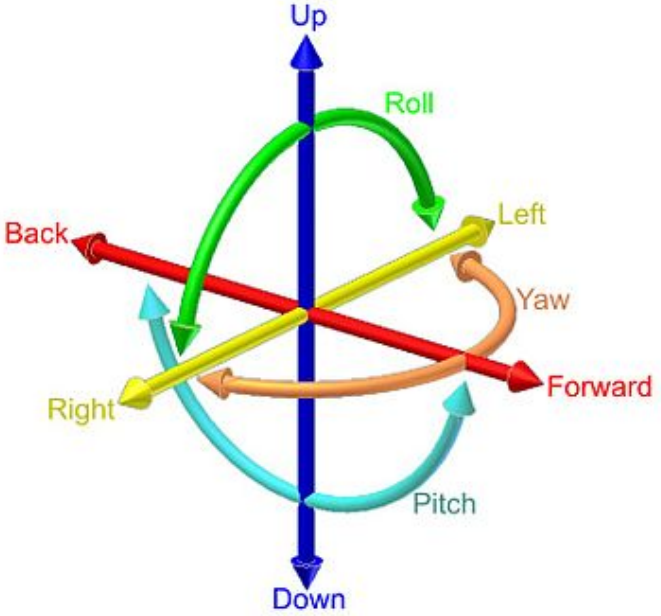
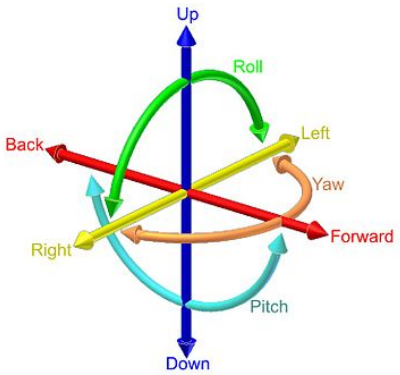
EXPLORE ROBOTICS – CISC 1003

DEGREES OF FREEDOM - REVIEW



Degrees of Freedom

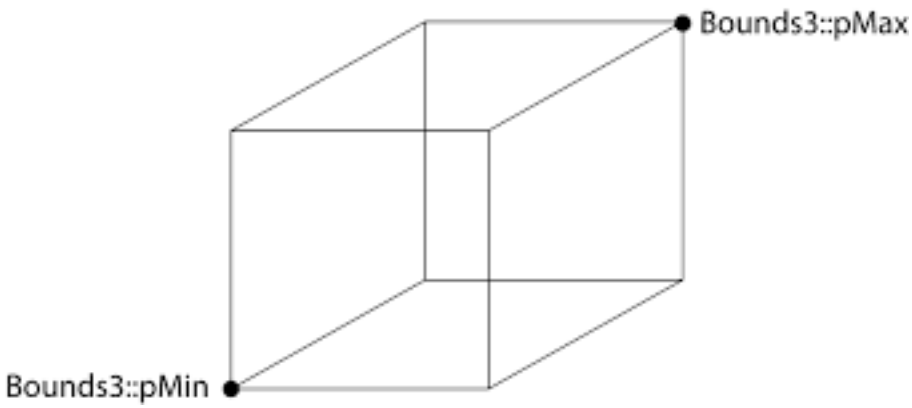
- Number of directions in which robot motion can be controlled
- Free body in space has 6 degrees of freedom:
  - Three for position (x,y,z)
  - Three for orientation (roll, pitch, yaw)



