Welcome to

MEAM 520
Introduction to Robotics

Cynthia Sung, Ph.D.

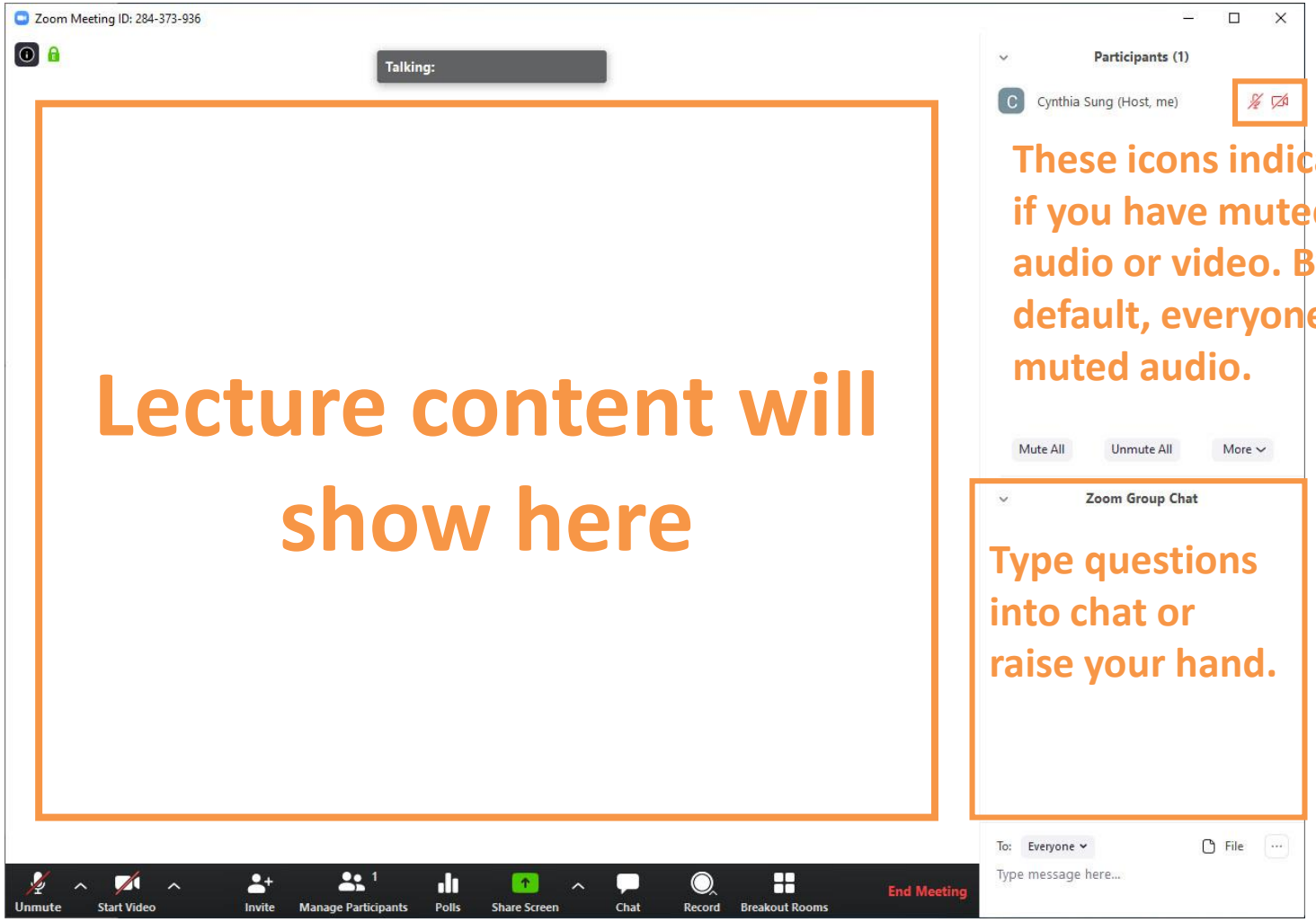
Mechanical Engineering & Applied Mechanics

University of Pennsylvania

Lecture 1

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

Welcome to Zoom lectures



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

Penn Engineering | GRASP Laboratory

General Robotics, Automation, Sensing & Perception Lab

Who am I?

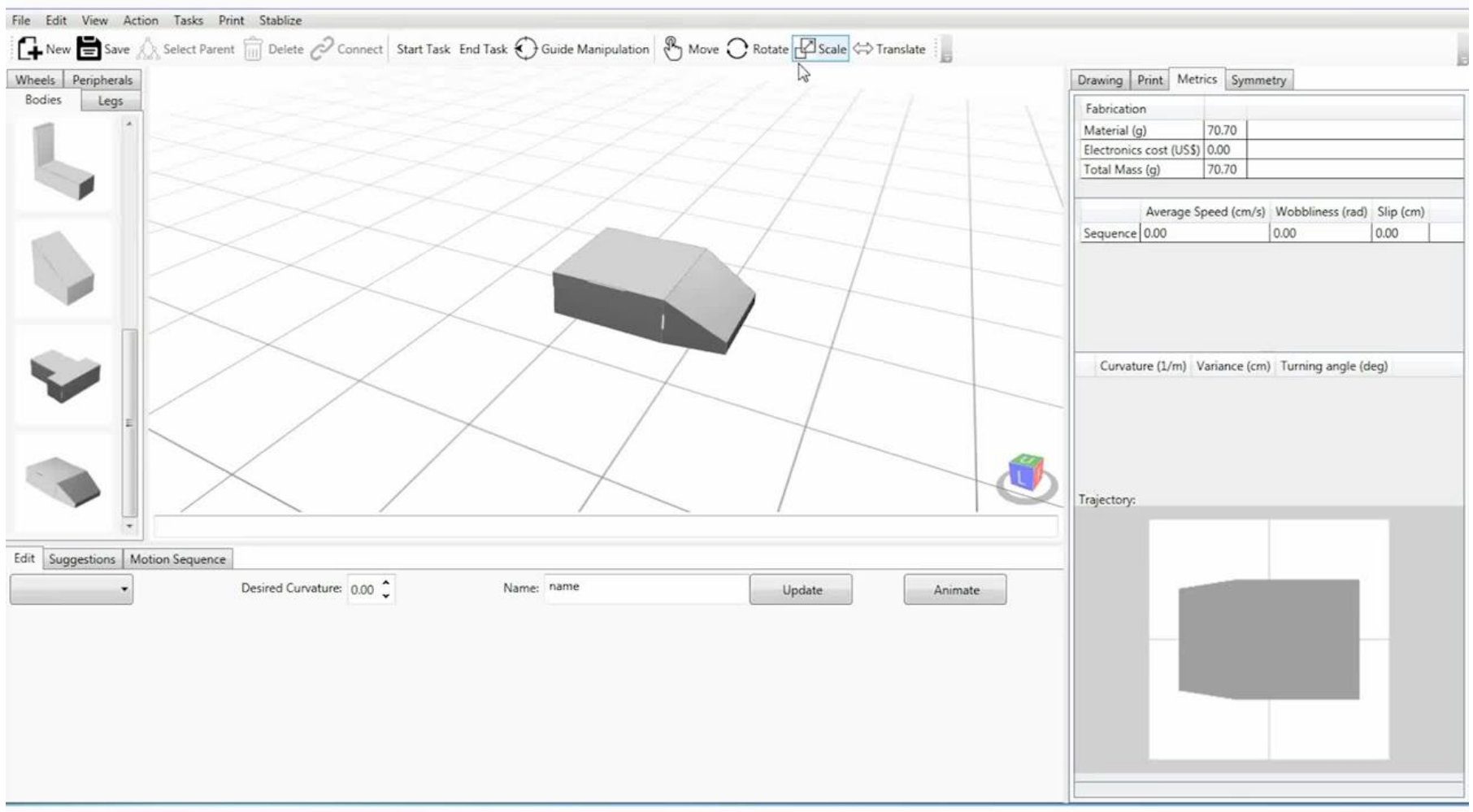
I joined Penn faculty in January 2017; this is my third year at Penn.

