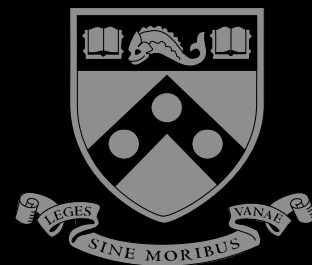


MEAM 520

Manipulator Kinematics

Katherine J. Kuchenbecker, Ph.D.

General Robotics, Automation, Sensing, and Perception Lab (GRASP)
MEAM Department, SEAS, University of Pennsylvania



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

Course Website

MEAM.Design : MEAM520 - Introduction to Robotics

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GENERAL

Hall of Fame
Laboratories
Contact Info

COURSES

MEAM 101
MEAM 201
MEAM 410/510
MEAM 520
IPD 501
SAAST

GUIDES

Materials
Laser Cutting
3D Printing
Machining
ProtoTRAK
PUMA 260
PHANToM
BeagleBoard
MAEVARM
Phidget
Tap Chart

SOFTWARE

SolidWorks
Matlab
NX
Nastran
Fluent, Gambit

Calendar [\(hide/show old\)](#)

| Date | Topic (Linked to Lecture Slides) | Reading | Assignments Due | Project Deadlines |
|---------------|-------------------------------------------------|--------------|-----------------------------------|-------------------|
| 01B Thu, 9/6 | Course Logistics and Motivation | 1.1-1.3 | | |
| 02A Tue, 9/11 | Rotation Matrices | B.1, 2.1-2.3 | | |
| 02B Thu, 9/13 | Homogenous Transformations | 2.4-2.8 | | |
| 03A Tue, 9/18 | Manipulator Kinematics | 1.3, 3.1 | HW01 (Flying Box) | |
| 03B Thu, 9/20 | Denavit-Hartenberg (DH) | 3.2 | | |

(note: all items are due at 5:00 p.m. unless otherwise specified)

Resources

[Plazza Forum](#)
[Blackboard \(Gradebook and Lecture Recordings\)](#)
[Matlab Tutorial](#)
[Textbook: Robot Modeling and Control by Spong, Hutchinson, and Vidyasagar](#)

Course Calendar

MEAM 520

Today Sep 16 - 22, 2012

Print Week Month Agenda

| | Sun 9/16 | Mon 9/17 | Tue 9/18 | Wed 9/19 | Thu 9/20 | Fri 9/21 | Sat 9/22 |
|------|----------|----------|------------------------|----------|----------------------------------|----------|----------|
| | | | Homework #1 due | | | | |
| 8am | | | | | | | |
| 9am | | | | | | | |
| 10am | | | | | 10 - 11 Office hours - Philip | | |
| 11am | | | | | | | |
| 12pm | | | 12p - 1:30p Lecture | | 12p - 1:30p Lecture | | |

Piazza Forum

MEAM 520 (1 unread)

https://piazza.com/class#fall2012/meam520/12

Google

MEAM 520 Q & A Course Page Manage Class

Katherine J. Kuchenbecker

+ New Post Search or add a post...

PINNED

- Form project teams & study groups!
- 1 Open Teammate Search

FAVORITES

YESTERDAY

- H32 or H23 in SHV 2-39?
- Viewing flying_box values
- My flying box leans.

THIS WEEK

- MATLAB Tutorial
- Homework SHV 2-39

LAST WEEK

- SHV 2.23 not about Axis/Angle represent...
- Ignoring the roll angle?
- Textbook in Library
- Changing Flying Box Animation Speed
- An instructor thinks this is a good question
- Instr Note Welcome to Piazza!

WEEK 8/26 - 9/1

- Private Introduce Piazza to your students
- Private Get familiar with Piazza
- Private Tips & Tricks for a successful class
- Welcome to Piazza!

Question History:

? question 42 views

My flying box leans.

I have a question to ask. I found it hard for me to combine the 3 steps of rotation to make my virtual box flying coincide with the real one perfectly. I have analyzed the box flying history data several times but I still could not find out the perfect solution. Would it been possible that there is a leaning angle when the sensor was fixed on the box?

Thank you! Have a nice day!

#homework1

edit save to favorites 0 good question 0 more 16 hours ago by Katherine J. Ku... 2 edits

S the students' answer, where students collectively construct a single answer

Yes, I have tried different sequences using different approaches, and the perfect one also has a slight tilt of the plane during its last period of movements. I guess this is okay. Don't worry.

edit good answer 0 more 10 hours ago by Tianyu Dong 1 edit

i the instructors' answer, where instructors collectively construct a single answer

Yes, I believe the sensor may have been slightly rotated when it was attached to the box. It was encapsulated in a cylindrical object and held in place with duct tape, so the sensor frame could easily have been rotated about 10 or 15 degrees from the box frame around the x axis of the sensor. You should also note that the magnetic tracking system is not perfect, so the angles may be slightly distorted for that reason as well. These slight perturbations should not be very obvious from the given camera angle, but I apologize for the difficulty they may have caused you.

edit good answer 1 more 16 hours ago by Katherine J. Ku... 1 edit

Average Response Time: 3 min

Special Mentions: Whoa! Katherine J. Kuchenbecker answered H32 or H23 in ... in 31 sec. 9 hours ago

Online Now: 3 This Week: 81

Views: Filter: All

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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.

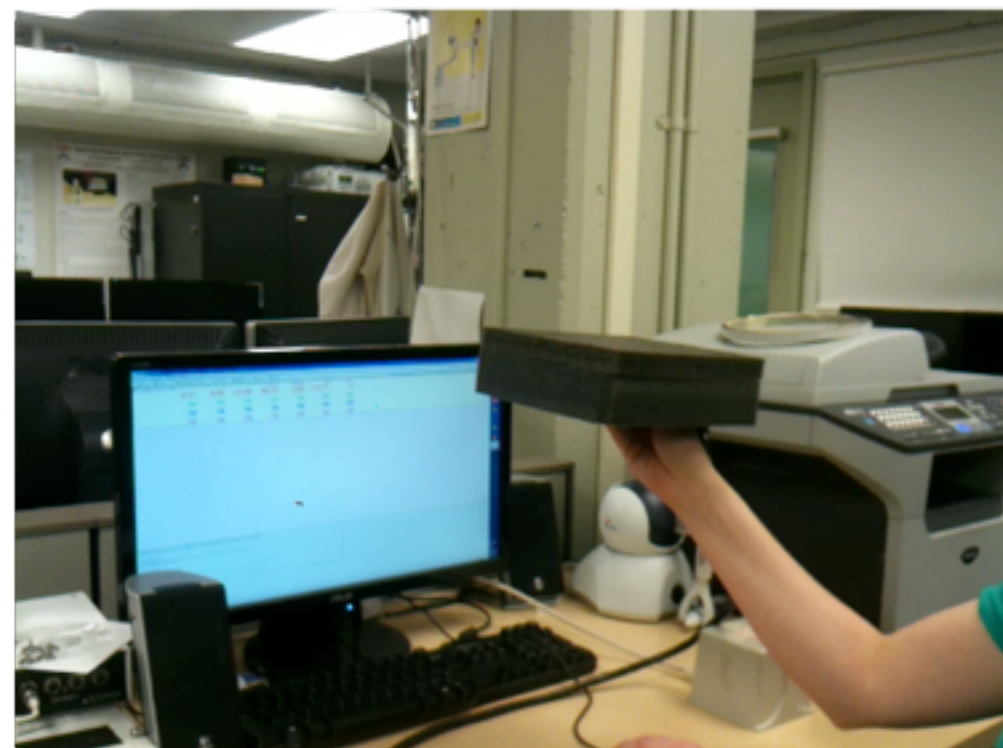
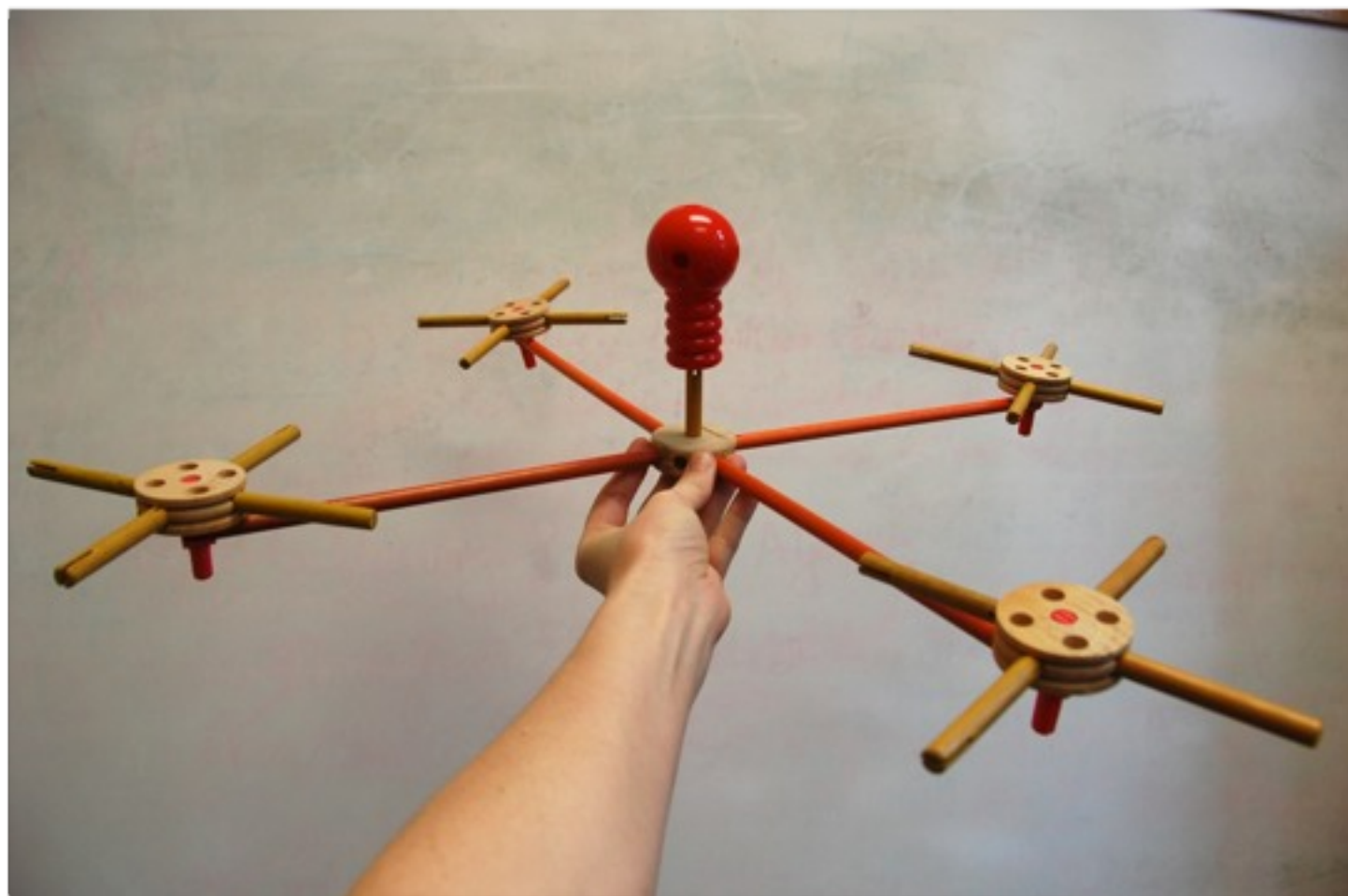
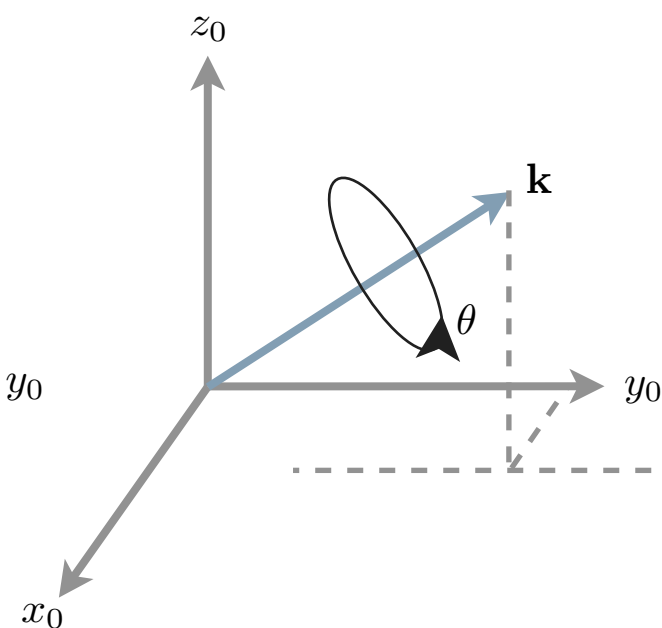
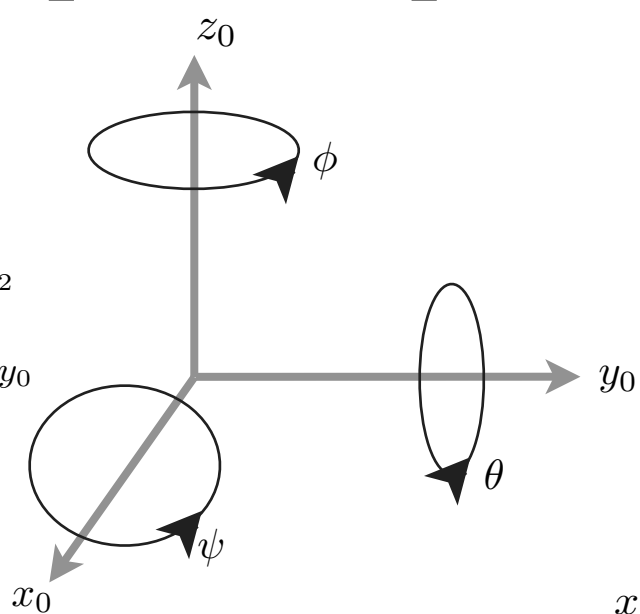
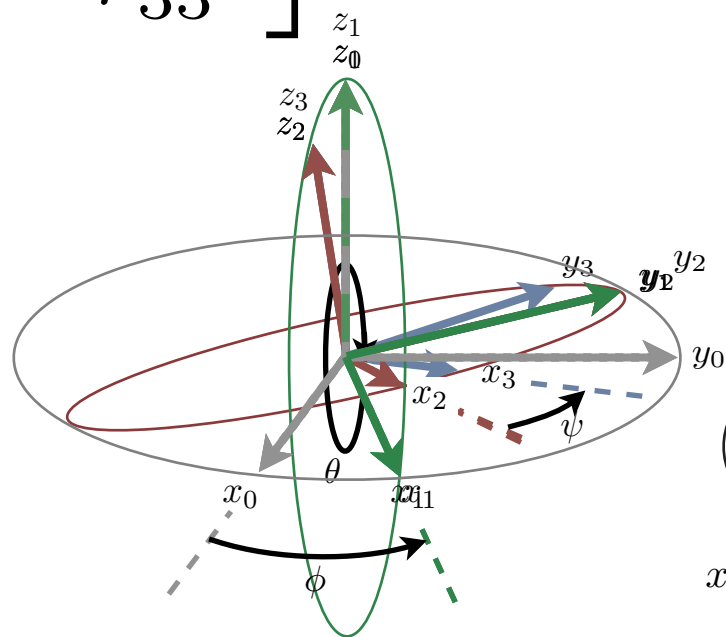
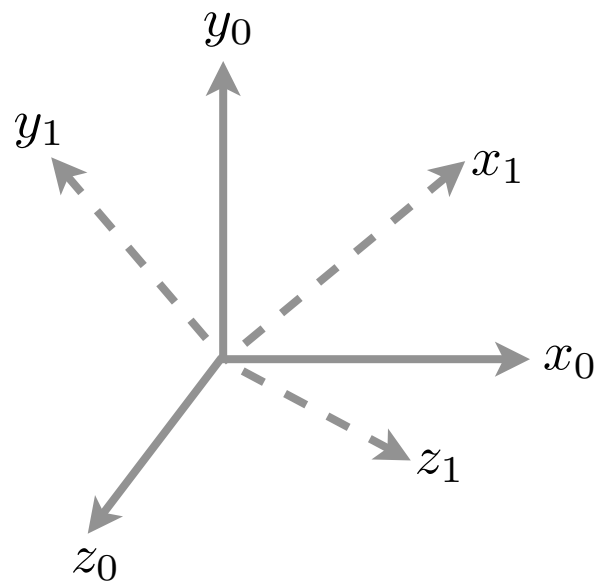
Reminders