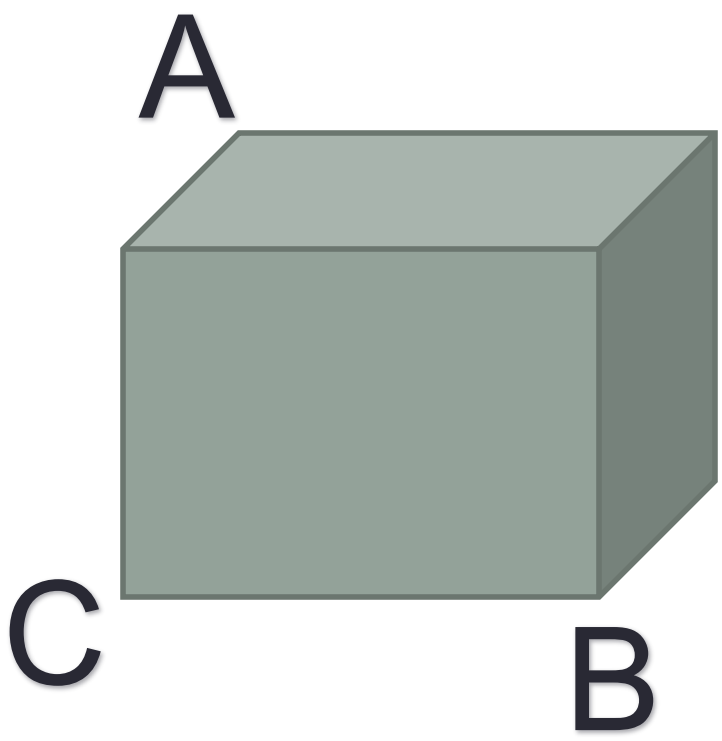
https://en.wikipedia.org/wiki/Six_degrees_of_freedom

