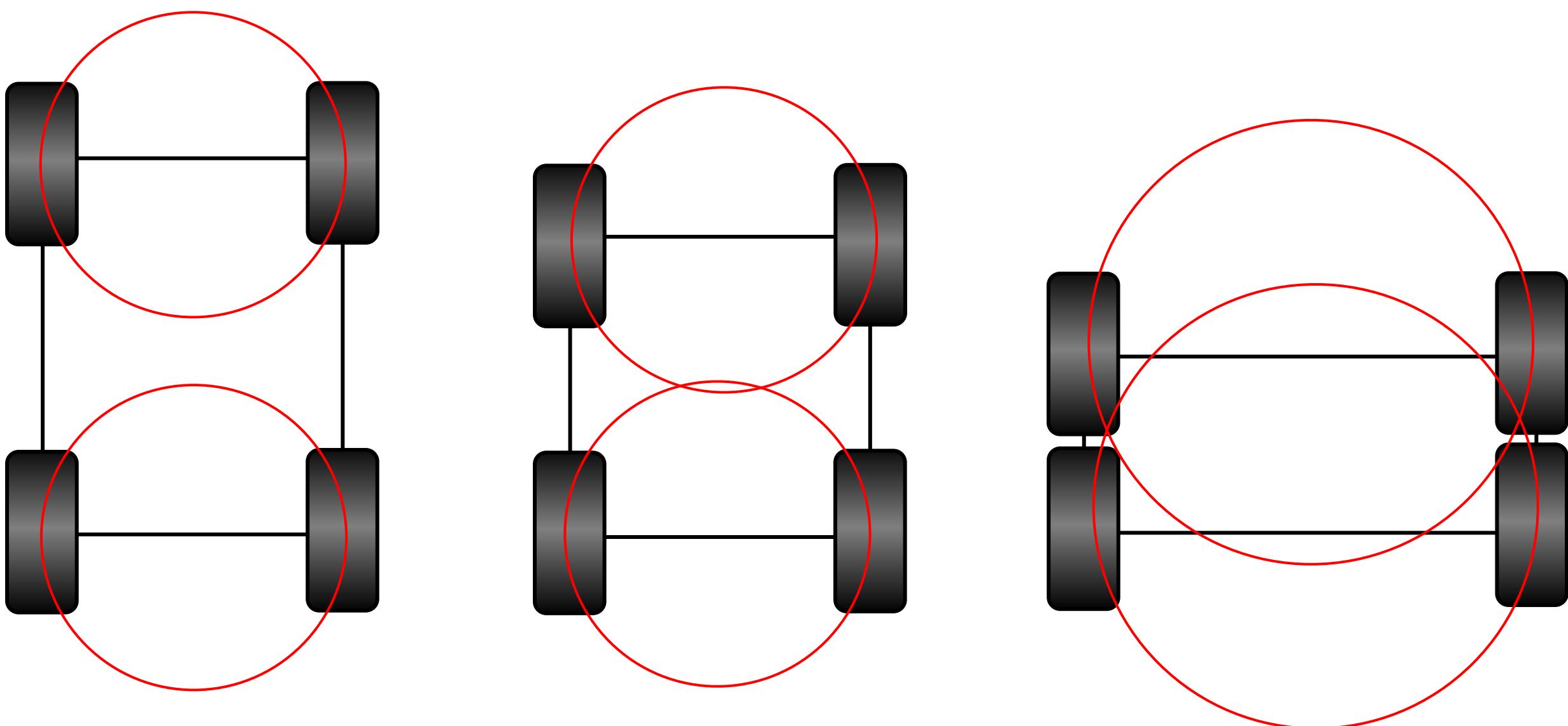
Lab 6-9: Feedback Control

**Lab 10-12: Localization  
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
- Skid steering



Lab 1-4: HW / Embedded SW

Lab 6-9: Feedback Control

**Lab 10-12: Localization  
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
- Skid steering

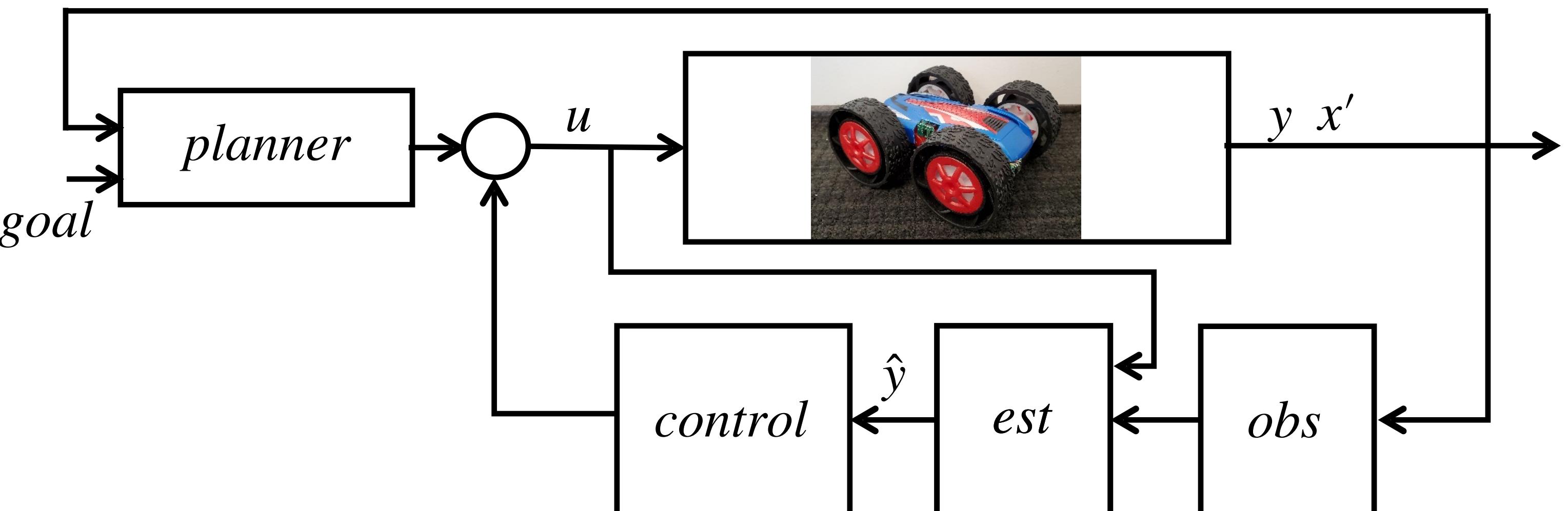
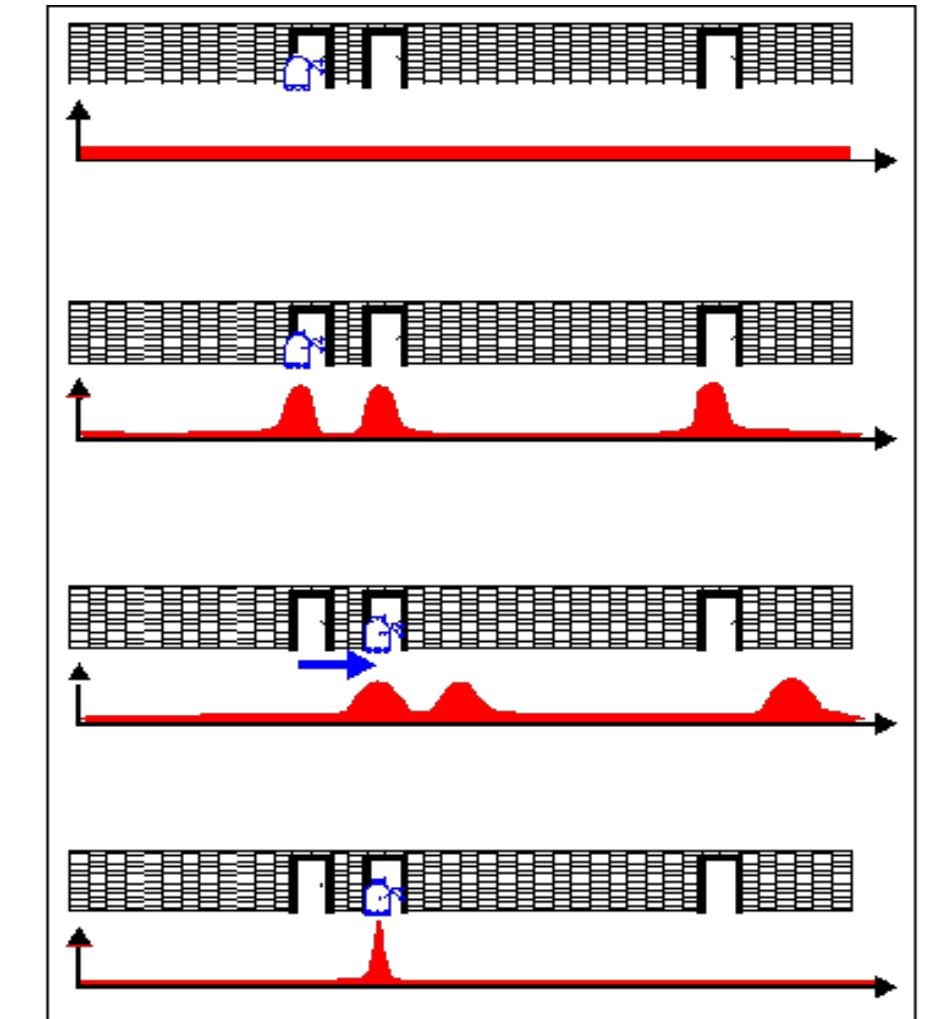


