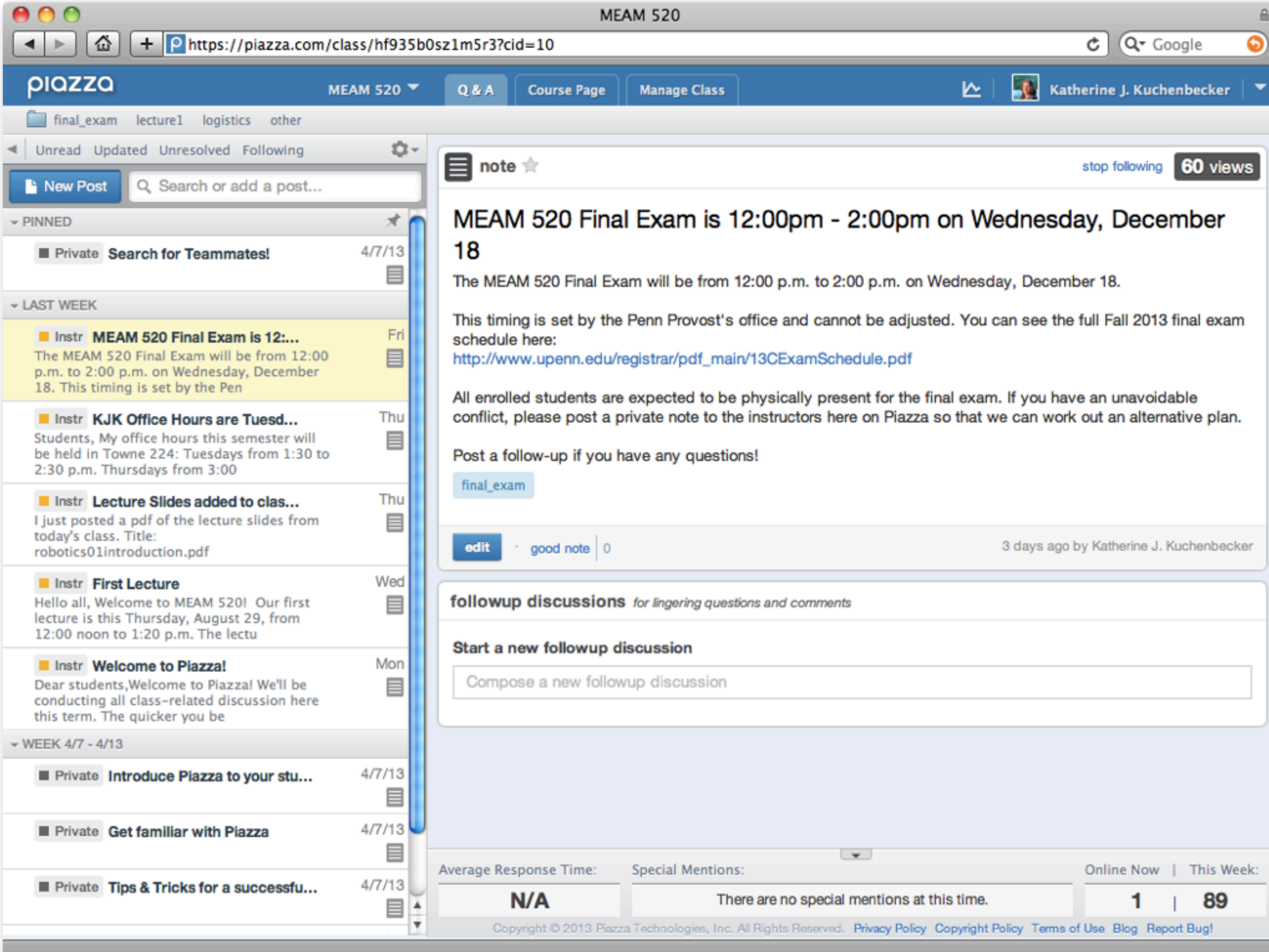
MEAM 520

Background

Katherine J. Kuchenbecker, Ph.D.
General Robotics, Automation, Sensing, and Perception Lab (GRASP)
MEAM Department, SEAS, University of Pennsylvania