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

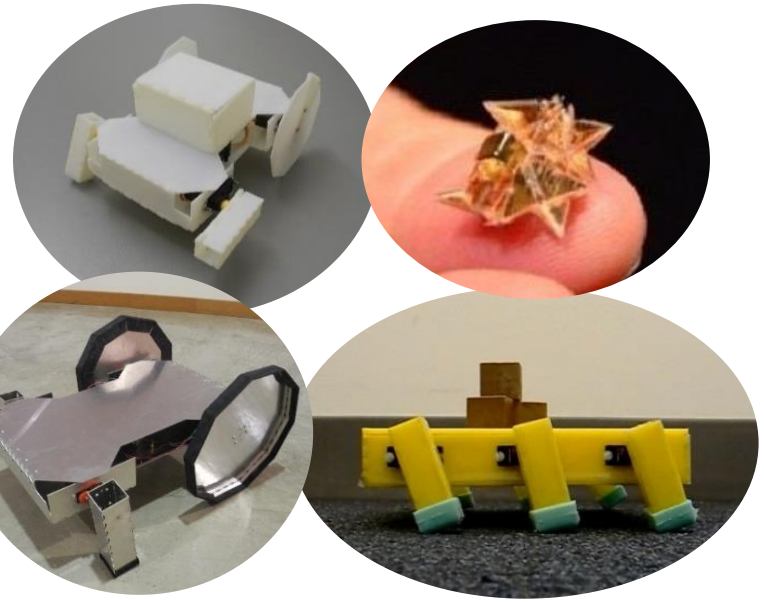
My primary research interests are:

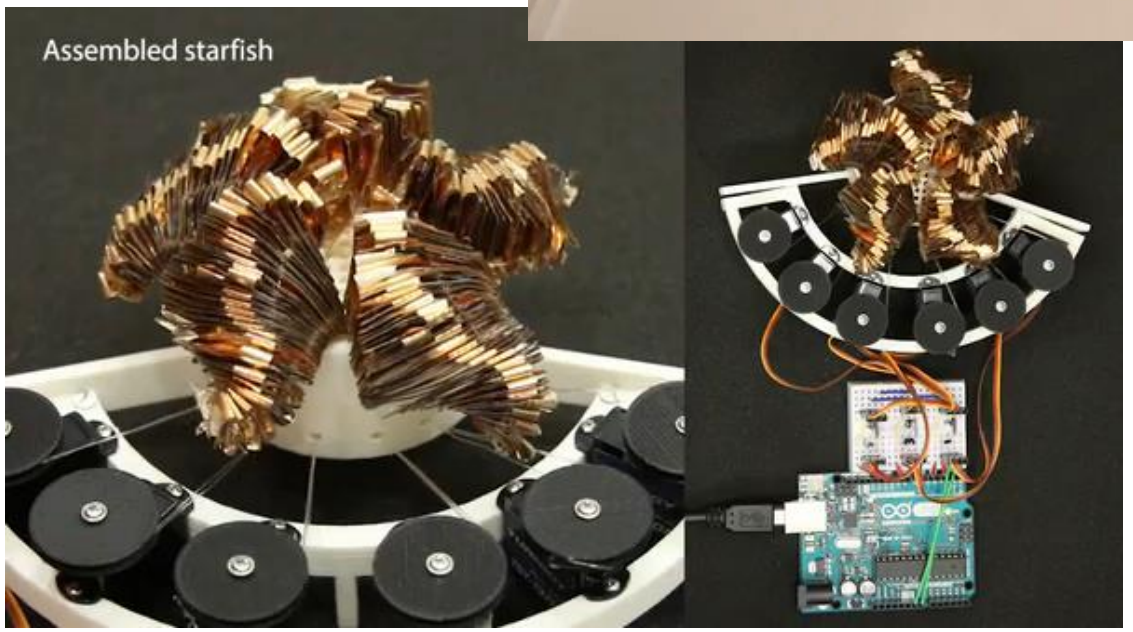
- Making computational tools for designing custom robots
- Developing new fabrication methods for creating custom robots
- Origami robots

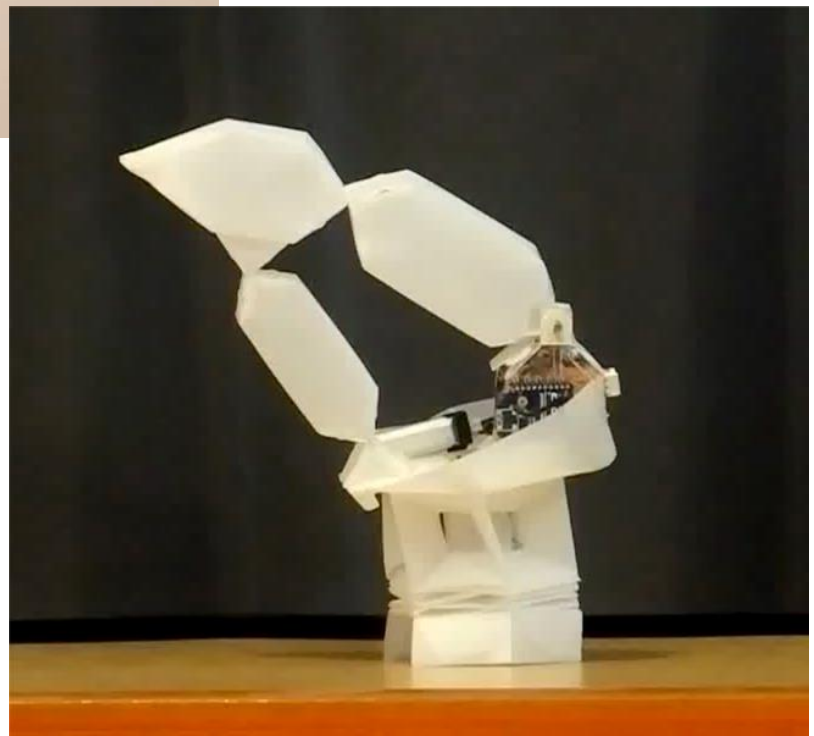
Who am I?


File Edit View Action Tasks Print Stablize
New Save Select Parent Delete Connect Start Task End Task Guide Manipulation Move Rotate Scale Translate
Wheels Peripherals
Bodies Legs
Drawing Print Metrics Symmetry
Fabrication
Material (g) 70.70
Electronics cost (US$) 0.00
Total Mass (g) 70.70
Average Speed (cm/s) Wobbliness (rad) Slip (cm)
Sequence 0.00 0.00 0.00
Curvature (1/m) Variance (cm) Turning angle (deg)
Trajectory:
Edit Suggestions Motion Sequence
Desired Curvature: 0.00
Name: name
Update
Animate