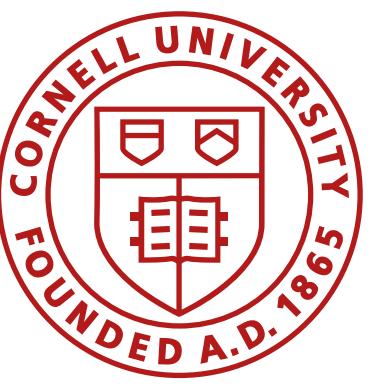
## Lab 1-4: HW / Embedded SW

## Lab 6-9: Feedback Control

## Lab 10-12: Localization and Planning

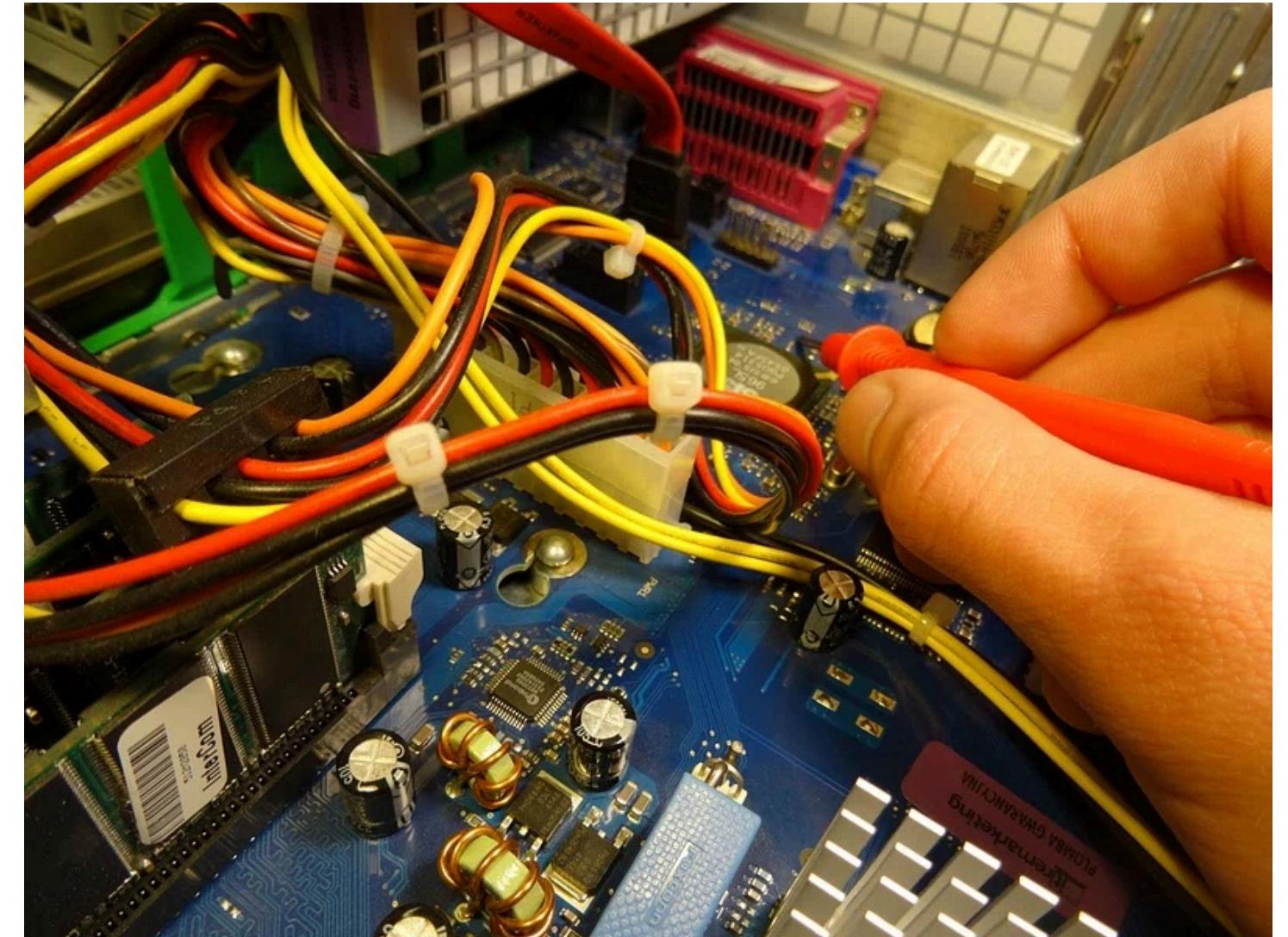
- Map representations
- Search and planning
- Noise, discrete probability
- Motion and sensor models
- Bayes theorem/ filters
- Localization, planning

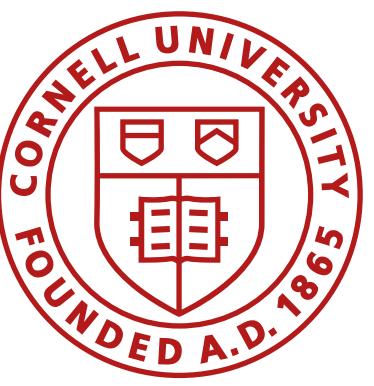




# Disclaimer

- 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

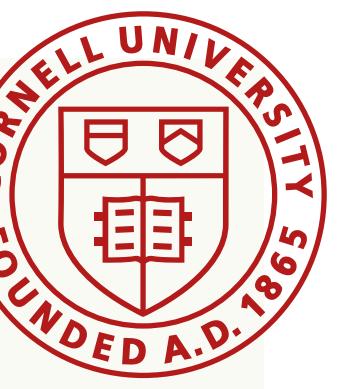
- Github page (<https://fastrobotscornell.github.io/FastRobots-2025/>)
  - Schedule, lecture slides, lab documents, tutorials, code examples, etc.
- Canvas
  - Lecture slides, deadlines, grades
- EdDiscussion
  - Post general questions to benefit all of your classmates, private messages to communicate with the course staff about extensions

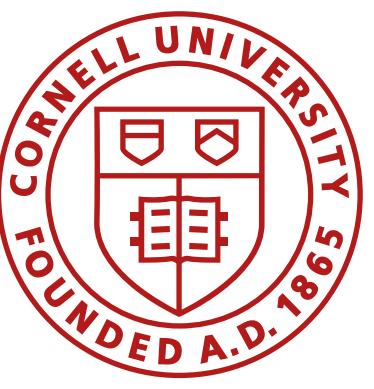
The screenshot shows the GitHub page for the Fast Robots 2025 course. It includes a brief description of the course, a "View On GitHub" button, and a note that it's maintained by FastRobotsCornell. Below this is a photograph of a robot setup with various electronic components labeled: Artemis Nano, Inertial Measurement Unit, Proximity sensor, and Time of flight sensor. A text block explains the use of peer-to-peer mentoring instead of traditional hand-ins.

The screenshot shows the Canvas course management system interface. It displays recent announcements, including a quick recap of Linear Algebra and Transformation Matrices, and sections on Robot Hardware, Control and Estimation, and a syllabus. On the right, there's a sidebar for course status with options like Import Existing Content, Choose Home Page, and View Course Stream.

The screenshot shows the Ed Discussion forum interface. It features a sidebar with courses like CS 0000, ECE 0000, ENGRD 2300, and Fast Robots. The main area shows a welcome message from Farrell Helbling and other course announcements. There are also sections for general messages, lectures, and labs.