- 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.

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

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

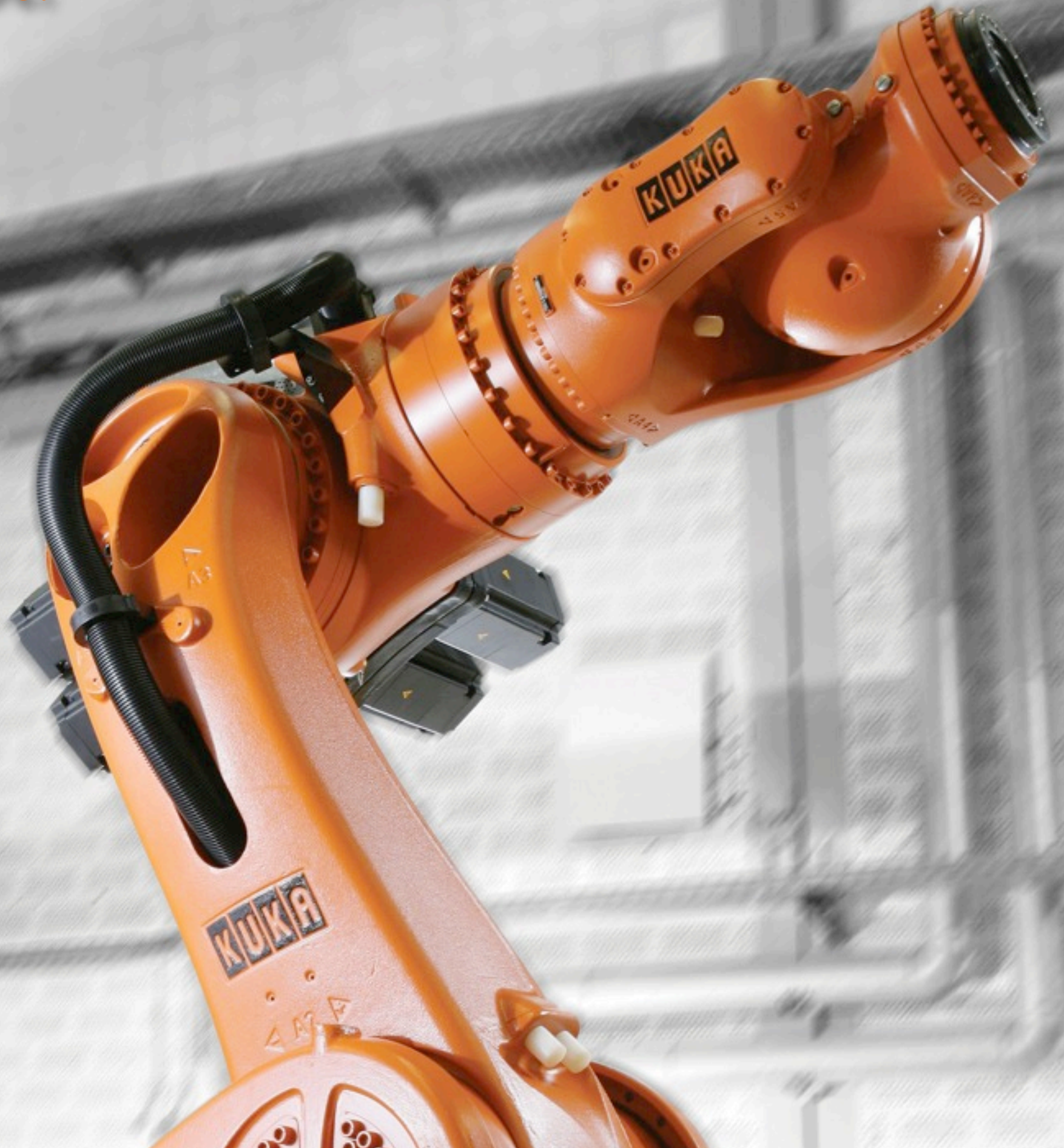
$$\mathbf{P}^0 = \mathbf{H}_1^0 \mathbf{P}^1$$

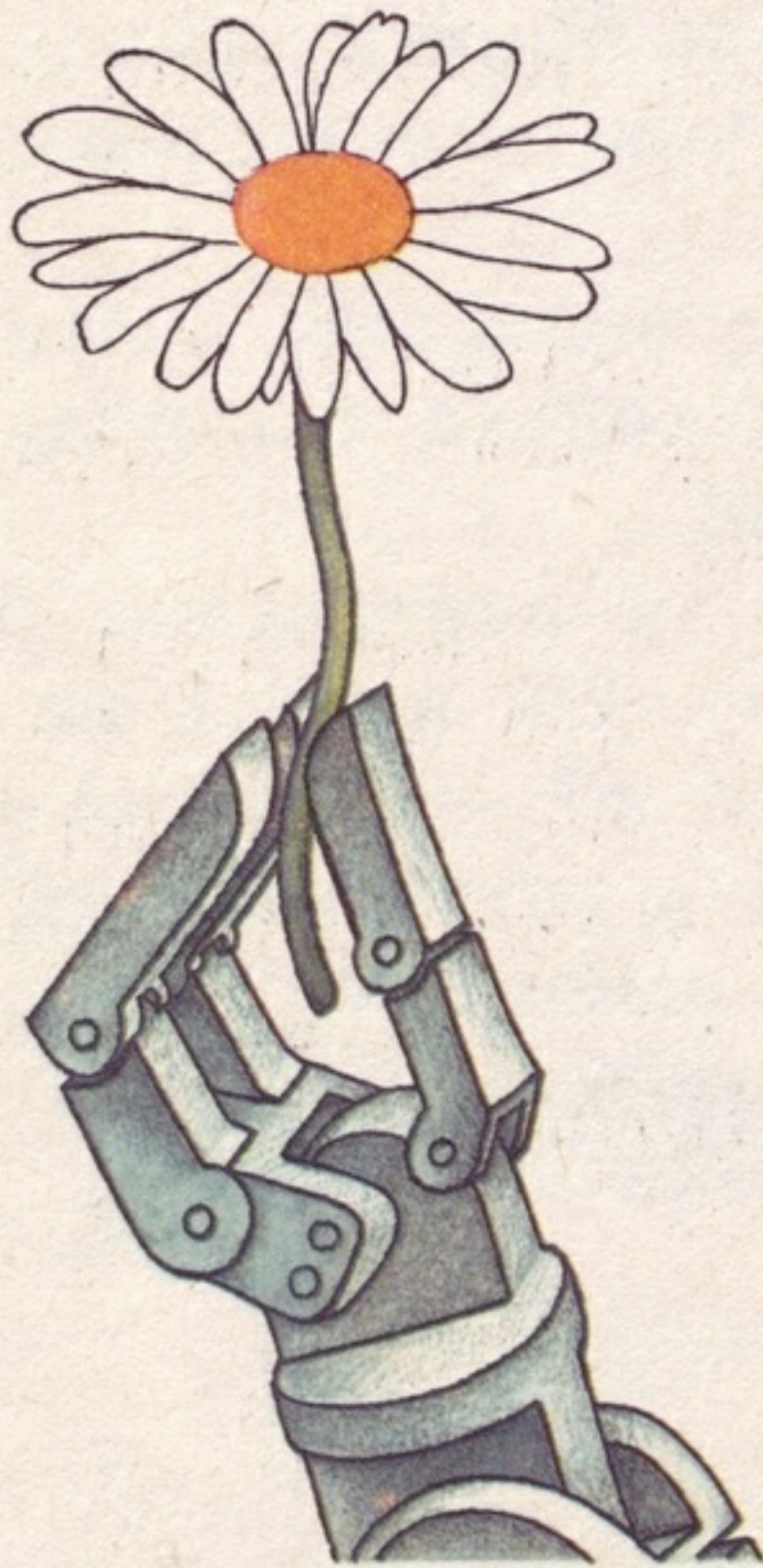


What is a robot?



Slides created by
Jonathan Fiene

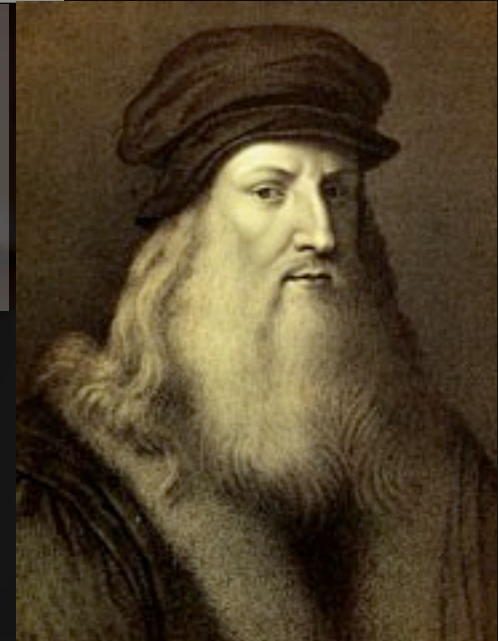






322 B.C. - “If every tool, when ordered, or even of its own accord, could do the work that befits it... then there would be no need either of apprentices for the master workers or of slaves for the lords.” - Aristotle

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!

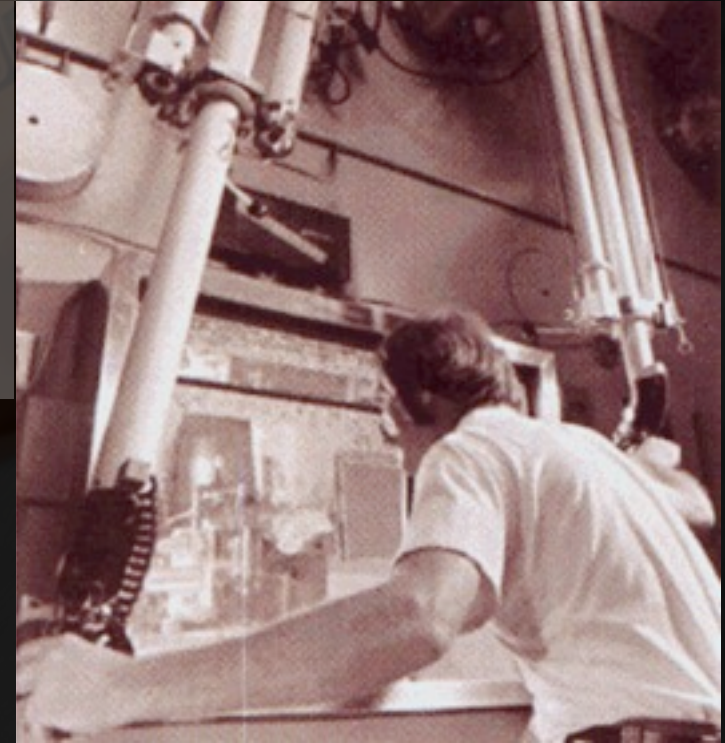
1921 - Karel Capek popularizes the term “robot” in a play called *R.U.R.* (*Rossum’s Universal Robots*) wherein robot workers take over the earth.



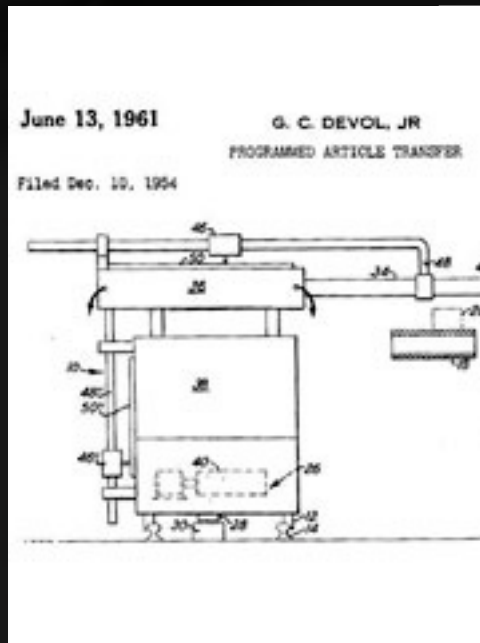


1942 - Isaac Asimov publishes *Runaround*, which introduces the three “laws” of robotics.

