

Welcome to

MEAM 520

Introduction to Robotics

Cynthia Sung, Ph.D.

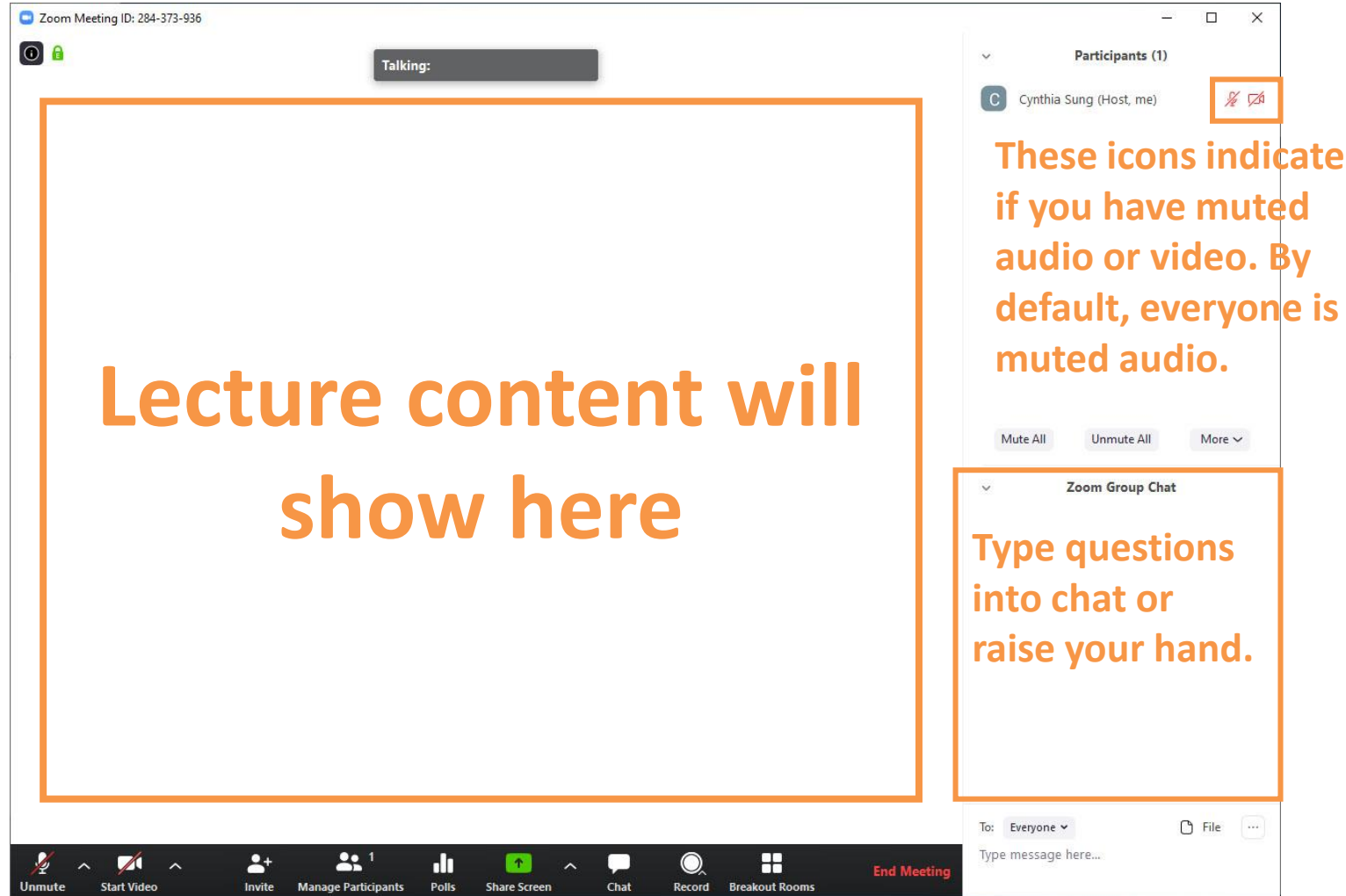
Mechanical Engineering & Applied Mechanics

University of Pennsylvania

Lecture 1

- Who?
- What?
- How?
- Why?

Welcome to Zoom lectures



The screenshot shows a Zoom meeting window with the following elements:

- Top Bar:** Zoom Meeting ID: 284-373-936, a lock icon, and a "Talking:" status bar.
- Participants Panel (Right):** Titled "Participants (1)", it lists "Cynthia Sung (Host, me)". Next to her name are two icons: a microphone with a slash and a video camera with a slash. These icons are highlighted with an orange box. Below the list are buttons for "Mute All", "Unmute All", and a "More" dropdown.
- Zoom Group Chat (Right):** A section titled "Zoom Group Chat" containing the text "Type questions into chat or raise your hand." This section is also highlighted with an orange box.
- Chat Area (Bottom Right):** Includes a "To:" dropdown set to "Everyone", a "File" button, and a text input field labeled "Type message here..."
- Bottom Toolbar:** A row of icons for "Unmute", "Start Video", "Invite", "Manage Participants", "Polls", "Share Screen", "Chat", "Record", "Breakout Rooms", and a red "End Meeting" button.
- Central Content Area:** A large white rectangle with an orange border containing the text "Lecture content will show here" in orange.

Annotations in orange text and boxes provide additional context:

- Next to the muted icons in the Participants panel: "These icons indicate if you have muted audio or video. By default, everyone is muted audio."
- Inside the Zoom Group Chat panel: "Type questions into chat or raise your hand."

Who am I?



Cynthia Sung, Ph.D.

Assistant Professor

Mechanical Engineering & Applied Mechanics

Secondary appointment in Computer & Information Sciences

You can call me: Professor, Professor Sung, Dr. Sung, Cynthia



Who am I?



I joined Penn faculty in January 2017; this is my third year at Penn.



