MEAM 520
Lecture 2: Background and Definitions

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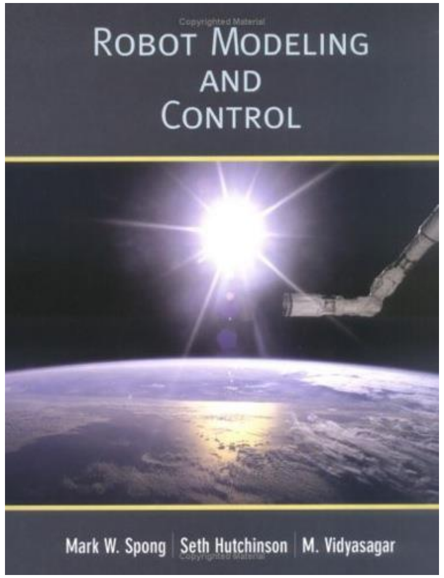
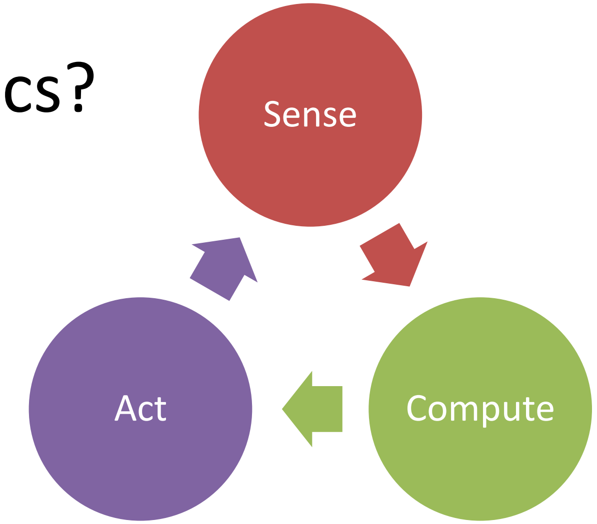
Last Time



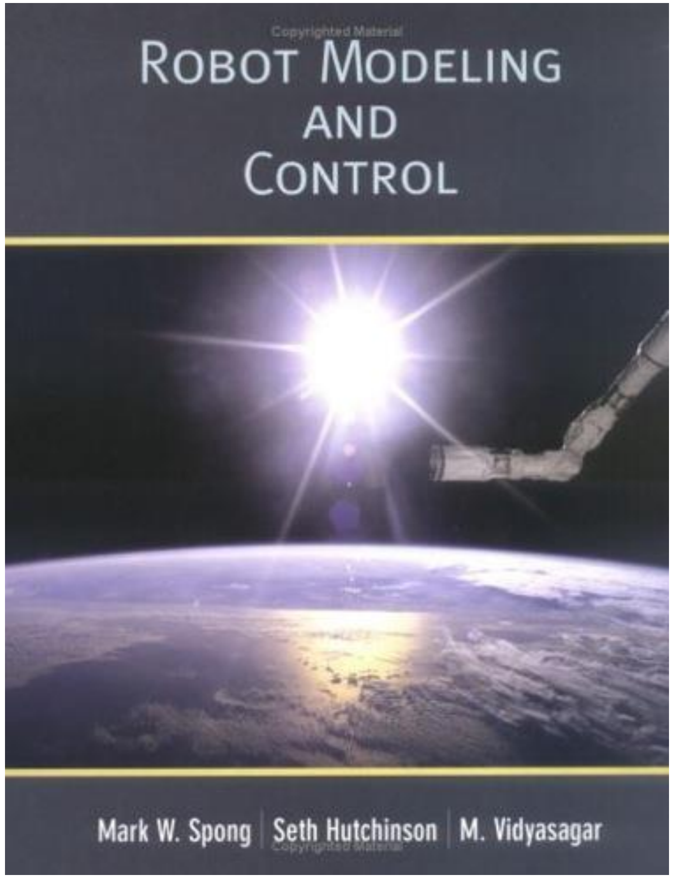
Class logistics

- Assignments and lecture slides on Canvas
- Announcements and questions on Piazza
- Office hours on Google Calendar
- 6 Labs + Final Project

What is robotics?

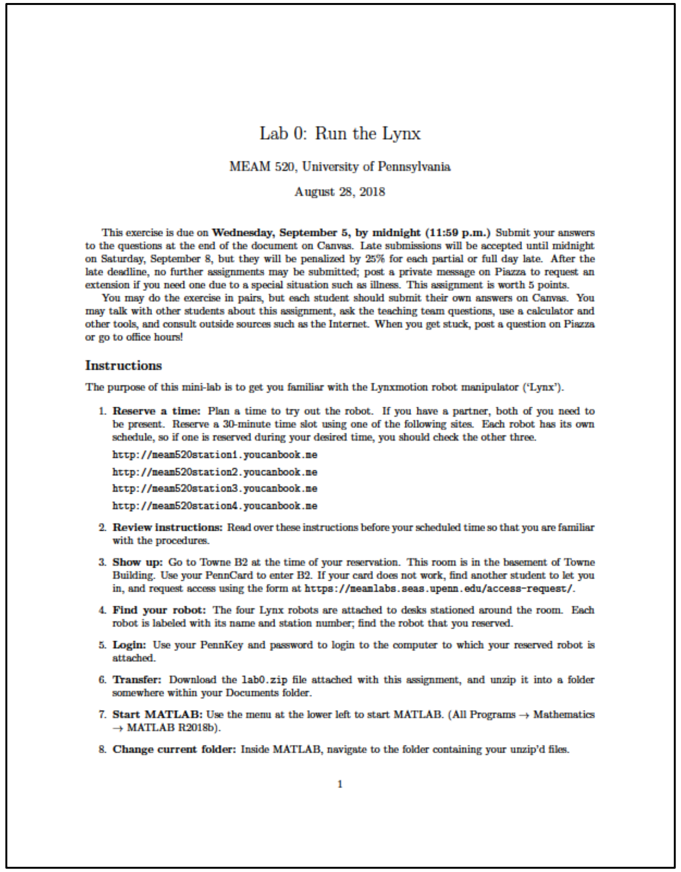


Reading



Chapter 1: Introduction

Lab 0



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`

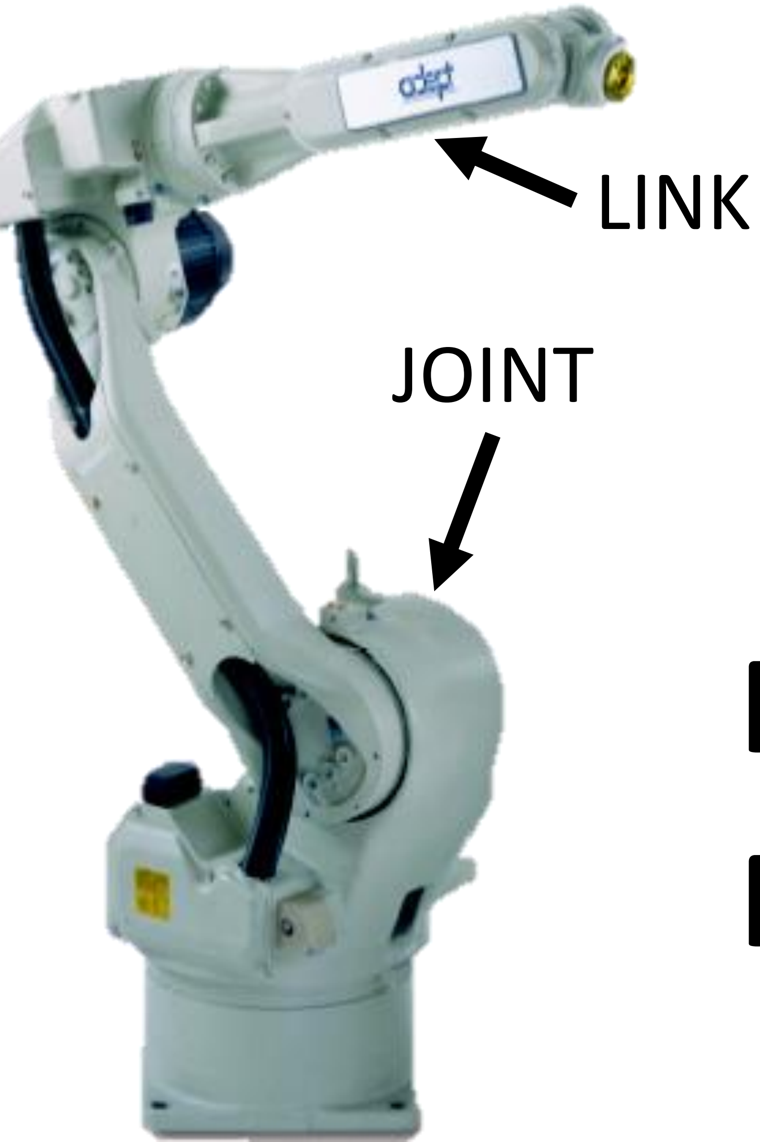
2. **Review instructions:** Read over these instructions before your scheduled time so that you are familiar with the procedures.
3. **Show up:** Go to Towne B2 at the time of your reservation. This room is in the basement of Towne Building. Use your PennCard to enter B2. If your card does not work, 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

Lab 0 is due by

11:59 p.m. on Wednesday, 9/5

Robot Manipulators



Are composed of

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

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

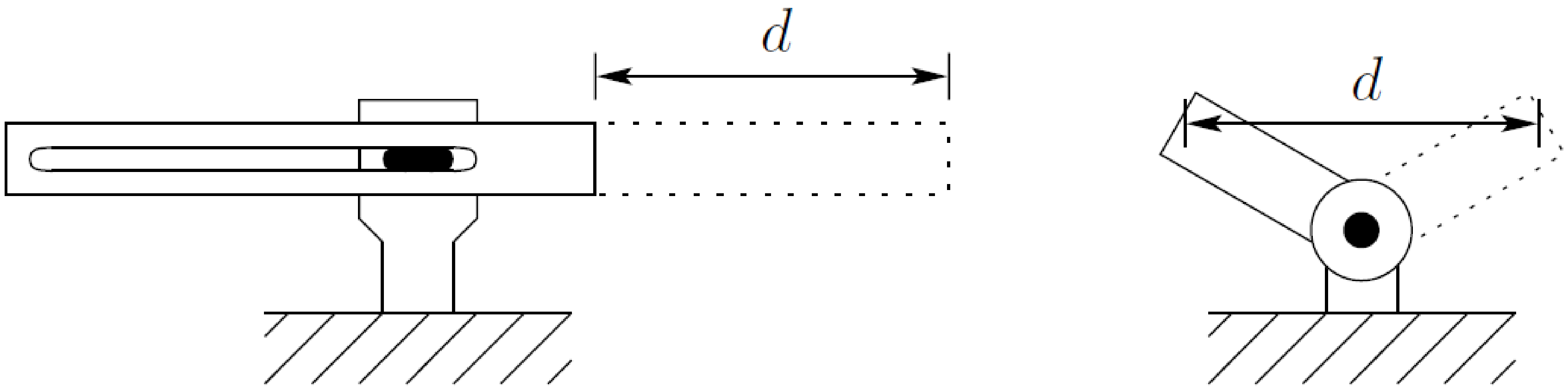
R • Revolute (rotary), like a hinge, allows relative rotation between two links

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

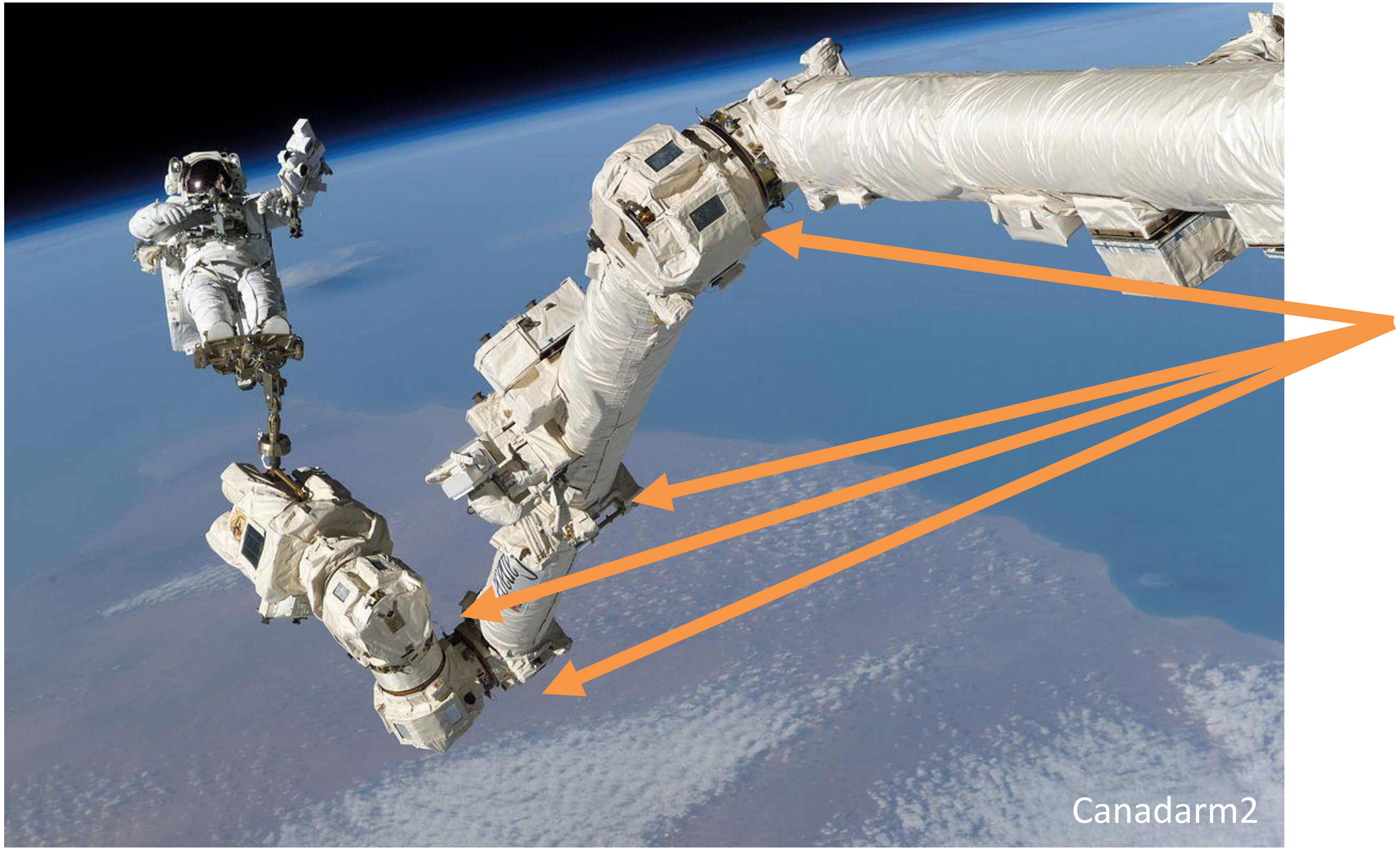
How to draw **R** and **P** joints

	Revolute	Prismatic	Examples
2D			
3D			

Which type of joint is better, **R** or **P**?