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

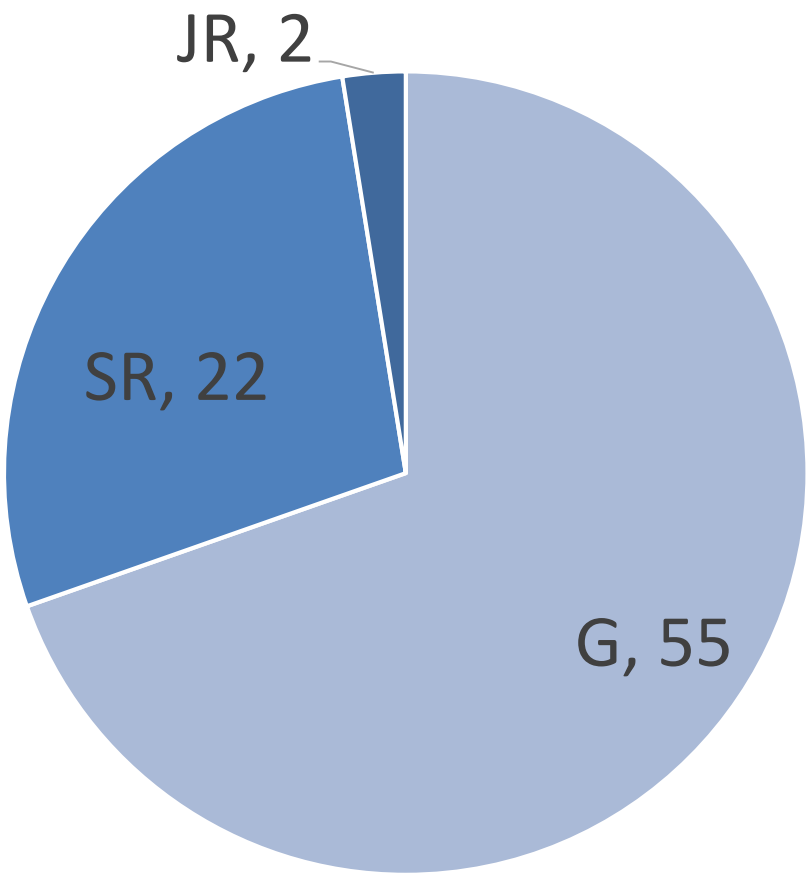
Ray Bjorkman
ROBO MS ‘21

Zichen Lao
MEAM MS ‘21

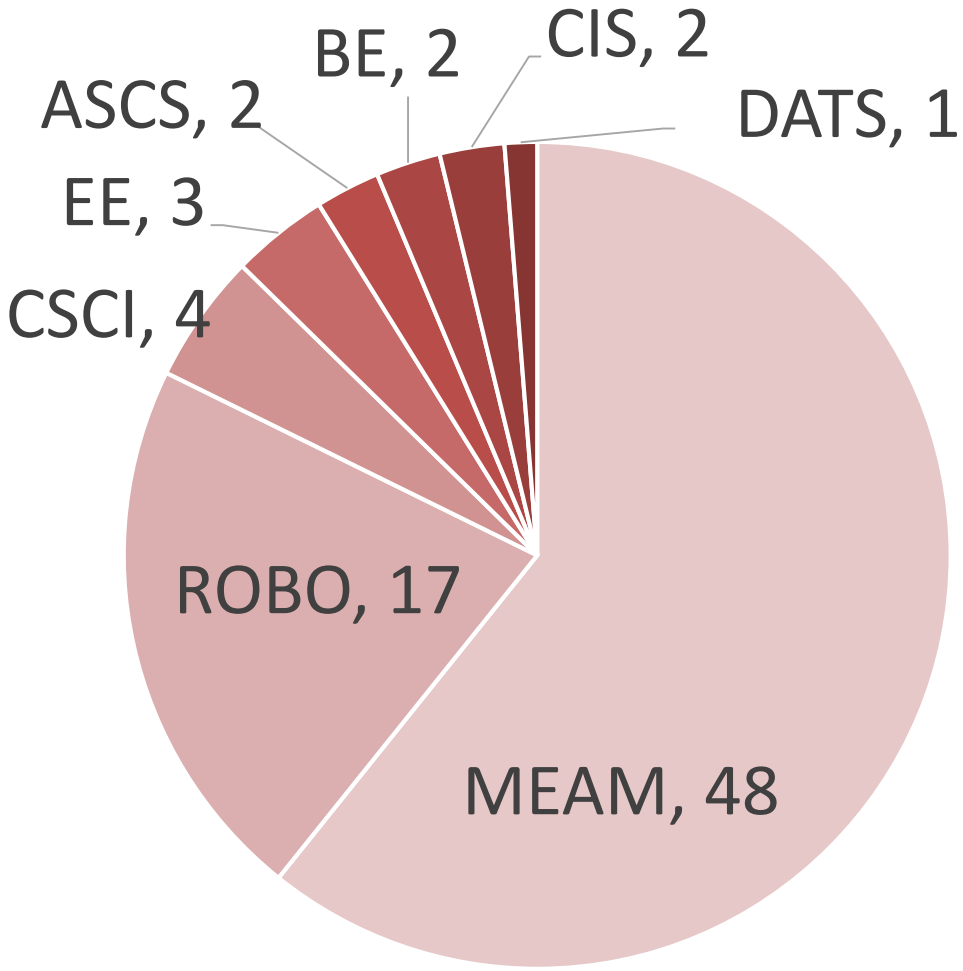
Nagarakshith Sreenivasulu
ROBO MS ‘21

Gabe Unger
MEAM MS ‘20

Who are you?