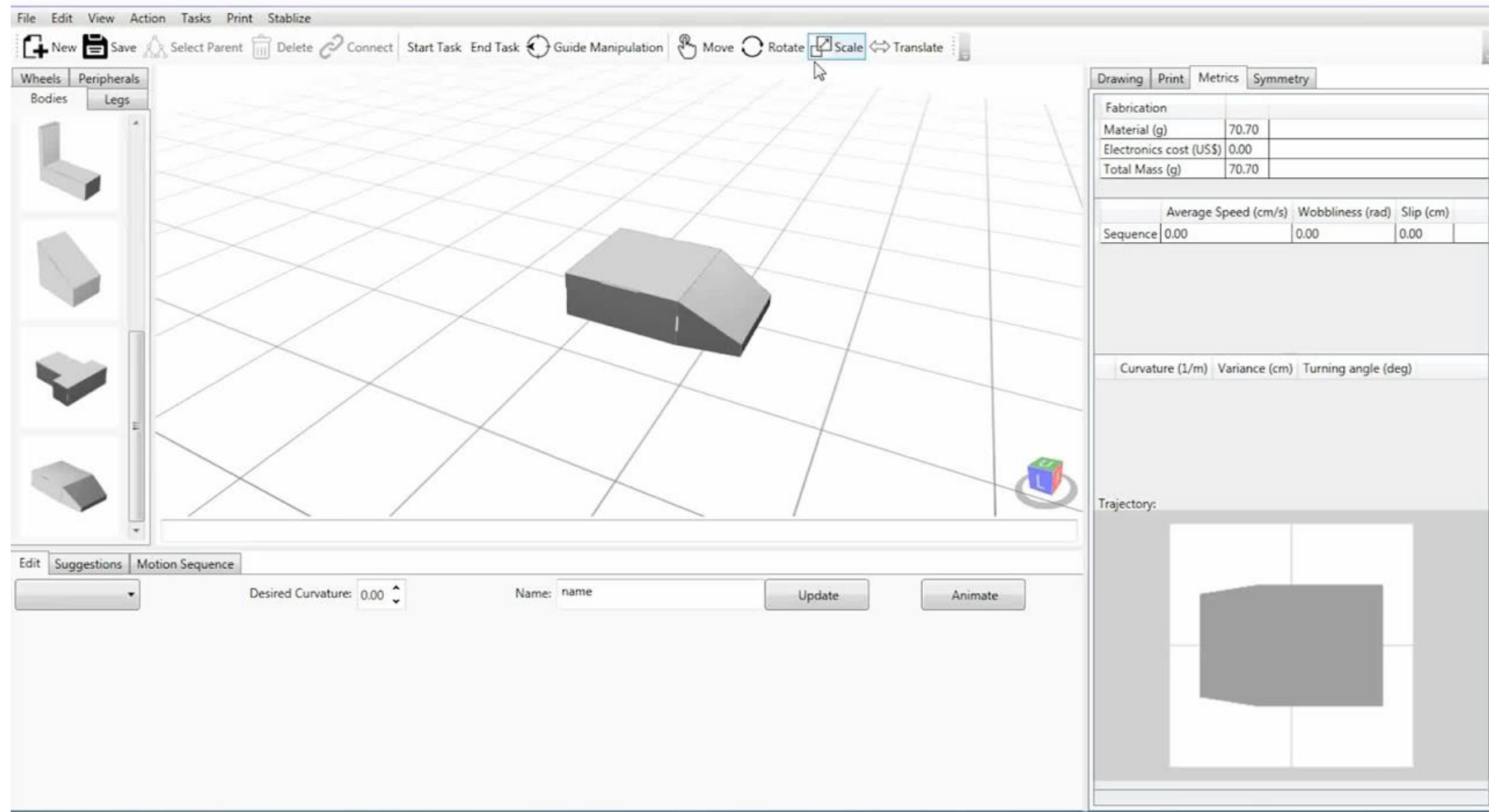
I earned my Ph.D. in EECS at MIT in 2016, and a B.S. in ME at Rice University.



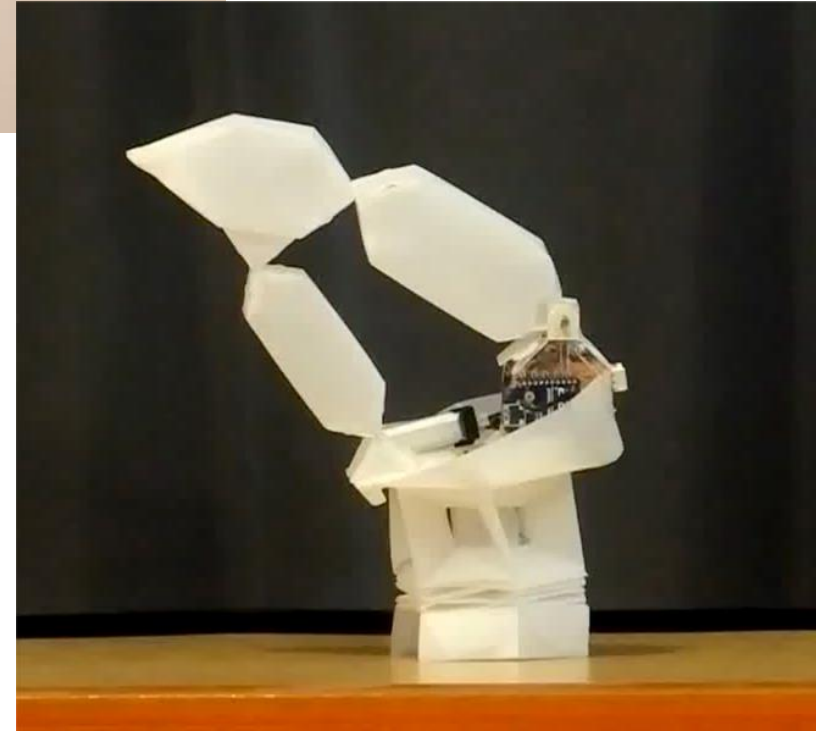
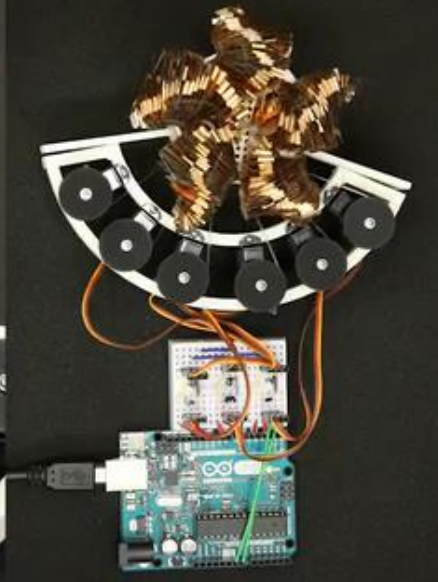
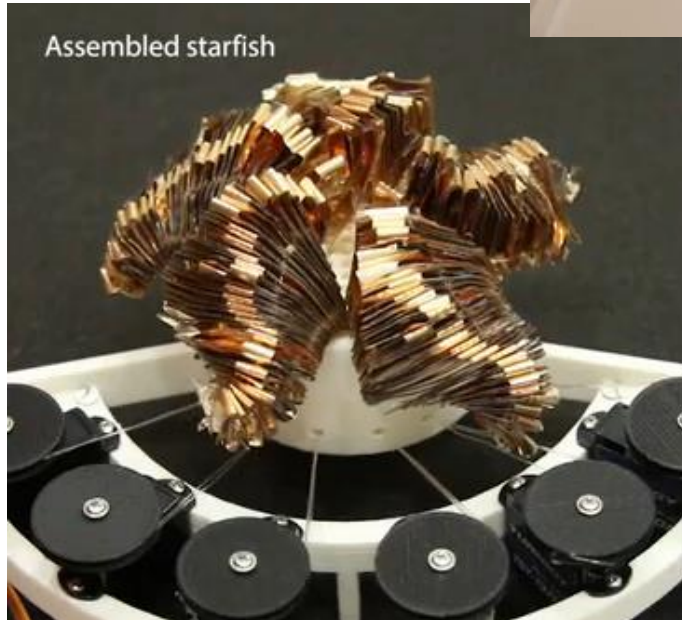
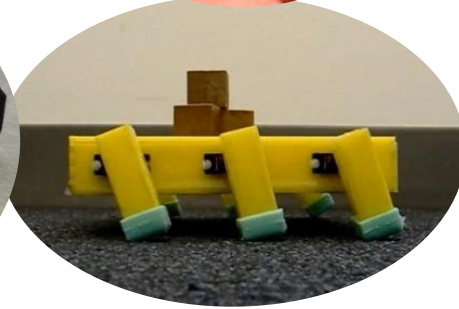
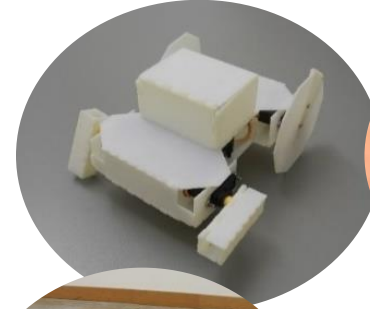
My primary research interests are:

- Making computational tools for designing custom robots
- Developing new fabrication methods for creating custom robots
- Origami robots

Who am I?



Who am I?



How do you contact me?

Mainly: In class, in office hours, via Piazza

Email: crsung@seas.upenn.edu

Please email me only for very
private class matters or for non-
class-related topics

Office Hours: Tuesdays 1:30 – 2:30 pm
Fridays 10:00 – 11:00 am

Who else is teaching us?