GRASP
LABORATORY

Lecture 2: September 3, 2013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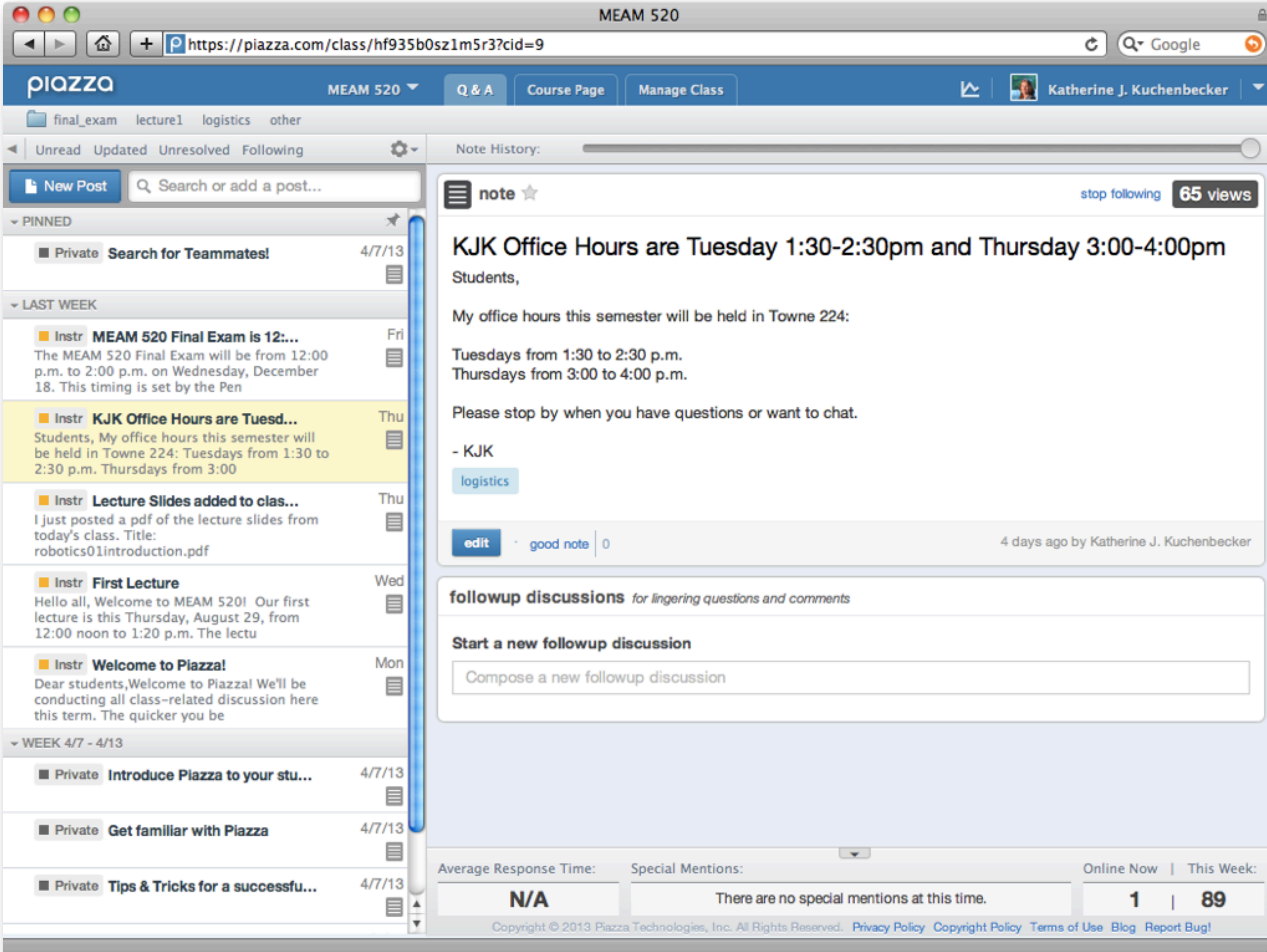
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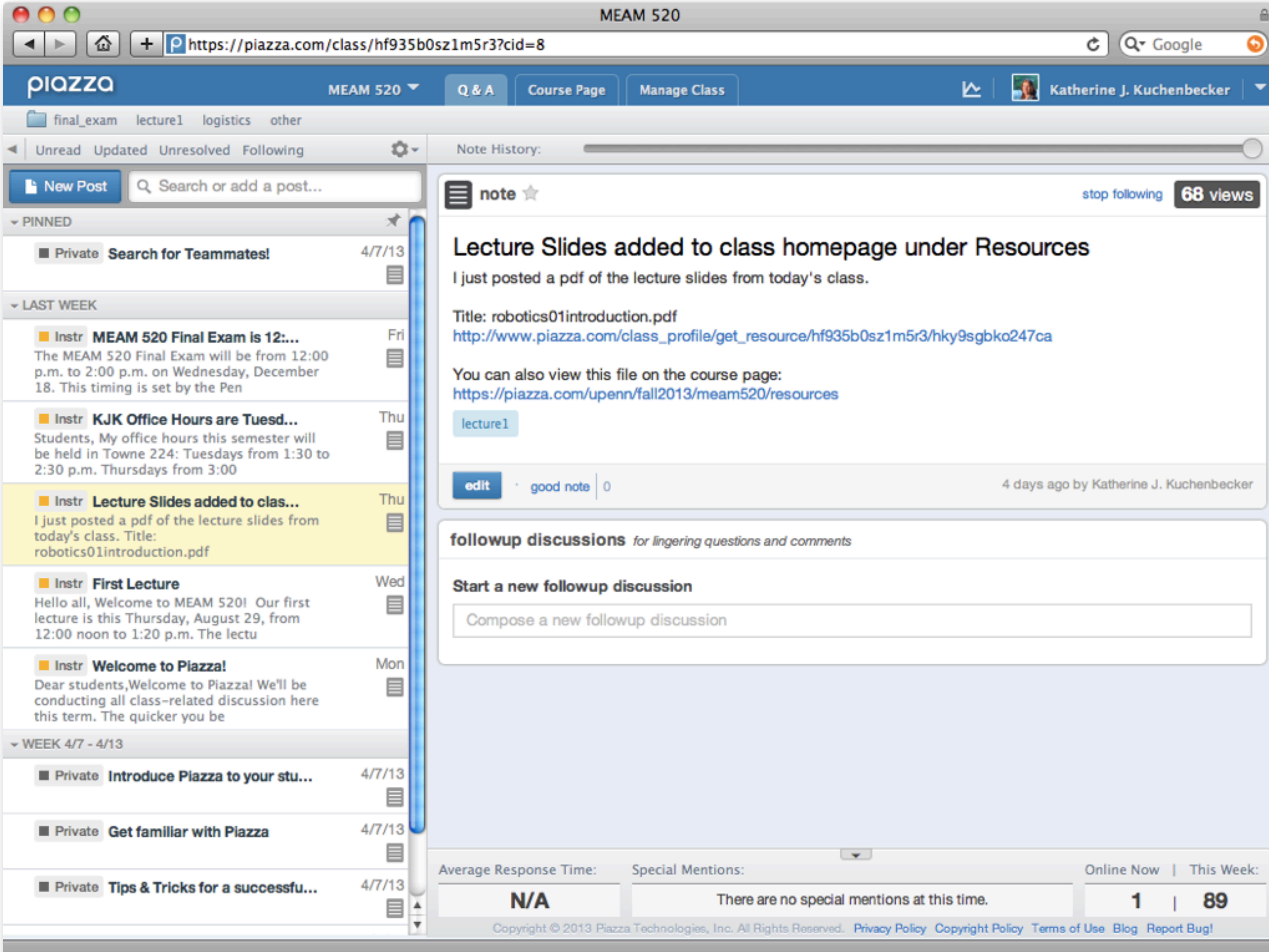
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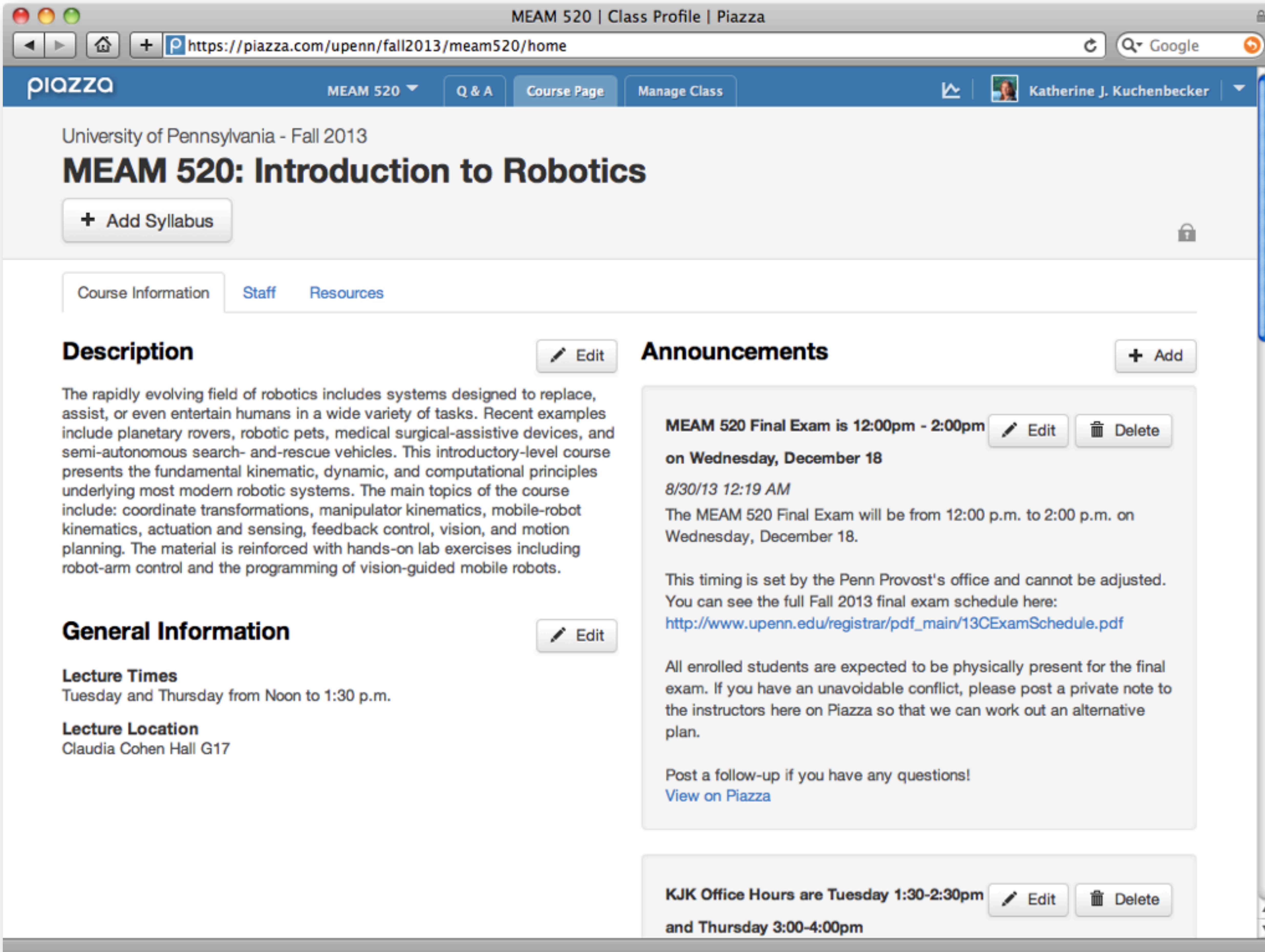
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The rapidly evolving field of robotics includes systems designed to replace, assist, or even entertain humans in a wide variety of tasks. Recent examples include planetary rovers, robotic pets, medical surgical-assistive devices, and semi-autonomous search- and-rescue vehicles. This introductory-level course presents the fundamental kinematic, dynamic, and computational principles underlying most modern robotic systems. The main topics of the course include: coordinate transformations, manipulator kinematics, mobile-robot kinematics, actuation and sensing, feedback control, vision, and motion planning. The material is reinforced with hands-on lab exercises including robot-arm control and the programming of vision-guided mobile robots.
General Information
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Lecture Times
Tuesday and Thursday from Noon to 1:30 p.m.
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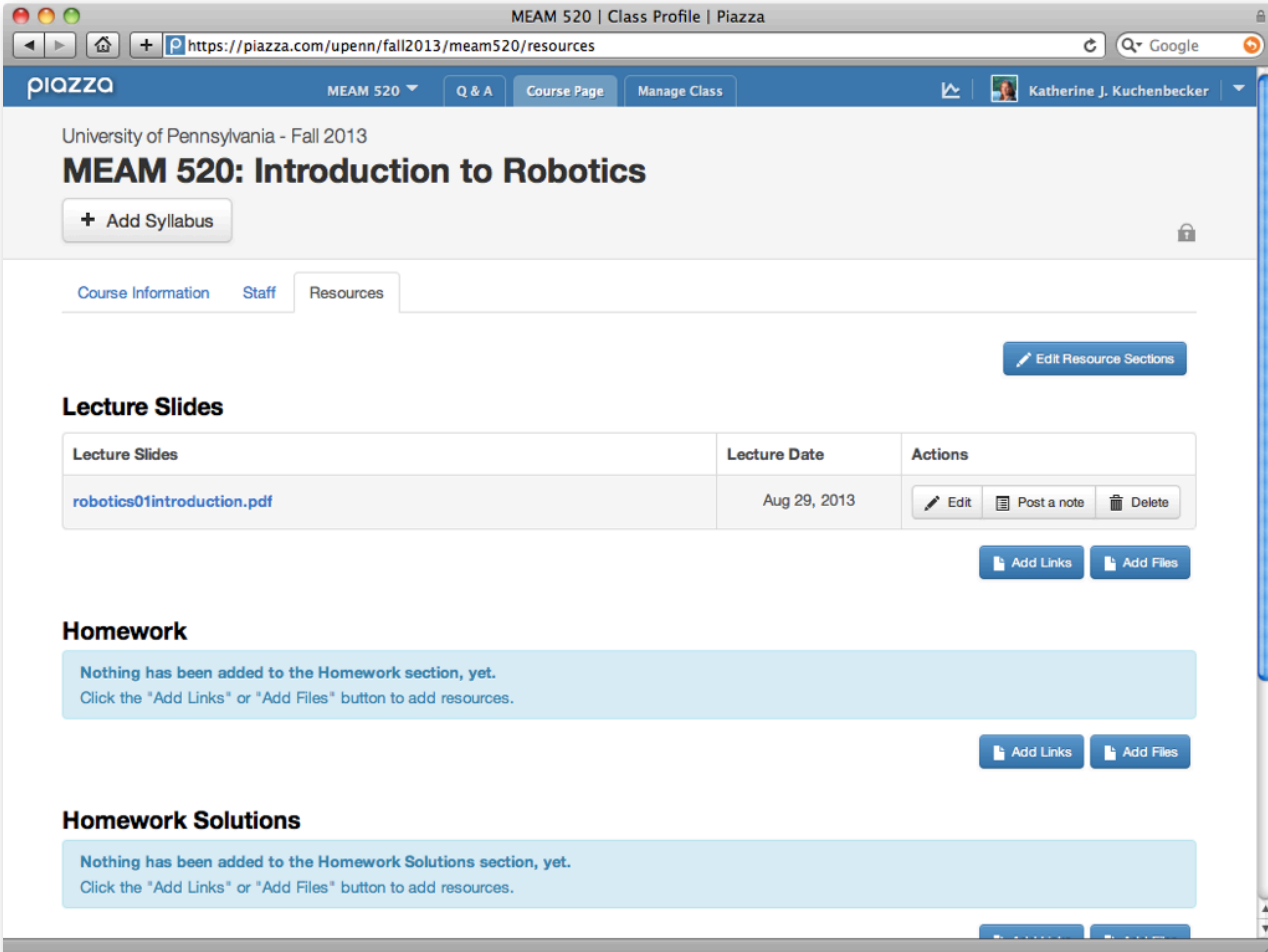
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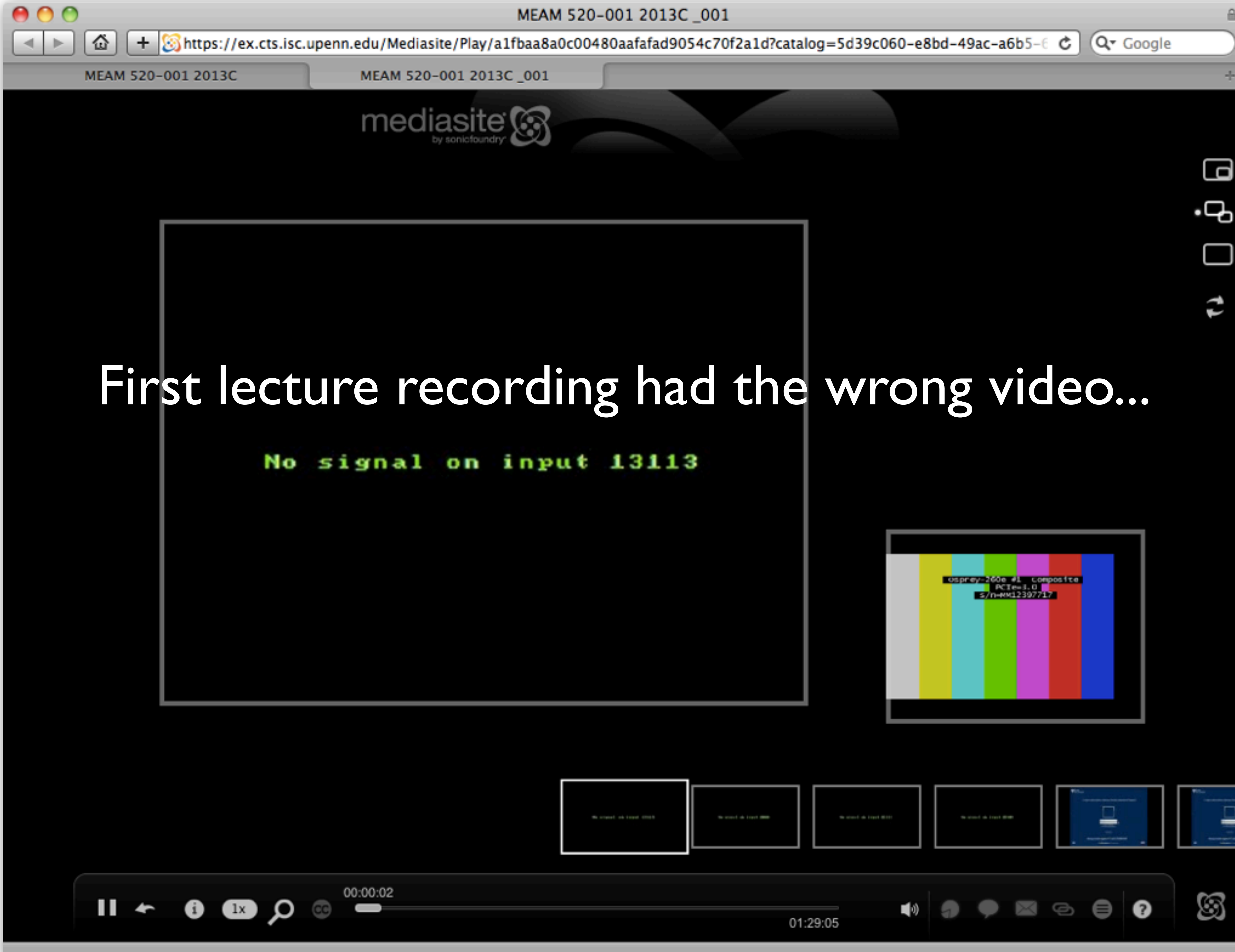
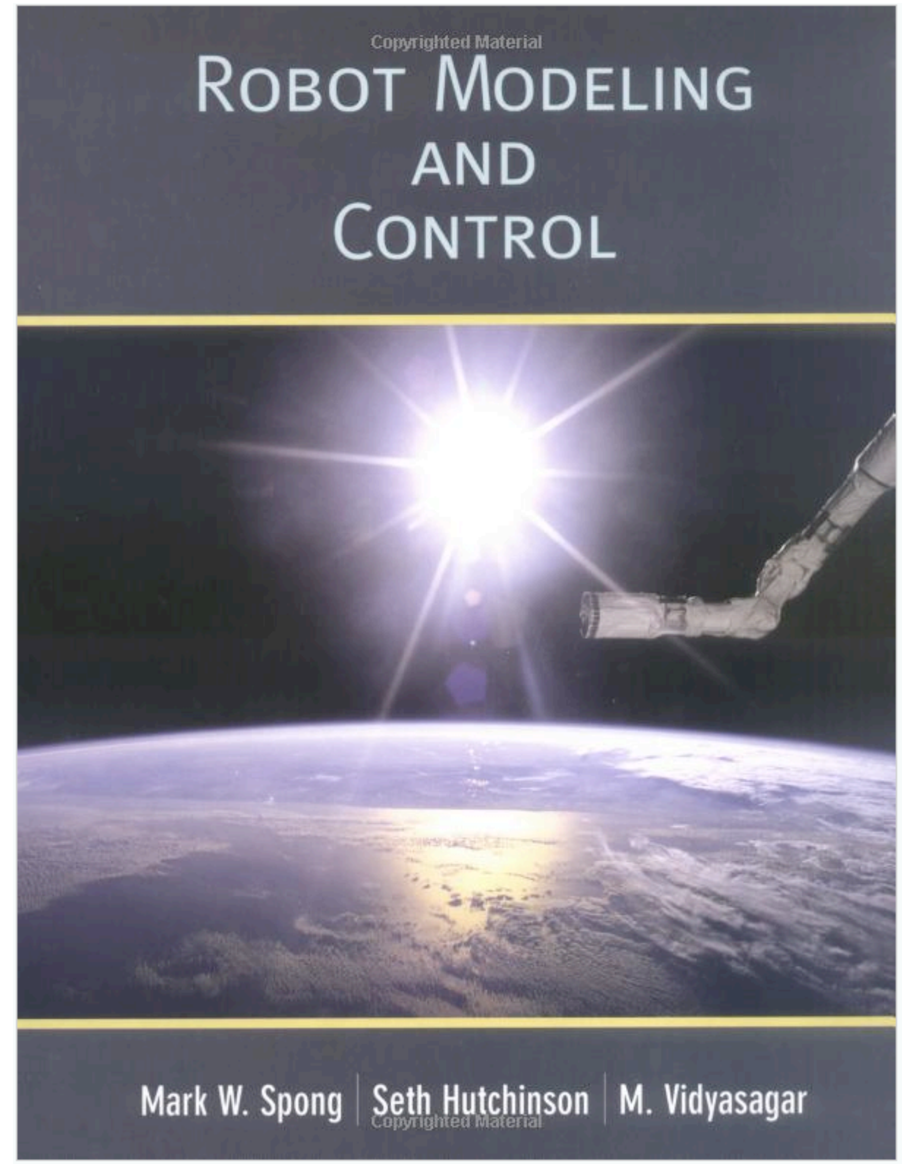


