ME 221: Kinematics and Dynamics of Robots
Fall 2022

Lecture 1
Logistics & Course Overview

Prof. Jonathan Realmuto
9/22/2022

Today’s Agenda

1. Introductions
2. Logistics
3. What are ‘Robots’?
4. Course Overview
5. Project Specifics

Let’s introduces ourselves

- Name, department, year of study
- If you’re doing research, what area? If not, what area are you most interested in?
- Why are you taking this course?

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Course Website

https://intra.engr.ucr.edu/~jrealmuto/courses/me221-f22/

Canvas

1. Grades
2. Piazza Discussion Board (??)

Typical Class Schedule

10:00 - 10:55	Lecture
5 minute break	
11:00-11:20	Project/HW/Code/Tutorials
11:20-11:50	Paper Presentations

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The idea of '*robots*' is very old

- ~1000 BC (China) / Yan Shi, an artisan, presents life-size mechanical humanoid to King Mu of Zhou
- Jewish Folklore / Golem is a creature formed out of a lifeless substance such as dust or earth, who Loew the Rabbi gave life to
- Greek Mythology / Hephaestus, god of fire, metalworking, blacksmiths, sculptors, built golden servants who helped people


Hephaestus, credit: wikipedia

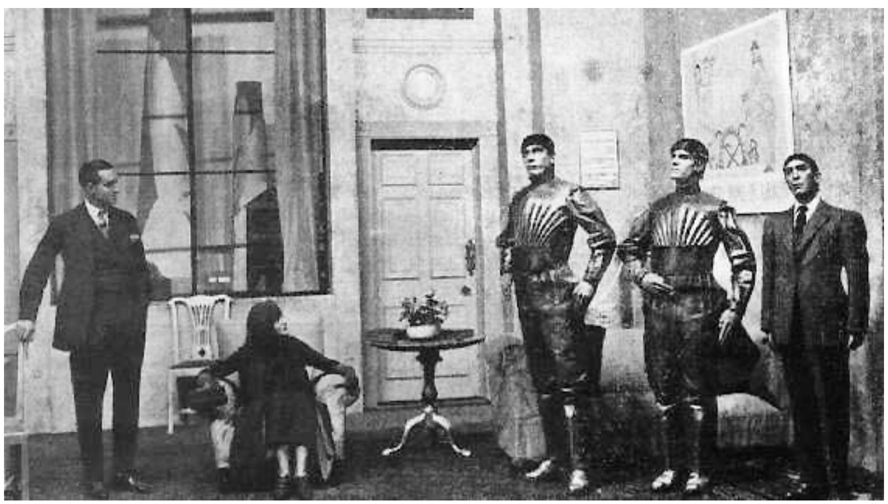
content credit: Oscar Ramos, UTEC

Etymology of *'Robot'*

- R.U.R. by Karel Čapel (1920)

  Science fiction play "Rossum's Universal Robots" Robota (in czech) = forced laborer

  Initially happy to work for humans, the robots revolt and cause the extinction of the human race



R.U.R., credit: wikipedia

R.U.R., credit: wikipedia

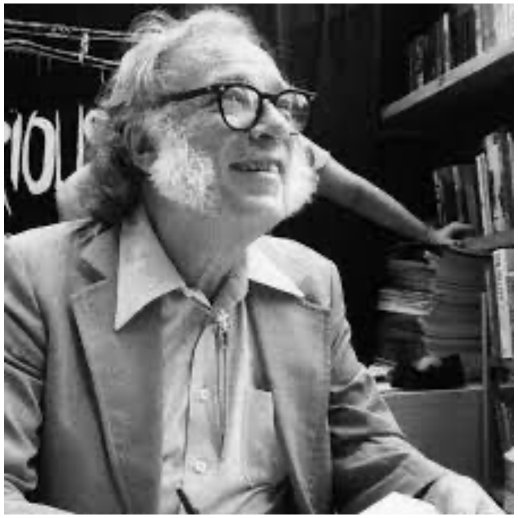
content credit: Oscar Ramos, UTEC

Issac Asimov's *Robotic Laws*

- **Issac Asimov (1920-1922)**

  Writer and Professor of Biochemistry

  - **First to use 'Robotics' in print ("Liar!", 1947)**



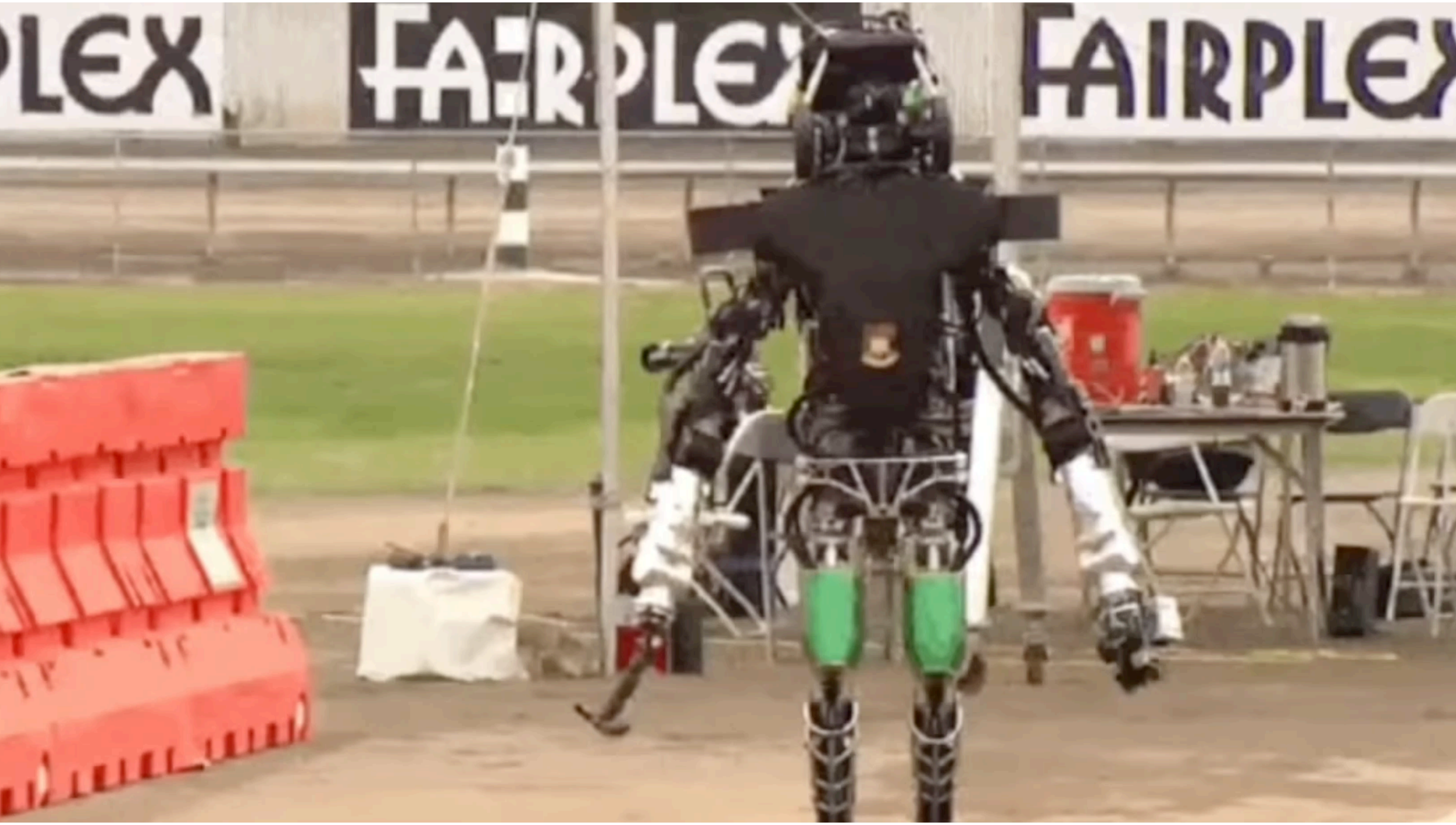
Issac Asimov, credit: Quartz

- **Robotic Laws**

  1. **A robot may not injure a human being**
  2. **A robot must obey orders given by humans**
  3. **A robot must protect its own existent**

(Very Brief) History of Robotics

- **1948 / Norbert Wiener formulates the principles of *cybernetics* laying the foundation for robotics**
- **1949 / William Grey Walter constructs *Elmer and Elsie*, three-wheeled tortoise like robots — they used *phototaxis* to find charging stations**
- **1954 / George Devol invents *Unimate*, widely recognized as the first digitally operated programmable robot**
- **1969 / Victor Scheinman, ME student, creates the *Stanford Arm***
- **1978-79 / Puma and Scara robots introduced**
- **1986 / Honda begins humanoid research program**
- **1990 / Cyberknife, first robotic-assisted surgery appliance cleared by FDA**
- **2002 / Roomba, a robotic vacuum, released by iRobot**
- **2004 / DARPA Grand Challenge, none of the 15 cars completed**
- **2012-2015 / DARPA Robotics Challenge, "complex tasks in dangerous, degraded, human-engineered environments."**


PLEX
FAIRPLEX
FAIRPLEX

What is a Robot?

International Federation of Robotics (IFR):

A robot is an *actuated mechanism* programmable in two or more axes with a degree of autonomy, moving with its environment to perform intended tasks.

- Remark 1: A robot includes the control system and interface of the control system.
- Remark 2: The classification of a robot into industrial robot or service robot is done according to its intended application.

Autonomy: Ability to perform intended tasks based on current state and sensing, without human intervention.



