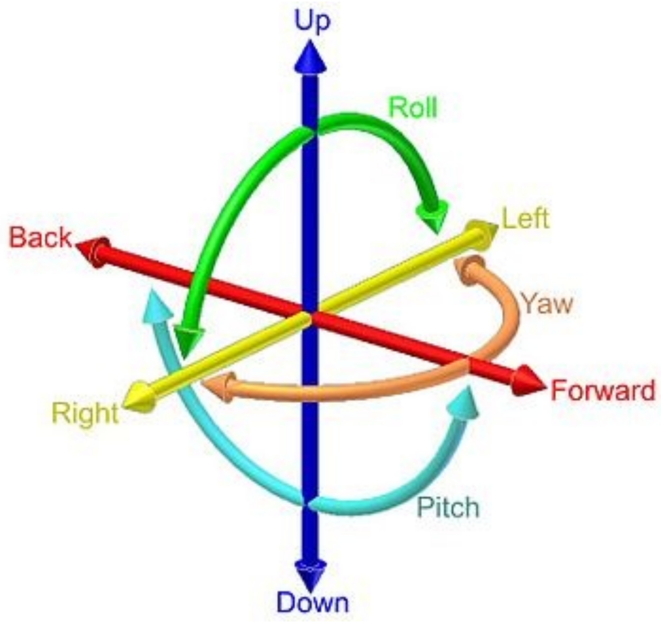
EXPLORE ROBOTICS – CISC 1003

DEGREES OF FREEDOM



REVIEW – LOCOMOTION AND DEGREES OF FREEDOM

Locomotion

- Locomotion = locus (place) + motion
- Locomotion refers to the way a body moves
  - from place to place.
- A fundamental function of humans, animals
  - Acquired through training
  - Requiring significant “brain power”
- It’s generally the first challenge for a robot
- Many modes of locomotion exist

Modes of Locomotion

- Most common, legged vs. Wheeled
- Benefits and challenges:
  - Wheeled:
    - Most efficient use of power
    - Low number of *Degrees of Freedom (DOFs)*.
  - Legged:
    - Large DOFs, challenge of stability.

Locomotion and Manipulations

- Choice of effectors and actuators sets the limits on what the robot can do
- Usually categorized as locomotion or manipulation
  - Locomotion: vehicle moving itself
  - Manipulation: An arm moving things
- In both cases can consider the ***degrees of freedom*** in the design

Degrees of Freedom (D.O.F.)

- The number of independent parameters that define a systems’ configuration or state

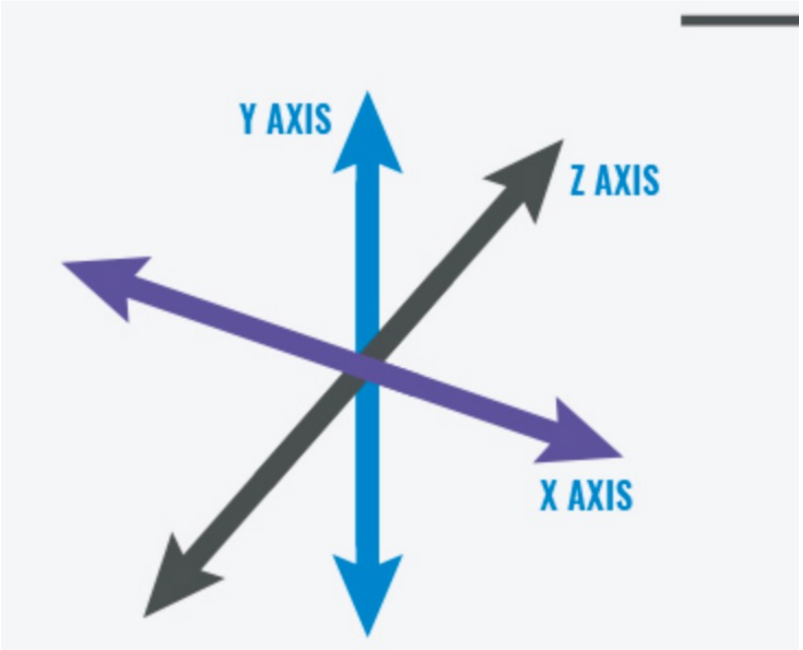
Degrees of freedom (D.O.F.)

- Degrees of Freedom of a point in space:
  - # of independent coordinates required to define position and orientation
  - How many such points?


QUESTIONS

Degrees of freedom (D.O.F.)

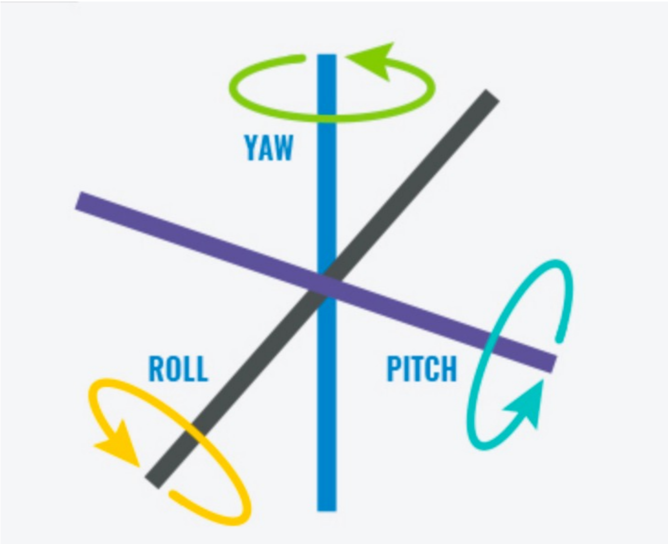
- Degrees of Freedom of a point in space:
  - # of independent coordinates required to define position and orientation
  - How many such coordinates?
    - 3 coordinates – x, y, and z



https://www.ceva-dsp.com/ourblog/what-is-an-imu-sensor/

Degrees of freedom (D.O.F.)

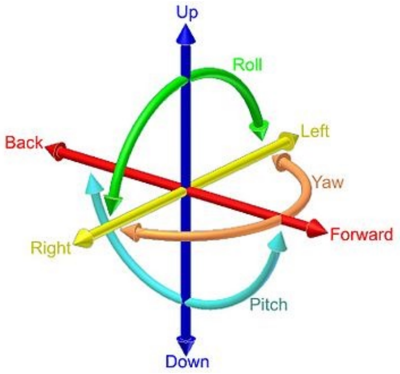
- Degrees of Freedom of a ***rigid body*** in space:
  - 3 linear movements across x, y and z dimensions
  - Three rotational movements about axis x, y and z
    - Called *roll*, *pitch*, and *yaw*



https://www.ceva-dsp.com/ourblog/what-is-an-imu-sensor/

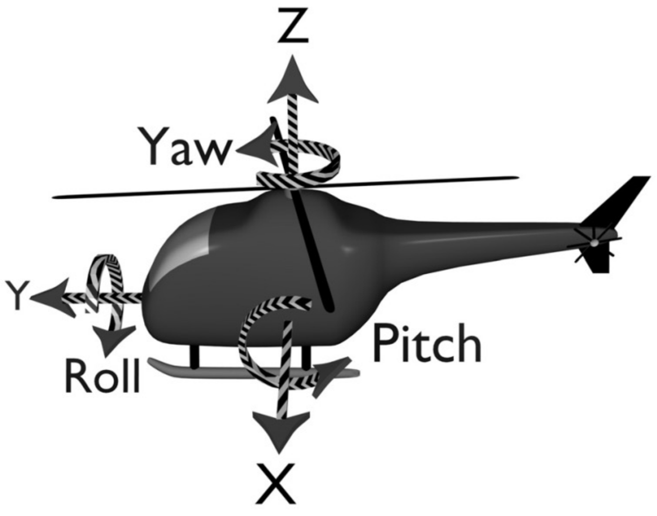
Degrees of freedom (D.O.F.)

