ROBOTIC FUNDAMENTALS (UMFF4X-15-M)

Introduction

UWE Bristol | University of the West of England

What are we going to do?

Manipulators (Serial & Parallel)

Degrees of Freedom

Workspace

Positioning + Kinematics

Trajectories of manipulators

Dynamics

What are we (not) going to do?

Robot Hardware Design

What you should learn

- Basic terms and characteristics of manipulators
- How to create a simple robot manipulator model and simulate its motion in Matlab
- How to model and simulate a Lynxmotion arm, executing simple tasks
- Serial and parallel manipulators kinematics and constraints
- Basic dynamics and control principles of manipulator motion

Schedule of Sessions

1. Introduction to concepts of kinematics
2. Homogenous transformation
3. Forward (direct) kinematics (DH)
4. Inverse kinematics
5. Velocities and accelerations
6. Parallel robots Intro
7. Parallel robots (Kinematics)
8. Robot arm – Trajectories
9. Trajectories II
10. Dynamics Intro
11. Dynamics – Newton Euler
12. Revision

UWE Blackboard

- Check announcements
- Check your UWE email
- Material will be uploaded on Blackboard weekly (check also the module handbook)
- Individual report (due on week 12) : Serial & Parallel robot kinematics modelling and simulation

Today’s lecture

Introduction to concepts of kinematics

Mechanisms

DOFs, Joints, Kinematic Chains

Mobility

Workspace

Manipulators - Key questions

When each joint is moved this much where would the end effector be?

How do I move each joint to place the end effector there?

How do I move each joint so the end effector is moving at a given velocity?

How to generate a trajectory of the arm?

How to control end effector's force?

How to control the end effector's position, velocity and acceleration/force?

MECHANISMS

DOF – JOINTS – KINEMATIC CHAINS

Mechanism

“A mechanism is a mechanical system that has the main purpose of transferring motion and/or forces from one or more sources to one or more outputs.”

Anatomy of a Manipulator

Link: rigid body

Joint: connection between two links

End-effector: interacts with the environment

Base: connected to the ground

MECHANISMS

DOF – JOINTS – KINEMATIC CHAINS

Degrees of Freedom

"Degrees of freedom (DOF or DOFs) *of a mechanism is the number of independent parameters that define its configuration."*

Degree of Freedom and Joints

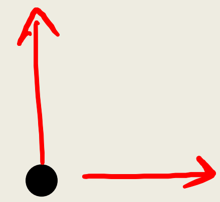
- Joints constraint free movement, measured in "**Degrees of Freedom**".

- Links start with 6 DOFs and joints reduce the number of DOFs by constraining some translations or rotations.

- Robots are classified by their total number of DOFs

Some Examples

- How many DOFs has a point on a plane?



2 DOF

Some Examples (2)

- How many DOFs has a pendulum? (assume rigid)

2 joints

6 − 2 = 4 DOFs

Some more Examples

- The mechanical system consisting of two planar rigid bodies connected by a revolute joint ?

4 DOFs: specifying the position and orientation of the first rigid body requires 3 variables. Since the 2nd one rotates relative to the 1st one, we need an additional variable to describe its motion. Thus, the total number of independent variables or the number of DOFs is 4.

- A rigid body in 3 dimensions has 6 DOFs:

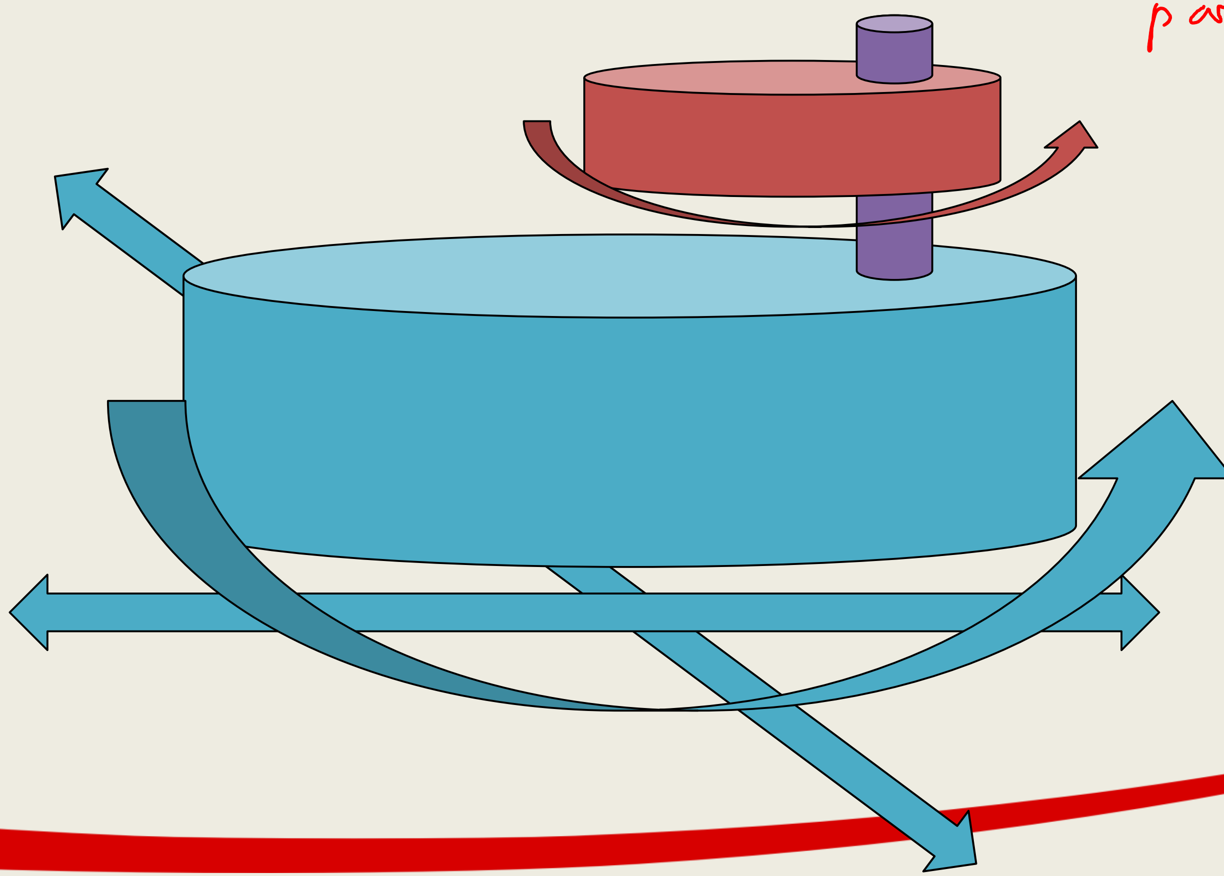
3 translational degrees of freedom and 3 different ways you can rotate a rigid body.

- How many degrees of freedom in your arm (not including your hand)?

Some More Examples (2)

for blue part,
6DOF
+ 1DOF for red part.

- How many DOF has this system?



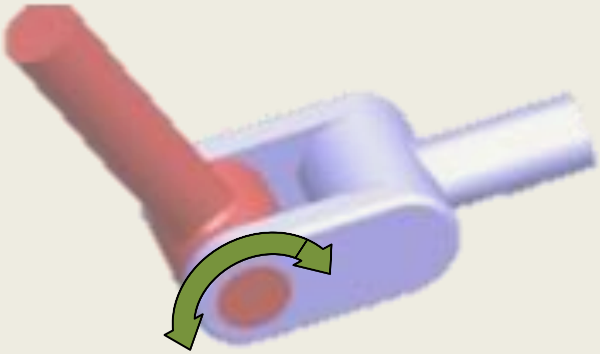
Controllable DOFs vs Total DOFs

- If a robot has an actuator for every DOF then all DOFs are *controllable*
- DOFs that are not actuated are (of course) *uncontrollable*
- *CDOF=TDOF   holonomic robot*
- *CDOF<TDOF   non-holonomic robot*
- *CDOF>TDOF   redundant robot (or the human arm)*