Degrees of Freedom

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



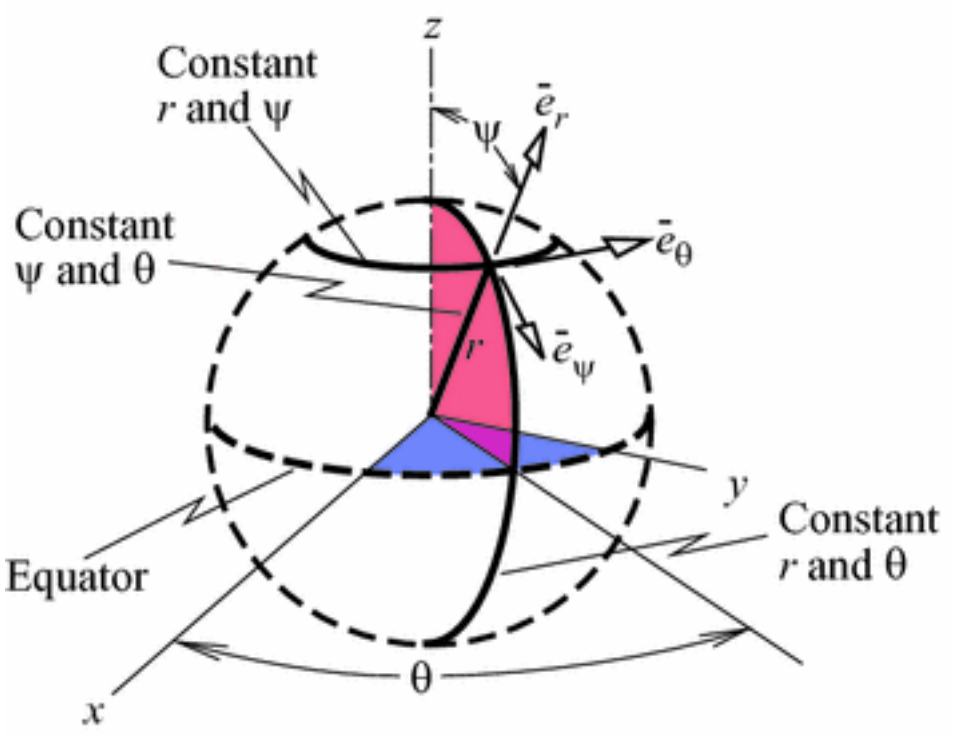
Degrees of Freedom



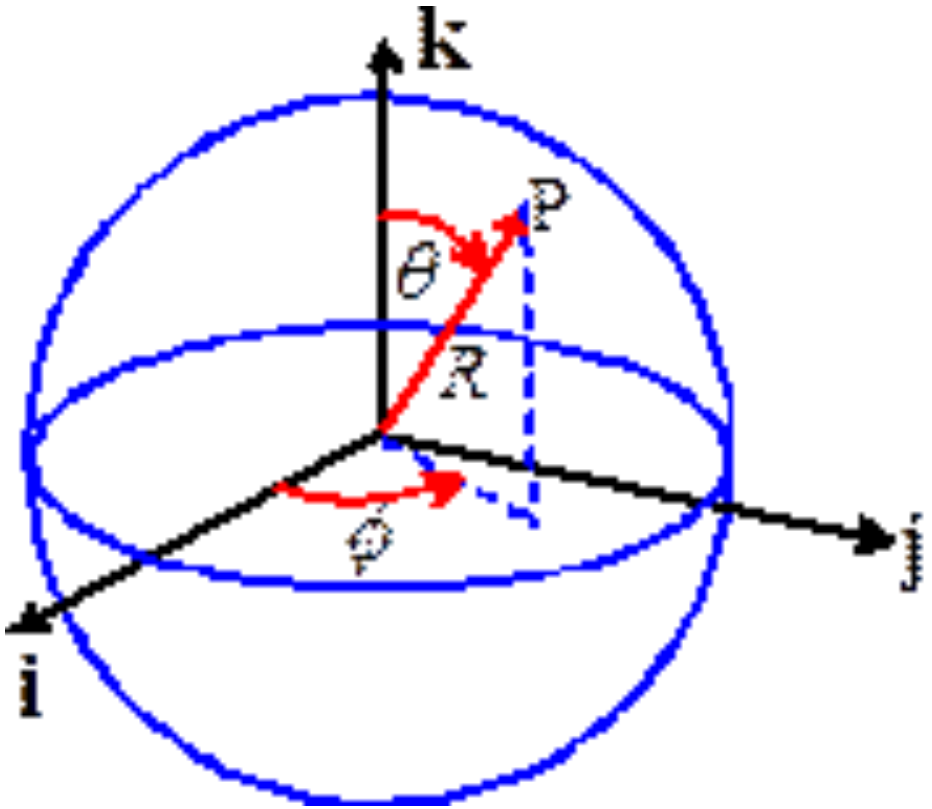
Degrees of Freedom

- 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

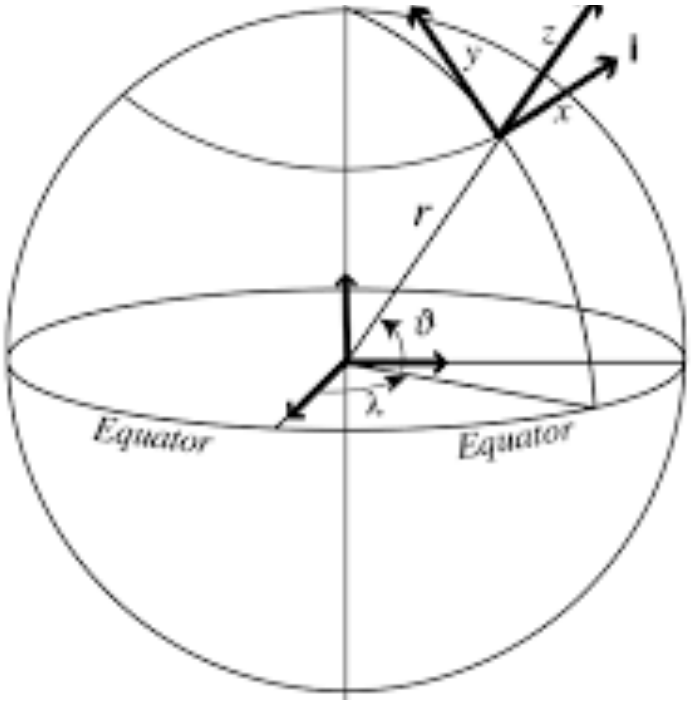
Degrees of Freedom



Degrees of Freedom