- Definition: How many independent factors needed to specify the motion of the system?
  - The specific number of axes that a rigid body is able to freely move in three-dimensional space
  - For robots: directions of independent motions

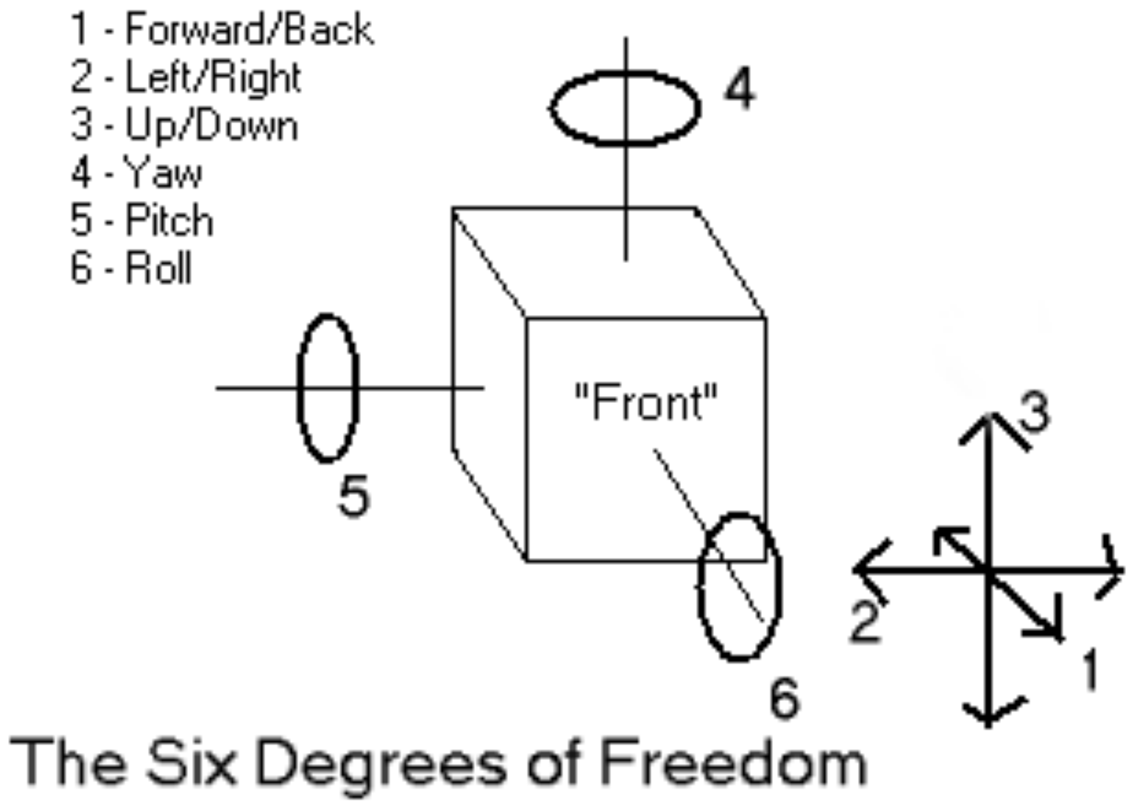


Degrees of freedom (D.O.F.)

- For a ***rigid object in space*** have:
  - The body can move straight in three dimensions:
    - Without rotation
    - on the ***X, Y*** and ***Z*** axes
    - A.K.A. Translational degrees of freedom
  - Also, it can change orientation between those axes though rotation
    - usually called ***pitch, yaw and roll***
    - ***Rotational degrees of freedom***
  - Total of 6 degrees of freedom



