MEAM 520
Manipulator Kinematics

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Lecture 4: September 18, 2012

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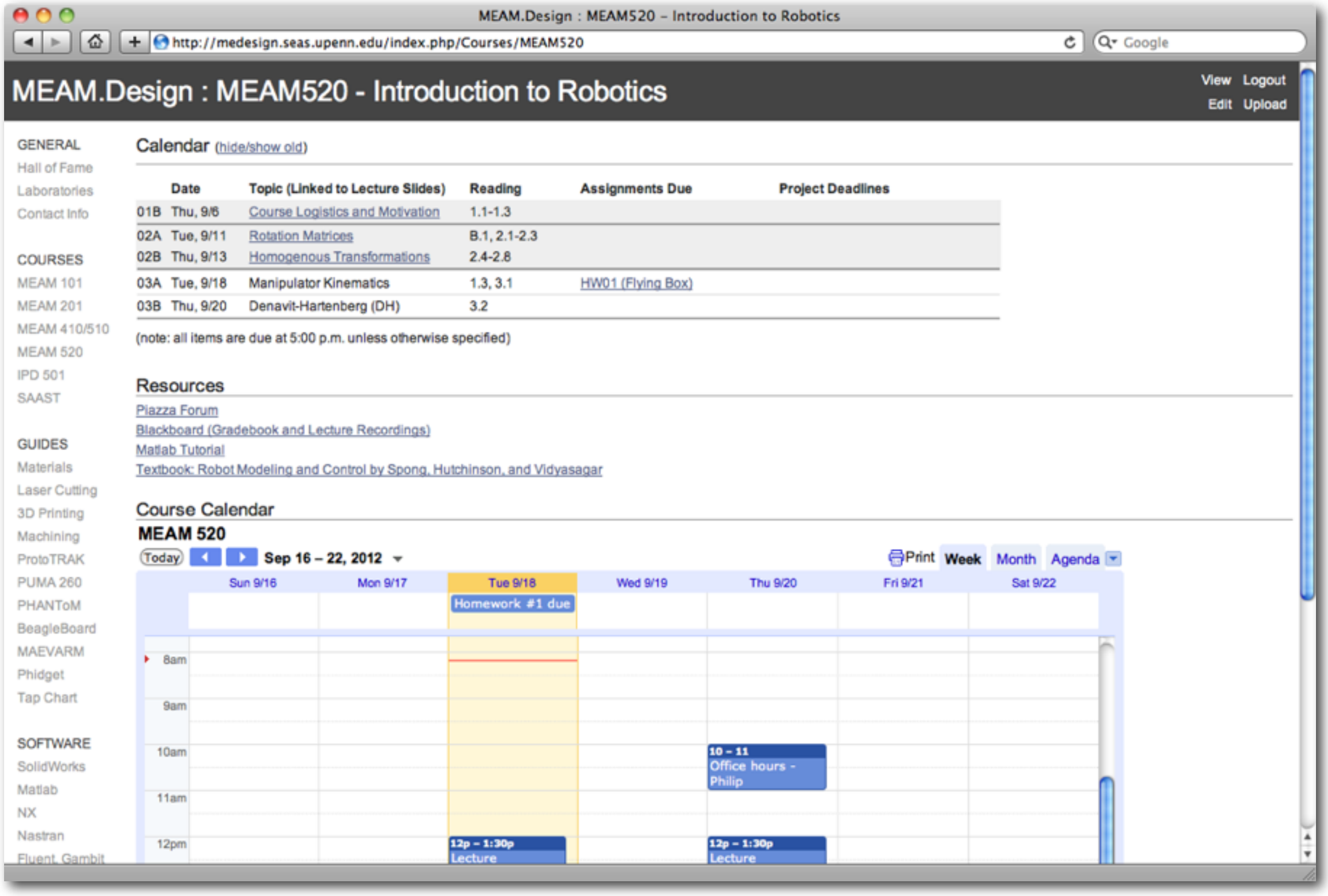
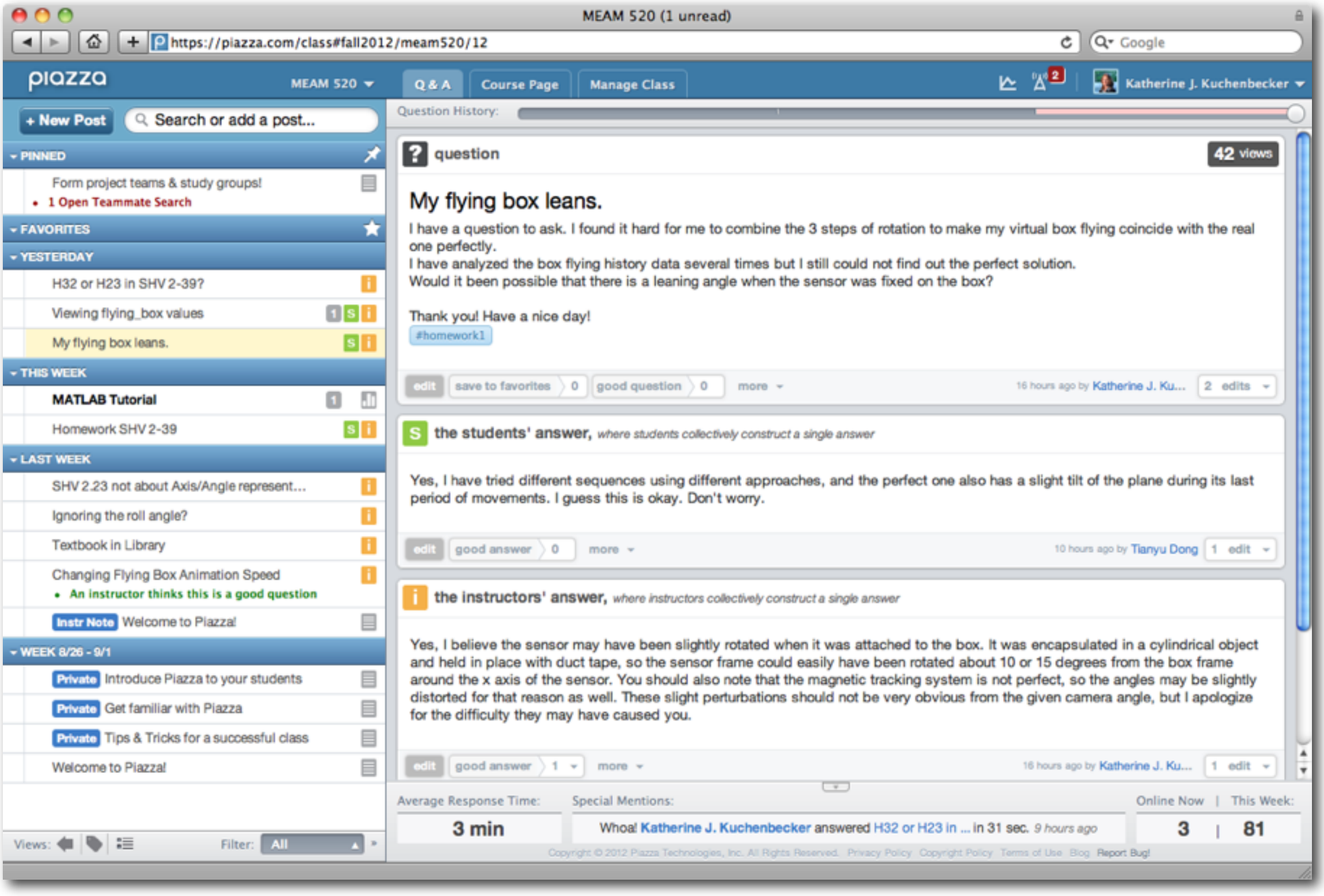
Joe Romano, Ph.D.
Graduated from Penn in May 2012
Now works at Rethink Robotics

Course Website



Piazza Forum



Guidelines

- Post questions to Piazza rather than emailing individuals on the teaching team.
- I am happy to answer both conceptual and specific questions, but I am not going to look at your code unless I suspect a systematic problem with the assignment.
- Want to talk in person? Visit office hours.

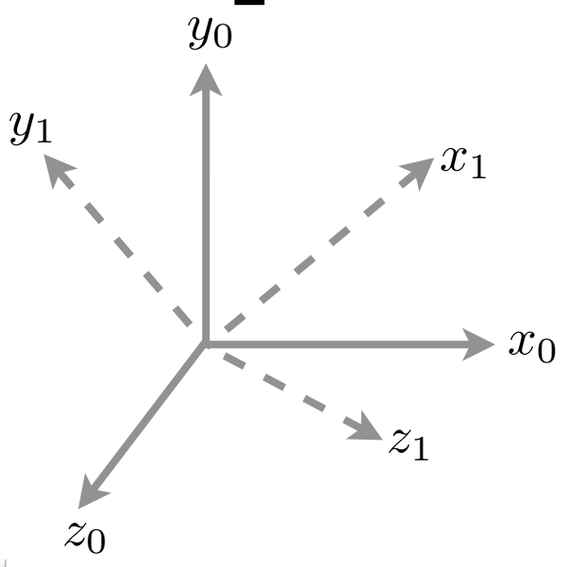
Reminders

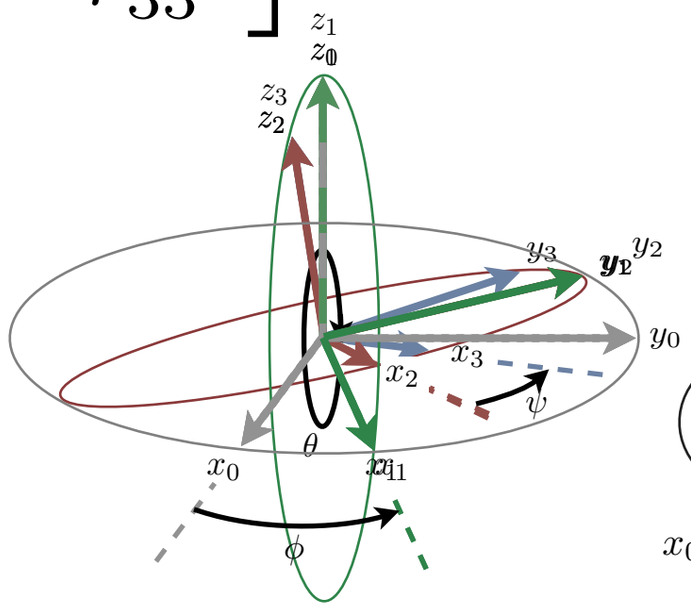
- Homework 1 is due today by 5:00 p.m. sharp.
- Late assignments can be turned in until 5:00 p.m. on Wednesday with a 25% penalty. After that, no further assignments will be accepted.
- Extensions are available for certain conflicts, including illness and sports – email KJK.
- Philip and Denise will be running a MATLAB tutorial for all those interested; respond about times and topics on Piazza.

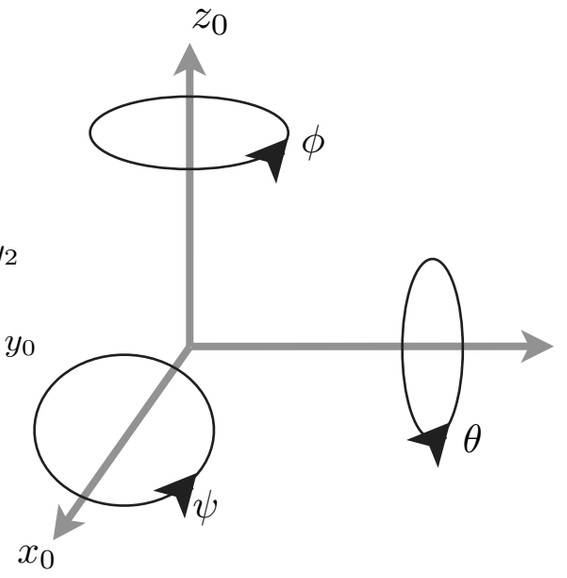
$$\mathbf{R} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

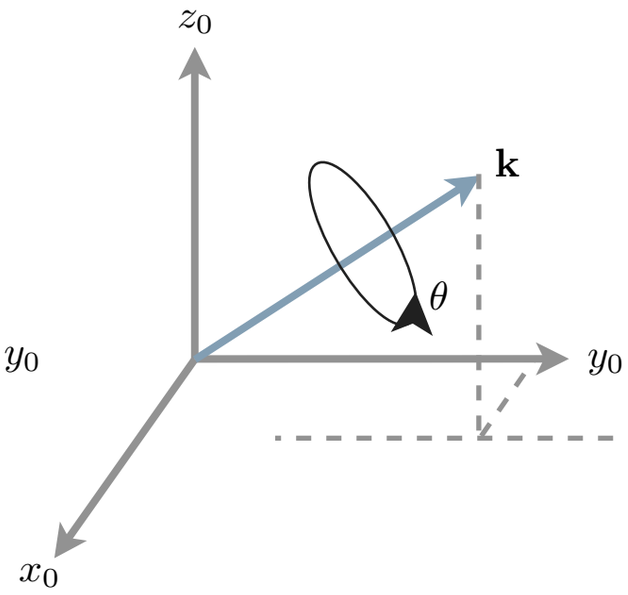
$$\mathbf{H} = \begin{bmatrix} \mathbf{R} & \mathbf{d} \\ \mathbf{0} & 1 \end{bmatrix}$$