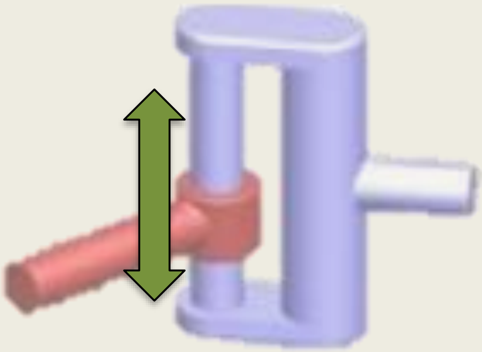
MECHANISMS

DOF – **JOINTS** – KINEMATIC CHAINS

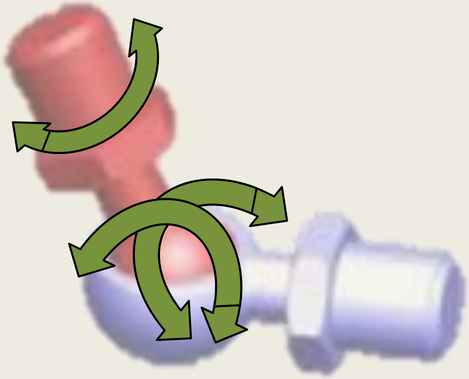
Joints



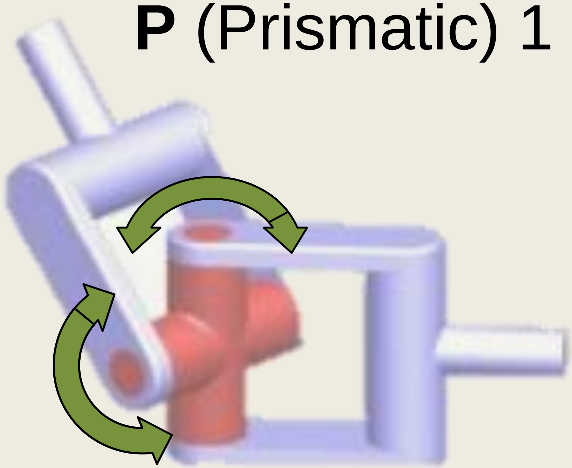
R (Revolute) 1 DOF



P (Prismatic) 1 DOF

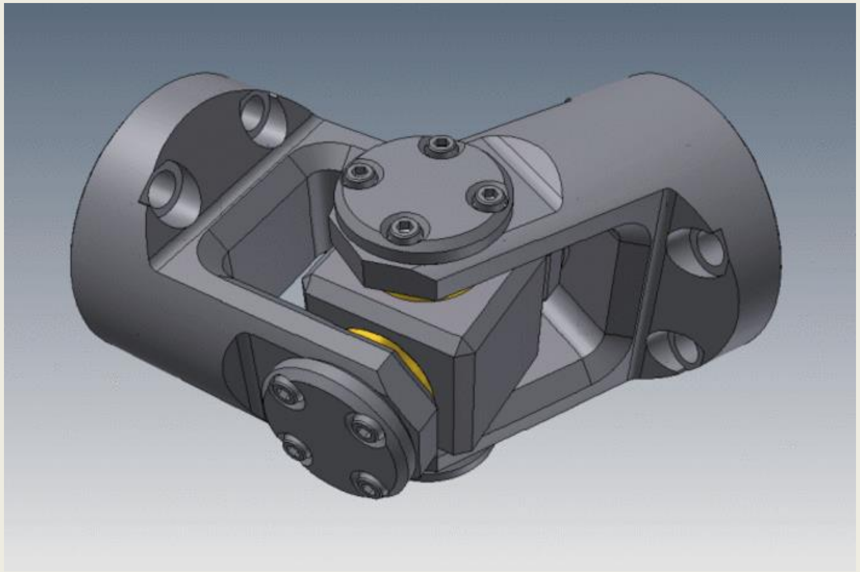


S (Spherical) 3 DOF

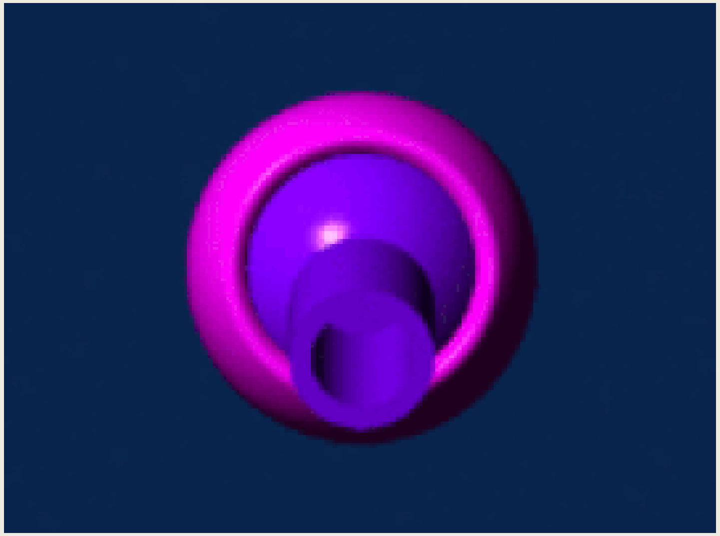


U (Universal) 2 DOF

Joints (2)



Universal joint

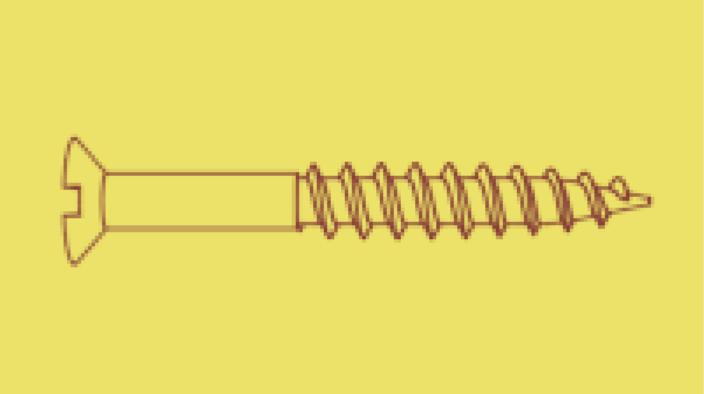


Spherical joint

Joints (3)

- Helical joint or screw joint - allows a helical motion between the two connecting bodies. A good example of this is the relative motion between a bolt and a nut.

Displacement is determined by the angle of rotation of the screw and the pitch of the screw $d=h\theta$.



Underactuated manipulators

Underactuated manipulators – less actuators than joints (active + passive joints). What are the advantages?

Cost + weight + reduced complexity

Note: Difficult to achieve!


Walking robot, no actuators!

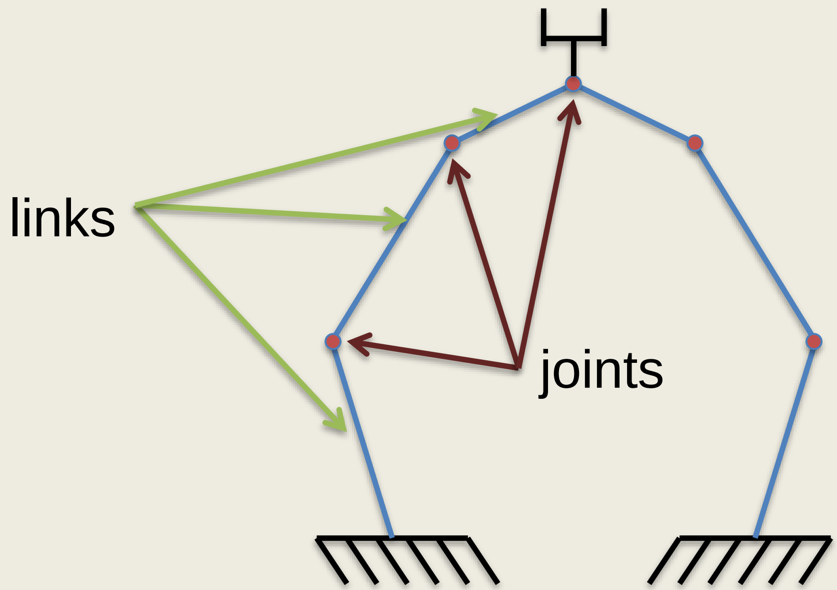
MECHANISMS

DOF – JOINTS – KINEMATIC CHAINS

Kinematic Chain

A mechanism ***connects*** *the base and the end-effector with one or more* ***kinematic chains***

Kinematic chain*: a system of rigid bodies connected together by joints.*



Parallel

Serial

?

