Welcome to

MEAM 520
Introduction to Robotics

Cynthia Sung, Ph.D.
Mechanical Engineering & Applied Mechanics
University of Pennsylvania

Lecture 1

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

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?

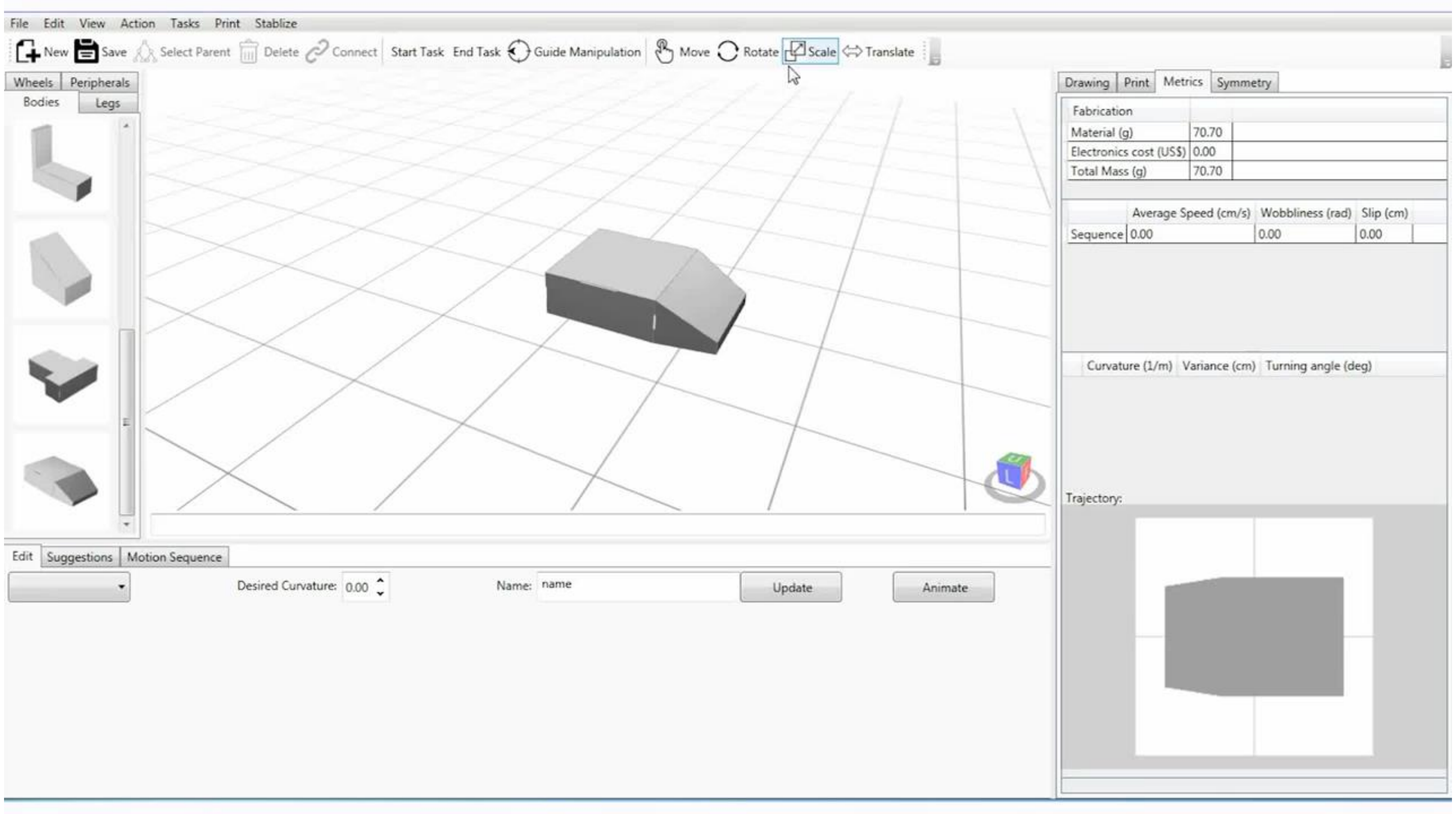
I joined Penn faculty in January 2017; this is my second year at Penn.

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:

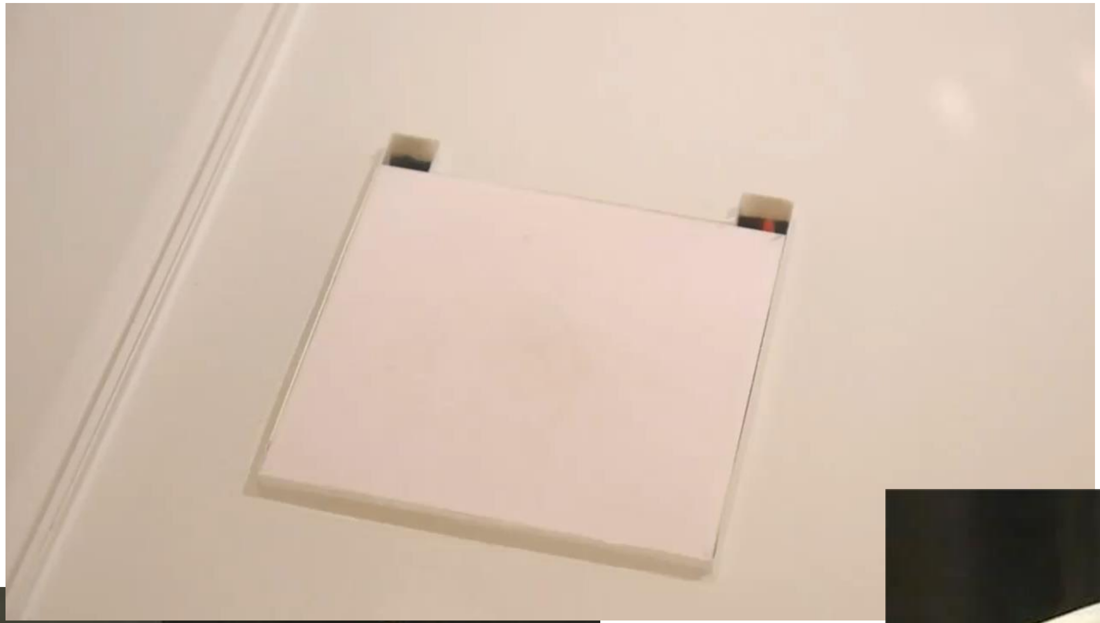
- Making computational tools for designing custom robots
- Developing new fabrication methods for creating custom robots
- Origami robots

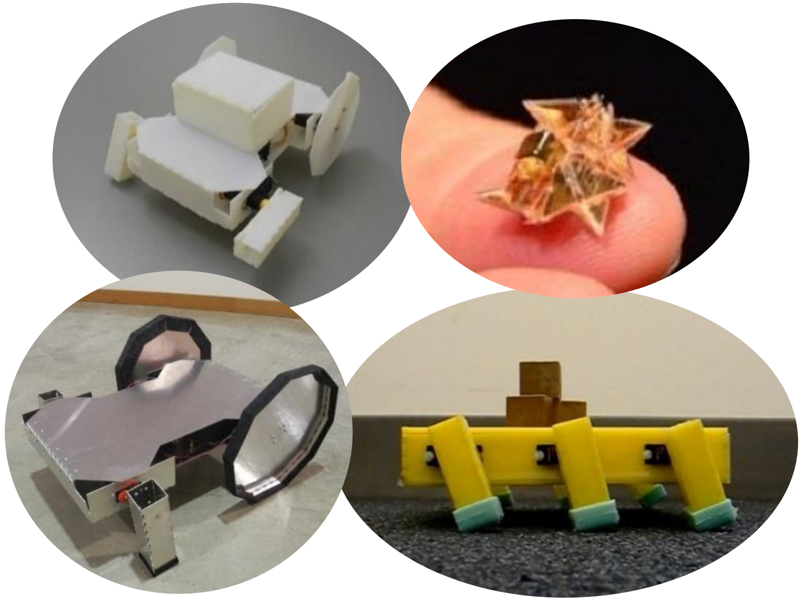
Who am I?