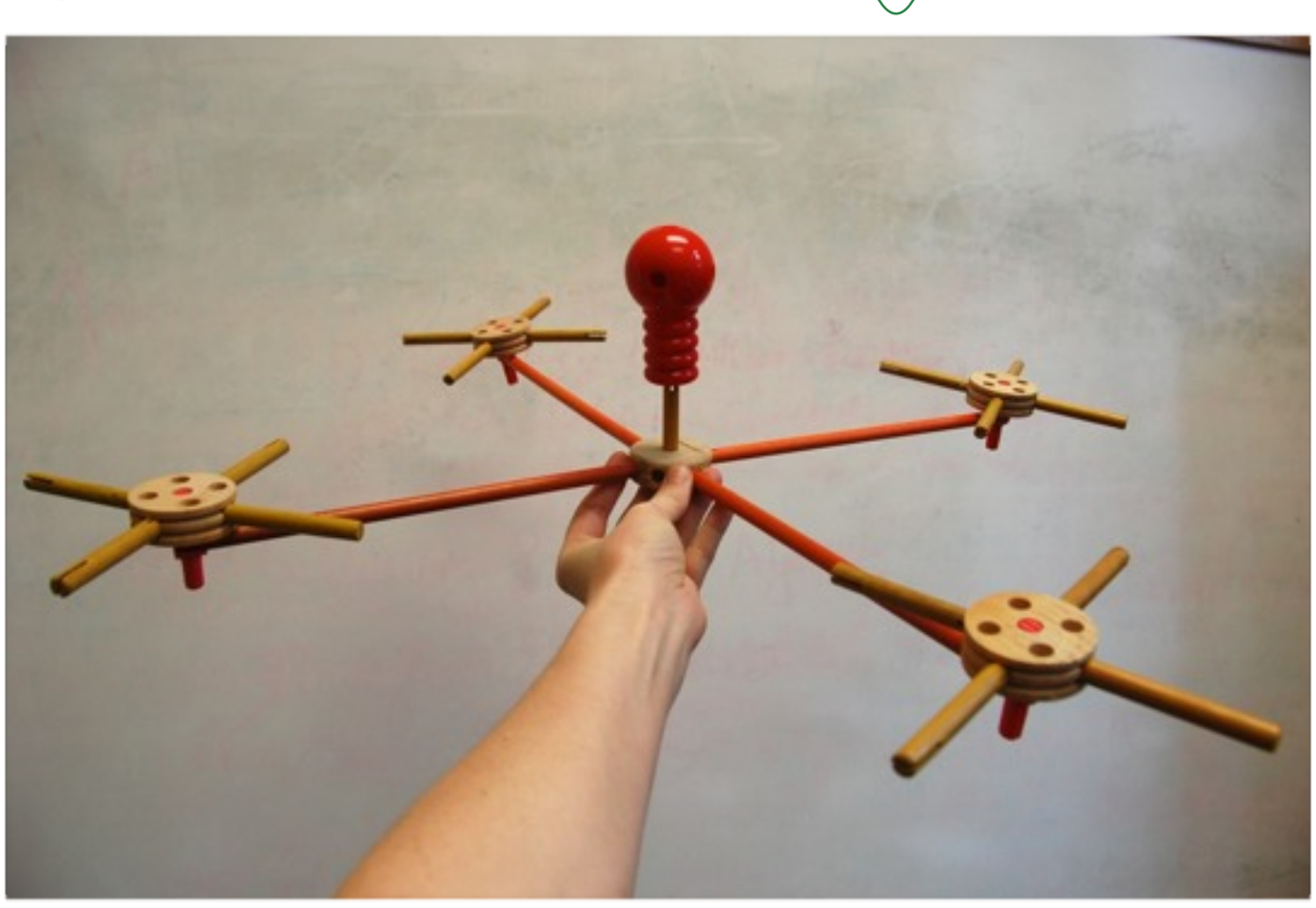
$$\mathbf{P}^0 = \mathbf{H}_1^0 \, \mathbf{P}^1$$

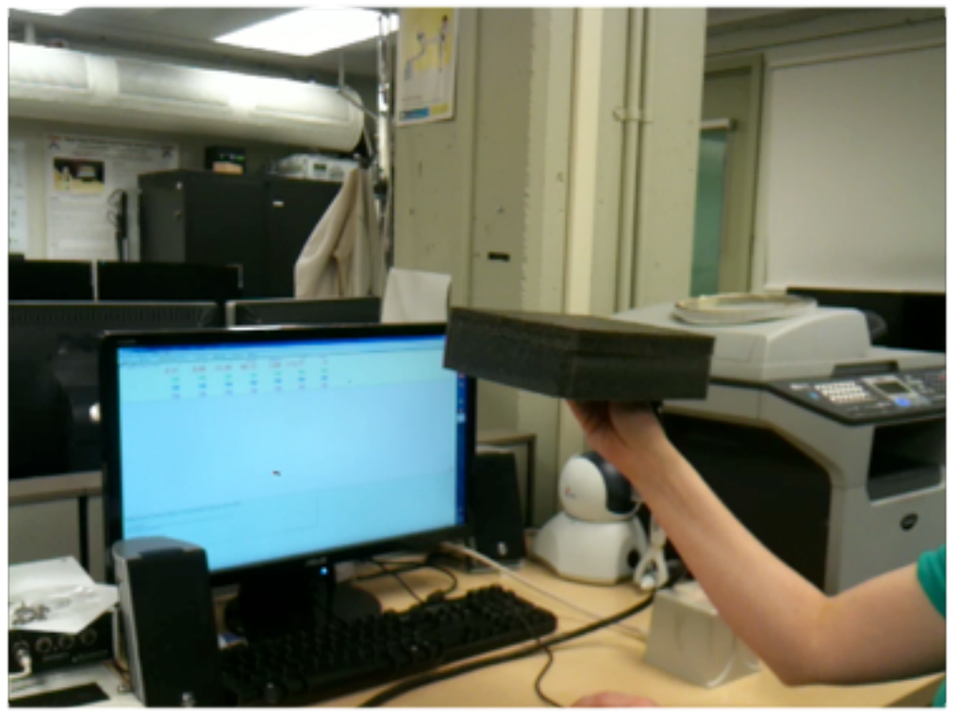




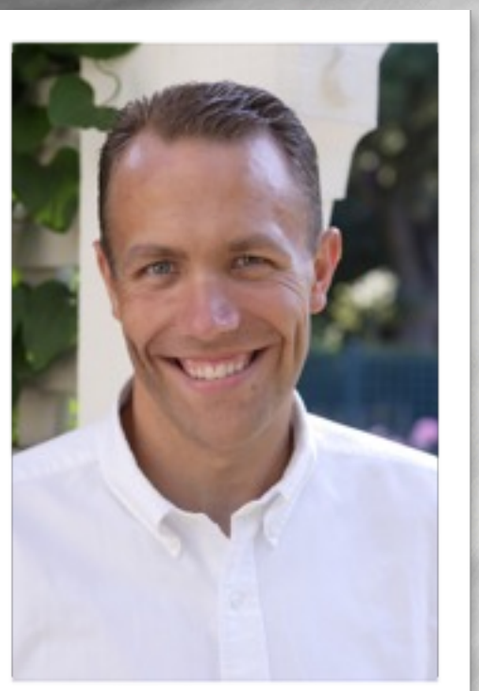








What is a robot?



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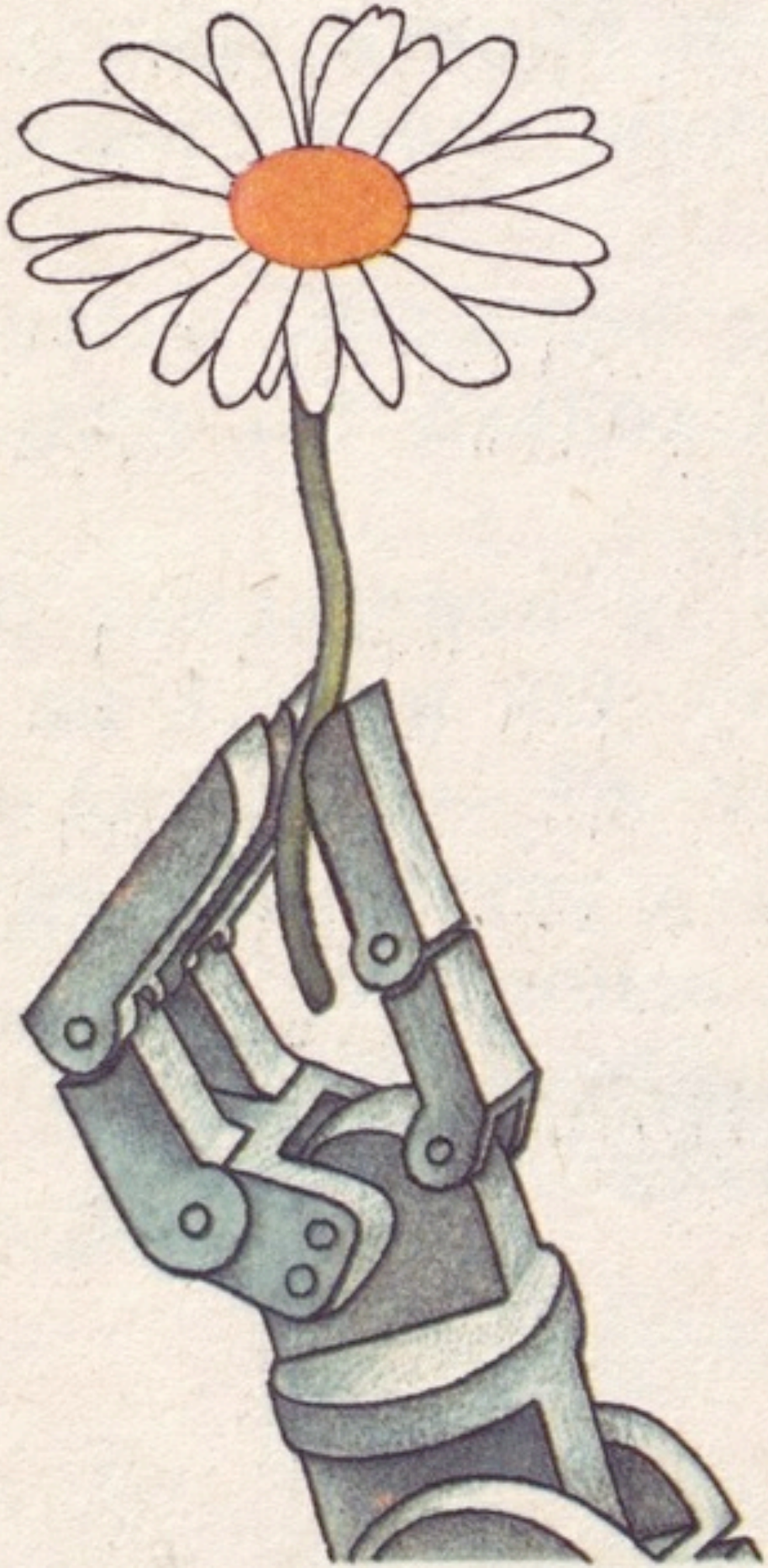
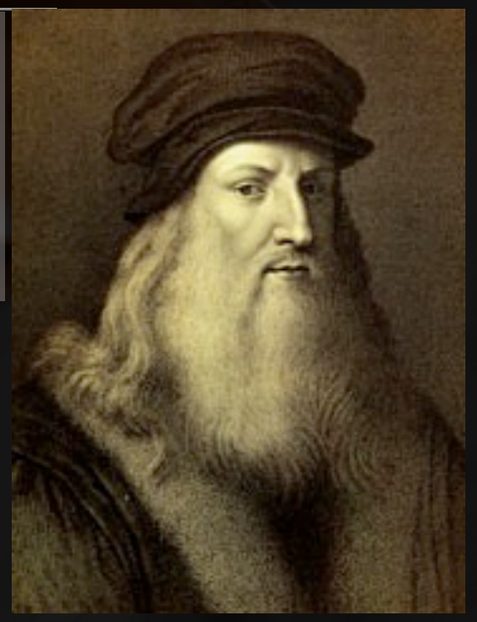


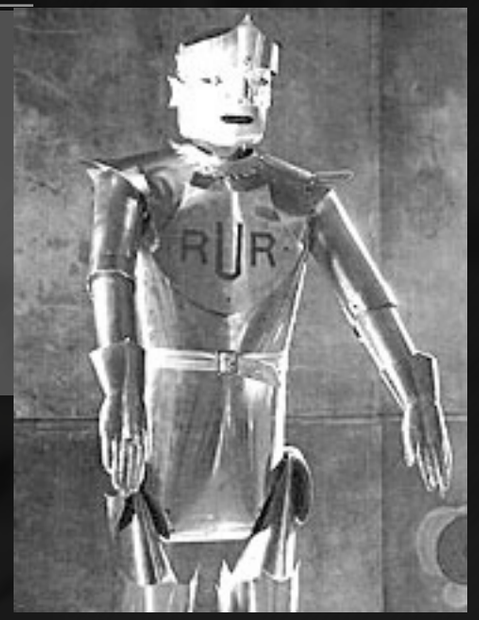
322 B.C. - “If every tool, when ordered, or even of its own accord, could do the work that befits it... then there would be no need either of apprentices for the master workers or of slaves for the lords.” - Aristotle

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!

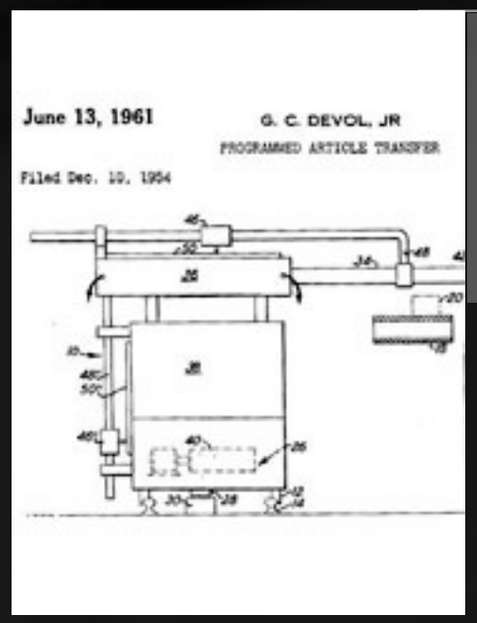
1921 - Karel Capek popularizes the term “robot” in a play called *R.U.R. (Rossum’s Universal Robots)* wherein robot workers take over the earth.