Variety of tasks

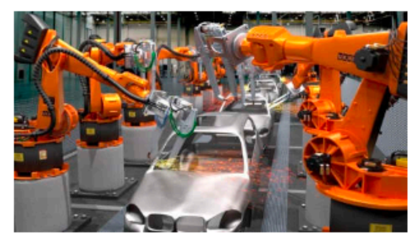
Reprogrammable mechanism

interacts

independent (and "intelligent") actions

Environment

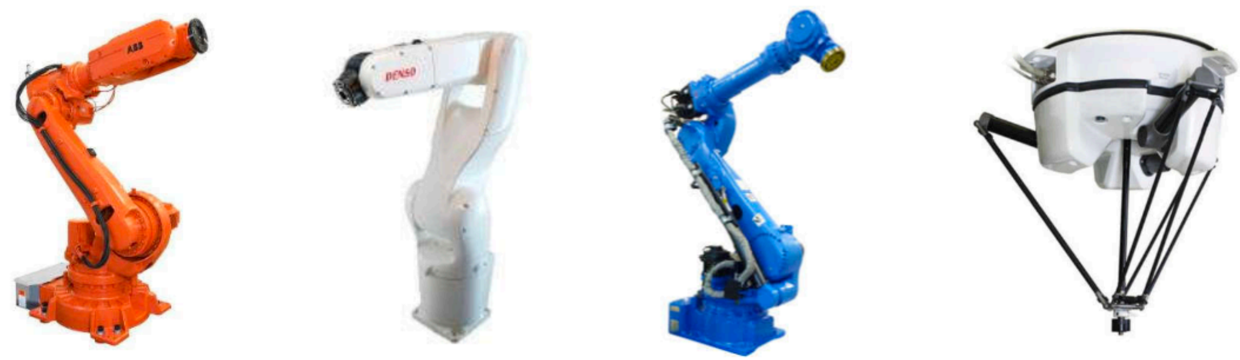
Variety of tasks




slide credit: Oscar Ramos, UTEC

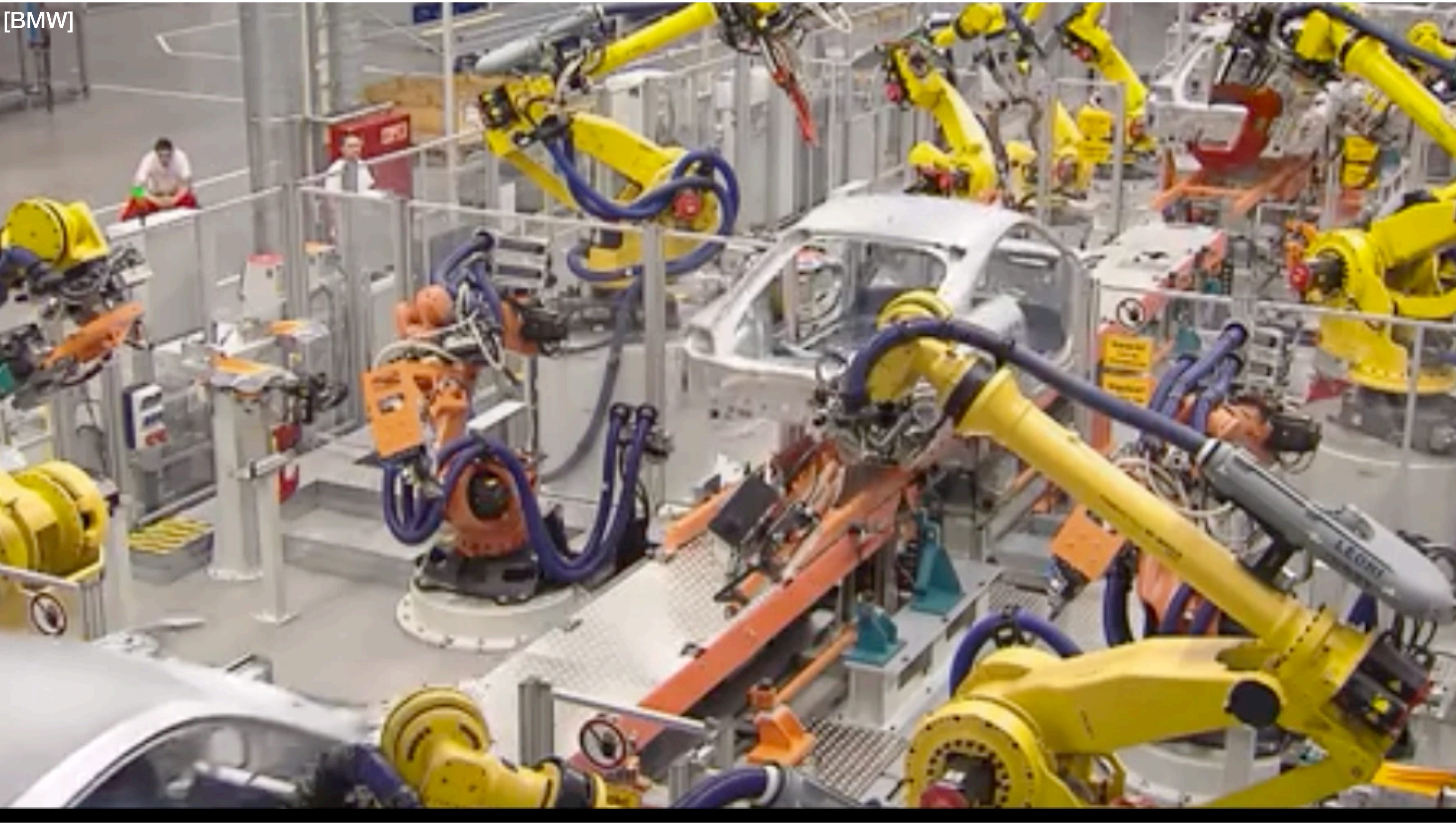
Types of Robots: Manipulators

a. **Industrial Robots**



b. **Collaborative Robots ("*cobots*")**

slide credit: Oscar Ramos, UTEC



[BMW]

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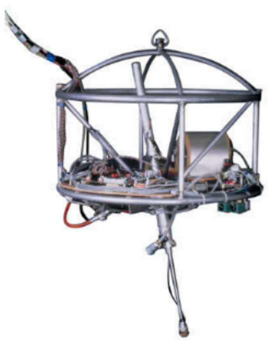
Types of Robots: Terrestrial Mobile

- Legged Mobile Robots


RoboSimian


Boston Dynamics's Robots


@MIT


Aibo


Festo's Robot

slide credit: Oscar Ramos, UTEC

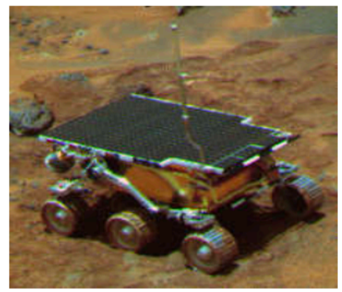
[RobotDigg]

Types of Robots: Terrestrial Mobile

- Wheeled Mobile Robots

Hospi (Panasonic)

EVA (@UCLA)



Sojourner Rover

Robot Podador

Turtlebot 3

E-puck

Roomba

@NREC

slide credit: Oscar Ramos, UTEC

Types of Robots: Aerial Mobile

- Also known as: "U*nmanned Aerial Vehicle"* (UAV)

Parrot AR. Drone

Erle Hexacopter

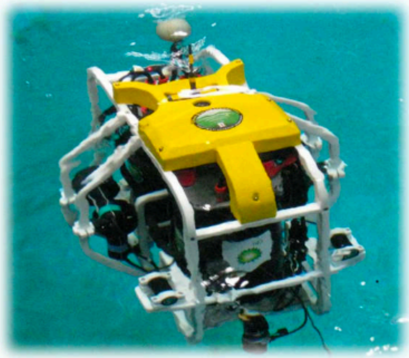
Crazyflie 2.0

DJI - Matrice 200

slide credit: Oscar Ramos, UTEC

Types of Robots: Underwater Mobile

- Also known as "*Autonomous underwater vehicles*" (AUV)



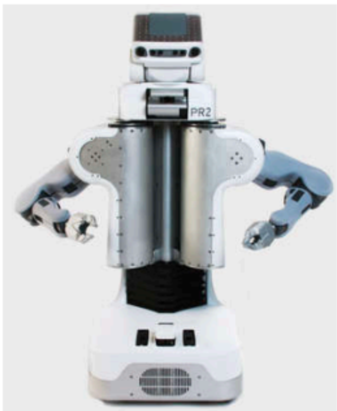
Mbari robot tiburón

@Heriot Watt

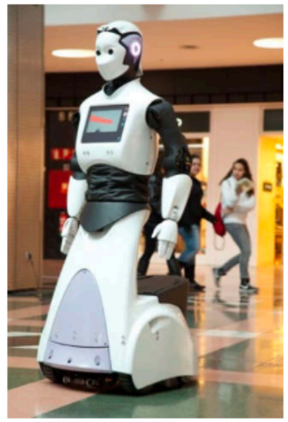
Girona 500

slide credit: Oscar Ramos, UTEC

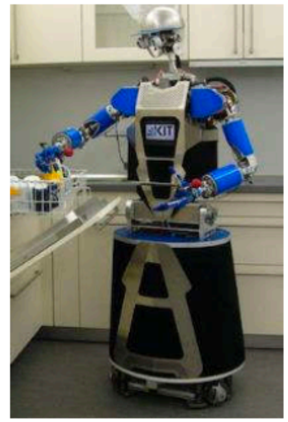
Types of Robots: Mobile Manipulators



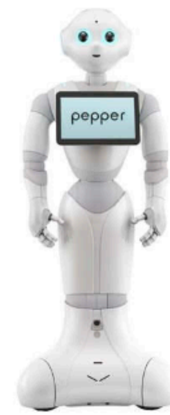
PR-2



Reem



Armar



Pepper

Packbot

Momaro

Spot mini

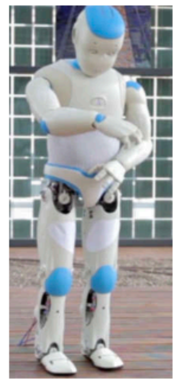
Justin

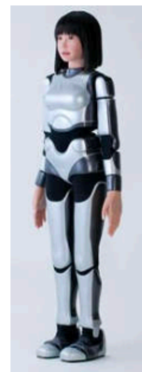
slide credit: Oscar Ramos, UTEC

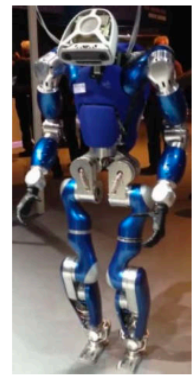
Types of Robots: Humanoid

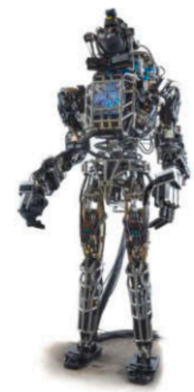

Asimo

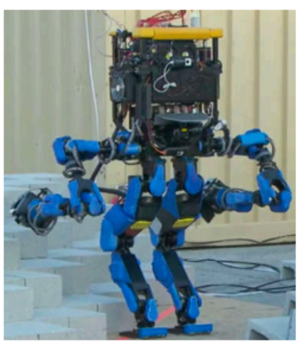

Hubo

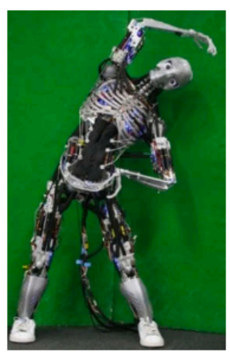

Romeo

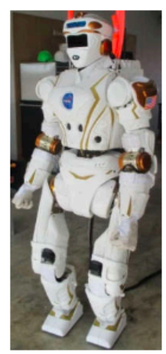

HRP-4C


Toro


Atlas


Schaft


Kenshiro


Valkyrie

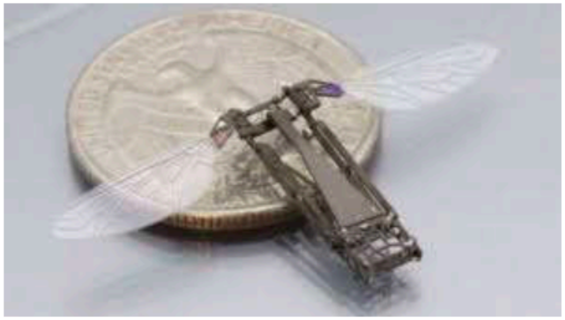

Sarcos


Talos

slide credit: Oscar Ramos, UTEC

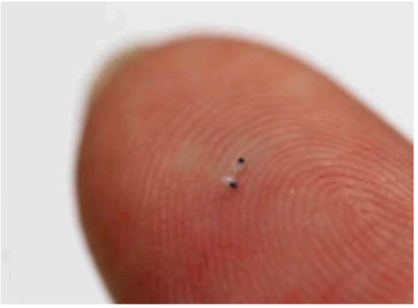
[Boston Dynamics]