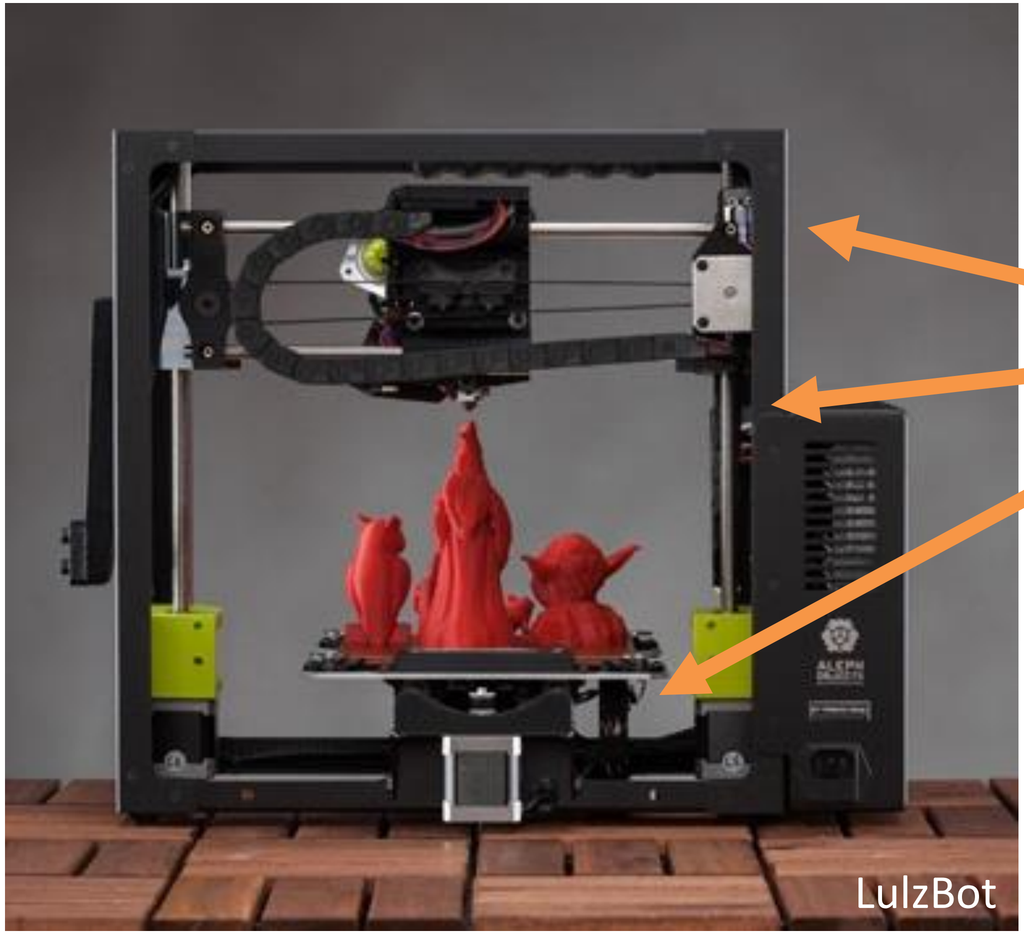


Which type of joint is better, **R** or **P**?



revolute

Which type of joint is better, **R** or **P**?



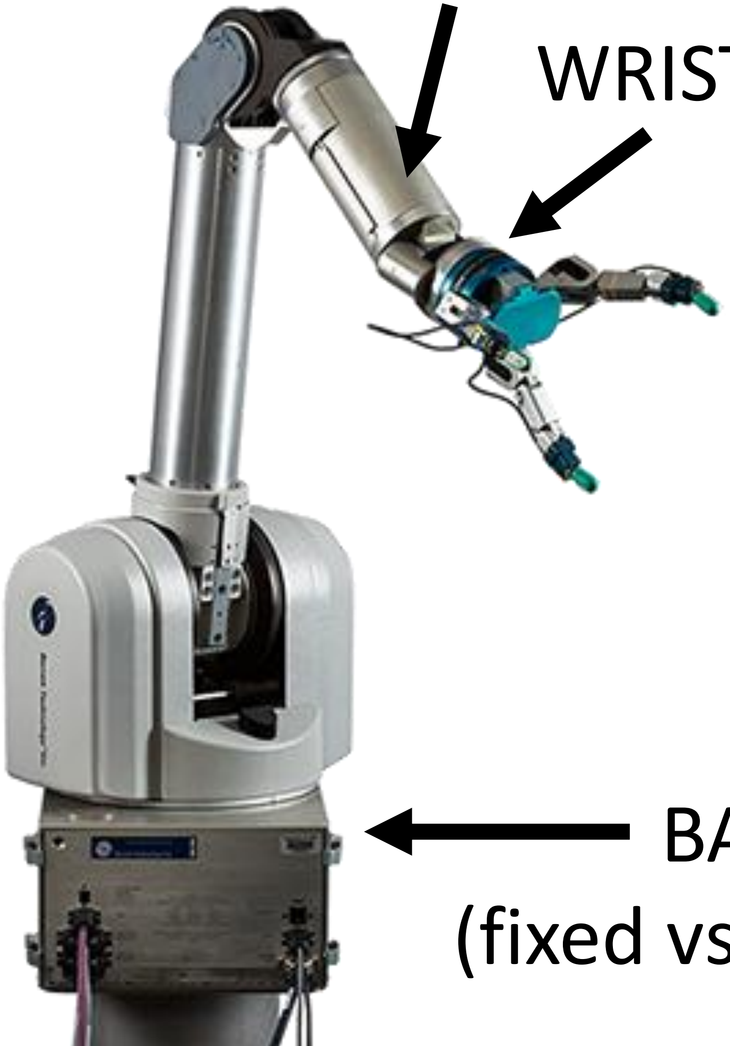
prismatic

Which type of joint is better, **R** or **P**?

General Lighting Company

prismatic
made of
revolute

Parts of a manipulator



Barrett WAM Arm

Symbolic representation

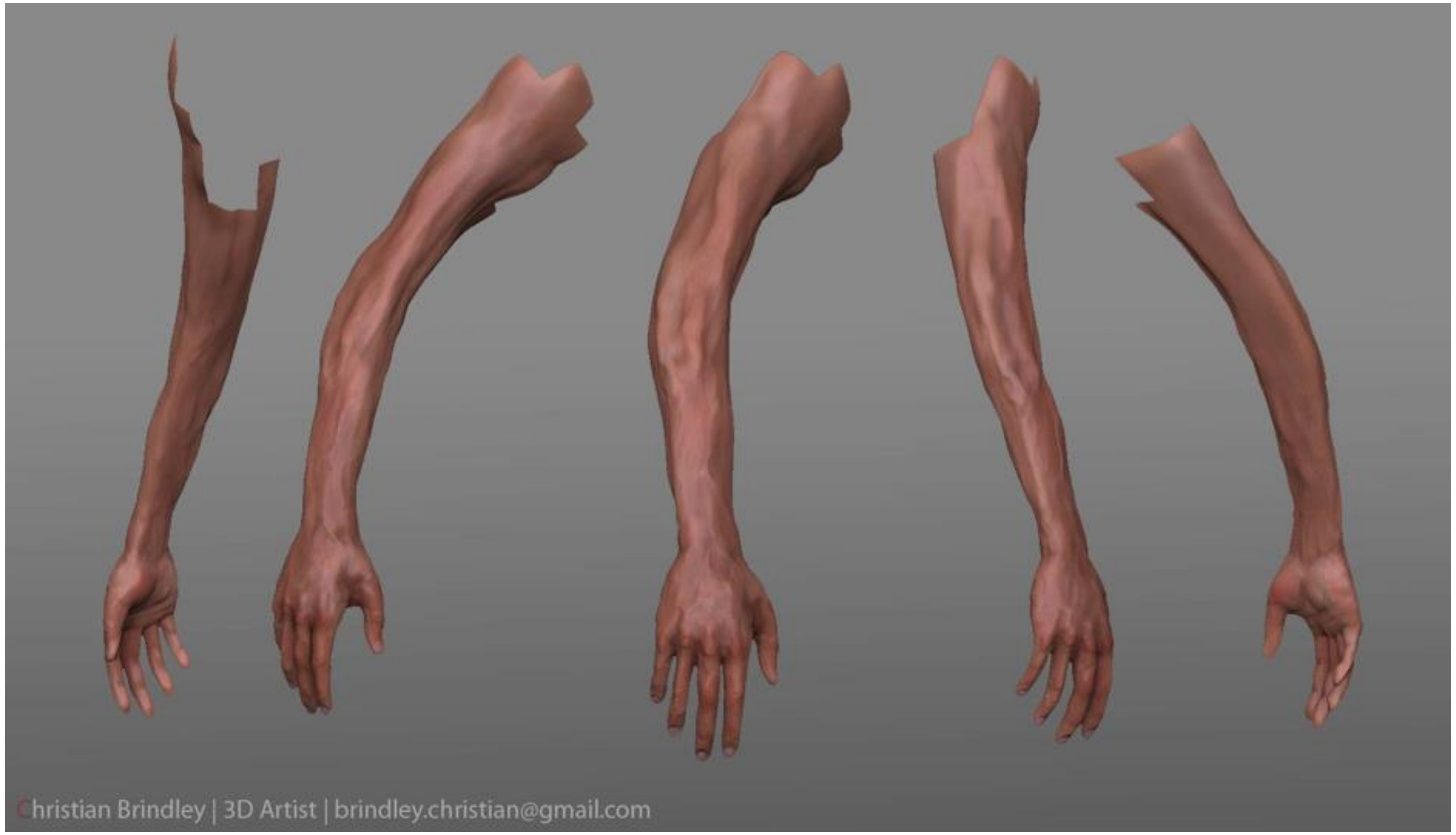
Types of Manipulators

SERIAL

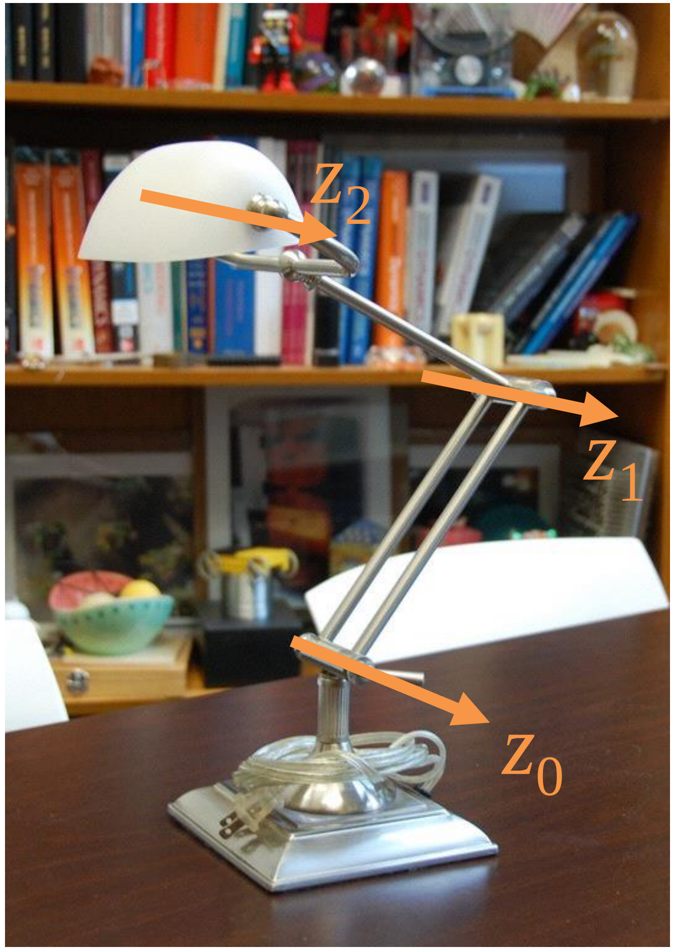
PARALLEL

Let’s describe this lamp like a robot.

What kind of joints does a human arm have?