Fast Robots 2025

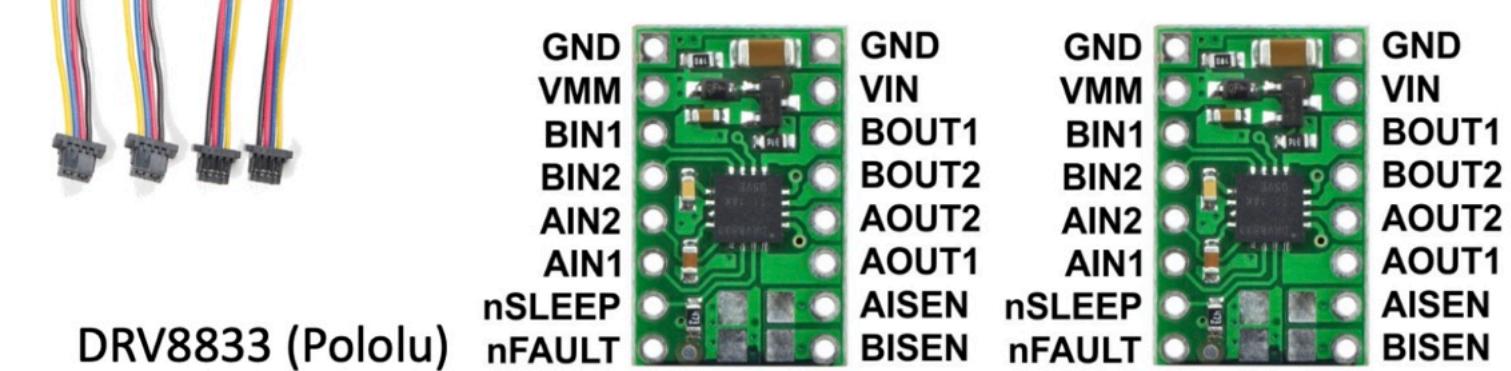
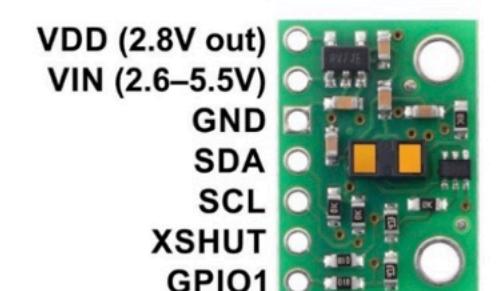
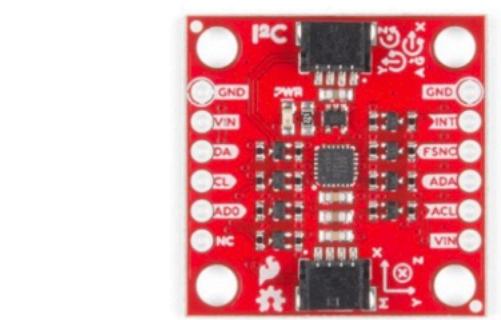
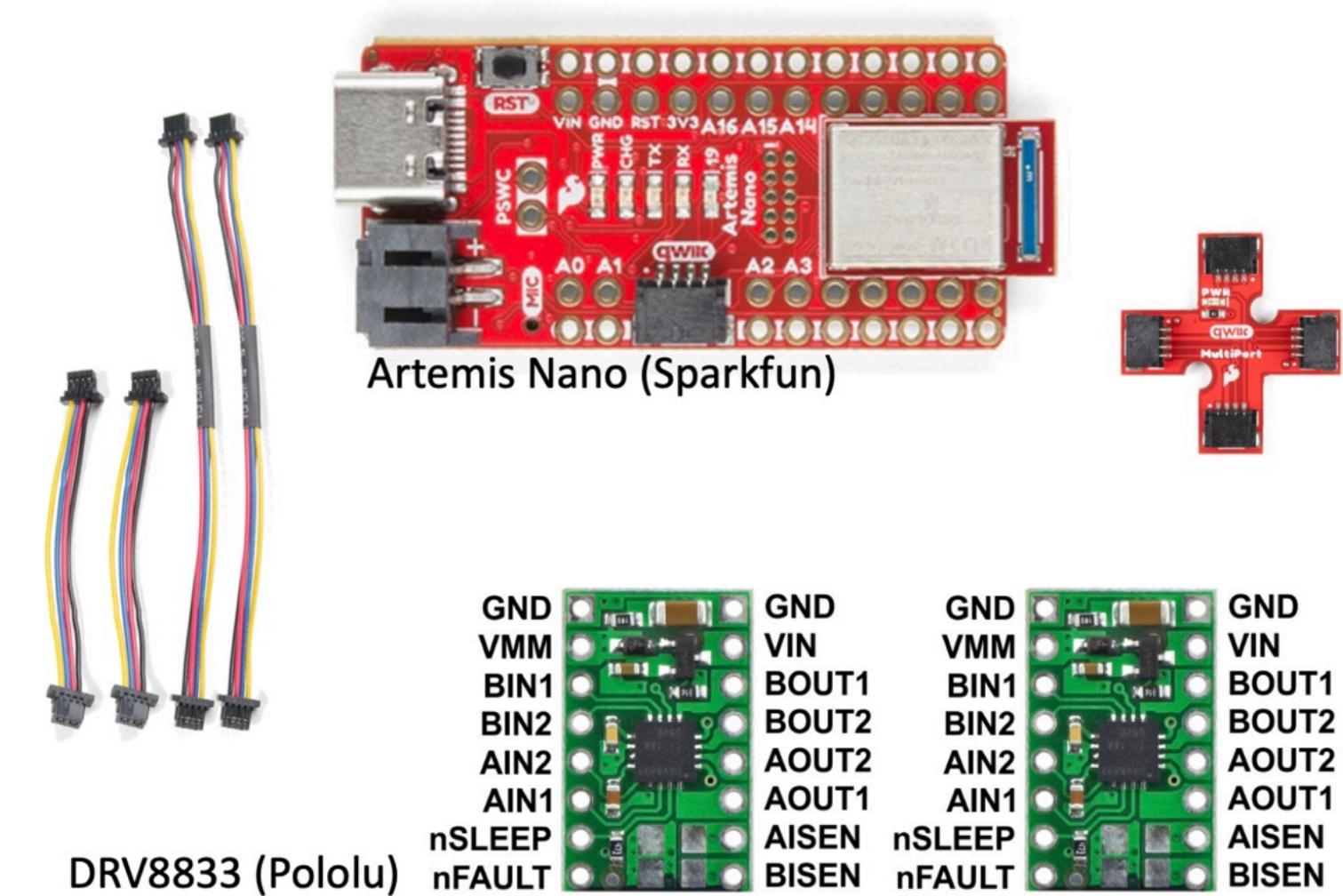




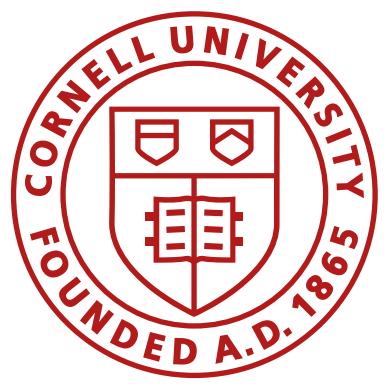
# Logistics

## 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!



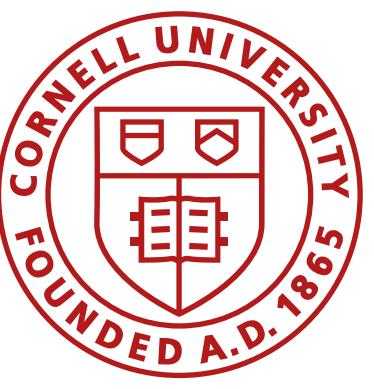
+ more cables



# Logistics

## Lab Software

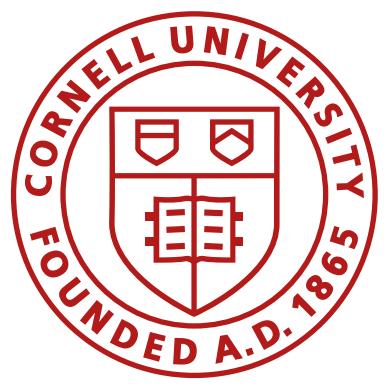
- Guaranteed support on the 13 lab computers in PH427 (Windows 10 and 11)
- The teaching team has tested these labs on their personal machines (Mac Intel/M1/ M1Pro and Windows 10/11) with minimal issues
- Minimum requirements:
  - Windows 10, MacOS 12, and Linux (bluez>4.58, kernel=4.15)
  - Processor: 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 MacOS Sequoia not recognizing the CH340 drivers. We have a solution (detailed in the Lab 1 documentation), but are looking for a better one. If you find one, please share with the rest of the class!



# Logistics

## Labs

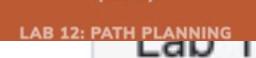
- Official lab times: T 2-4:30pm, W 8:30-11am, W 2-4:30pm. I will attend the first 60 minutes of every lab as my regular “office hours”
- Open lab times: TBD, will add a google calendar to the website later this week
- Time Commitment: 8-10 hrs/week
  - Spread this out over multiple days (batteries last 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.