Shane Rozen-Levy
MEAM PhD



Jake Welde
MEAM PhD



Ray Bjorkman
ROBO MS '21



Zichen Lao
MEAM MS '21

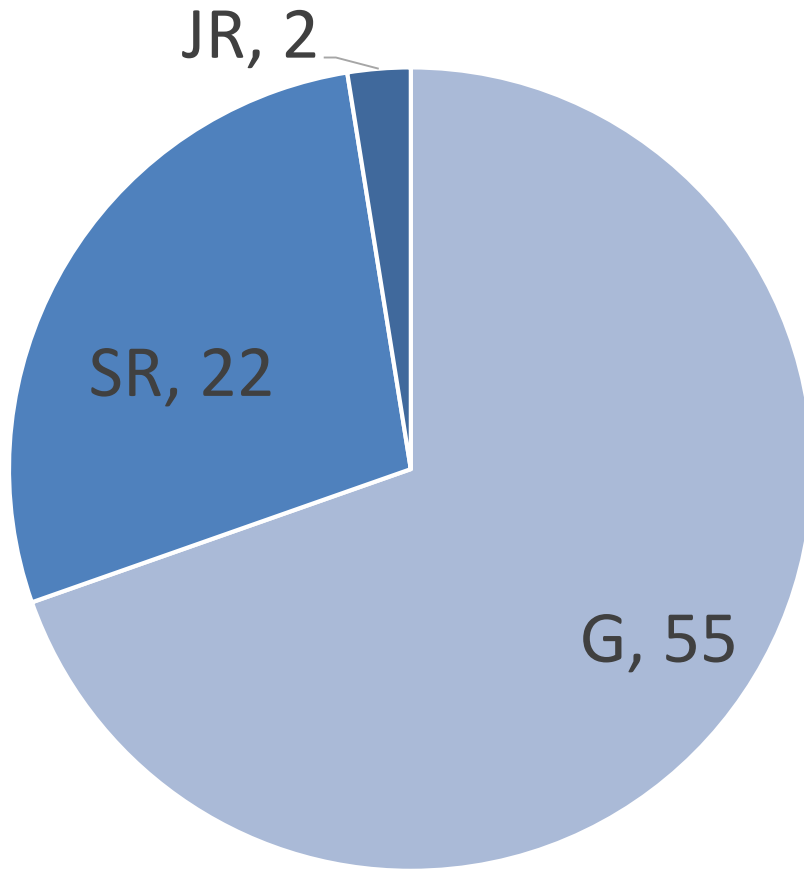


Nagarakshith Sreenivasulu
ROBO MS '21

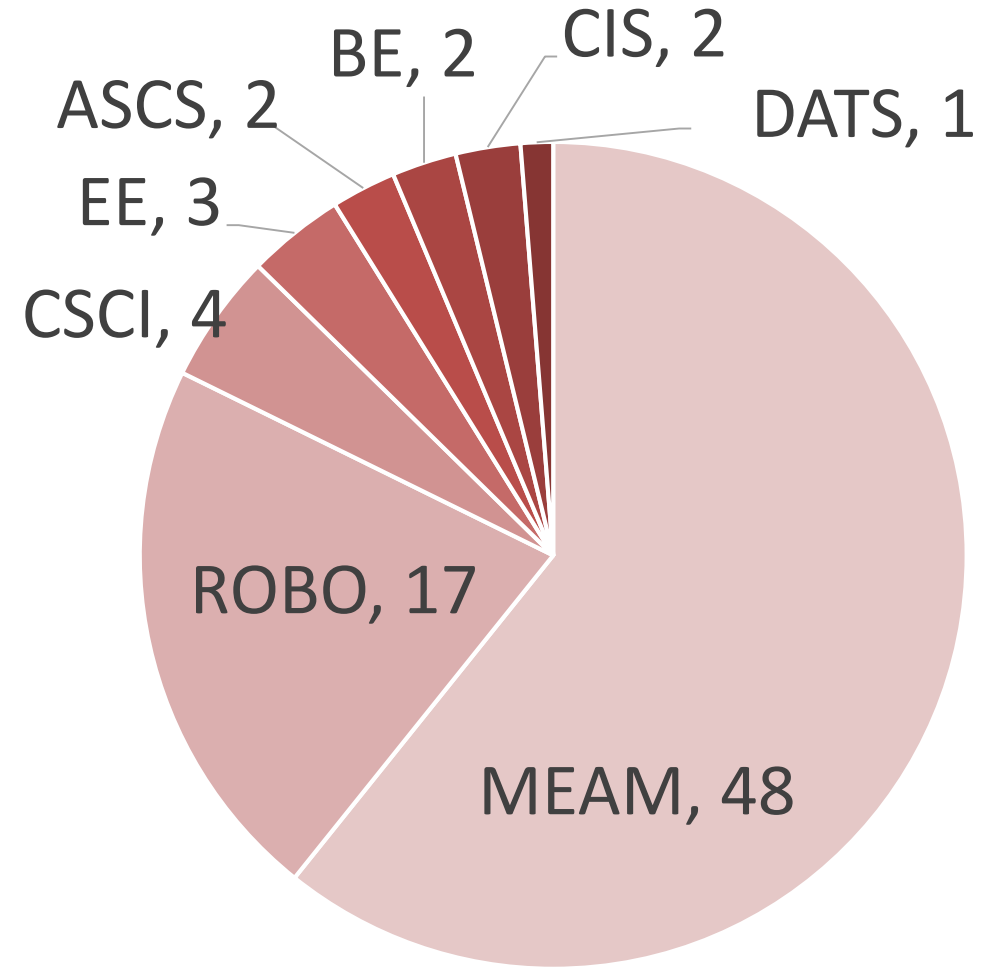


Gabe Unger
MEAM MS '20

Who are you?