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



Slides created by
Jonathan Fiene

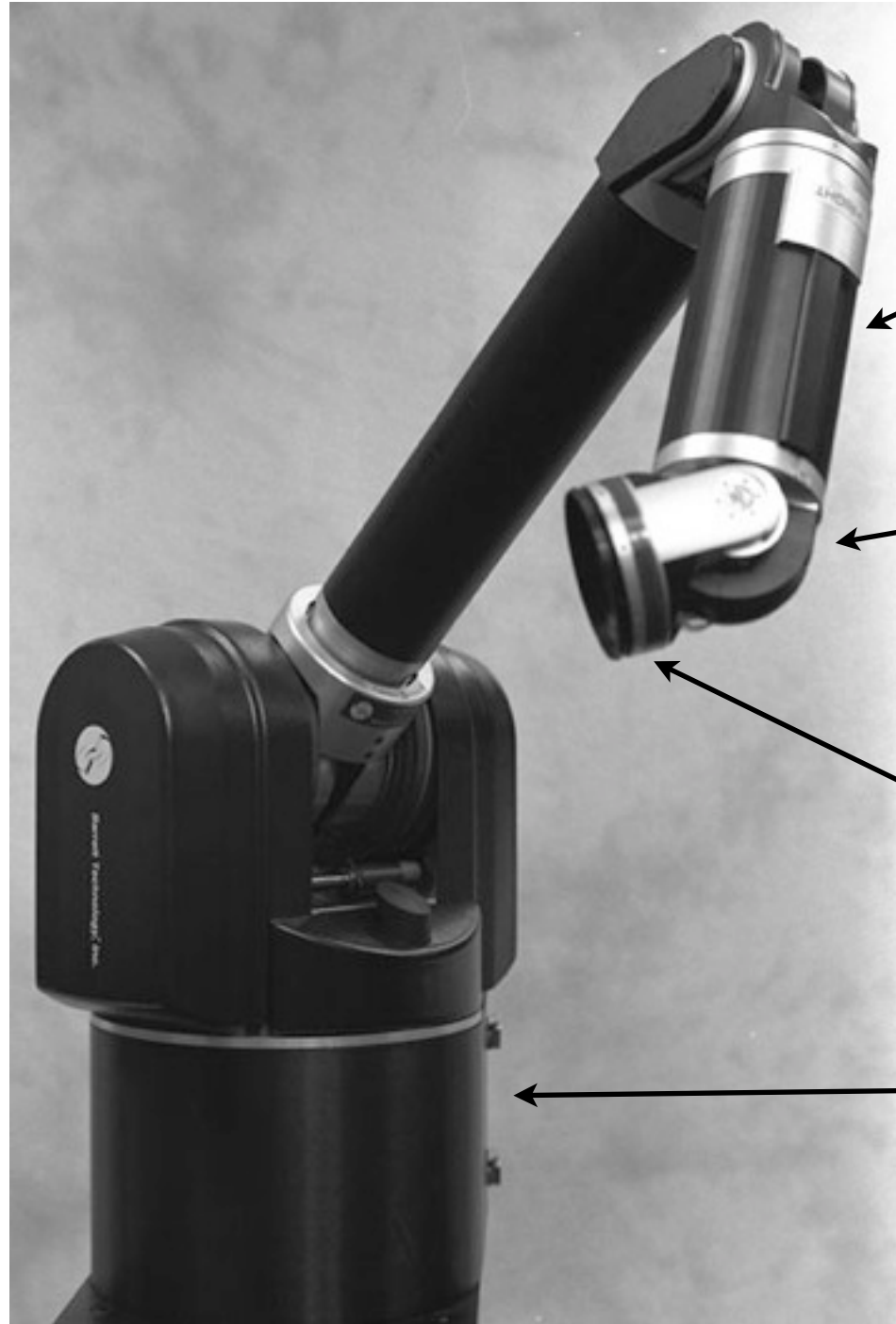


Manipulators : Terminology

SHV 1.1-1.3, 3.1



General Terminology



Link : rigid body, 6 degrees of freedom

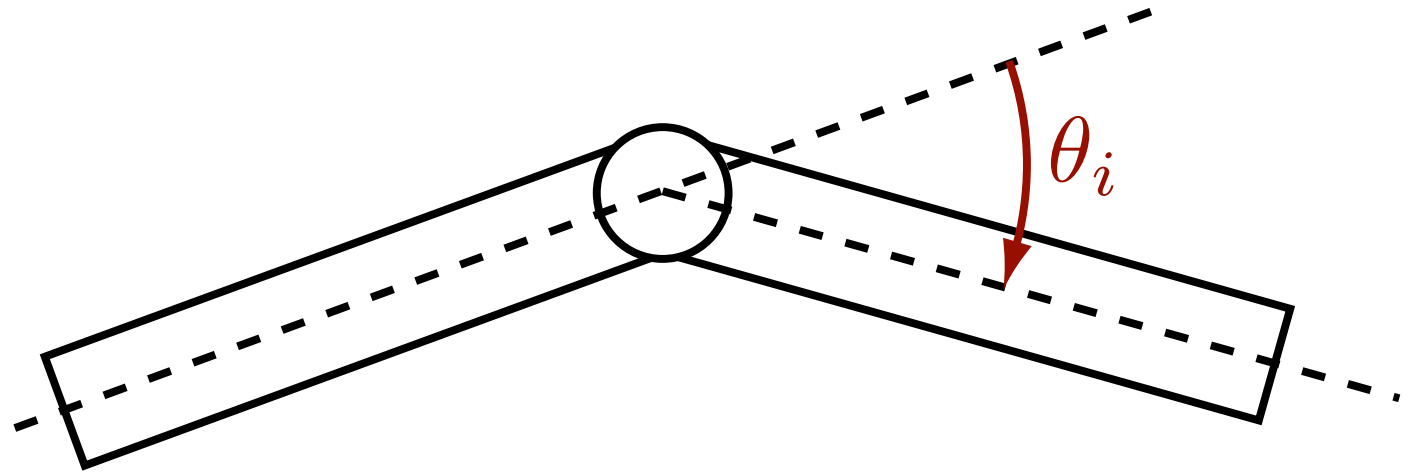
Joint : connection between two links

End-effector : interacts with the environment

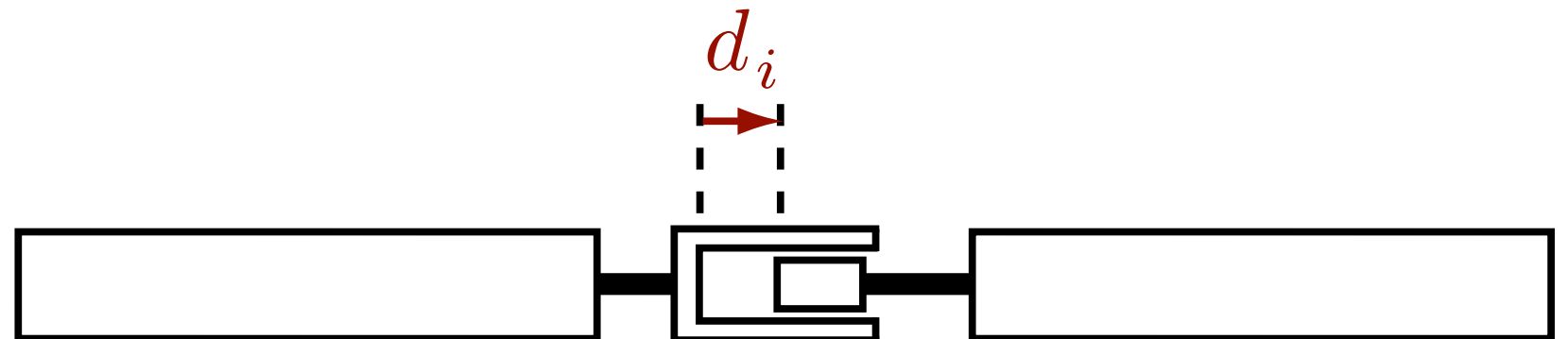
Base : connected to ground

Joint Descriptions

(R)evolute : angular displacement between adjacent links



(P)rismatic : linear displacement between adjacent links



Where are the joints?

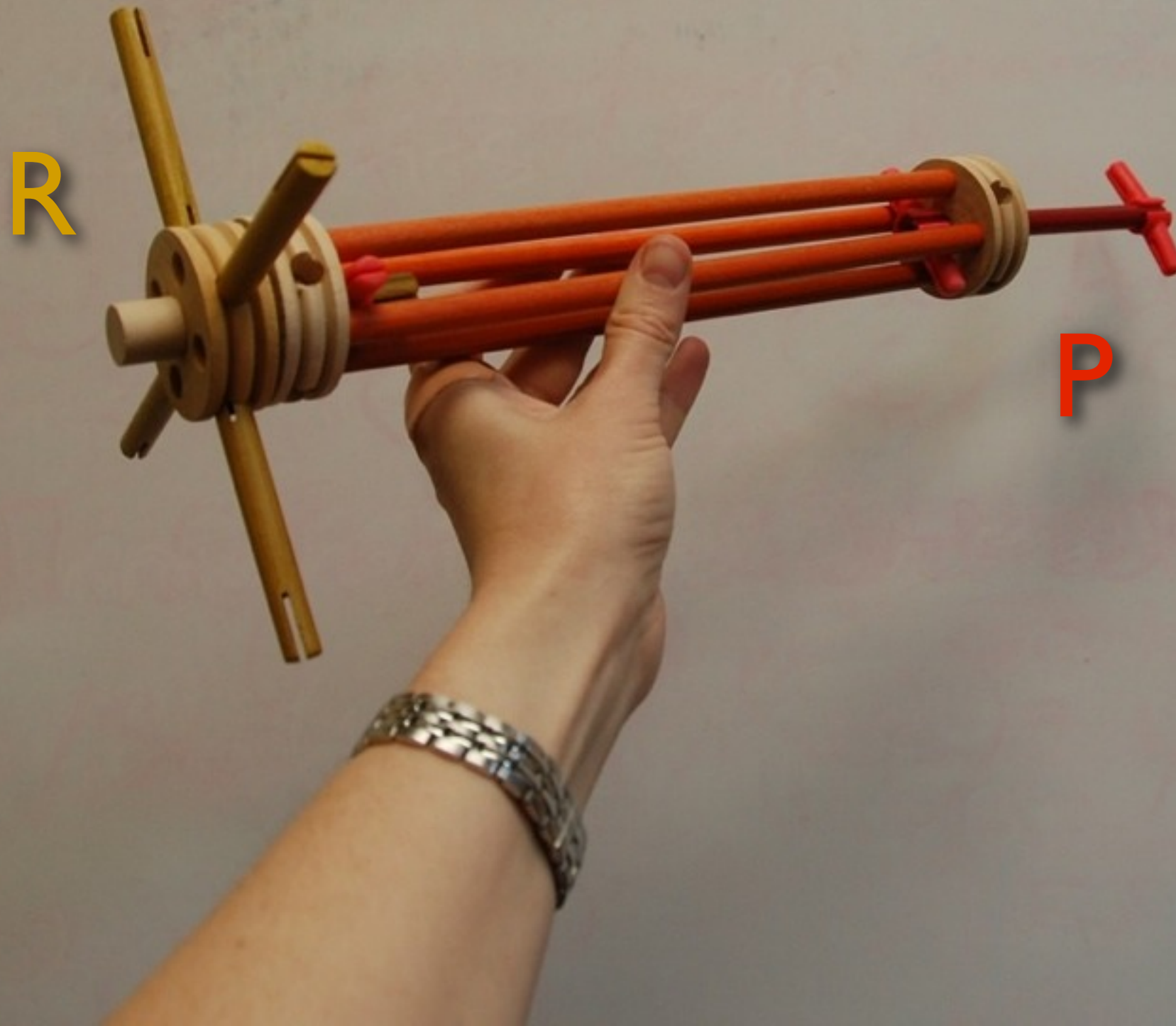


Where are the joints?

R

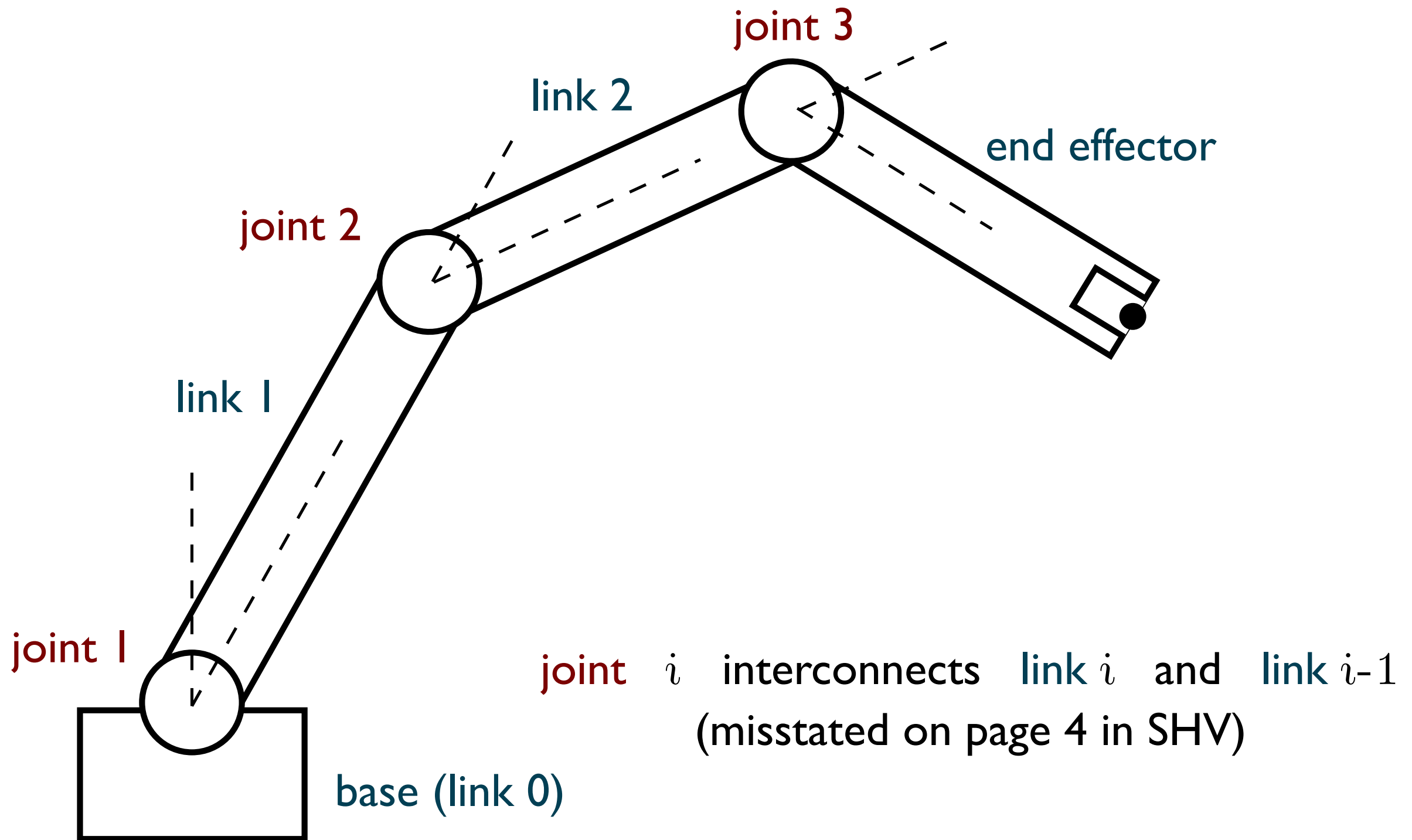


Where are the joints?