Configuration Space (C-Space)

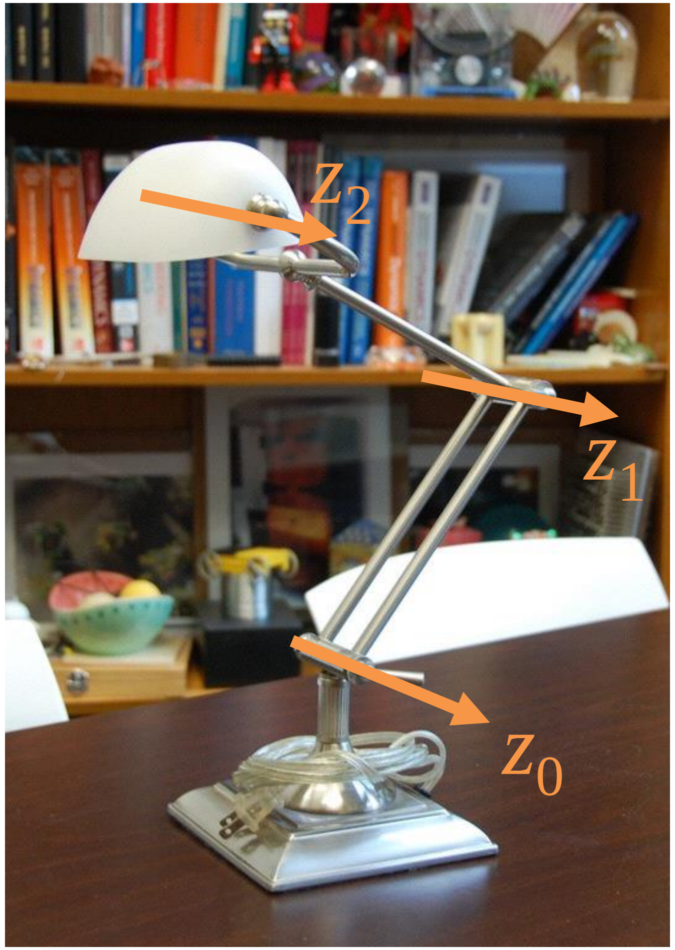


Configuration: complete specification of the location of every point on the manipulator

Configuration space: set of all configurations

How many possible configurations does this lamp have?

Joint variables



Joint variables to denote each joint's position.

Joint displacements are defined relative to the **zero configuration**.

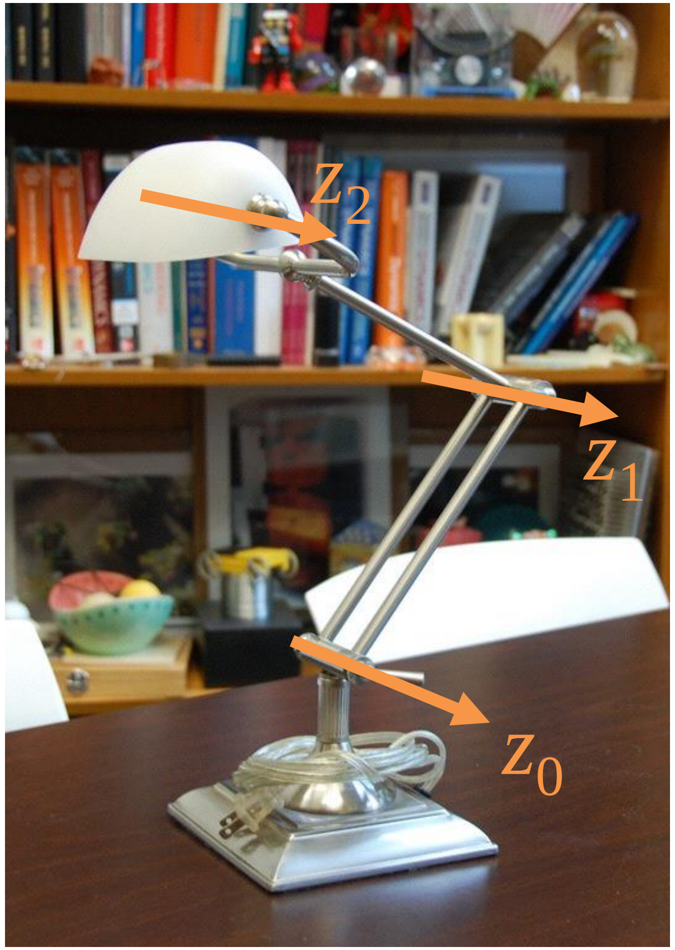
Use θ_i for revolute joints

Use d_i for prismatic joints

Axis orientation defines the positive direction (use the RHR for revolute joints)

For rigid manipulators, knowing all joint variable values defines the configuration

Degrees of Freedom

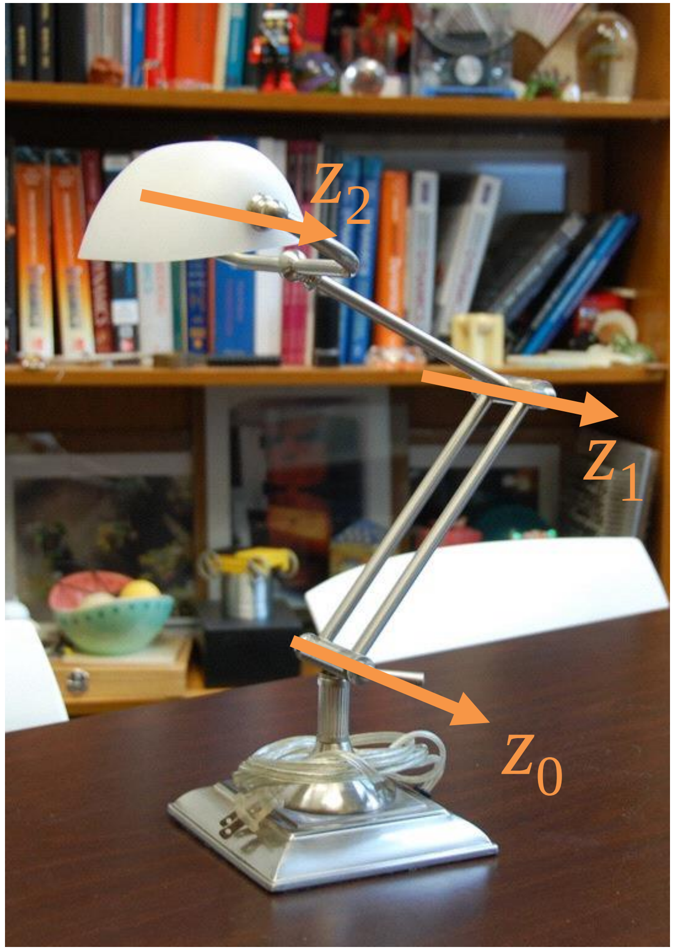


Degrees of Freedom (DOF): The minimum number of parameters needed to specify the configuration

How many DOF does a rigid body in 3D space have?

Robots need at least ___ joints (_____ DOF) for the end-effector to reach every point in the workspace with arbitrary orientation

Workspace

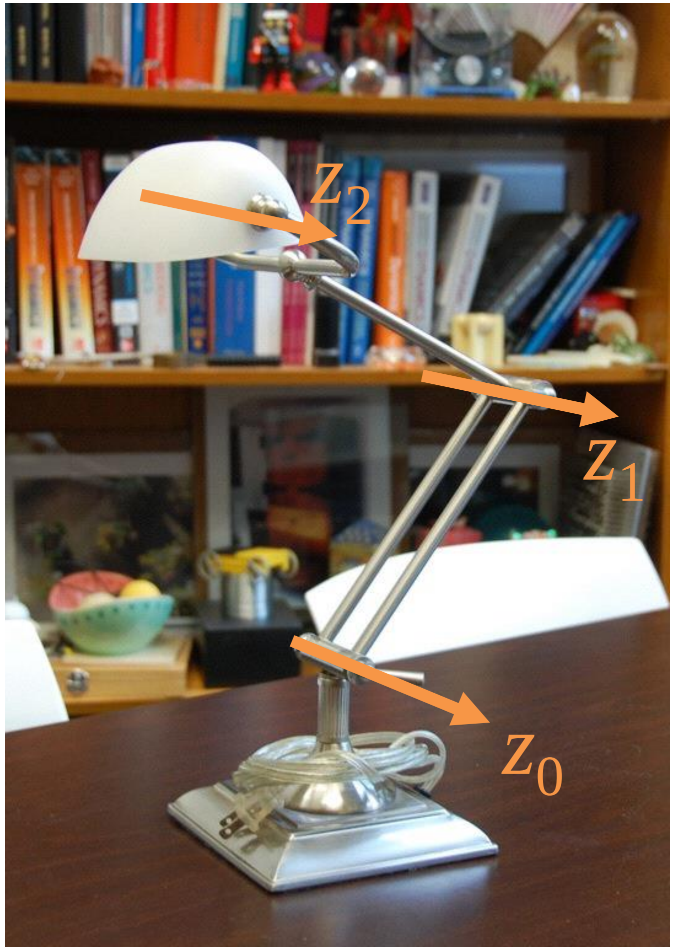


Workspace: volume swept out by the end-effector as the robot does all possible motions

- Depends on robot geometry
- Depends on joint limits
- Depends on the point on the end-effector

dexterous workspace **reachable workspace**

Workspace



NOTE: Workspace and configuration space have different dimensionality!

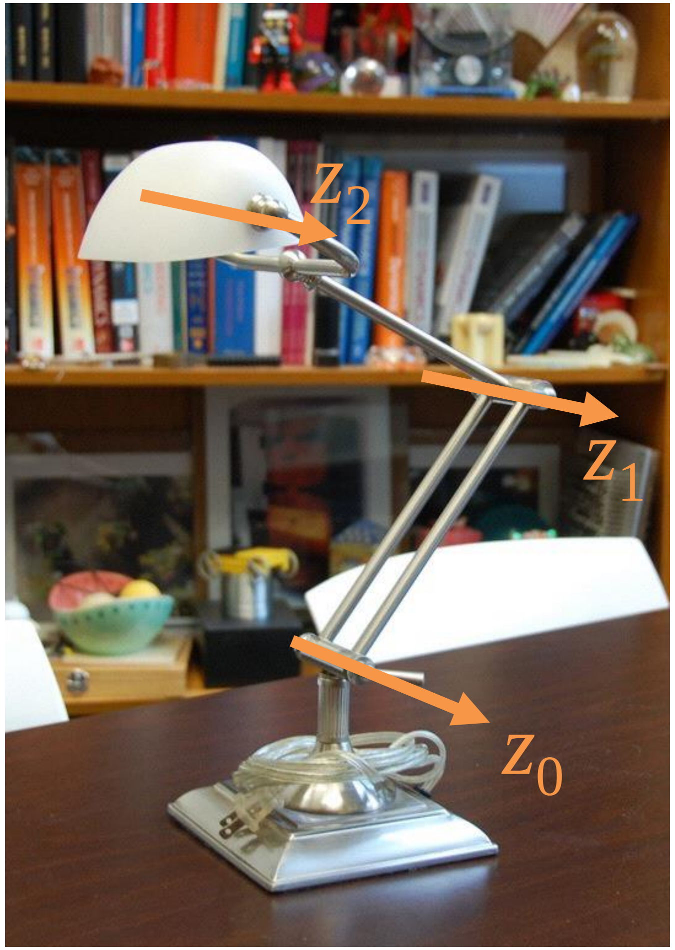
Configuration space: #{DOF} dimensions

Workspace: 3D or 2D depending on task

Task space: the parameter space for the task.

Often this is the 6D space of position/orientation

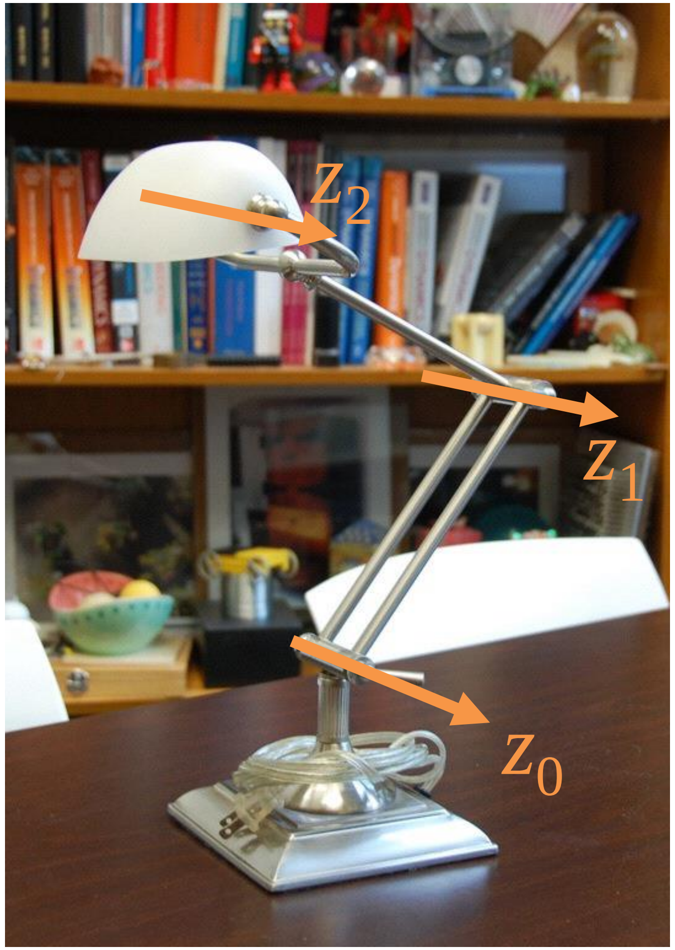
Workspace



What is the reachable workspace of the lamp?