Open/Closed chain

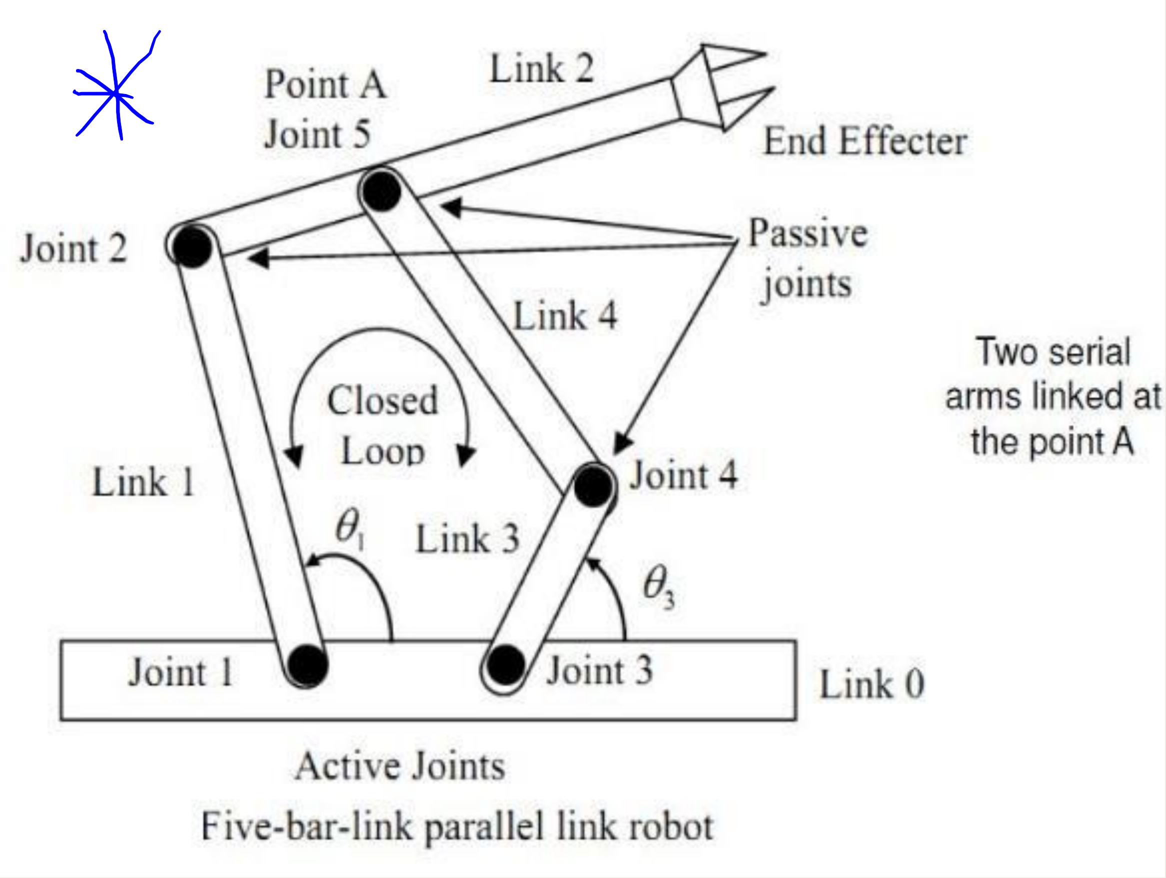
- A chain is called **closed** if it forms a closed loop. A chain that is not closed is called an **open** chain.

- **Serial** chain - If each link of an open chain except the first and the last link is connected to two other links it is called a serial chain.

Closed loop mechanisms

Advantages of closed loop mechanisms?

- Actuators at the base make the robot lighter
- Larger load can be carried

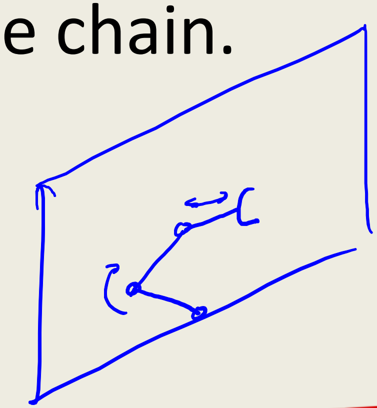


Planar mechanism

- All the links of a planar chain are constrained to move in or parallel to the same plane.

  * (like the example above)

- A planar chain can only allow prismatic and revolute joints. The axes of the revolute joints must be perpendicular to the plane of the chain while the axes of the prismatic joints must be parallel to or lie in the plane of the chain.



confined to plane

Mobility

Mobility

The ***number of parameters*** *that define the* ***configuration of a mechanism***

It answers the question:

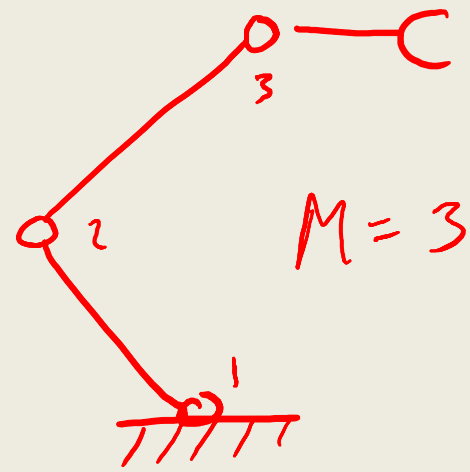
"What is the minimum number of actuators you need for a mechanism?"

Mobility Equation

The Grubler-Kutzbach equation for the general mobility in a mechanism is:

3 joints
3 links.

$$M = d(n - g - 1) + \sum_{i=0}^{g} f_i$$



M = 3

d = 6 for spatial mechanisms, d = 3 for planar

n : number of links including the ground link,

g : is the total number of joints

f_i : is the degrees of freedom in joint i

i = 1, 2, 3

Planar Serial Manipulator

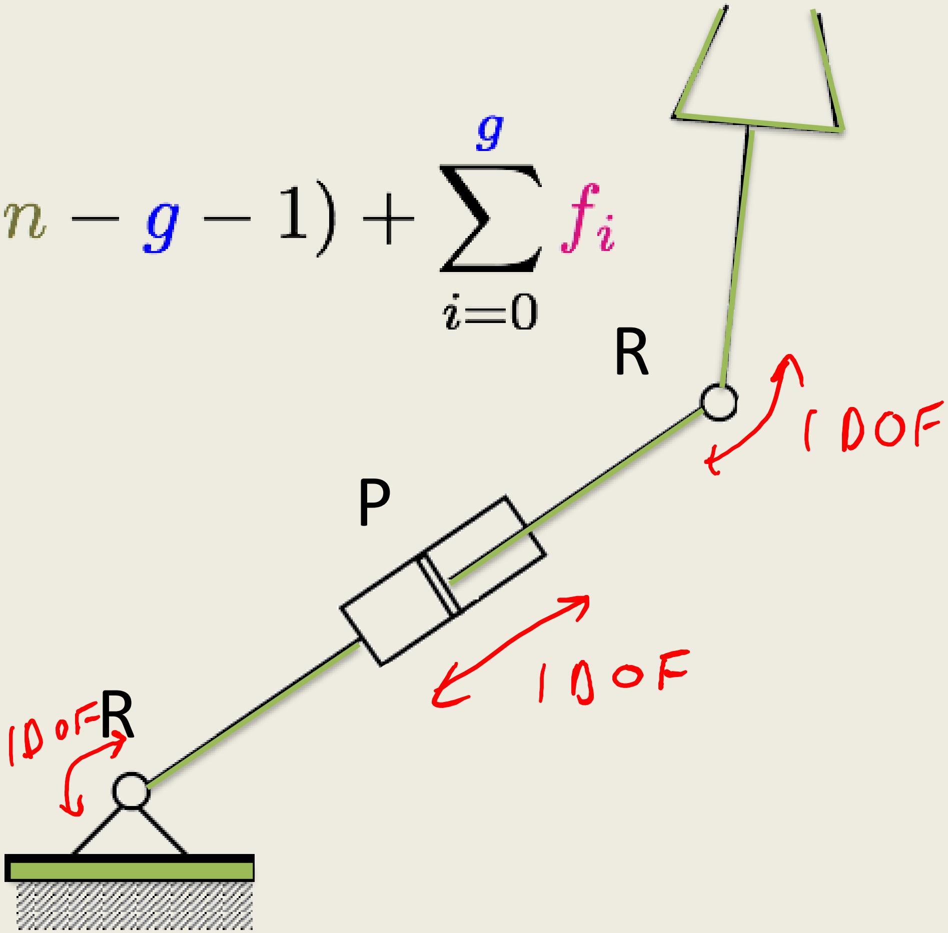
d = 6/3

n : links

g : joints

f_i : DOF in i

$$M = 3(n - g - 1) + \sum_{i=0}^{g} f_i$$



n=4 (don't forget the base)