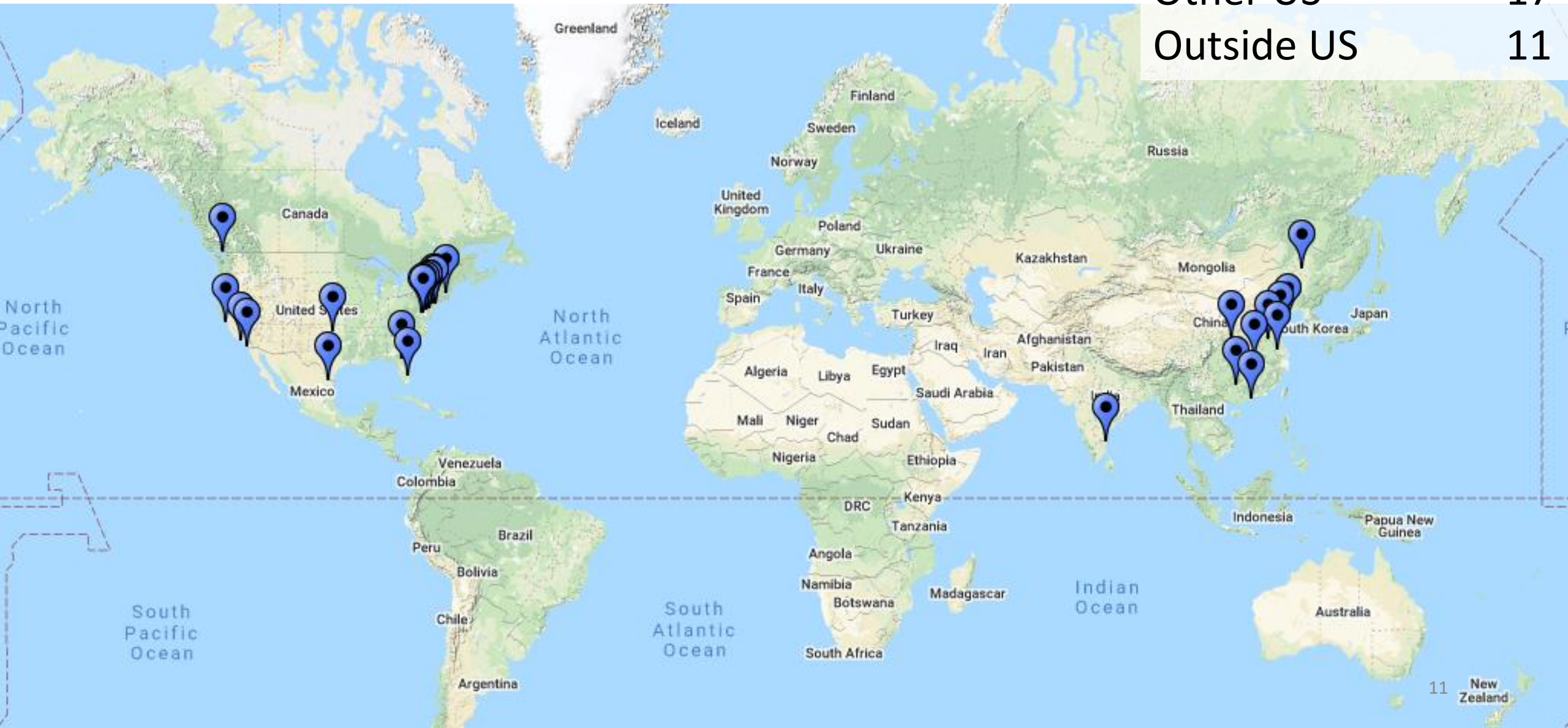
Class



Major

Where are you?

Philadelphia	48
Other PA	3
Other US	17
Outside US	11



What is this class about?

Robots! Particularly manipulator arms and mobile robots

List of topics:

- Translation and rotation in 2D and 3D
- Forward and inverse kinematics for manipulators
- Velocity kinematics
- Trajectory planning
- Statics
- Dynamics



How will we communicate?



Canvas: <https://canvas.upenn.edu>

The screenshot shows the Canvas LMS interface for the course MEAM 520-001 2020C Intro To Robotics. On the left is a sidebar with navigation links: Account, Dashboard, Courses, Calendar, Inbox, Help, and Files. The main content area has a header with the course name and a search bar. Below the header is a navigation menu with links: Home, Syllabus, Piazza, Modules, Class Recordings, Course Materials @ Penn Libraries, Assignments, Grades, People, Search, and Gradescope. The main content area displays the course description, syllabus link, tentative schedule, and live lectures information. At the bottom, there is a calendar view for August 2020.

2020C (Fall 2020)

MEAM 520-001 2020C Intro To Robotics

Description: This course introduces the fundamental kinematic, dynamic, and computational principles underlying most modern robotic systems. The main topics of the course include: homogeneous transformations, manipulator forward kinematics, manipulator inverse kinematics, Jacobians, and trajectory planning. The purpose of the course is to provide you with a mathematical and practical foundation for future explorations into the robotics field.

Syllabus: [Syllabus.pdf](#) (last updated: August 30)

Tentative schedule: [Schedule.pdf](#) (last updated: August 13)

Live lectures TR 12pm at <https://upenn.zoom.us/j/95341324727?pwd=dk5jY2RWRjlvWmM1cVd1ZUFKcXg2dz09>

<--- Click on the Link labeled "Piazza" to see our most recent announcements

Quick Start Guide: [Quick Start Guide](#)

MEAM 520

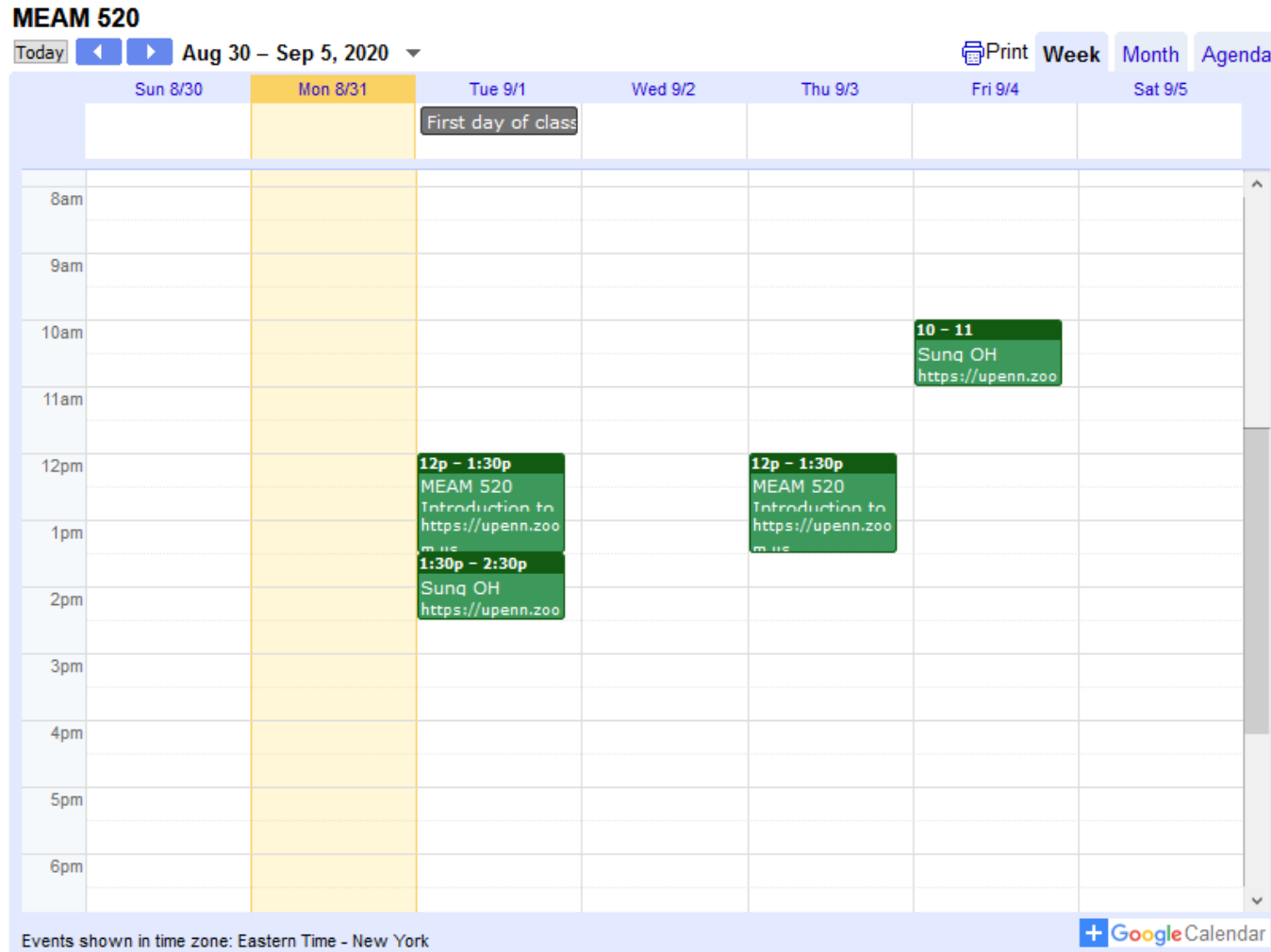
Today | August 2020 | Print | Week | Month | Agenda

Sun	Mon	Tue	Wed	Thu	Fri	Sat
26	27	28	29	30	31	Aug 1
2	3	4	5	6	7	8

- Syllabus
- Assignments
- Grades
- Lecture notes
- Course schedule

How will we communicate?

Google Calendar



- Lecture times and links
- Due dates
- OFFICE HOURS!
Fill in this survey by
Thursday
<https://whenisgood.net/meam520>

How will we communicate?