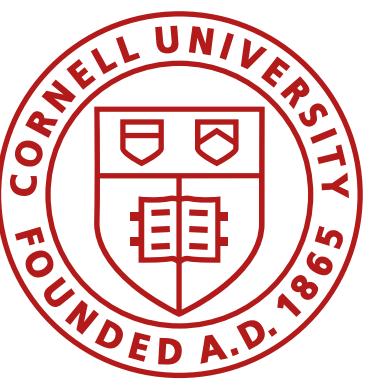


# Logistics

## 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-2025/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
 <b>LAB1 ARTEMIS</b>	
The goal of lab 1 was to setup and familiarize myself with the Sparkfun Artemis board, which will be used for the entire duration of the course and handle all robot to robot-master (m) communication.	
<b>PRELAB</b> First, I installed the latest version of the Arduino IDE, 2.2.1. From there, I was able to install the necessary libraries to work with the Artemis Nano, and get started on the tasks at hand.	
 <b>TASK 1: BLINK</b>	
MAE 4190 Lab 1 Task 1: Blink  Following the lab instructions, I first tested the new board by running the Blink.io file. <a href="#">Watch on YouTube</a>	
 <b>Lab 10 Localization (sim)</b>	5/5
Lab 11 Localization (real)	10
Lab 12 Planning and Execution	12.5
Participation	10
Bonus points for midterm and final course evals	2
<b>Total:</b>	<b>102</b>

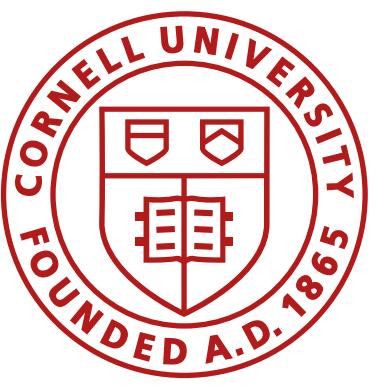


# Logistics Collaborations

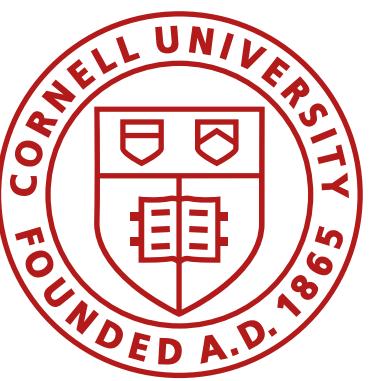
- You are welcome to check the write-ups from last year (links to the previous years student pages are clearly visible on our front page).
- You are welcome to work together, teams of 2-3 usually function best in this class. **Everyone is still responsible to implement the electronics/ software/mechanics 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 used genAI, tell us how you used the resource.



\*Chatgpt created this image



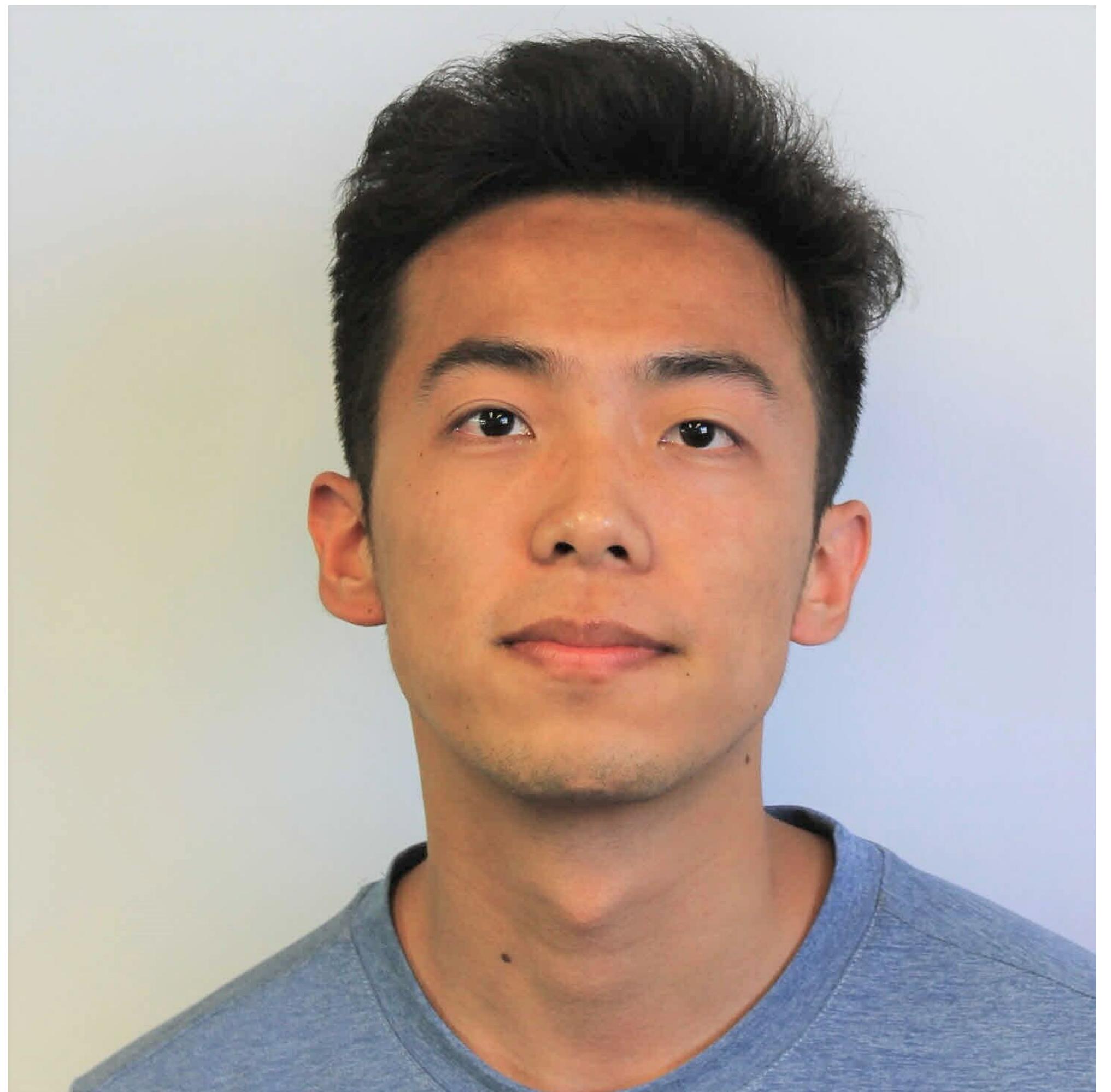
# Teaching Team

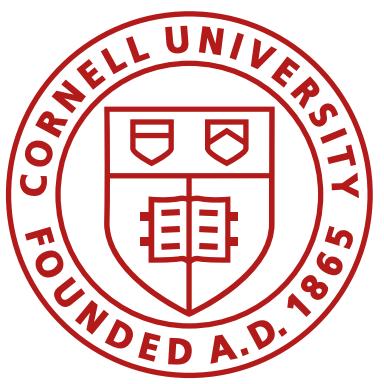


# Teaching Team

**Hang “Harry” Gao (he/him)**

- **Wednesday Morning Lab**
- Graduate Student in the Helbling Lab
- Research focus on locomotion and autonomy at the water-air interface
- Enjoys skiing and reading (sci-fi)



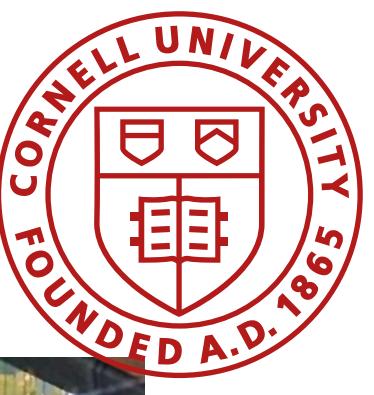


# Teaching Team

## Cameron Urban (he/him)

- **Wednesday Afternoon Lab**
- Graduate Student in the Helbling Lab
- Research focus on locomotion and autonomy for underwater robots
- He enjoys contributing to open-source software projects, scuba diving, and getting beaten in chess.