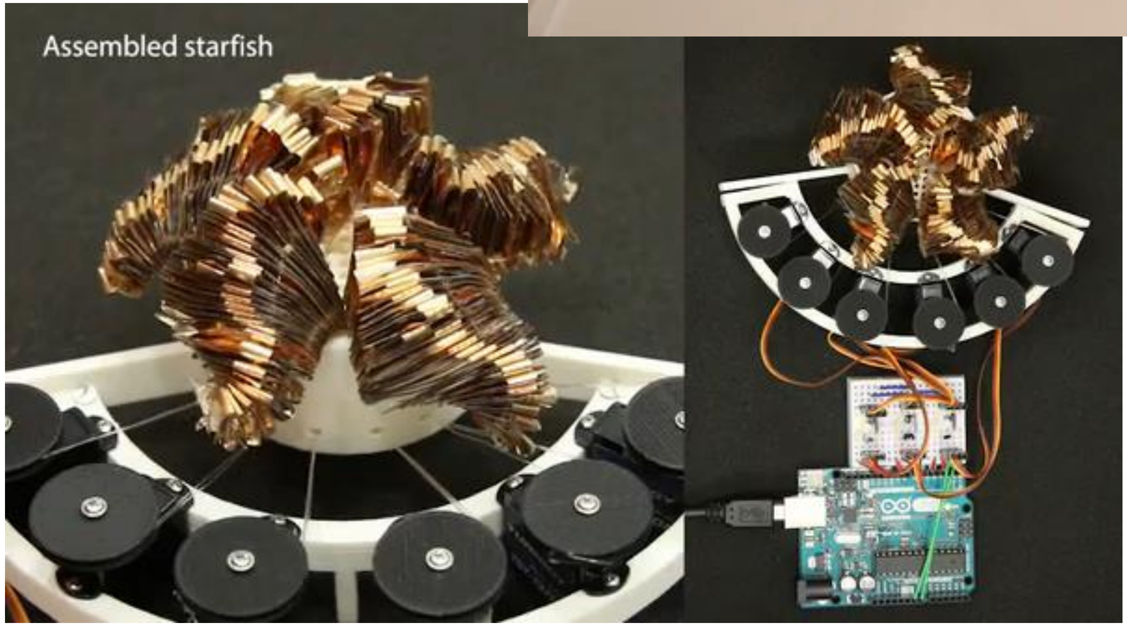


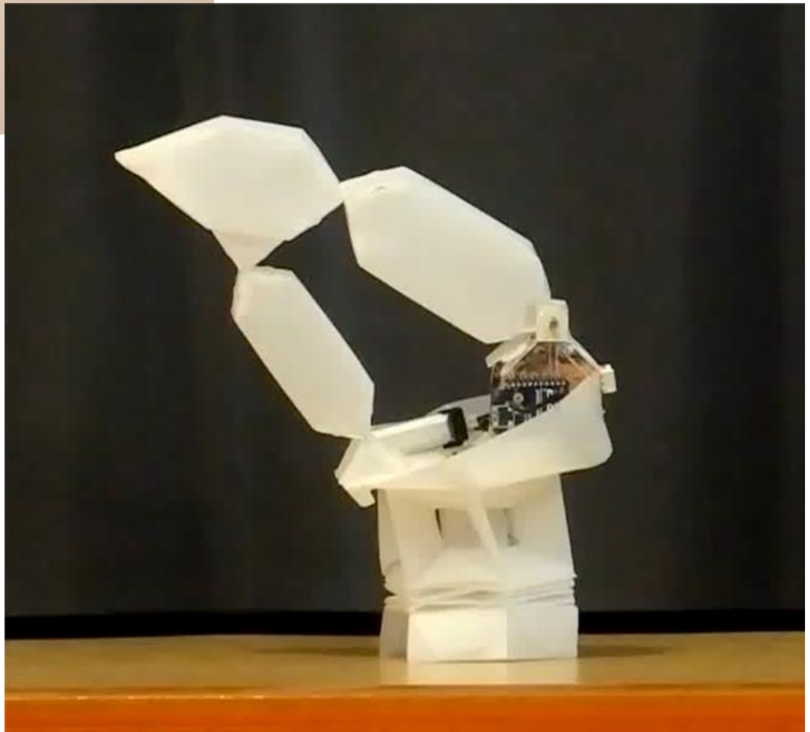
File Edit View Action Tasks Print Stablize
New Save Select Parent Delete Connect Start Task End Task Guide Manipulation Move Rotate Scale Translate
Wheels Peripherals
Bodies Legs
Drawing Print Metrics Symmetry
Fabrication
Material (g) 70.70
Electronics cost (US$) 0.00
Total Mass (g) 70.70
Average Speed (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

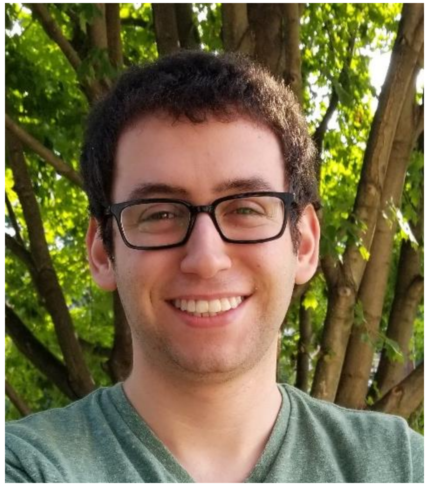
Email: crsung@seas.upenn.edu

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

Office: 273 Towne

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

Who else is teaching us?