Types of Robots: Micro



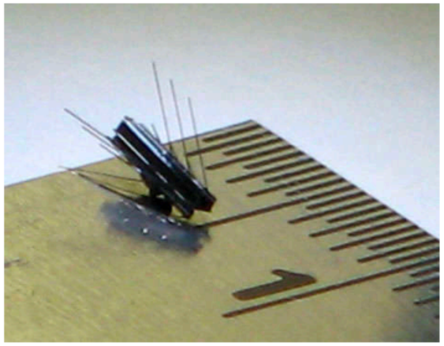
Harvard's Robobee

https://youtu.be/hEZ7rHRifVc

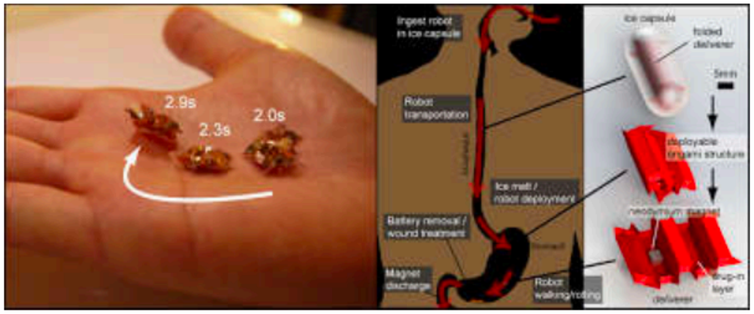


Max Planck's micro-scallop

https://youtu.be/eZ05z6ebKDQ

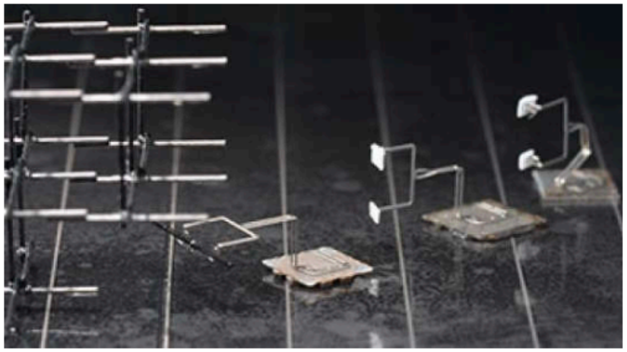


Technion: ViRob



MIT, TUMunich: Self-assembling origami robots

https://youtu.be/f0CluQiwLRg

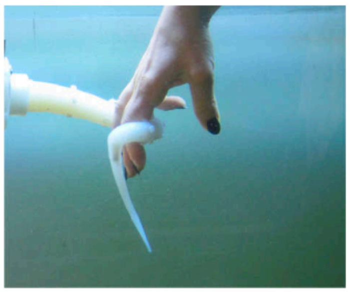


SRI International: micro-manufacture

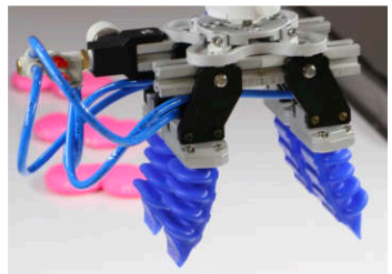
https://youtu.be/uL6e3co4Qqc

slide credit: Oscar Ramos, UTEC

Types of Robots: Soft



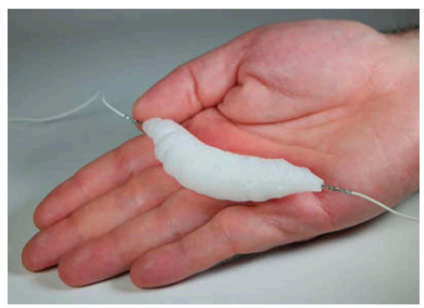
Octopus Project (FP7)
https://youtu.be/Xn-bG8_aazM



SoftRobotics, Inc.
https://youtu.be/o8DoSvv4P3w

EPFL, Reconfig Robotics Lab
https://youtu.be/enMIWpHxPDs

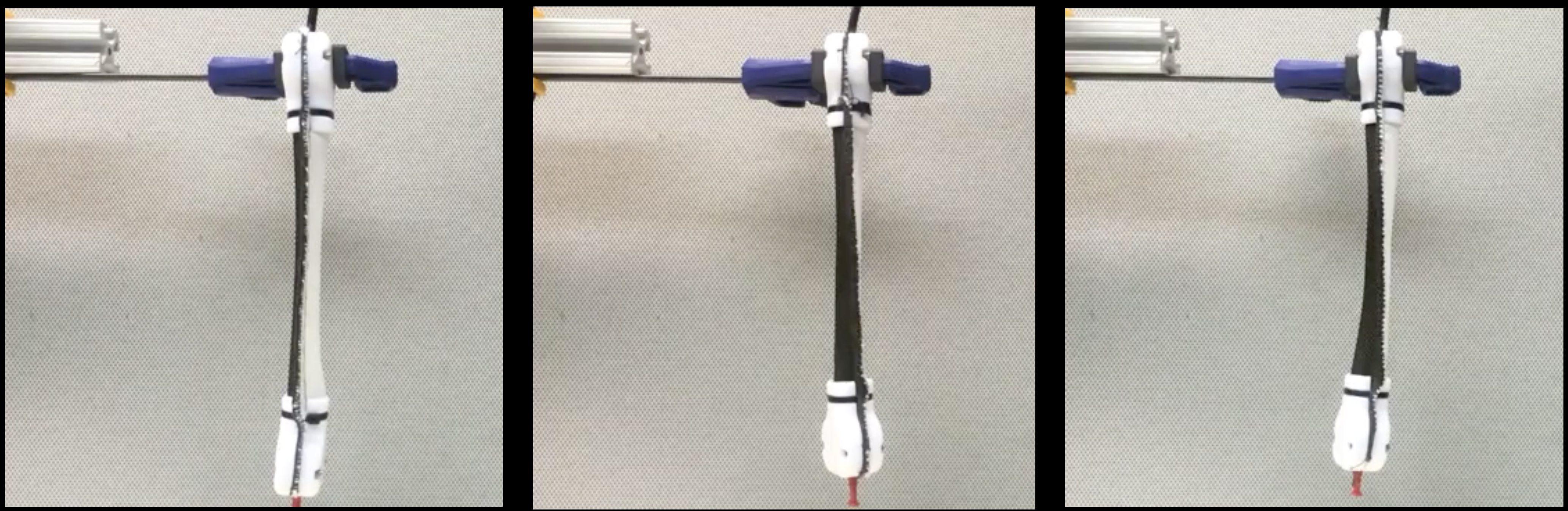
Wyss Institute, Artif. Muscles
https://youtu.be/_tKI8BUHFLo



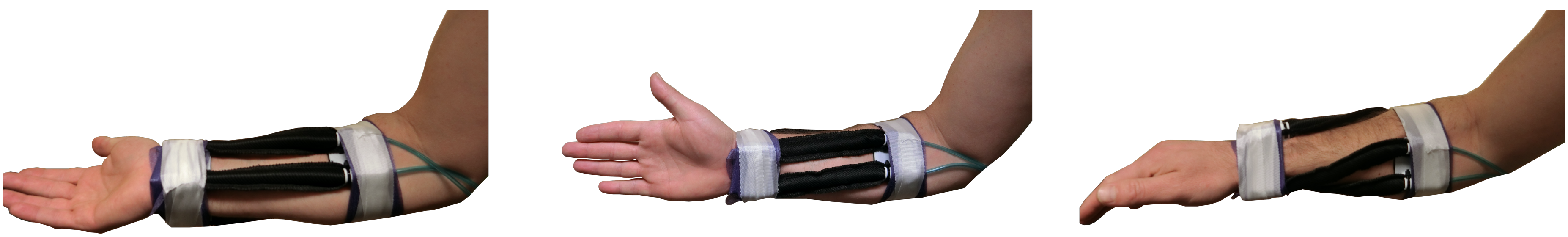
Columbia Univ. Soft materials
https://youtu.be/1J47difr3oo

Harvard's Whitesides Group
https://youtu.be/2DsbS9cMOAE

slide credit: Oscar Ramos, UTEC



J Realmuto, T Sanger. IEEE RoboSoft. 2019



Of course many other types…

Snake Robot (CMU)

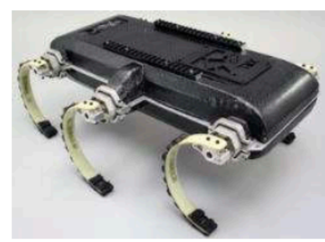
Salamander Robot EPFL)

Exoskeletons

Legged chair

Geminoid
(Ishiguro Lab, Osaka)

Sophia
(Hanson Robotics)



XLR (UPenn)