What is the dexterous workspace of the lamp?

Spatial mechanisms



If we let the **base move and rotate** on the table, what type of robot is the lamp?

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

We can apply the same terminology to mobile robots.

BUT it is **non-holonomic**.

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

The configuration gives you an **instantaneous description** of the geometry

State: set of variables sufficient to tell you the future time response when combined with dynamics and future inputs

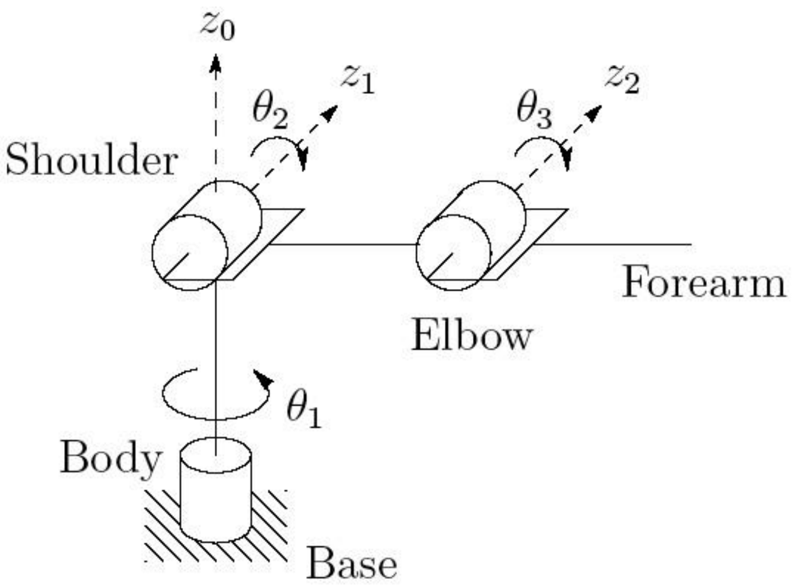
A robot's dynamics equations determine accelerations ($\boldsymbol{F} = m\boldsymbol{a}$)

State requires **joint variables** q and **derivatives** $\dot{q}$

Practice: Unimate’s 1960 manipulator arm

https://youtu.be/hxsWeVtb-JQ

5 most common serial manipulators



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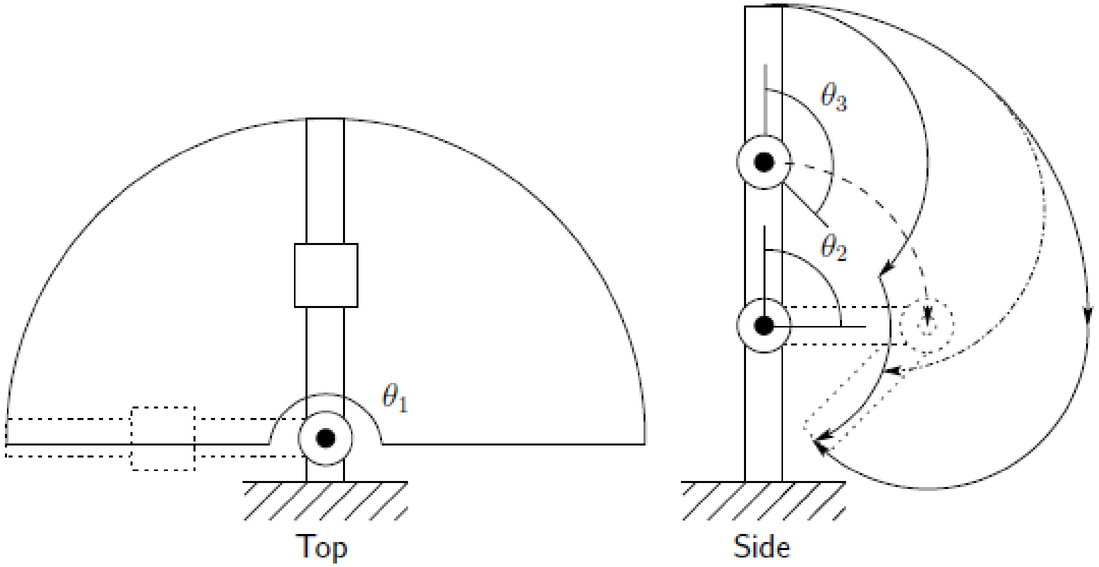
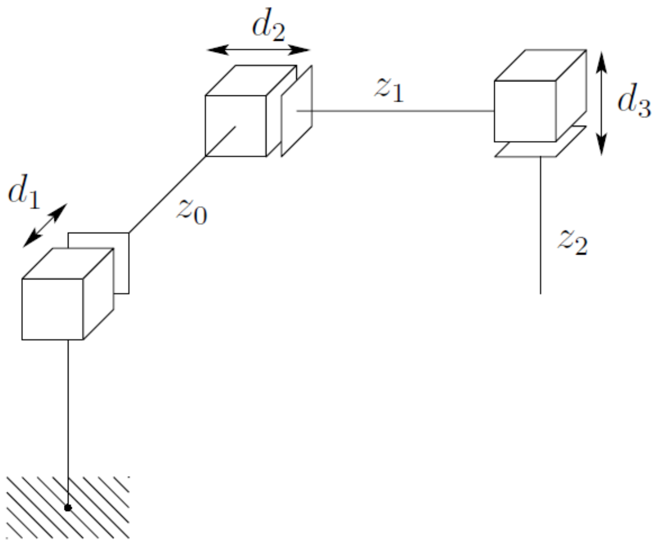
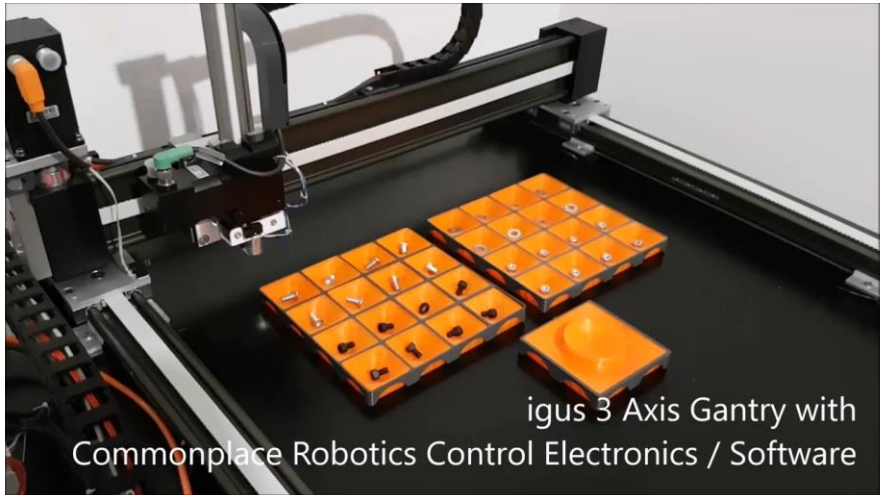


Articulated (RRR)

Useful for: small workspaces

5 most common serial manipulators





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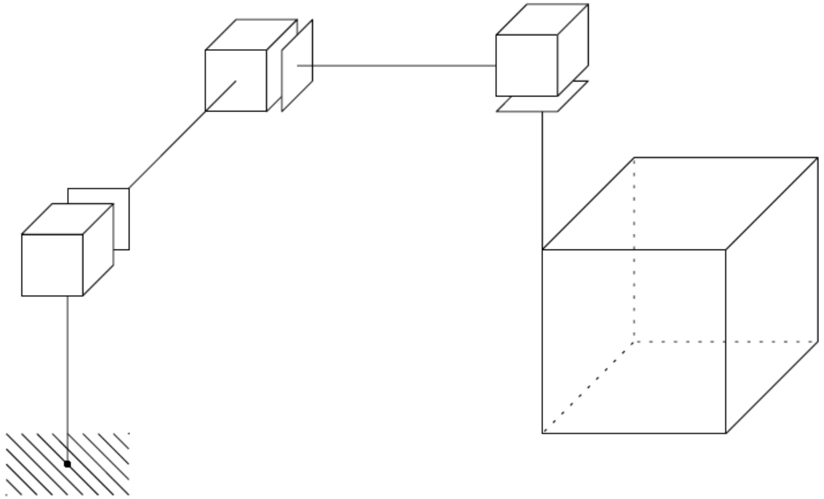
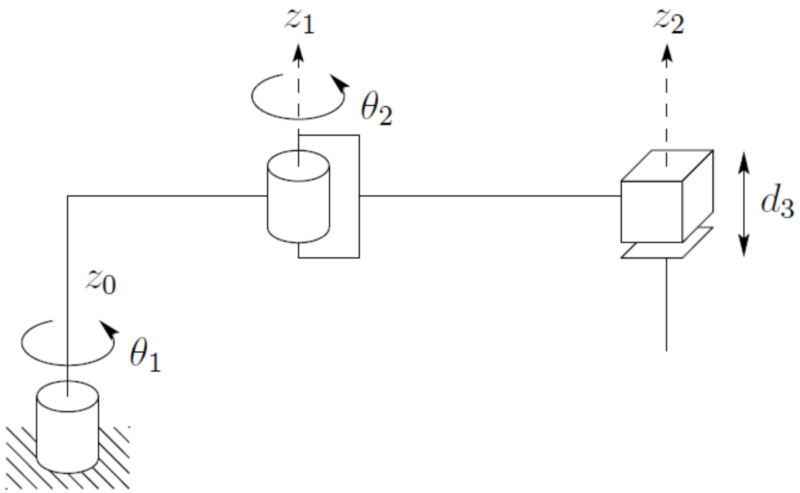
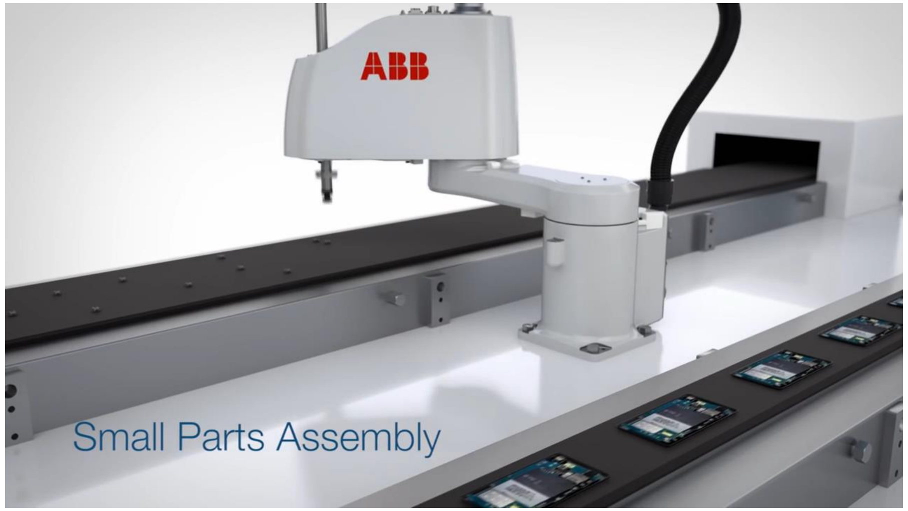