Gedaliah Knizhnik
MEAM PhD

Daniel Mox
MEAM PhD

Jay Anjankar
ROBO MSE

Jaimie Carlson
ROBO MSE

Miranda Cravetz
ROBO MSE

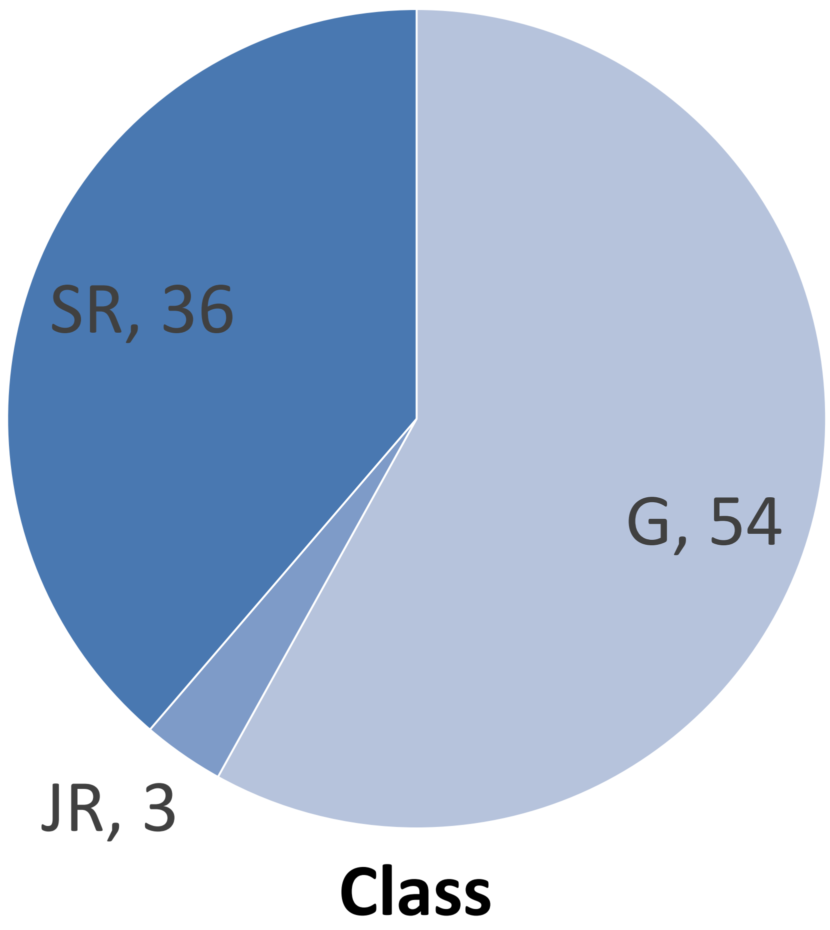
Prakash Veerasekar
ROBO MSE

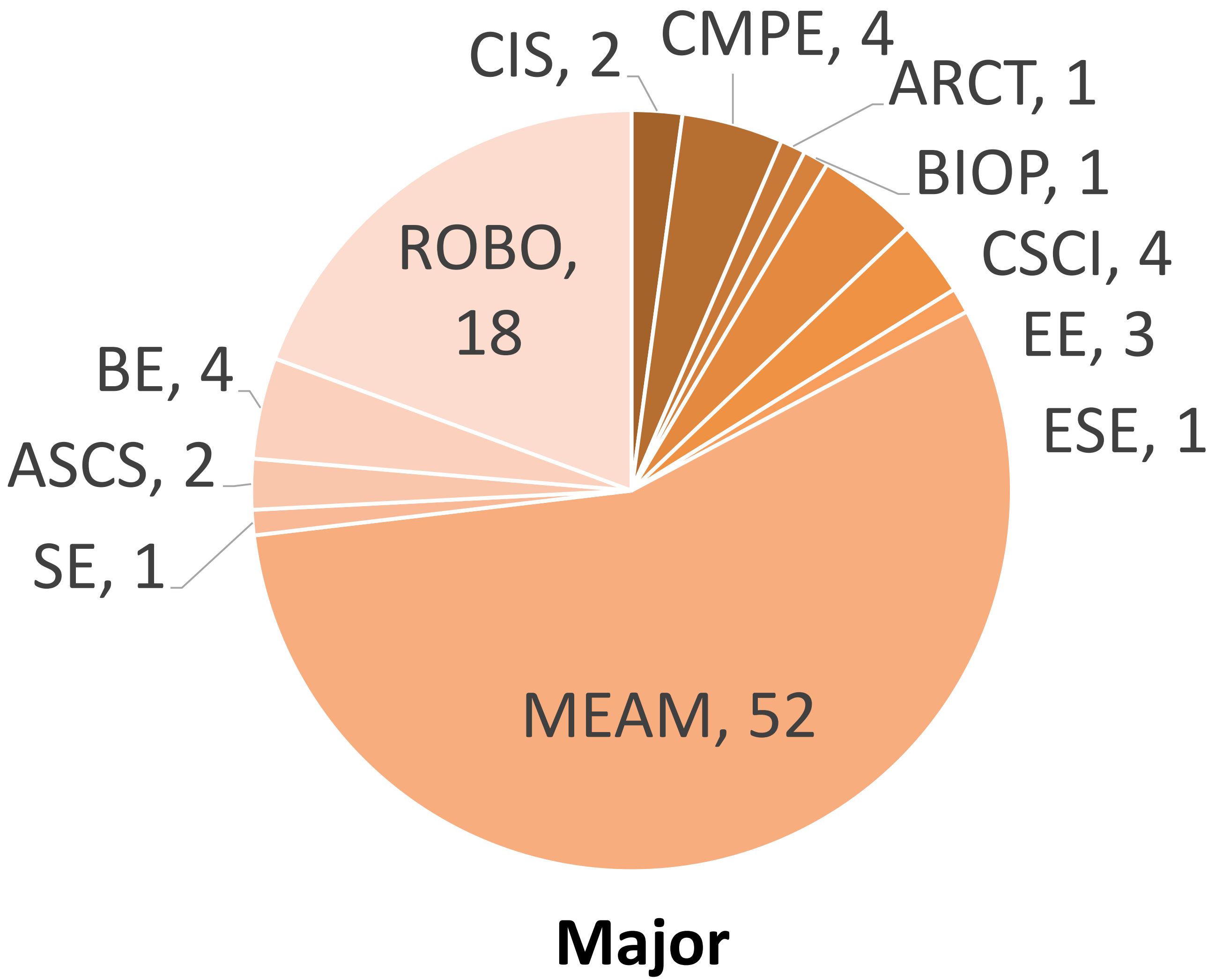
Yulai Weng
ROBO MSE

Haomin Zhu
ROBO/CIS MSE

Who are you?

94 students





What is this class about?

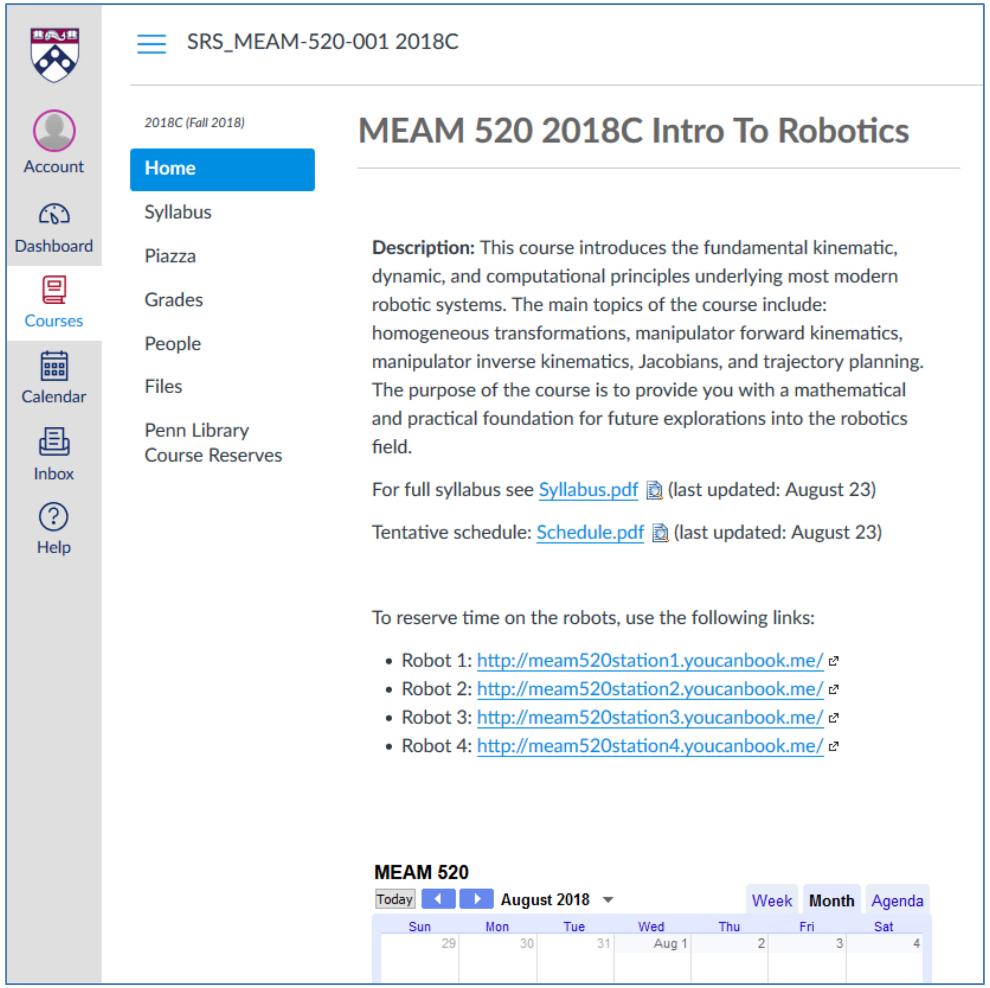
Robots! Particularly manipulator arms and mobile robots

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?