g=3

$\sum_{i=0}^{g} f_i$=3

M=3

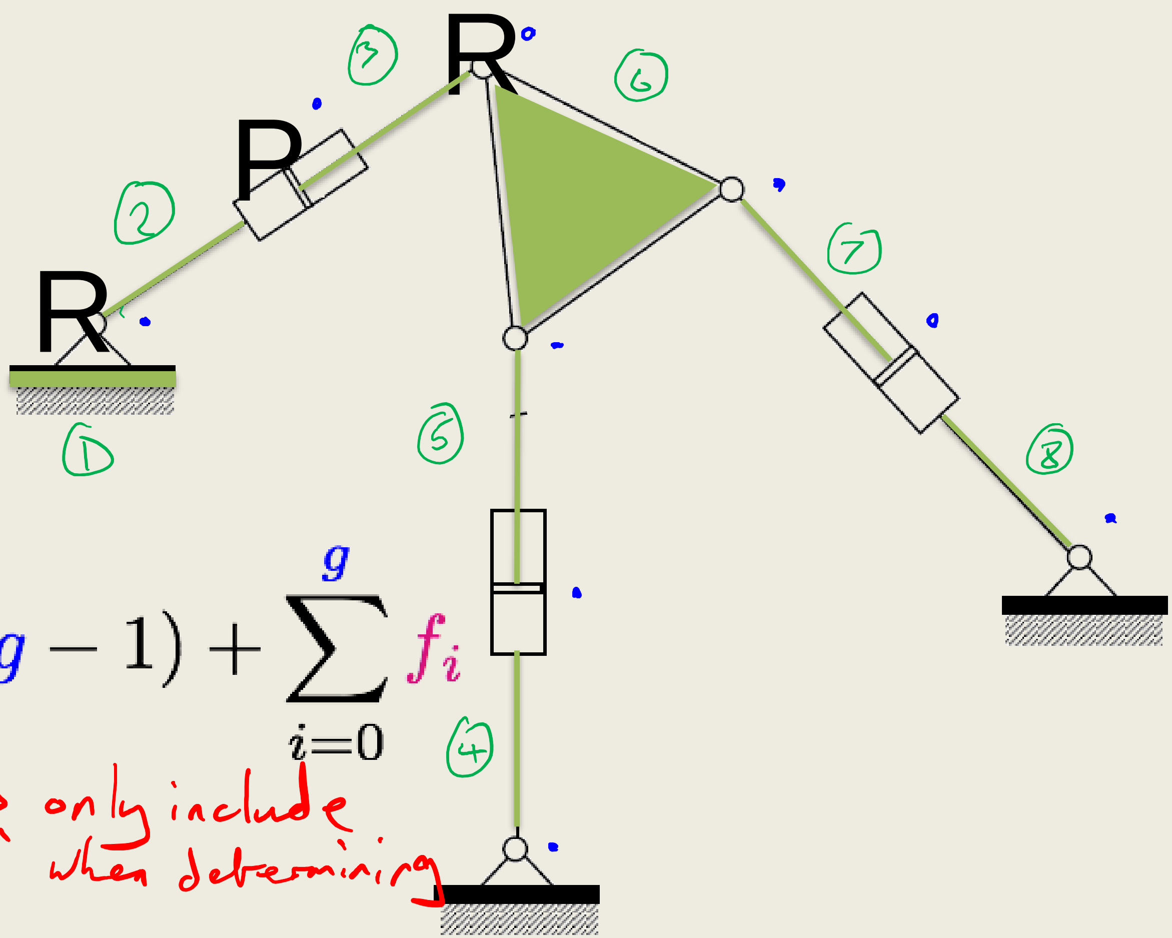
Planar Parallel Manipulator

d = 6/3

n : links

g : joints

f_i : DOF in i



n=8

g=9

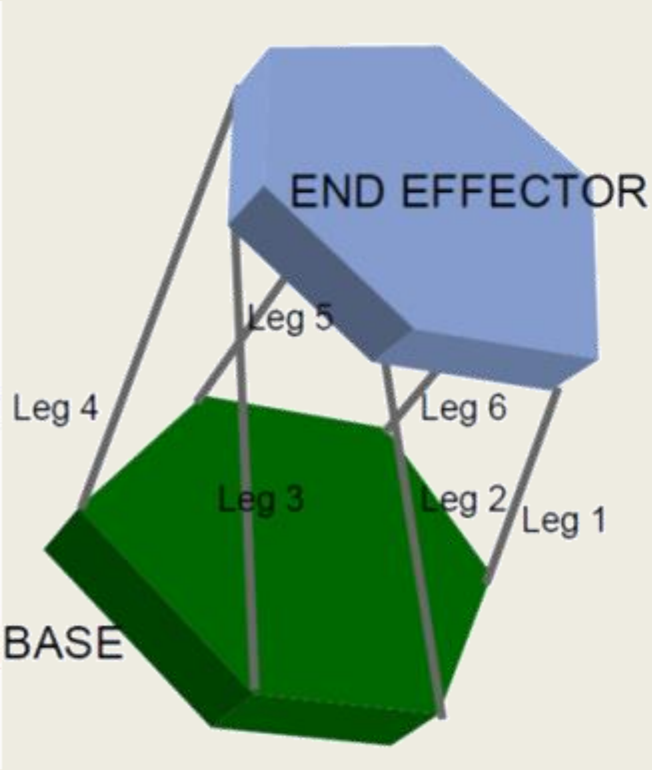
$\sum_{i=0}^{g} f_i$=9

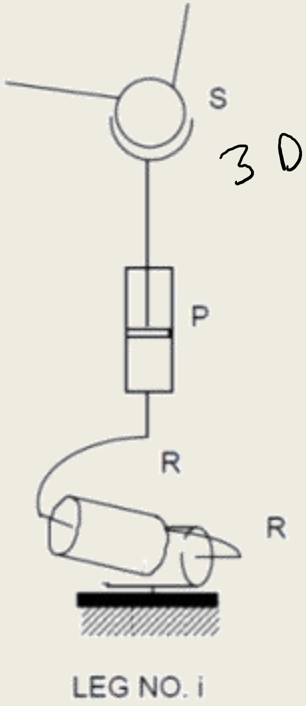
M=3

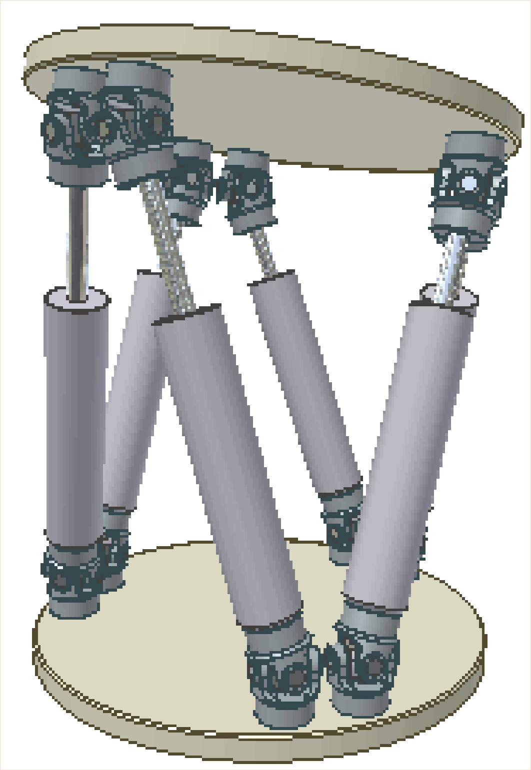
$$M = 3(n - g - 1) + \sum_{i=0}^{g} f_i$$

Important → only include one 'base' when determining.