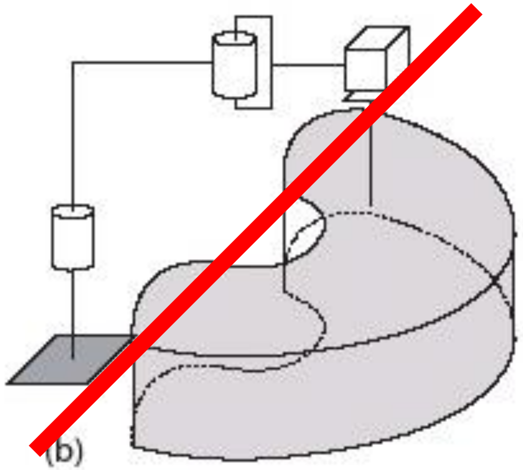
Cartesian (PPP)
Useful for: gantries

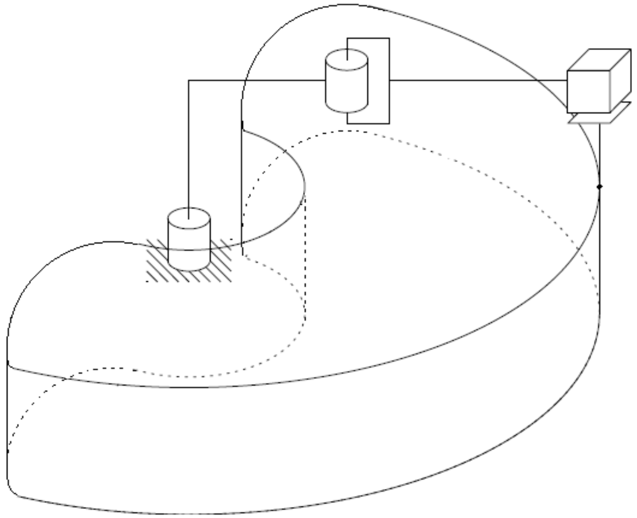
5 most common serial manipulators





https://youtu.be/97KX-j8Onu0

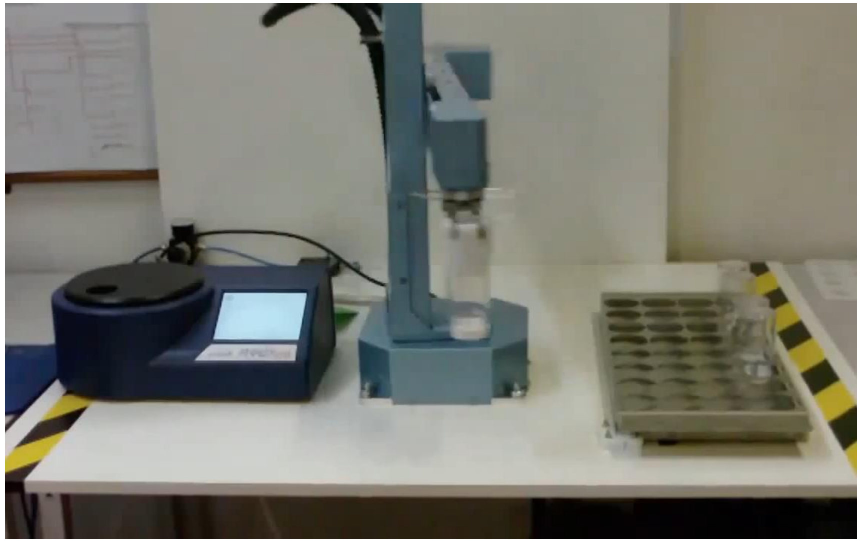




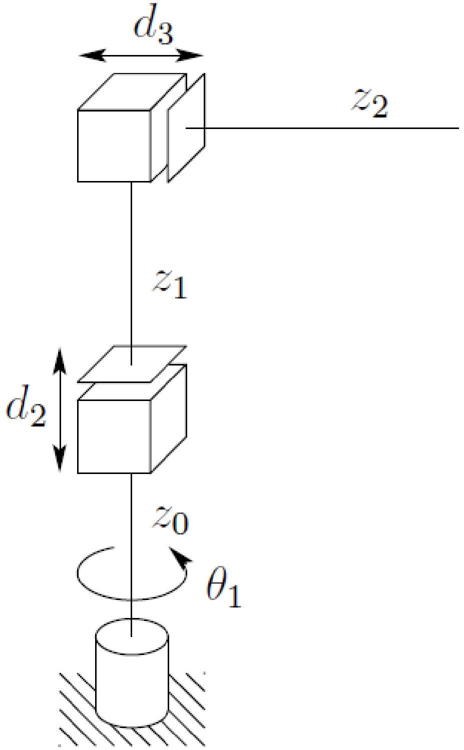
SCARA (RRP)

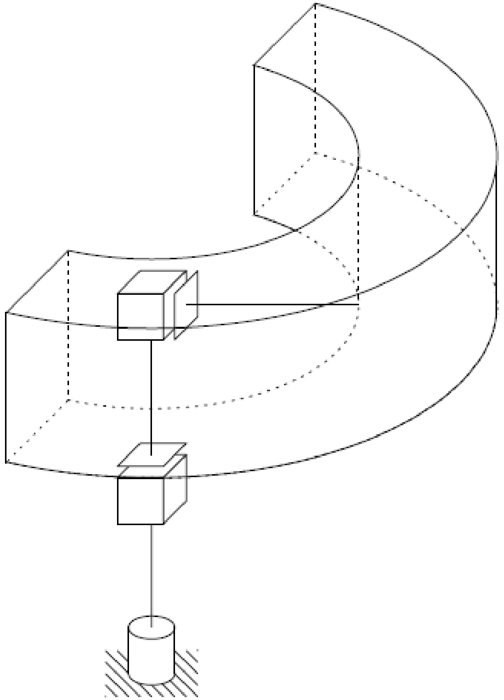
Useful for: speed, planar tasks

5 most common serial manipulators



https://youtu.be/Hj7PxjeH5y0





Cylindrical (RPP)

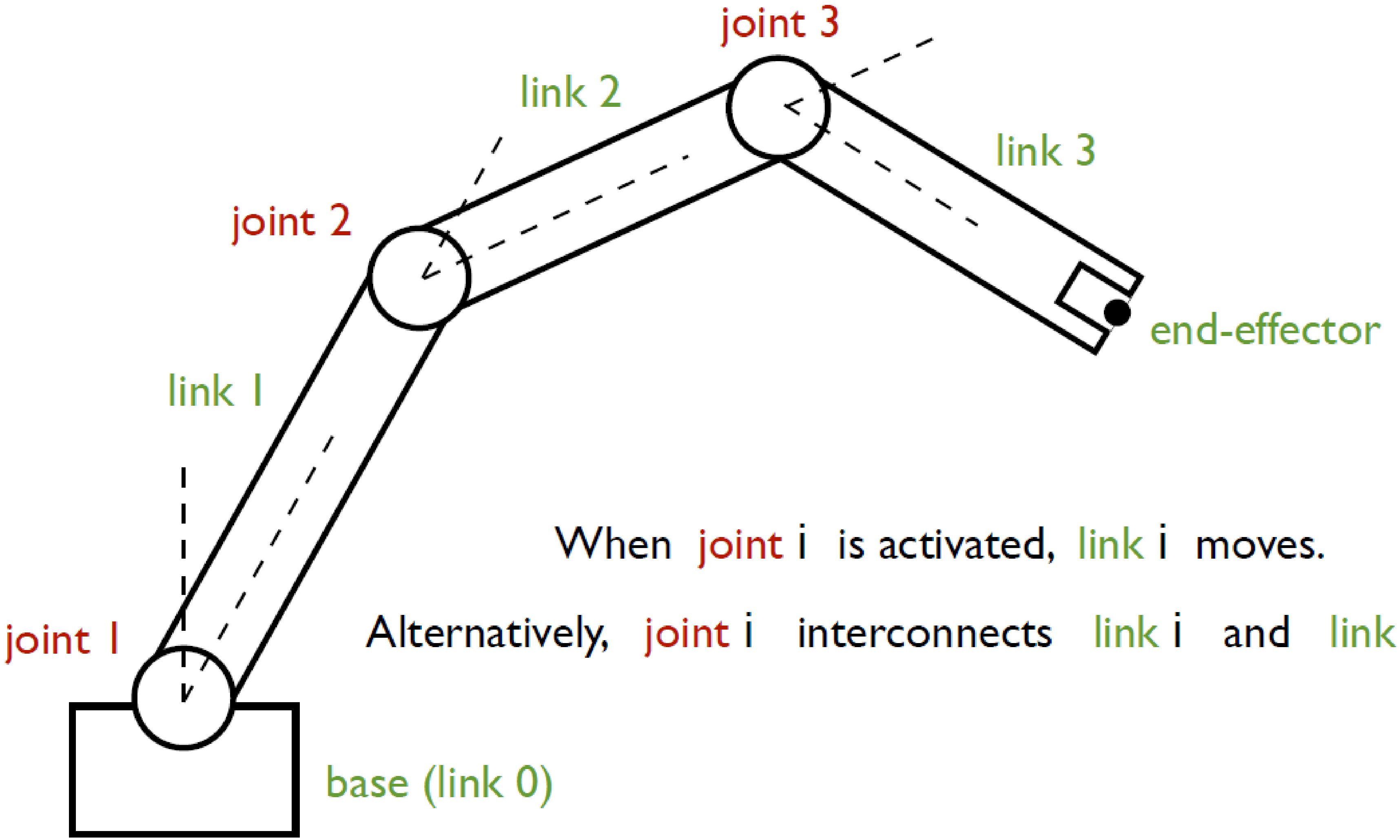
Useful for: material transfer

Kinematics

Kinematics is the study of motion without

references to the causes of that motion.

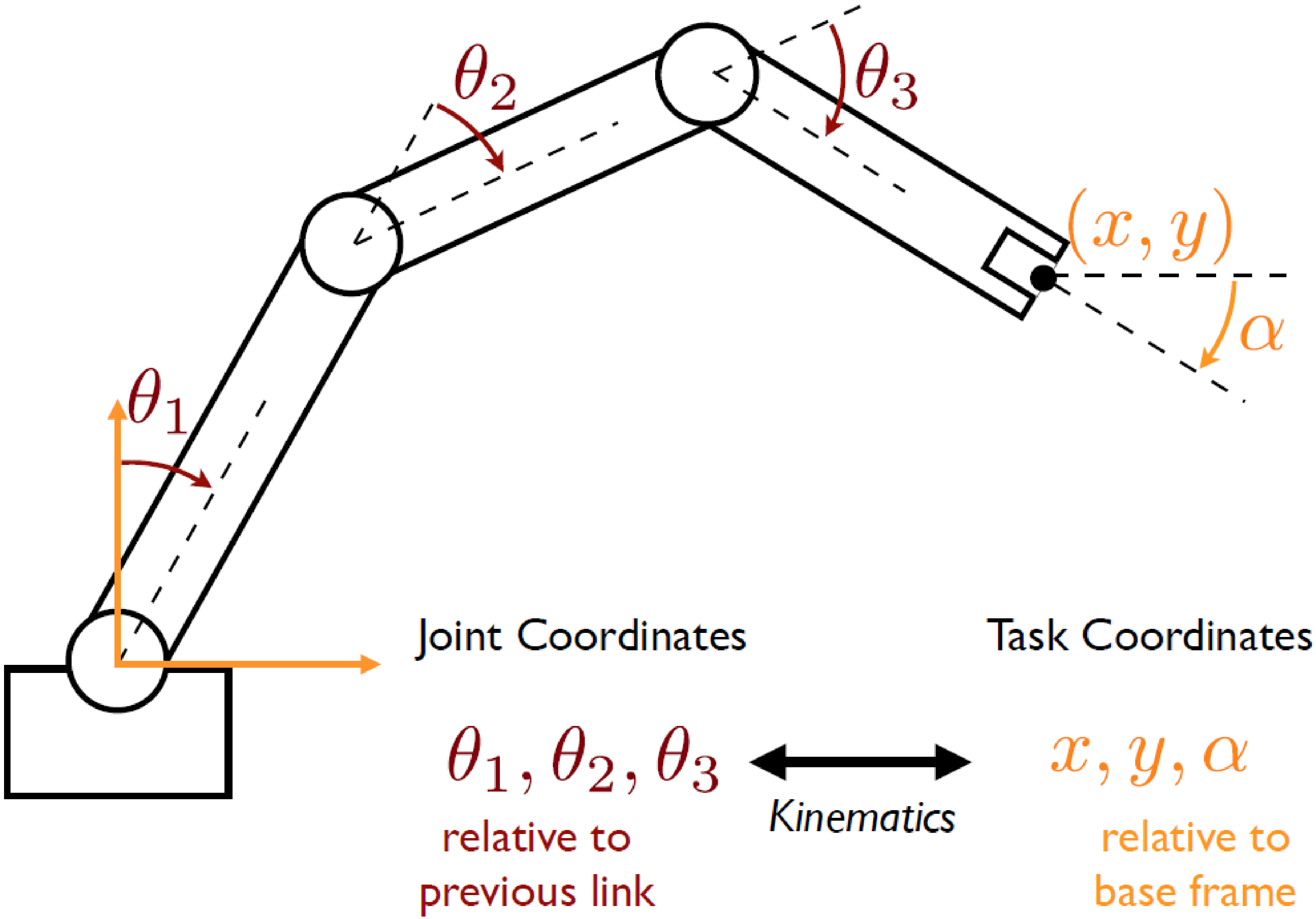
Kinematics



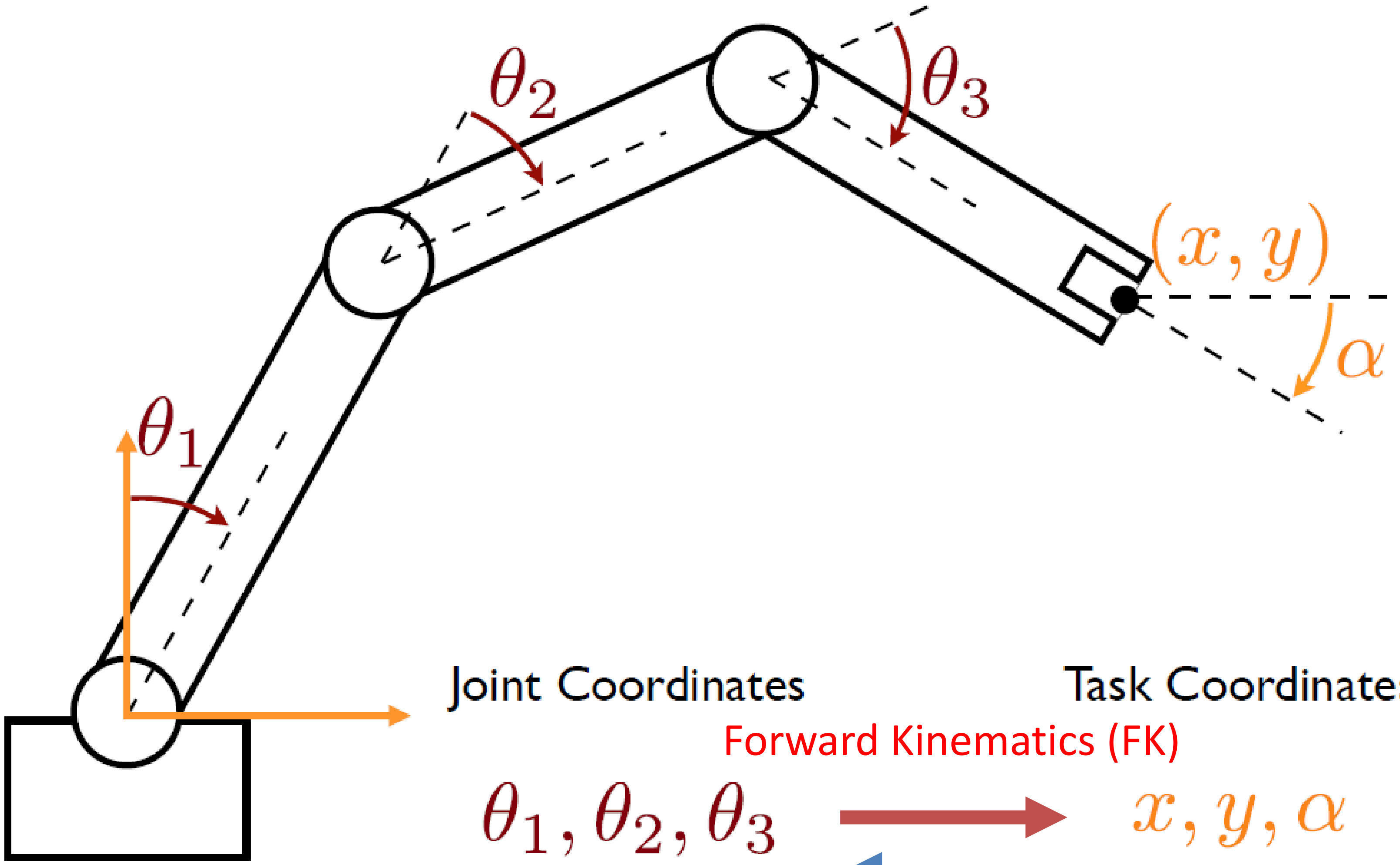
When joint i is activated, link i moves.