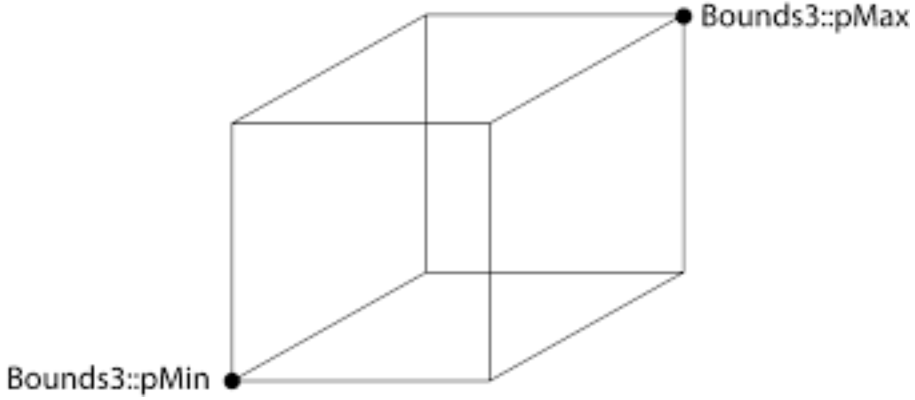
D.O.F. of a Rigid Body in space



https://en.wikipedia.org/wiki/File:6_degrees_freedom.png

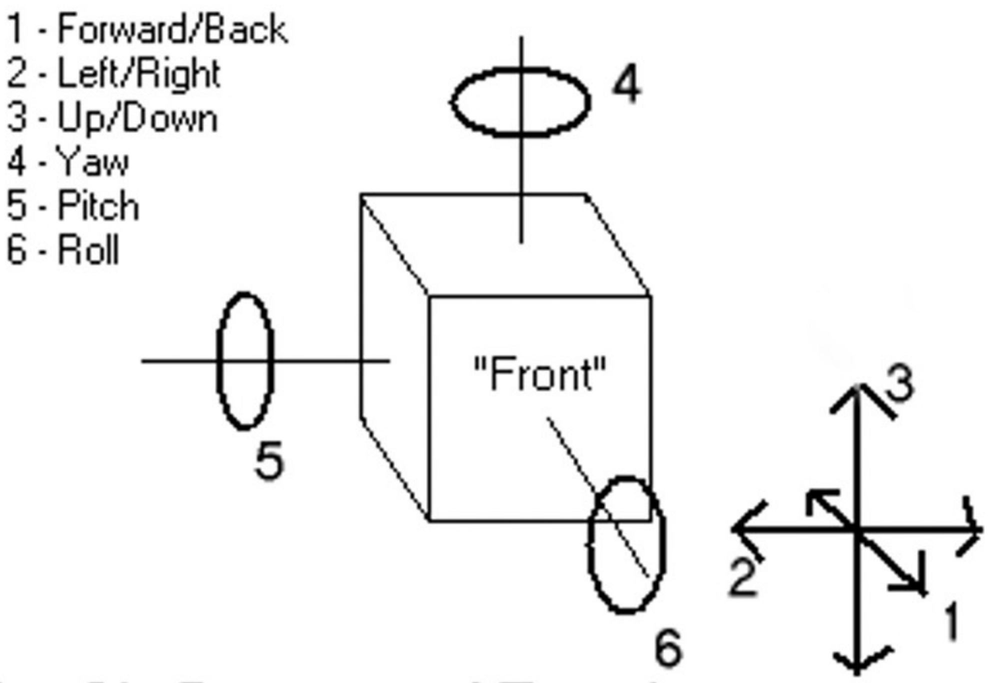
Degrees of Freedom

- How can we see this?
- Let's say we have a square object



D.O.F. of a Rigid Object in Space

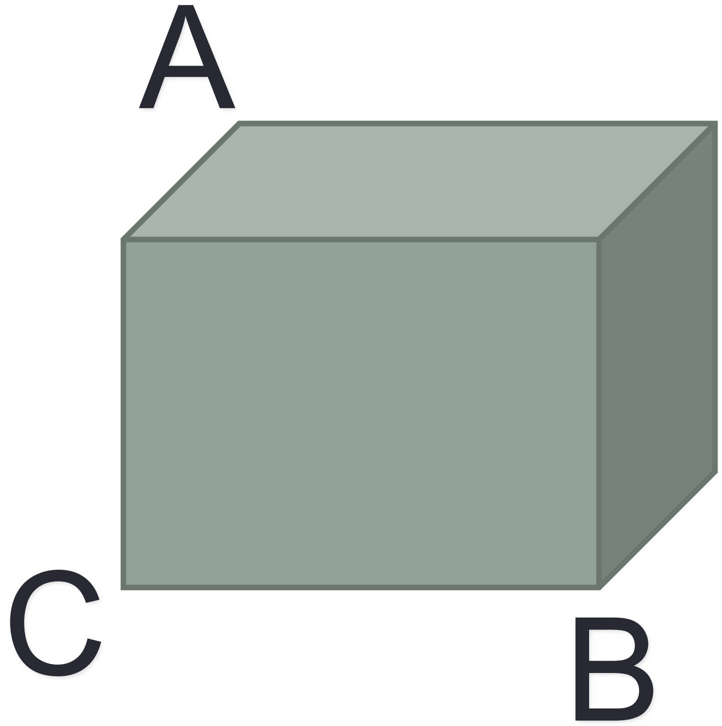
- We can first set the middle point of the cube
  - 3 Degrees of freedom – **x,y and z**
- Then, we can rotate the cube around each of the axis
  - ***pitch, yaw and roll***



D.O.F. of a Rigid Body in Space

- Alternatively, we can try to position each of the corners
  - How many D.O.F. do we have?

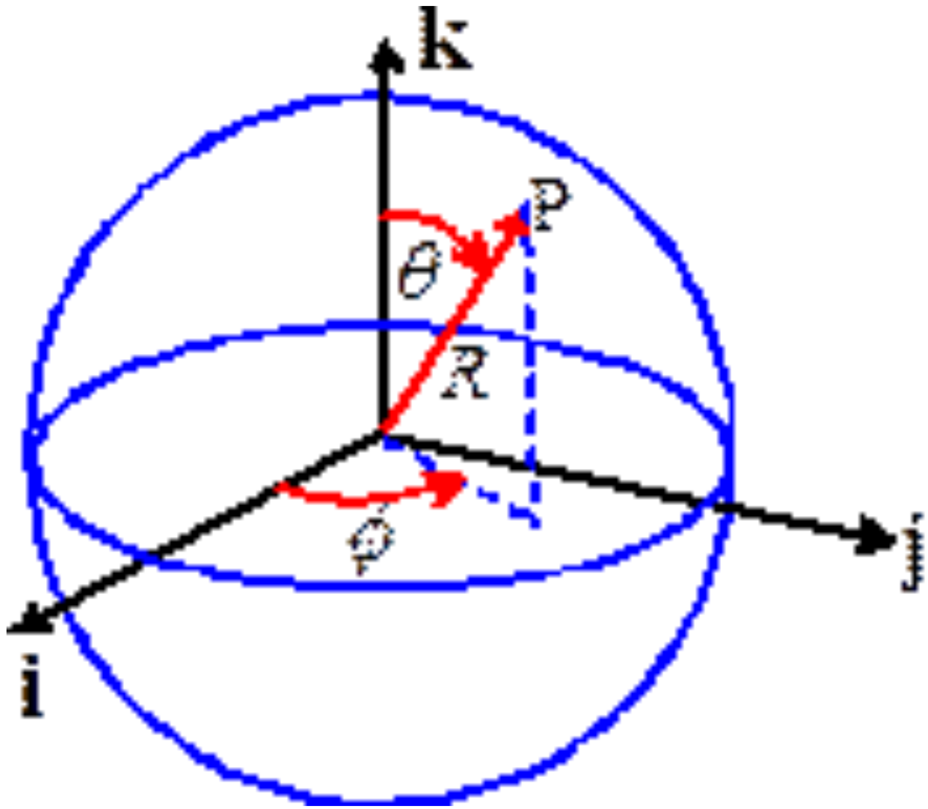
Degrees of Freedom



Degrees of Freedom

- Point A can have 3 values (x,y,z)
- Once point A is set, we want to fix point B
- However, the length between A and B is constant
  - So only two angles can be fixed
    - We have one constrain on the location of B
  - What is the constraint on B?
    - B can be located on a sphere
      - The sphere radios is the length between A and B