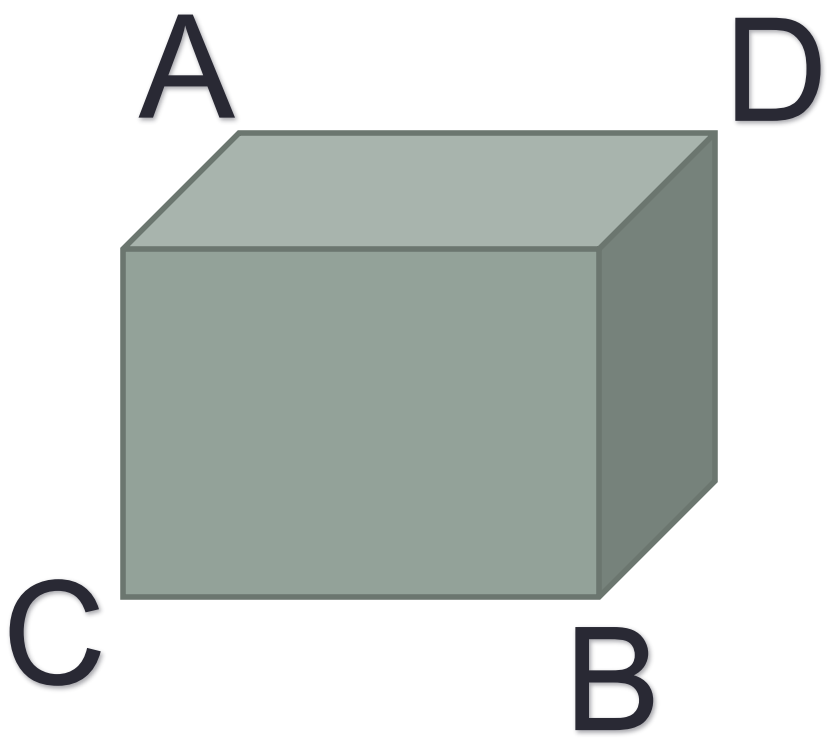
Degrees of Freedom



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
- 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

Degrees of Freedom



Degrees of Freedom

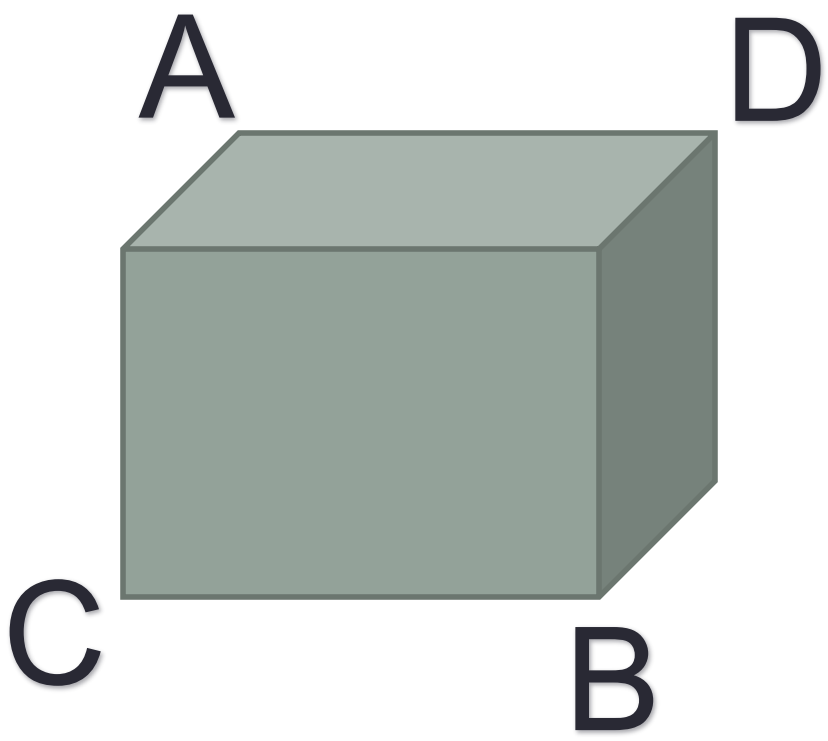
- How many possibilities for point D?
  - Zero D.O.F. – only one possible location