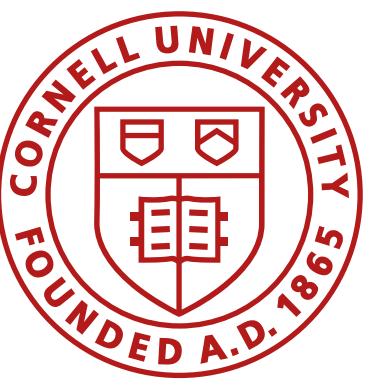


# Teaching Team

**Chenyu “Cheney” Zhang (he/him)**

- **Wednesday Afternoon Lab**
- Graduate student in the Helbling Lab
- Research focus on bio-inspired robotics
- He enjoys classical music, tennis, fossil hunting, and cross country



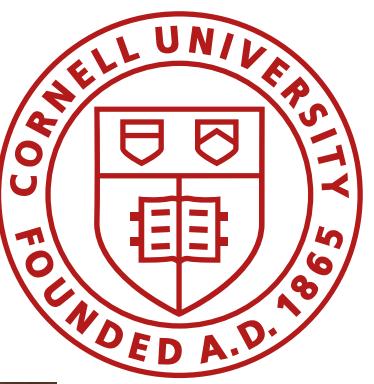


# Teaching Team

## Daria Kot (she/her)

- **Tuesday Afternoon Lab**
- Top student in the 2024 class, check out her website!
- CS major, Robotics and Fine Arts minor, member of the Cornell Rocketry Team.
- She enjoys painting and printmaking



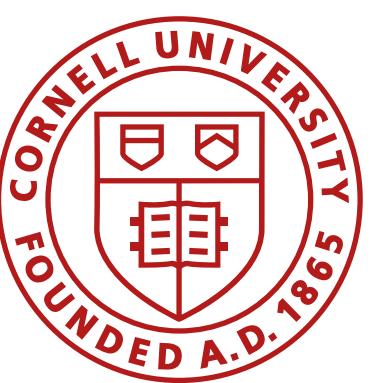


# Teaching Team

## Mikayla Lahr (she/her)

- **Wednesday Morning Lab**
- Top student in the 2024 class, check out her website!
- Major/ research/ project team
- She enjoys rowing and has a corgi named Belle





# Teaching Team

Nandita Nagarajan (she/her)

- **Tuesday Afternoon Lab**
- TA'd 2300 with me last year
- ECE major, ME minor, Electrical Subteam Lead of Cornell Rocketry
- She loves singing!