Degrees of Freedom

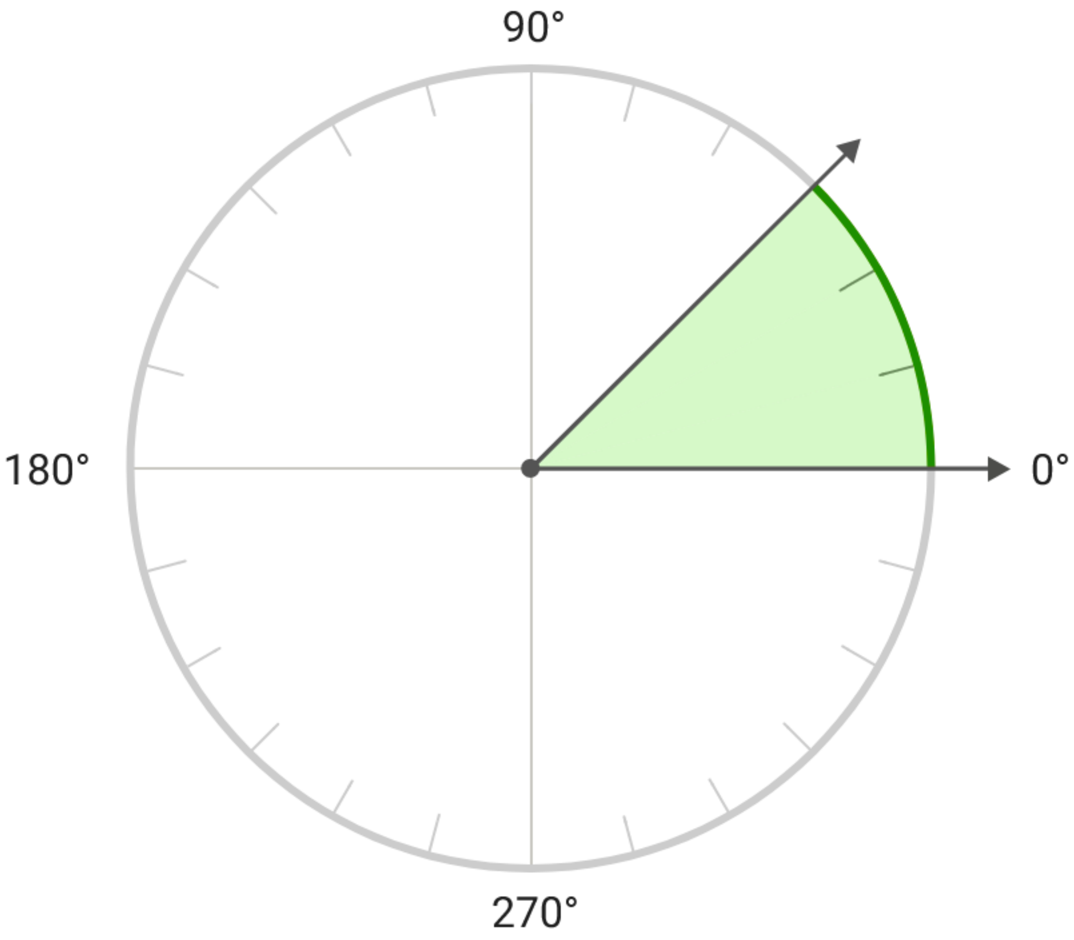


Degrees of Freedom

- Point A can have 3 values (x,y,z)
- Once point A is set, we want to fix point B
- However, the length between A and B is constant
  - So only two angles can be fixed
    - We have one constrain on the location of B

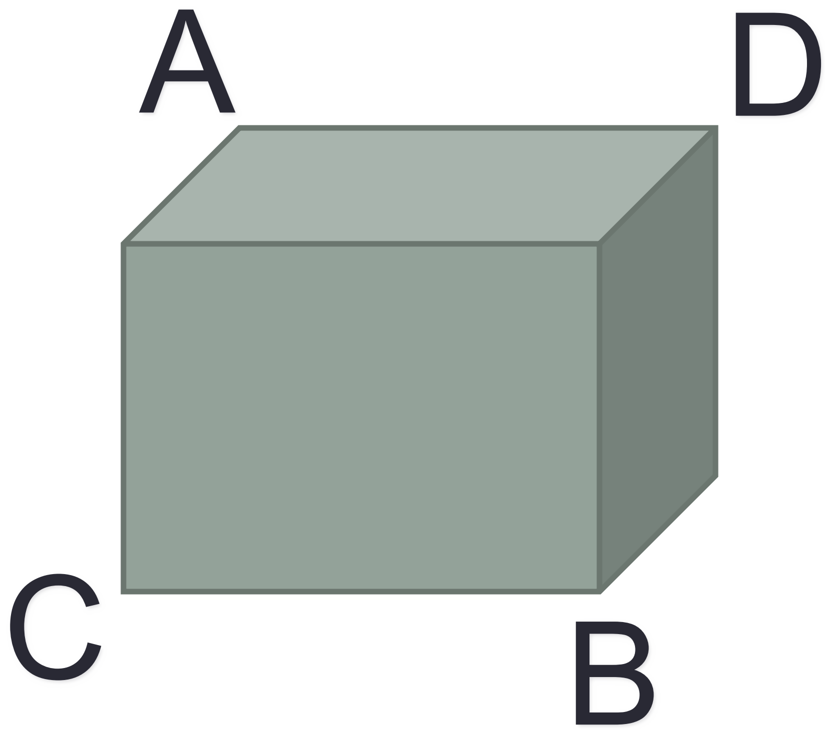
Degrees of Freedom

- Once A and B are fixed, only one angle is possible for point C
  - One additional degree of freedom
    - We have two constraints on the location of C
      - All points will be on a circle with consant radius
        - One D.O.F. = angle



https://www.ixl.com/math/grade-4/measure-angles-on-a-circle

Degrees of Freedom



Degrees of Freedom

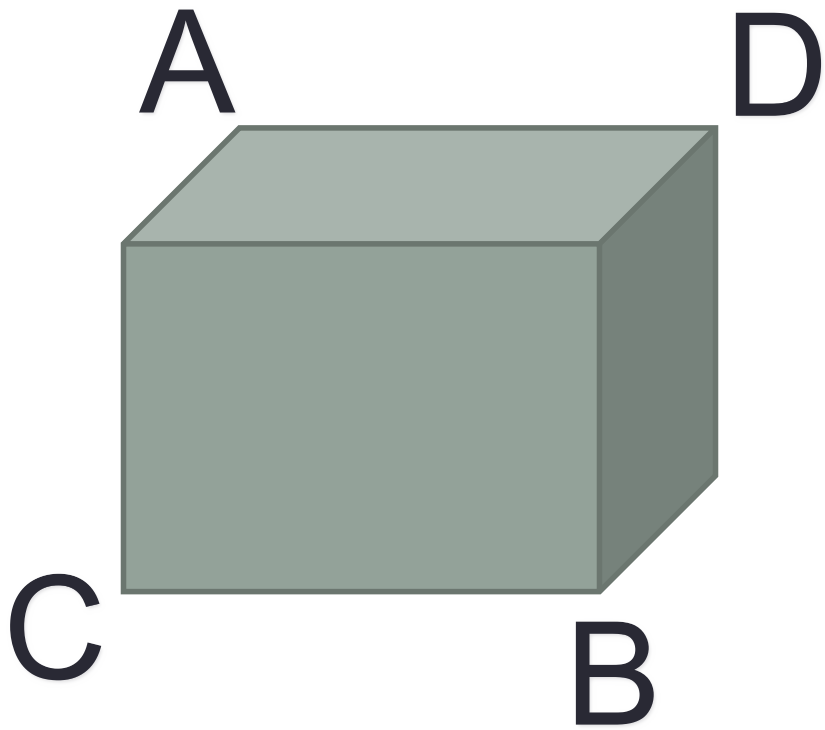
- How many possibilities for point D?
  - Zero D.O.F. – only one possible location

Degrees of Freedom

- $\# \; of \; D.O.F. = \sum (Freedom \; of \; Points) - \# \; of \; independent \; constraints$

- Since robot is made of rigid bodies:
- $\# \; of \; D.O.F. = \sum (Freedom \; of \; bodies) - \# \; of \; independent \; constraints$

Degrees of Freedom



Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	?	?	
B			
C			
D			

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	?
B			
C			
D			

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	3
B	?	?	
C			
D			

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	3
B	3	1	?
C			
D			

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	3
B	3	1	2
C	?	?	
D			

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	3
B	3	1	2
C	3	2	?
D	?	?	

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	3
B	3	1	2
C	3	2	1
D	3	3	0

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	3
B	3	1	2
C	3	2	1
D	3	3	0
Total Degrees of Freedom			?