Kinematic Chains

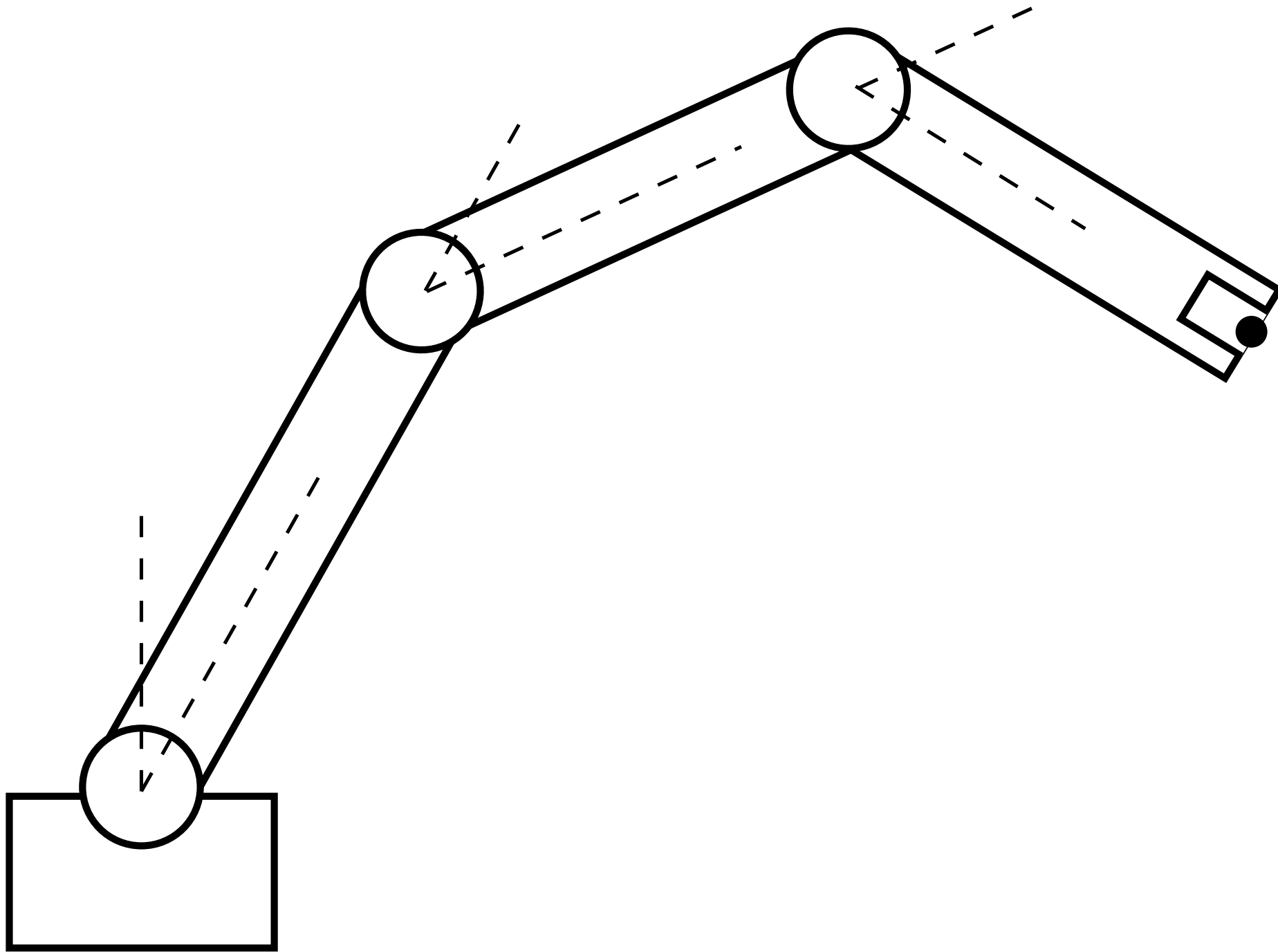
A **kinematic chain** is a system of rigid bodies connected by joints



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

Configuration Space

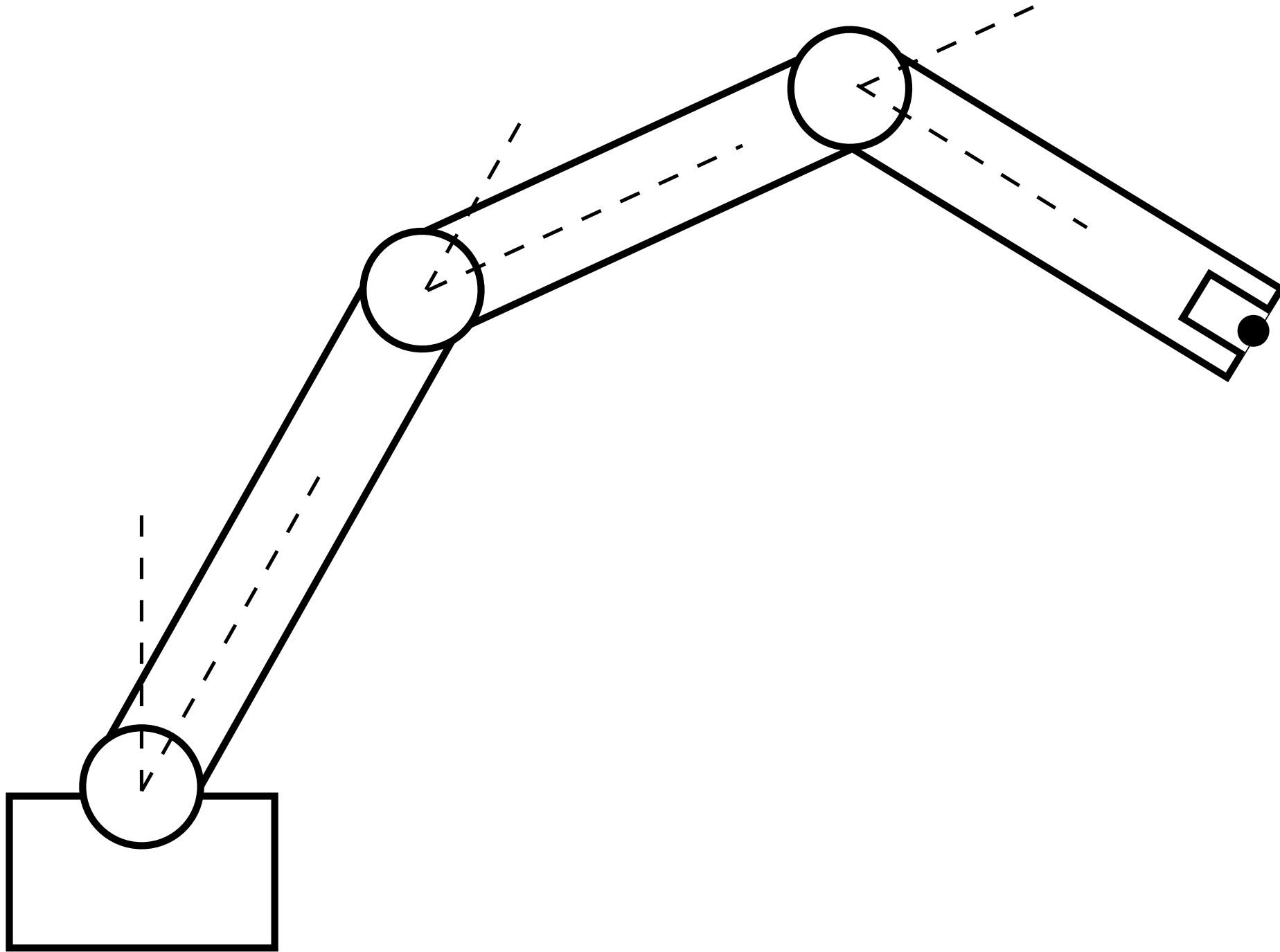
The **configuration** defines the location of every point of the manipulator