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

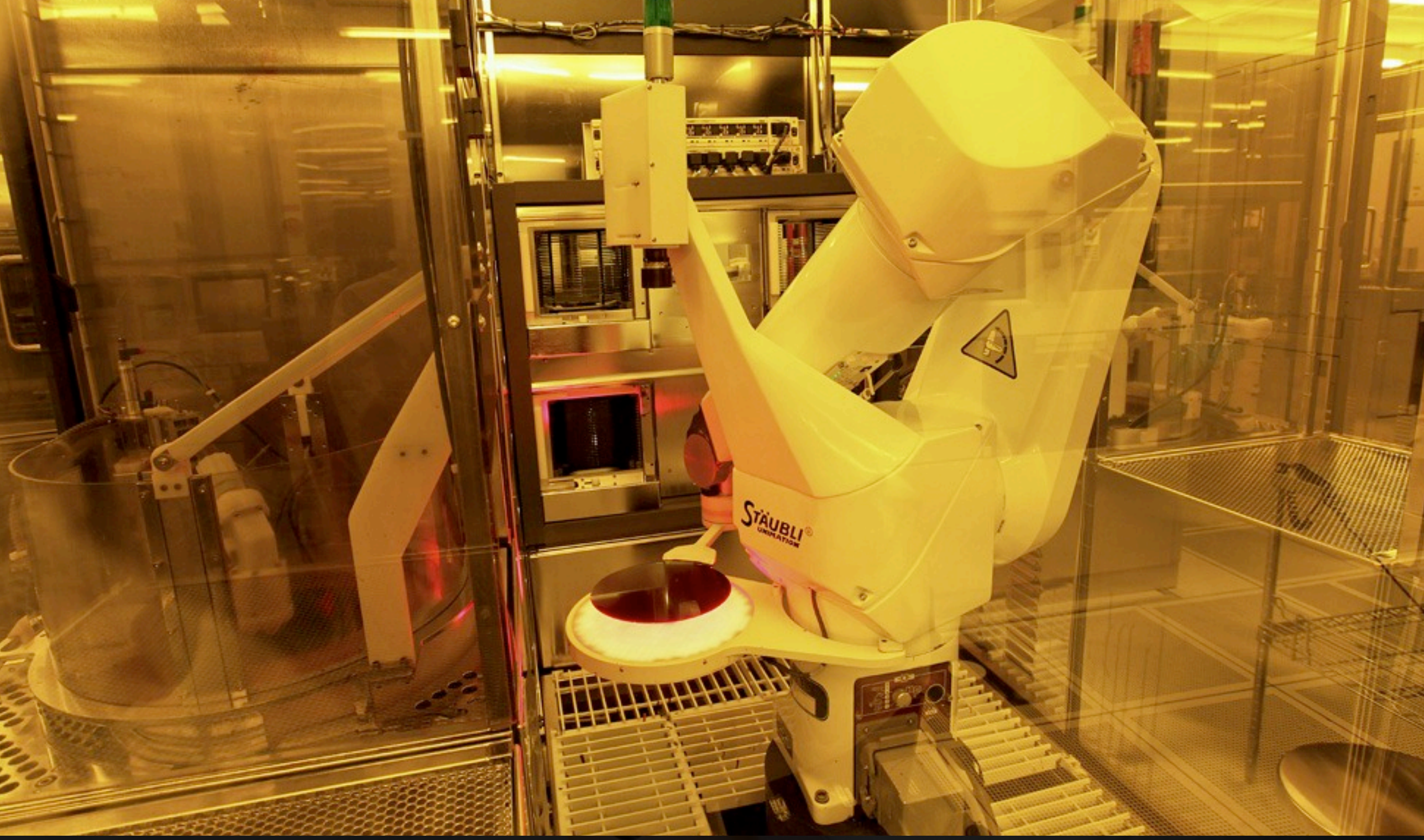
1942 - Isaac Asimov publishes *Runaround*, which introduces the three "laws" of robotics.

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".

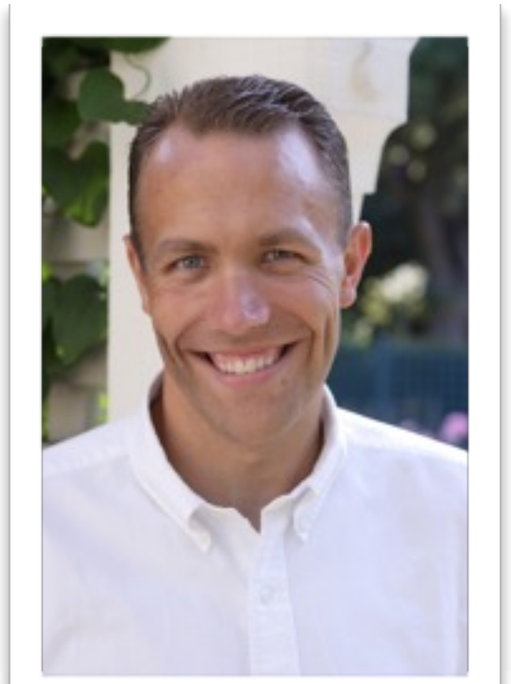
1961- *Unimate*, the first industrial robot, begins work on a General Motors assembly line.



"A robot is 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."

(The Robotics Institute of America)

Manipulators



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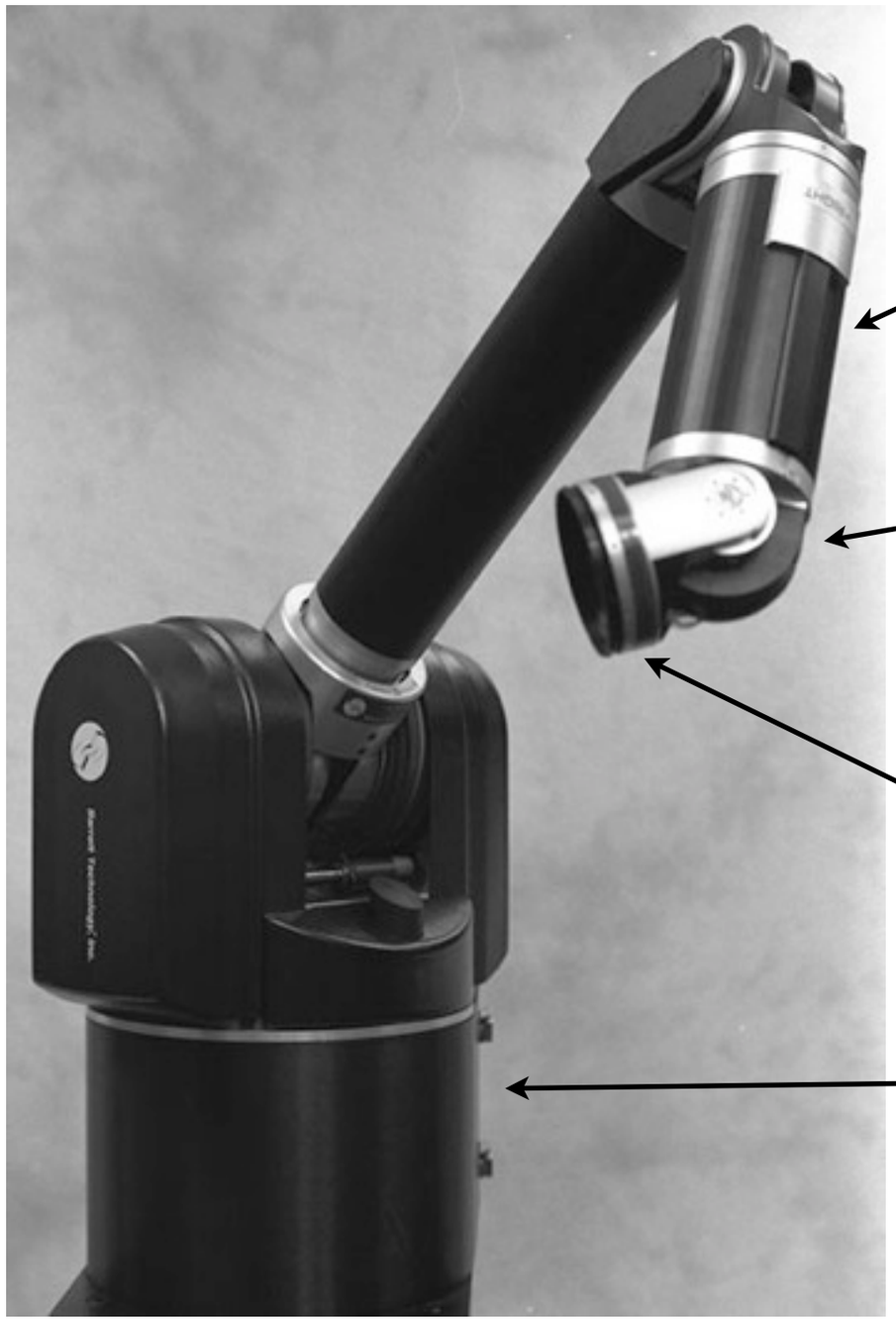
Manipulators : Terminology

SHV 1.1-1.3, 3.1

General Terminology



Link : rigid body, 6 degrees of freedom

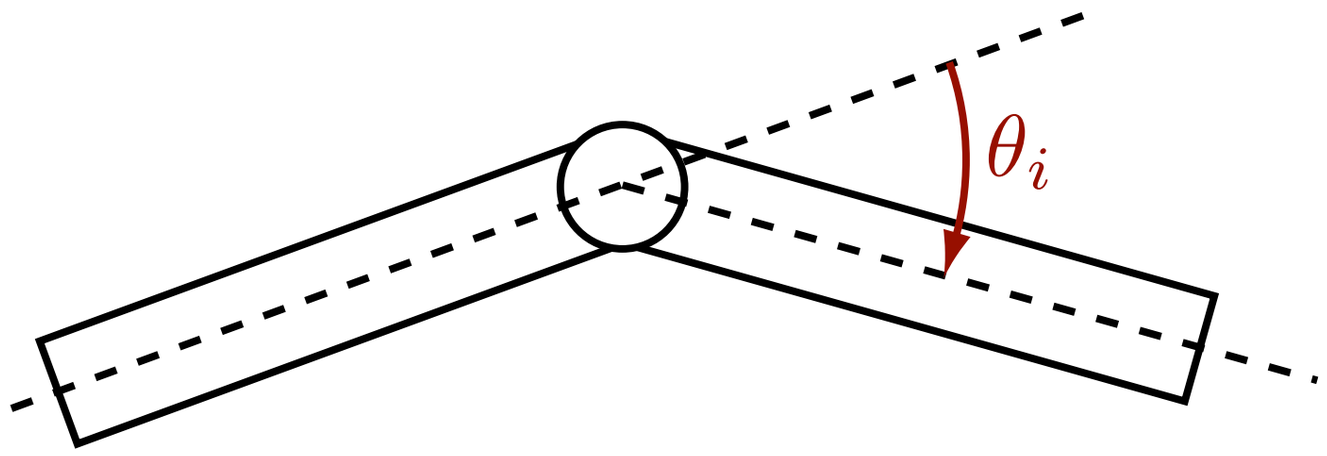
Joint : connection between two links

End-effector : interacts with the environment

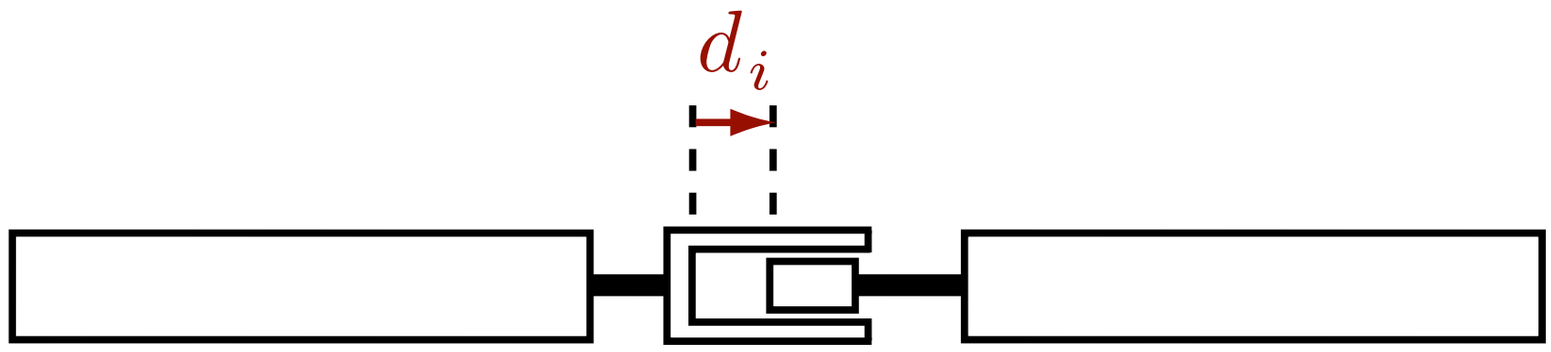
Base : connected to ground

Joint Descriptions

(R)evolute : angular displacement between adjacent links



(P)rismatic : linear displacement between adjacent links



Where are the joints?

Where are the joints?