Hand

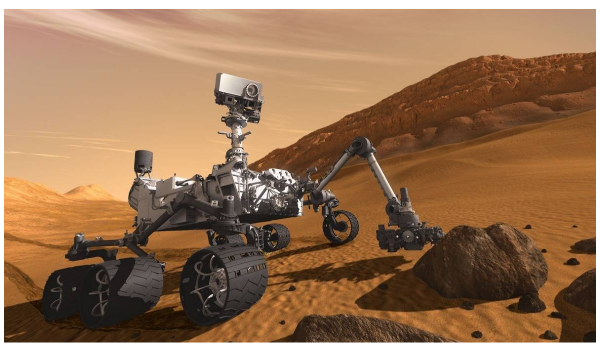
slide credit: Oscar Ramos, UTEC

Applications

Industrial

Service

Medical



Exploratory

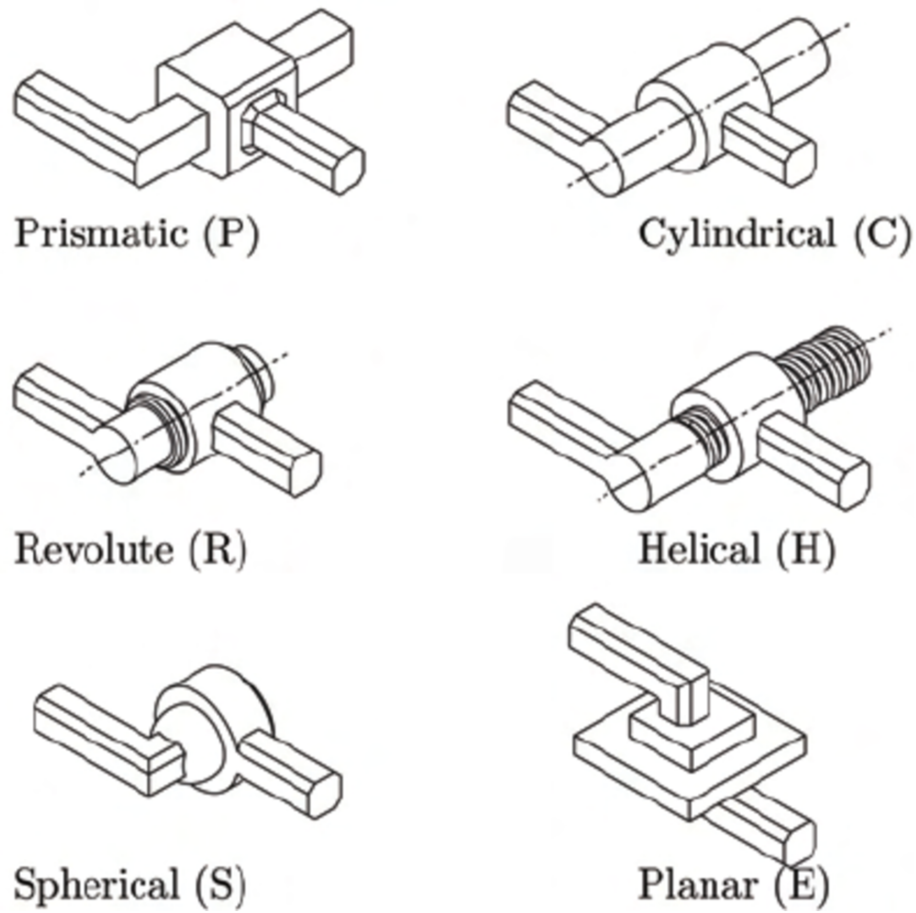
Consumer

In this course we will focus almost exclusively on manipulators

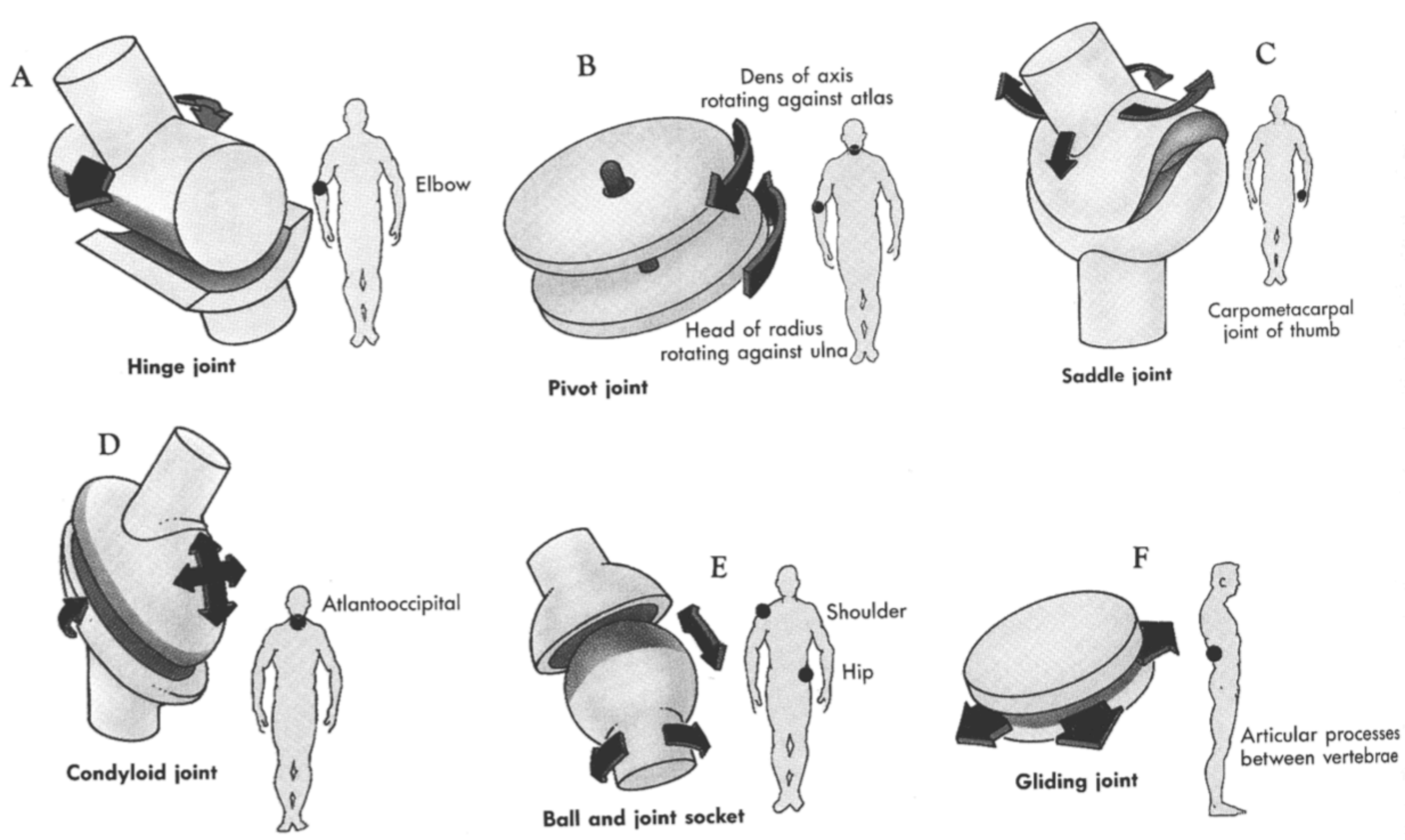
Anatomy of a manipulator

- **Links (rigid bodies)**
- **Joints**
- **End-effector**
- **Actuators**
- **Sensors**
    - **proprioceptors**
    - **exteroceptors**
- **Controller**

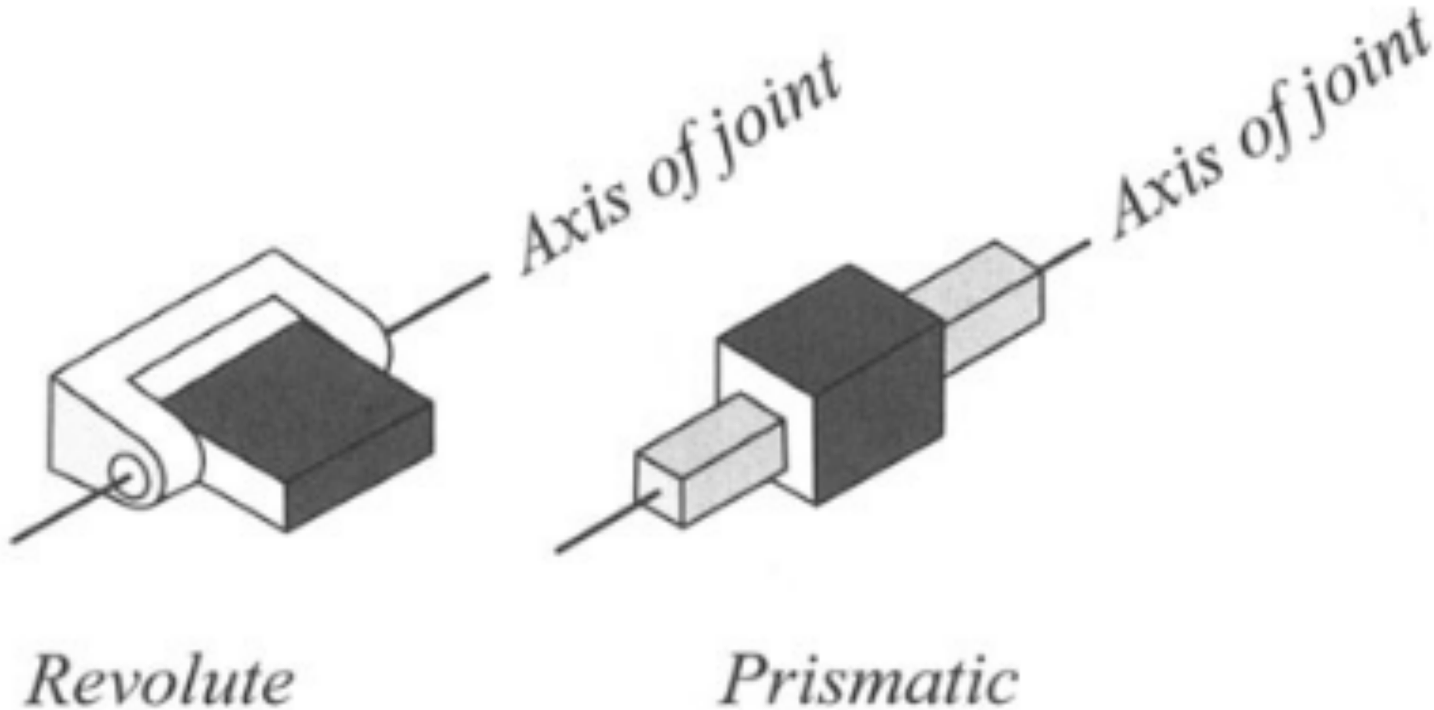
‘Lower pair joints’



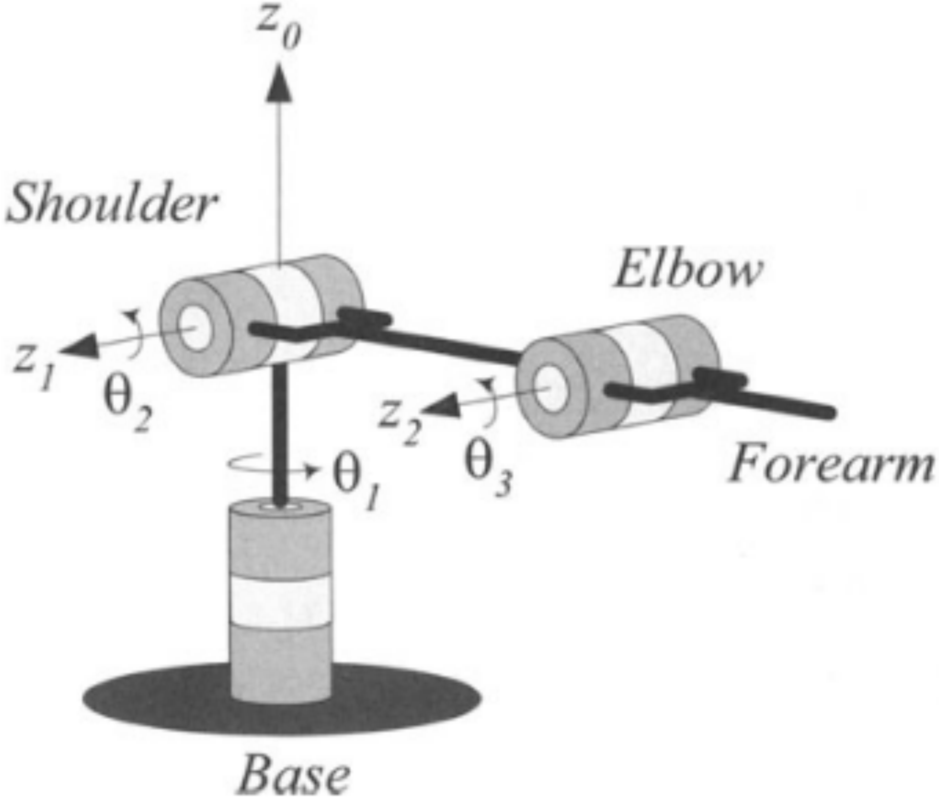
Anatomical joints analogs



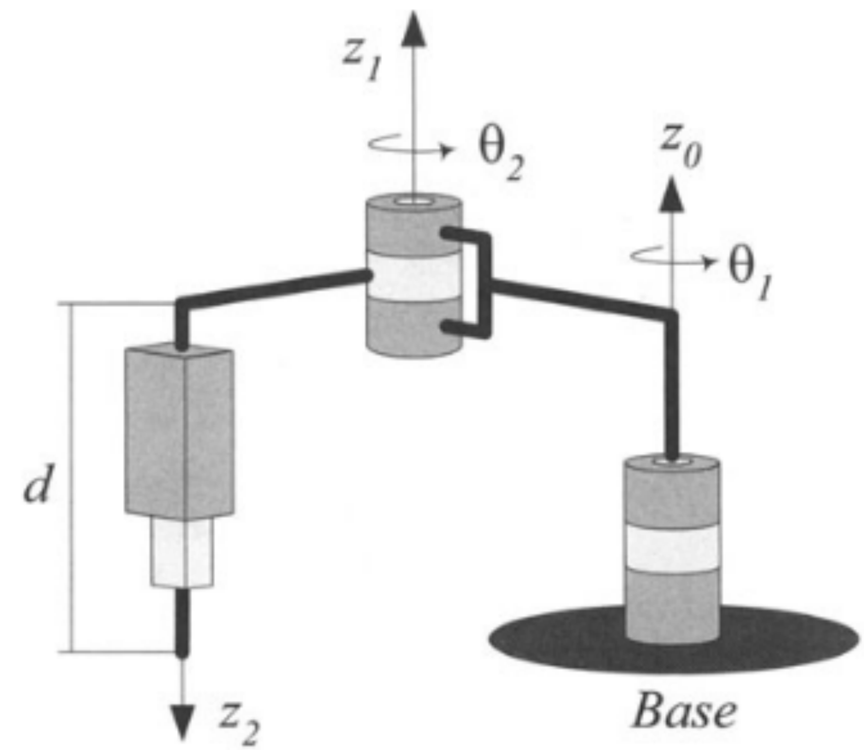
Typically active manipulator joints come in two main flavors