Alternatively, joint i interconnects link i and link i−1

Kinematics


θ_1
θ_2
θ_3
(x, y)
α
Joint Coordinates
Task Coordinates
$\theta_1, \theta_2, \theta_3$
Kinematics
x, y, α
relative to
previous link
relative to
base frame

Kinematics



Joint Coordinates | Task Coordinates

Forward Kinematics (FK)

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

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

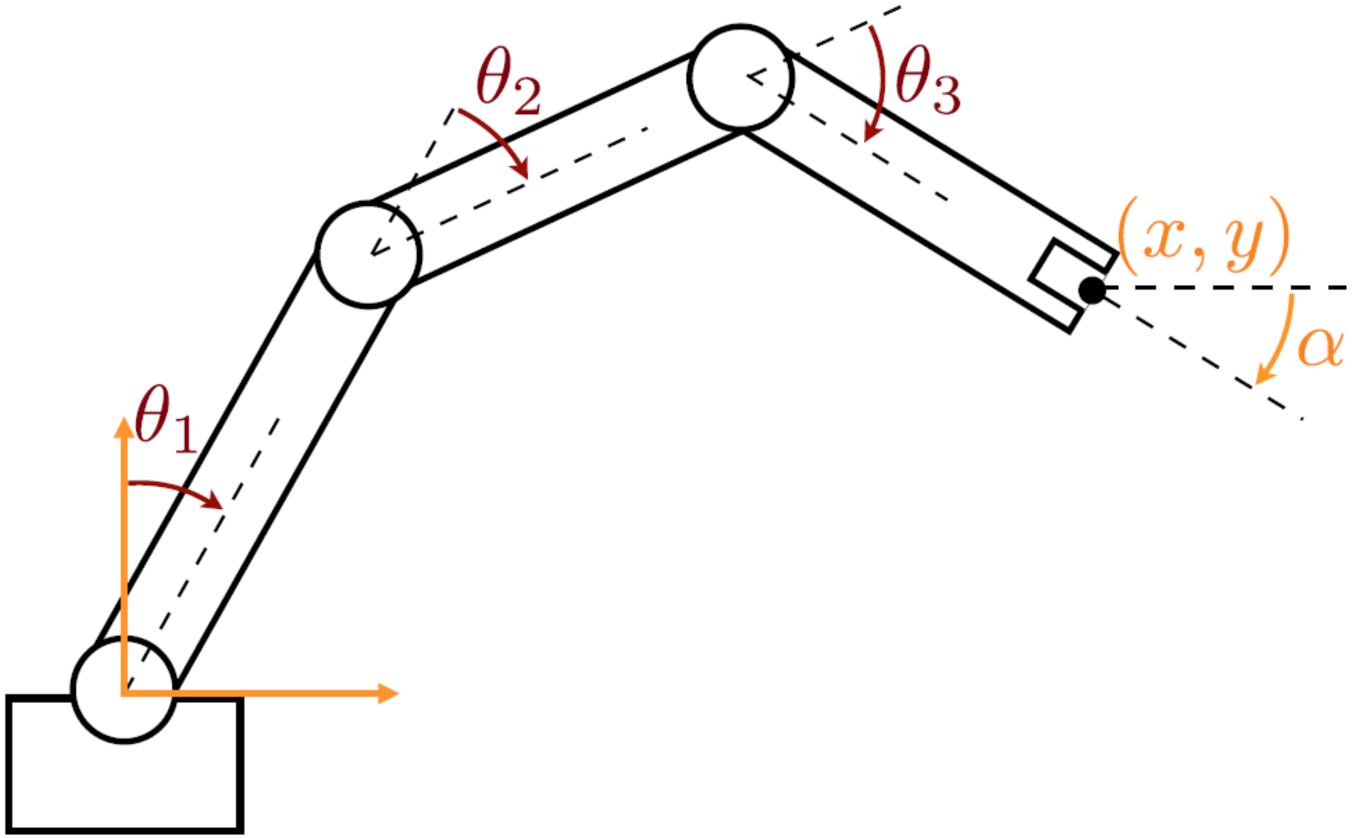
Inverse Kinematics (IK)

relative to previous link

relative to base frame

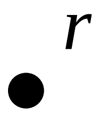
Forward Kinematics

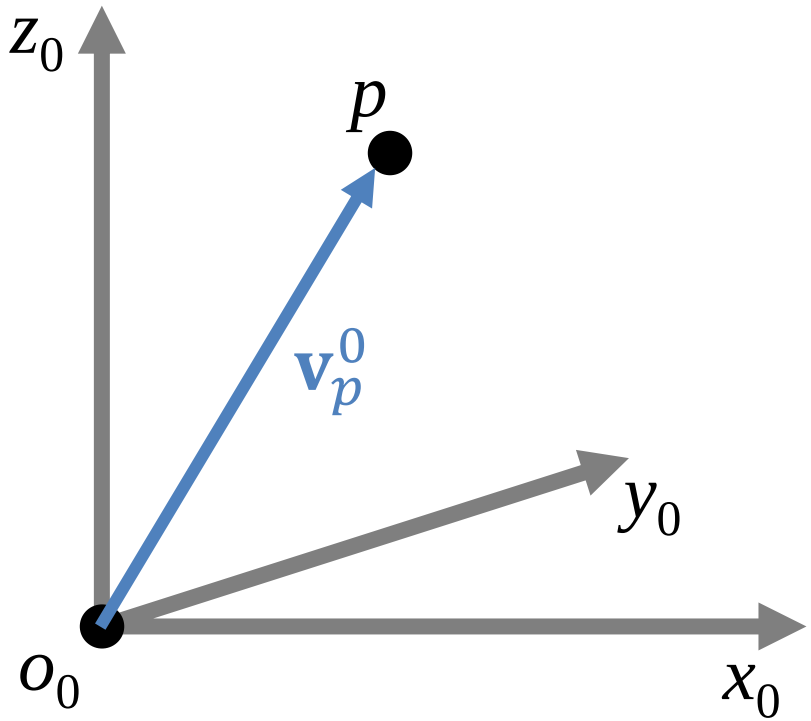
Given the joint coordinates, what are the task coordinates?



Representing positions

A **point** exists in space as a geometric entity





Coordinate frame

- an origin (point in space)
- 2 or 3 orthogonal coordinate axes

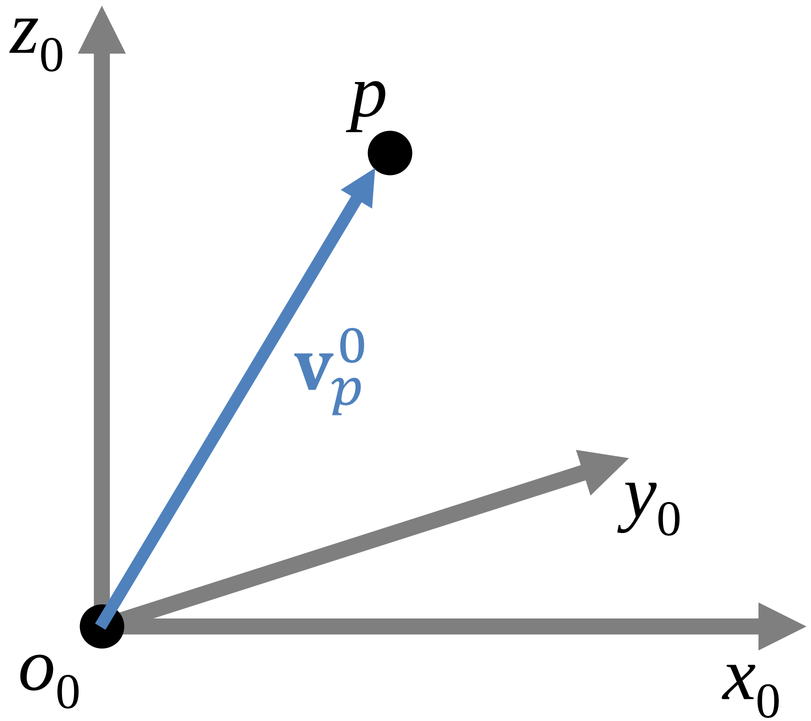
Call this frame $\boldsymbol{o_0x_0y_0z_0}$ or **frame 0**

Point p is written as a vector

superscript = frame

$$\mathbf{v}_p^0 = p^0 = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = [x \quad y \quad z]^\top$$

Vectors



A vector has a **magnitude/length**

$$\left\|\mathbf{v}_p^0\right\| = \sqrt{x^2 + y^2 + z^2}$$

$$\left\|\mathbf{v}_p^0\right\| = \left(\left(\mathbf{v}_p^0\right)^\top \mathbf{v}_p^0\right)^{\frac{1}{2}}$$

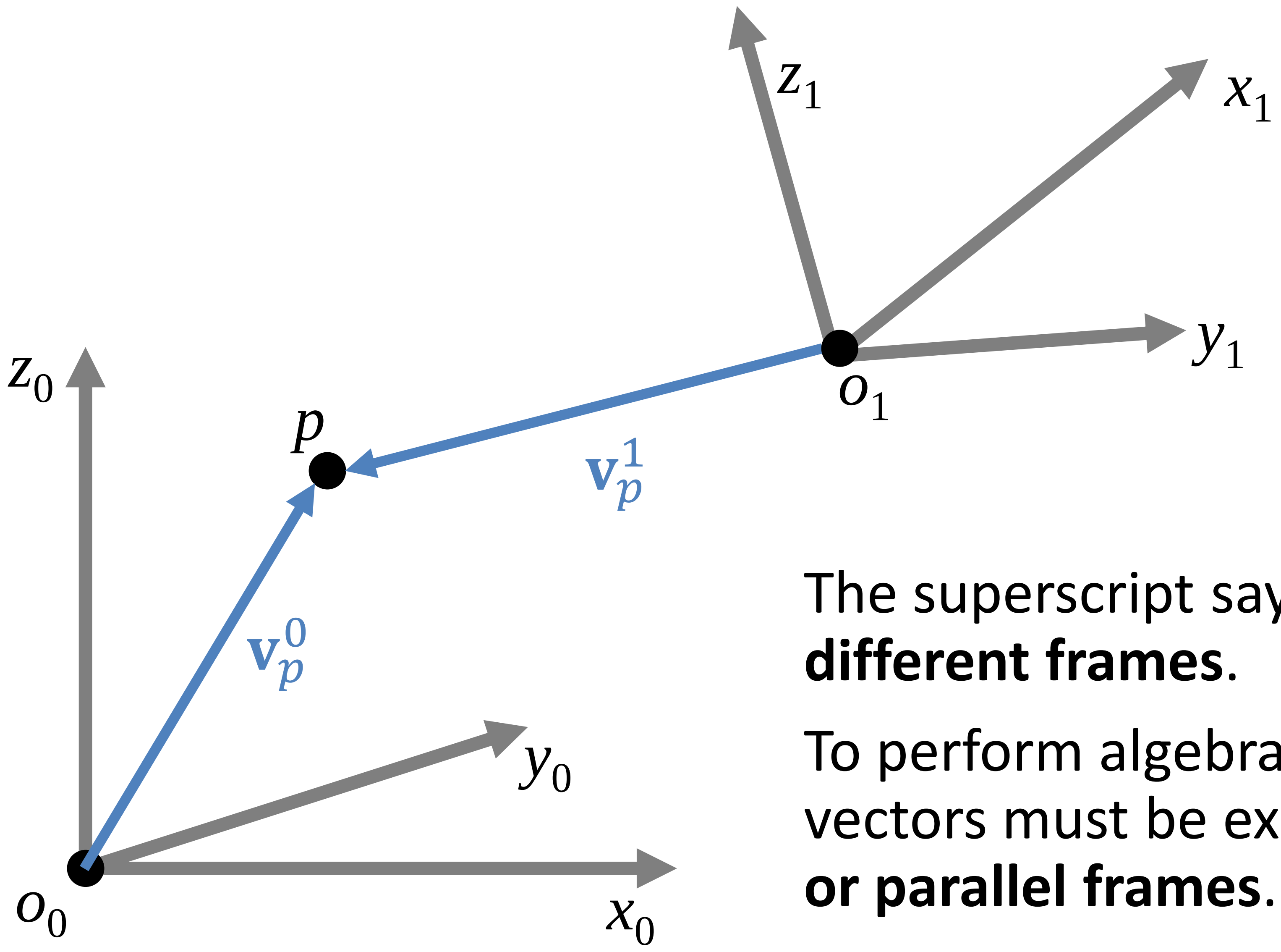
This is called the ***ℓ*² norm**.