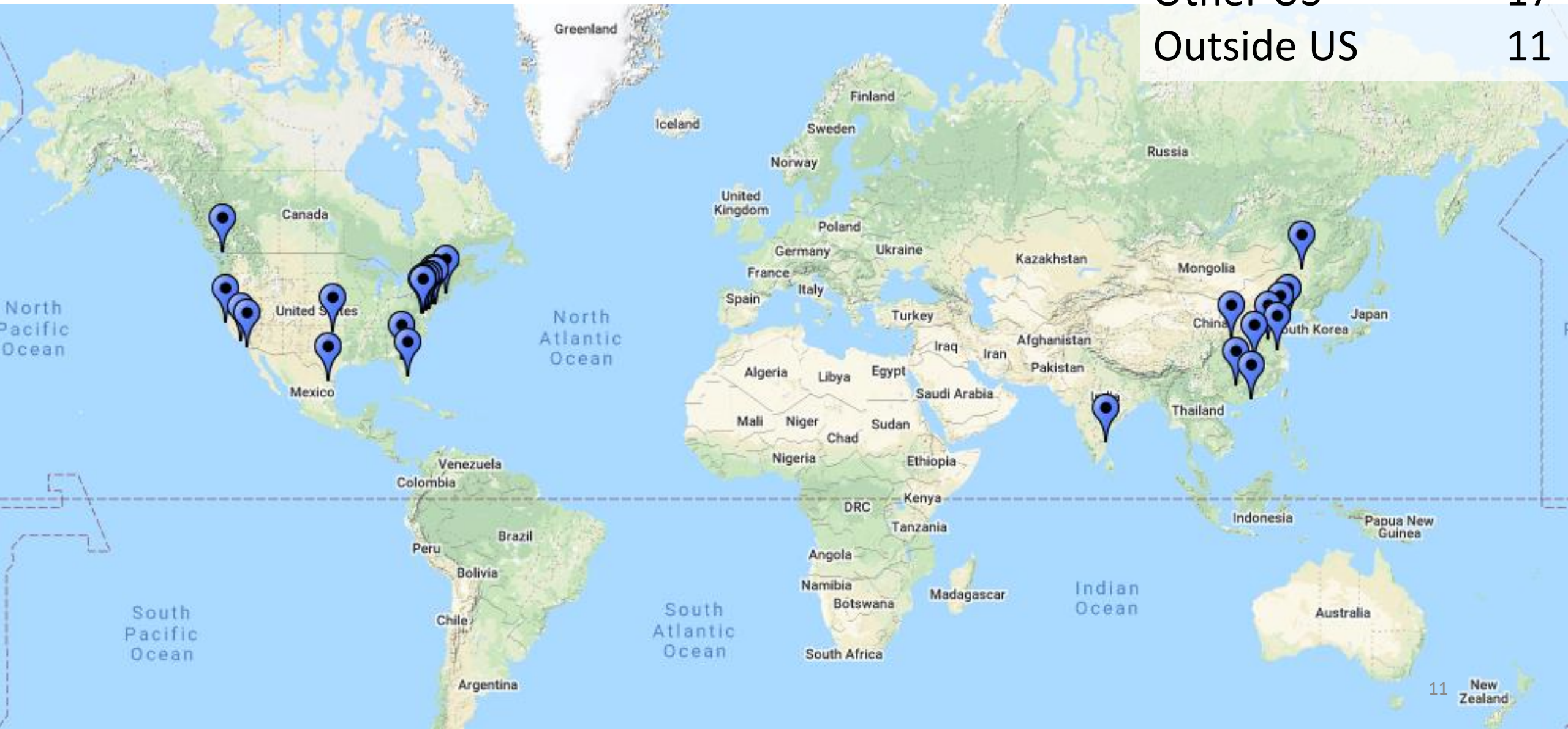
Class



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

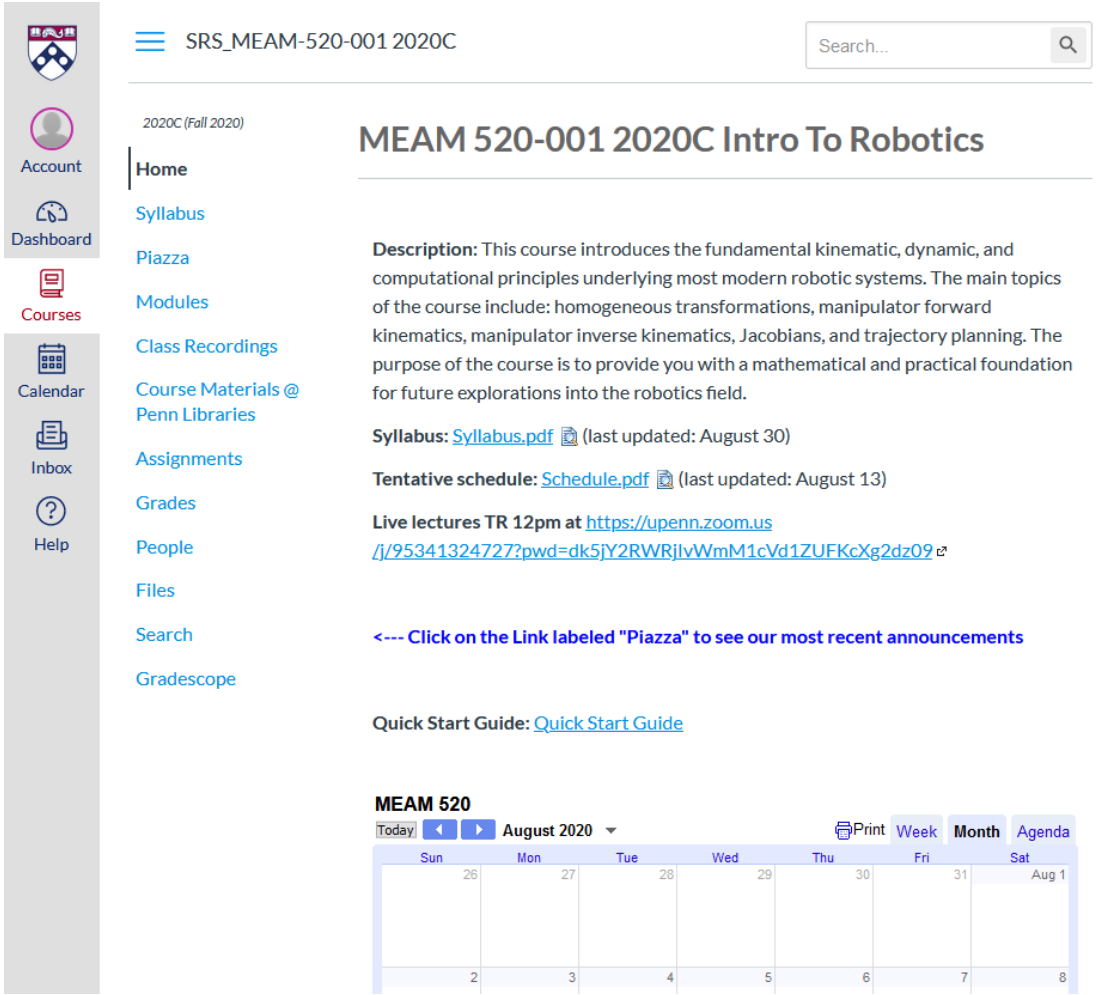
List of topics:

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

How will we communicate?

canvas

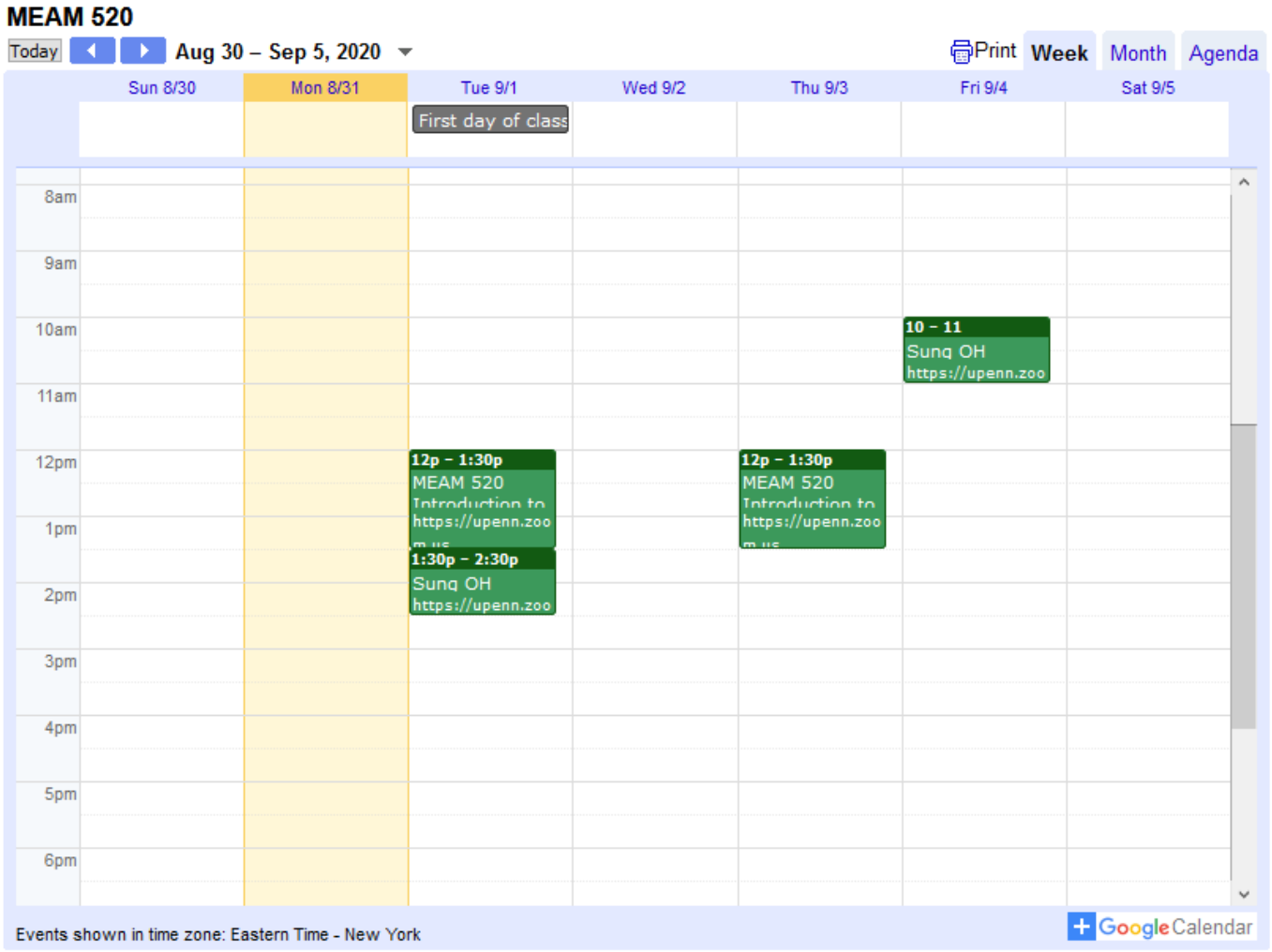
Canvas: https://canvas.upenn.edu



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

How will we communicate?