What logistical questions do you have about MEAM 520?

Additional workshops are being planned.



Robotics is difficult
or, somewhat equivalently,
humans are very good
at what they do.

Preface of Spong, Hutchinson, and Vidyasagar

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

The robot is the ultimate mechatronic system.

Preface of Spong, Hutchinson, and Vidyasagar

What applications can robots do?

manufacturing
household cleaning
lawn mowing
undersea exploration
planetary exploration
satellite retrieval and repair
defusing explosive devices
radioactive work
prosthetics
surgery
medical training

Chapter 1 of Spong, Hutchinson, and Vidyasagar

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 - Leonard da Vinci designs a mechanical clockwork that sits up, waves its arms, and moves its head.

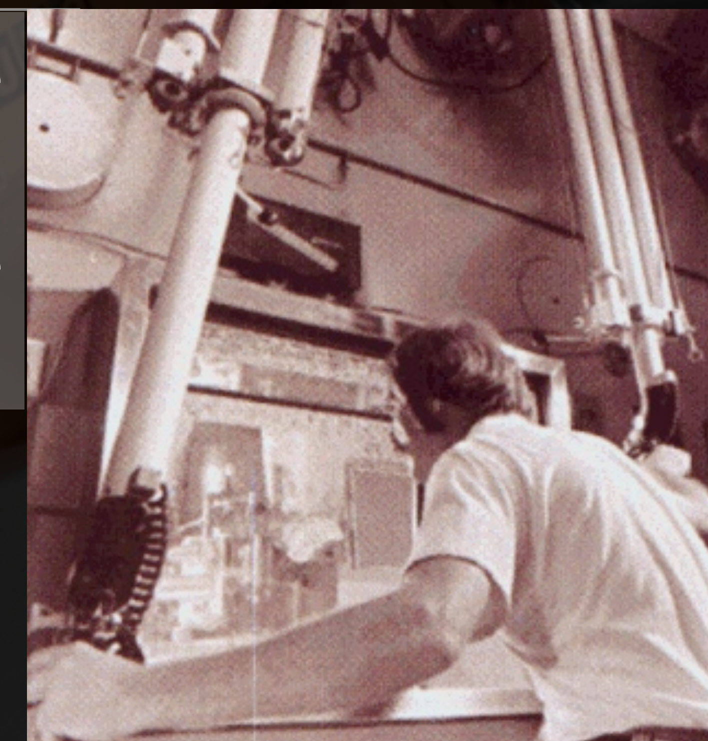
1769 - Wolfgang von Kempelen builds “The Turk”, which gains fame as an automaton capable of playing chess - until the hidden human operator was discovered!

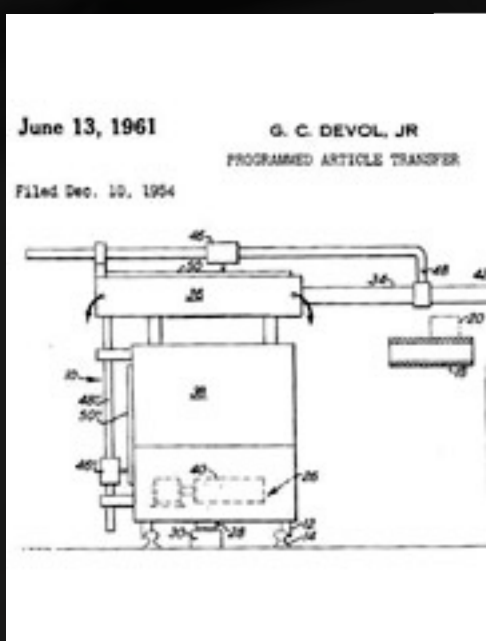
1921 - Karel Capek popularizes the term “robot” in a play called *R.U.R. (Rossum’s Universal Robots)* wherein robot workers take over the earth.

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

1942 - Isaac Asimov publishes *Runaround*, which introduces the three "laws" of robotics.

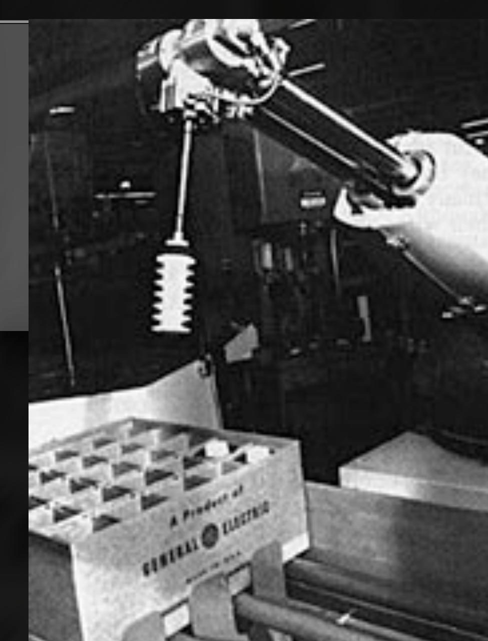
1951 - Raymond Goertz builds the first master/slave teleoperation system for handling radioactive material.





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.



What is a robot?

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
- Robot Institute of America (RIA)

Chapter 1 of Spong, Hutchinson, and Vidyasagar


Is this mixer a robot?

Is this coffeemaker
a robot?


Is a washer a robot? Is a dryer?

Is this cat feeder a robot?

Is this Roomba a robot?

What is a robot?

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

- Robot Institute of America (RIA)

Chapter 1 of Spong, Hutchinson, and Vidyasagar

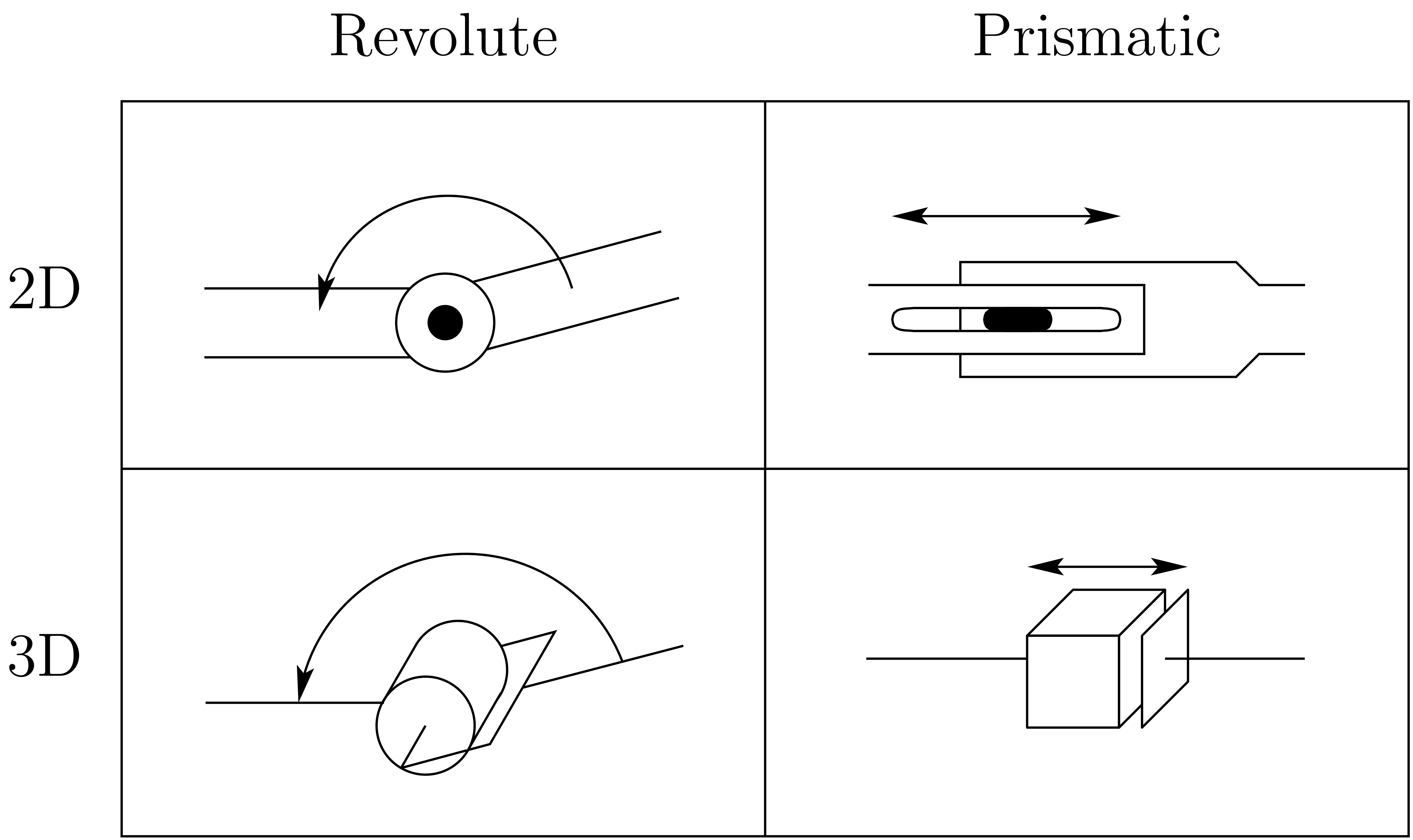
Robot manipulators are composed of:

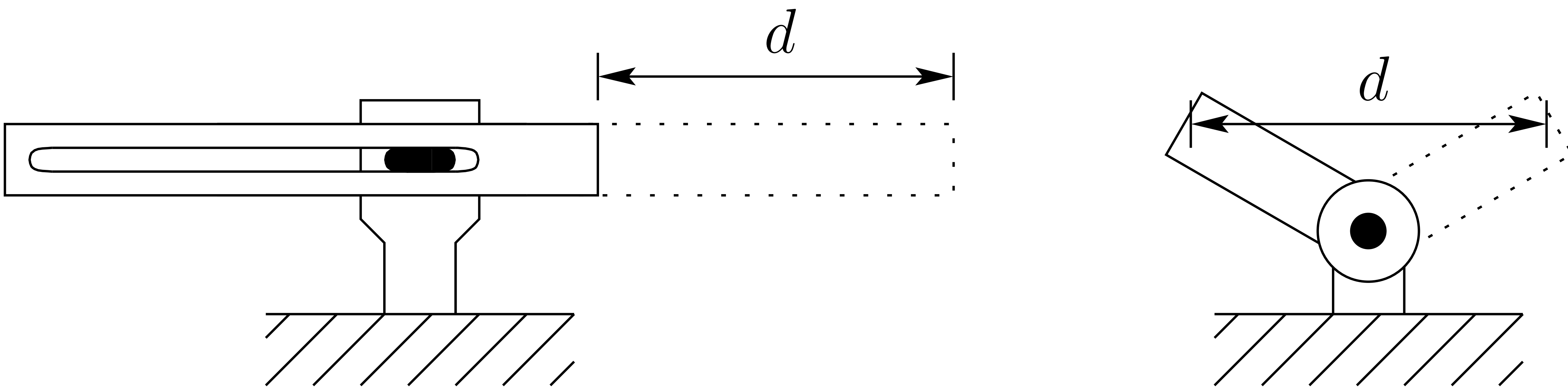
- Rigid **links**
- Connected by **joints**
- To form a **kinematic chain**

There are two types of **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


Revolute
Prismatic
2D
3D



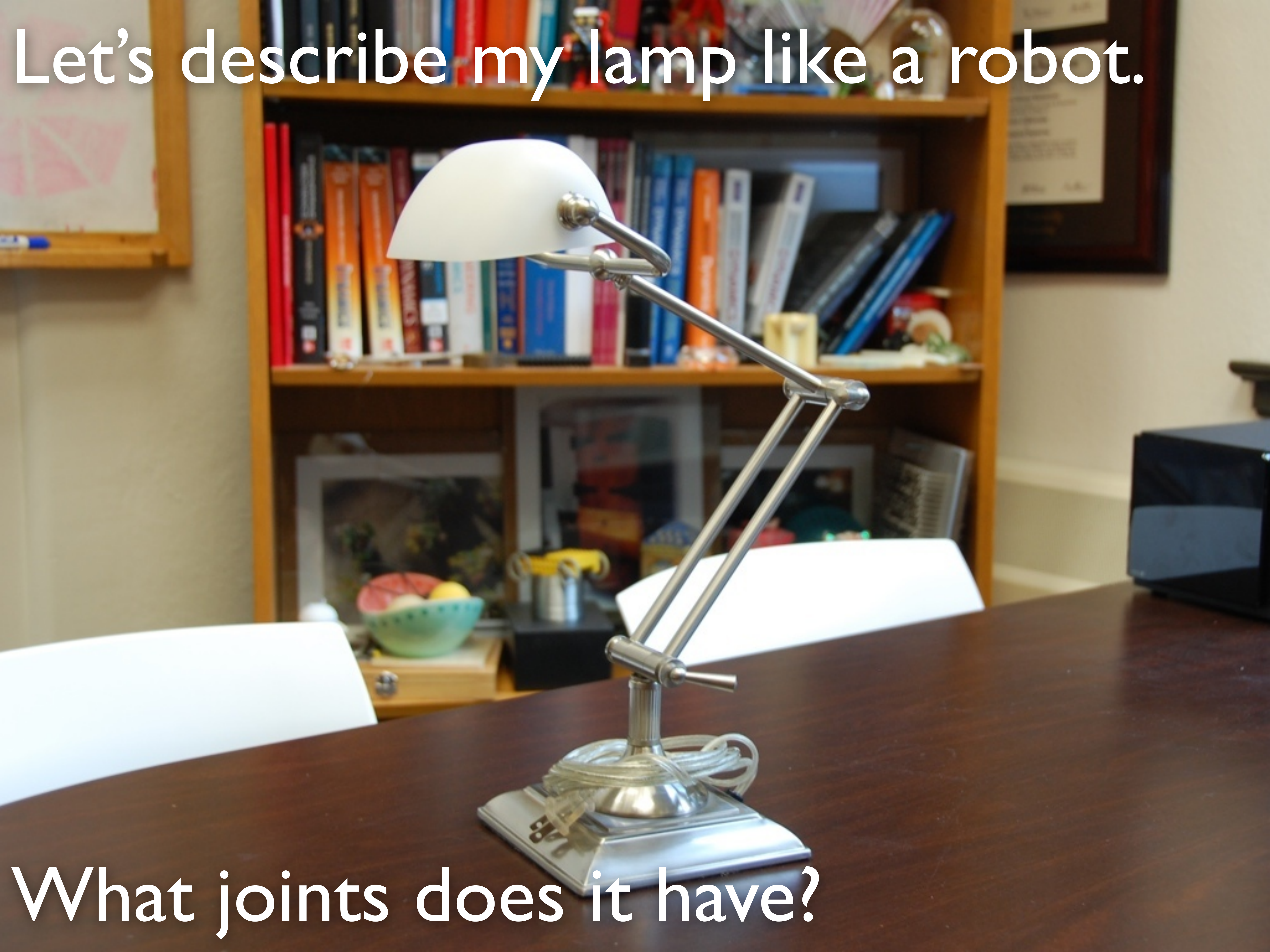
Prismatic joints are easier to model and analyze, but they are bulkier.

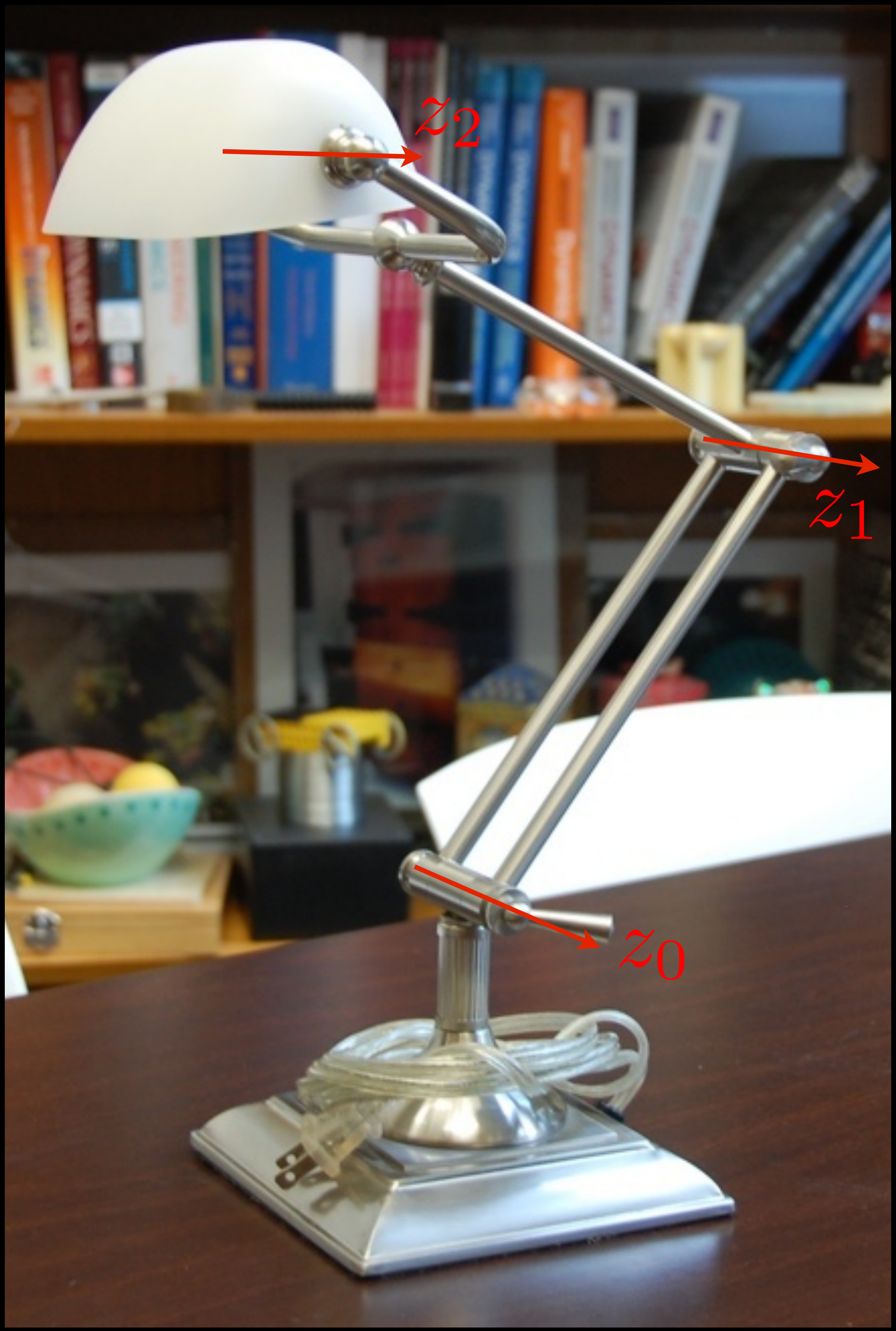
In other words, they take up more space to achieve the same amount of movement.

What kind of joints does a human leg have?

Revolute!

Ignoring arch and toes, it's RRRRRRR


Let’s describe my lamp like a robot.
What joints does it have?

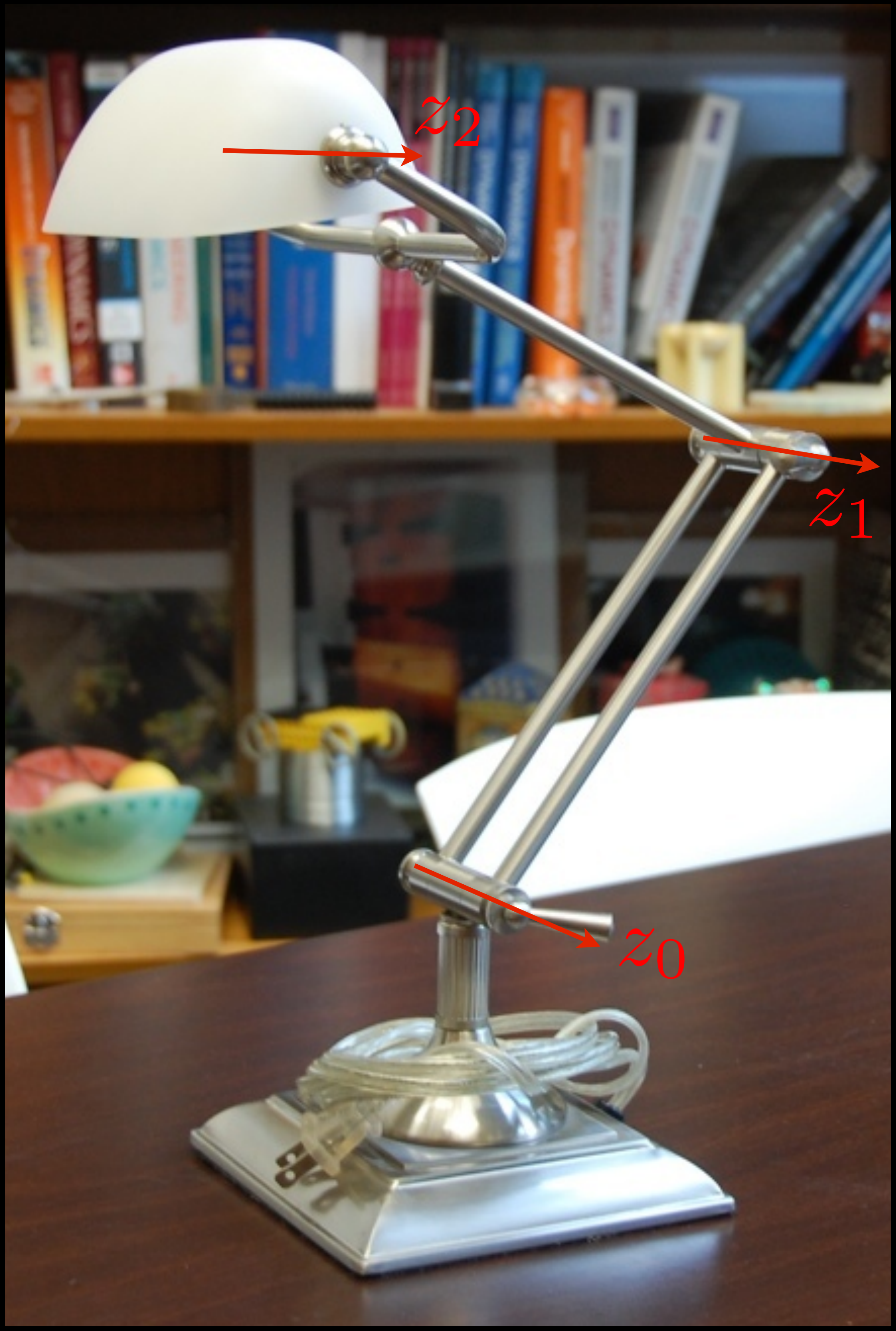


Which **parts** are we describing, and which are we neglecting?