Degrees of Freedom

Point	Coordinates	Indep. constraints	# Actual freedoms
A	3	0	3
B	3	1	2
C	3	2	1
D	3	3	0
Total Degrees of Freedom			6

Degrees of Freedom

- How many degrees of freedom will be in 4-dimensional space?
  - 10 degrees of freedom

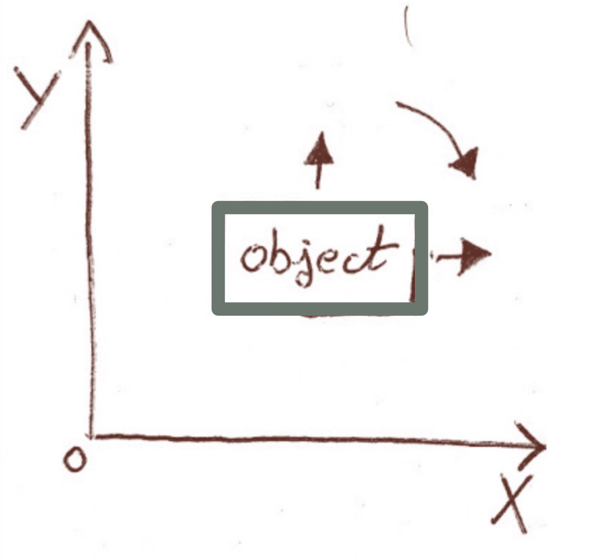
Degrees of Freedom

- $\# \ of \ D.O.F. = \sum (Freedom \ of \ Points) - \# \ of \ independent \ constraints$

- Since robot is made of rigid bodies:
- $\# \ of \ D.O.F. = \sum (Freedom \ of \ bodies) - \# \ of \ independent \ constraints$

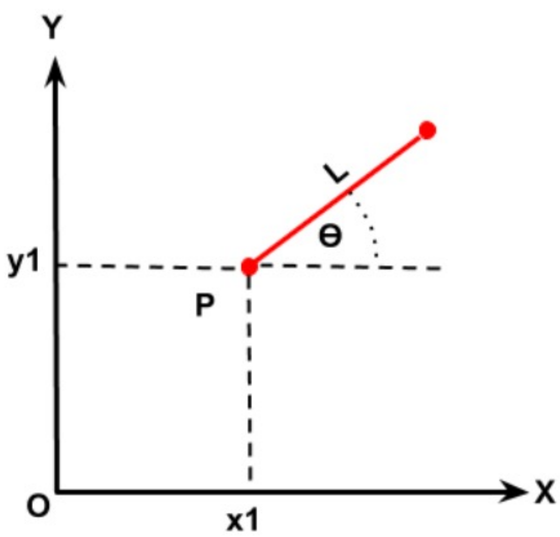
Degrees of Freedom

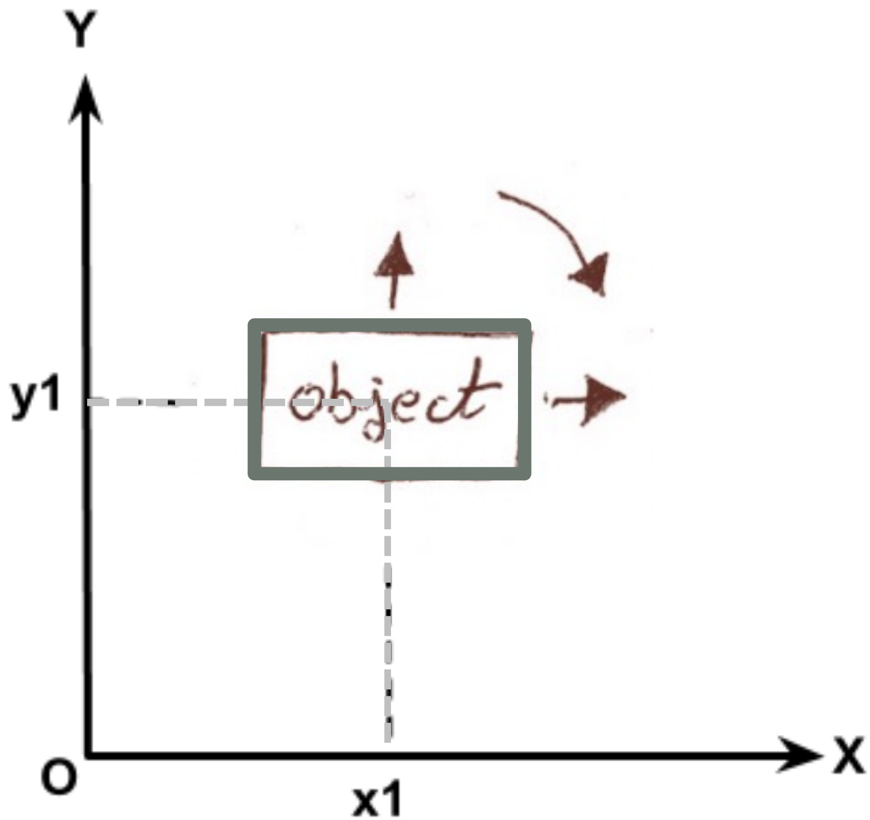
- How many degrees of freedom are for an object on a linear space?
  - I.e., a car
- Linear space is a 2D space
- 3 degrees of freedom
  - 2 on the linear space (x,y)
  - One is the angle



https://www.quora.com/How-many-degrees-of-freedom-of-rigid-body

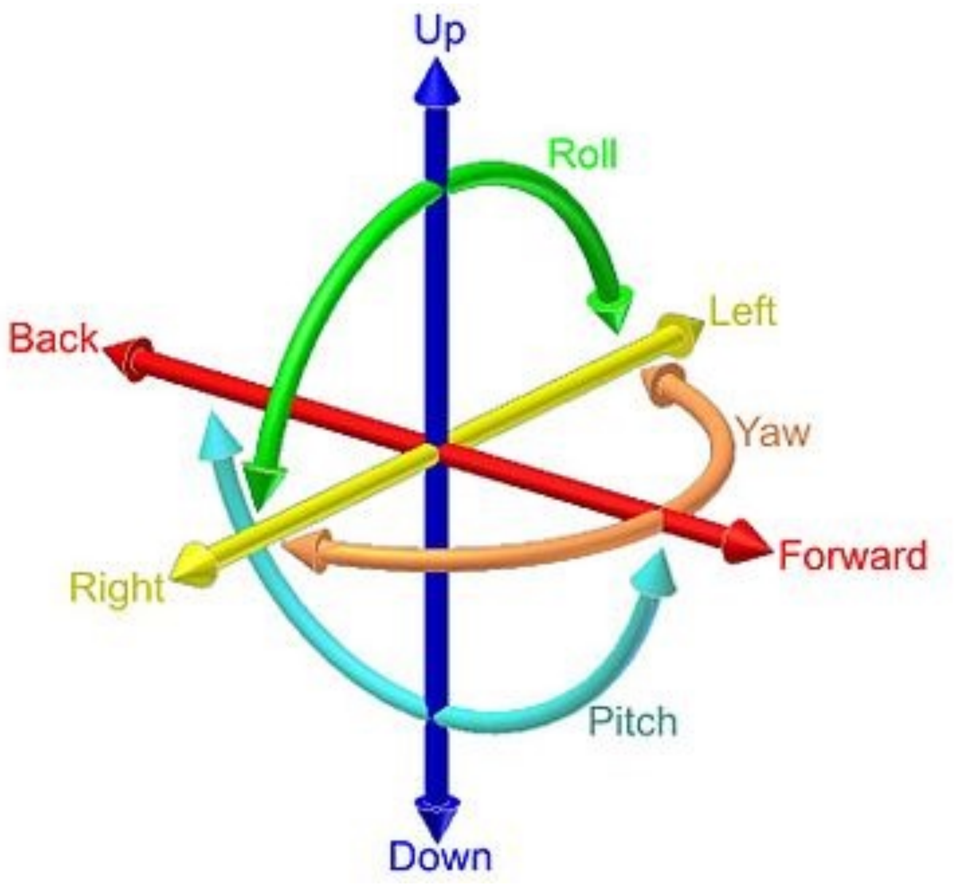
Degrees of Freedom – 2D space



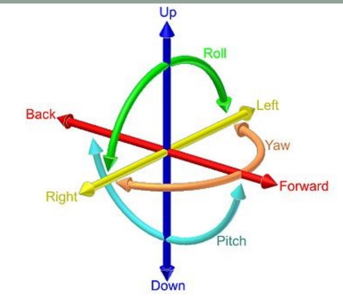


https://www.smlease.com/entries/mechanism/what-is-degree-of-freedom-dof-in-mechanics/
https://www.quora.com/How-many-degrees-of-freedom-of-rigid-body