Naming convention based on joints



R-R-R



R-R-P

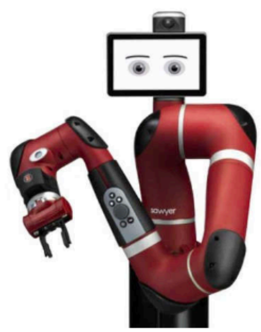
Degrees-of-freedom (dof)

- **The minimum number of independent coordinates needed to represent the configuration of a robot**

$$\text{dof} = \sum \text{dof of every rigid body} - \text{independent constraints}$$

4 dof

6 dof



7 dof

30 dof

~244 dof

image credit: Oscar Ramos, UTEC

Serial vs Parallel Manipulators

Open kinematic chain

Closed kinematic chain

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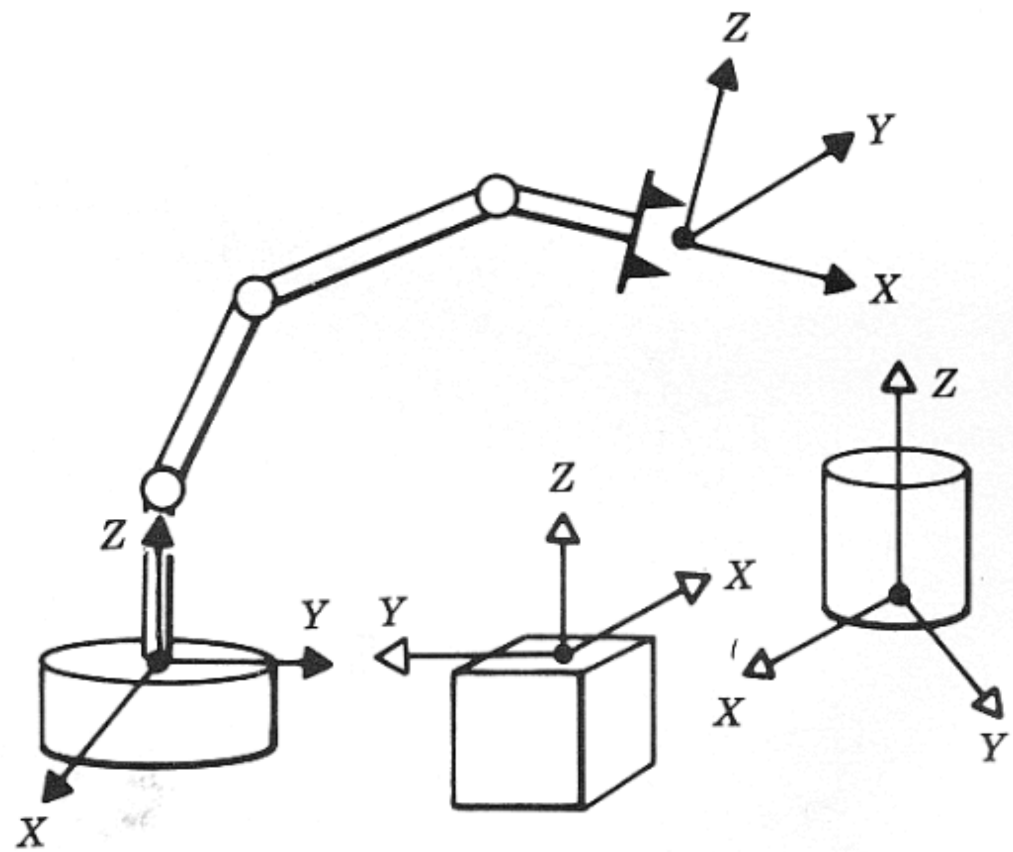
Problems in Robots: Spatial Descriptions

Given: The geometric parameters of the manipulator and targets

Specify: The position and orientation of the manipulator and targets

Solution

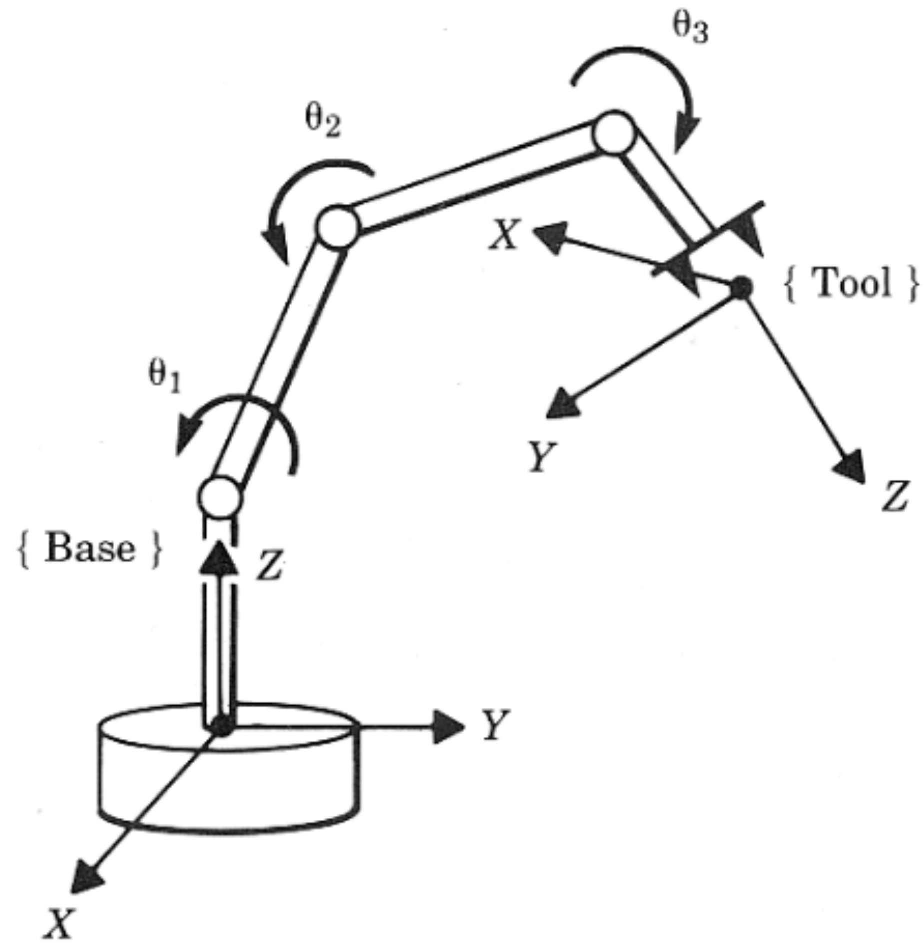
Use coordinate frames attached to joints and environmental objects



Problems in Robots: Forward Kinematics

Given: The manipulator geometry and joint angles (joint or configuration space)

Compute: The position and orientation of the end effector (tasks or cartesian space)



Solution

Transformation matrices to map joint space to cartesian space

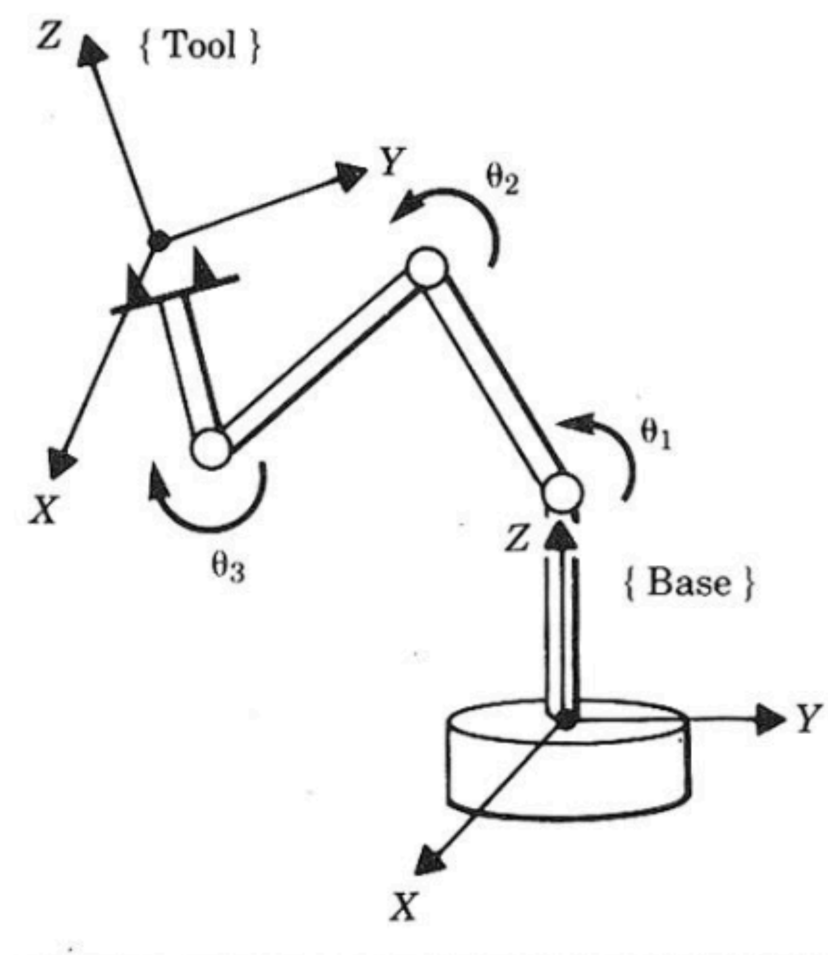
Problems in Robots: Inverse Kinematics

Given: End effort (desired) position relative to base frame

Compute: The set of joint angles which result in the desired end effector position

Solution

In general much more challenging than forward kinematics. Some times analytic solution is possible. Often numeric solution is required.



Problems in Robots: Velocity Transformation

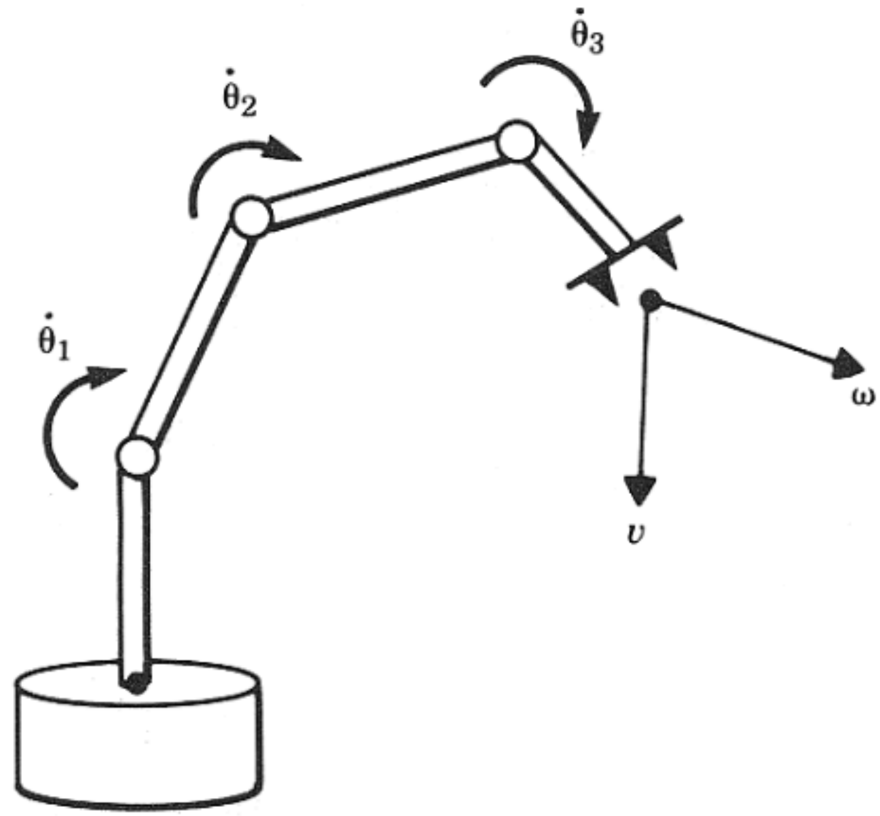
Given: Joint velocities

Compute: End effector velocity

Solution

The time derivative of the position and orientation is taken given the forward kinematics to extract the *Jacobian*