R

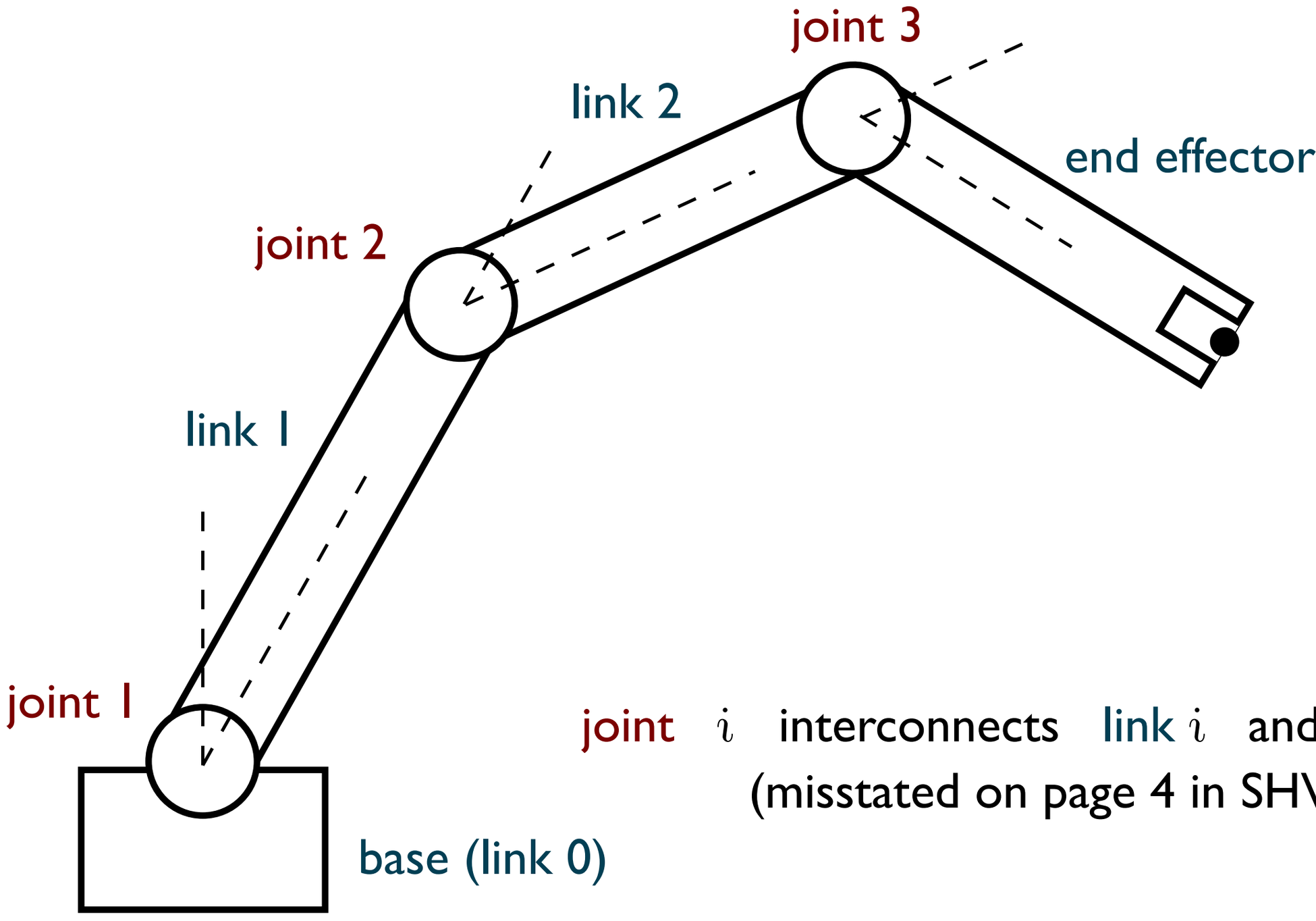
Where are the joints?

R

P

Kinematic Chains

A **kinematic chain** is a system of rigid bodies connected by joints

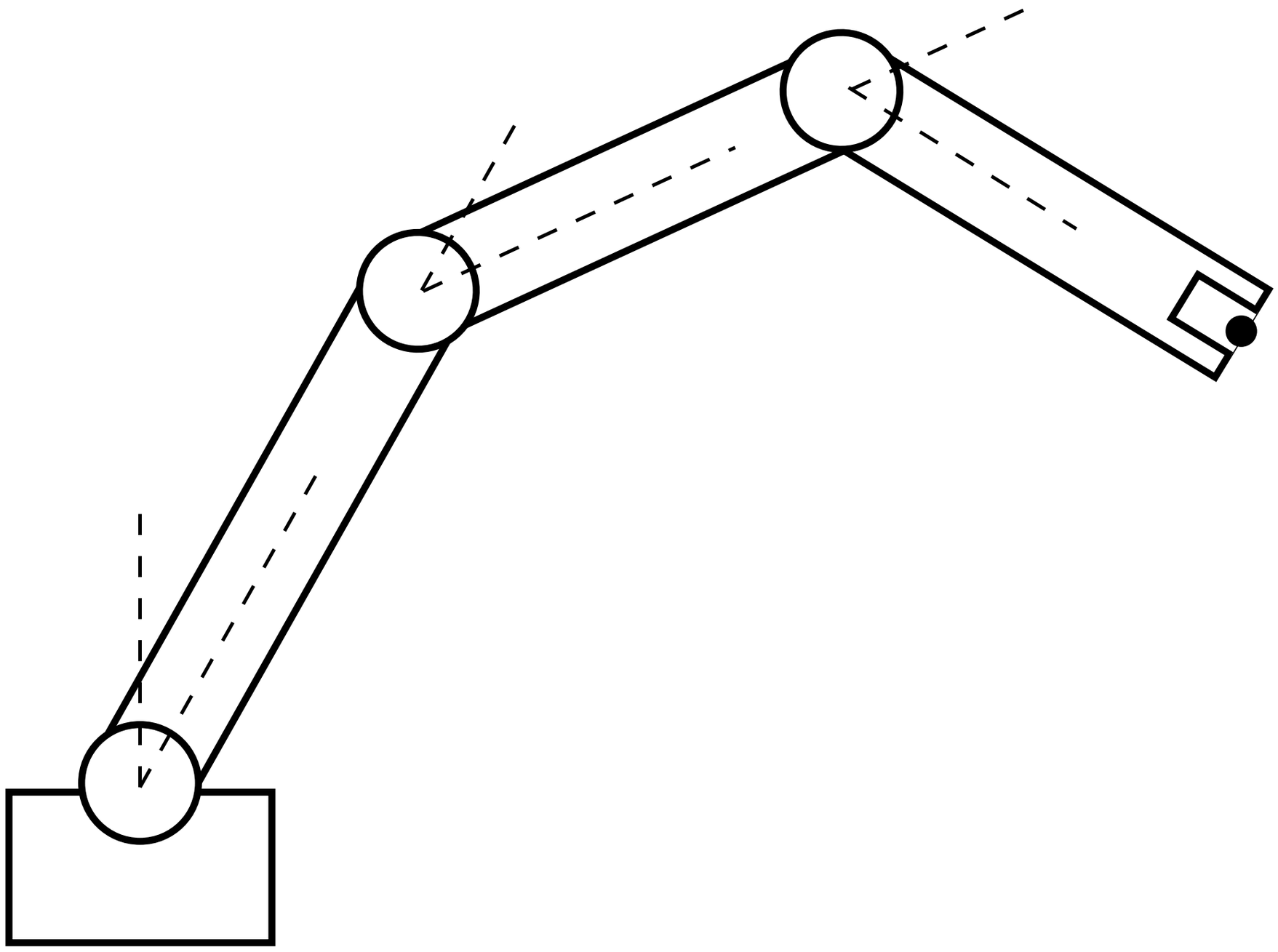


joint i interconnects link i and link i-1
(misstated on page 4 in SHV)

In a **serial** kinematic chain, each intermediate link is connected to two others

Configuration Space

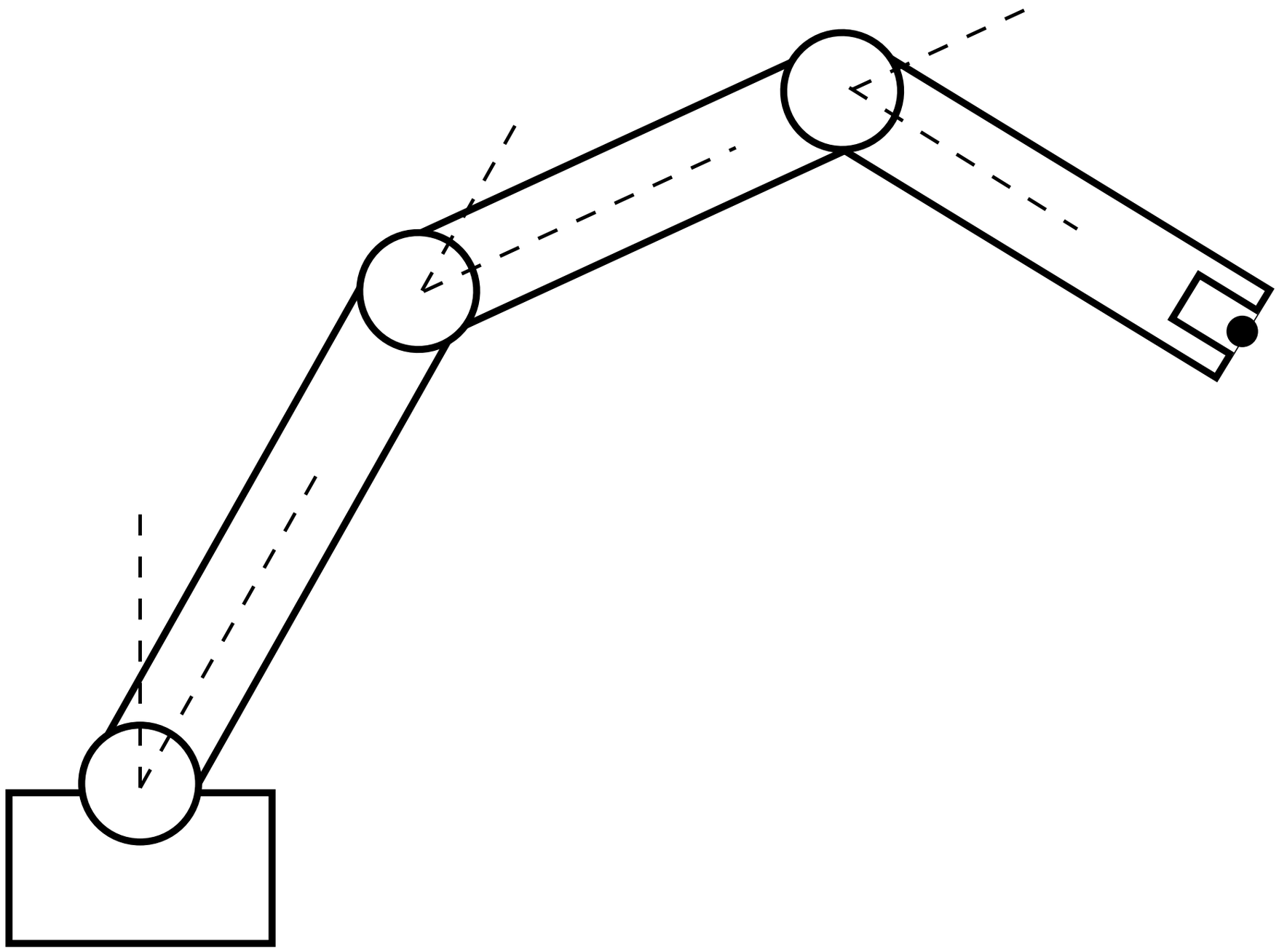
The **configuration** defines the location of every point of the manipulator



The **configuration space** is the set of all possible configurations

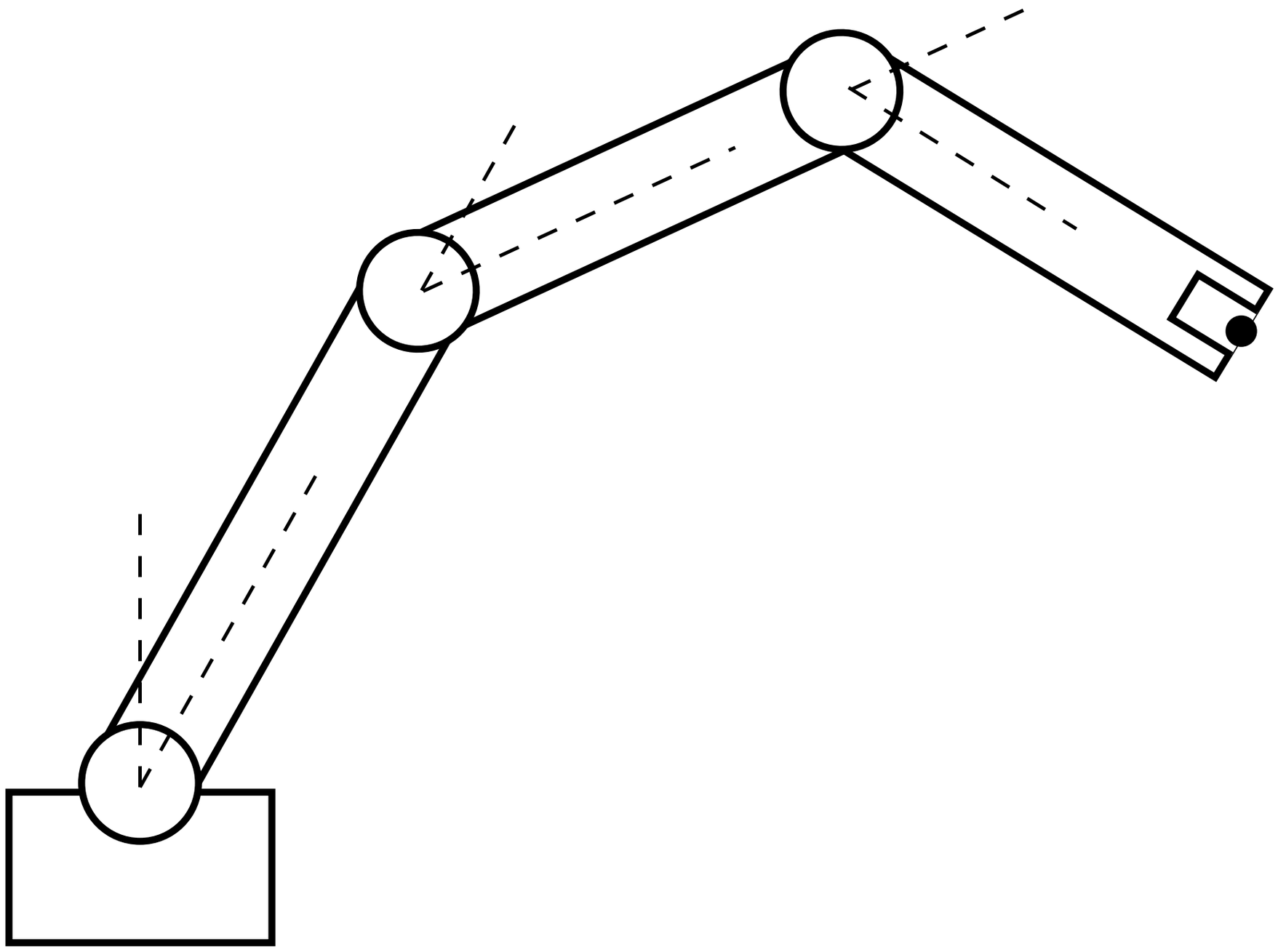
Degrees of Freedom

The **degrees of freedom (DOF)** are the minimum number of parameters necessary to specify the configuration