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

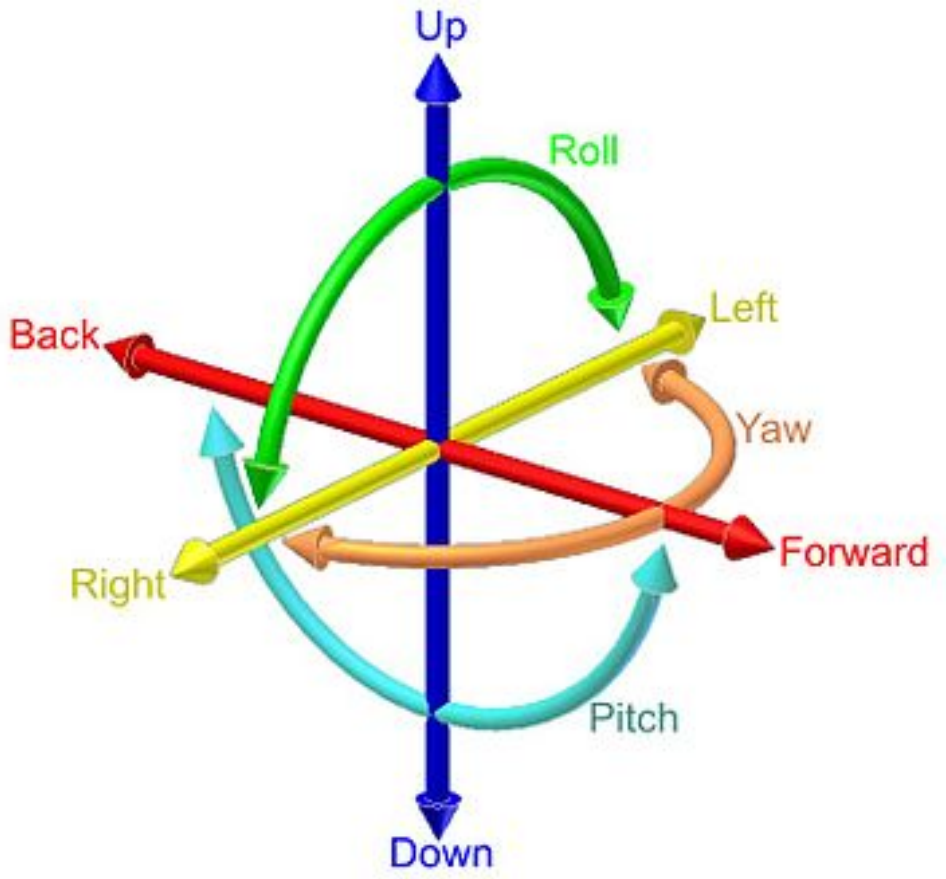
- $\#\ of\ D.O.F. = \sum (Freedom\ of\ Points) - \#\ of\ independent\ constraints$