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

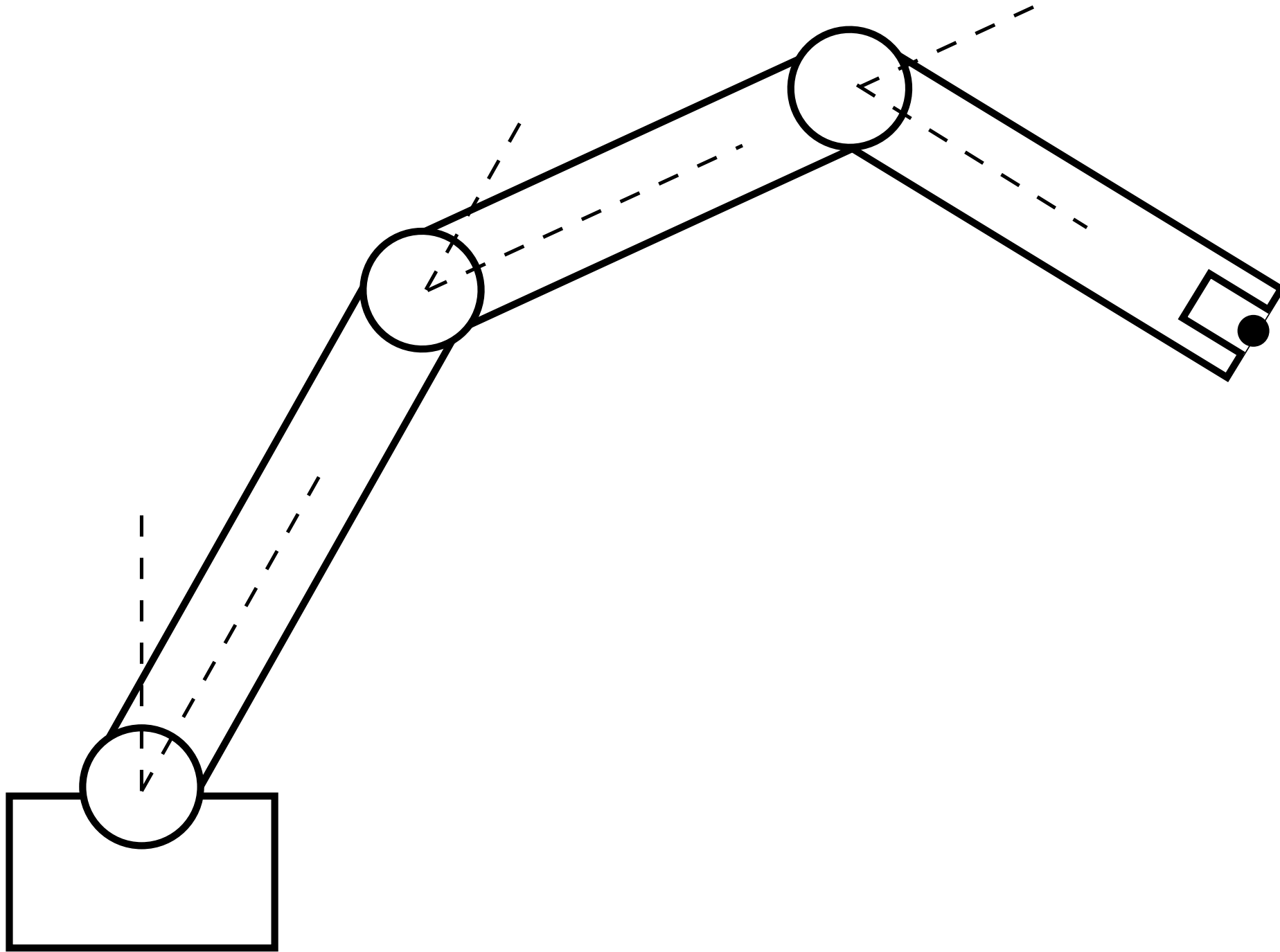
Degrees of Freedom

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



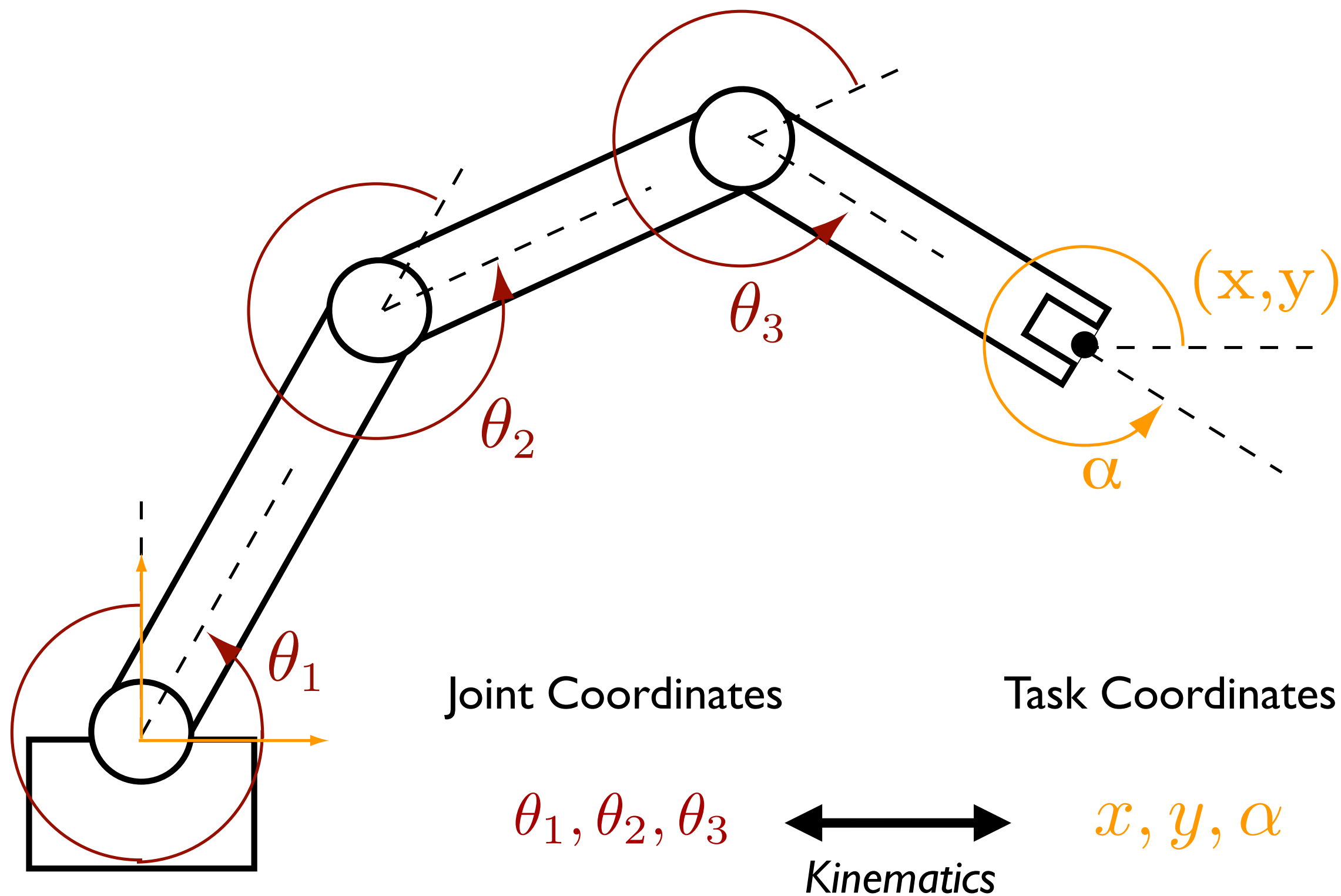
Workspace

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

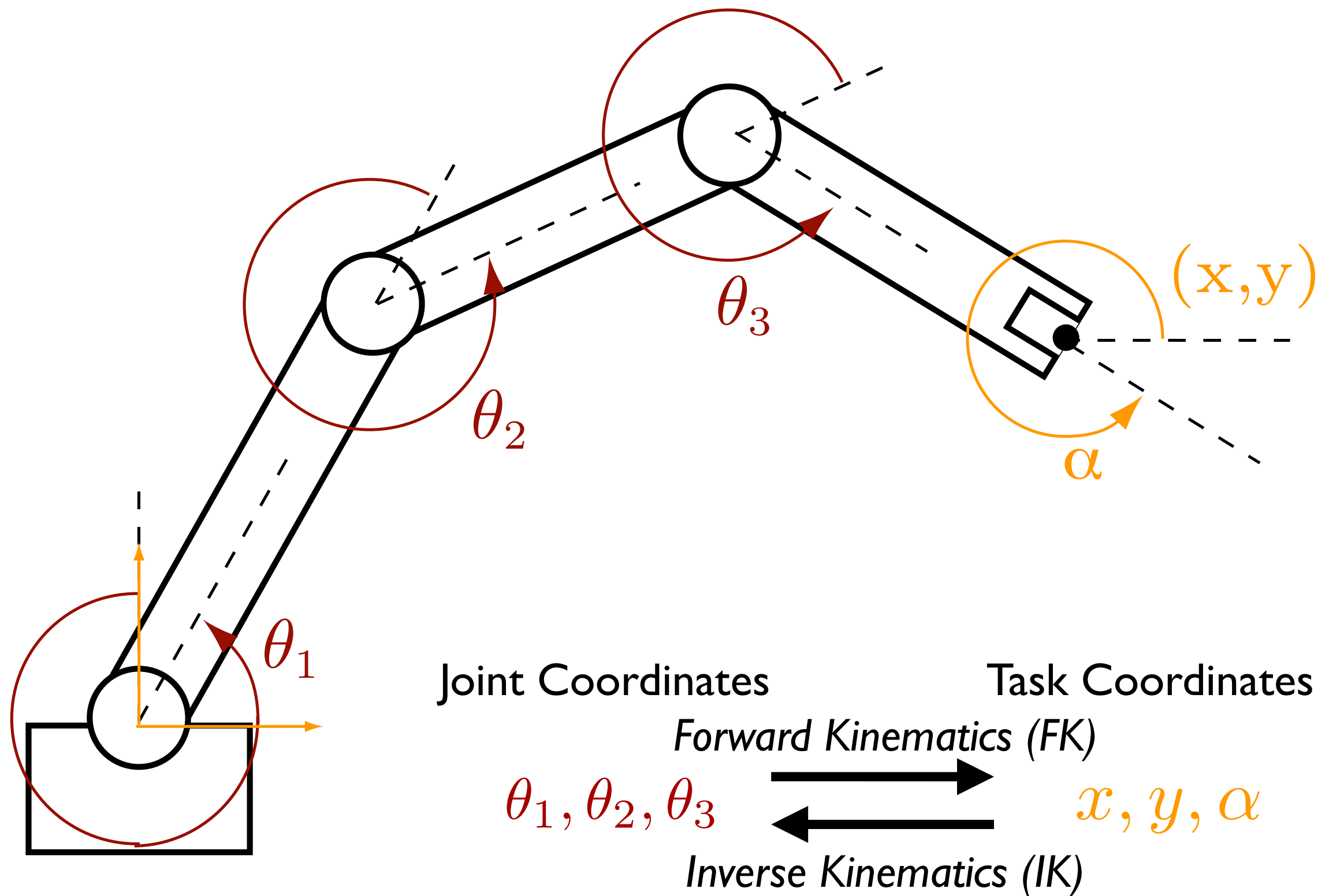


The **dexterous workspace** is a subset of the reachable workspace wherein the end effector can obtain an *arbitrary* orientation

Joint and Task Coordinates



Joint and Task Coordinates



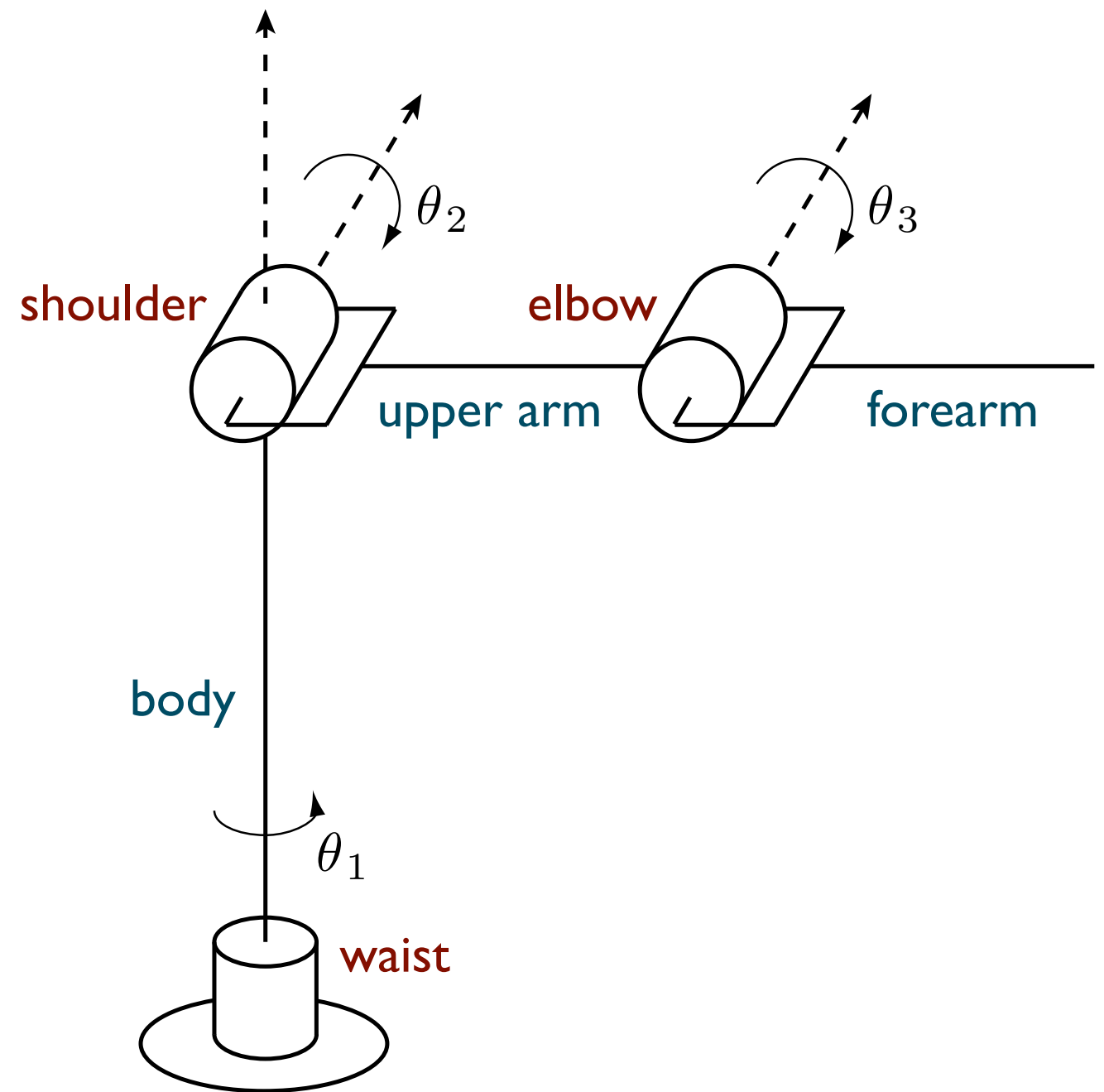
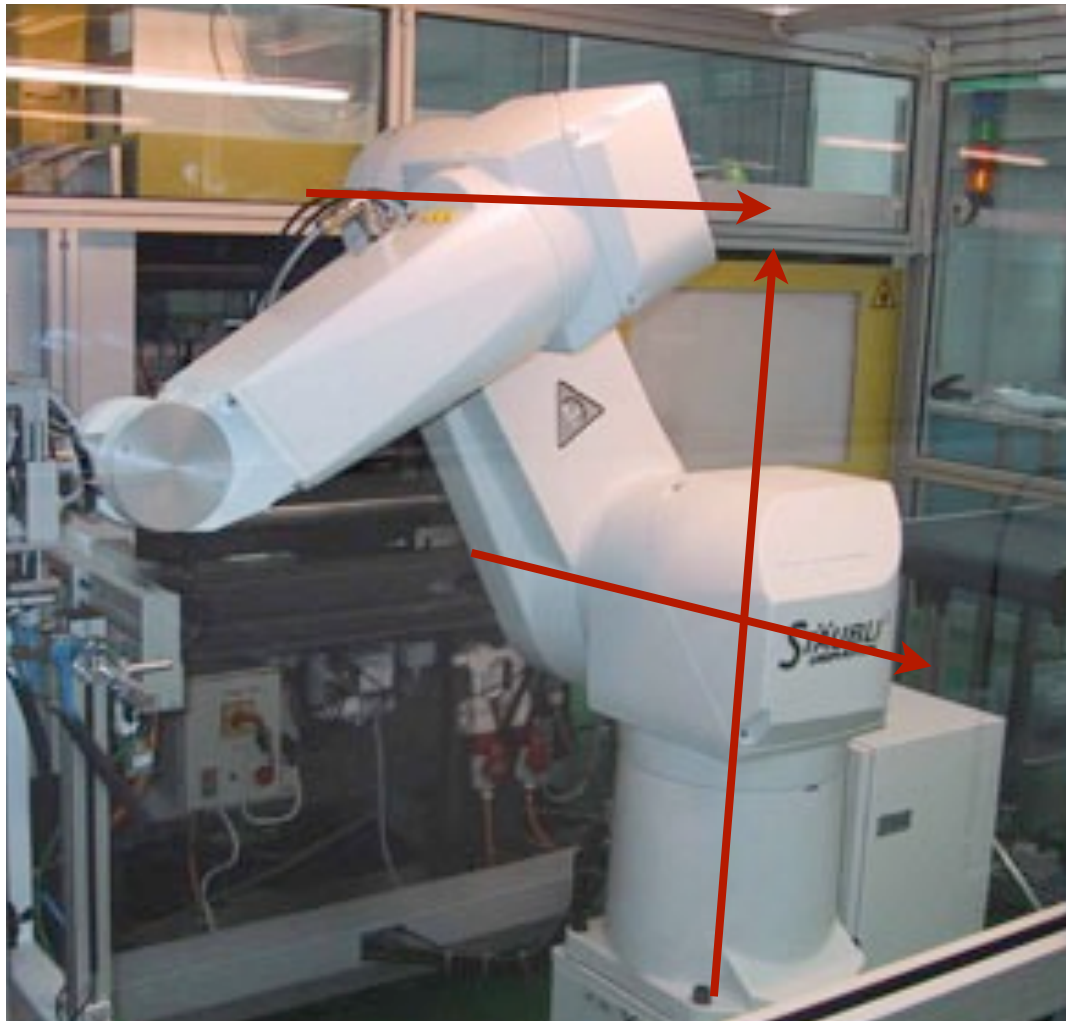
Manipulators : Common Configurations