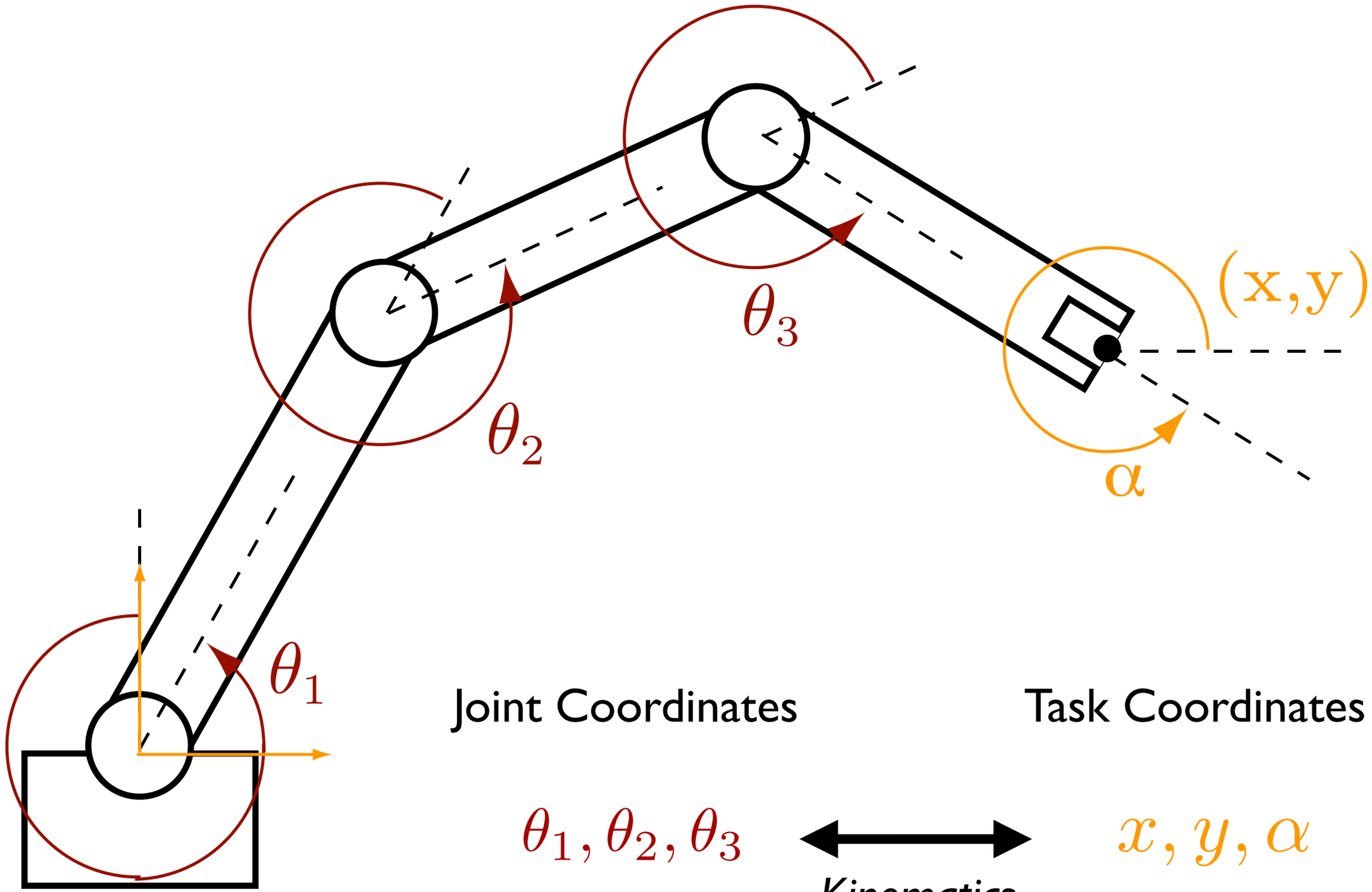
Workspace

The **reachable workspace** is the set of points *reachable* by the end effector



The **dexterous workspace** is a subset of the reachable workspace wherein the end effector can obtain an *arbitrary* orientation

Joint and Task Coordinates



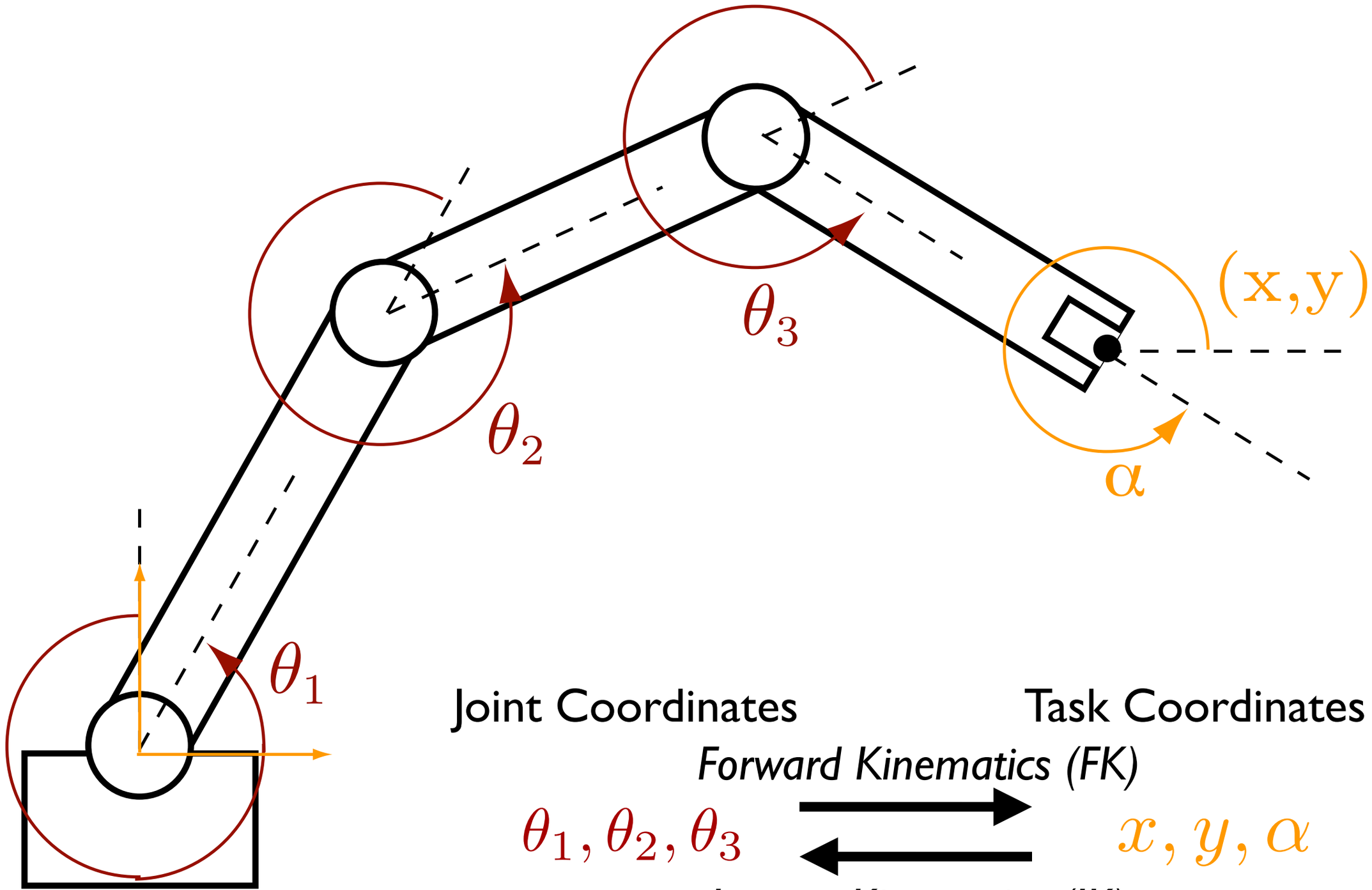
Joint Coordinates

Task Coordinates

$\theta_1, \theta_2, \theta_3$ ⟷ x, y, α

Kinematics

Joint and Task Coordinates



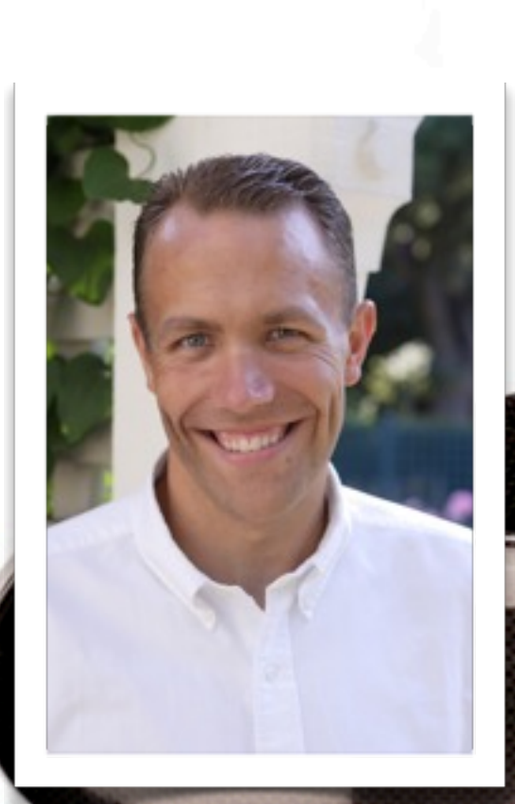
Joint Coordinates Task Coordinates

Forward Kinematics (FK)

$\theta_1, \theta_2, \theta_3 \rightleftarrows x, y, \alpha$

Inverse Kinematics (IK)