$$\nu = \mathbf{J}(\Theta)\dot{\Theta}$$



Problems in Robots: Force Transformation

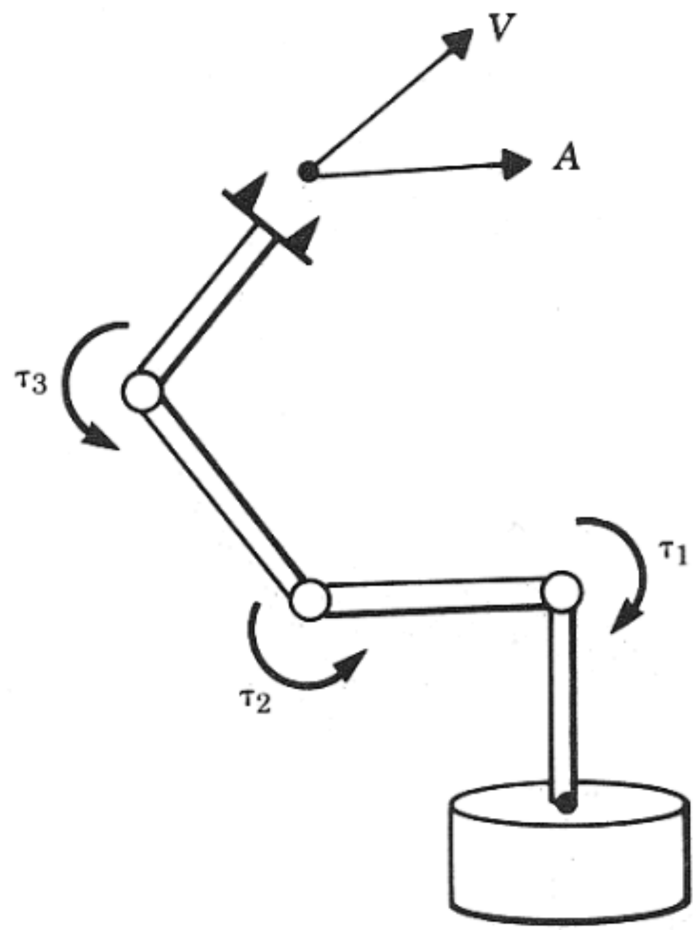
Given: Applied loads at the end effector

Compute: Joint torques

Solution

Force/Moment propagation from the end effector to the base. The Jacobian transposec maps cartesian force/moment to joint torques

$$\tau = \mathbf{J}^T f$$



Problems in Robots: Forward Dynamics

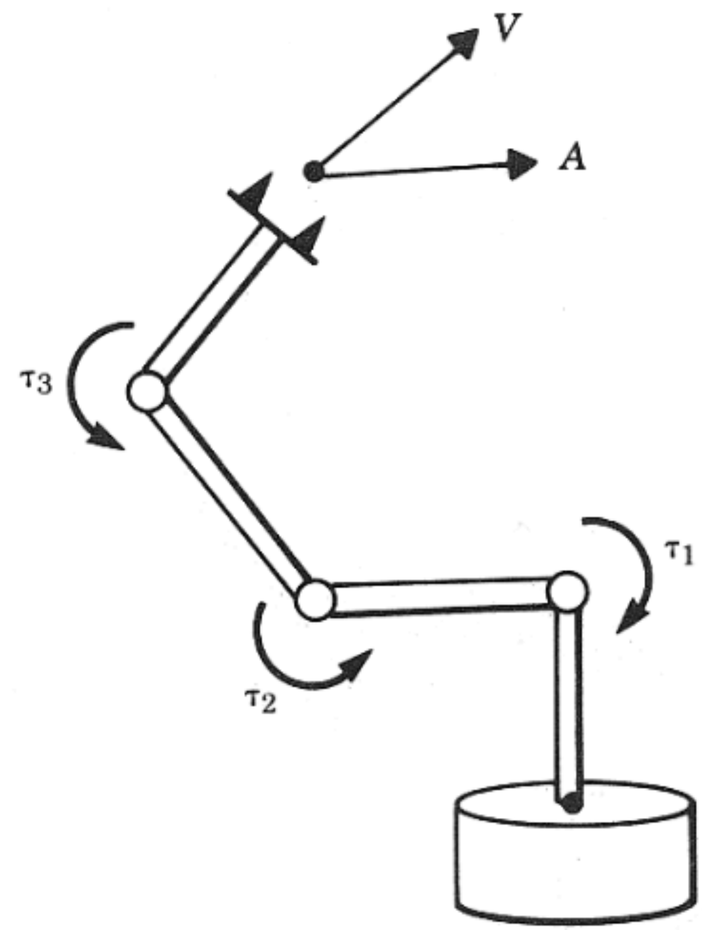
Given: Joint torques, mass and inertia of the links

Compute: Angular acceleration of the links (equations of motion)

Solution

Use the Newton-Euler method or Lagranian Dynamics

$$\tau = \mathbf{M}(\Theta)\ddot{\Theta} + \mathbf{C}(\Theta, \dot{\Theta}) + \mathbf{G}(\Theta)$$



Problems in Robots: Inverse Dynamics

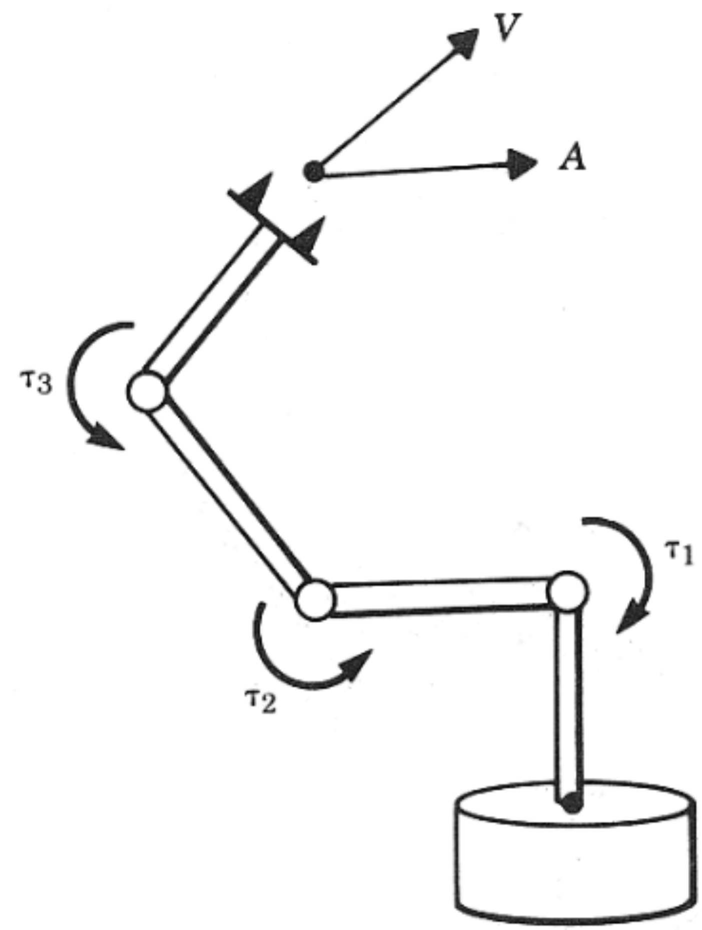
Given: (Desired) Angular acceleration, velocity of links

Compute: Required joint torques

Solution

Use the Newton-Euler method or Lagranian Dynamics

$$\tau = \mathbf{M}(\Theta)\ddot{\Theta} + \mathbf{C}(\Theta, \dot{\Theta}) + \mathbf{G}(\Theta)$$



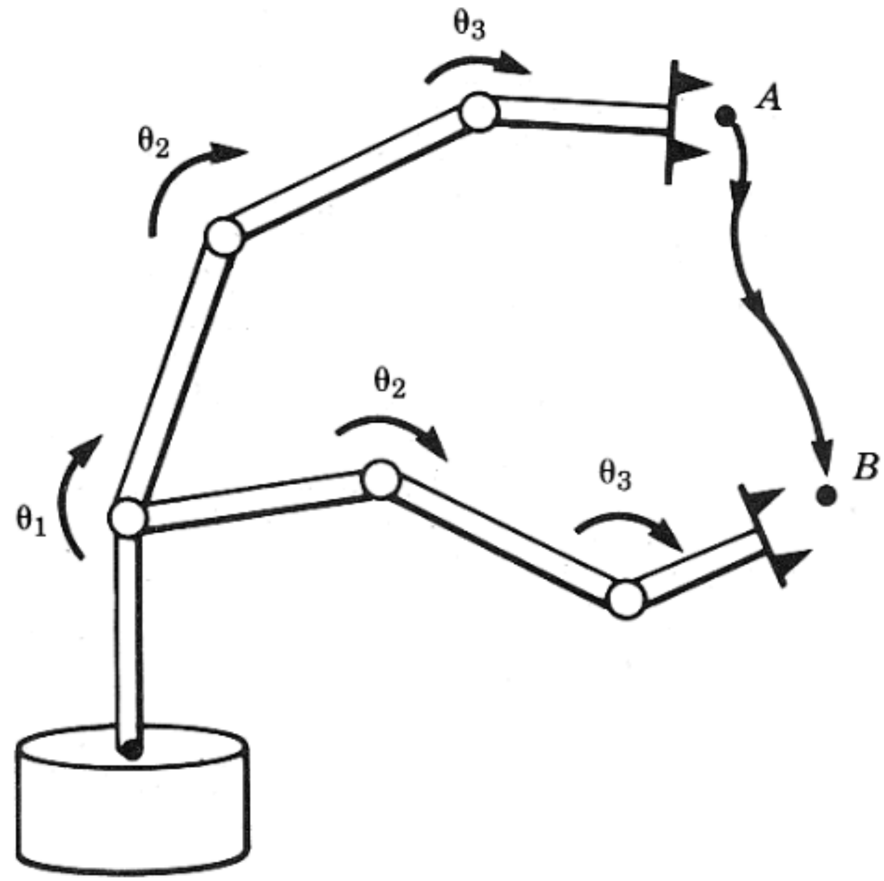
Problems in Robots: Trajectory Generation