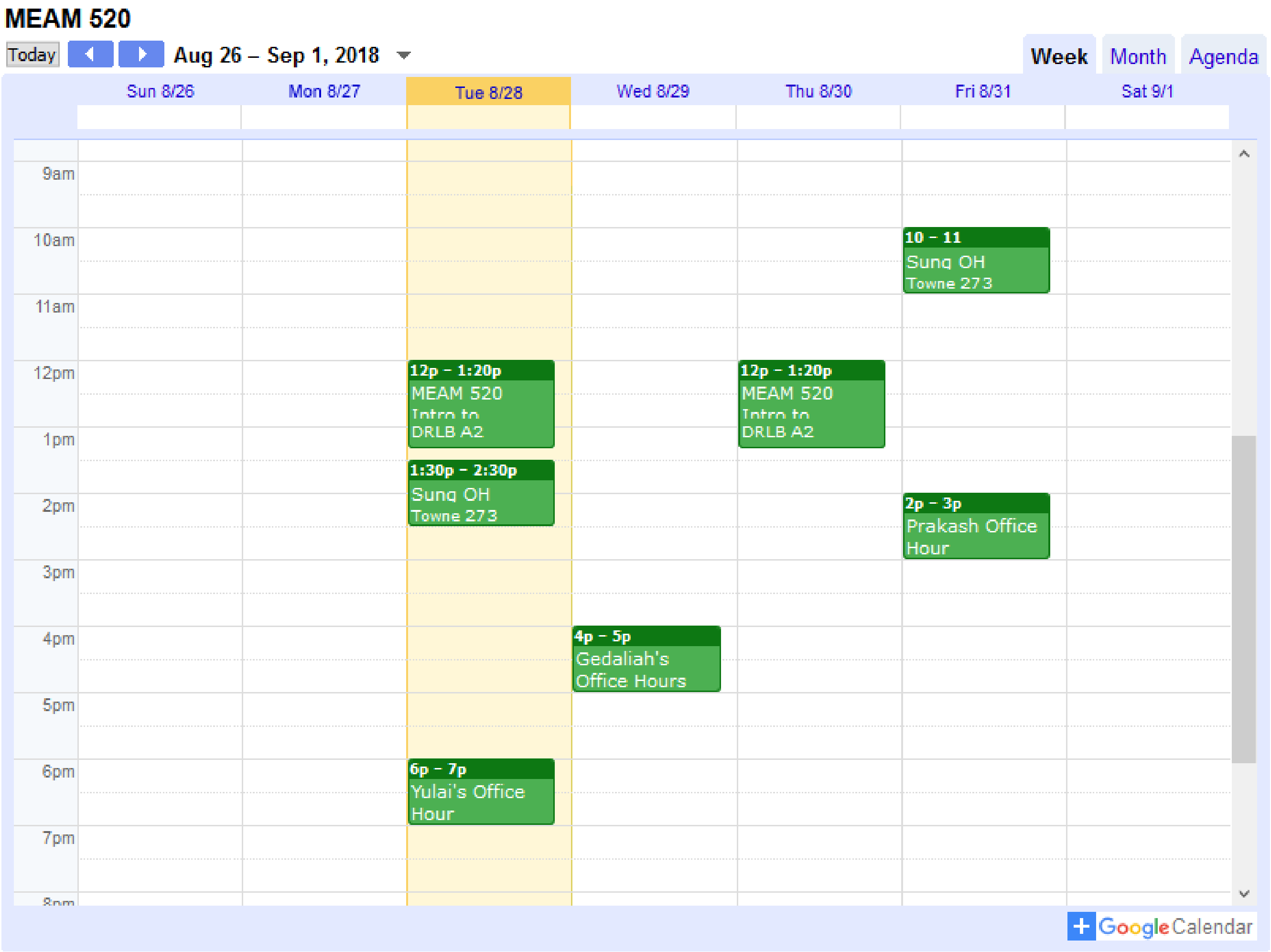
Canvas: https://canvas.upenn.edu



- Syllabus
- Lab assignments
- Grades
- Lecture notes
- Course schedule

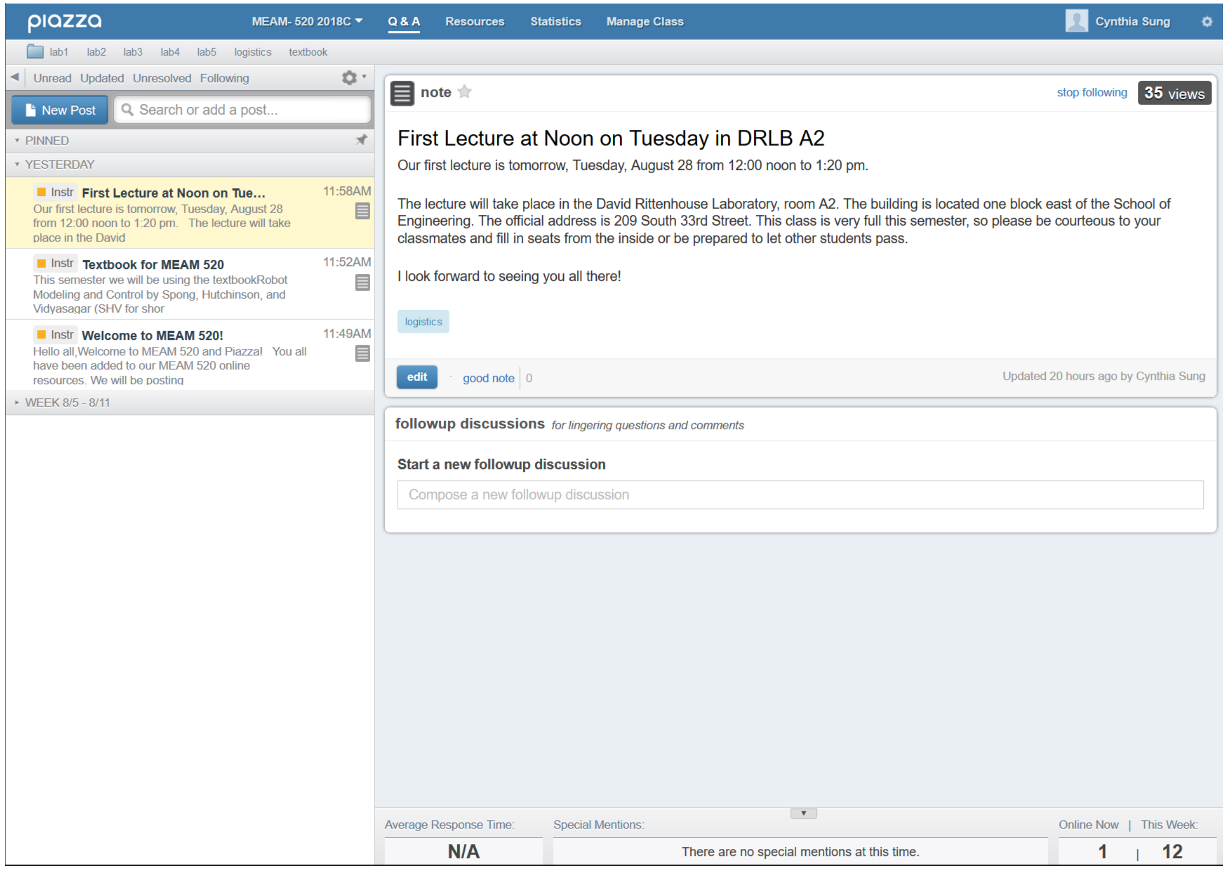
How will we communicate?

Google Calendar



How will we communicate?

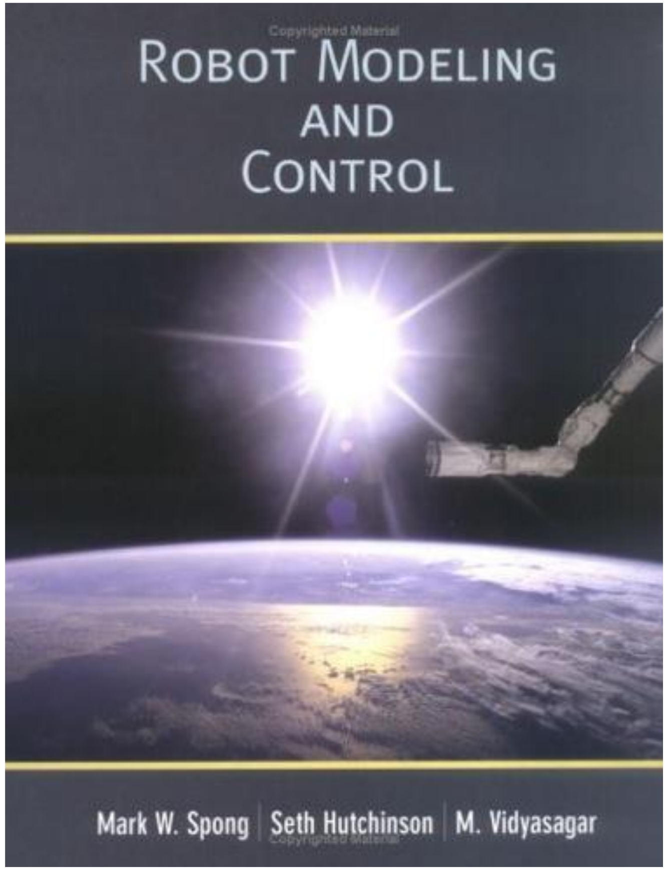
MEAM 520 Piazza: https://piazza.com/upenn/fall2018/meam5202018c



- Announcements
- 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.



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 preferred)

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

Tentative Schedule (posted on Canvas)

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	Planning on Other Robot Types
14	Velocity Kinematics

Position/Orientation

Planning

Lecture	Topic
15	More Velocity Kinematics
16	Inverse Velocity Kinematics
17	Guest: Medical Robotics
18	Jacobians and Statics
19	Trajectory Planning with Potential Fields
20	Guest: Legged Robotics
21	Joint Space Dynamics
22	More Joint Space Dynamics
23	Control and Actuation
24	Modern Planning and Control
25	Guest: Multi-Robot Systems
26	Manipulator Design
27	Final Presentations
28	Final Presentations

Velocity

Statics and Dynamics

Extensions

Labs

Theory from lecture will be complemented by virtual and real experiments

- Simulate robots in MATLAB
- Hands-on use of Lynxmotion robot arm

6 Labs (due every 2 wks):

- Lab 0: Get familiar with the hardware (5 pts) Lab 0 due Sep. 5!
- Labs 1-5: Apply concepts from class (30 pts each)

Labs

Four robots are in **B2 Towne**. You should all have access.

https://meamlabs.seas.upenn.edu/access-request/

We are a large class. Be courteous to your classmates!

Book a time on:

- Robot 1: http://meam520station1.youcanbook.me/
- Robot 2: http://meam520station2.youcanbook.me/
- Robot 3: http://meam520station3.youcanbook.me/
- Robot 4: http://meam520station4.youcanbook.me/

Only book up to 1 hr at a time.

Lab Grading Rubric

Pre-lab (5 pts) Individual submission

Lab reports (25 pts) May do in pairs

Completeness (5 pts) Did the report address all assigned tasks?
Method (5 pts) Was the approach technically sound and reproducible?
Evaluation (5 pts) Were all relevant results reported? Are the test cases chosen sufficient?
Analysis (5 pts) Was the analysis complete and free of error?
Clarity (5 pts) Was the report clear and organized?

Full description on Canvas

Final Project

Open-ended project equivalent in effort to 2 labs

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

We’ll talk more about this later.

There are no exams.

MATLAB

- We use MATLAB to control the Lynx robots.