Degrees of Freedom



Degrees of Freedom



- Roll, pitch, yaw:
  - Degrees of freedom used for orientation
  - ***Yaw*** refers to the direction in which the body is facing
    - i.e., its orientation within the xy plane
  - ***Roll*** refers to whether the body is upside-down or not
    - i.e., its orientation within the yz plane
  - ***Pitch*** refers to whether the body is tilted
    - i.e., its orientation within the xz plane

https://en.wikipedia.org/wiki/Six_degrees_of_freedom

Degrees of Freedom

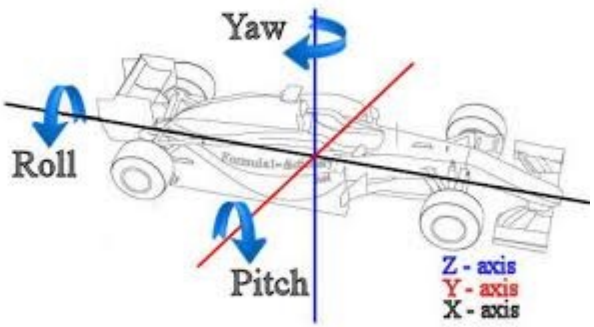
- Degrees of Freedom
- Example: Degrees of Freedom - 6 axis robot

Controllable D.O.F.’s

- If the object can move in each direction of the D.O.F., it is ***Holonomic***
  - All are controllable
- For this, it needs to have an actuator in each direction

Degrees of freedom (D.O.F.)

- How many D.O.F. to specify movement of a vehicle on a flat surface?
  - Three: X,Y and yaw (turn in x-y dimension)
- How many Controllable D.O.F.'s?
  - In which direction can driver drive the car?

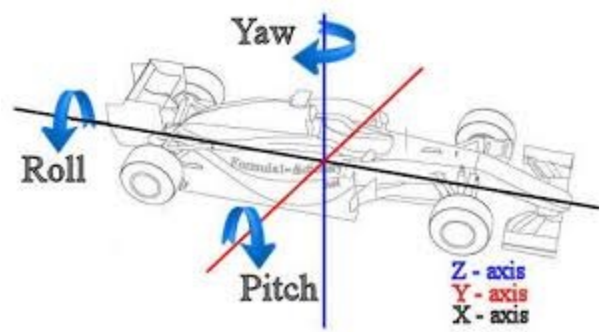


http://www.f6tech.com/our-solution/, http://www.formula1-dictionary.net/motions_of_f1_car.html


QUESTIONS

Degrees of freedom (D.O.F.)

- How many D.O.F. to specify movement of a vehicle on a flat surface?
  - Three: X,Y and yaw (turn in x-y dimension)
- How many Controllable D.O.F.'s?
  - In which direction can driver drive the car?
  - X and yaw



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Degrees of freedom (D.O.F.)

- Is a car ***Holonomic***?

- Yes, a car is holonomic
- No, a car is not holonomic
- Depending on the car design


QUESTIONS

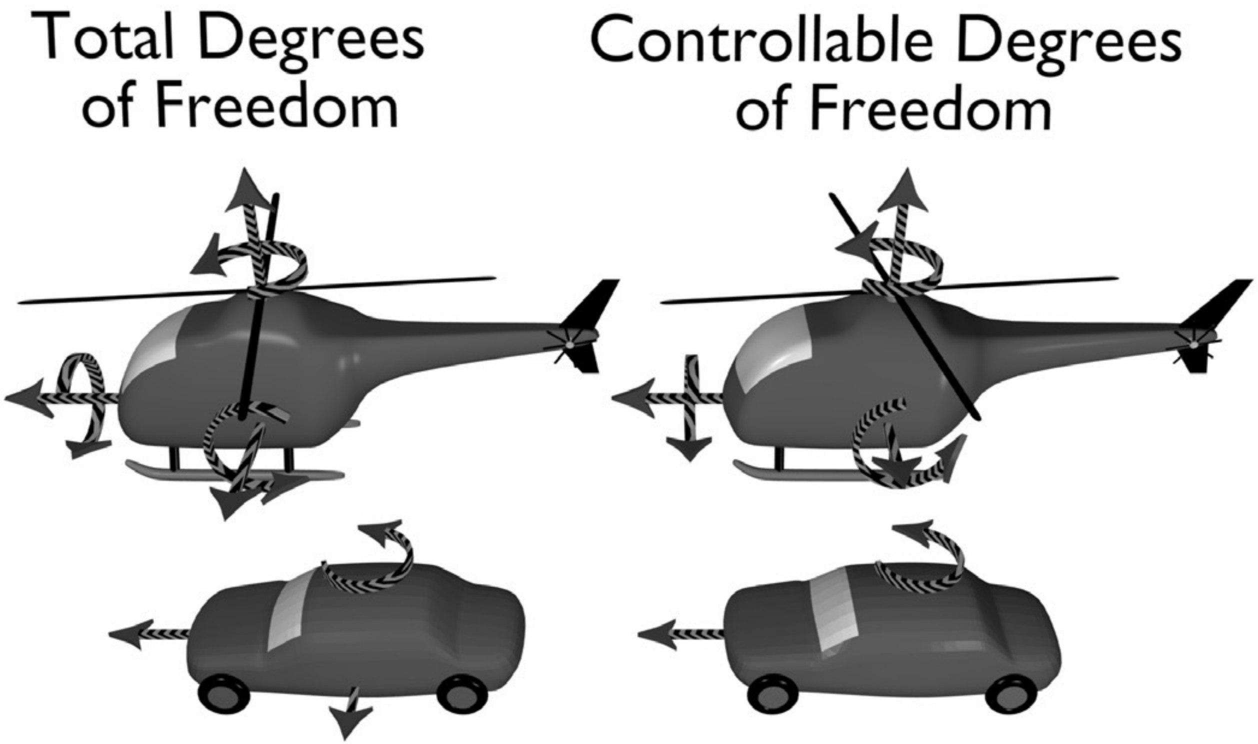
Degrees of freedom (D.O.F.)

- Is a car ***Holonomic***?

- Yes, a car is holonomic
- No, a car is not holonomic
- Depending on the car design

- Why?
  - A car can not drive sideways – not holonomic
    - Only controllable in two dimensions

Degrees of freedom (D.O.F.)