Manipulators : Common Configurations



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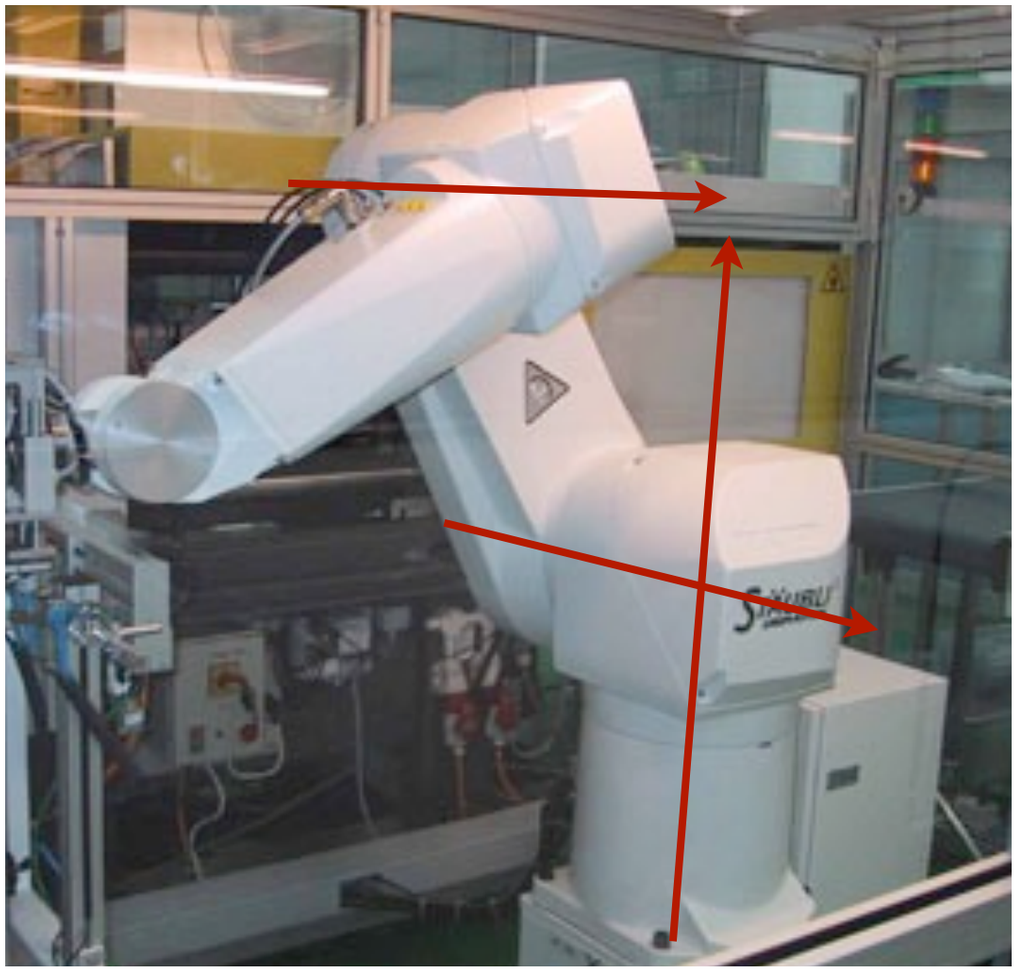
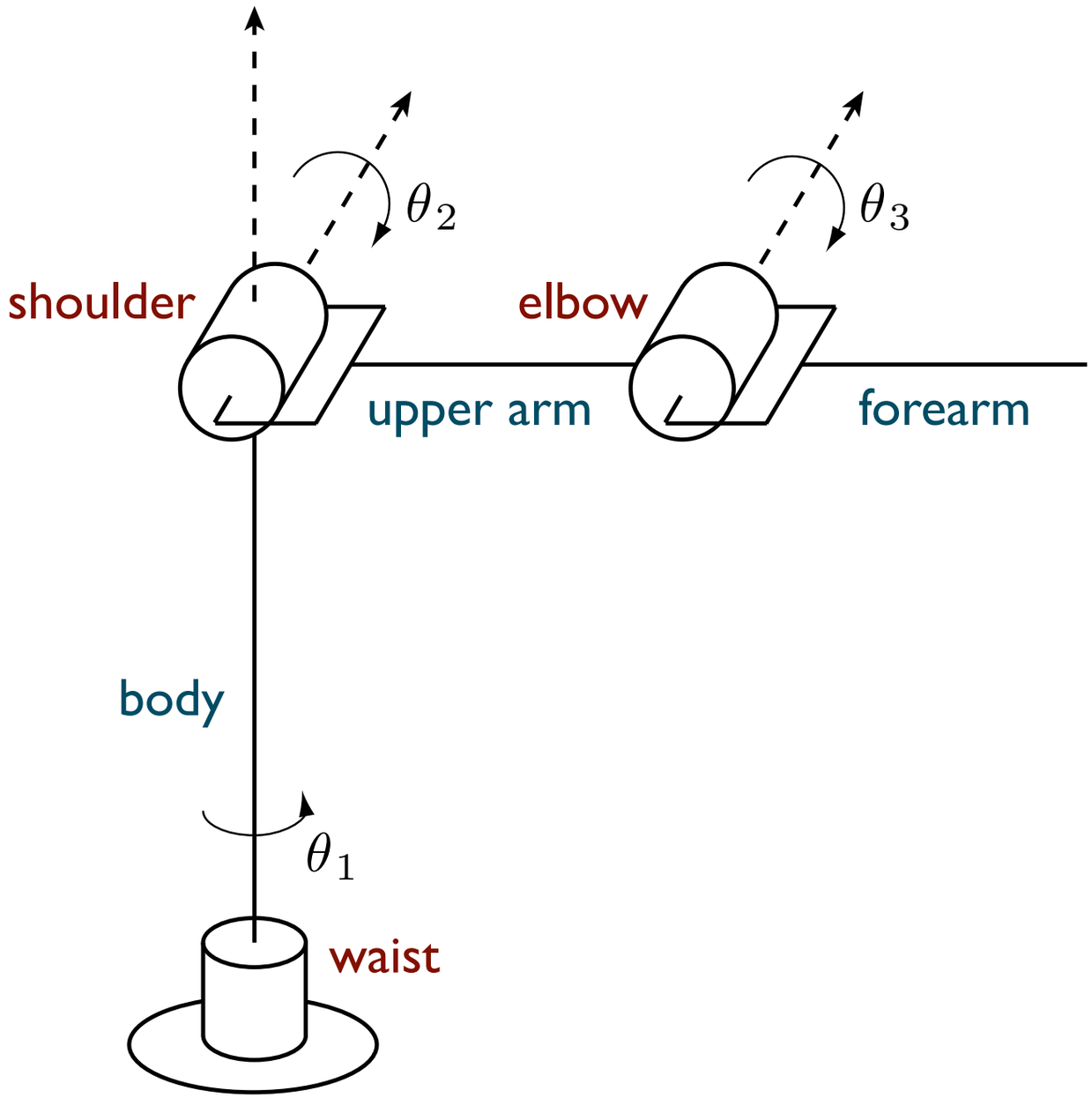
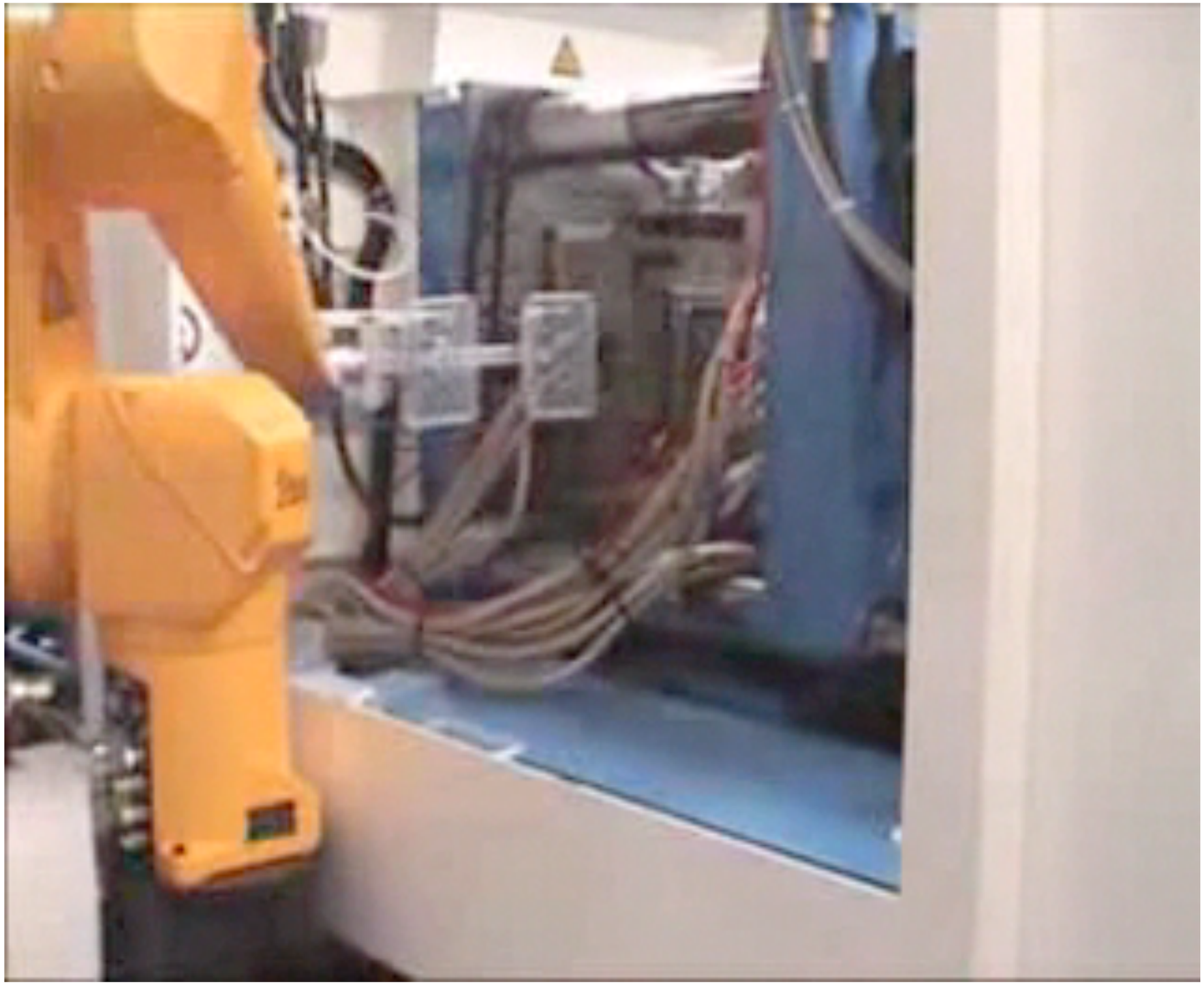
Working with a partner,
come up with a serial robotic linkage using 3 joints
(R and/or P).
Sketch your design in your notes.

Articulated (RRR)

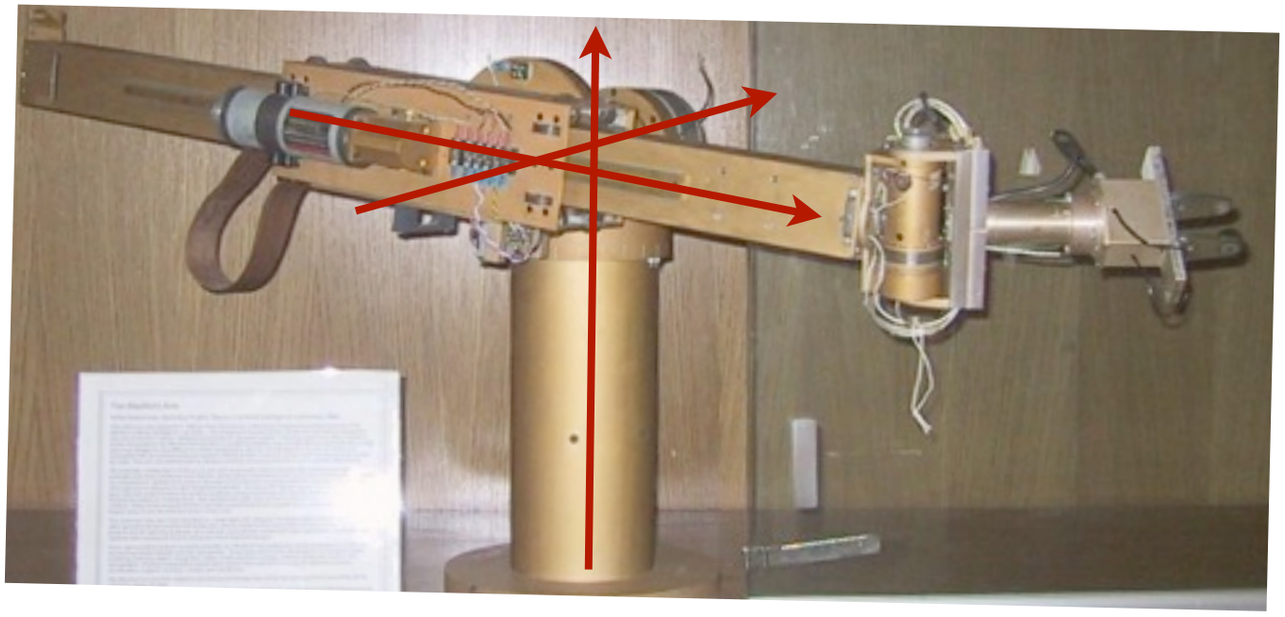




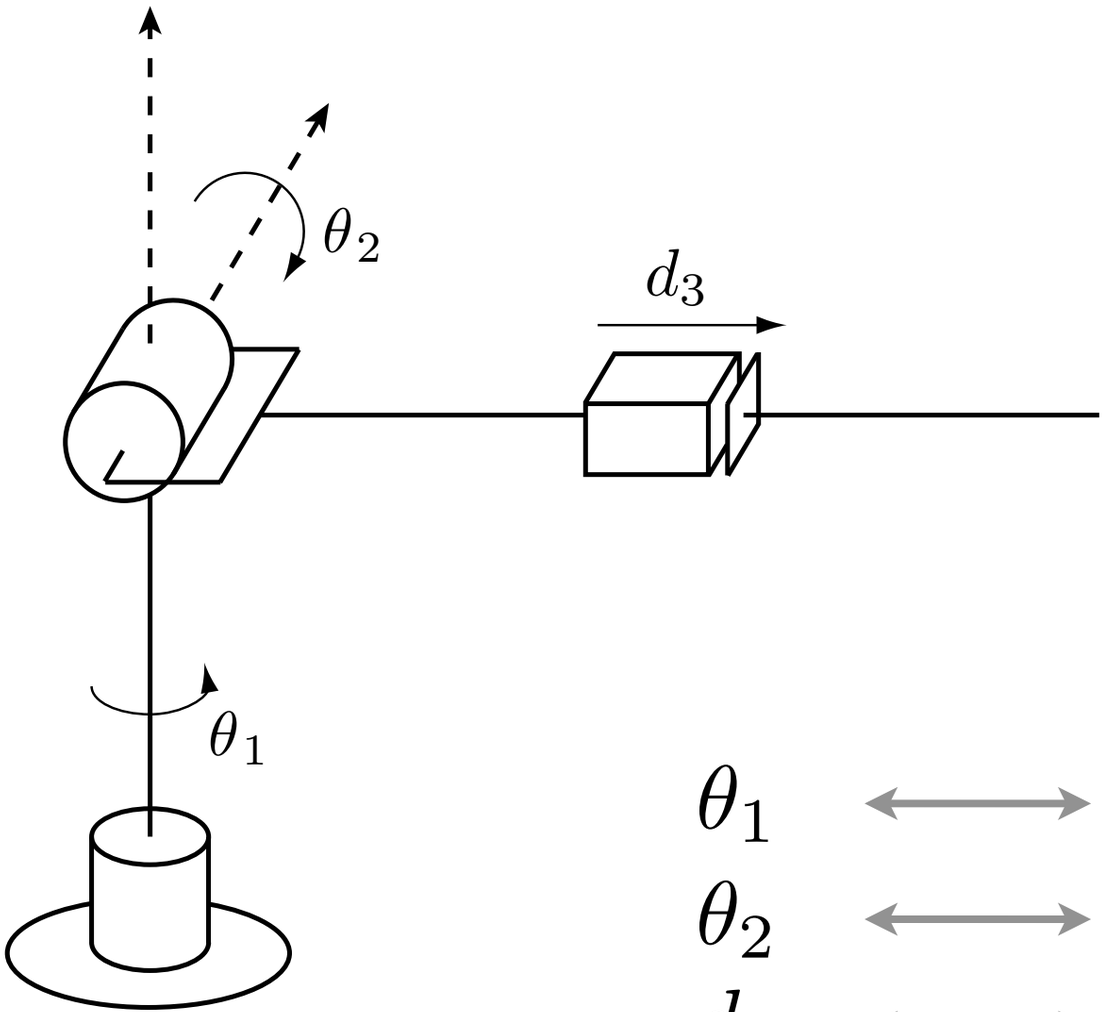
Articulated (RRR)