- Need to learn MATLAB? Try the free online tutorial, which takes about one hour:
  https://matlabacademy.mathworks.com/

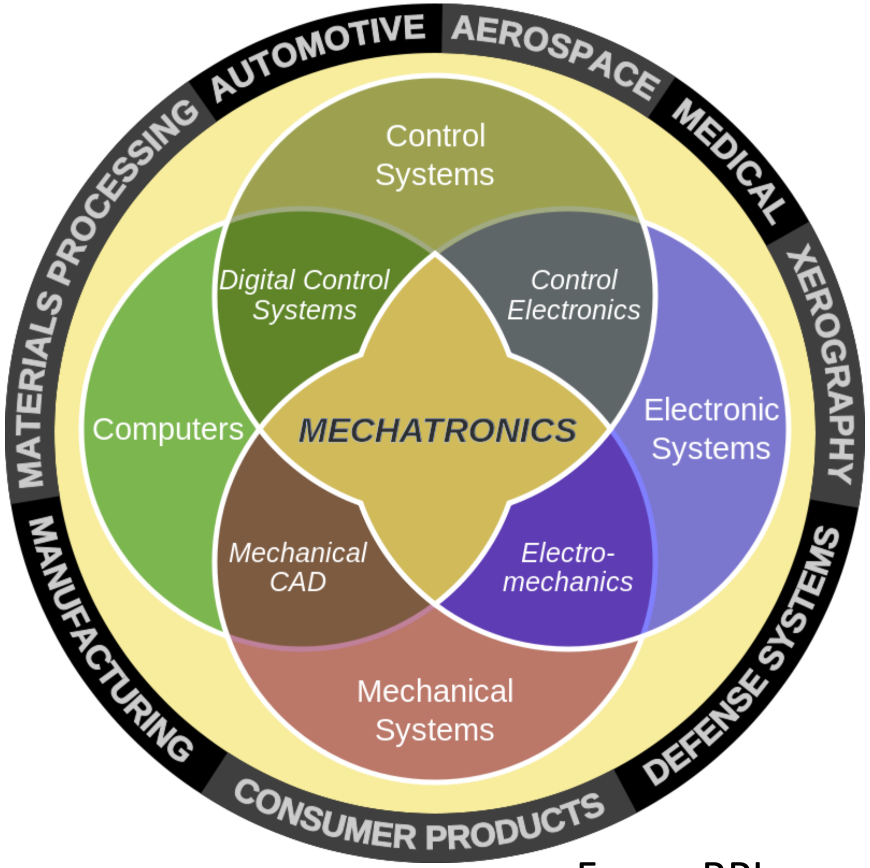
- SEAS lets all engineering students install MATLAB on their personally owned computer. You can read the installation instructions on this website (PennKey login required):
  https://www.seas.upenn.edu/cets/software/matlab/student/

What questions do you have?

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?

Write your own criteria for what a robot is.

Is this a robot?

A mixer

Is this a robot?

A washing machine

Is this a robot?

A self-parking car

Is this a robot?

A telepresence base

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.

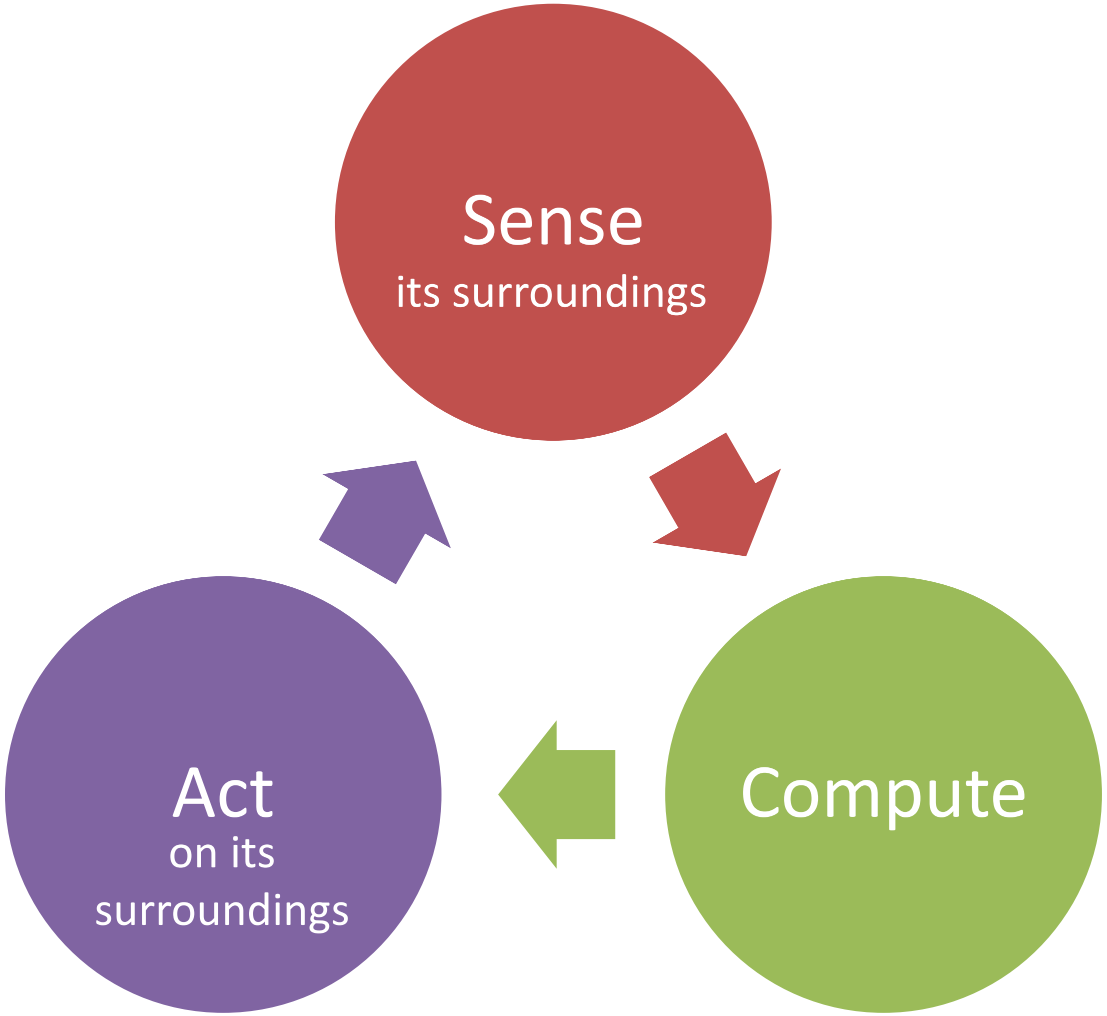
Kevin Dowling, CMU:

Force through intelligence. Where AI meets the real world.

Rodney Brooks, MIT:

A machine that acts and reacts.

What is a robot?



MEAM 520 focuses on
Compute > Act

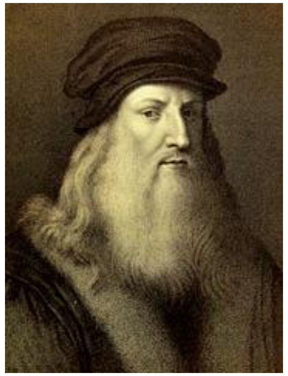
Other classes in the Robotics curriculum

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

A brief history of robotics

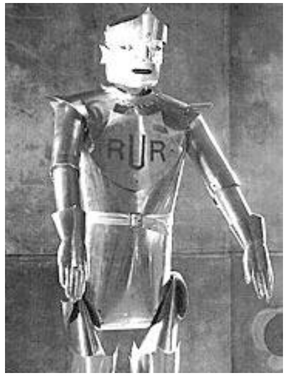
322 B. C. – “If every tool, when ordered, or even of its own accord, could do the work that befits it… then there would be no need either of apprentices for the master workers or of slaves for the lords.” – Aristotle

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



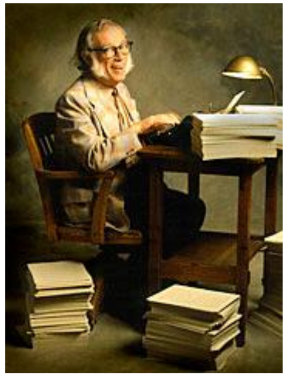
1769 – Wolfgang von Kempelen builds “The Turk,” which gains fame as an **automaton** capable of playing chess – until the hidden human operator was discovered!

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.



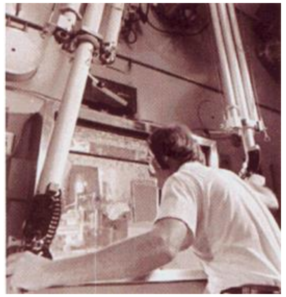
Adapted from “25 Great Moments in Robotics History” on *The Mr. Beng* Blog

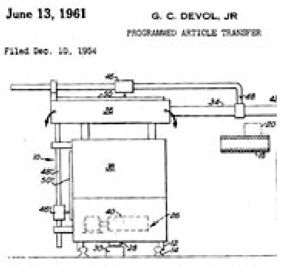
A brief history of robotics



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

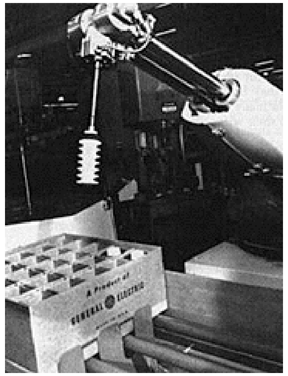
1951 – Raymond Goertz builds the first master/slave teleoperation system for handling radioactive material.