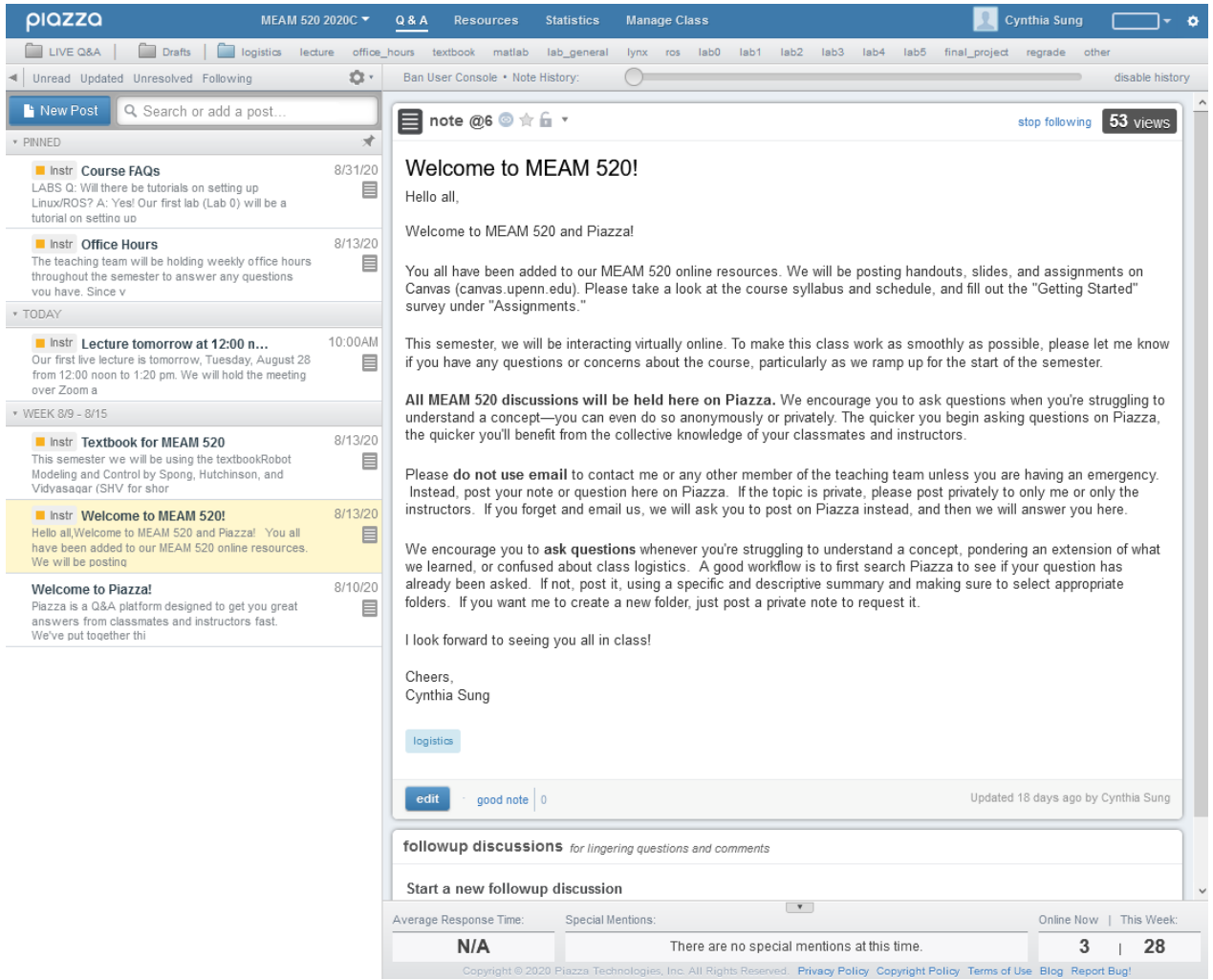
Google Calendar



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

How will we communicate?

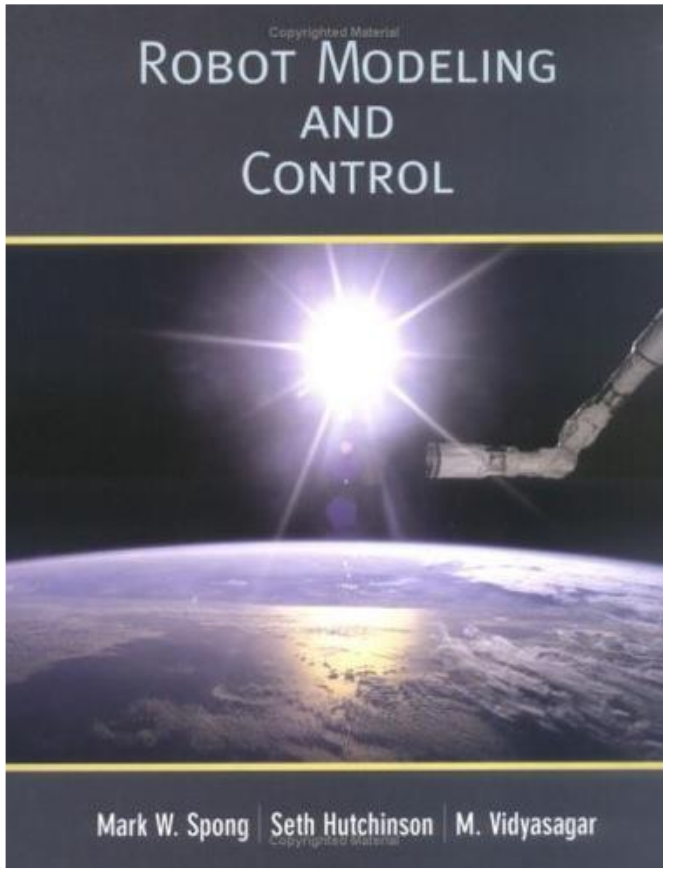
MEAM 520 Piazza: https://piazza.com/upenn/fall2020/meam5202020c



- 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

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

Planning

Lecture	Topic
10	Trajectory Planning in Joint Space
11	Trajectory Planning in Configuration Space
12	Probabilistic Trajectory Planning

Velocity

Lecture	Topic
13	Velocity Kinematics
14	More Velocity Kinematics
15	Inverse Velocity Kinematics

Statics and Dynamics

Lecture	Topic
16	Jacobians and Statics
17	Trajectory Planning with Potential Fields
18	Real-Time Planning
19	Joint Space Dynamics
20	More Joint Space Dynamics

Control

Lecture	Topic
21	Actuation and Control
22	PID Control
23	Sensing and State Estimation
24	Modern Planning and Control

Extensions

Lecture	Topic
25	Special Topics
26	Special Topics
27	Special Topics
28	Final Presentations
29	Final Presentations

Labs

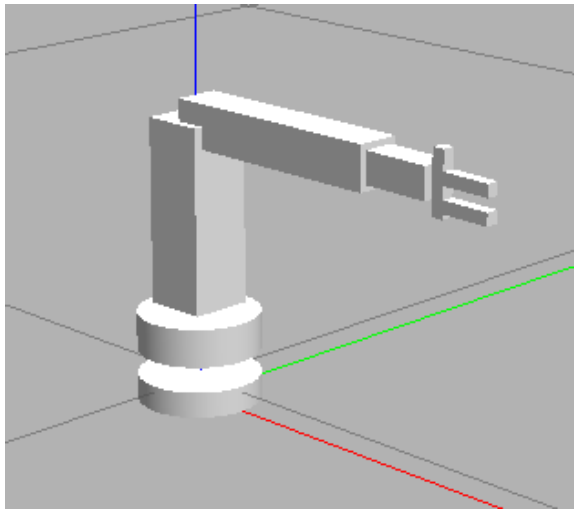
Theory from lecture will be complemented by virtual experiments in ROS

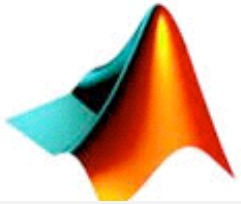
Short demo in class on Thursday

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

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.