Homework – Stewart platform





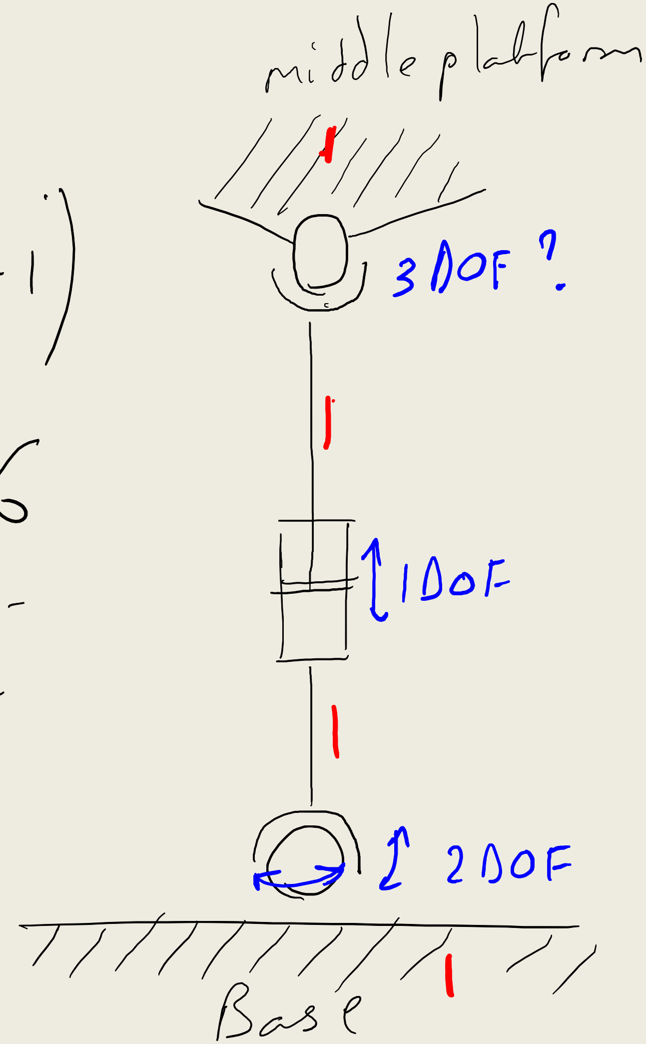


M=?

One leg.

$$M = 6\left(\left[\underbrace{(2\times 6)}_{\text{legs}} + \underset{\text{base}}{1} + \underset{\text{plat.}}{1}\right] - (3\times 6) - 1\right)$$

$$+ \sum(\text{DOFs}) = 6$$



Workspace

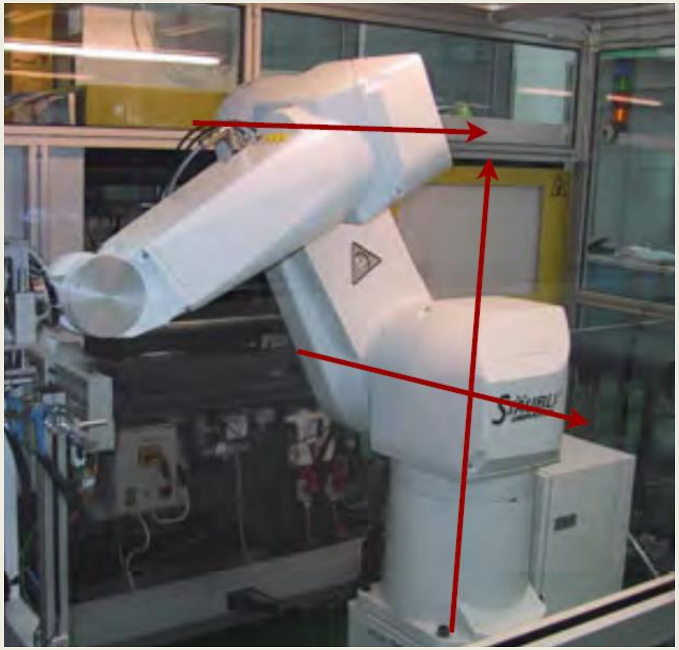
AND MOVING IN IT

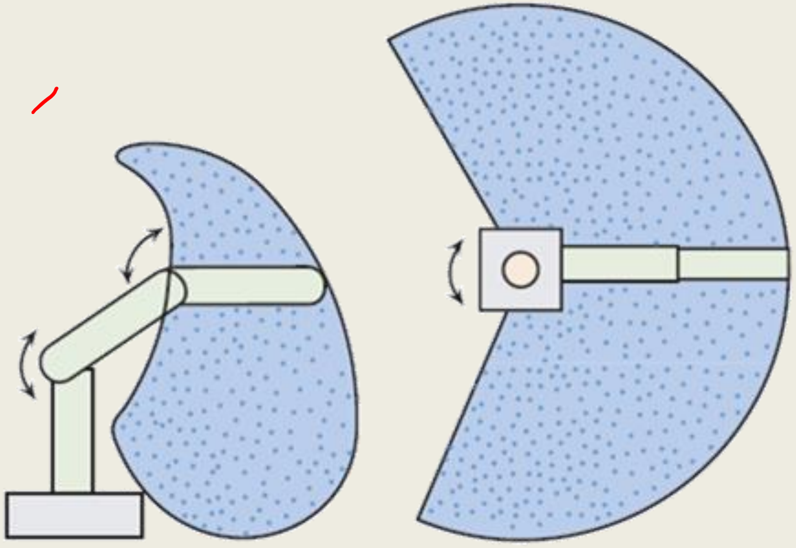
Workspace

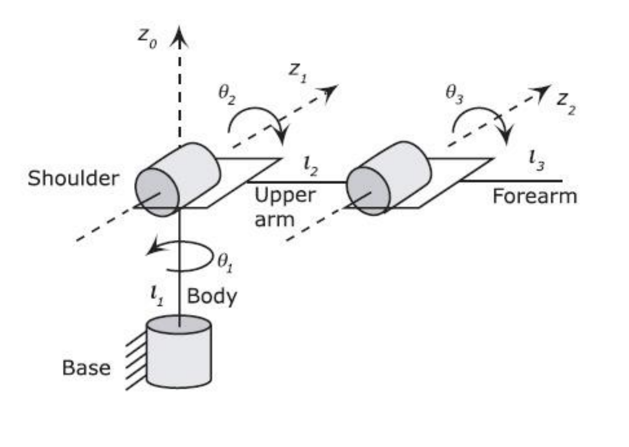
"Workspace is the set of points reachable by the end-effector"

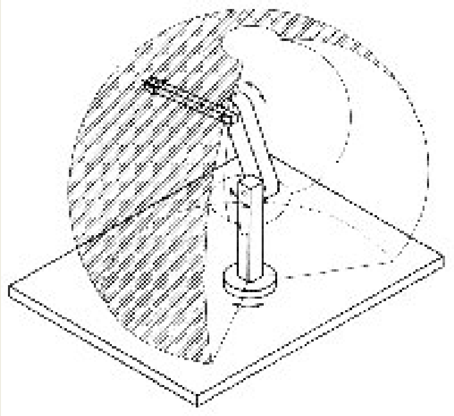
R for rotational.

Articulated Manipulator (RRR)