MEAM 520 Piazza: <https://piazza.com/upenn/fall2020/meam5202020c>

The screenshot displays the Piazza interface for the MEAM 520 2020C course. The top navigation bar includes links for LIVE Q&A, Drafts, and various course resources like logistics, lecture, office_hours, textbook, matlab, lab_general, lymx, ros, lab0, lab1, lab2, lab3, lab4, lab5, final_project, regrade, and other. The user profile for Cynthia Sung is visible in the top right.

The main content area shows a note titled "Welcome to MEAM 520!" by Cynthia Sung. The note includes a welcome message, information about the course resources, and a reminder to post questions on Piazza. The note has 53 views and was updated 18 days ago.

The sidebar on the left shows a list of pinned posts, including "Course FAQs", "Office Hours", "Lecture tomorrow at 12:00 n...", "Textbook for MEAM 520", and "Welcome to MEAM 520!".

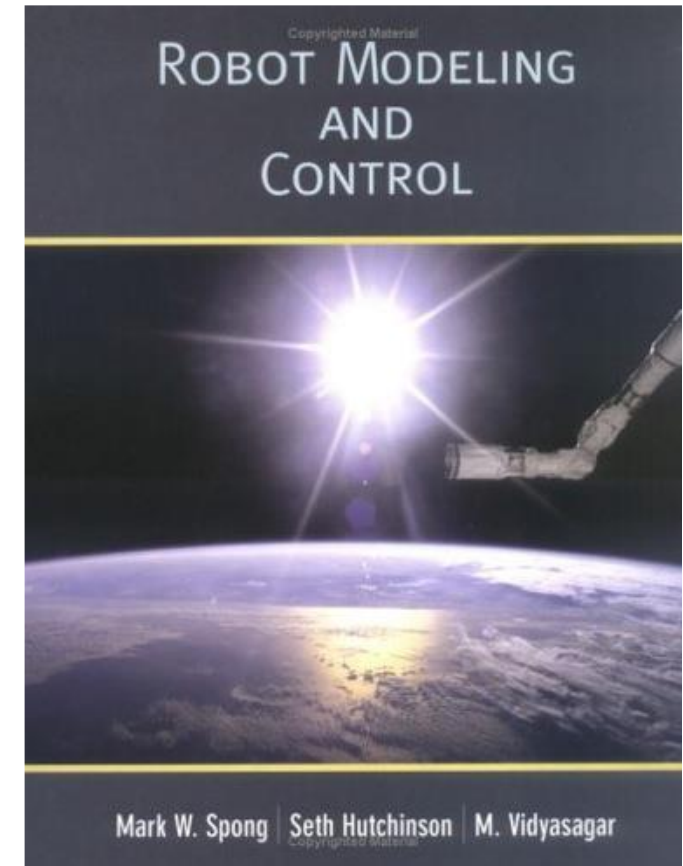
The bottom section of the interface includes a "followup discussions" section for lingering questions and comments, a "Start a new followup discussion" button, and a statistics section showing the average response time (N/A), special mentions (0), and online status (3 online now, 28 this week).

- Questions and comments
- Top participants earn extra credit
- Post anonymously (hidden name) if you don't want other students to identify you
- Post privately (only to instructors) if you think your question may disclose important information about an assignment or if you are asking about something personal.

Textbook

- “Robot Modeling and Control” by Spong, Hutchinson, and Vidyasagar (SHV), published in 2006
- One copy on reserve at Van Pelt library in the Rosengarten Reserve Room
- A list of errors is posted on Canvas. You should transfer them into your copy of the textbook.
- Post new errors **privately** on Piazza for extra credit.

Note, there is a recently published 2nd edition of this text. I have not yet had a chance to read it in depth, but the content is generally the same.



Paper Readings

- Robotics is a dynamic field that is 50-75 years old.
- New developments are happening now and do not always appear in a textbook.
- We will be supplementing our readings with papers (~4) throughout the semester.

What background is required?

- Knowledge of simple geometry (sine, cosine)
- Linear algebra (matrices and vectors)
- Previous programming experience (MATLAB/Python preferred)

Come talk to me if you are concerned about your background!

Tentative Schedule (posted on Canvas)

Position/Orientation Planning Velocity	Lecture	Topic
	1	Introduction
	2	Background and Definitions
	3	Rotations in 2D and 3D
	4	Homogeneous Transformations
	5	Forward Kinematics of a Serial Manipulator
	6	Denavit-Hartenberg Parameters
	7	Inverse Position Kinematics
	8	Inverse Orientation Kinematics
	9	Quaternions
	10	Trajectory Planning in Joint Space
	11	Trajectory Planning in Configuration Space
	12	Probabilistic Trajectory Planning
	13	Velocity Kinematics
	14	More Velocity Kinematics
	15	Inverse Velocity Kinematics

Lecture	Topic	Statics and Dynamics
16	Jacobians and Statics	
17	Trajectory Planning with Potential Fields	
18	Real-Time Planning	
19	Joint Space Dynamics	
20	More Joint Space Dynamics	Control
21	Actuation and Control	
22	PID Control	
23	Sensing and State Estimation	
24	Modern Planning and Control	Extensions
25	Special Topics	
26	Special Topics	
27	Special Topics	
28	Final Presentations	
29	Final Presentations	

Labs

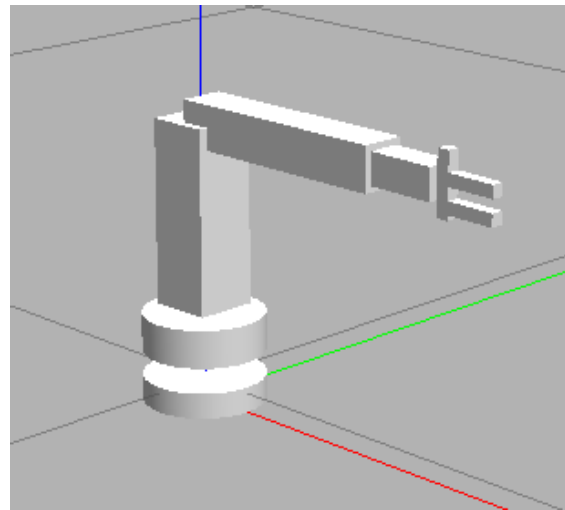
Theory from lecture will be complemented by virtual experiments in ROS

Short demo in class on Thursday

6 Labs (due every 2 wks):

- Lab 0: Get familiar with the hardware (10 pts) Lab 0 due Sep. 9!
- Labs 1-5: Apply concepts from class (50 pts each)

This is the first year we are using ROS for labs in this class. Please be patient with the setup. Let us know if you find any bugs or have any questions!





MATLAB® combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly.

<https://www.mathworks.com/>

- Need to learn MATLAB? Try the online tutorial, which takes about one hour: <https://matlabacademy.mathworks.com/>
- SEAS lets all engineering students install MATLAB on their personally owned computer.
Installation (PennKey login required):
<https://www.seas.upenn.edu/cets/software/matlab/student/>



Python's elegant syntax and dynamic typing, together with its interpreted nature, make it an ideal language for scripting and rapid application development in many areas on most platforms.

<https://www.python.org/>

- Need to learn Python? This is the official tutorial: <https://docs.python.org/2/tutorial/index.html>
- Python is free and distributed under an OSI-approved open source license.

Final Project

Open-ended project equivalent in effort to 1 lab / person

- Proposal (5 pts)
- Presentation (10 pts)
- Final report (60 pts)

We'll talk more about this later.

There are no exams.

What questions do you have?

What is a robot?

Write your own criteria for what a robot is.