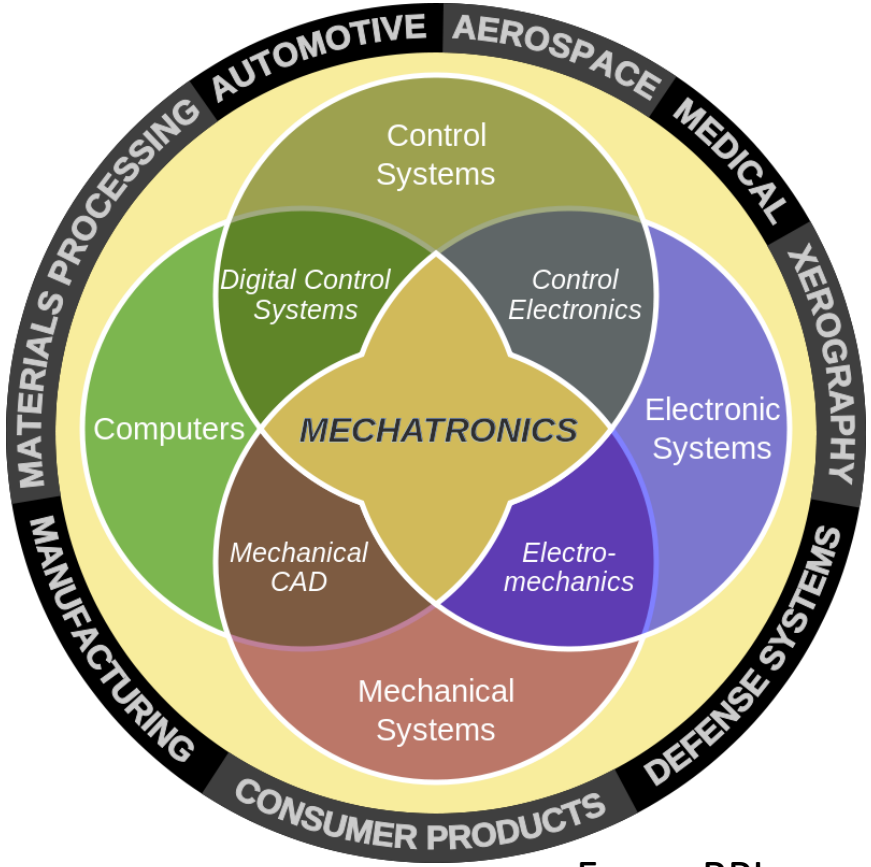
We're going to go into breakout rooms of ~5 people.

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.

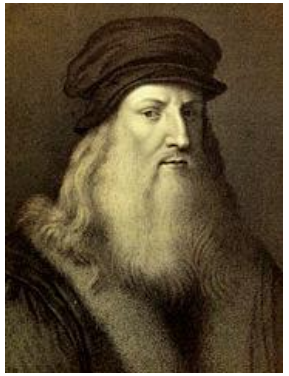
Rodney Brooks, MIT:

A machine that acts and reacts.

A brief history of robotics

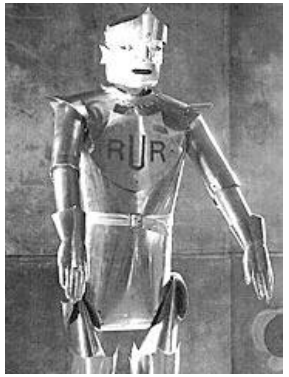
322 B. C. – “If every tool, when ordered, or even of its own accord, could do the work that befits it… then there would be no need either of apprentices for the master workers or of slaves for the lords.” – Aristotle

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



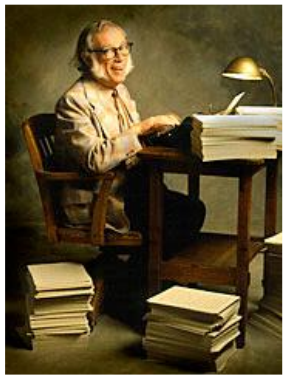
1769 – Wolfgang von Kempelen builds “The Turk,” which gains fame as an **automaton** capable of playing chess – until the hidden human operator was discovered!

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.



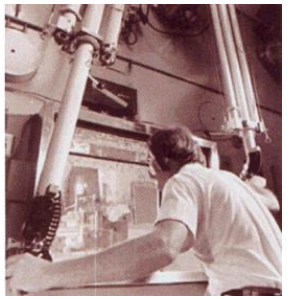
Adapted from “25 Great Moments in Robotics History” on *The Mr. Beng* Blog

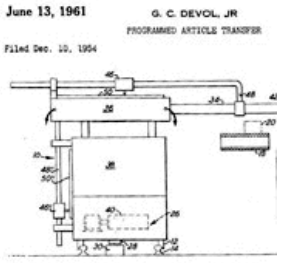
A brief history of robotics



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

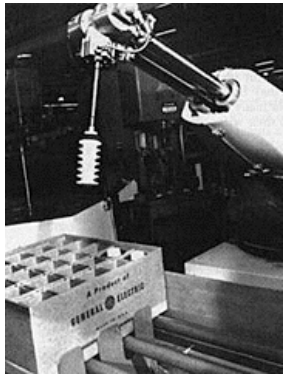
1951 – Raymond Goertz builds the first master/slave teleoperation system for handling radioactive material.





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.



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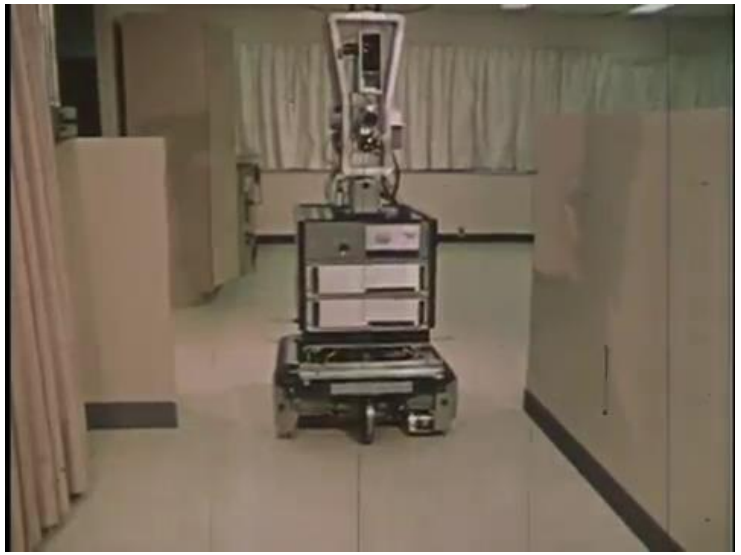
Mobile robots



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

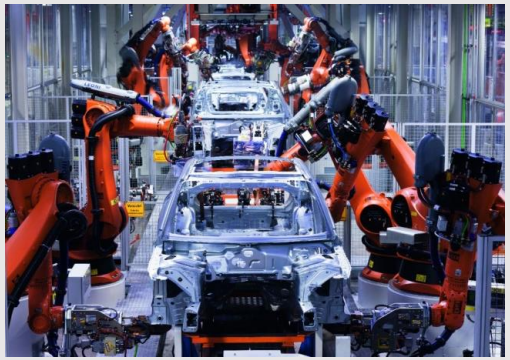
1988 –The first walking robot to carry a human driver (Ohio State University)

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

Slide courtesy of Vijay Kumar

Manufacturing

(80% automation)