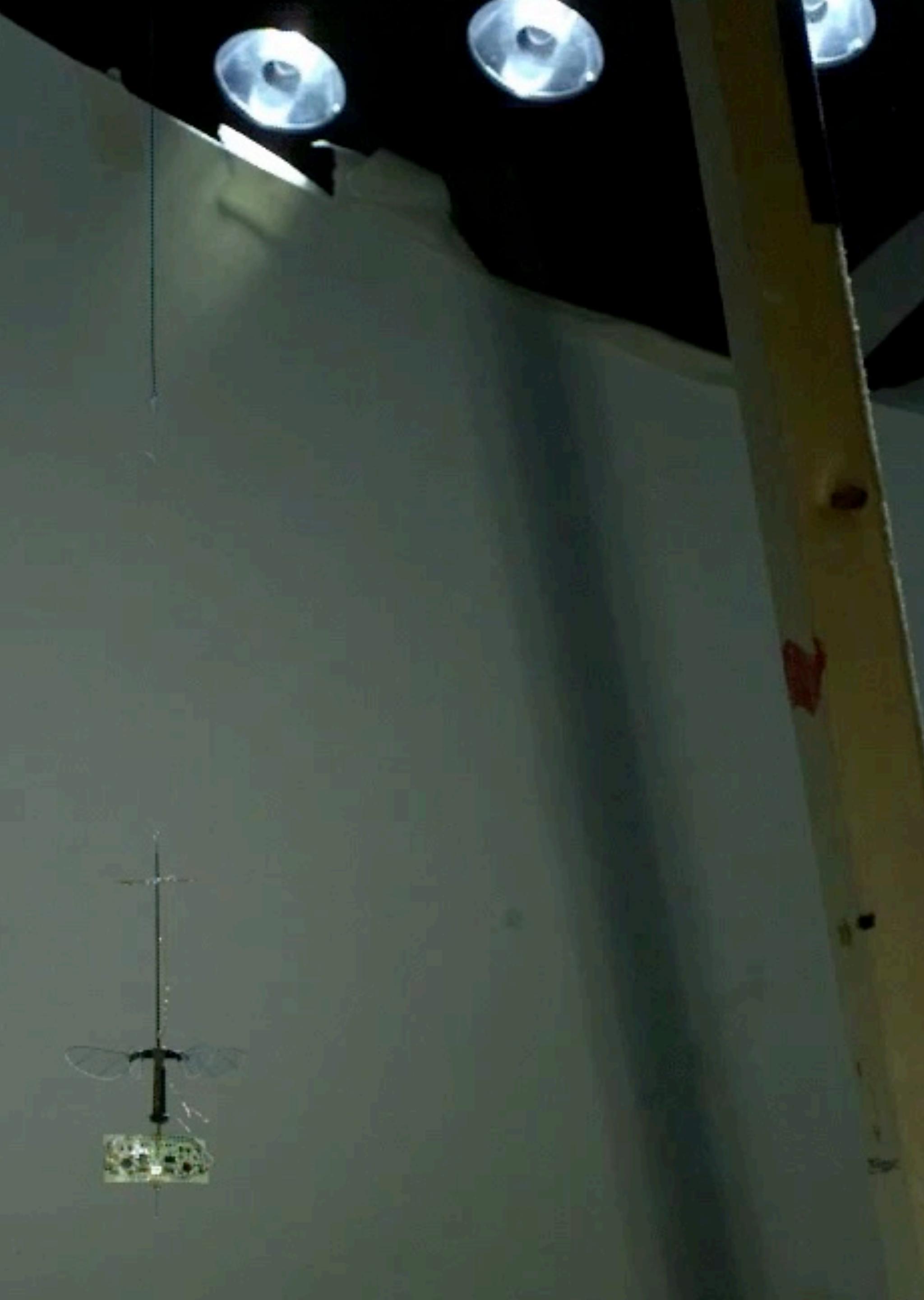
# Teaching Team

E. Farrell Helbling (she/her)



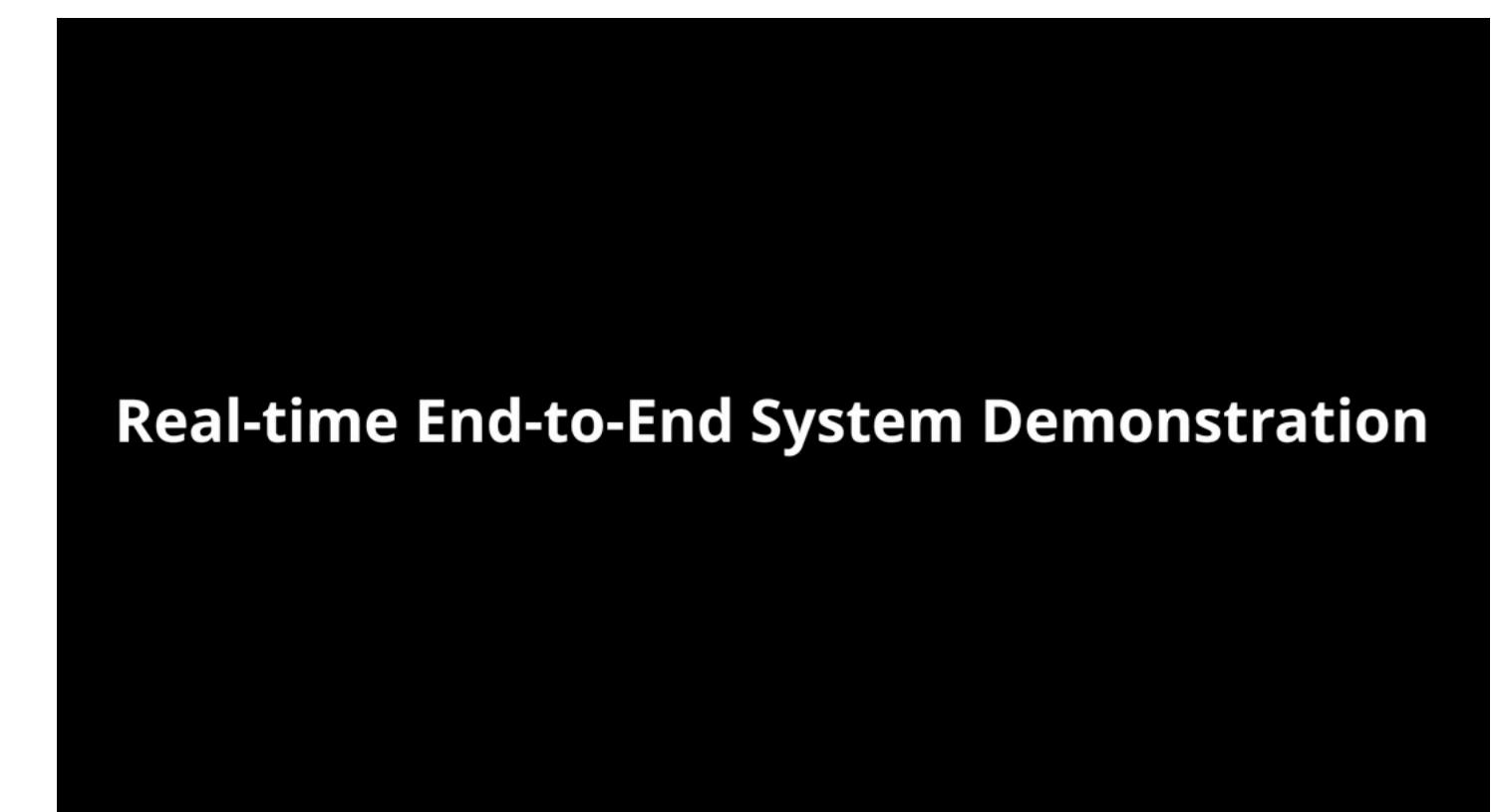
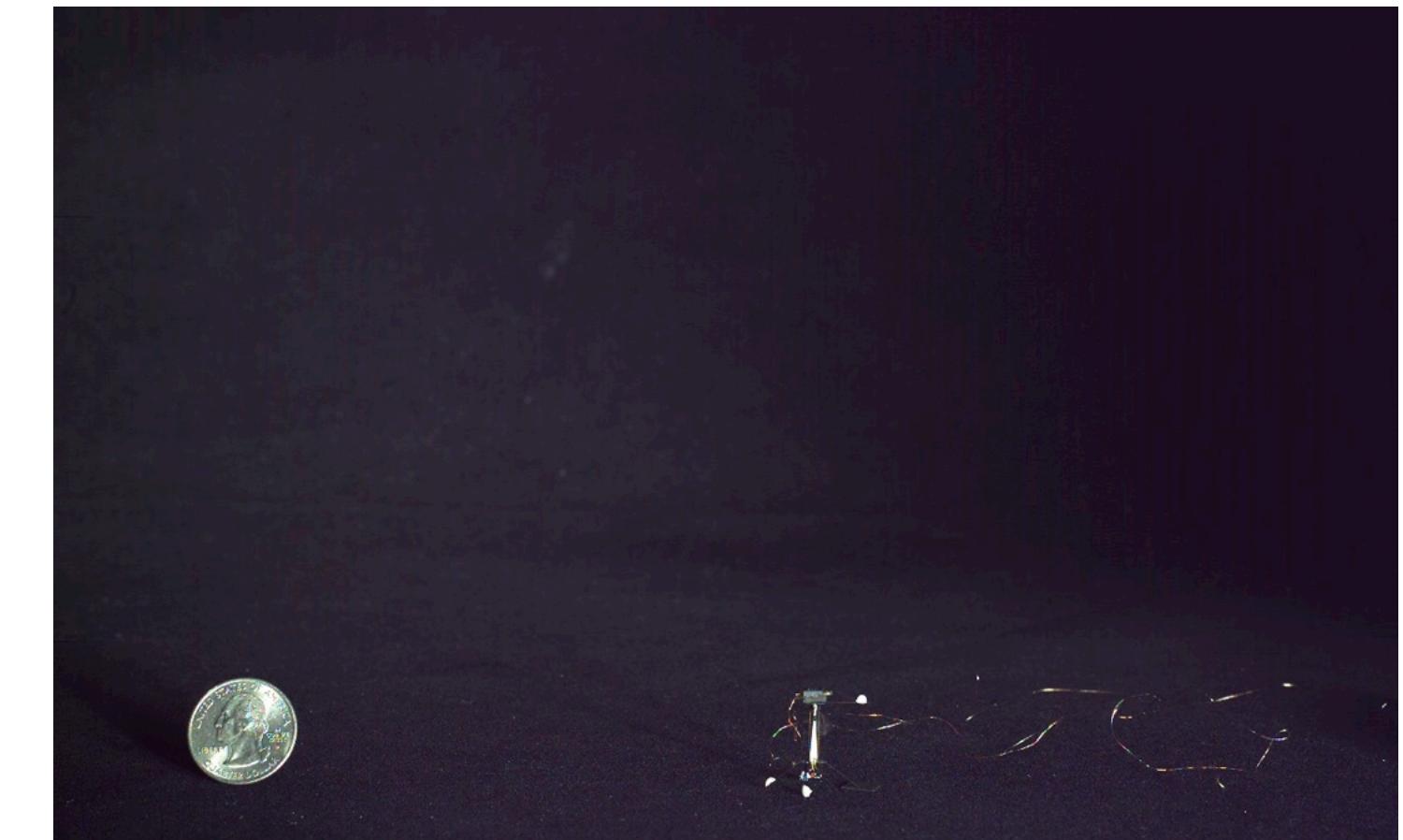