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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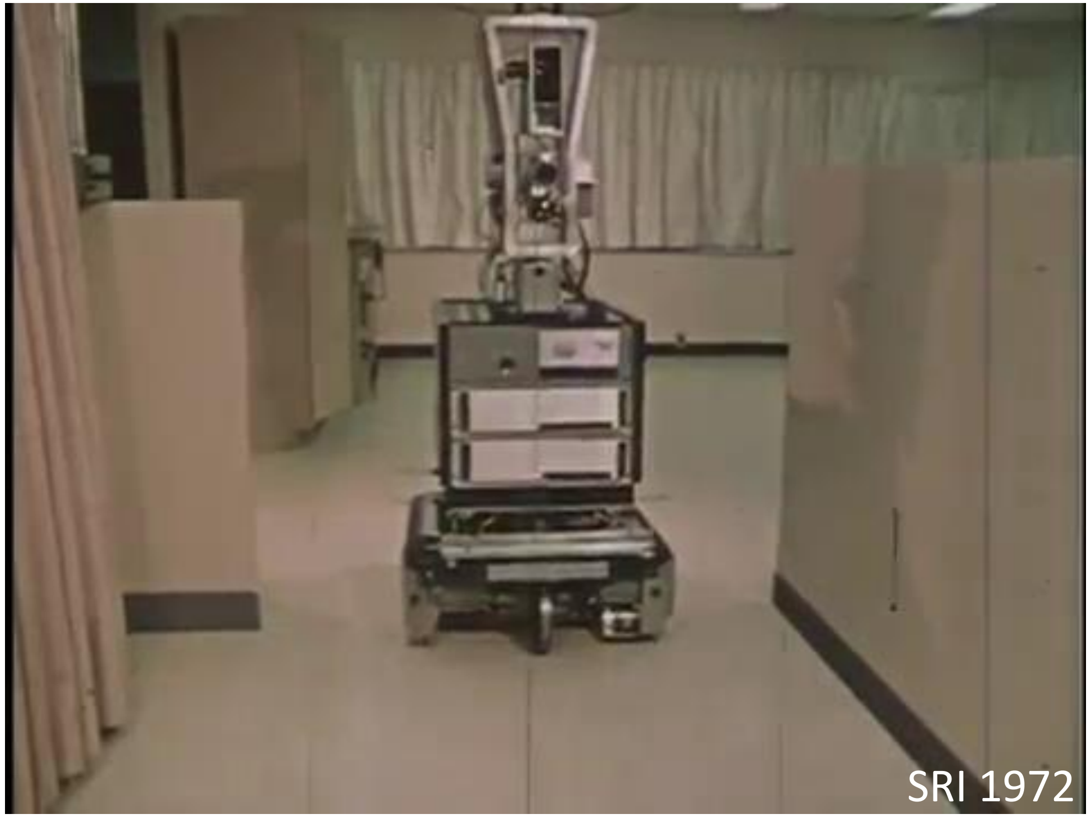
A brief history of robotics



1966 – Stanford Research Institute makes Shakey, the first mobile robot to navigate autonomously.

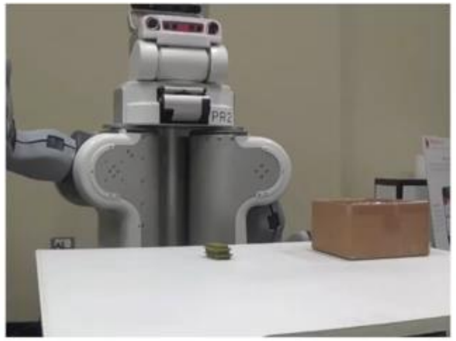
Adapted from "25 Great Moments in Robotics History" on *The Mr. Beng* Blog

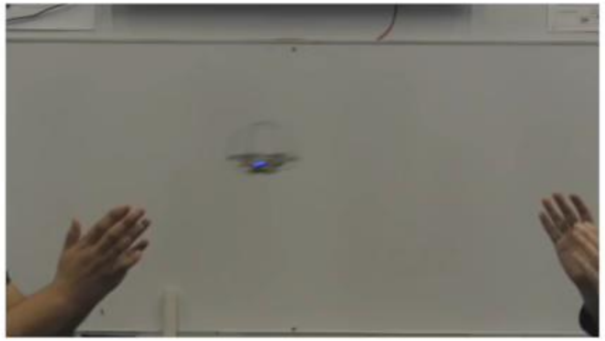
What can robots do?

manufacturing
autonomous vehicles
household cleaning and lawn mowing
undersea exploration
planetary exploration
satellite retrieval and repair
defusing explosive devices
handling dangerous materials
search and rescue
military pack carrying
exoskeletons and prosthetic limbs
surgery and medical training
personal assistance
entertainment

What questions do roboticists answer?

Robotics and Automation





ICRA 2015 Trailer

Subfields of robotics (non-exhaustive)

DESIGN
mechanisms
actuators
kinematics/dynamics
bioinspired design
manufacturing

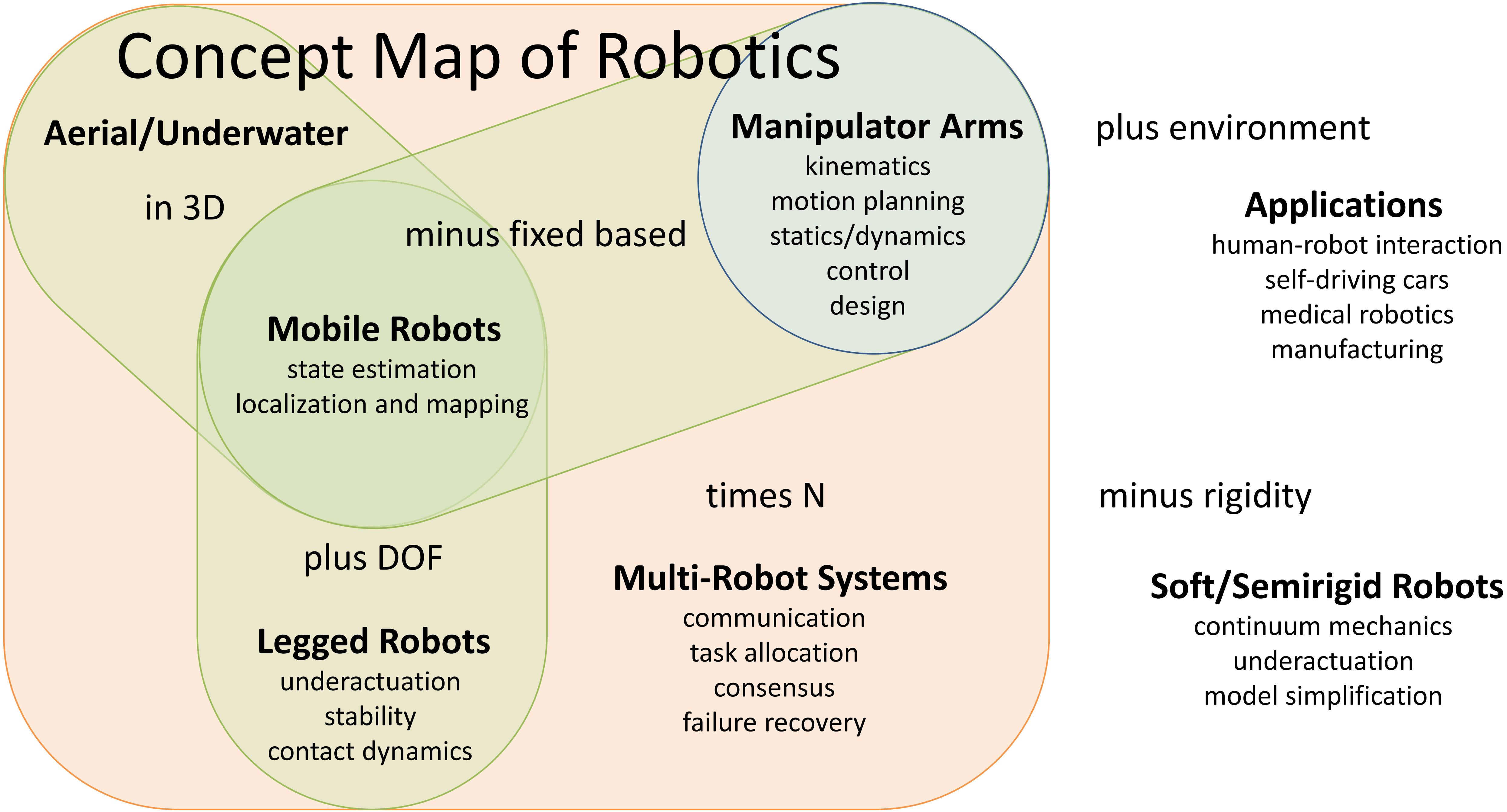
TYPES/APPLICATIONS
legged
mobile
aerial
underwater
micro/nano
manipulators and graspers
parallel robots
soft robots

SENSING
force and tactile sensing
perception
computer vision
range sensing
sensor fusion