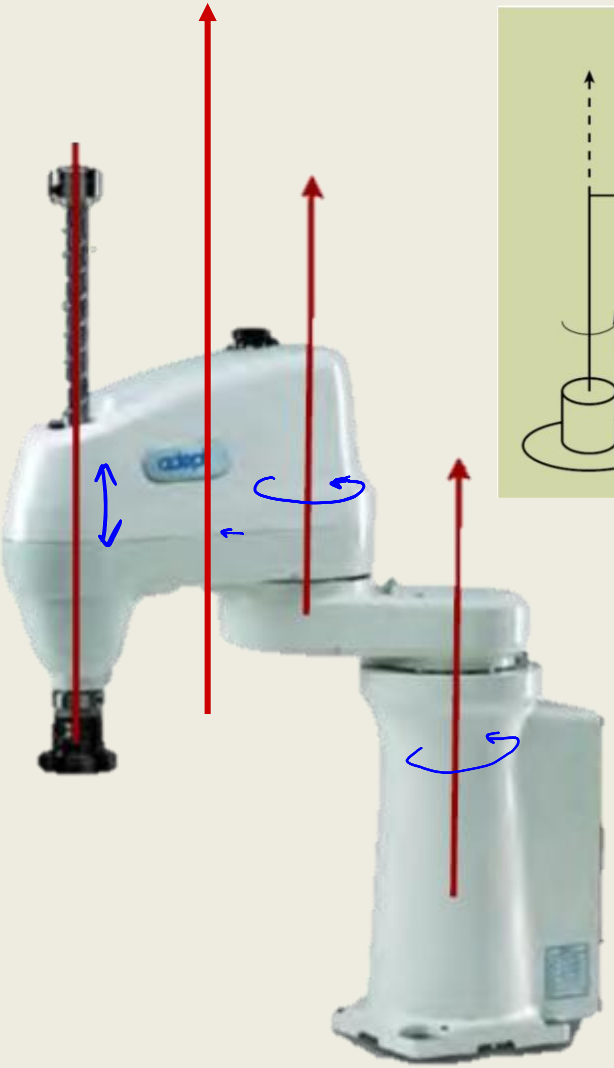


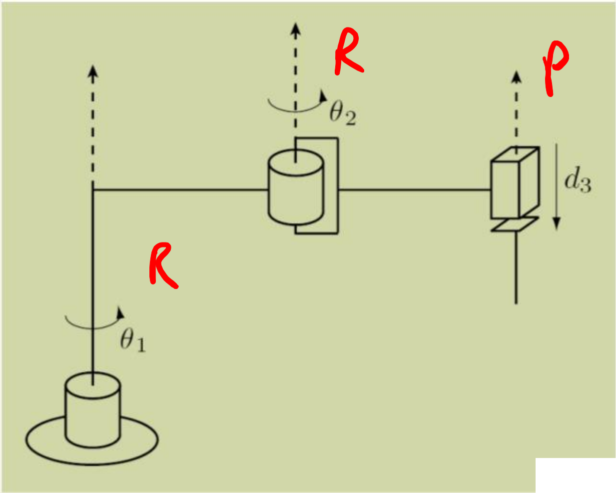


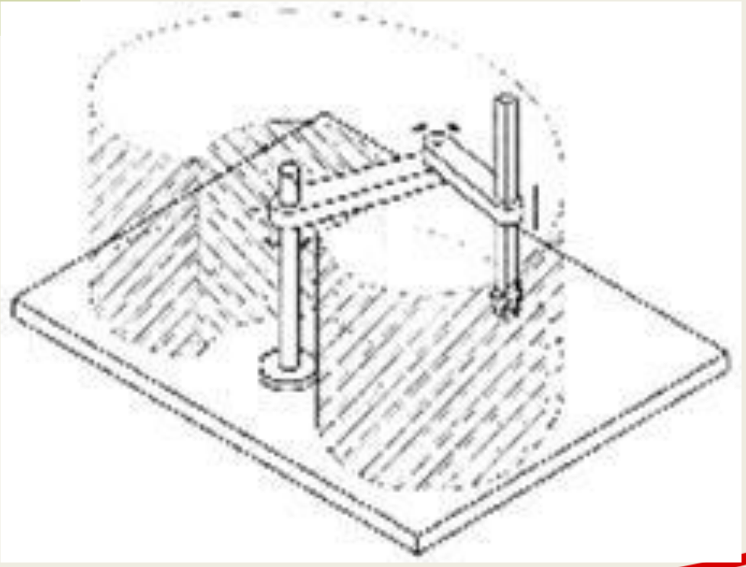


Selective Compliant Articulated Robot for Assembly (SCARA) (RRP)

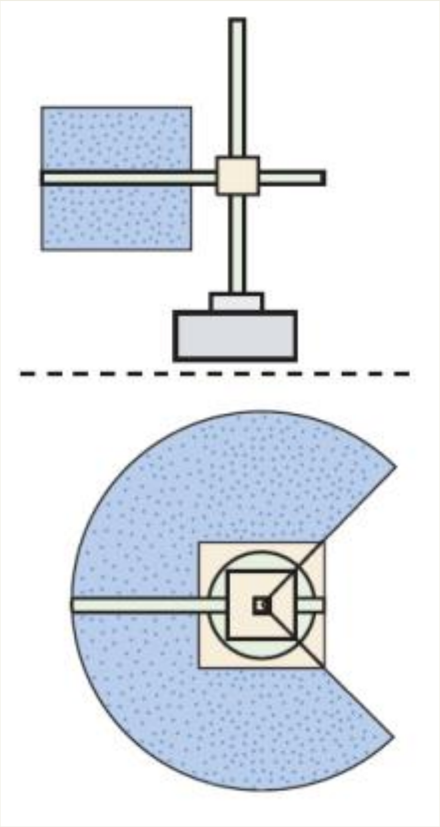
P for positional

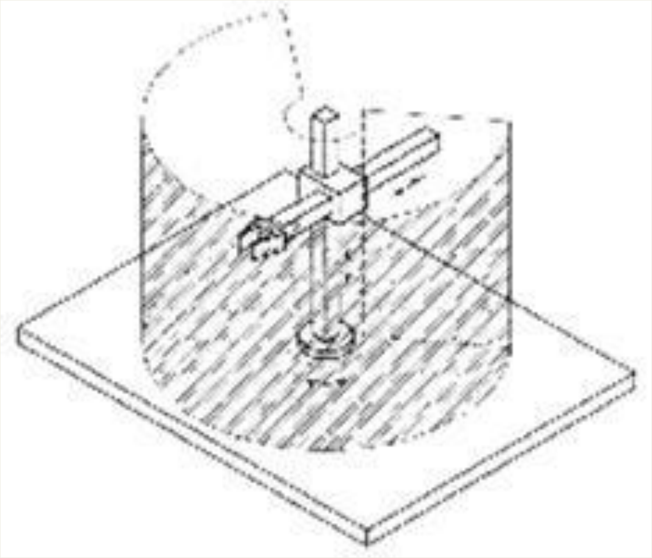




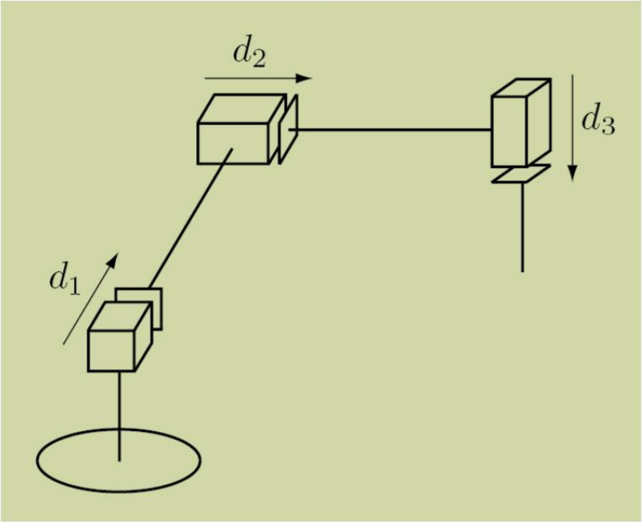


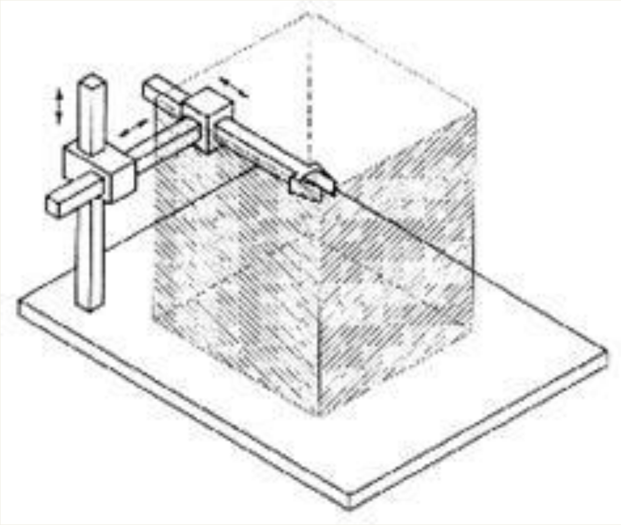
Cylindrical Manipulator (RPP)