You need to see it **move** in order to know where the joints are.

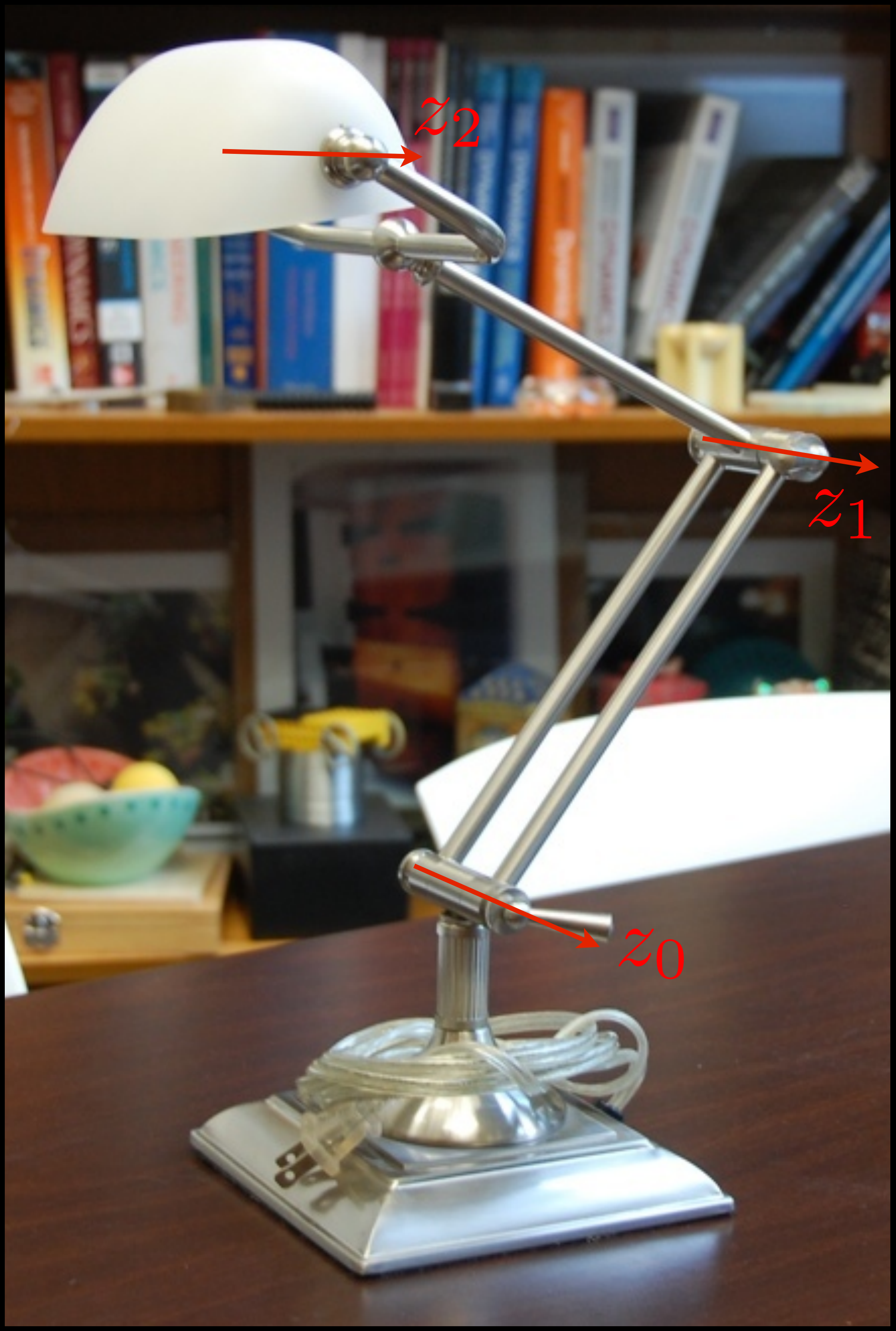
If we keep the **base fixed** (stationary) and treat the white glass shade as the **end-effector**, what type of robot is the lamp?

- **RRR** manipulator
- All rotational axes are **parallel**
- **Planar** mechanism



A manipulator's **configuration** is a complete specification of the location of every point on the manipulator.

- We use a **joint variable** to denote each joint's position.
- Value defines the joint's displacement from a **zero configuration**.
- Use **θ** for revolute joints.
- Use **d** for prismatic joints.
- Axis orientation defines the **positive direction**.
- Knowing all joint variable values defines the configuration.



A manipulator's **configuration space** is the set of all configurations.

How many **configurations** does this lamp have?

- Infinitely many!

How many **numbers** do I need to define the lamp's configuration?

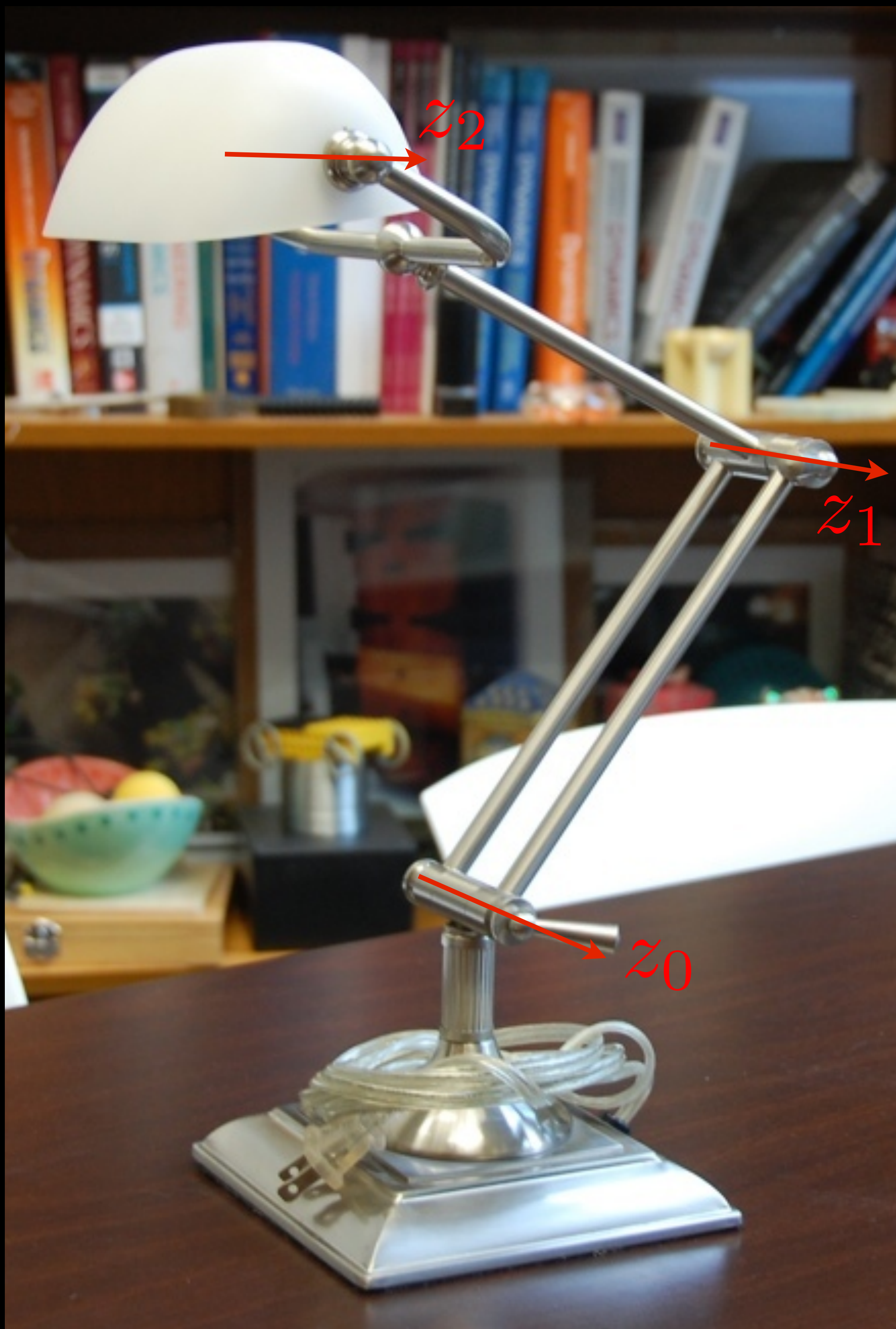
- Three: θ_1, θ_2, θ_3

This value is the **degrees of freedom (DOF)** of the robot.

How many **DOF** does the lamp have if I lock the joints and move it around in three dimensions?

- Six
- Three for positioning
- Three for orientation

Robots need at least 6 joints **(6 DOF)** for the end-effector to reach every point in its workspace with arbitrary orientation.