A vector has a **direction**

$$\hat{e}_p^0 = \frac{\mathbf{v}_p^0}{\left\|\mathbf{v}_p^0\right\|}$$

This **unit vector** has length 1

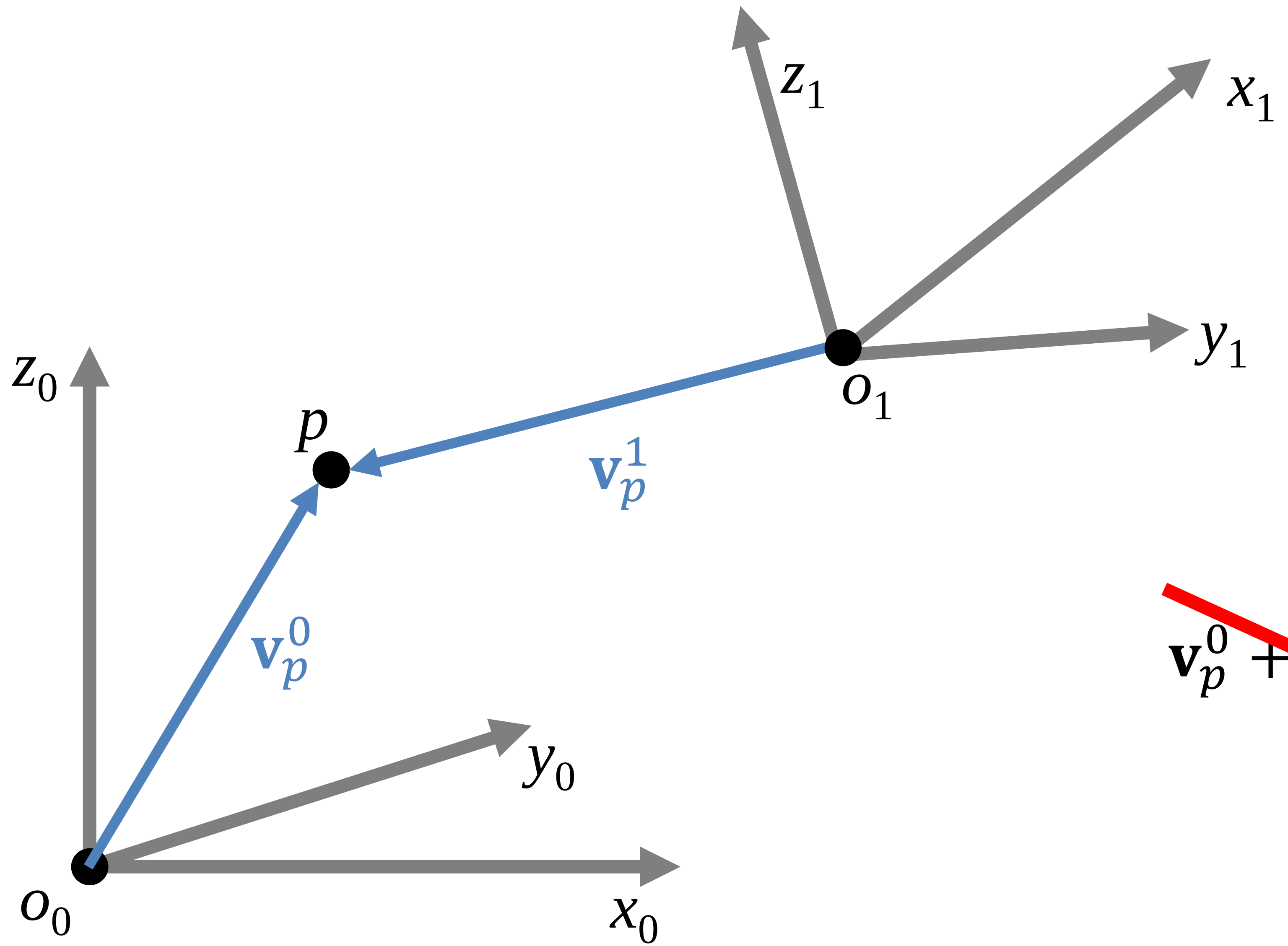
Multiple coordinate frames



The superscript says they are in **different frames**.

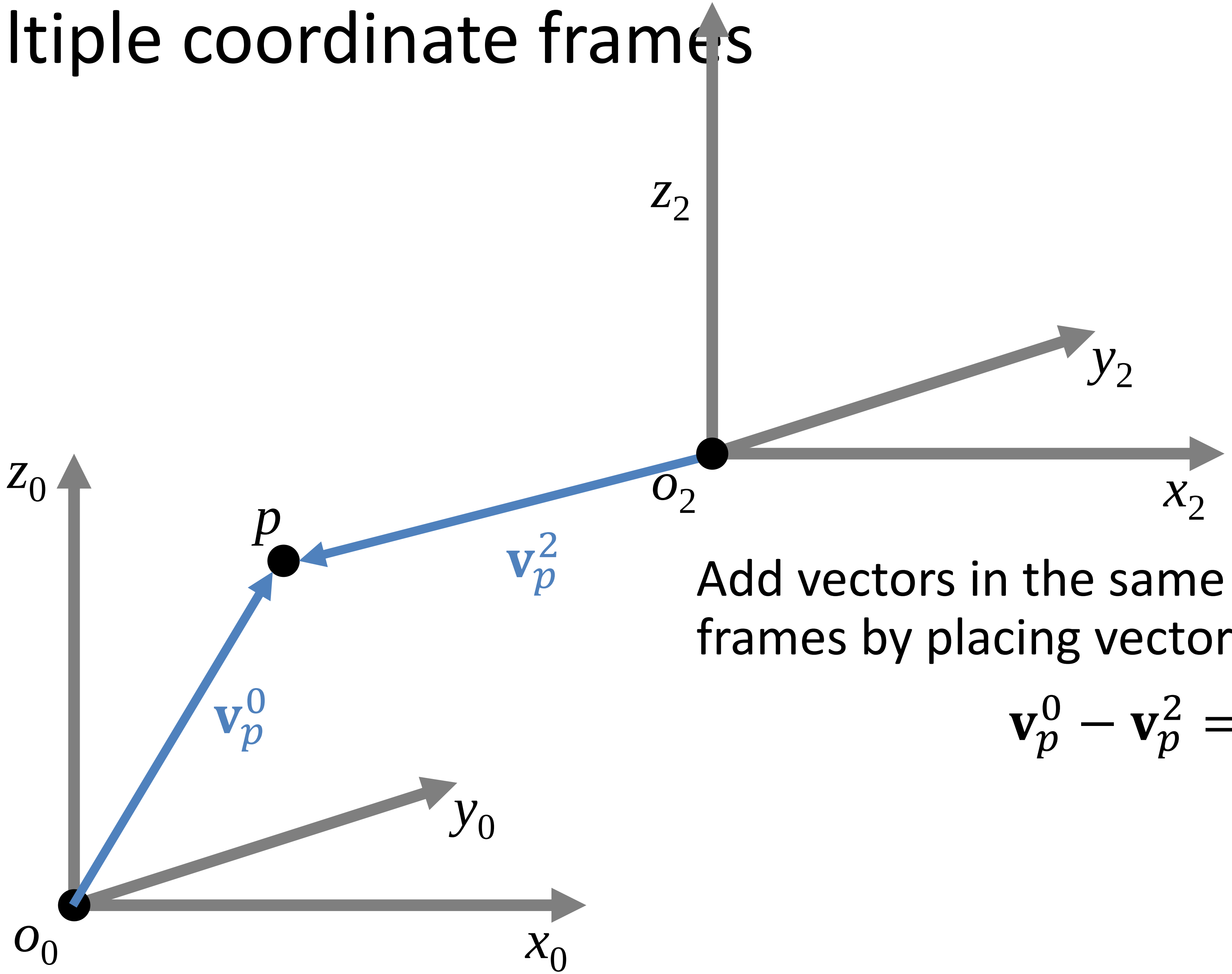
To perform algebraic manipulation, the vectors must be expressed in the **same or parallel frames**.