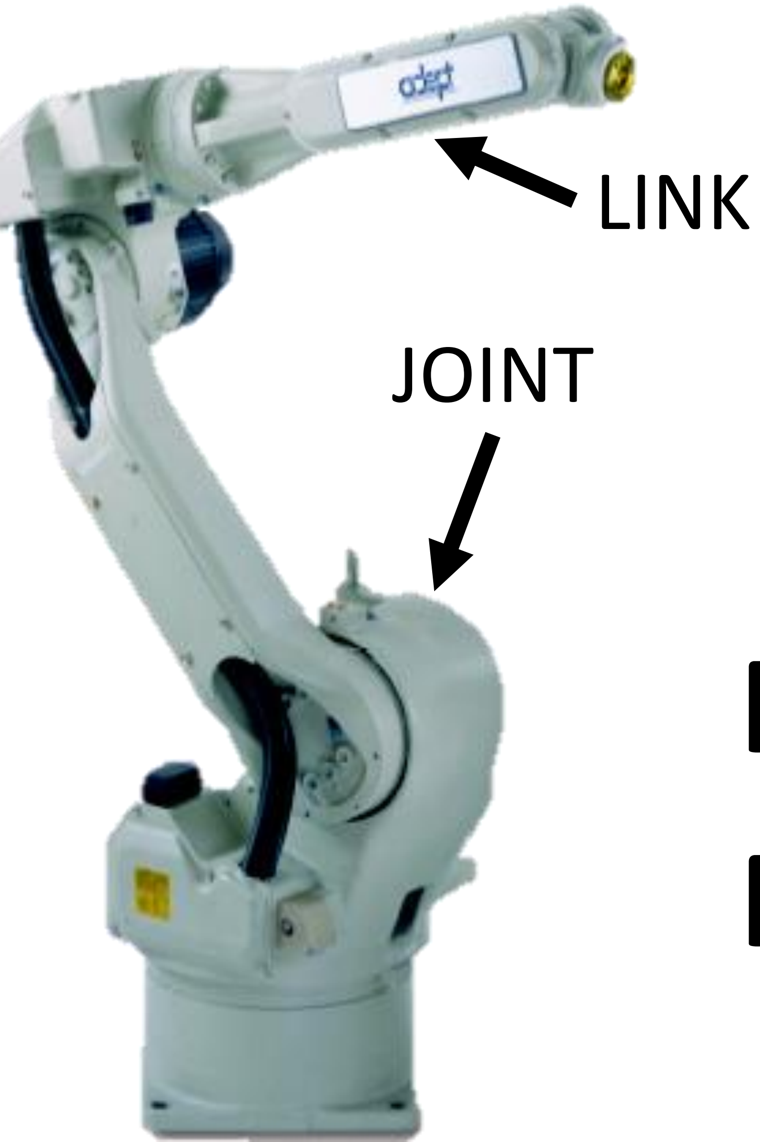
ALGORITHMS
learning
motion planning
navigation
localization and mapping
failure recovery
robot networks
multi-robot coordination
scheduling

CONTROL
PID control
adaptive control
optimization and optimal control
collision avoidance
distributed robotics
grasping and manipulation
human-robot interaction
underactuated robotics

Concept Map of Robotics



Robot Manipulators



Are composed of

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

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

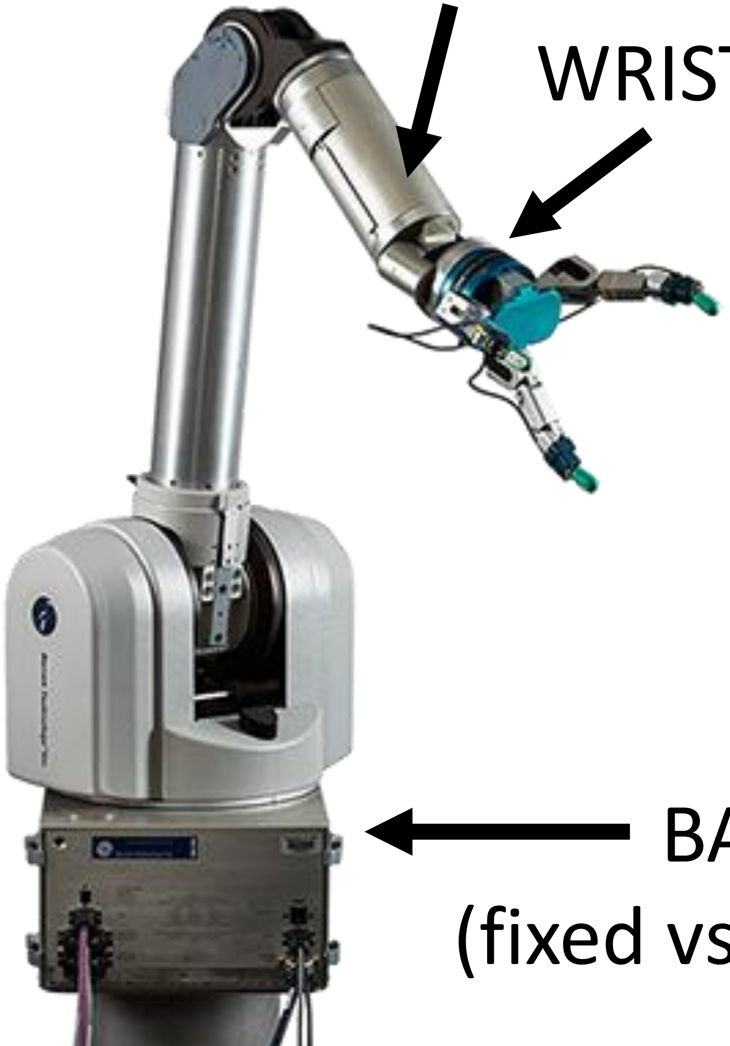
R
- Revolute (rotary), like a hinge, allows relative rotation between two links

P
- Prismatic (linear), like a slider, allows a relative linear motion (translation) between two links

Parts of a manipulator

FOREARM

WRIST

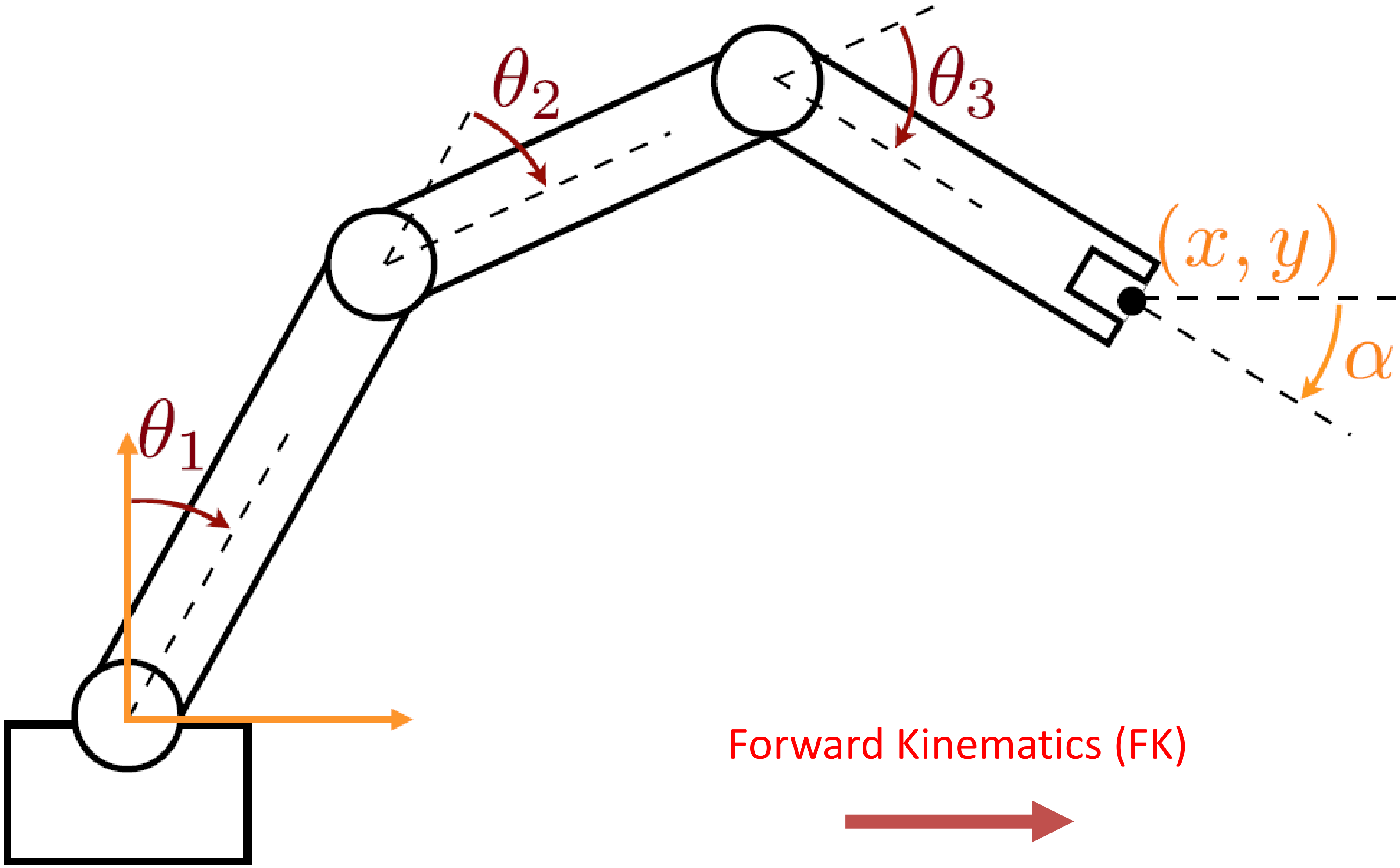


END-EFFECTOR
HAND
TOOL

BASE
(fixed vs. mobile)