Robot's Variables Affecting D.O.F.

- Number of joints/articulations/moving parts
  - If parts are linked, fewer parameters needed to specify them.
- Number of Individually controlled moving part
  - Need parameters for each to define configuration
  - Often described as 'controllable degrees of freedom'
  - But some may be *redundent*
    - Two movements may be in the same axis

D.O.F. OF A ROBOT

Degrees of Freedom

- $\# \; of \; D.O.F. = \sum (Freedom \; of \; Points) - \# \; of \; independent \; constraints$

- Since robot is made of rigid bodies:
- $\# \; of \; D.O.F. = \sum (Freedom \; of \; bodies) - \# \; of \; independent \; constraints$

Degrees of Freedom

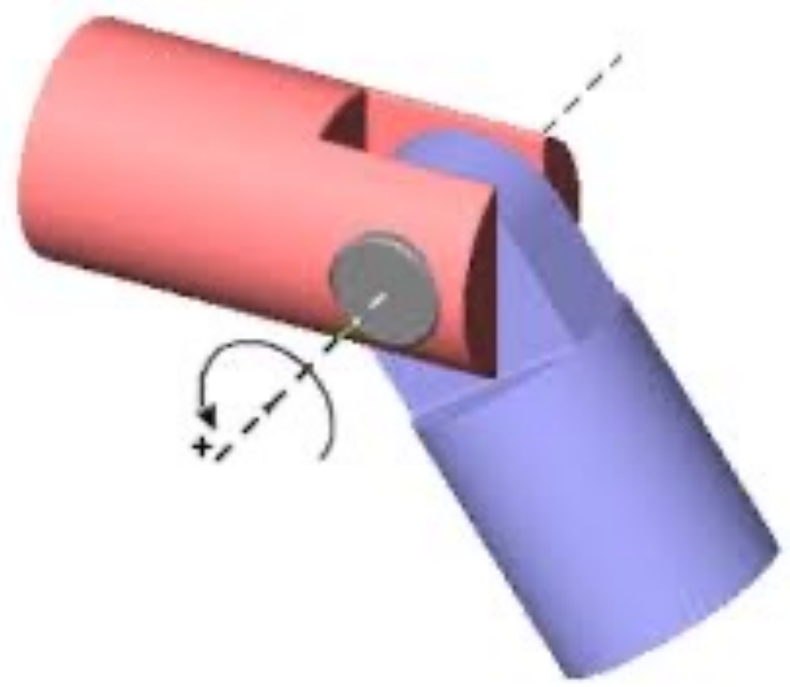
- Where do the constraints come from?
  - For a robot?
    - Typically, from joints

ROBOTS JOINTS

Robot Joints

- Revolute Joint:
  - 5 constraints
  - 1 Degree of freedom
    - Angle of rotation
  - Revolute Joint

Revolute joint – Degrees of Freedom

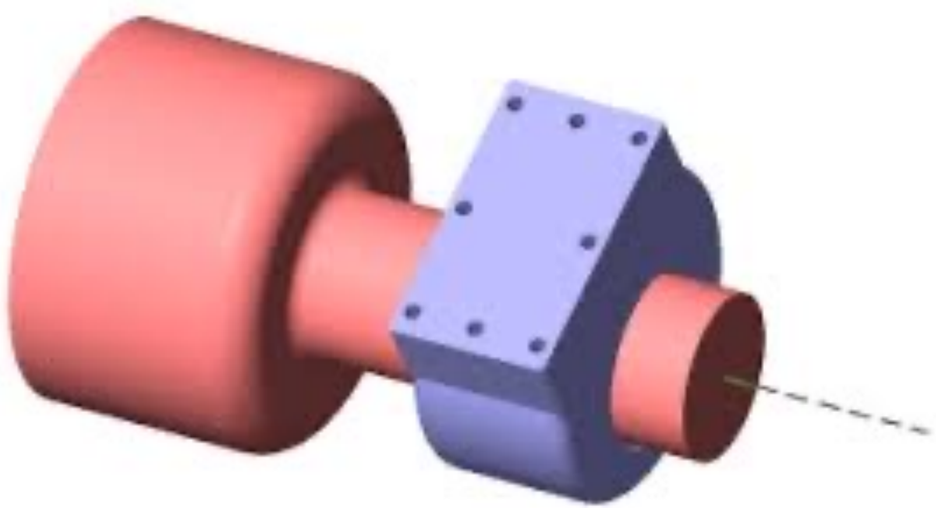


https://www.mathworks.com/help/physmod/sm/mech/ref/revolute.html

Robot Joints

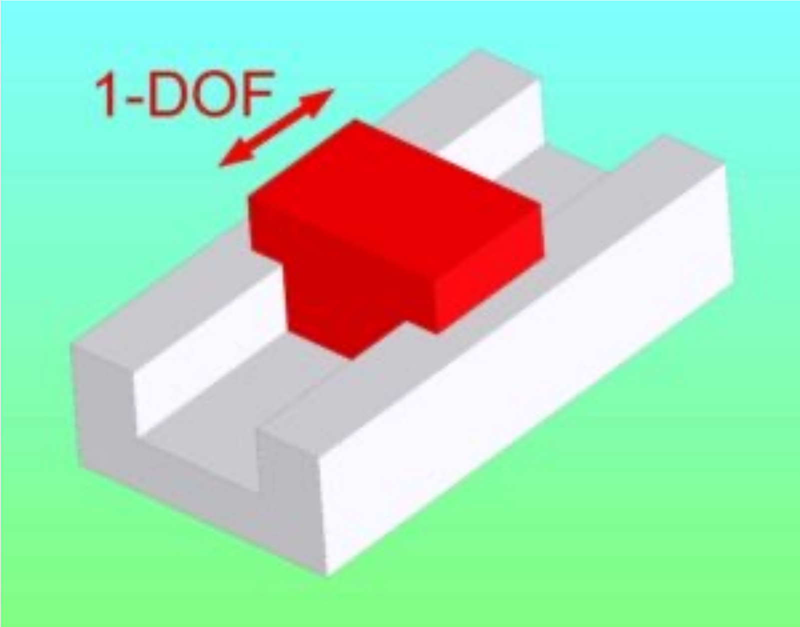
- Prismatic joint:
  - A.K.A. linear joint
  - 5 constraints
  - 1 Degree of freedom
  - Prismatic Joint