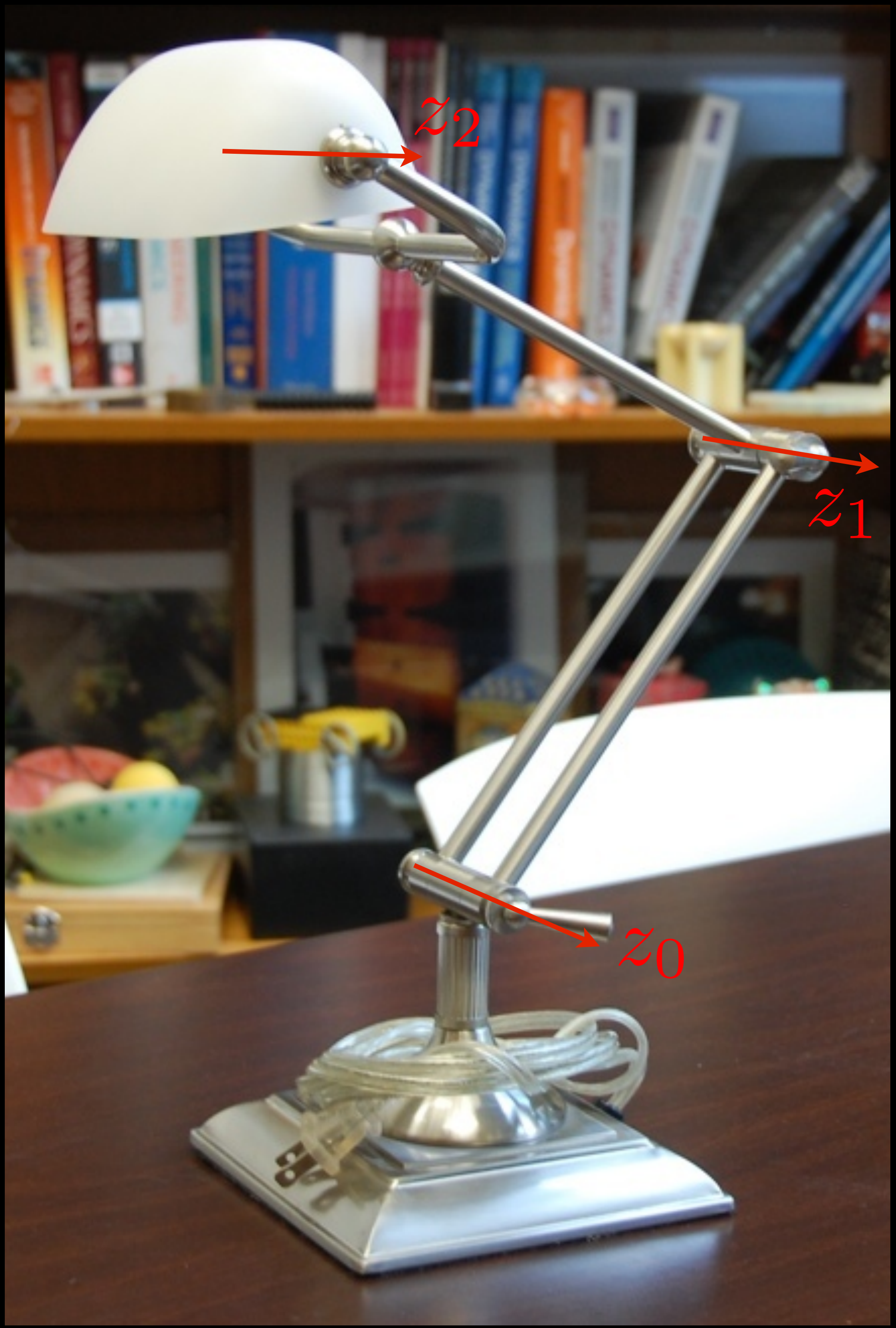


The **workspace** of a manipulator is the total volume swept out by the end-effector as the manipulator executes all possible motions.

- Depends on robot geometry as well as mech. limits on the joints.
- Choose a particular point to represent end-effector location.

The **reachable workspace** is the entire set of points that the end-effector can reach.

The **dexterous workspace** is the set of points that the manipulator can reach with arbitrary orientation.



Define a point on the shade along the final axis (z_2) as the end-effector location.

What is the **reachable workspace** of the lamp?

- Everywhere the point can go when joints are rotated.
- This is a two-dimensional shape.

What is the **dexterous workspace** of the lamp?

- If we consider motion only in 2D, dexterous is the same as reachable workspace.
- Considering 3D, there is none!

What if we let the **base move and rotate** on the table. What type of robot is the lamp now?

- **PPRRRR** manipulator
- Not all rotational axes are **parallel**
- **Spatial** mechanism

What is the **reachable workspace** of the lamp?

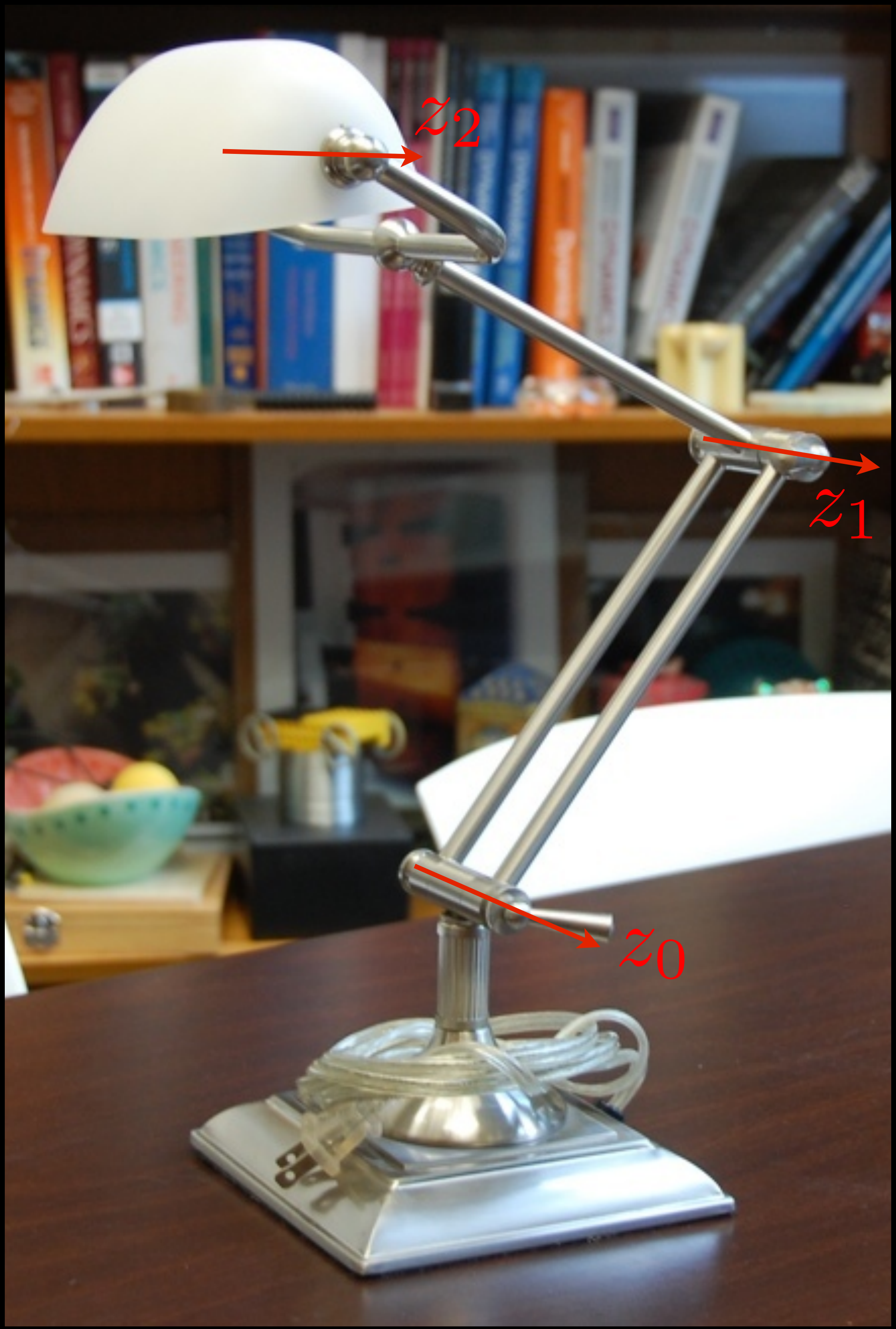
- Everywhere the shade can go when joints rotate, base slides.

What is the **dexterous workspace** of the lamp?

- There is none! The shade can't tilt left/right; z_5 always horizontal.

Can we apply the same terminology of revolute and prismatic joints to the **Roomba**?

- It's sort-of a **PPR** manipulator.
- With chassis lift, **PPRP**.
- But it can't move in any direction at any time.
- This is a **non-holonomic constraint**, and it makes mobile robots with wheels more challenging to model and control.



Does the **configuration** of a manipulator fully define how it will move in the future?

- No. It only gives you an **instantaneous description** of the geometry.
- The manipulator's **state** is a set of variables that is sufficient to tell you its future time response when combined with dynamics and future inputs.
- State requires both the joint variables and their **derivatives**.

Some Common Manipulator Designs

Real Robot
Kinematic Diagram
Workspace Diagram

Try to envision the diagrams on your own!

Articulated Manipulator (RRR)

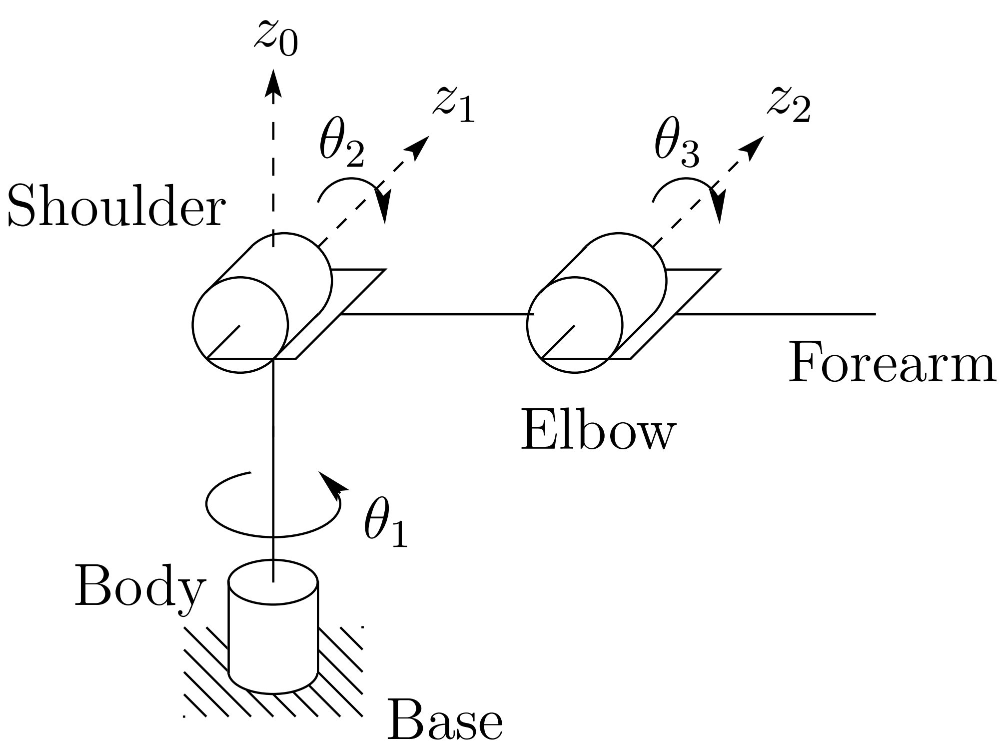


Fig. 1.8 Structure of the elbow manipulator.

Fig. 1.6 The ABB IRB1400 Robot. Photo courtesy of ABB.

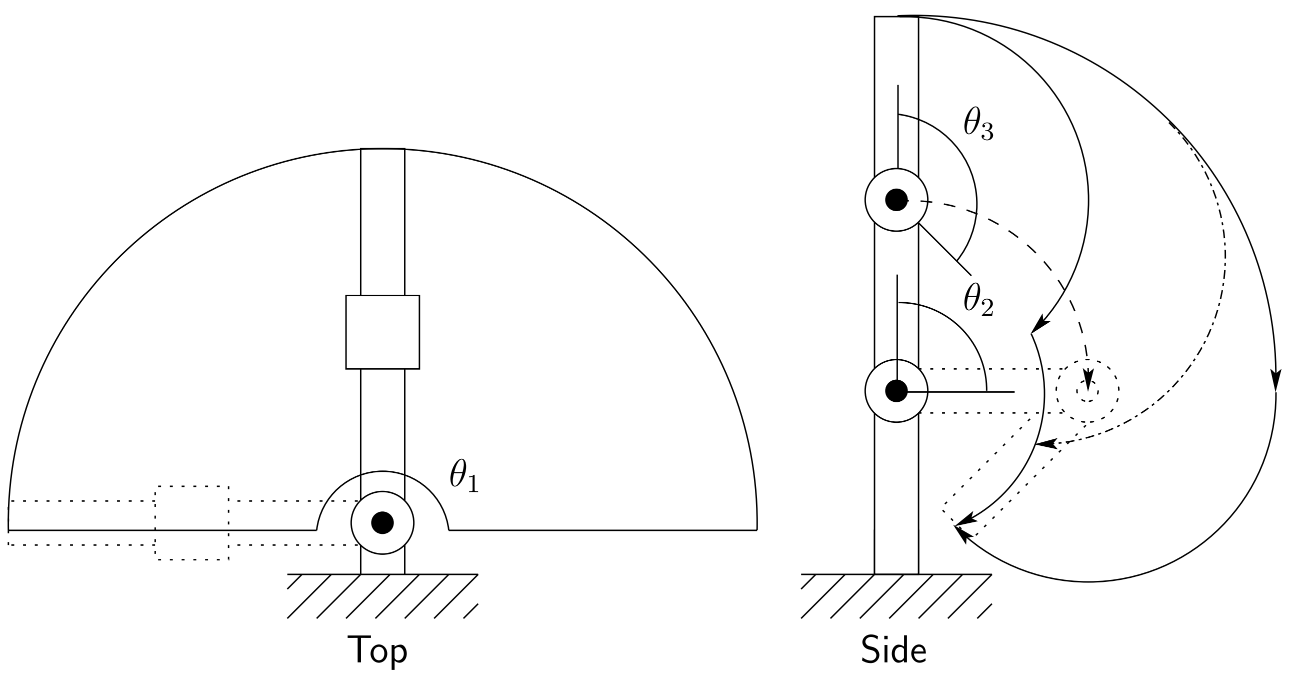


Fig. 1.9 Workspace of the elbow manipulator.