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

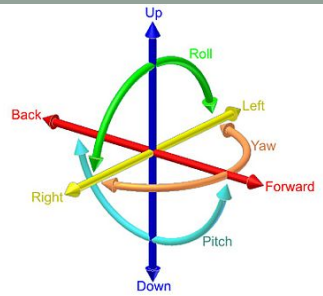
Degrees of Freedom

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

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

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

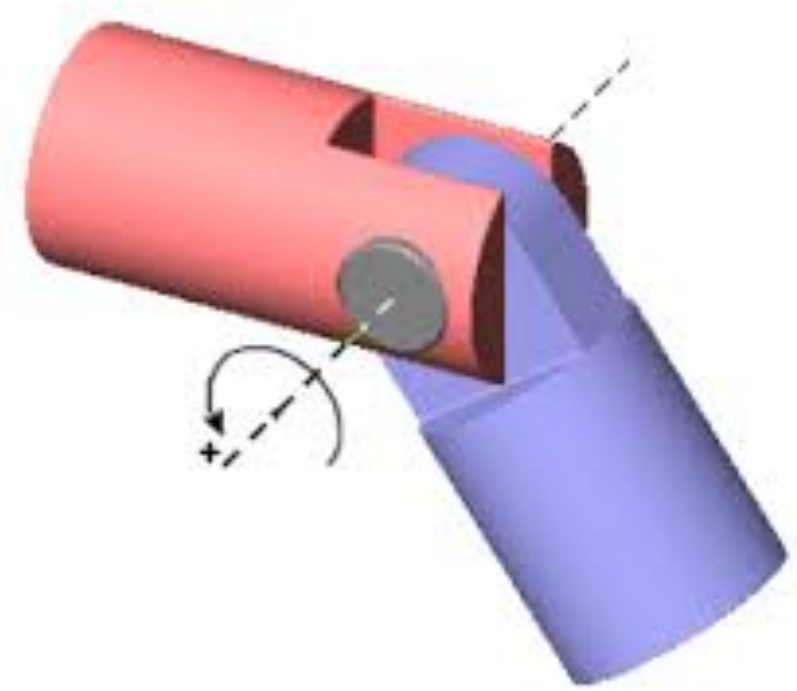
Degrees of Freedom

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

Robot Joints

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

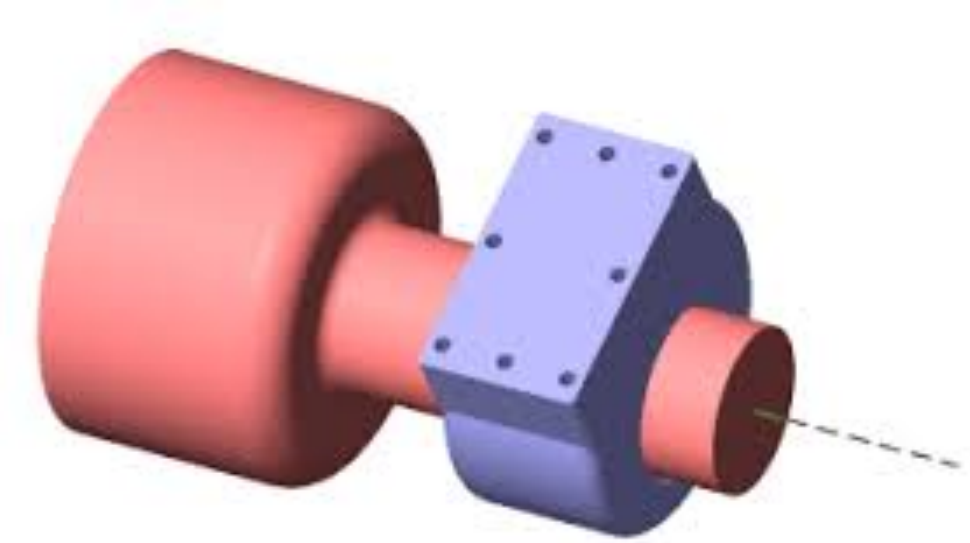
Revolute joint – Degrees of Freedom