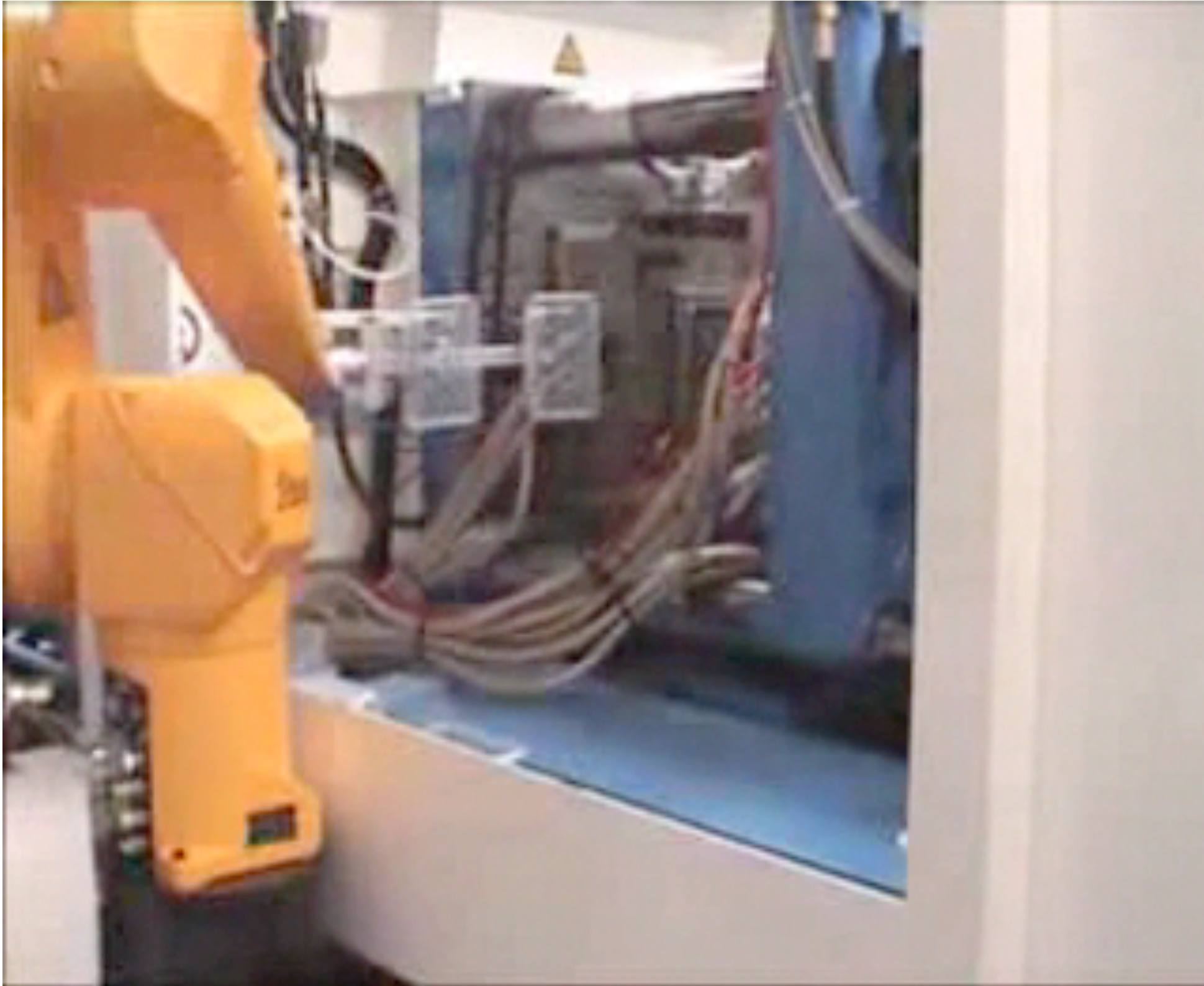
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Working with a partner,
come up with a serial robotic linkage using 3 joints
(R and/or P).
Sketch your design in your notes.

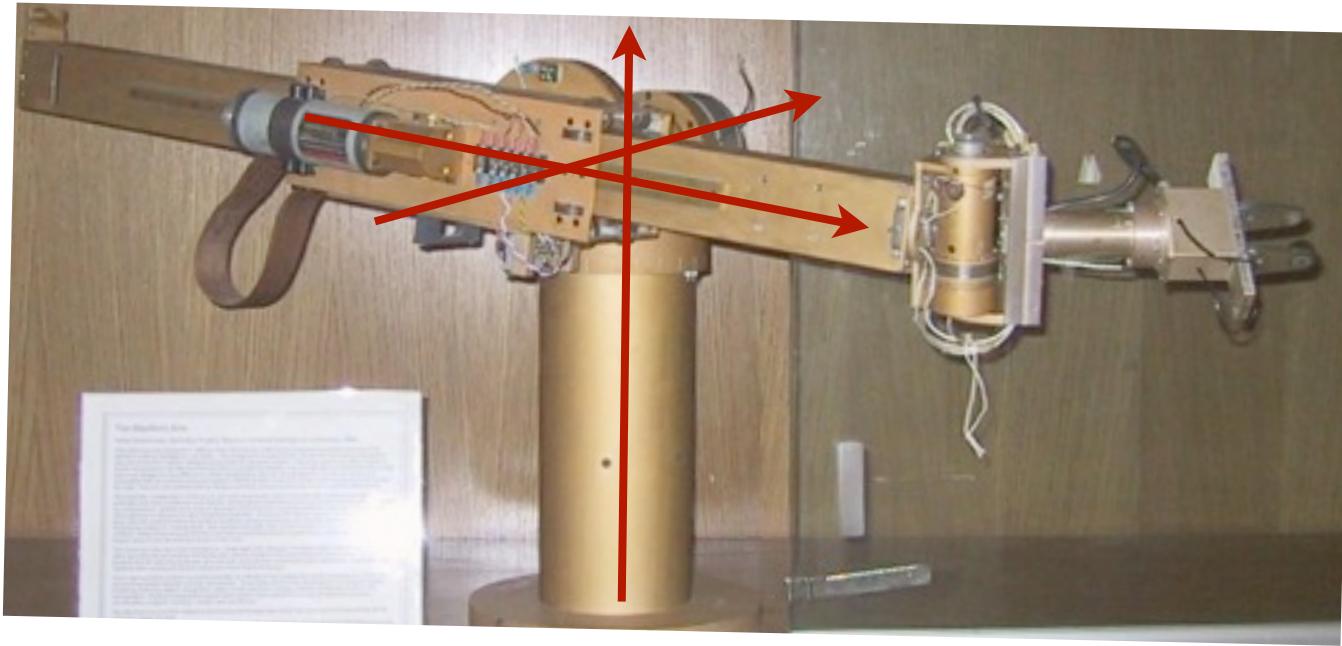
Articulated (RRR)



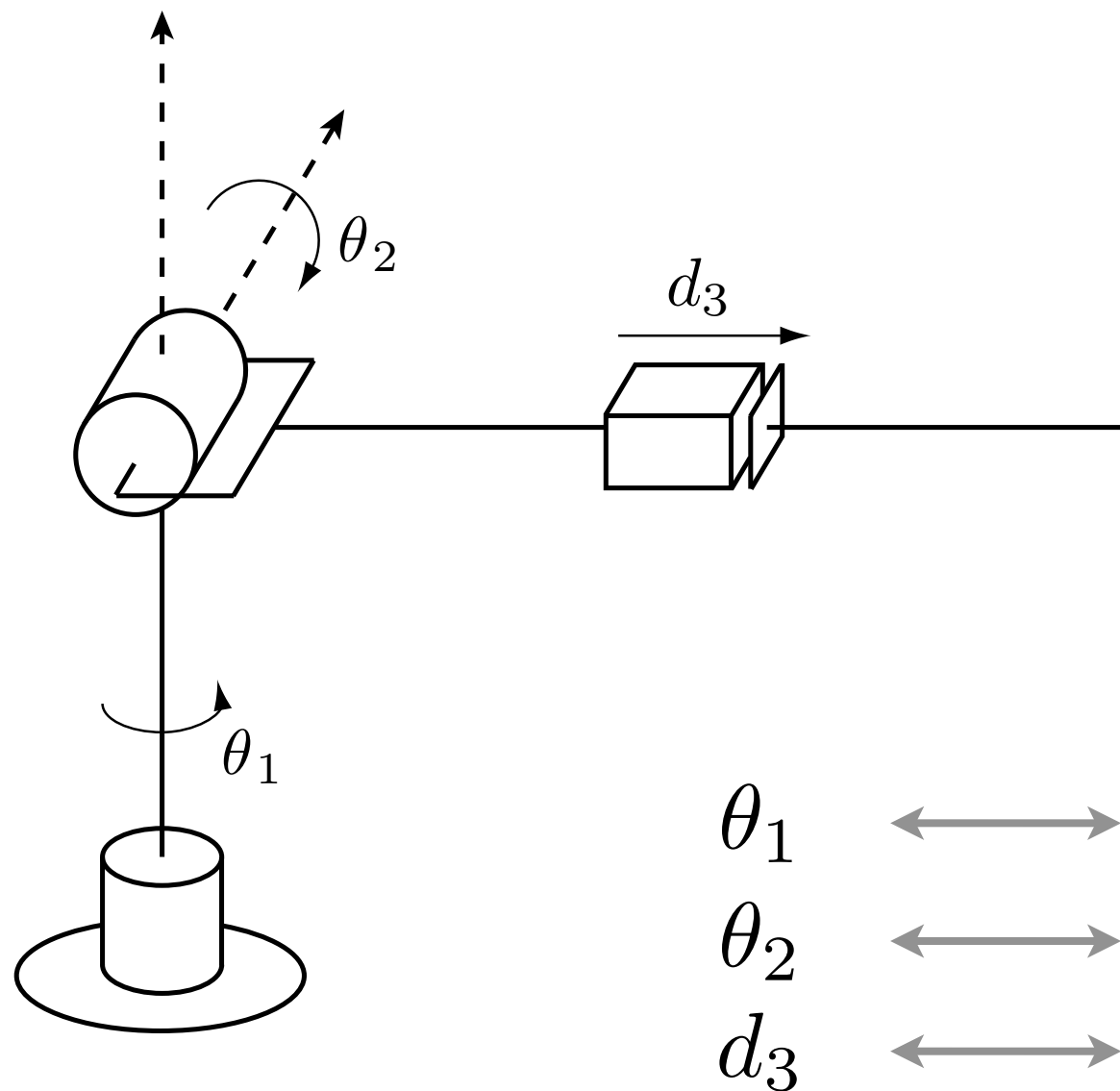
Articulated (RRR)



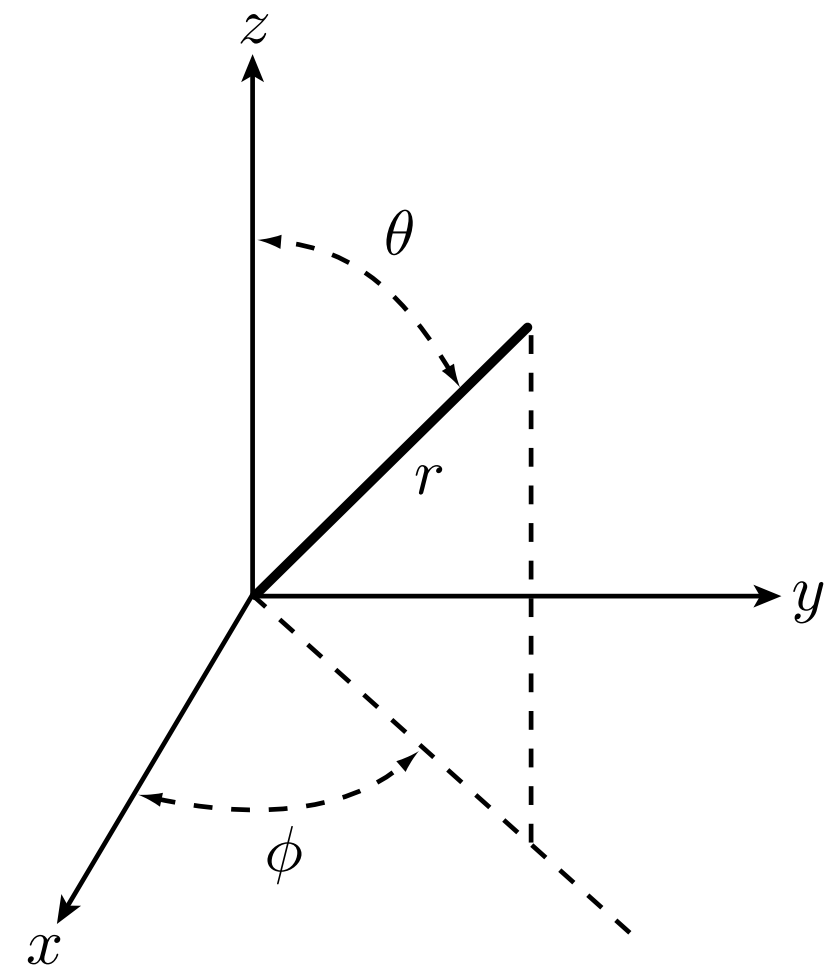
Spherical (RRP)



joint coordinates map to
standard spherical coordinates

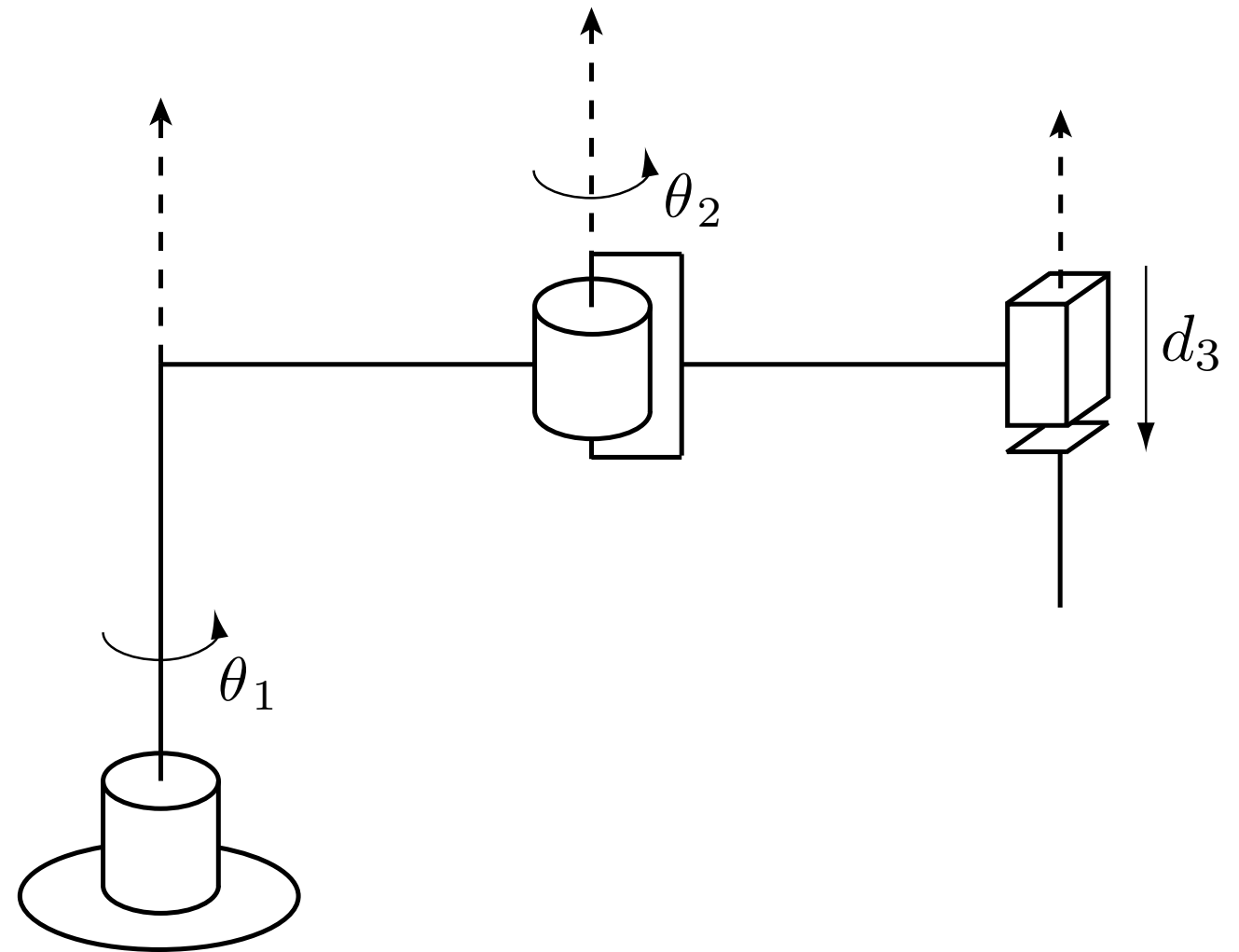


| | | |
|------------|-----------------------|----------|
| θ_1 | \longleftrightarrow | ϕ |
| θ_2 | \longleftrightarrow | θ |
| d_3 | \longleftrightarrow | r |