a.k.a. Revolute, Elbow, or Anthropomorphic

Spherical Manipulator (RRP)

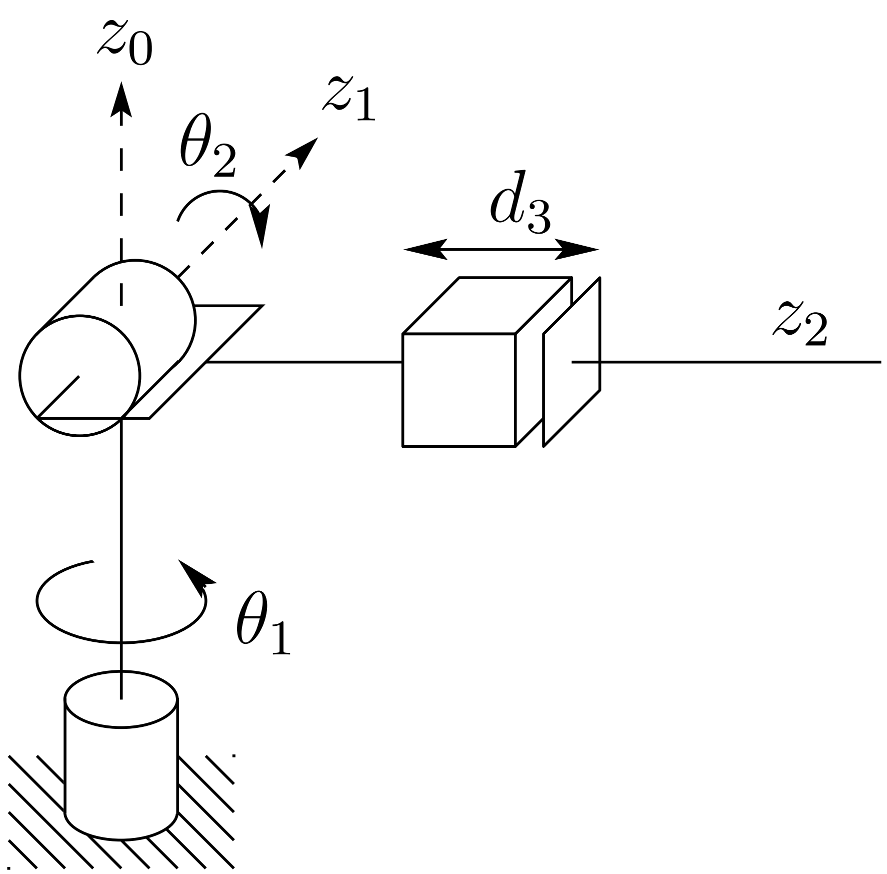


Fig. 1.10 The spherical manipulator.

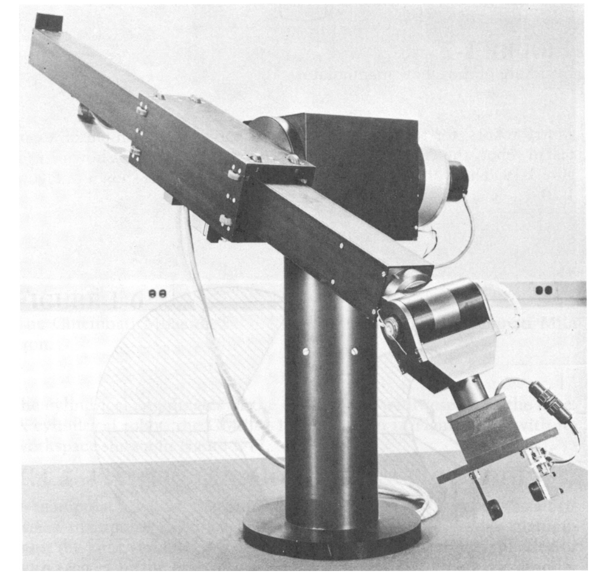


Fig. 1.11 The Stanford Arm. Photo courtesy of the Coordinated Science Lab, University of Illinois at Urbana-Champaign.

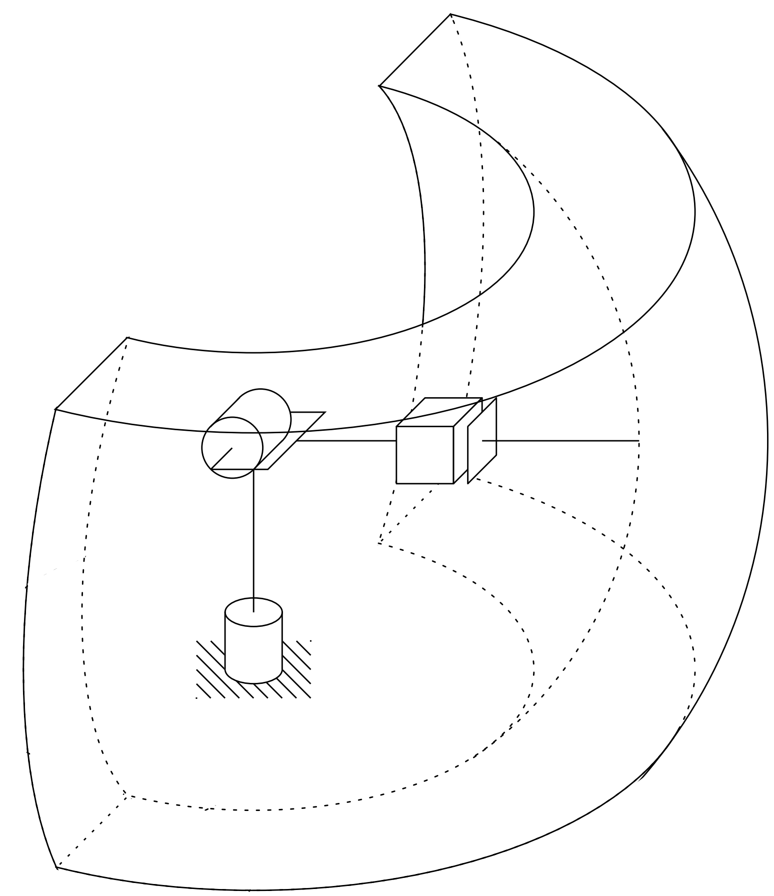


Fig. 1.12 Workspace of the spherical manipulator.

SCARA Manipulator (RRP)

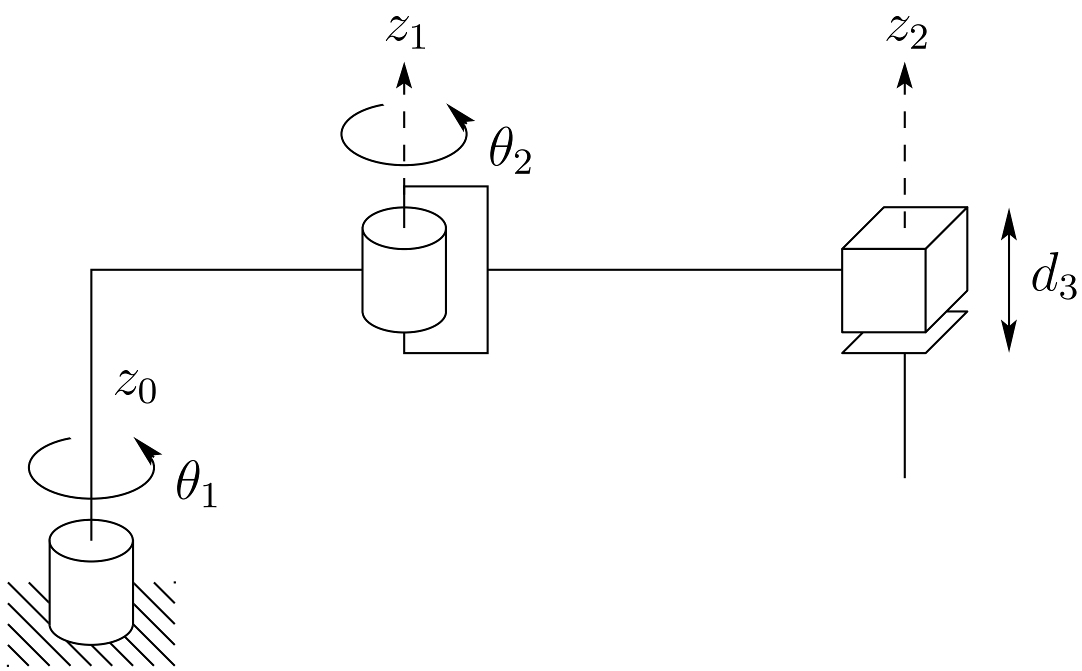


Fig. 1.13 The SCARA (Selective Compliant Articulated Robot for Assembly).

Fig. 1.14 The Epson E2L653S SCARA Robot. Photo Courtesy of Epson.

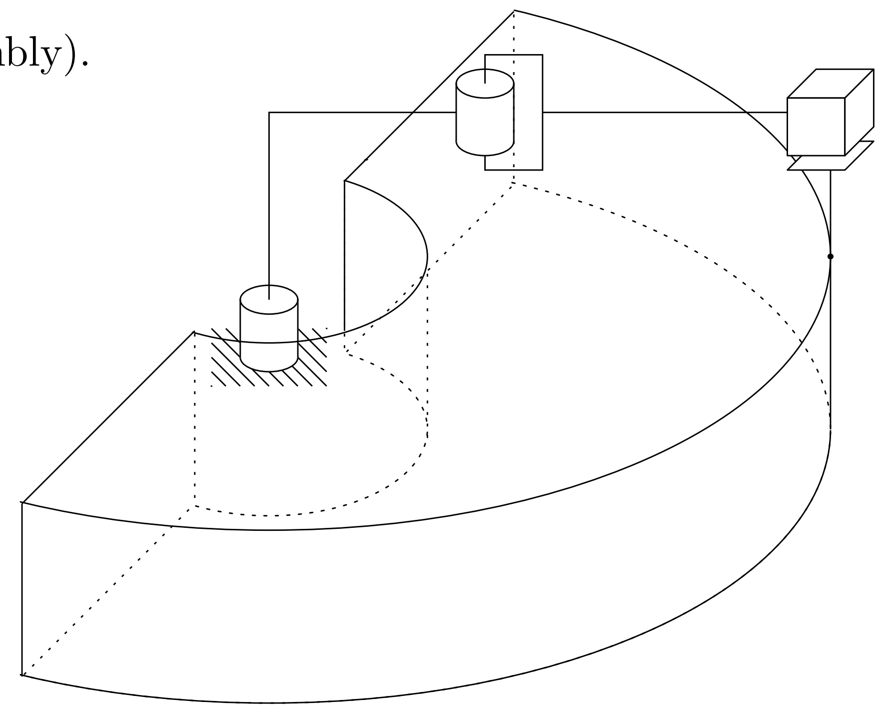


Fig. 1.15 Workspace of the SCARA manipulator.