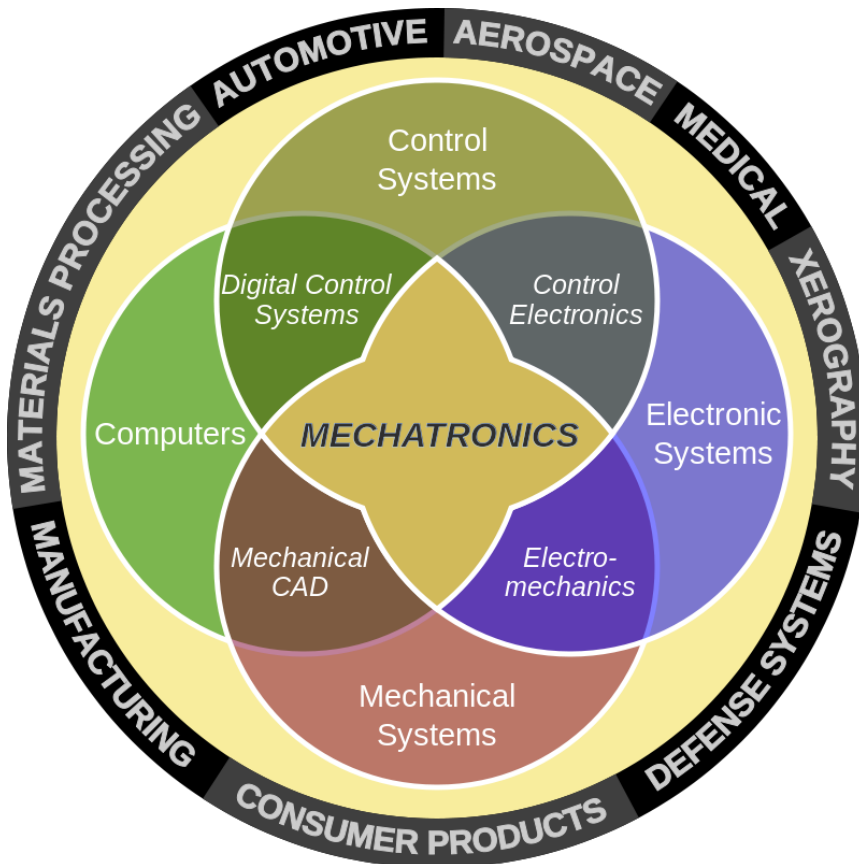
We're going to go into breakout rooms of ~5 people.

1. Introduce yourself (name, year, favorite robot)
2. Agree on criteria for what makes a robot
3. Enter your major keywords at <https://pollev.com/meam520>

What is robotics?

Robotics is a subset of Mechatronics, the synergistic integration of mechanics, electronics, controls, and computer science.

Preface of SHV



From: RPI

The robot is the ultimate mechatronic system.

What is a robot?

Robot Institute of America (RIA):

A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

Kevin Dowling, CMU:

Force through intelligence. Where AI meets the real world.

Rodney Brooks, MIT:

A machine that acts and reacts.

A brief history of robotics



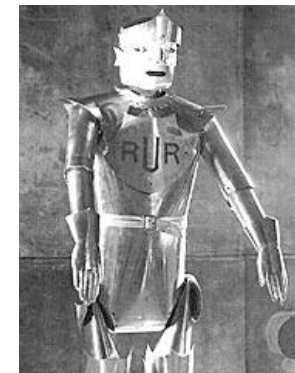
322 B. C. – “If every tool, when ordered, or even of its own accord, could do the work that befits it... then there would be no need either of apprentices for the master workers or of slaves for the lords.” – Aristotle

1495 – Leonardo da Vinci designs a mechanical clockwork device that sits up, waves its arms, and moves its head.



1769 – Wolfgang von Kempelen builds “The Turk,” which gains fame as an **automaton** capable of playing chess – until the hidden human operator was discovered!

1921 – Karel Capek popularizes the term ‘**robot**’ in a play called *R.U.R. (Rossum’s Universal Robots)*, wherein robot workers take over the earth.

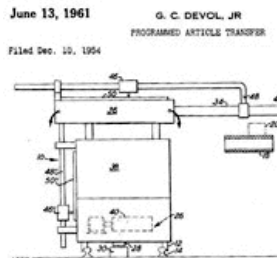
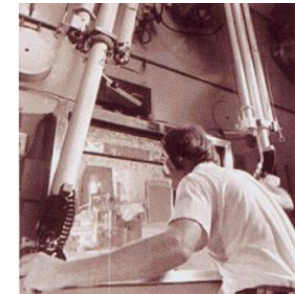


A brief history of robotics



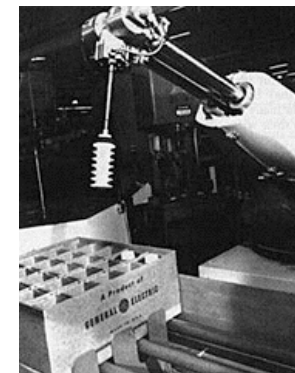
1942 – Isaac Asimov publishes *Runaround*, a short story that introduces the three ‘laws’ of robotics.

1951 – Raymond Goertz builds the first master/slave teleoperation system for handling radioactive material.



1954 – George Devol files a patent for the first programmable robot, and calls it ‘universal automation.’

1961 – *Unimate*, the first industrial robot, begins work on a General Motors assembly line. Since then, robots have been increasingly used in manufacturing.



Mobile robots



1966 –Shakey, the first mobile robot to navigate autonomously (Stanford Research Institute)



1988 –The first walking robot to carry a human driver (Ohio State University)



2002 - The Roomba robotic vacuum from the iRobot Corp. is released. Over 20 M sold by 2017.

Industrial versus Service Robots

What is a service robot?

Industrial Robots



Industrial environments

Service Robots

Professional Use



Personal/domestic



Non-industrial environments

Picture source: Goldbeck, ;KUKA AG, Bosch Bonirob, Hetwin, SMP Robotics, Omron, International Submarine Engineering , Robert Bosch Hausgeräte , Wonder Workshop

Manufacturing



(80% automation)



(50% automation)



(10% automation)

Healthcare

1 Surgical robots

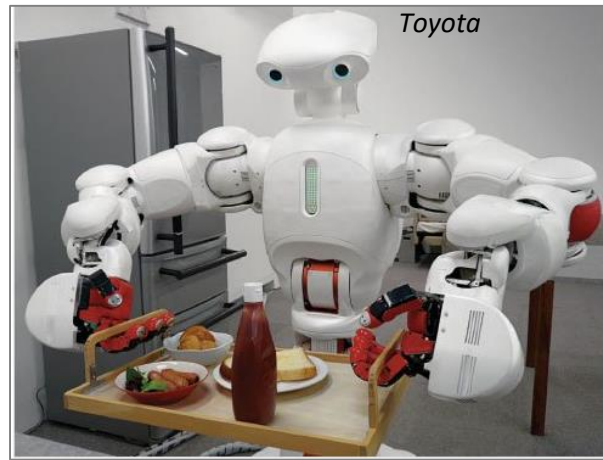
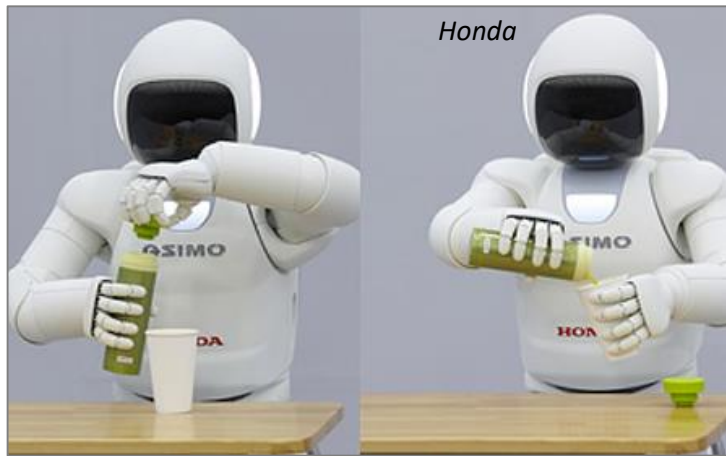