Prismatic joint



- https://www.mathworks.com/help/physmod/sm/mech/ref/cylindrical.html

Prismatic Joint

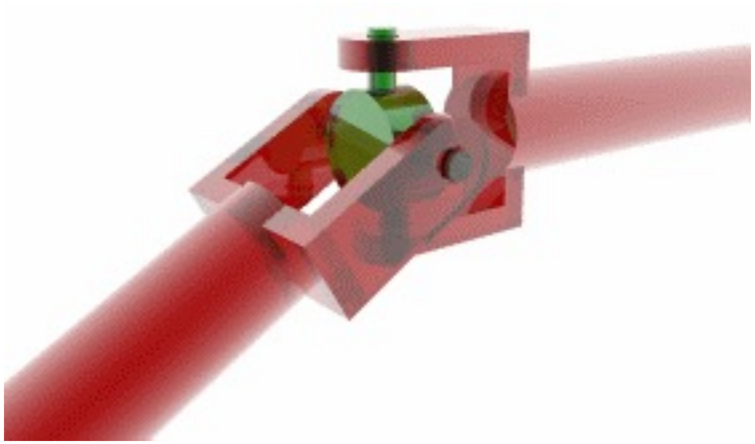


- https://fastenerengineering.com/what-is-a-prismatic-joint/

Robot Joints

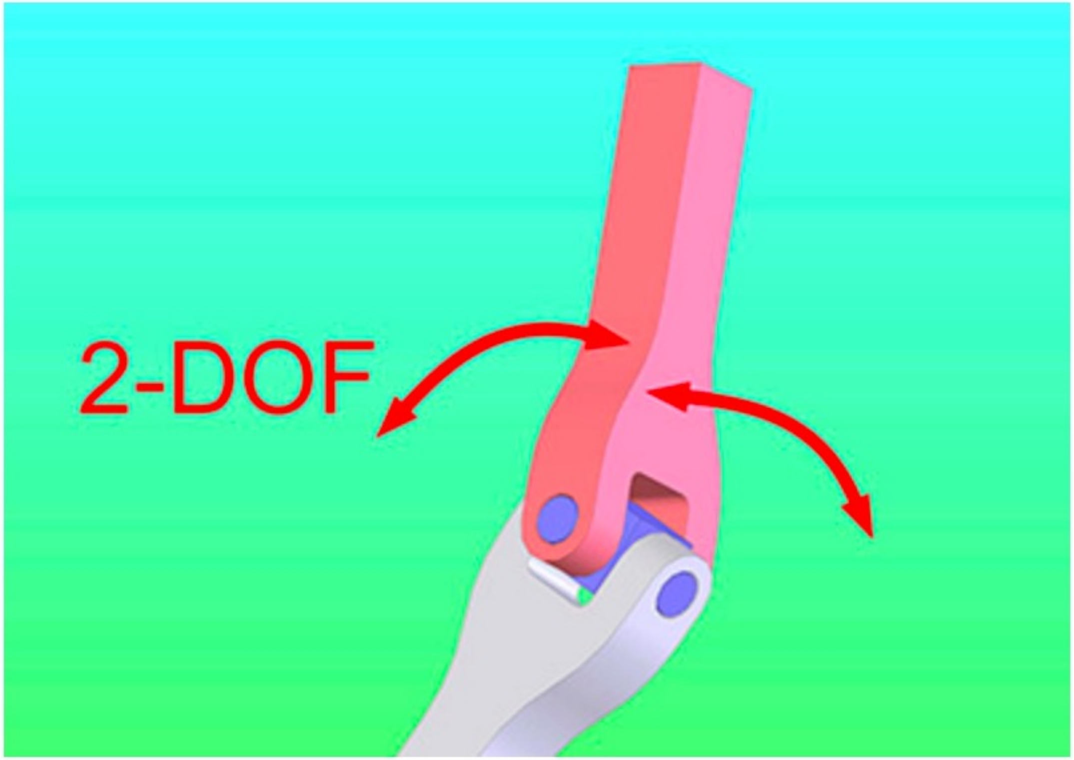
- Universal Joint:
  - 4 constraints
  - 2 degrees of freedom
  - Universal joint, Universal joint 2

Universal Joint



https://en.wikipedia.org/wiki/Universal_joint

Universal Joint

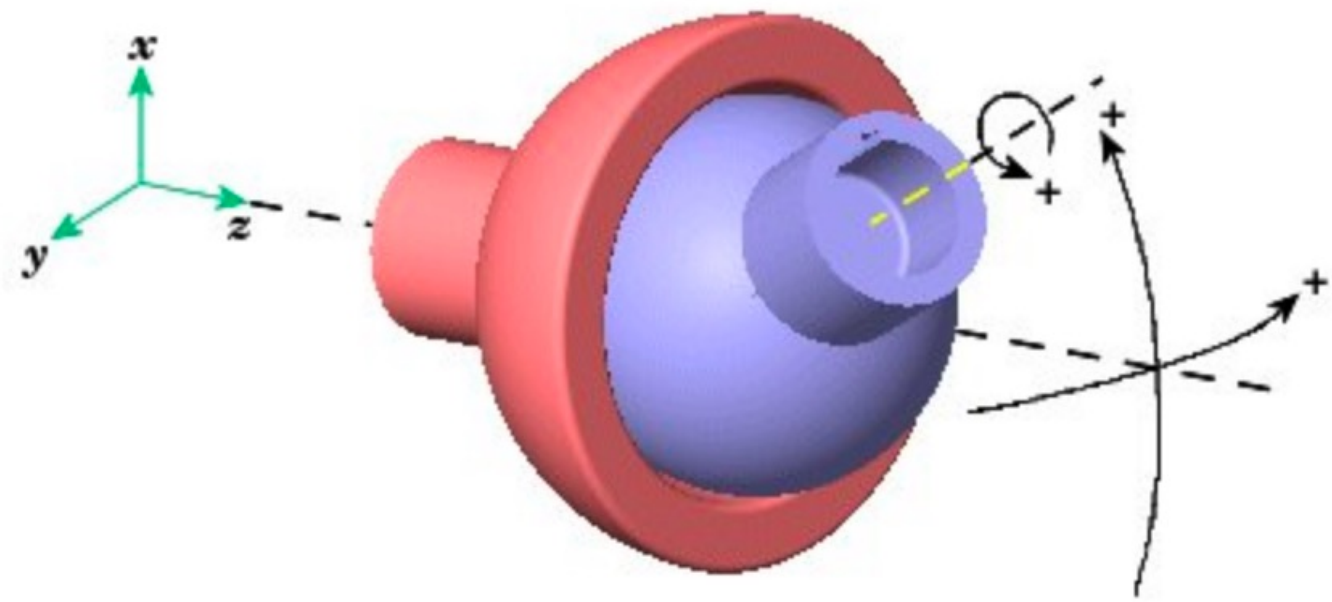


A universal joint may also known as a universal coupling, a

Robot Joints

- Spherical joint:
  - 3 constraints
  - 3 degrees of freedom
  - Spherical Joint

Spherical Joint



- https://www.researchgate.net/publication/311414943_Research_on_Oscillation-Free_Robust_Control_for_Active_Joint_Dental_Automation/figures?lo=1

D.O.F. of Robot Joints

Joint Type	D.O.F.	# CONSTRAINTS
Revolute	?	?
Prismatic	?	?
Universal	?	?
Spherical	?	?

D.O.F. of Robot Joints

Joint Type	D.O.F.	# CONSTRAINTS
Revolute	?	5
Prismatic	?	5
Universal	?	4
Spherical	?	3

D.O.F. of Robot Joints

Joint Type	D.O.F.	# CONSTRAINTS
Revolute	1	5
Prismatic	1	5
Universal	2	4
Spherical	3	3

Robot's D.O.F.

- Total D.O.F. = $\Sigma\,(freedom\ of\ body\ parts)\ -\ \#\ of\ independent\ constraints$

- $N\ = \#\ of\ bodies, not\ including\ ground$
- $J\ =\ \ \#\ of\ joints$
- $m\ = 6\ for\ spatial\ bodies, 3\ for\ planar$

- $D.O.F. = m\ *N\ - \Sigma_{i=1}^{J}\ c_i$


QUESTIONS