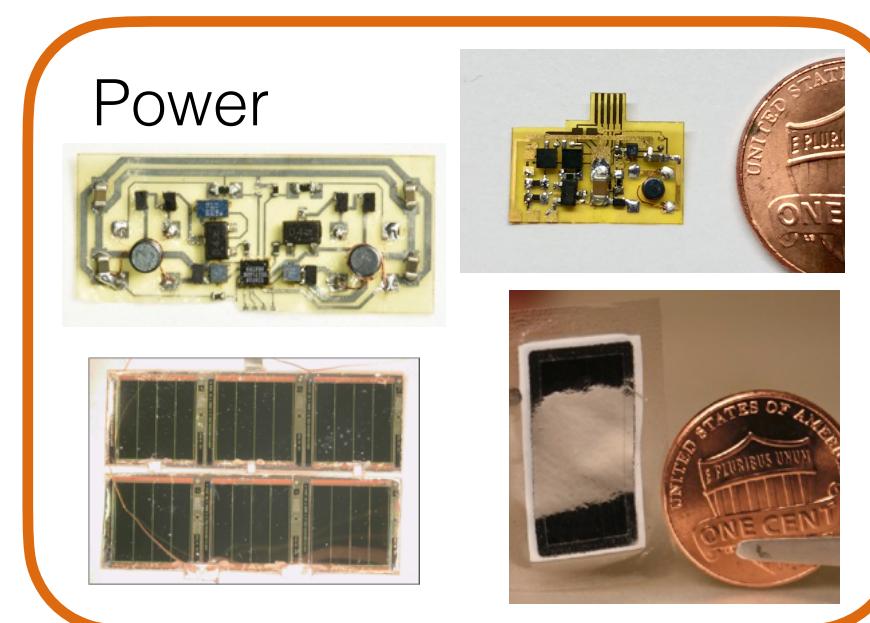
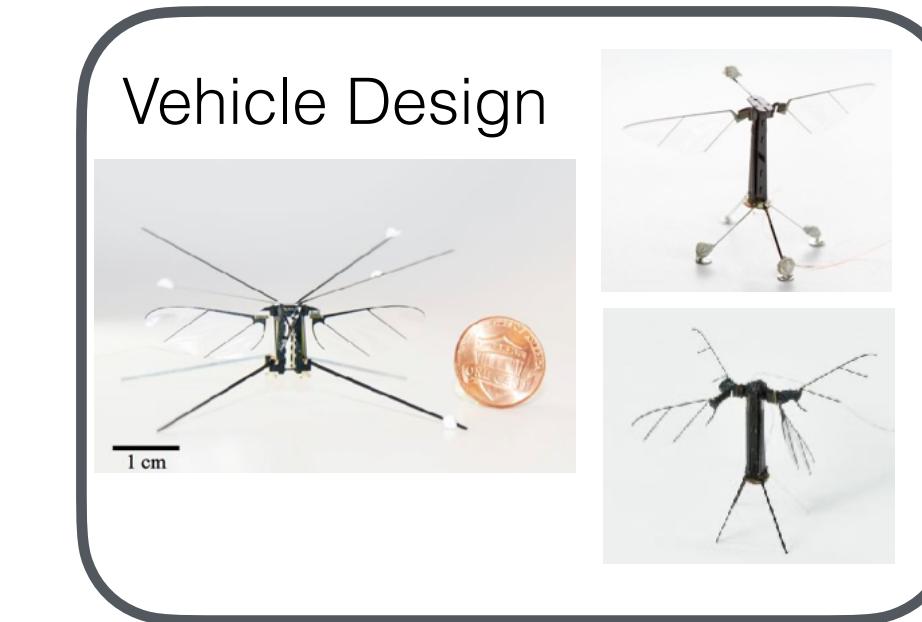
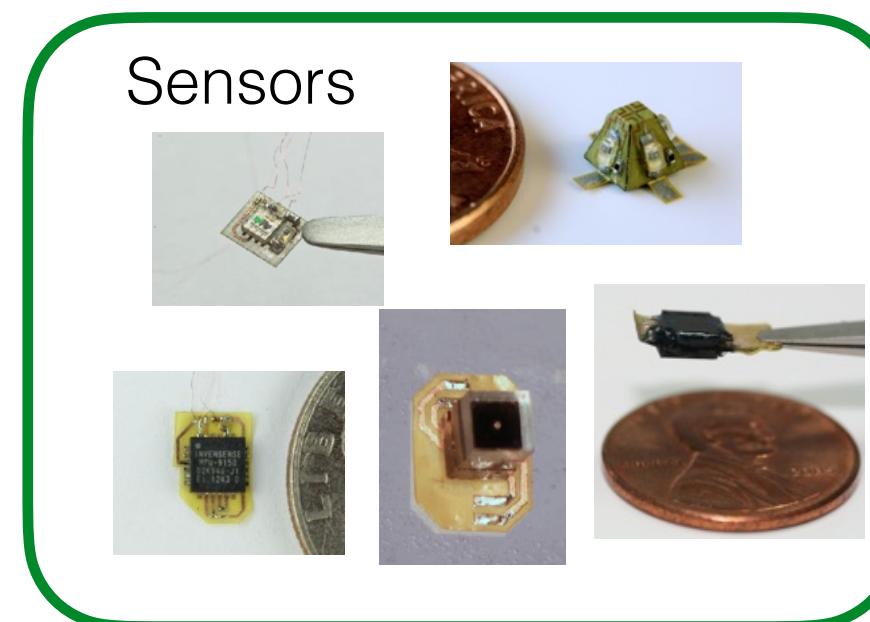
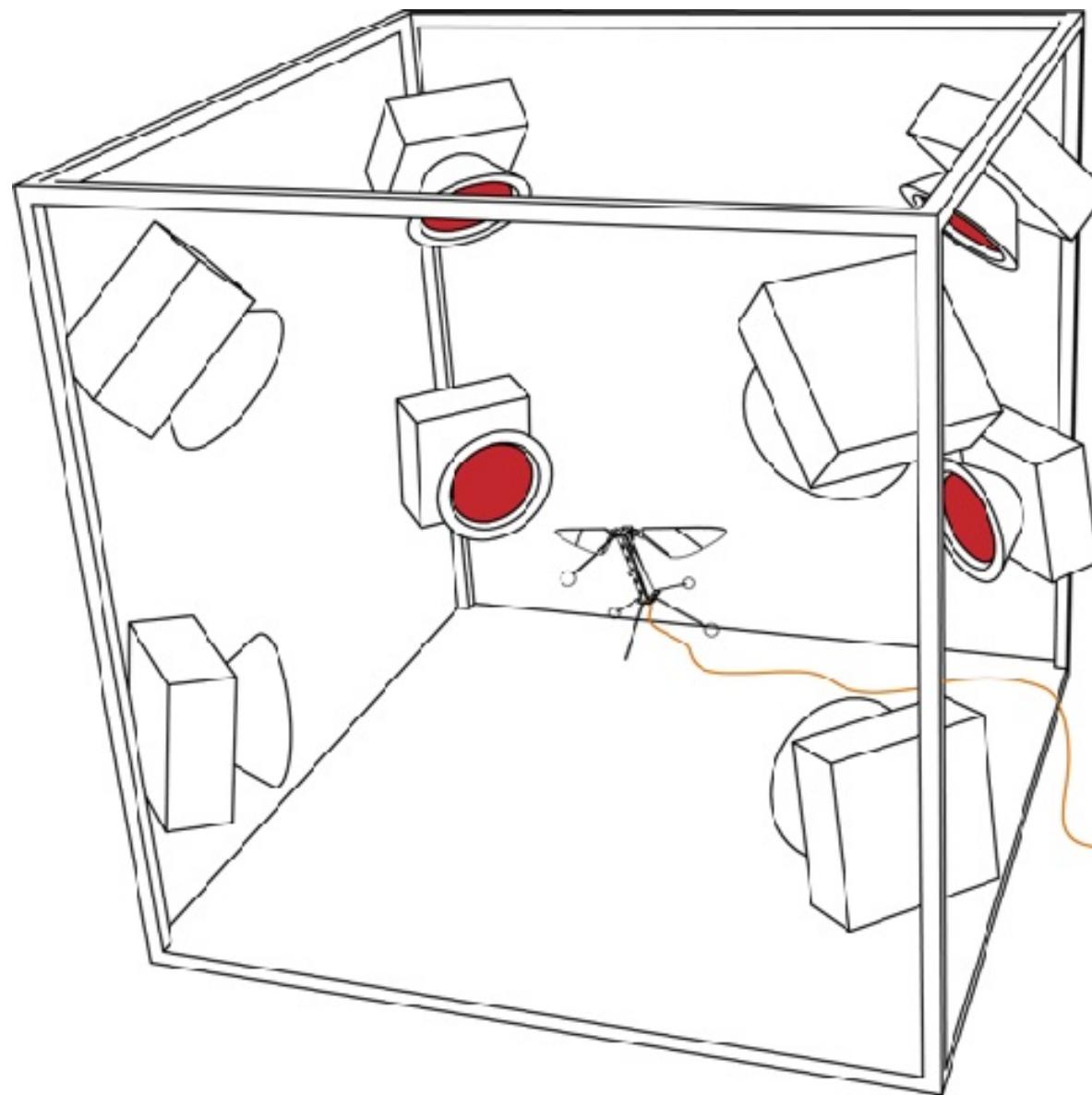
# Teaching Team