SCARA (RRP)

Selective Compliant Articulated Robot for Assembly



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

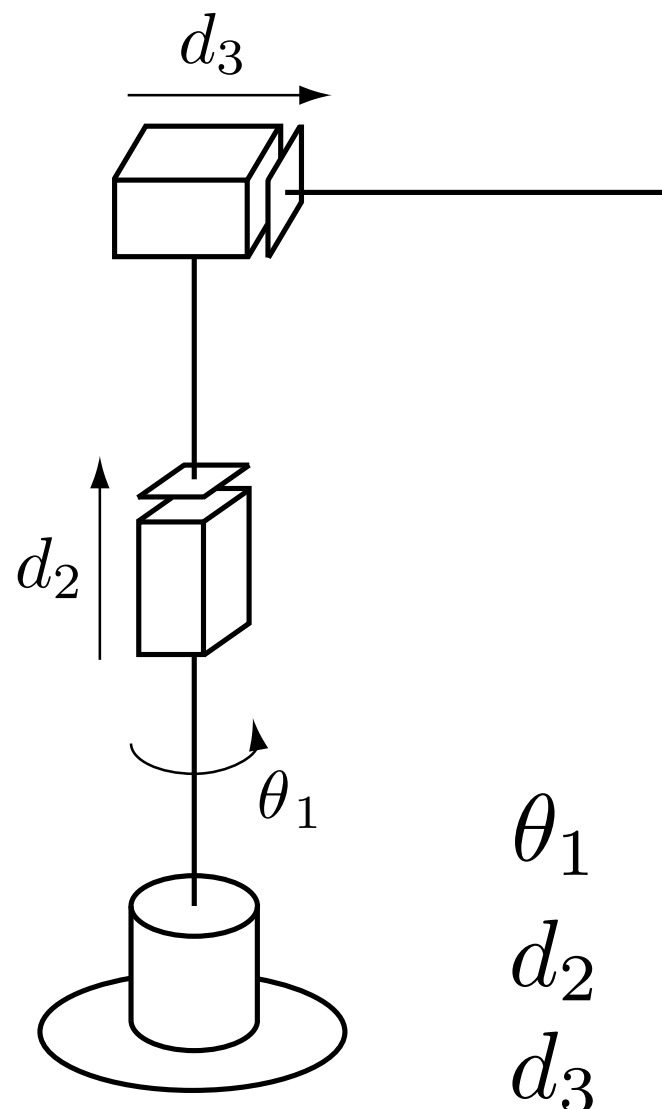
SCARA (RRP)



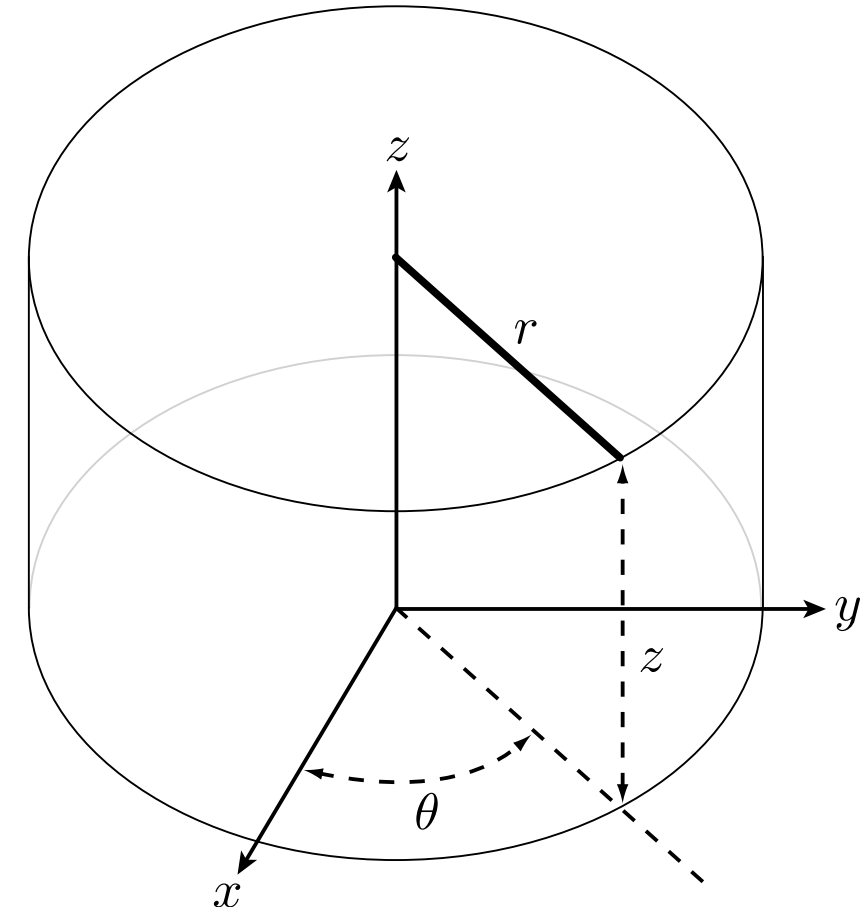
Cylindrical (RPP)



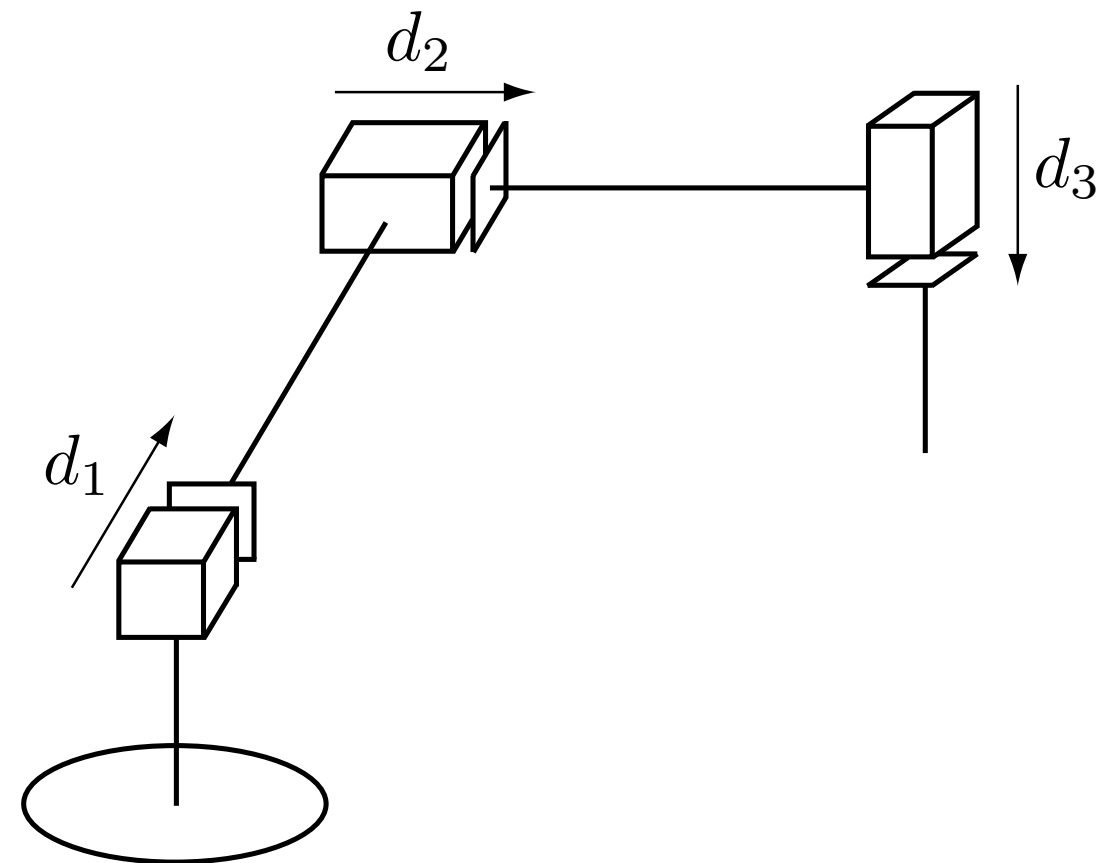
joint coordinates map to
cylindrical coordinates



| | | |
|------------|-----------------------|----------|
| θ_1 | \longleftrightarrow | θ |
| d_2 | \longleftrightarrow | z |
| d_3 | \longleftrightarrow | r |

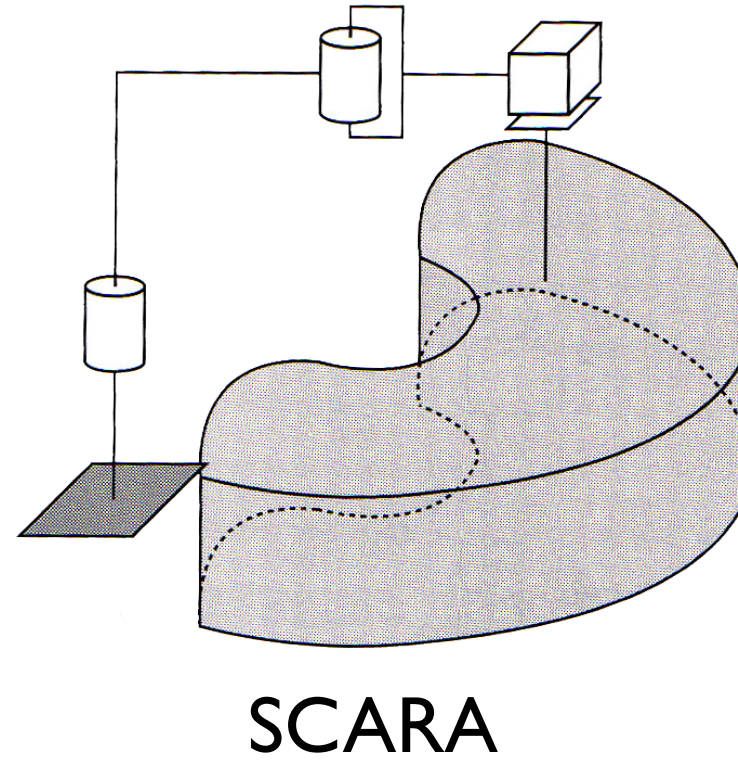
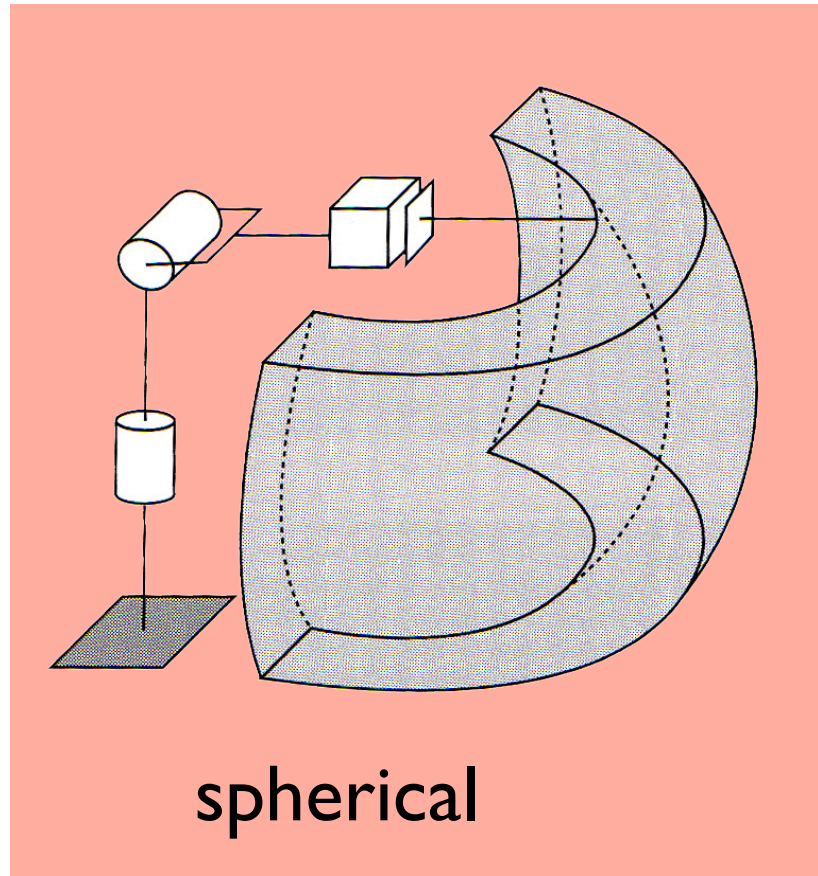


Cartesian (PPP)