Barrett WAM Arm

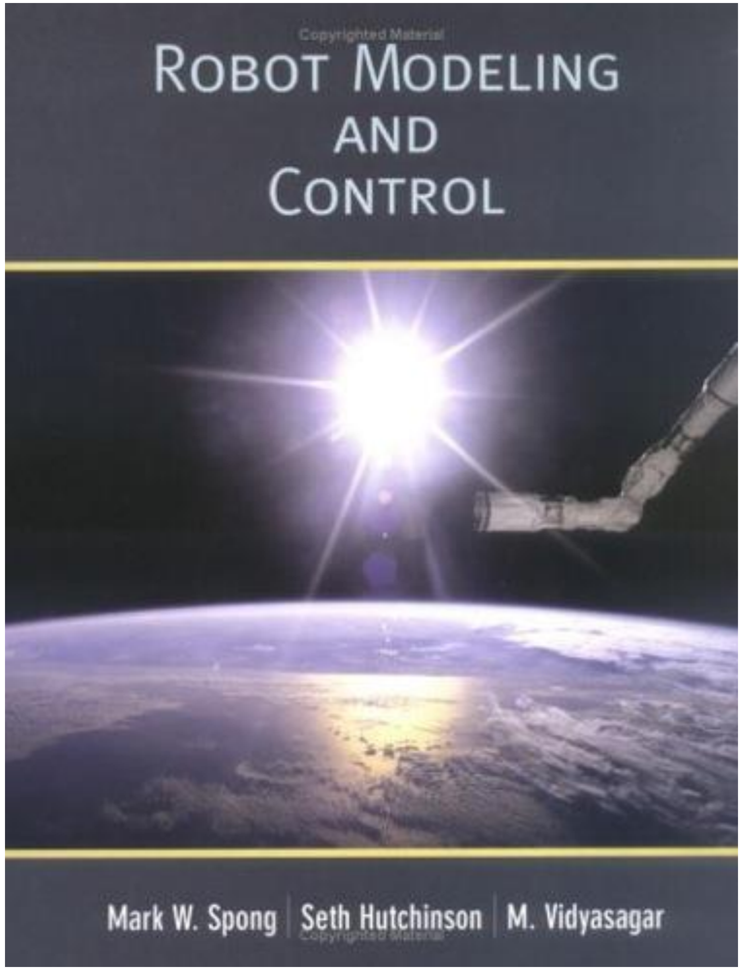
Next few weeks: Forward Kinematics



Next time

Chapter 1: Introduction

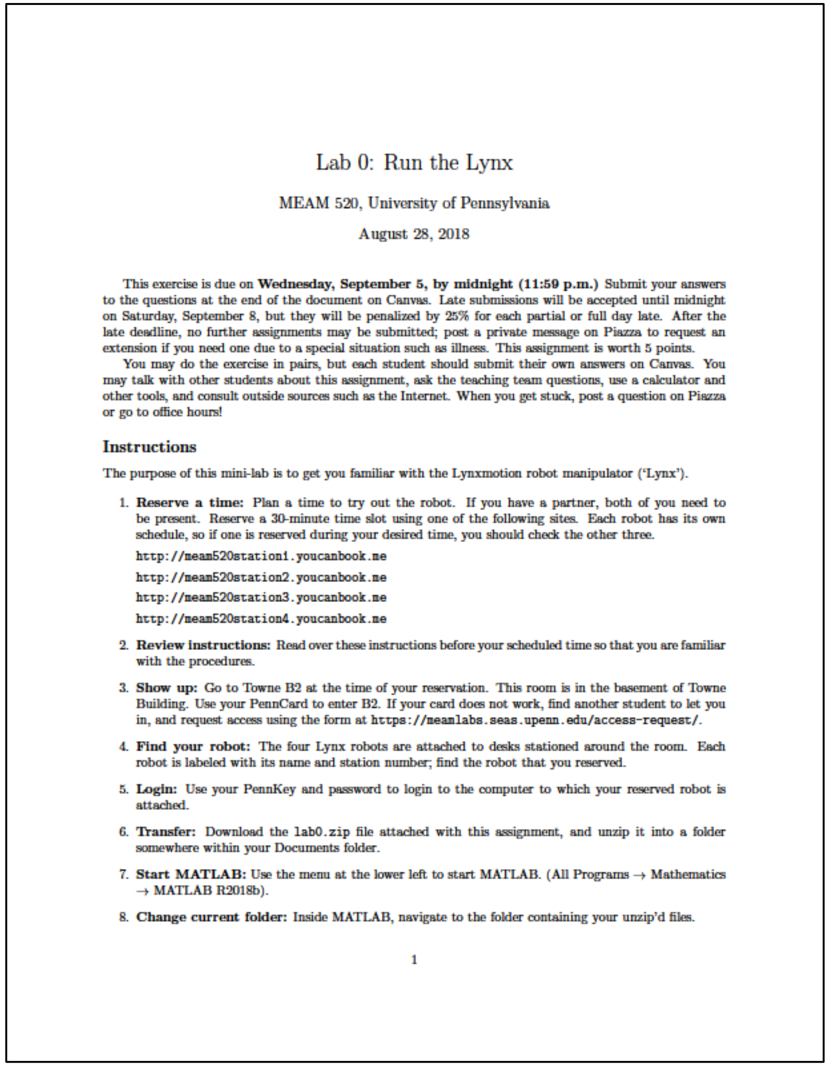
- Read Sec. 1.intro-1.3
- Find the error(s) in Fig. 1.17
- Skim Sec. 1.4
  (Outline of the text)



Also brush up on
MATLAB if needed!

Lab 0: Run the Lynx (due by midnight on 9/5)

- Instructions posted on Canvas after class
- Download the starter code from Canvas
- Book a time slot using the following links:
  - Robot 1: http://meam520station1.youcanbook.me/
  - Robot 2: http://meam520station2.youcanbook.me/
  - Robot 3: http://meam520station3.youcanbook.me/
  - Robot 4: http://meam520station4.youcanbook.me/
- Individually answer the 5 questions
- Post questions on Piazza!



Lab 0: Run the Lynx

MEAM 520, University of Pennsylvania

August 28, 2018

This exercise is due on **Wednesday, September 5, by midnight (11:59 p.m.)** Submit your answers to the questions at the end of the document on Canvas. Late submissions will be accepted until midnight on Saturday, September 8, but they will be penalized by 25% for each partial or full day late. After the late deadline, no further assignments may be submitted; post a private message on Piazza to request an extension if you need one due to a special situation such as illness. This assignment is worth 5 points.

You may do the exercise in pairs, but each student should submit their own answers on Canvas. You may talk with other students about this assignment, ask the teaching team questions, use a calculator and other tools, and consult outside sources such as the Internet. When you get stuck, post a question on Piazza or go to office hours!

Instructions

The purpose of this mini-lab is to get you familiar with the Lynxmotion robot manipulator ('Lynx').

1. **Reserve a time:** Plan a time to try out the robot. If you have a partner, both of you need to be present. Reserve a 30-minute time slot using one of the following sites. Each robot has its own schedule, so if one is reserved during your desired time, you should check the other three.

   `http://meam520station1.youcanbook.me`

   `http://meam520station2.youcanbook.me`

   `http://meam520station3.youcanbook.me`

   `http://meam520station4.youcanbook.me`

2. **Review instructions:** Read over these instructions before your scheduled time so that you are familiar with the procedures.
3. **Show up:** Go to Towne B2 at the time of your reservation. This room is in the basement of Towne Building. Use your PennCard to enter B2. If your card does not work, find another student to let you in, and request access using the form at `https://meamlabs.seas.upenn.edu/access-request/`.
4. **Find your robot:** The four Lynx robots are attached to desks stationed around the room. Each robot is labeled with its name and station number; find the robot that you reserved.
5. **Login:** Use your PennKey and password to login to the computer to which your reserved robot is attached.
6. **Transfer:** Download the `lab0.zip` file attached with this assignment, and unzip it into a folder somewhere within your Documents folder.
7. **Start MATLAB:** Use the menu at the lower left to start MATLAB. (All Programs → Mathematics → MATLAB R2018b).
8. **Change current folder:** Inside MATLAB, navigate to the folder containing your unzip'd files.

1