## E. Farrell Helbling (she/her)



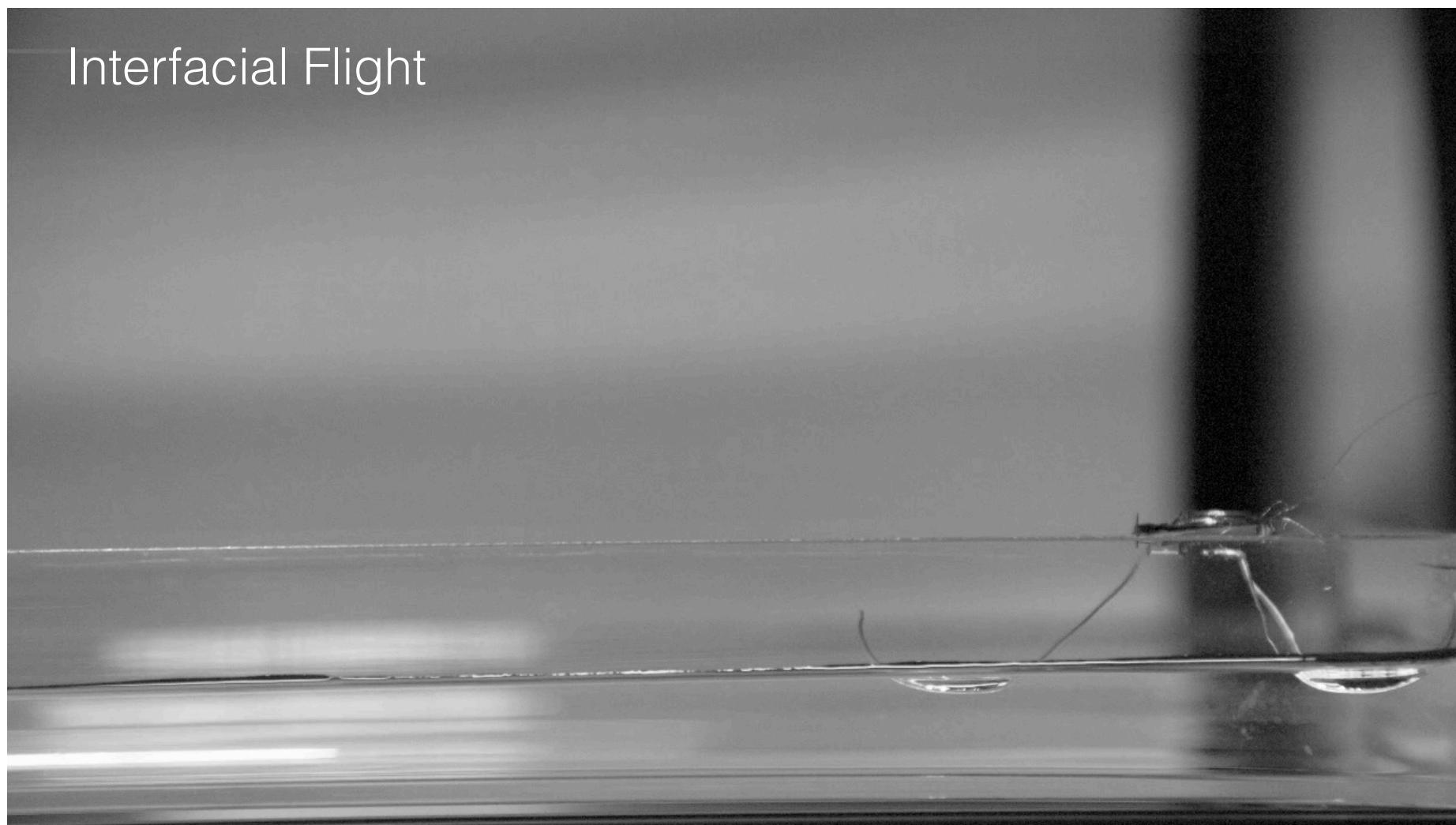
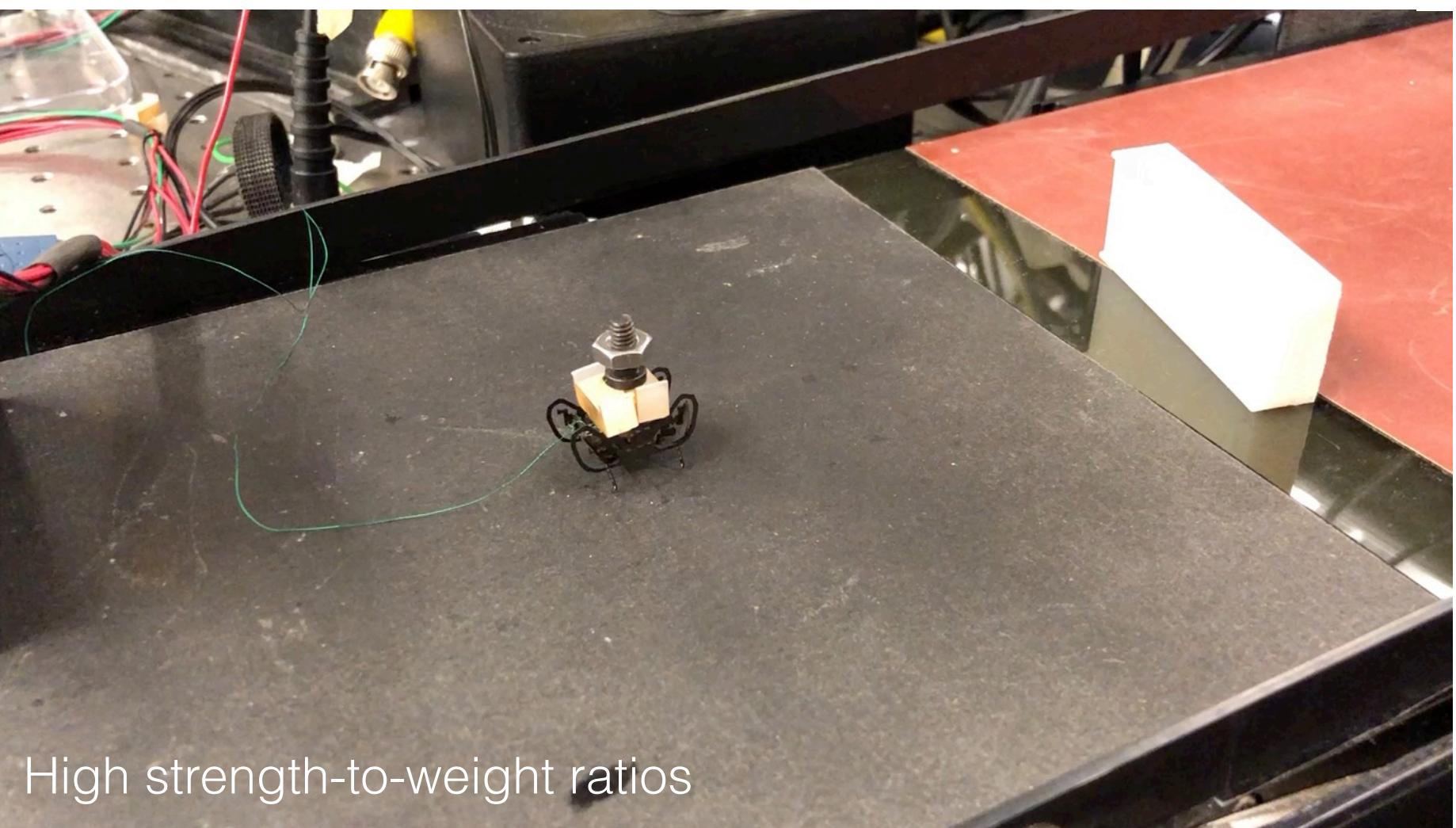
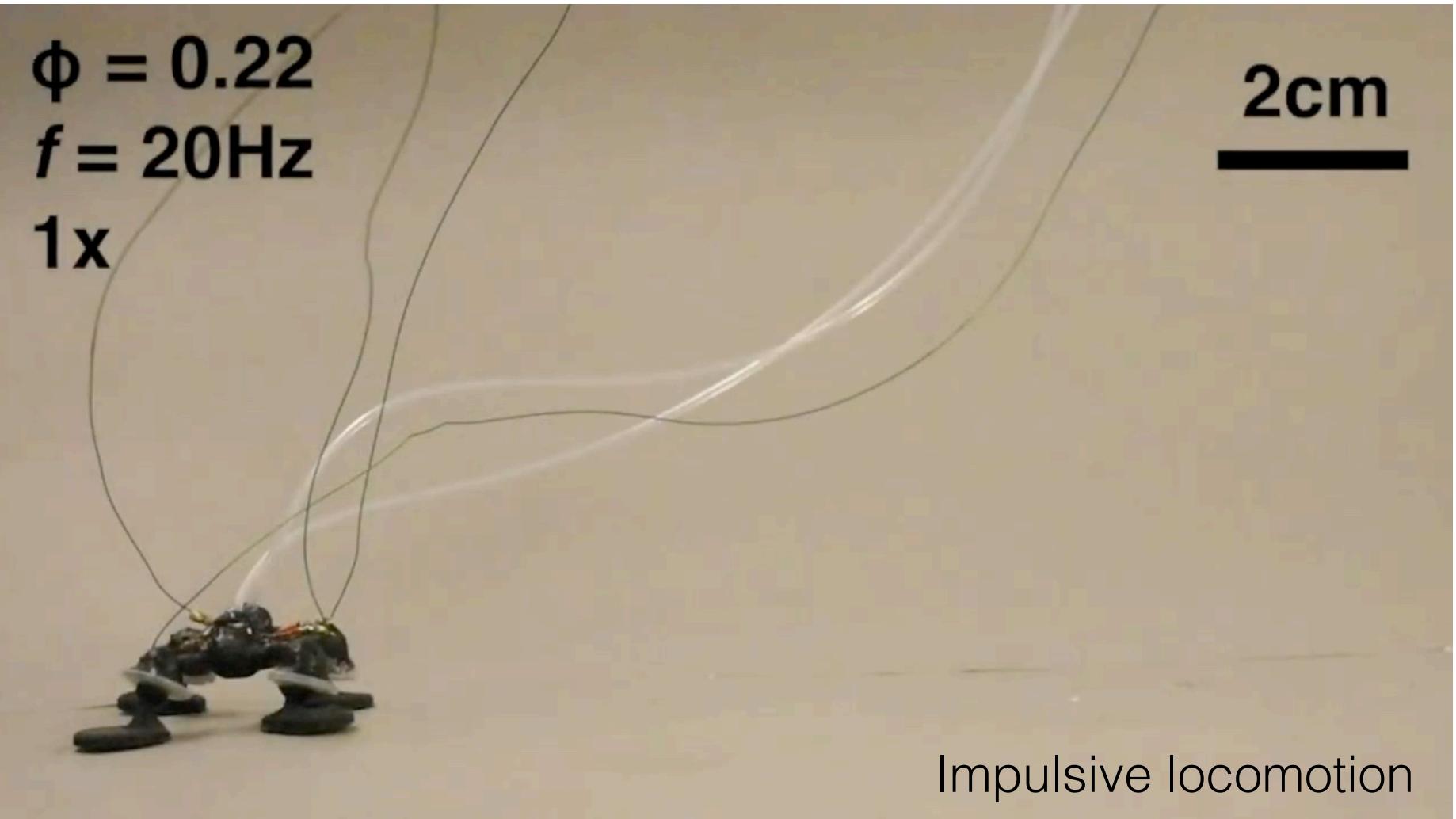
# Teaching Team

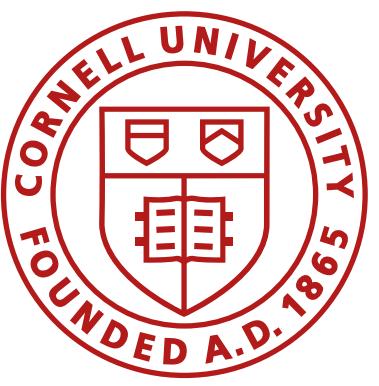
E. Farrell Helbling (she/her)



# Teaching Team

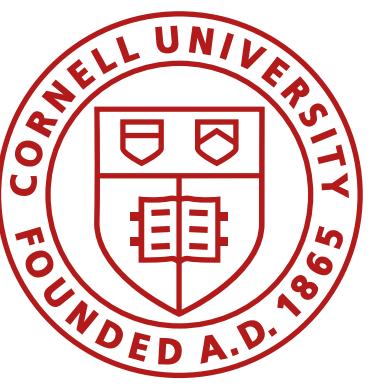
E. Farrell Helbling (she/her)





# Class Action Items

- Please if you have decided not to take the course, let me know ASAP. **Email [farrell@cornell.edu](mailto:farrell@cornell.edu).** We have 40+ people on the waitlist.
- **January 31st, 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 Phillips 427 later today! The rest I will see tomorrow!



**See you later today (or tomorrow)**