Given: Desired start and end configuration

Compute: Smooth trajectory

Solution

Polynomial splines



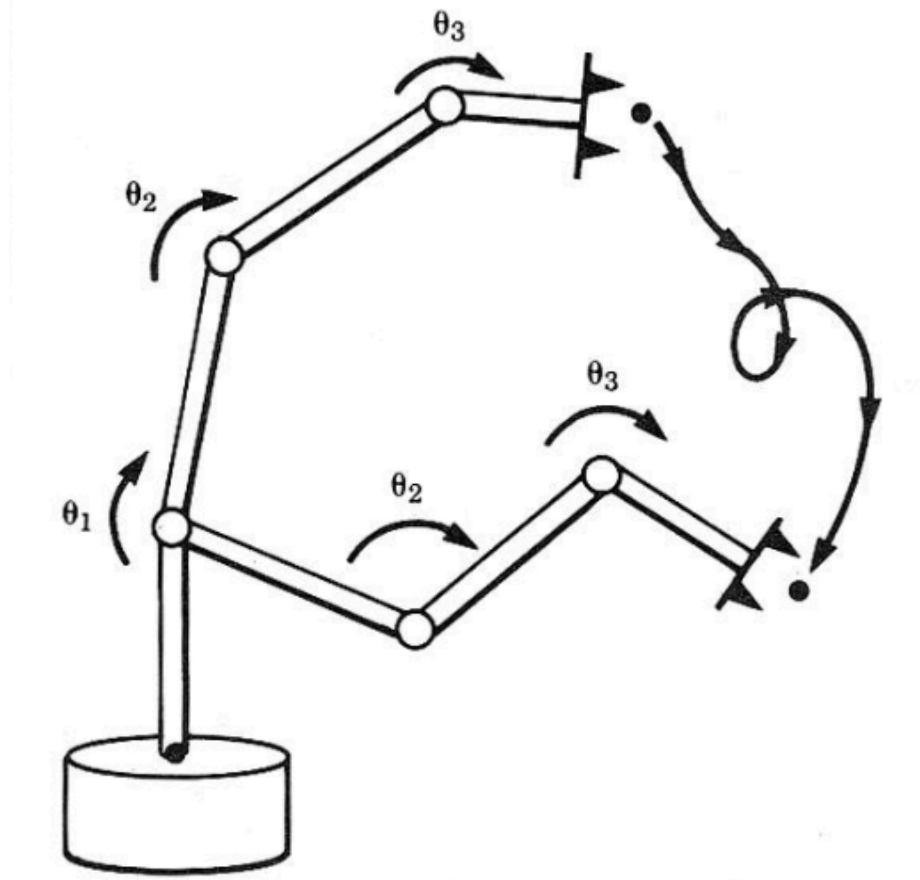
Problems in Robots: Robot Control (Position)

Given: Desired end effector trajectory

Compute: Joint torques required to follow the trajectory

Solution

Feedback control



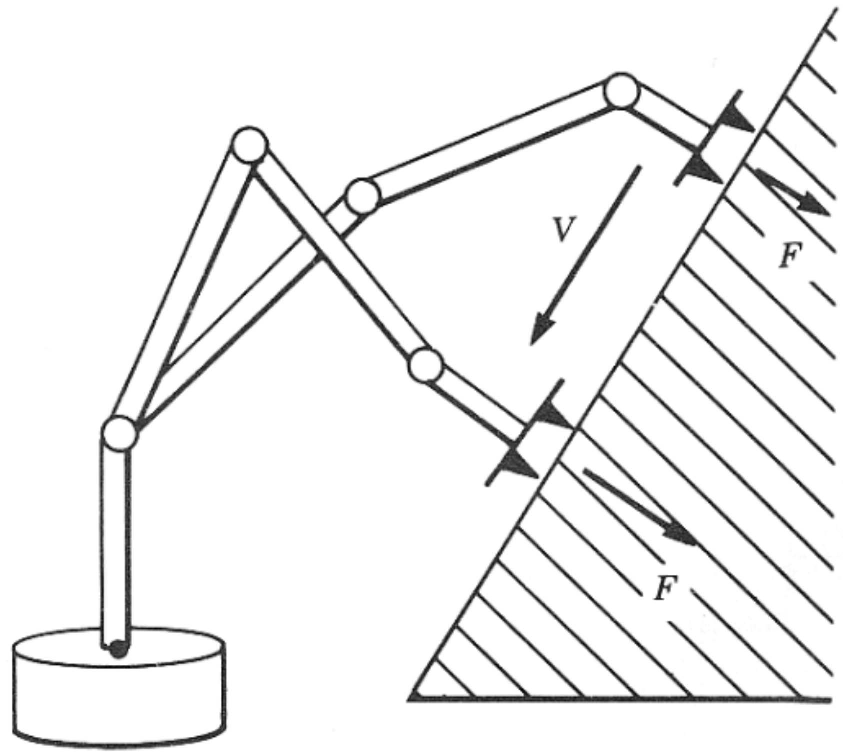
Problems in Robots: Robot Control (Force)

Given: Desired force interaction

Compute: Joint torques

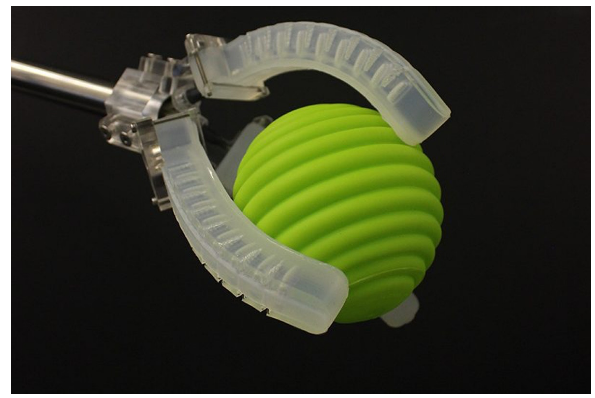
Solution

Force feedback control



Potential Advance Topics to Introduce

Walking Robots



Soft Robots

Parallel Robots

Human Robot Interaction

Index Cards

1. What are the specific things you are hoping to learn? (list a few)

- “I want to learn how to model the dynamics of robots.”
- “I want to learn how to design robots.”

2. What specific applications are you hoping to learn about?

- “I want to learn how about walking robots.”
- “I want to learn about rehabilitation robots.”