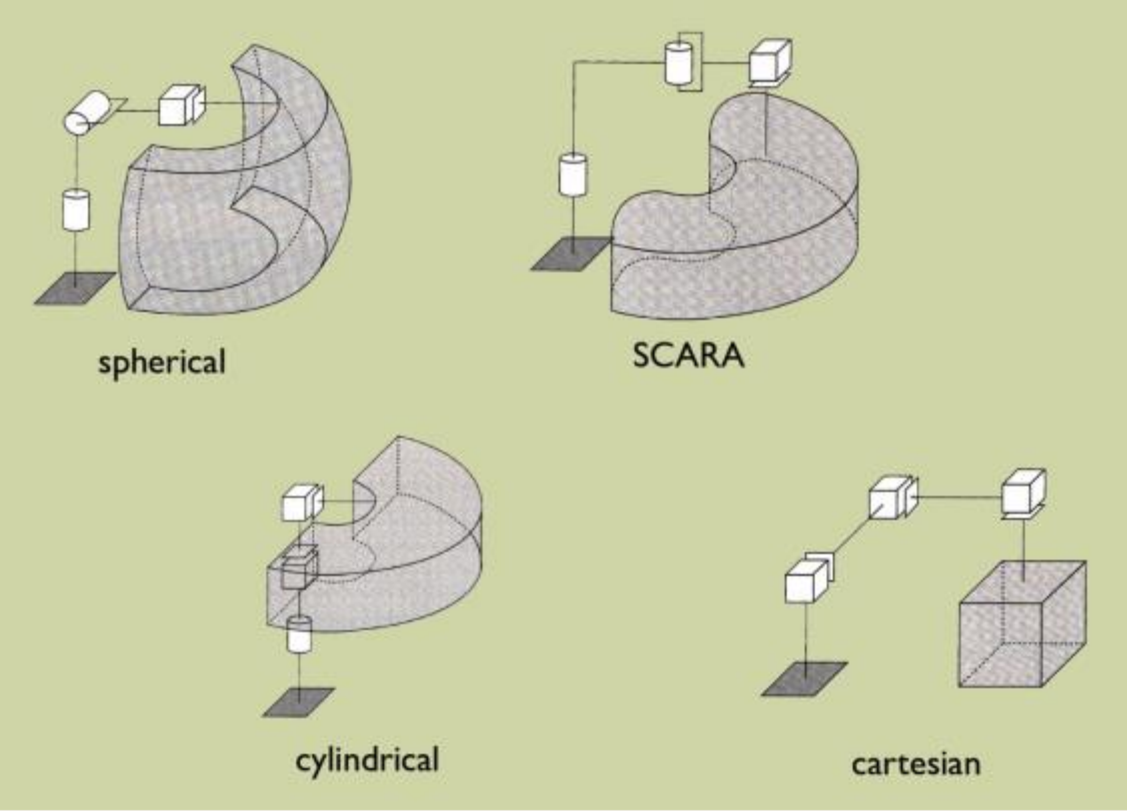
Cartesian manipulator (PPP)





Reachable vs Dexterous Workspace

- *“region that end-effector centre point can reach (in one orientation)”*
- *“region that the end-effector can reach in all its possible orientations”*



Manipulation

Manipulation

In locomotion (mobile robots), the ***body of the robot*** is moved to get to a particular position and orientation.

A manipulator moves

typically to get the ***end effector*** (e.g., the hand, the finger, the fingertip) to the ***desired 3D position and orientation***.

So imagine having to touch a specific point in 3D space with the tip of your index finger;

that's what a typical manipulator has to do.

Manipulation - Teleoperation

- Manipulation was first used in **tele-operation**, where human operators would move artificial arms to handle *hazardous materials*.
- Complicated duplicates of human arms, with 7 DOF were built.
- It turned out that it was <u>quite difficult</u> for human operators to learn how to tele-operate such arms

Basic Problems of Ma

Where is my hand?

Forward Kinematic

Direct Kinematics: HERE!

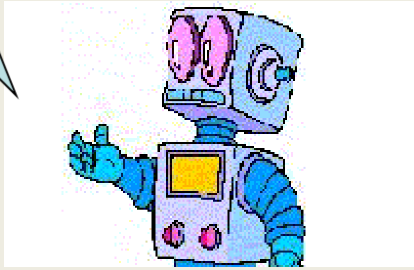
Given all the joint ar … tor ?

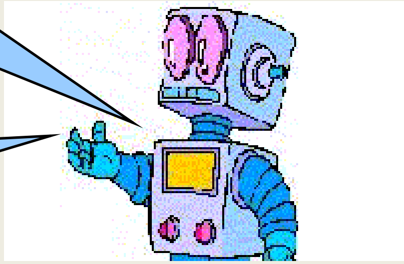
How do I put my hand here?

Inverse Kinematics

Given a tip position - what are the pos… angles ?

IK: Choose these angles!





Velocity Kinematics

How fast I am moving (Forw.) or should go (Inv.)?

Dynamics

To accelerate the tip how must torque must my motor apply? And what if the tip must apply a specific force?

Kinematics vs Inverse Kinematics

- Kinematics is the study of motion without regard to the forces which are required to produce that motion.

- We can formalize all of this mathematically.

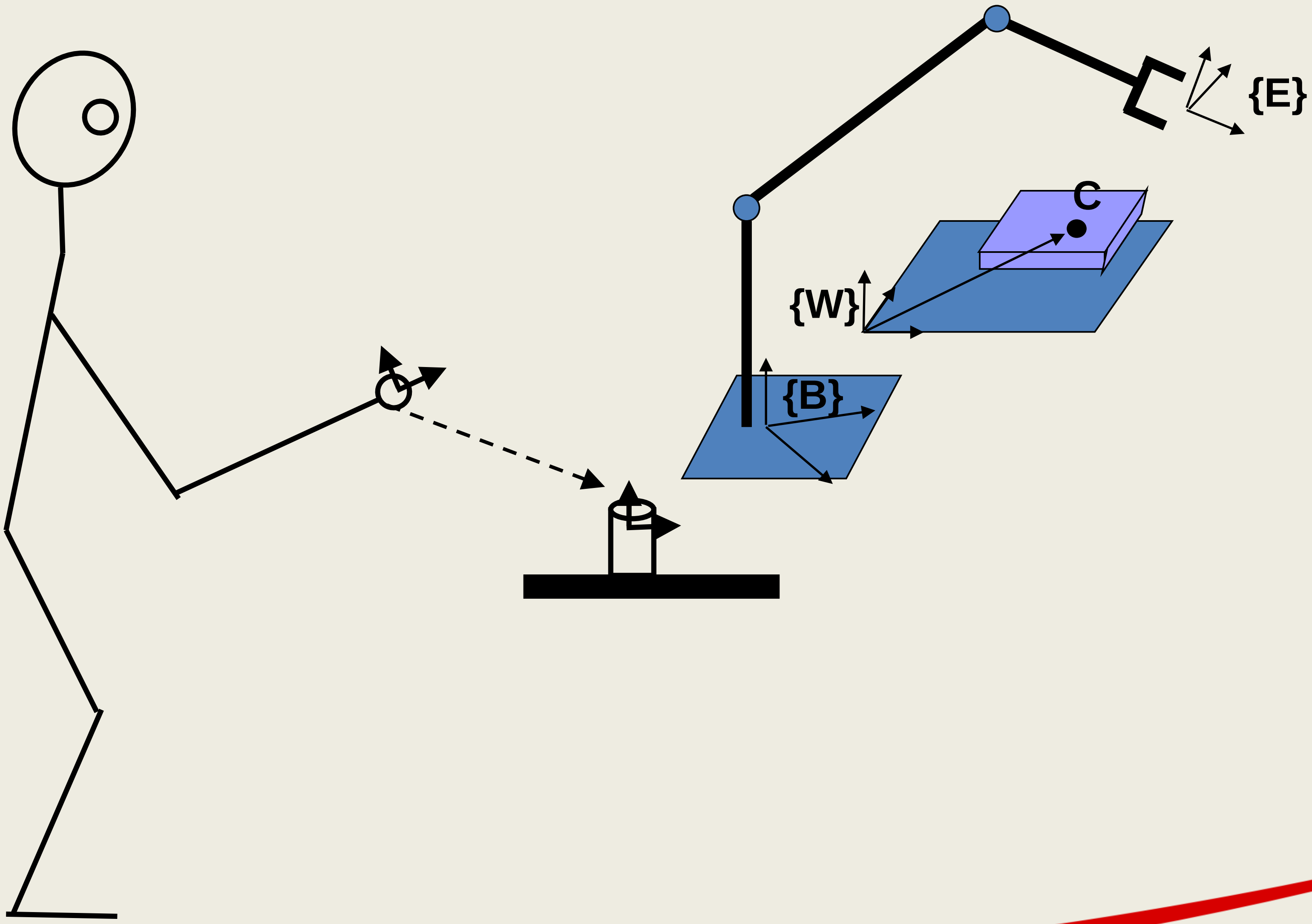
To get an equation which will tell us how to convert from, say, angles in each of the joints, to the Cartesian positions of the end effector/point is called:

forward kinematics

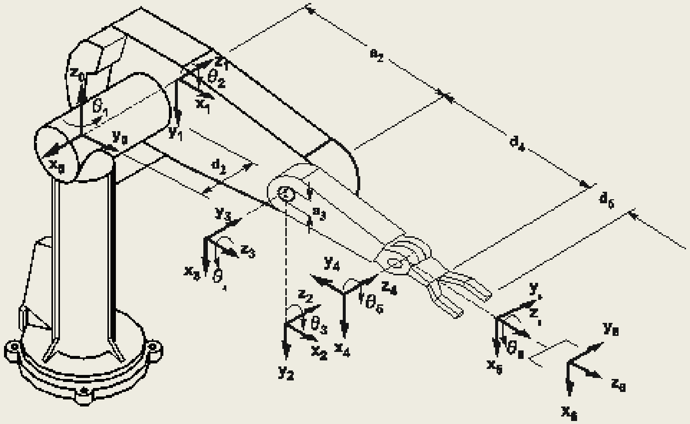
The process of converting the Cartesian (x,y,z) position into a set of joint angles for the arm (thetas) is called:

inverse kinematics

Representing Position: Vectors

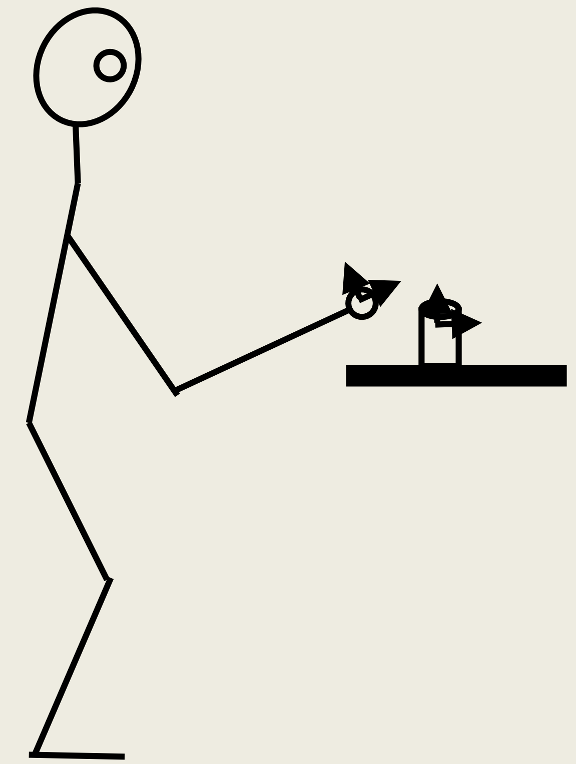


Pose



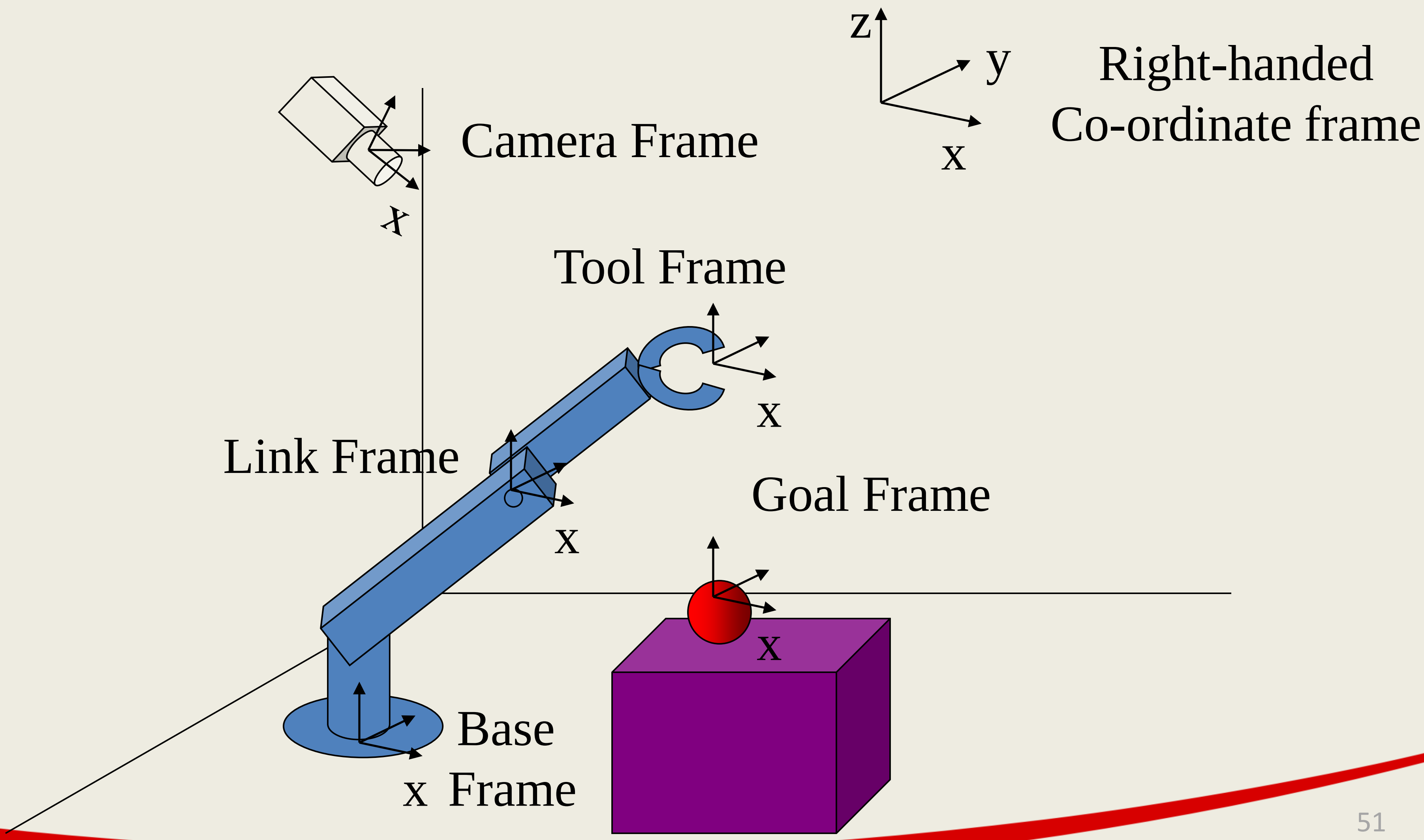
In order to put your hand on the object, you want to align the coordinate frame of your hand w.r.t. that of the object.

In order for a robot to pick a work piece its gripper needs to align with it.



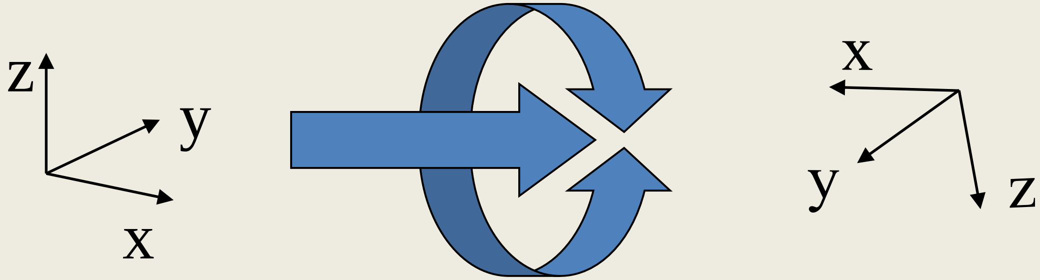
These kinds of problems make representation of pose important.

Co-ordinate Frames



Kinematic Relationship

– Between two frames we have a *kinematic relationship* - translation and rotation.



– This relationship is mathematically represented by a 4 × 4 Homogeneous Transformation Matrix.

Summary

- DOFs define a robot, its mobility and ultimately its workspace – revolute/prismatic/universal/spherical/helical joints
- Controllable/Uncontrollable DOFs, holonomic/non-holonomic/redundant systems
- Serial/Parallel robots – planar or 3D
- Kinematics define the mapping between the robot’s actuators and its end effector’s position (and vice versa)
- Kinematic relationships – relationships between frames: translation and/or rotation

Tutorial – Matlab examples

- Create your own function which multiples 2 matrices (e.g. matrices with 2x2 dimension)

  my_mult(L,K)

- Create a simple script which uses your *my_mult* function. Compare the results with a simple matrix multiplication L*K.

- A coordinate frame is rotated counter-clockwise around z axis (using right hand rule) by 120 degrees and translated by p =[-3 2 0]‘. Plot this new frame using Matlab.

Rotation matrices (x, y z)

$$ROT(z,\theta)=\begin{bmatrix}\cos\theta & -\sin\theta & 0\\ \sin\theta & \cos\theta & 0\\ 0 & 0 & 1\end{bmatrix} ROT(y,\theta)=\begin{bmatrix}\cos\theta & 0 & \sin\theta\\ 0 & 1 & 0\\ -\sin\theta & 0 & \cos\theta\end{bmatrix}$$

$$ROT(x,\theta)=\begin{bmatrix}1 & 0 & 0\\ 0 & \cos\theta & -\sin\theta\\ 0 & \sin\theta & \cos\theta\end{bmatrix}$$