2 Brain Machine Interfaces

CBS 60 Minutes, December 30, 2012



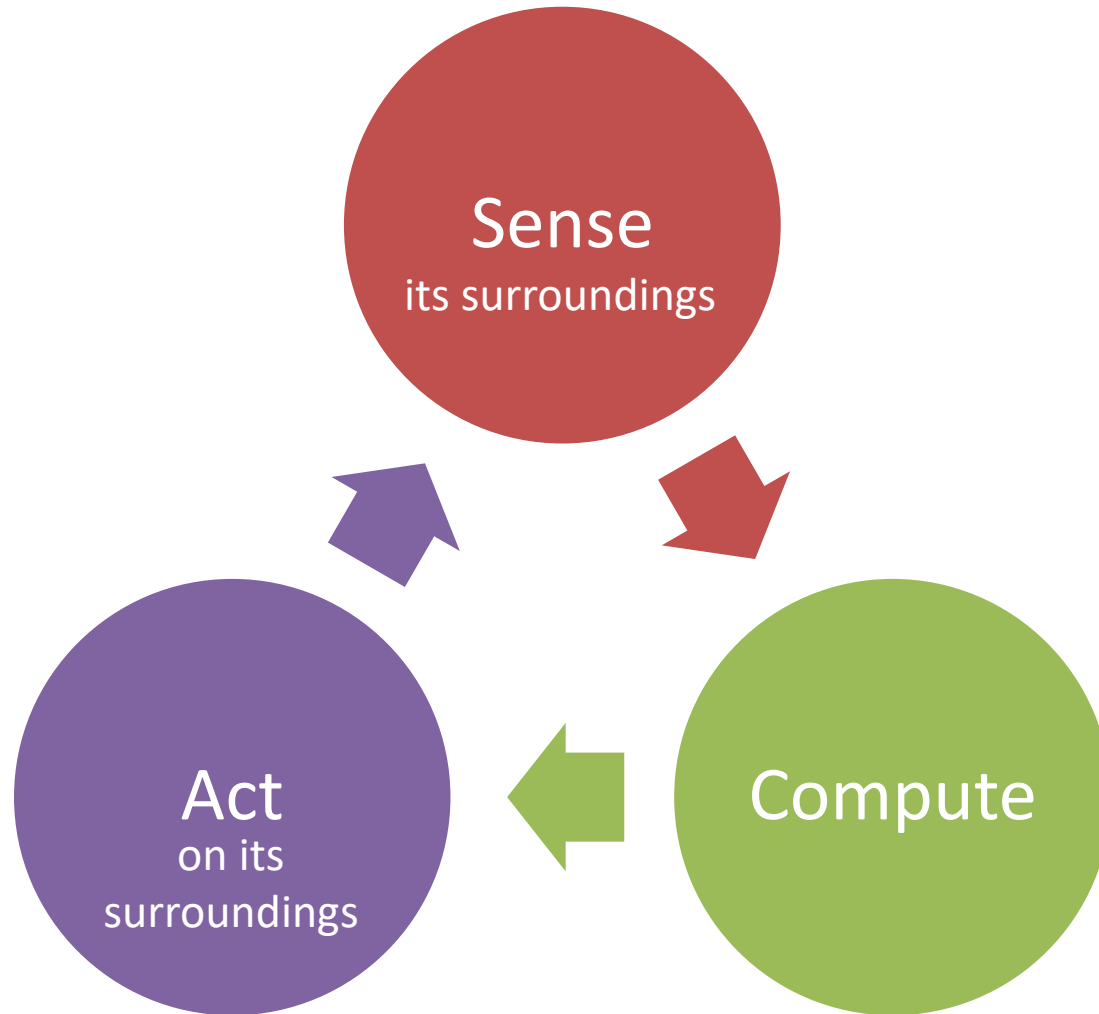
3 Personal assistants



4 Healthcare facility logistics



What is a robot?

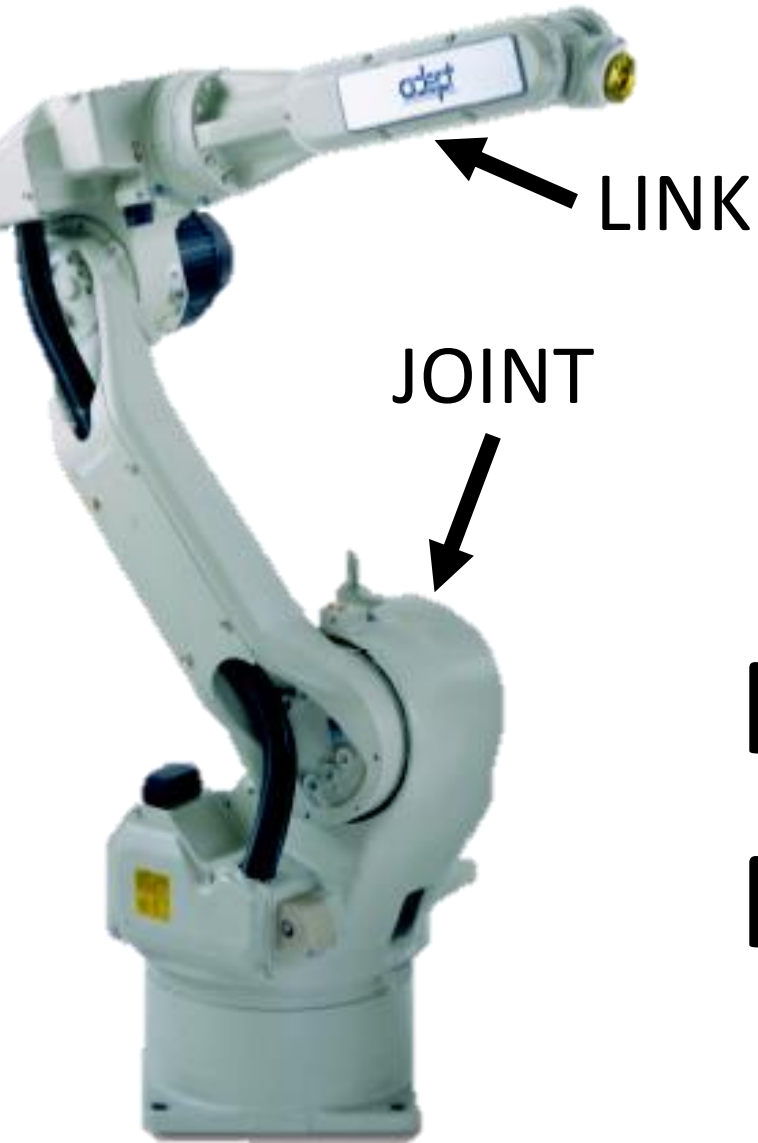


MEAM 520 focuses on
Compute > Act

Other classes in the Robotics curriculum

- MEAM 510: Act > Sense
- MEAM 620: Sense > Compute

Robot Manipulators



Are composed of

- Rigid **links**
- Connected by **joints**
- To form a **kinematic chain**.