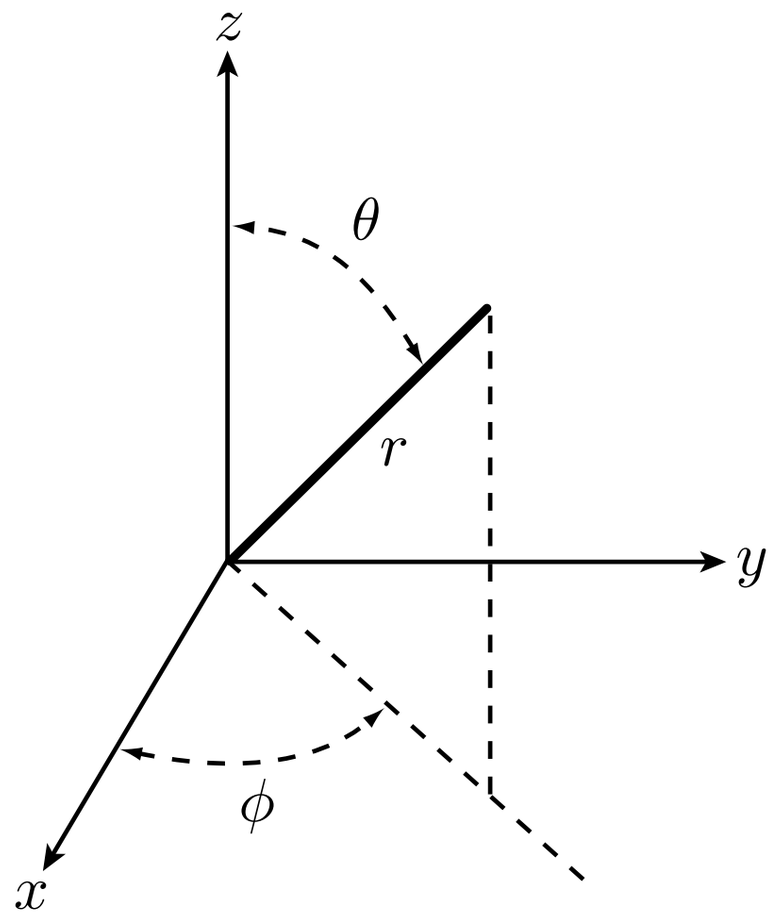
Spherical (RRP)



joint coordinates map to
standard spherical coordinates

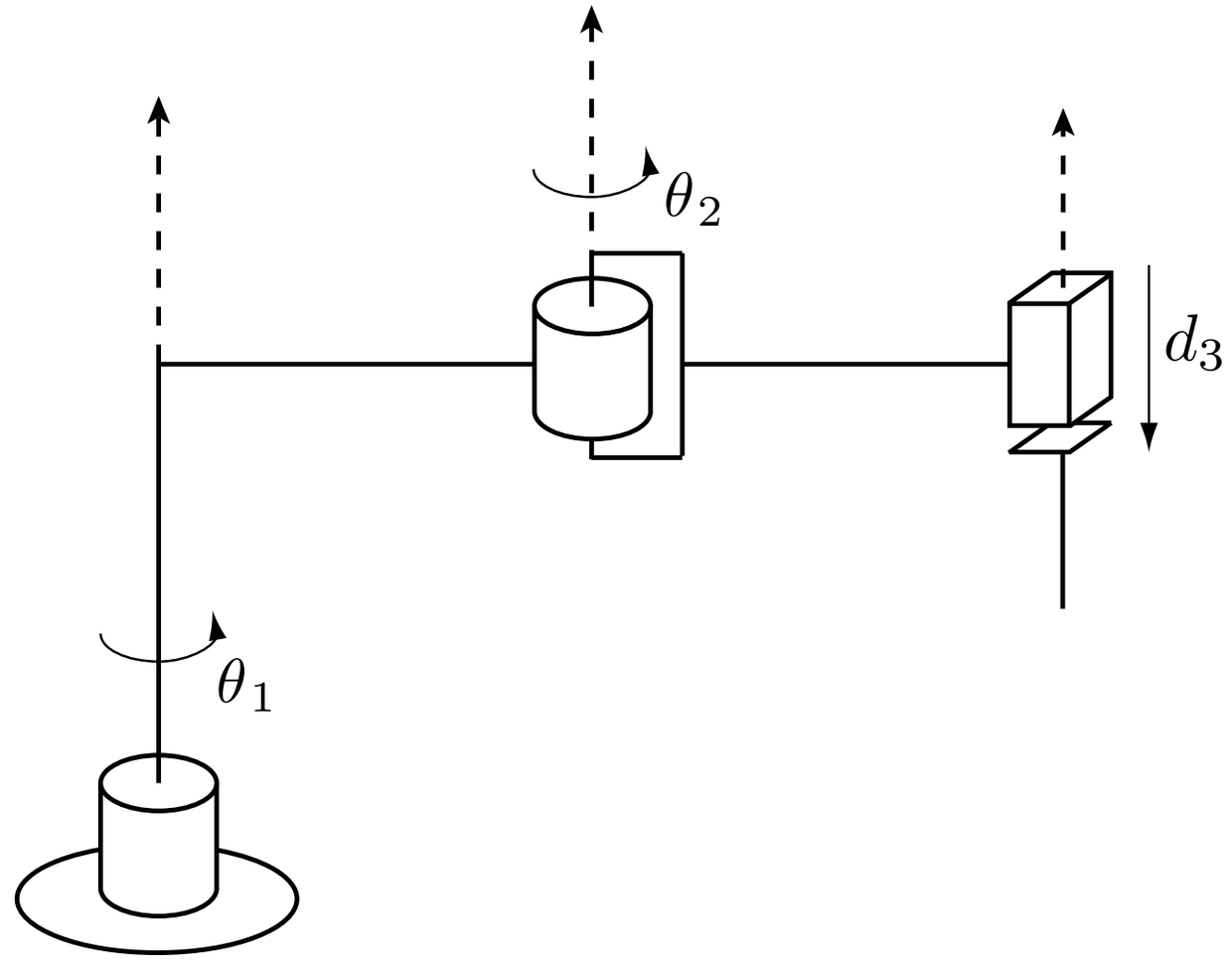


$$\theta_1 \longleftrightarrow \phi$$
$$\theta_2 \longleftrightarrow \theta$$
$$d_3 \longleftrightarrow r$$



SCARA (RRP)

Selective Compliant Articulated Robot for Assembly

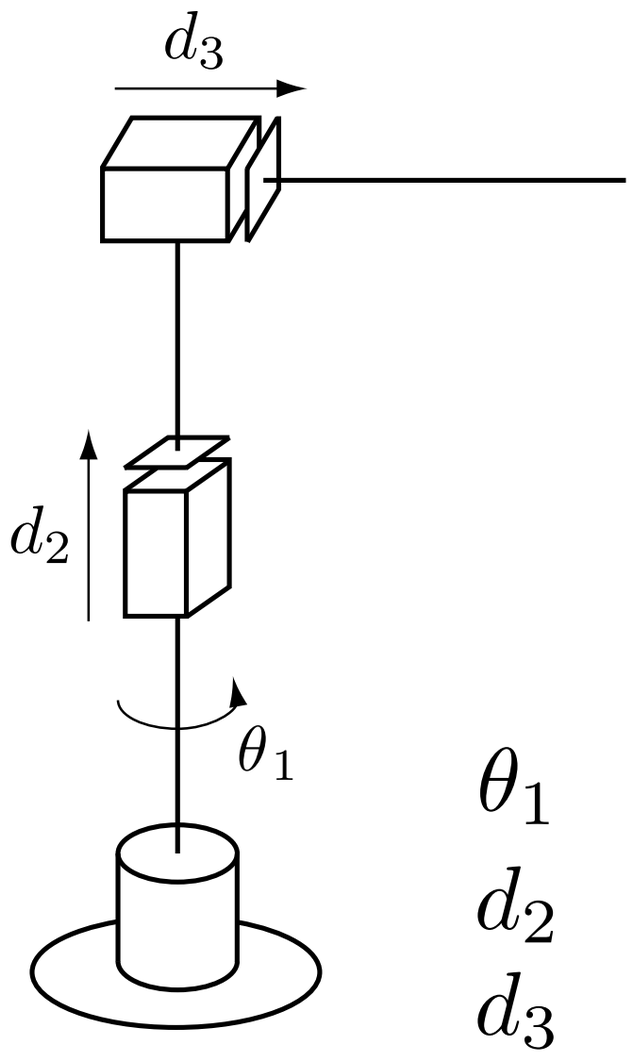


Introduced in 1979, The SCARA manipulator design revolutionized the assembly of small electronics

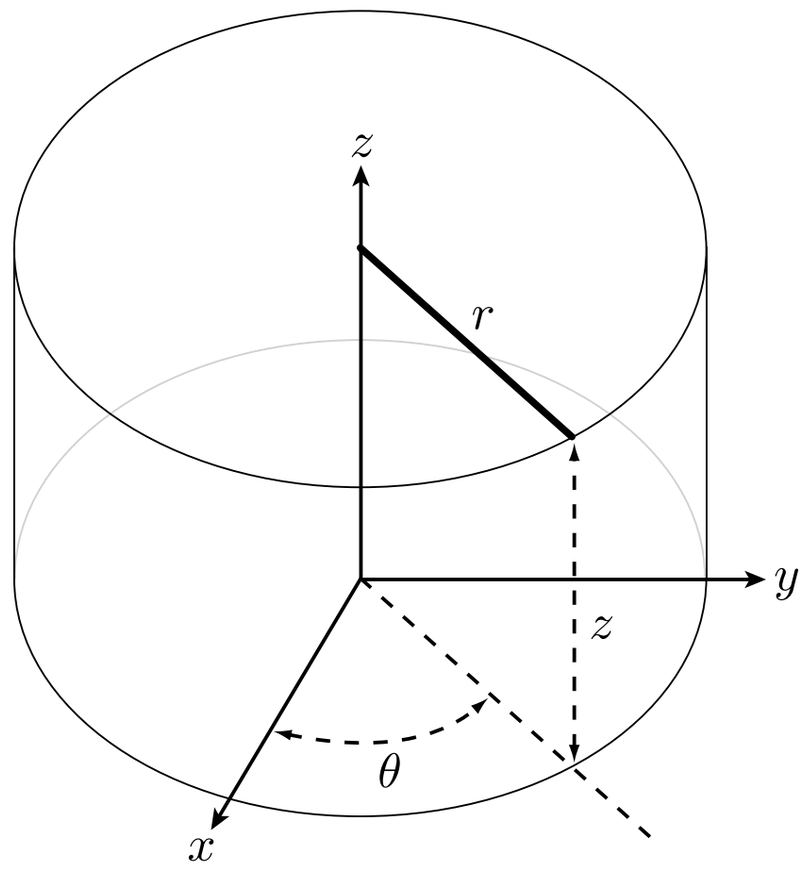
SCARA (RRP)

Cylindrical (RPP)

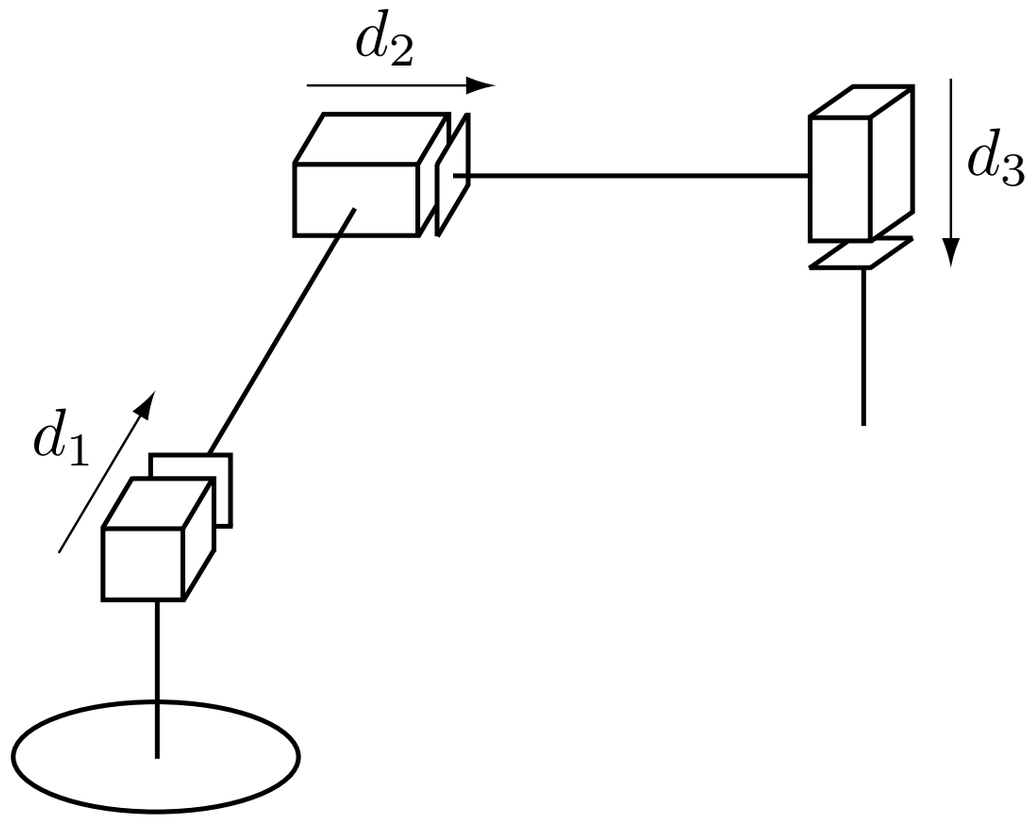
joint coordinates map to
cylindrical coordinates



$$\theta_1 \longleftrightarrow \theta$$
$$d_2 \longleftrightarrow z$$
$$d_3 \longleftrightarrow r$$

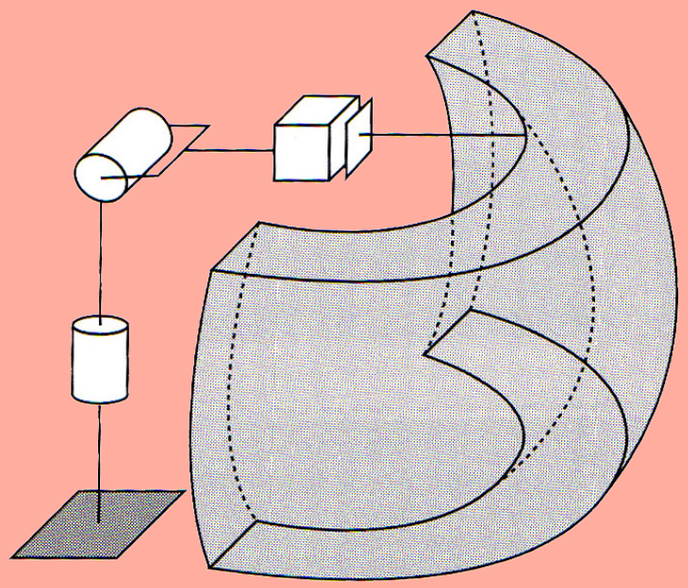


Cartesian (PPP)

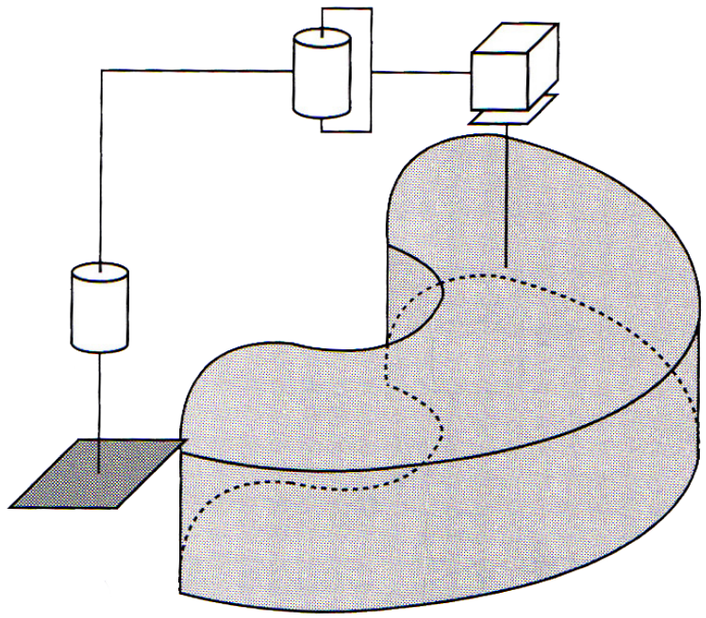


Joint variables directly correspond to the cartesian coordinates of the end-effector