(50% automation)

(10% automation)

Slide courtesy of Vijay Kumar

Healthcare

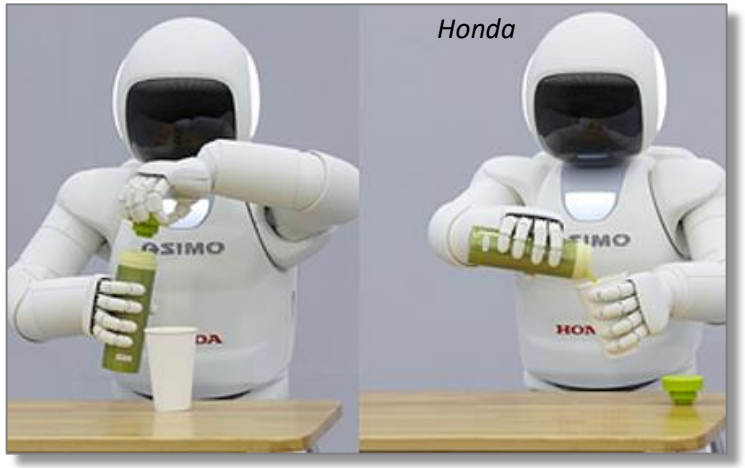
1 Surgical robots

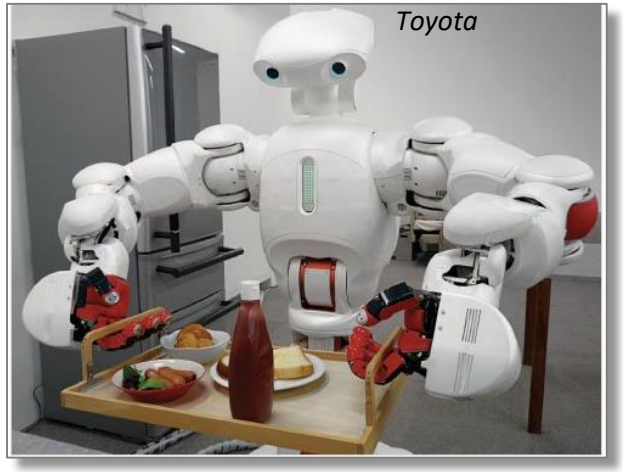
Intuitive Surgical

2 Brain Machine Interfaces

CBS 60 Minutes, December 30, 2012

3 Personal assistants

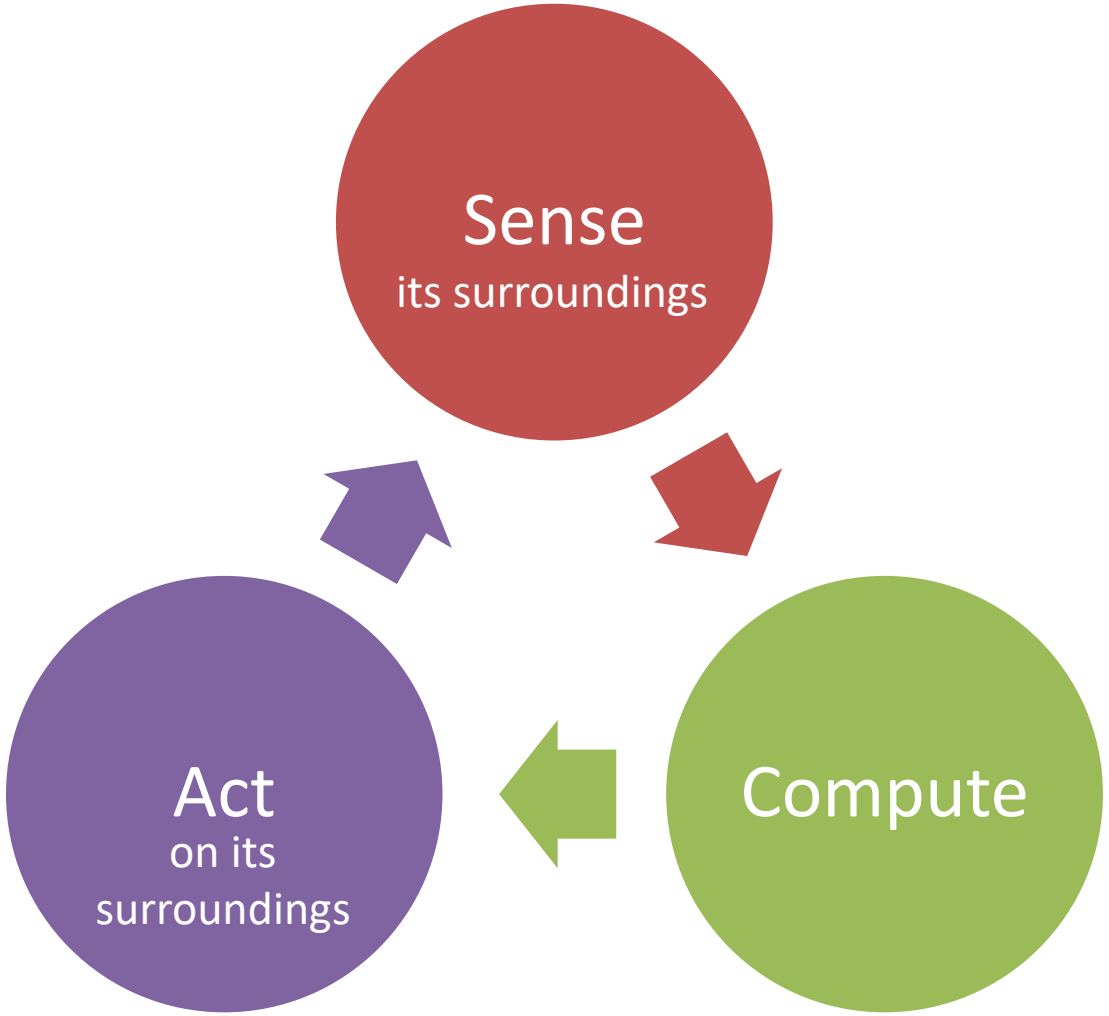




4 Healthcare facility logistics

Slide courtesy of Vijay Kumar

What is a robot?