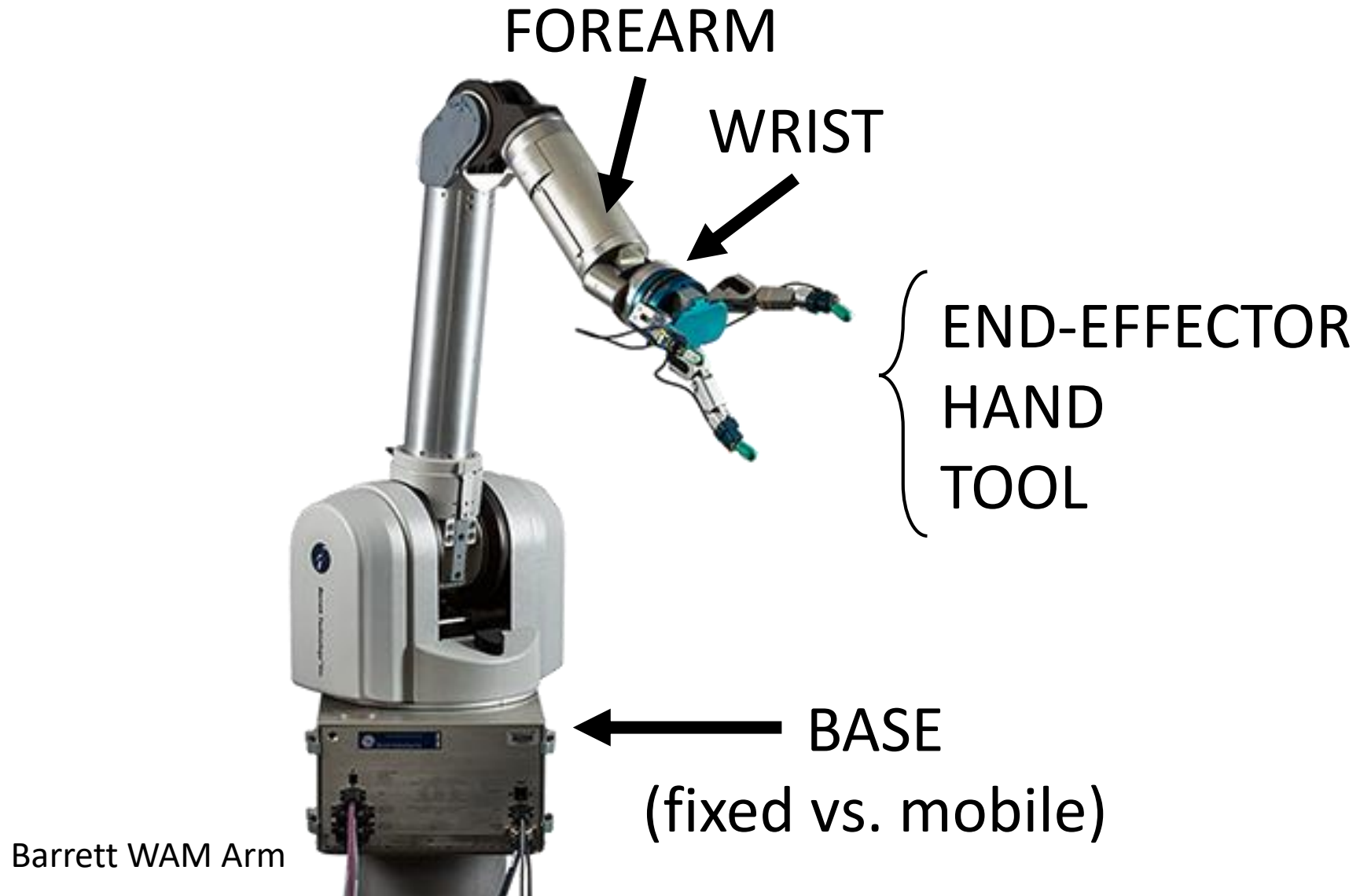
There are two types of basic **joints**:

- R** • Revolute (rotary), like a hinge, allows relative rotation between two links
- P** • Prismatic (linear), like a slider, allows a relative linear motion (translation) between two links

How to draw **R** and **P** joints

	Revolute	Prismatic	Examples
2D			
3D			

Parts of a manipulator



Symbolic representation



Types of Manipulators

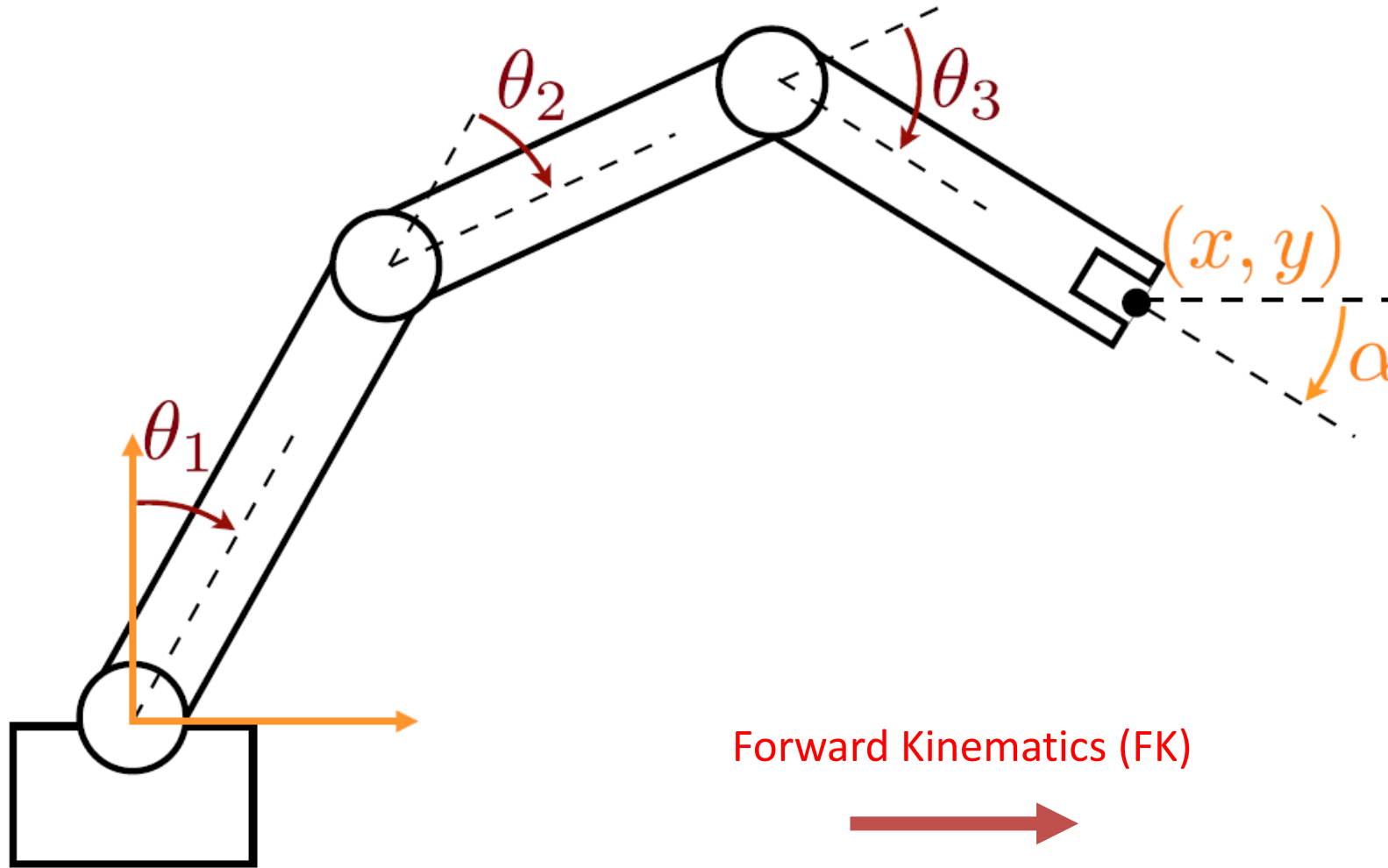


SERIAL



PARALLEL

Next few weeks: Forward Kinematics



Next time

Chapter 1: Introduction

- Read Sec. 1.intro-1.3
- Find the error(s) in Fig. 1.17
- Skim Sec. 1.4
(Outline of the text)