Reachable Workspaces

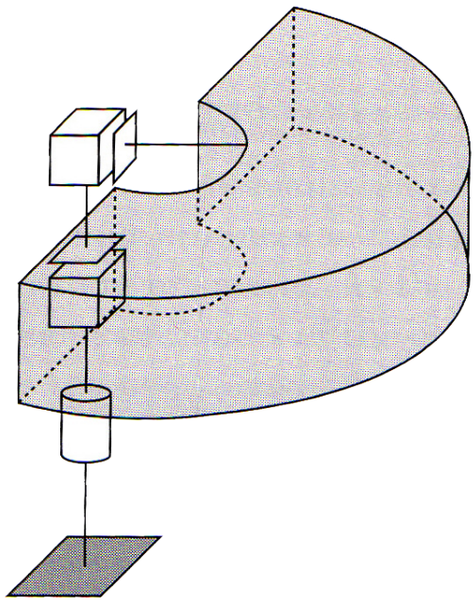


spherical

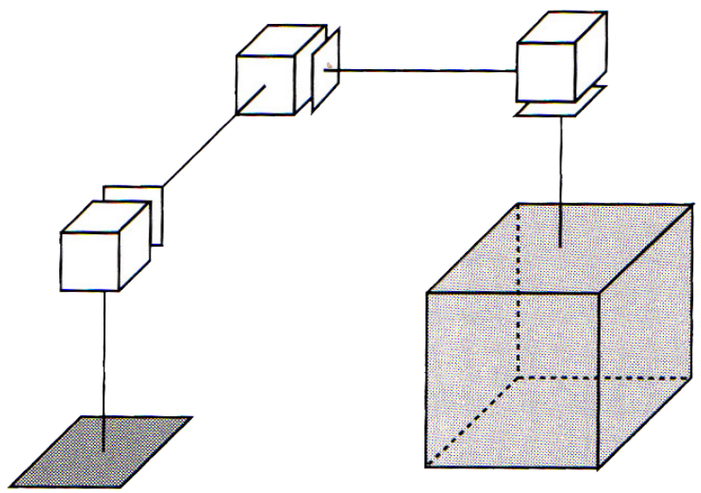


SCARA

All correct?

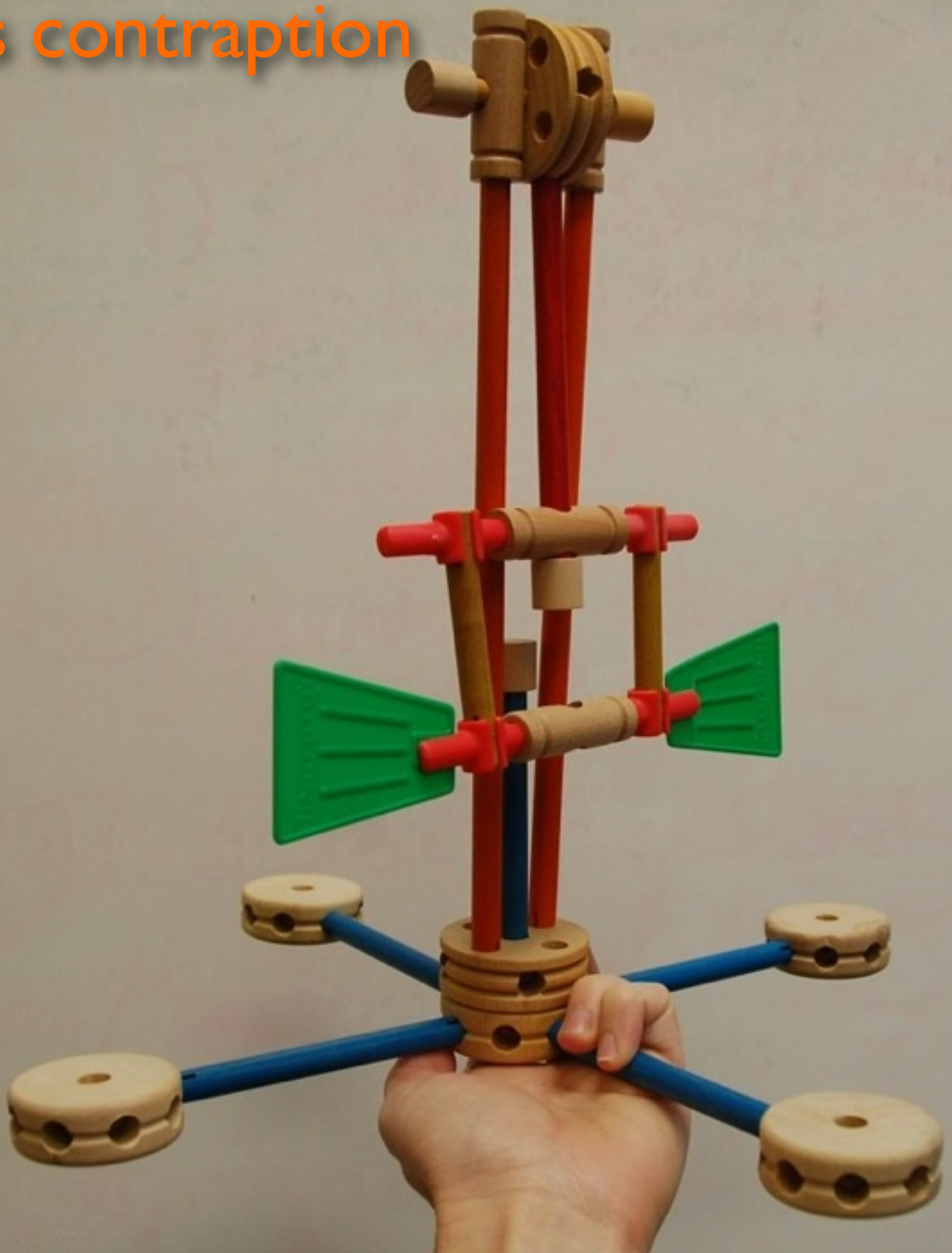


cylindrical

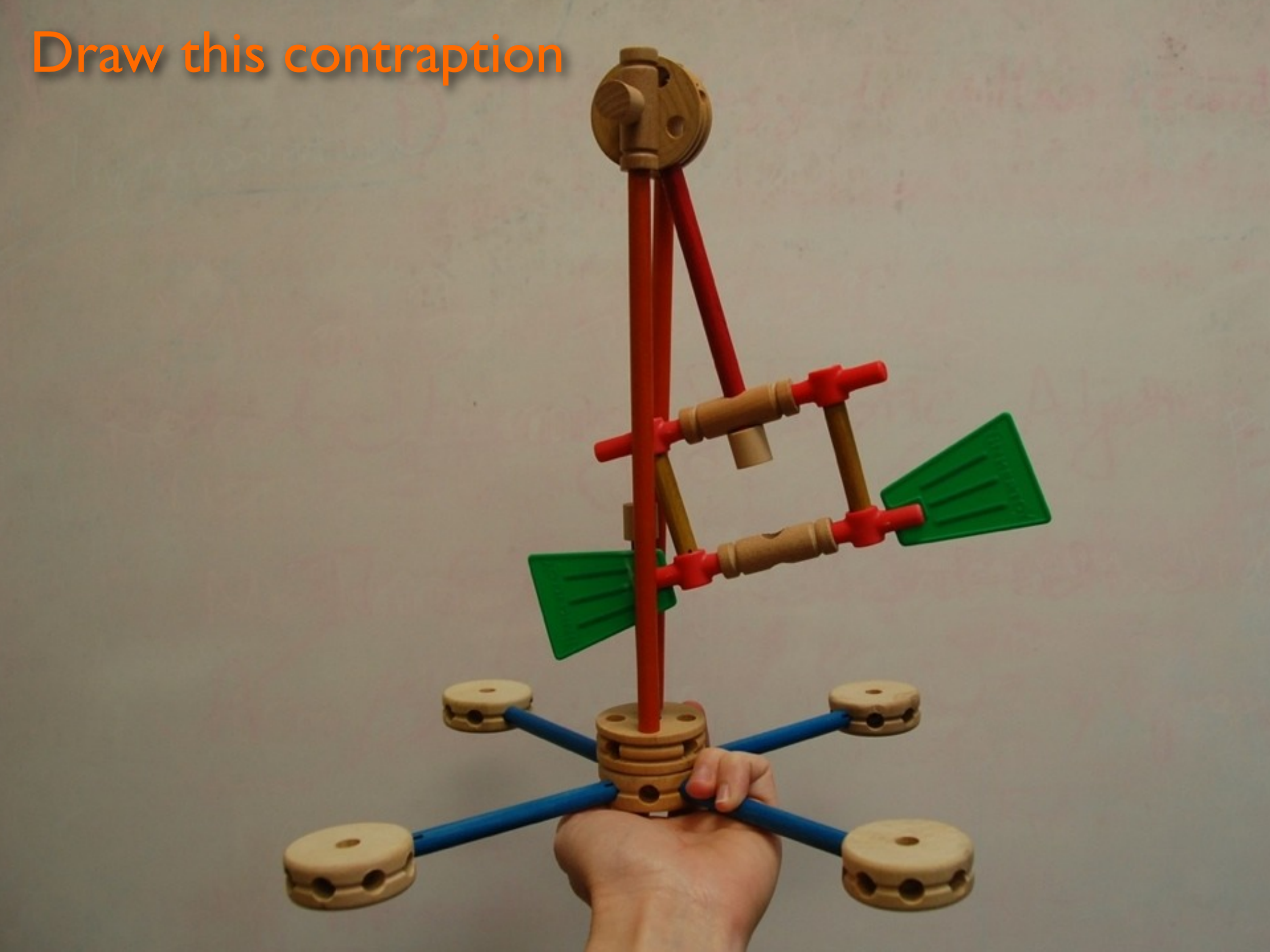


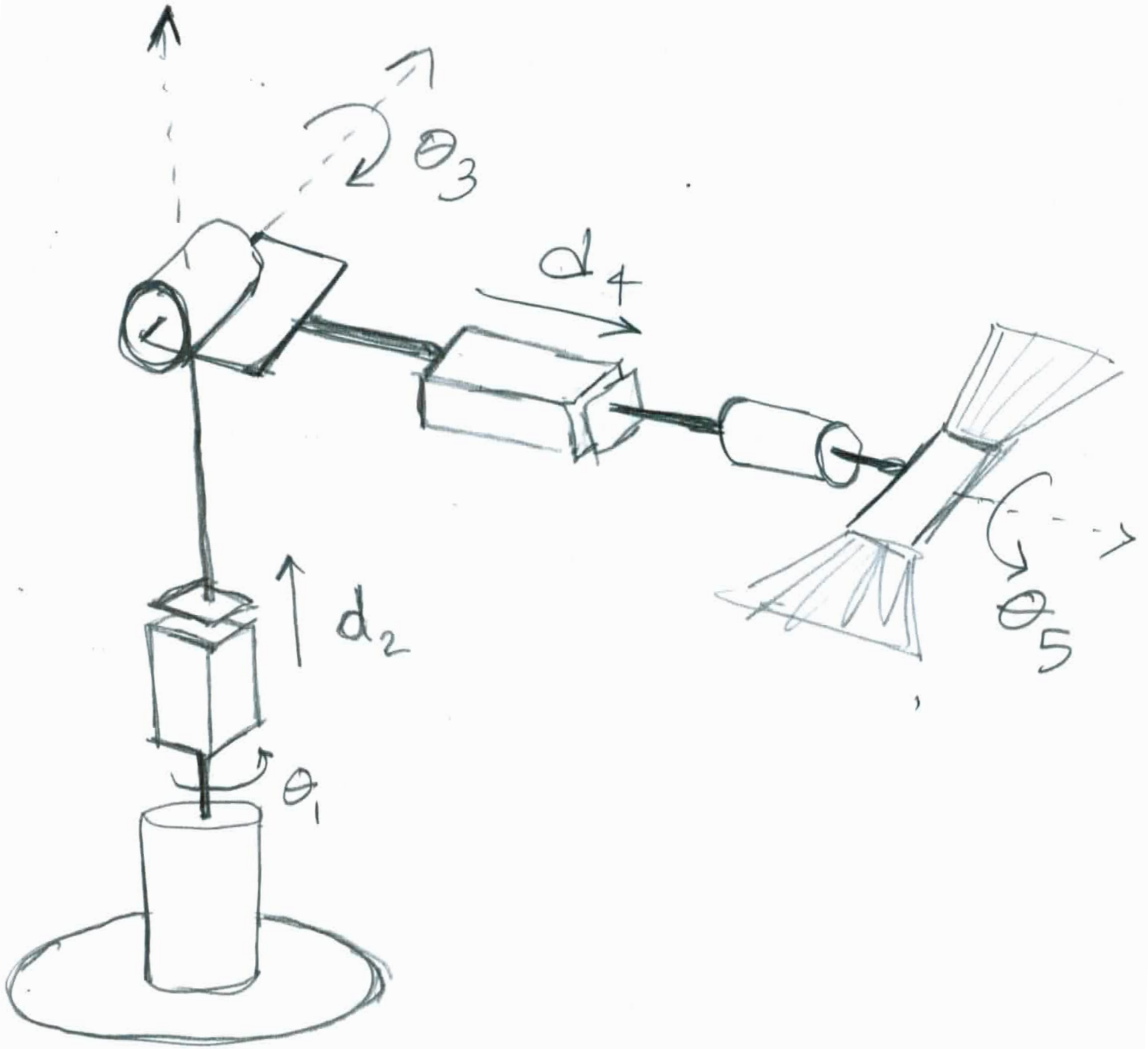
cartesian

Draw this contraption



Draw this contraption




θ_3
d_4
d_2
θ_1
θ_5

Homework #2 is coming...

Questions ?