Multiple coordinate frames



$$\cancel{\mathbf{v}_p^0 + \mathbf{v}_p^1} = ?$$

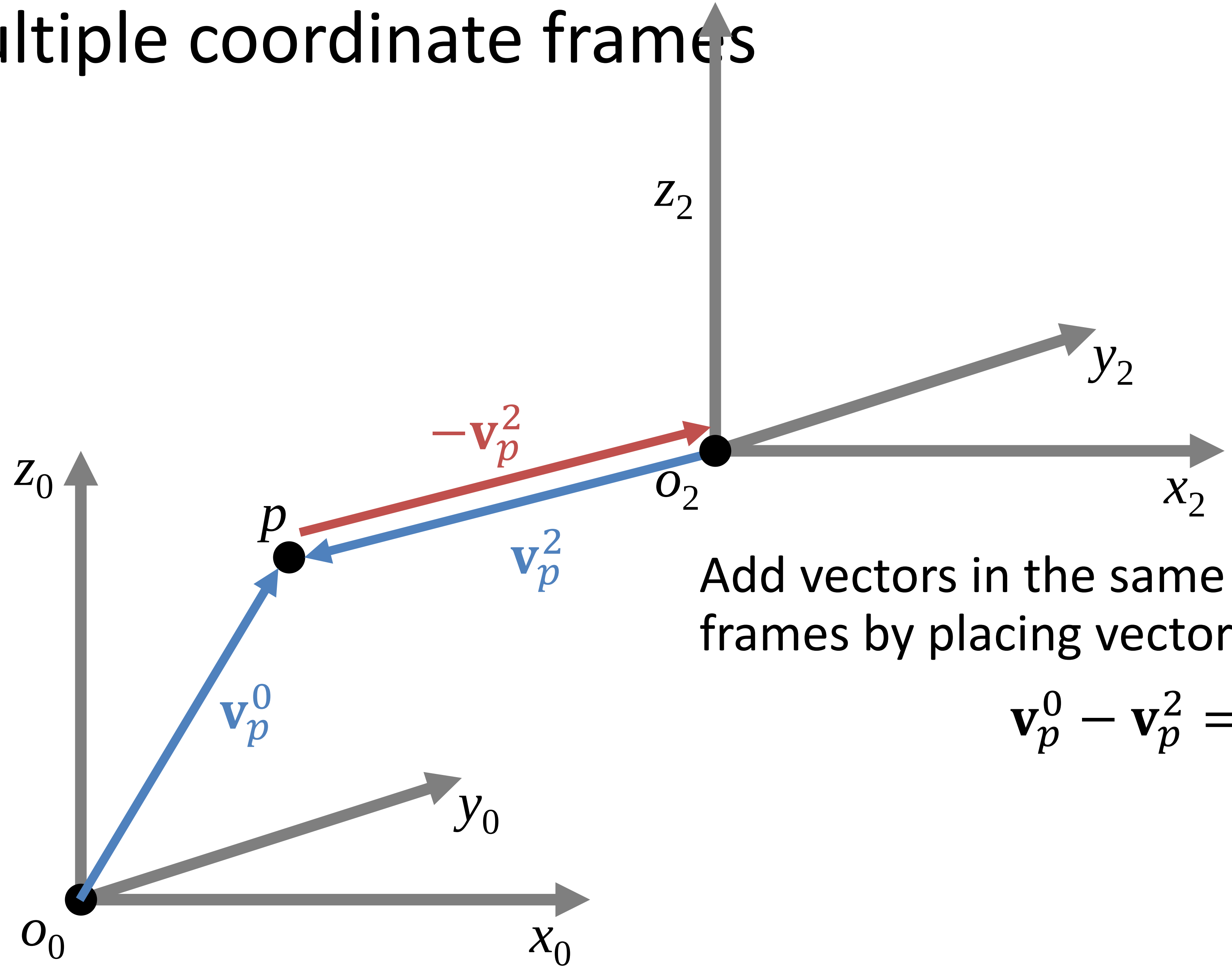
Multiple coordinate frames



Add vectors in the same or parallel frames by placing vectors tip to tail

$$\mathbf{v}_p^0 - \mathbf{v}_p^2 = ?$$

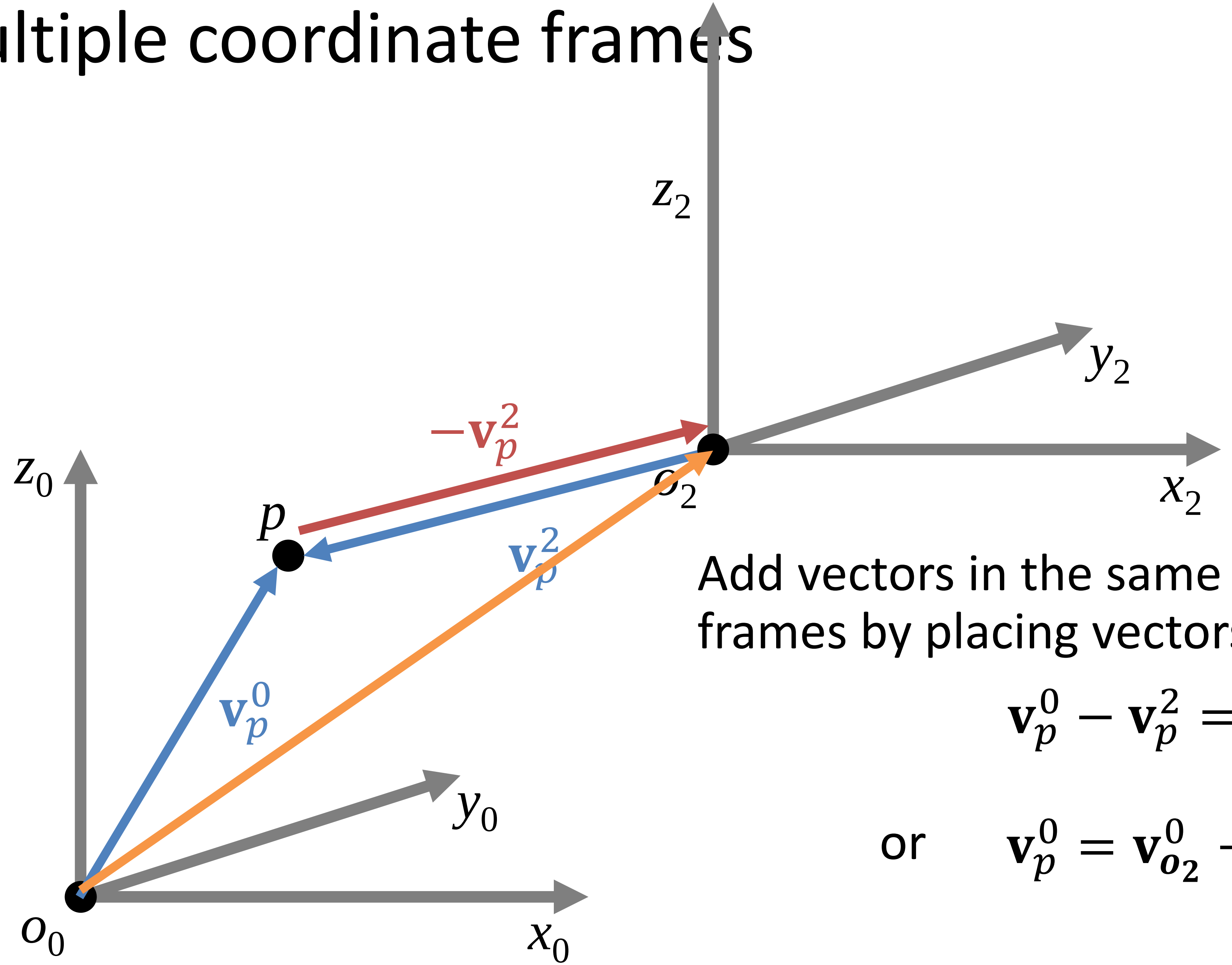
Multiple coordinate frames



Add vectors in the same or parallel frames by placing vectors tip to tail

$$\mathbf{v}_p^0 - \mathbf{v}_p^2 = ?$$

Multiple coordinate frames

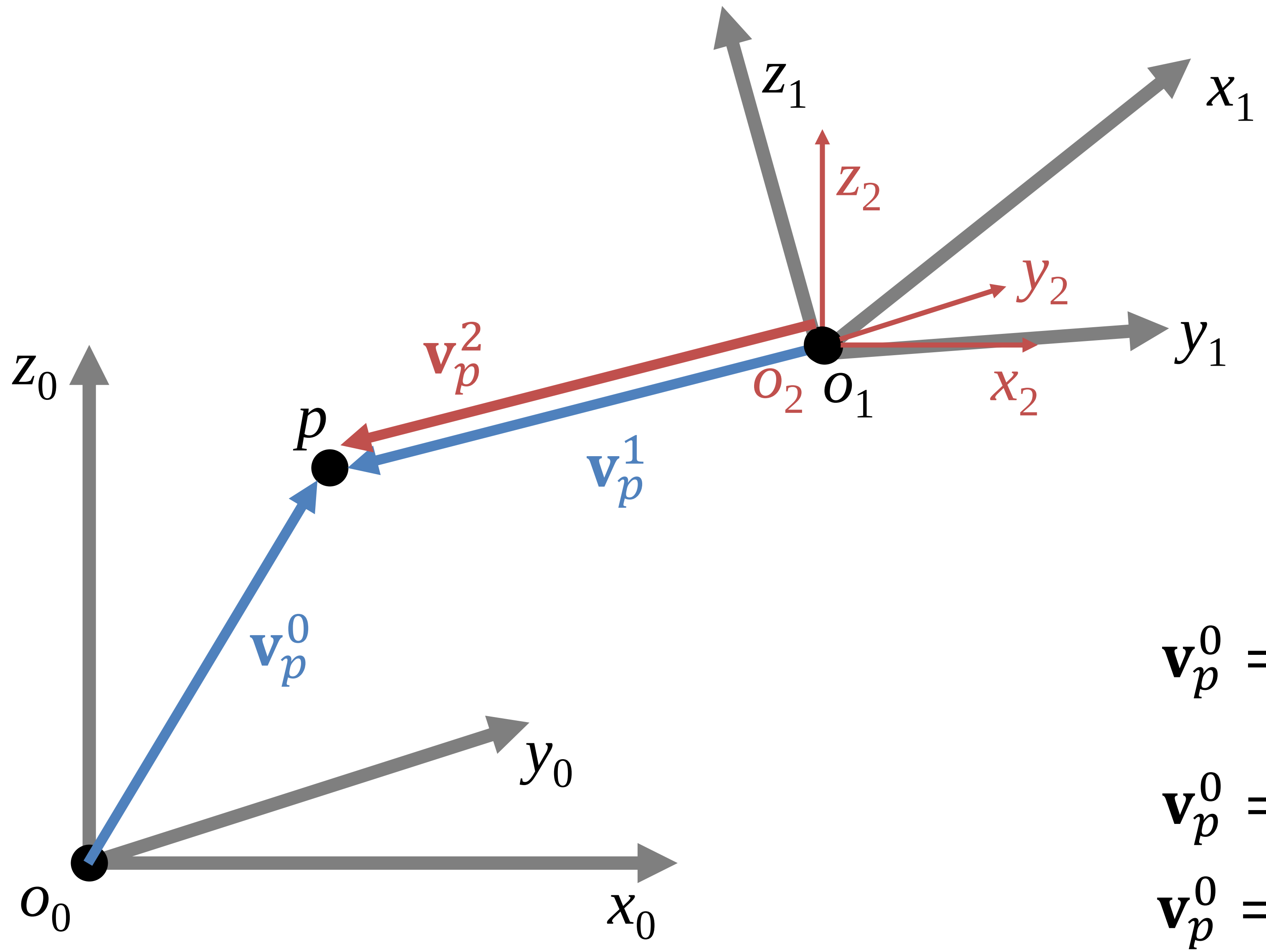


Add vectors in the same or parallel frames by placing vectors tip to tail

$$\mathbf{v}_p^0 - \mathbf{v}_p^2 = \mathbf{v}_{o_2}^0$$

or $$\mathbf{v}_p^0 = \mathbf{v}_{o_2}^0 + \mathbf{v}_p^2$$

How do we deal with rotated frames?



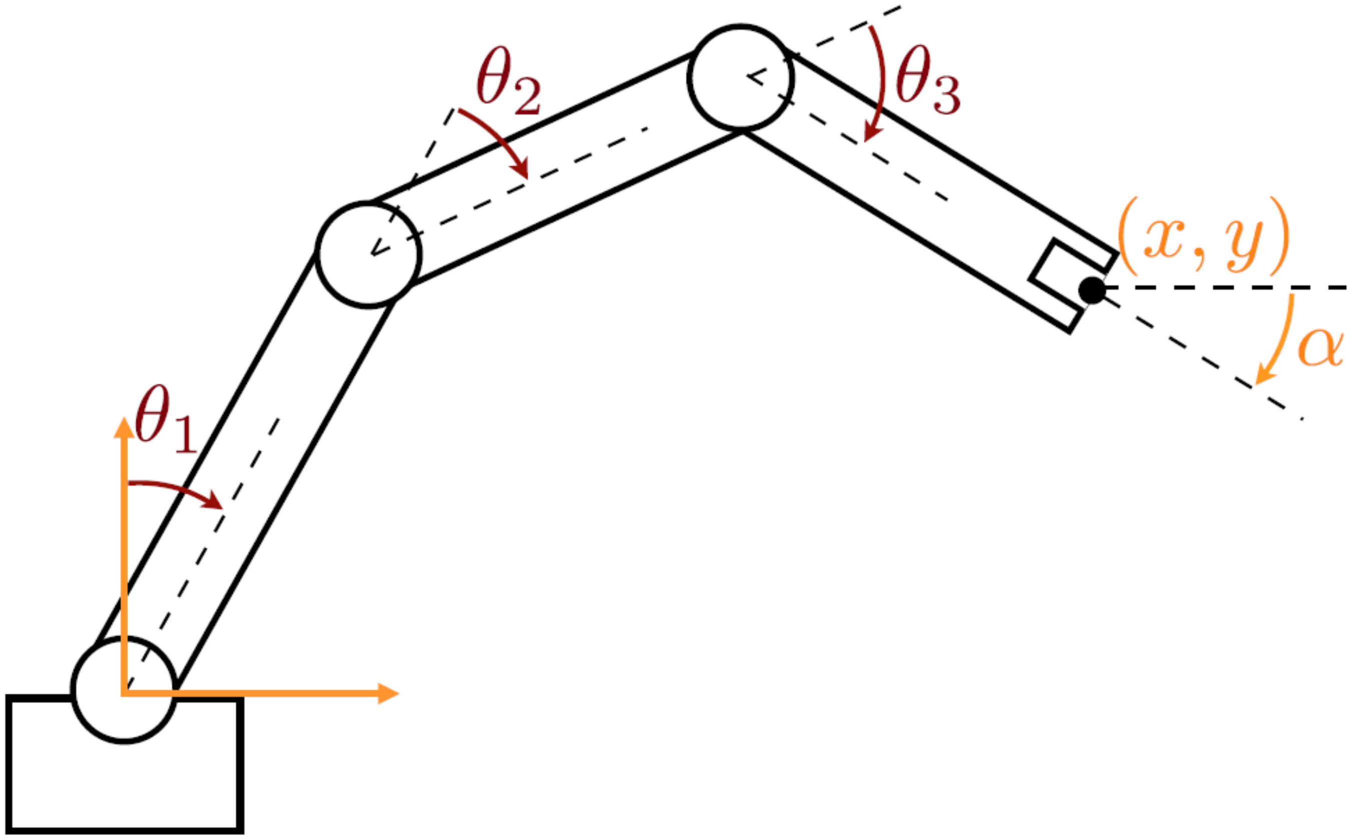
$$\mathbf{v}_p^0 = f\left(\mathbf{v}_p^1\right)$$

$$\mathbf{v}_p^0 = \mathbf{v}_{o_2}^0 + \mathbf{v}_p^2$$

$$\mathbf{v}_p^0 = \mathbf{v}_{o_2}^0 + \mathrm{Rotate}\left(\mathbf{v}_p^1\right)$$

Forward Kinematics

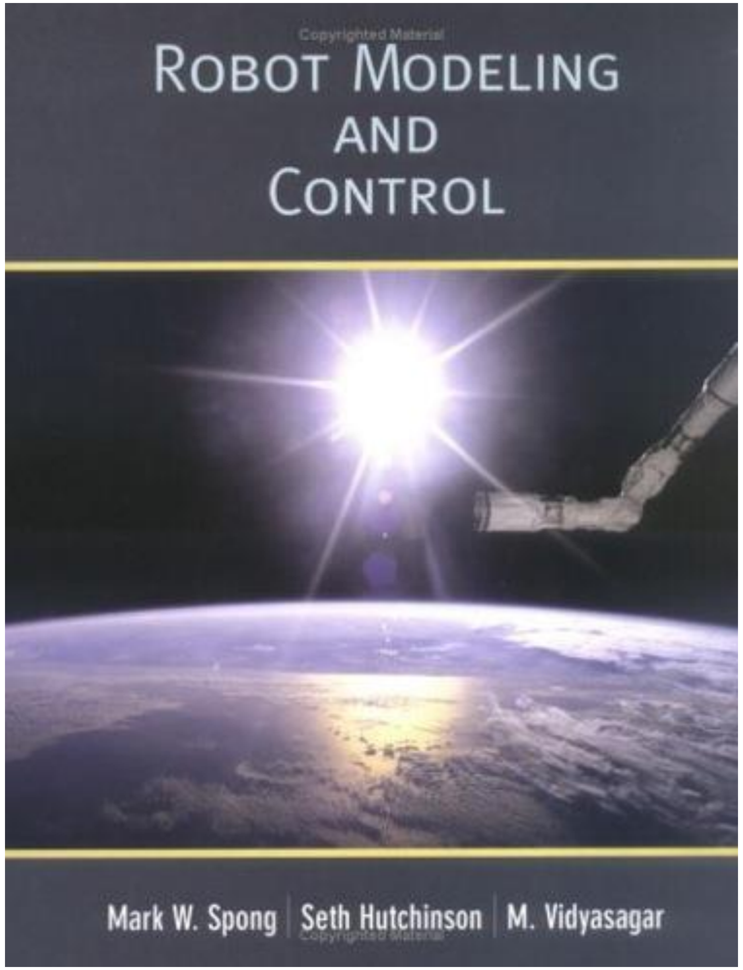
Given the joint coordinates, what are the task coordinates?



Next time: Rotation Matrices in 2D and 3D

Chapter 2: Rigid Motions

- Read Sec. 2.intro-2.5
- Brush up on B.1-B.4 if necessary
  - Key concepts: vector, matrix, transpose, dot product, norm, matrix multiplication



I will be traveling for a research conference
Prof. Mark Yim will substitute
This material will be important for Lab 1