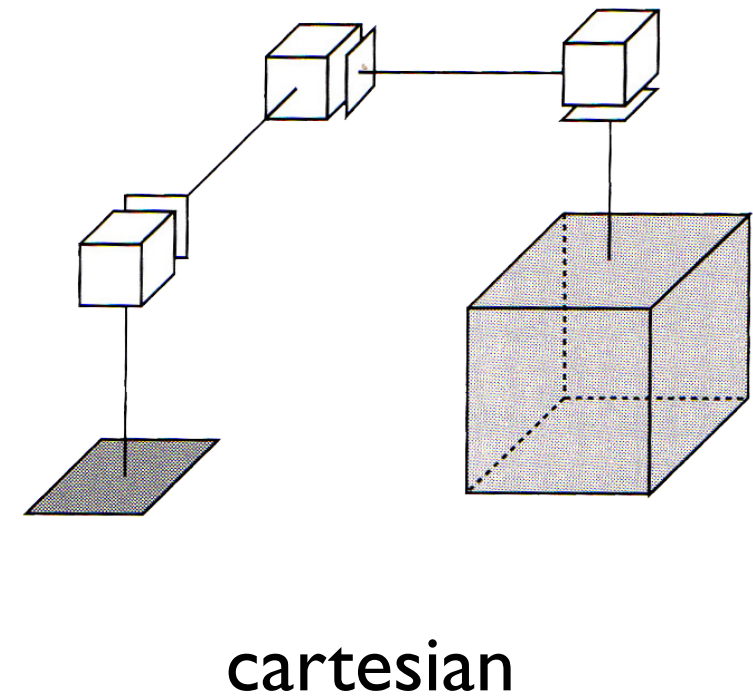
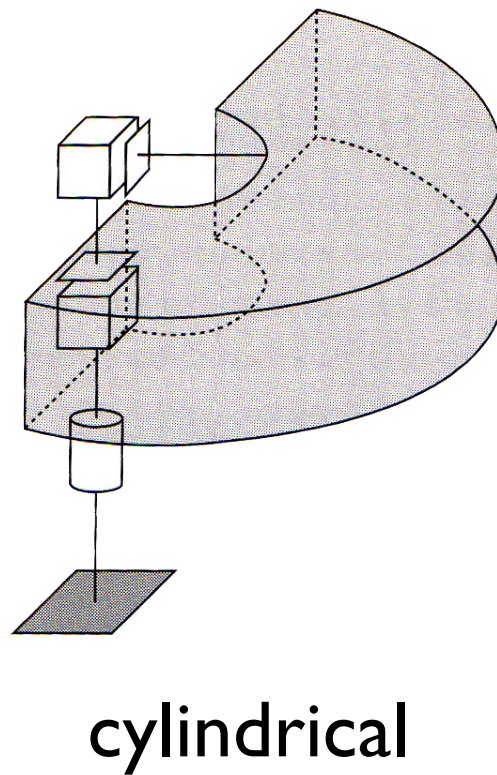


Joint variables directly correspond to the cartesian coordinates of the end-effector

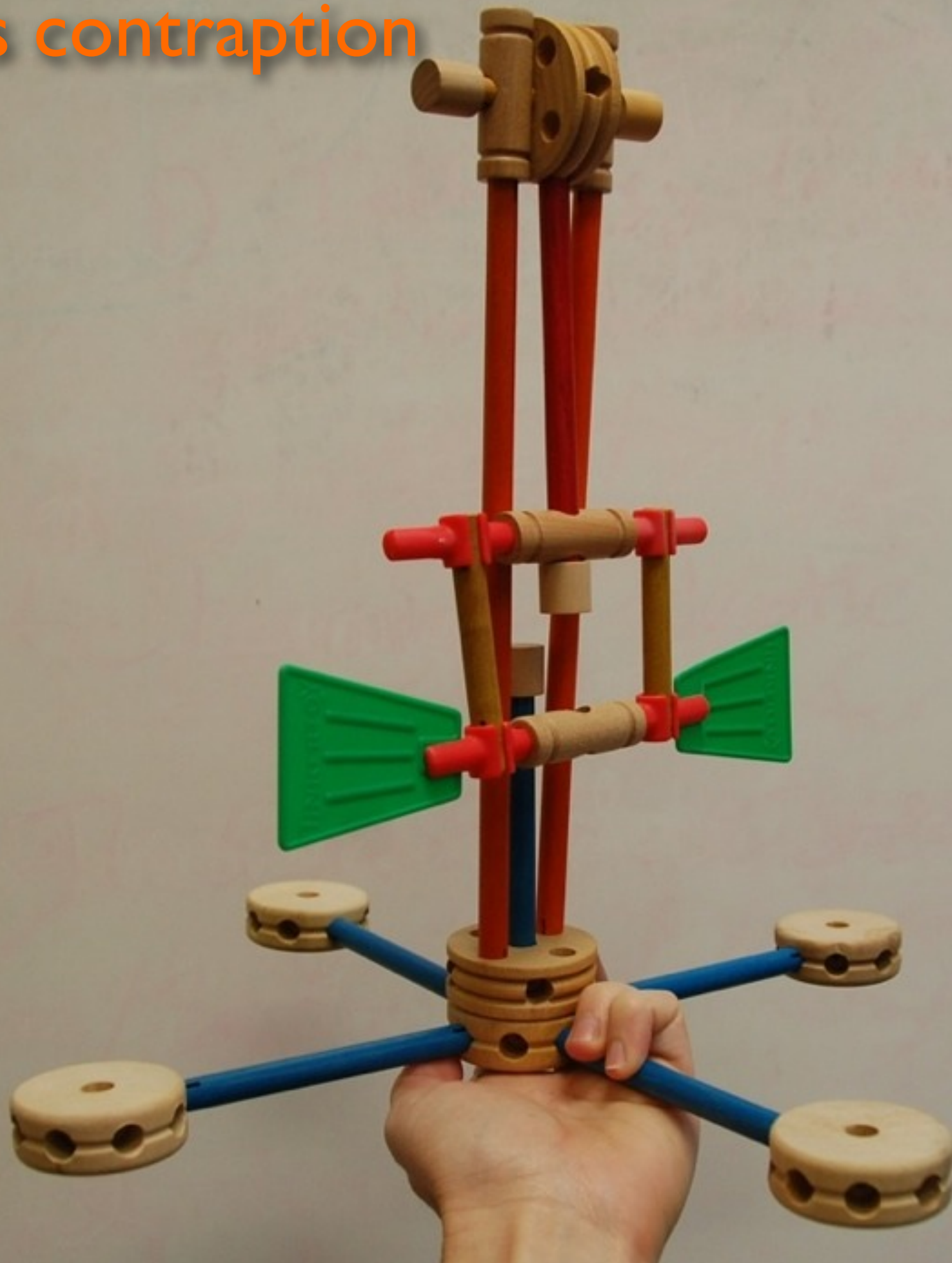
Reachable Workspaces



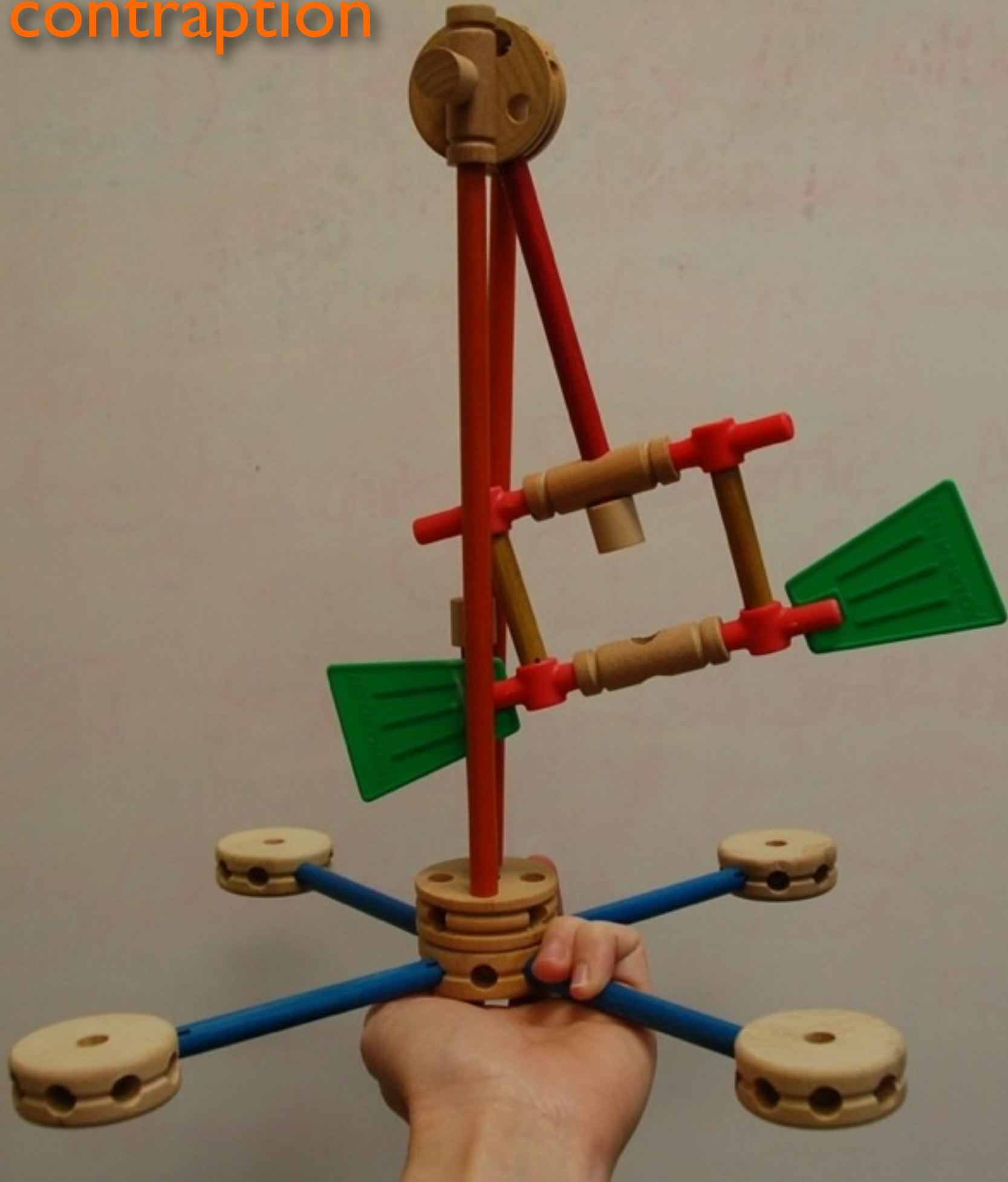
All correct?

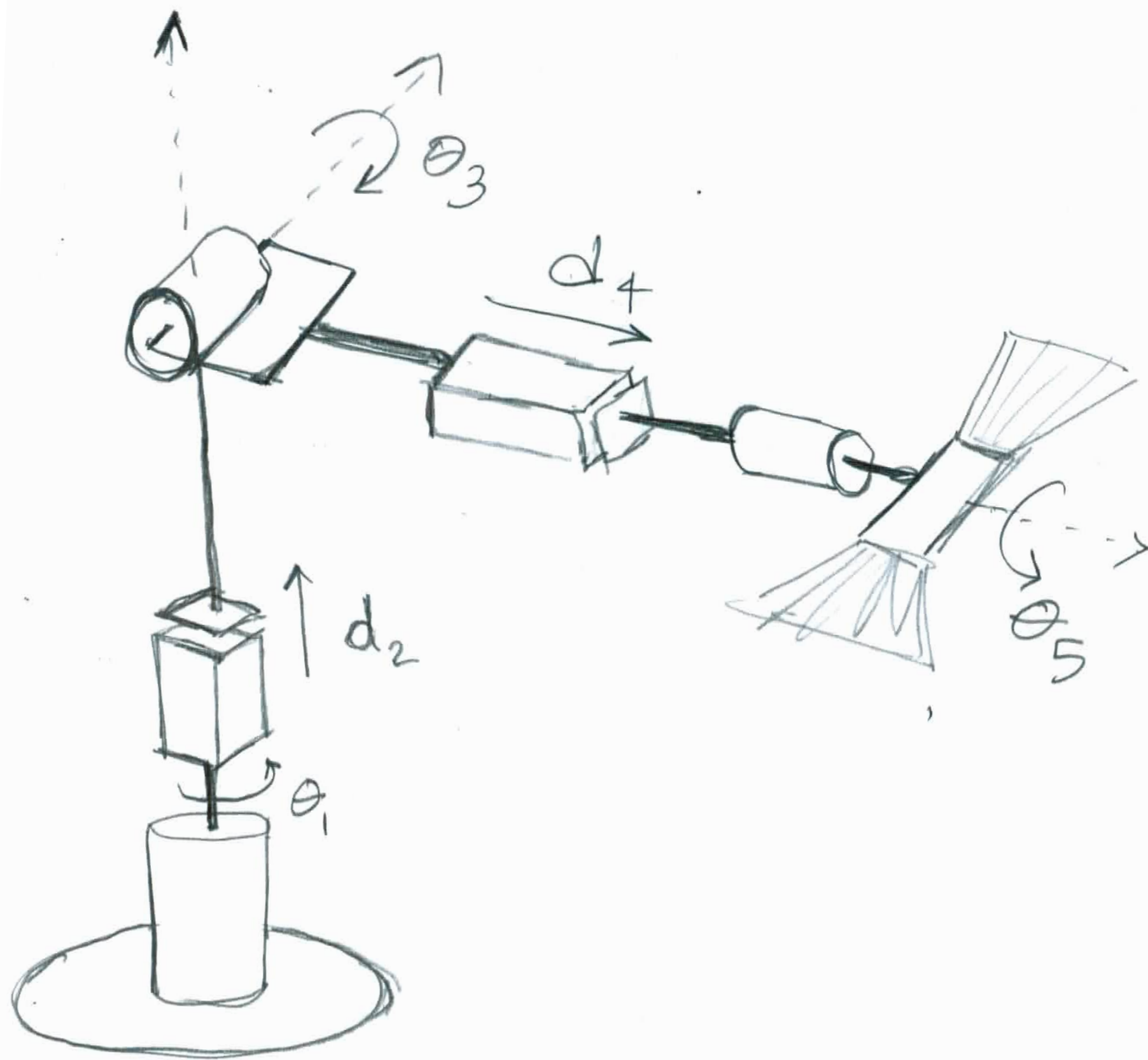


Draw this contraption



Draw this contraption





Homework #2 is coming...

Questions ?