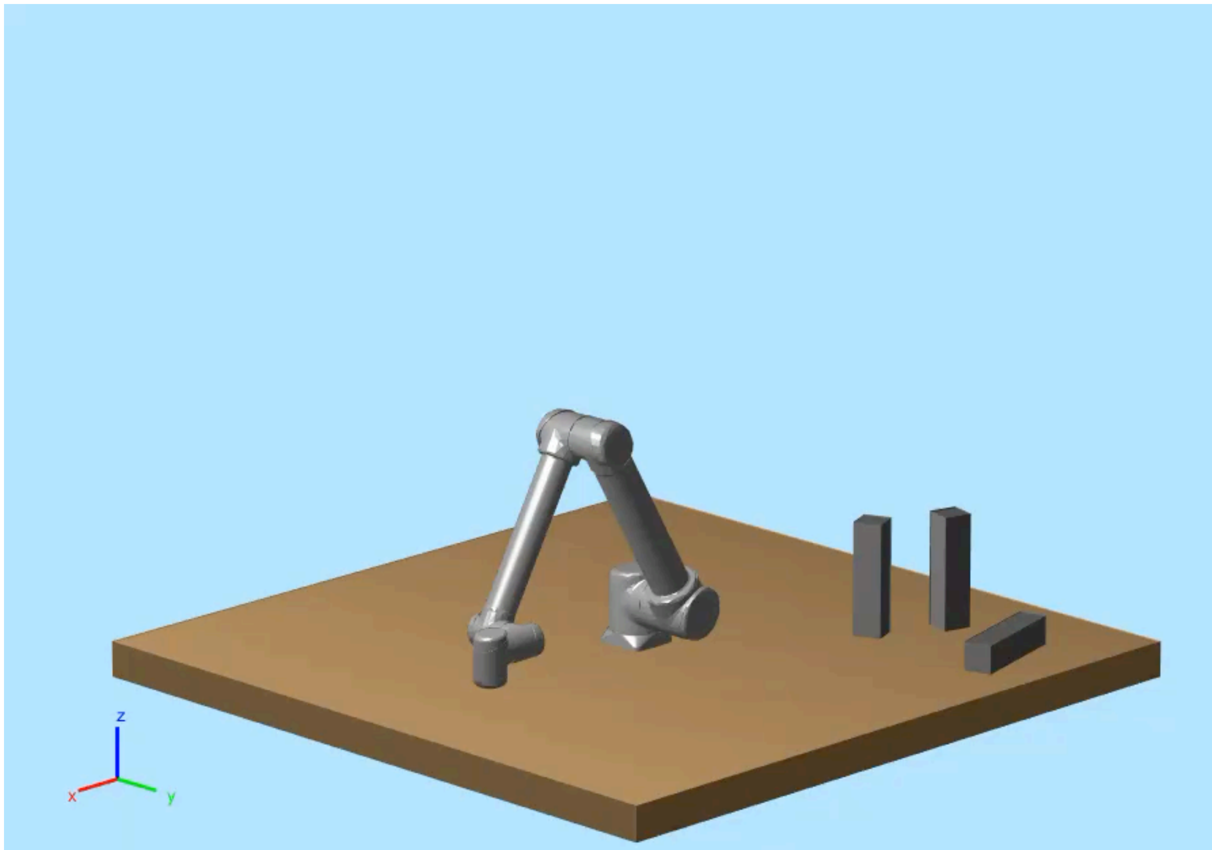
Today's Agenda

1. Introductions
2. Logistics
3. What are ‘Robots’?
4. Course Overview
5. Project Specifics

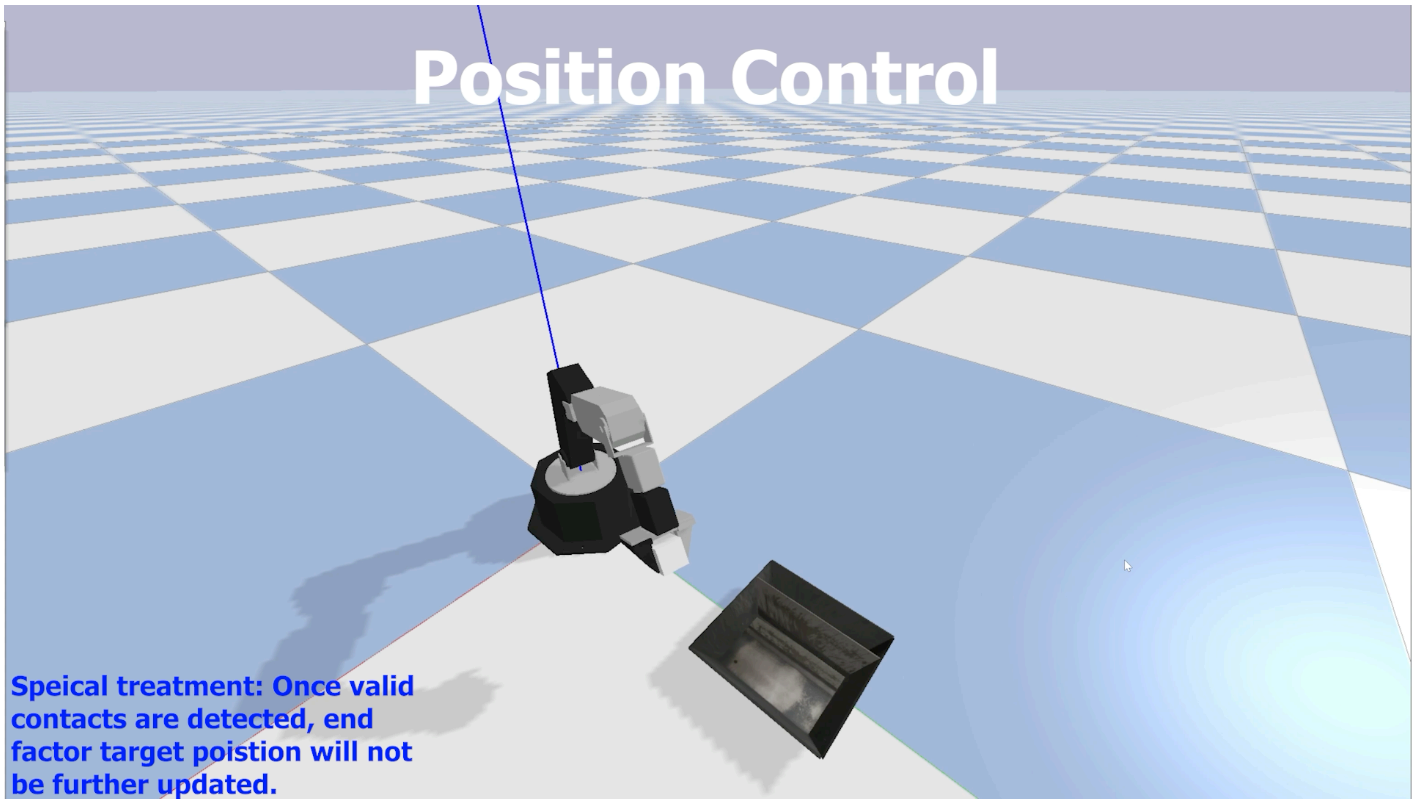
Course Website

https://intra.engr.ucr.edu/~jrealmuto/courses/me221-f22/

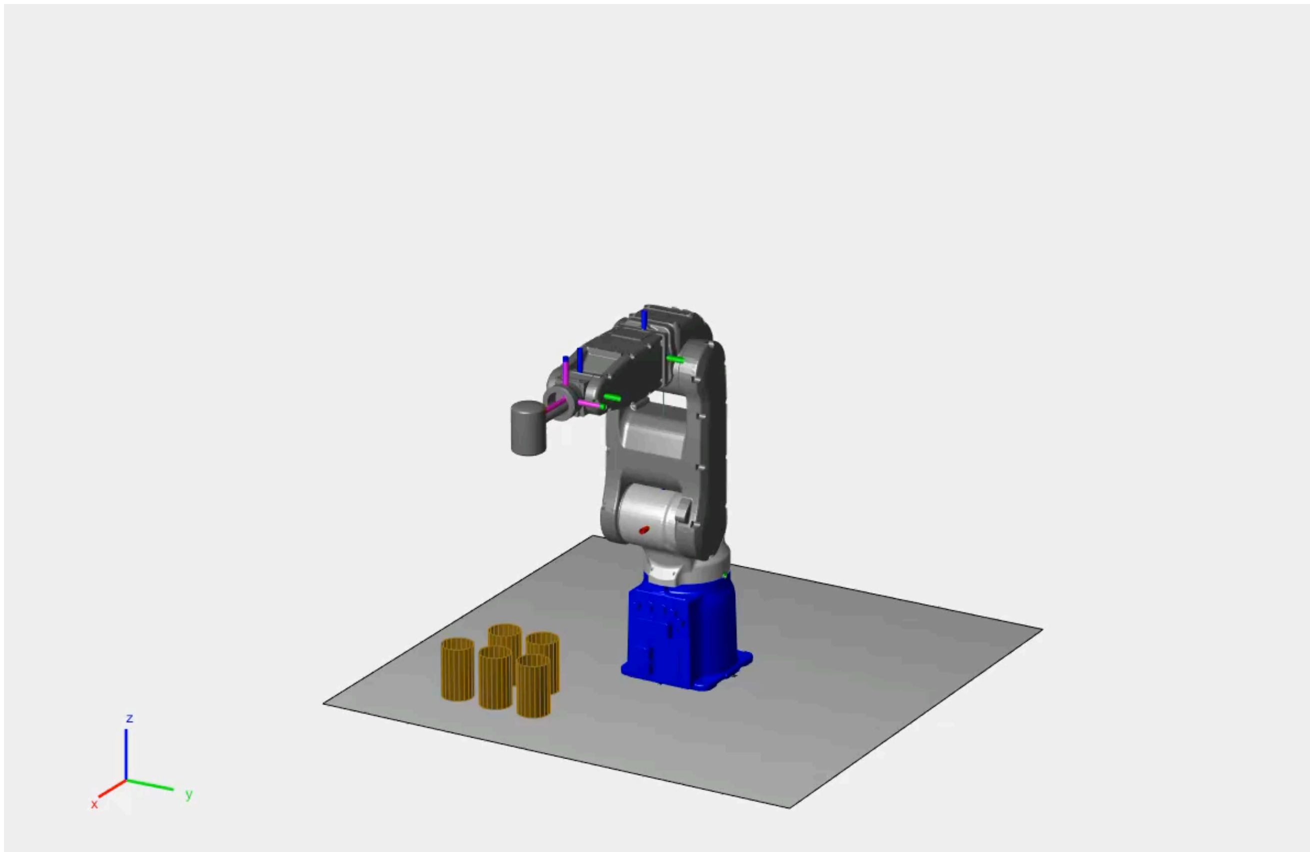
Last Years Projects



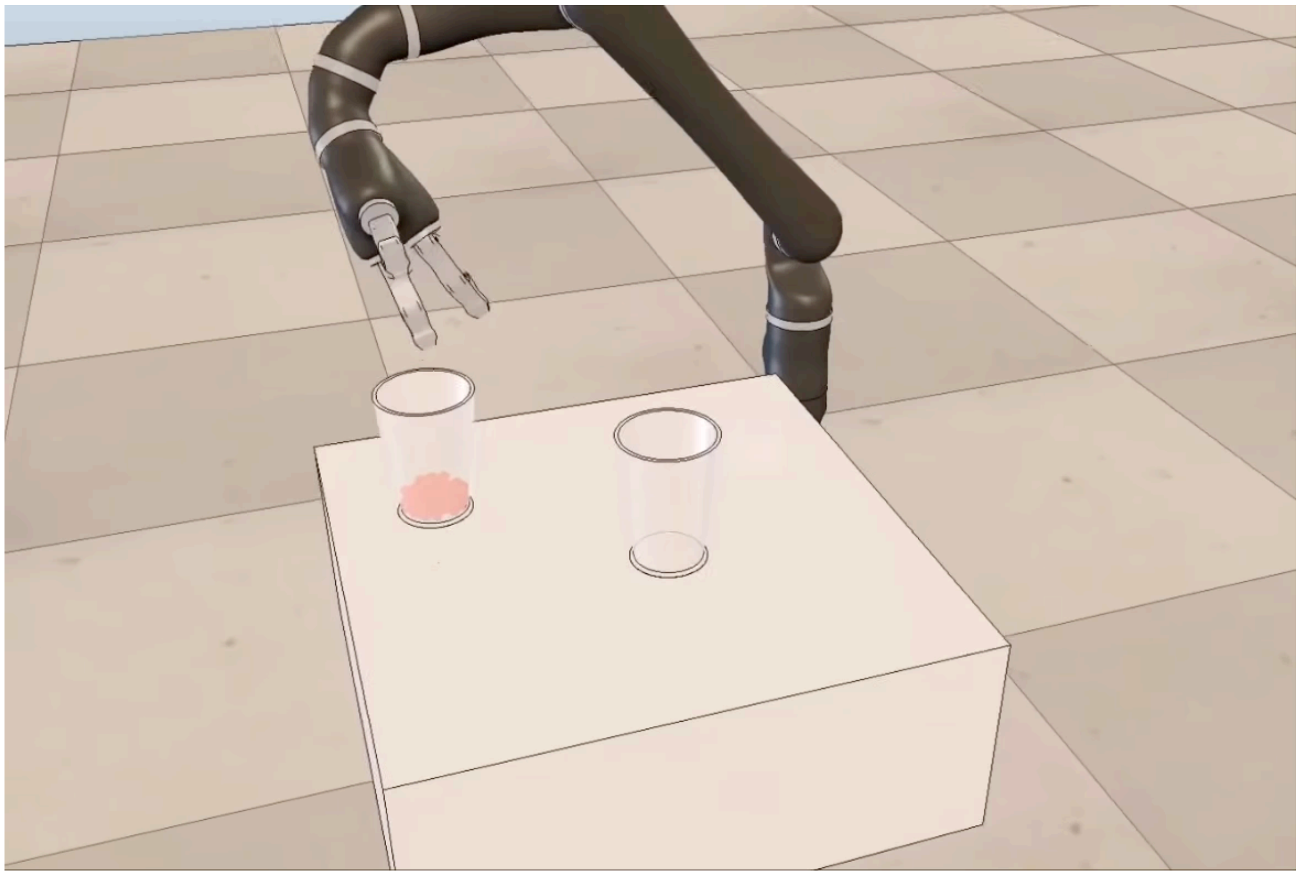
Last Years Projects



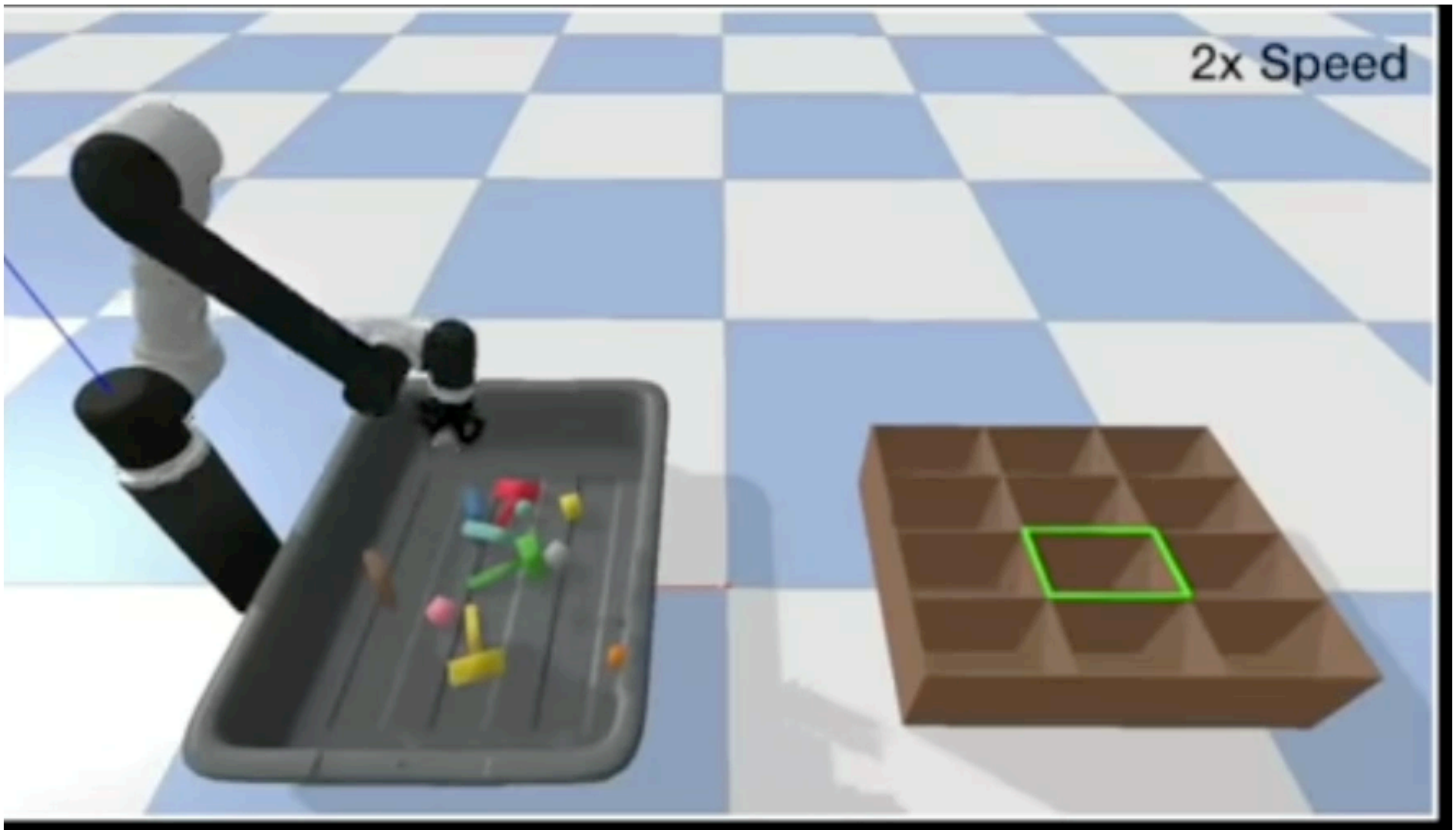
Last Years Projects



Project Example: Pick and Pour



Project Example: Pick and Toss



Project Example: Assistive Robot

Project Example: Passive Walker