Cylindrical Manipulator (RPP)

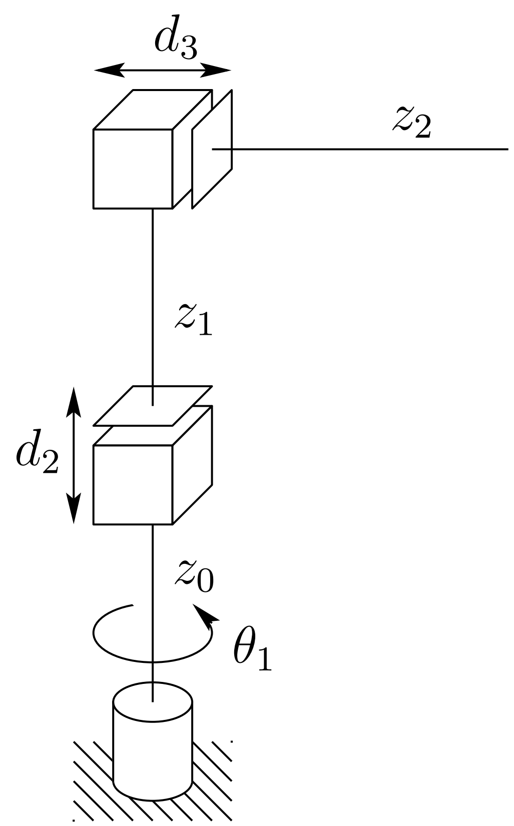


Fig. 1.16 The cylindrical manipulator.

Fig. 1.17 The Seiko RT3300 Robot. Photo courtesy of Seiko.

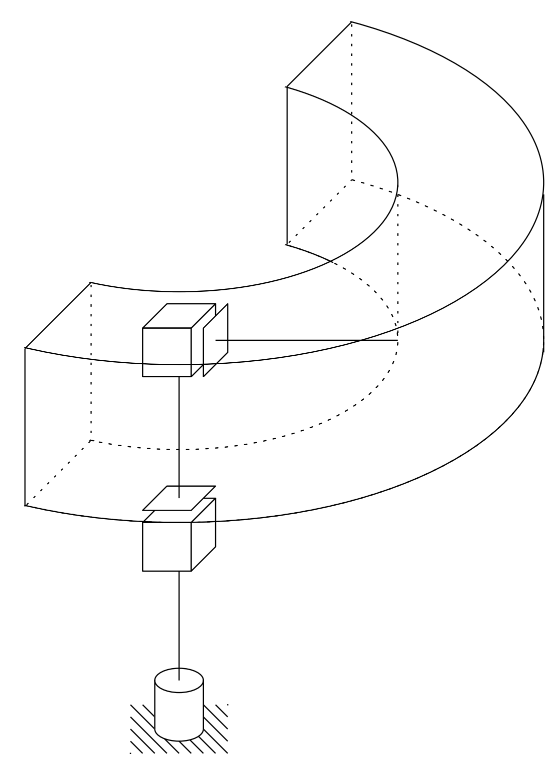


Fig. 1.18 Workspace of the cylindrical manipulator.

Cartesian Manipulator (PPP)

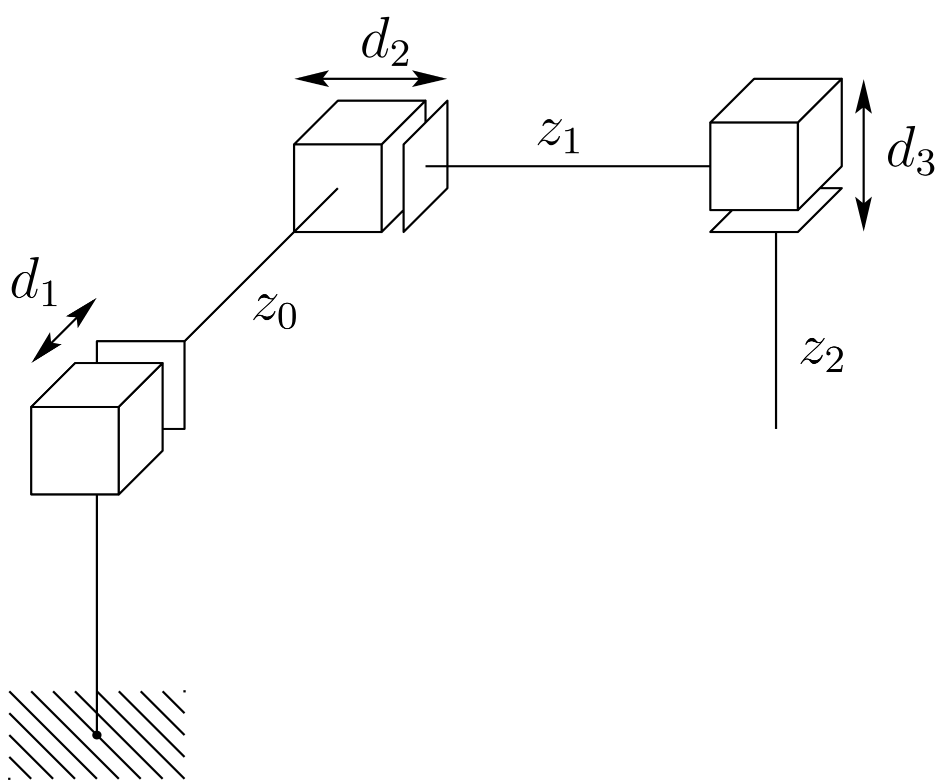


Fig. 1.19 The Cartesian manipulator.

Fig. 1.20 The Epson Cartesian Robot. Photo courtesy of Epson.

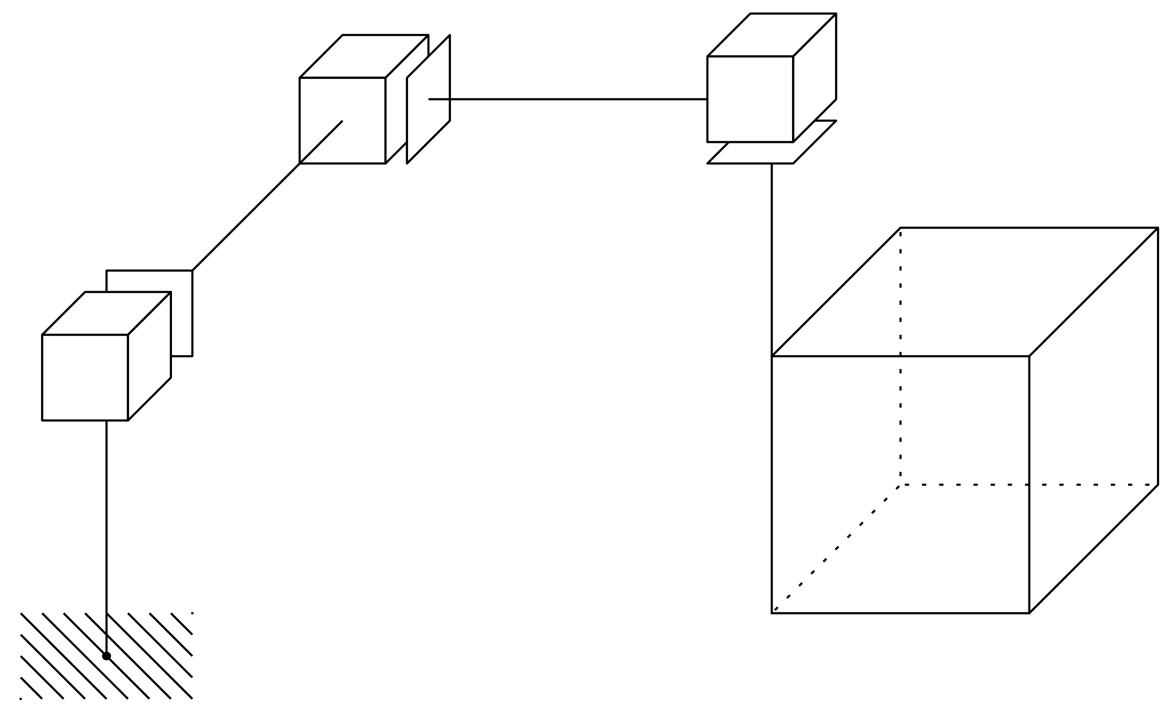


Fig. 1.21 Workspace of the Cartesian manipulator.

workspace too low!

workspace too far out!

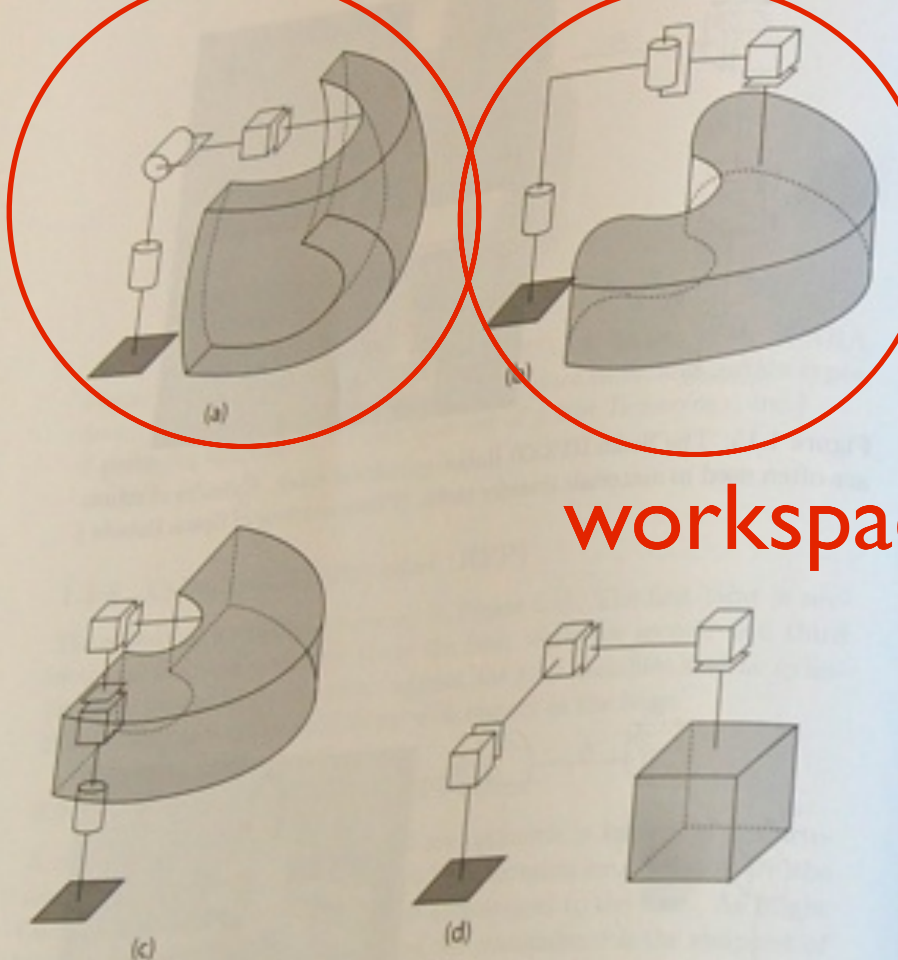


Figure 1.17: Comparison of the workspaces of the (a) spherical, (b) SCARA, (c) cylindrical, and (d) Cartesian robots. The nature of the workspace dictates the types of application for which each design can be used.

1.3.6 Parallel Manipulator

A **parallel manipulator** is one in which some subset of the links form a closed chain. More specifically, a parallel manipulator has two or more kinematic chains connecting the base to the end effector. Figure 1.18 shows the ABB IRB940 Tricept robot, which is a parallel manipulator. The closed-chain kinematics of parallel robots can result in greater structural rigidity, and hence greater accuracy, than open chain robots. The kinematic description of parallel robots is fundamentally different from that of serial link robots and therefore requires different methods of analysis.

Figure 1.18: The ABB IRB940 Tricept parallel robot. Parallel robots generally have much higher structural rigidity than serial link robots. (Photo courtesy of ABB.)

1.4 OUTLINE OF THE TEXT

A typical application involving an industrial manipulator is shown in Figure 1.19. The manipulator is shown with a grinding tool that it must use to remove a certain amount of metal from a surface. In the present text we are concerned with the following question: *What are the basic issues to be resolved and what must we learn in order to be able to program a robot to perform such tasks?* The ability to answer this question for a full six degree-of-freedom manipulator represents the goal of the present text. The answer is too complicated to be presented at this point. We can, however,

Upcoming Material

Chapter 2 in SHV

Rigid Motions and Homogeneous Transformations

Appendix B in SHV

Linear Algebra

Key Linear Algebra Concepts

vector

transpose operator

scalar product (dot product) between two vectors

norm (length) of a vector

matrix

matrix multiplication

Questions ?