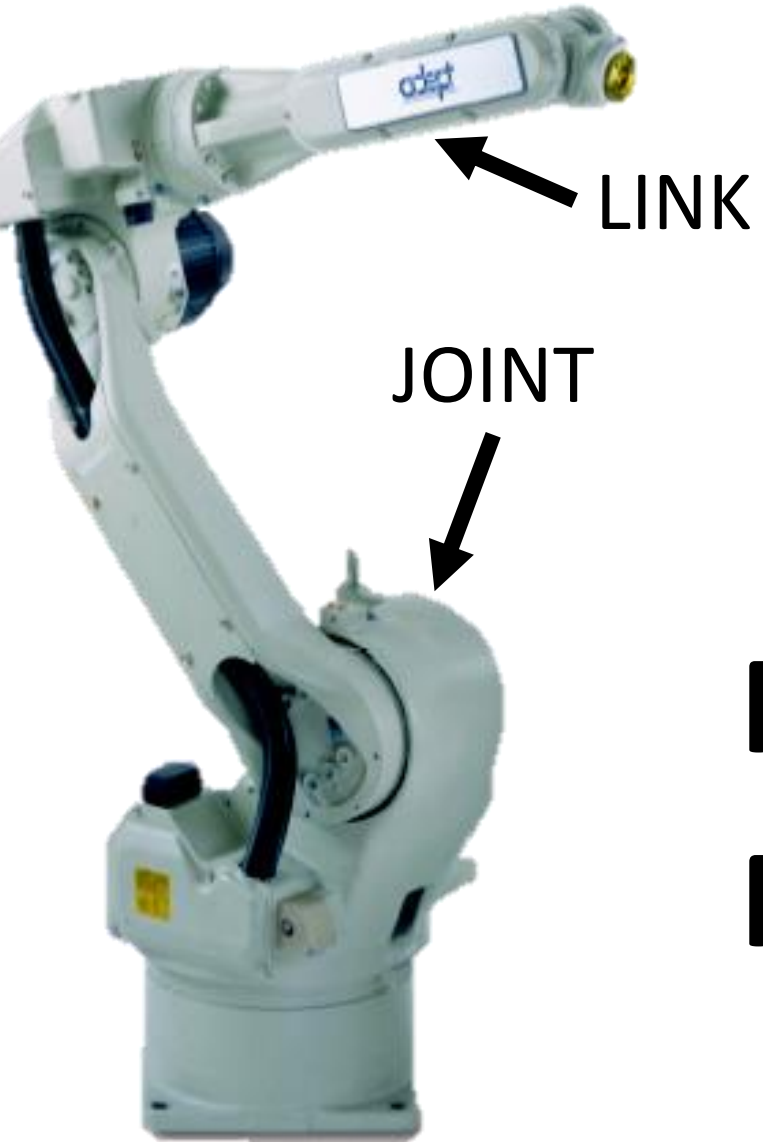


MEAM 520 focuses on
Compute > Act

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**:

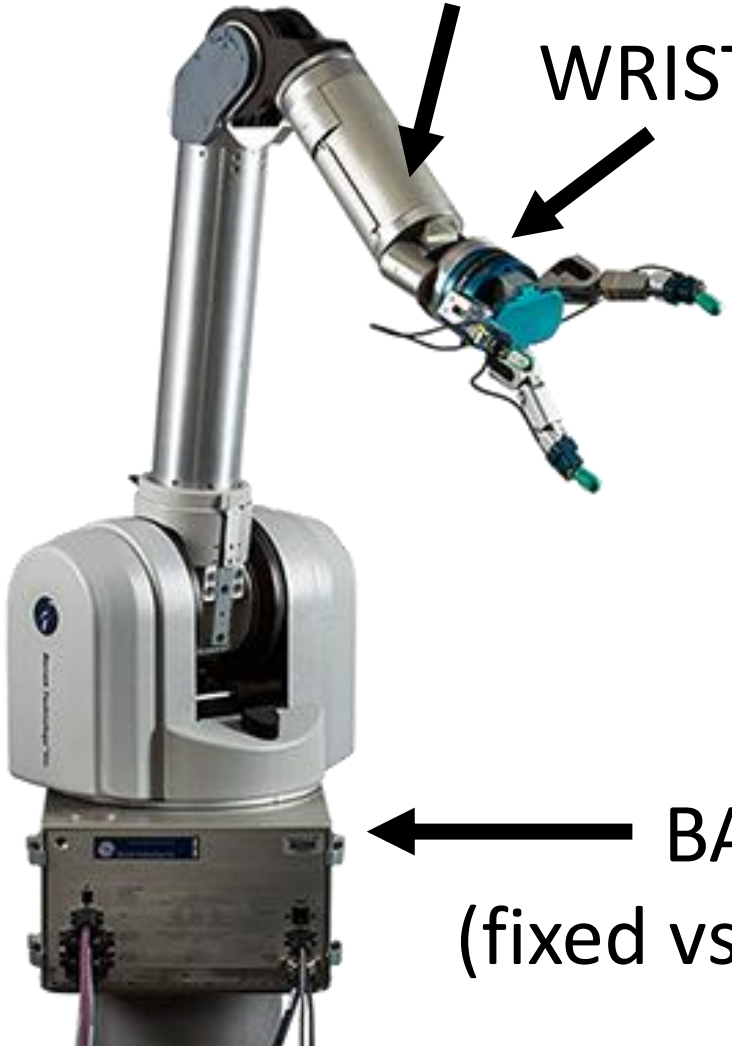
R
- Revolute (rotary), like a hinge, allows relative rotation between two links

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



Barrett WAM Arm

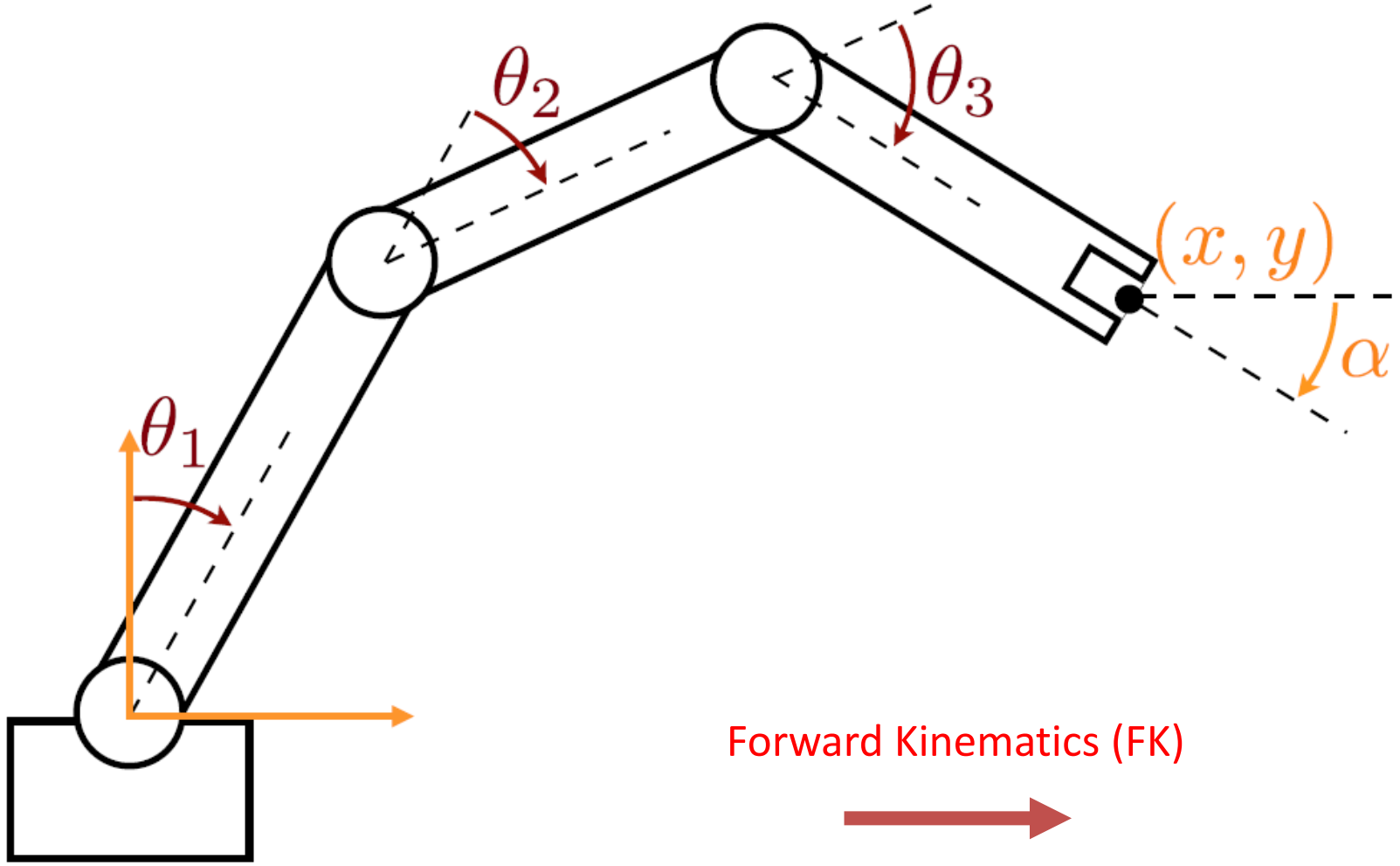
Symbolic representation

Types of Manipulators

SERIAL

PARALLEL

Next few weeks: Forward Kinematics



Forward Kinematics (FK)

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)