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

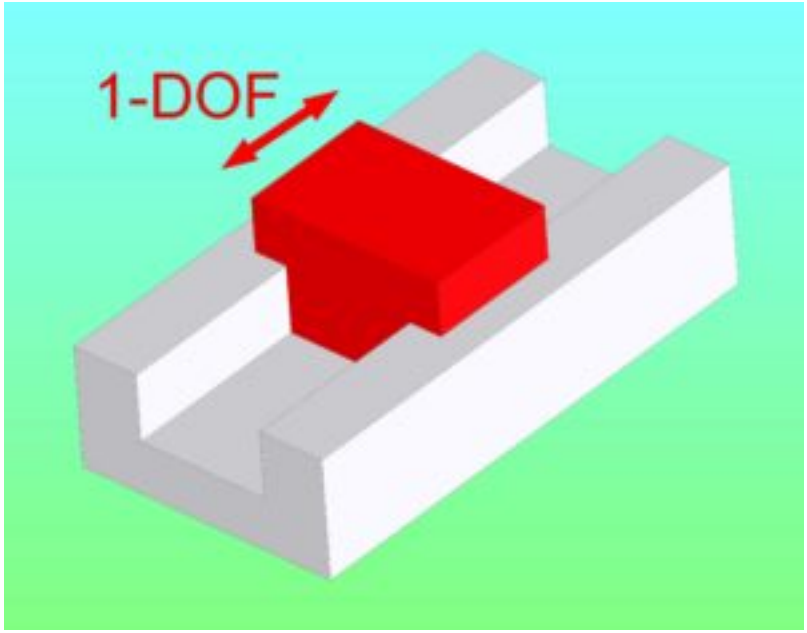
Robot Joints

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



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

Prismatic Joint

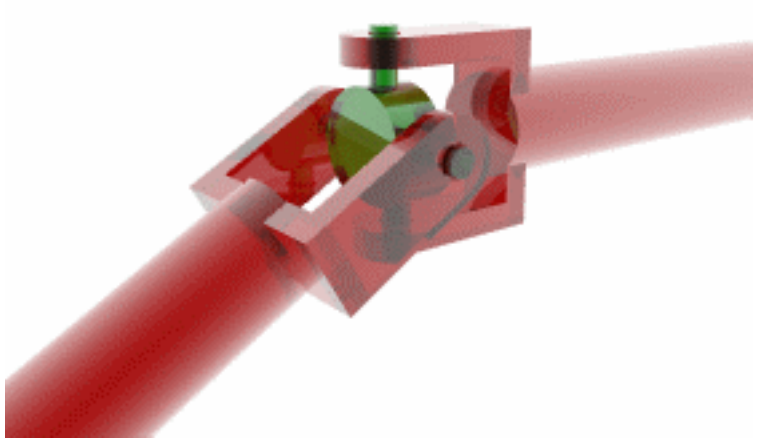


- https://fastenerengineering.com/what-is-a-prismatic-joint/

Robot Joints

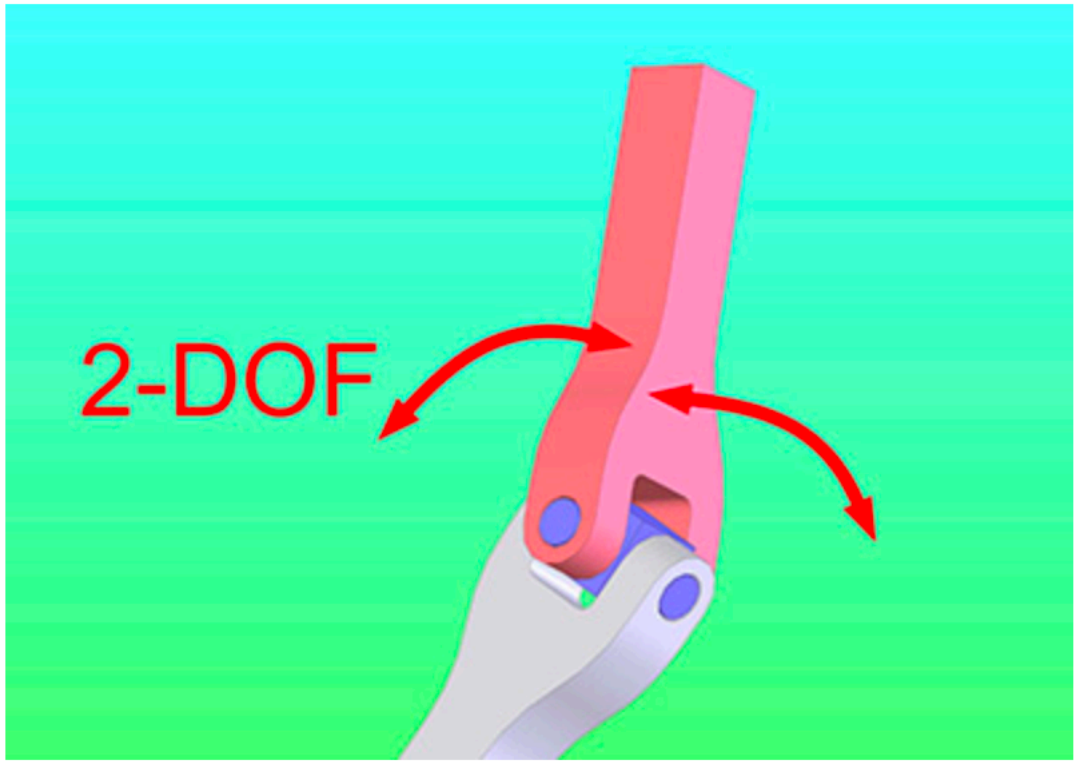
- Universal Joint:
  - 4 constraints
  - 2 degrees of freedom
  - Universal joint, Universal joint 2

Universal Joint



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

Universal Joint

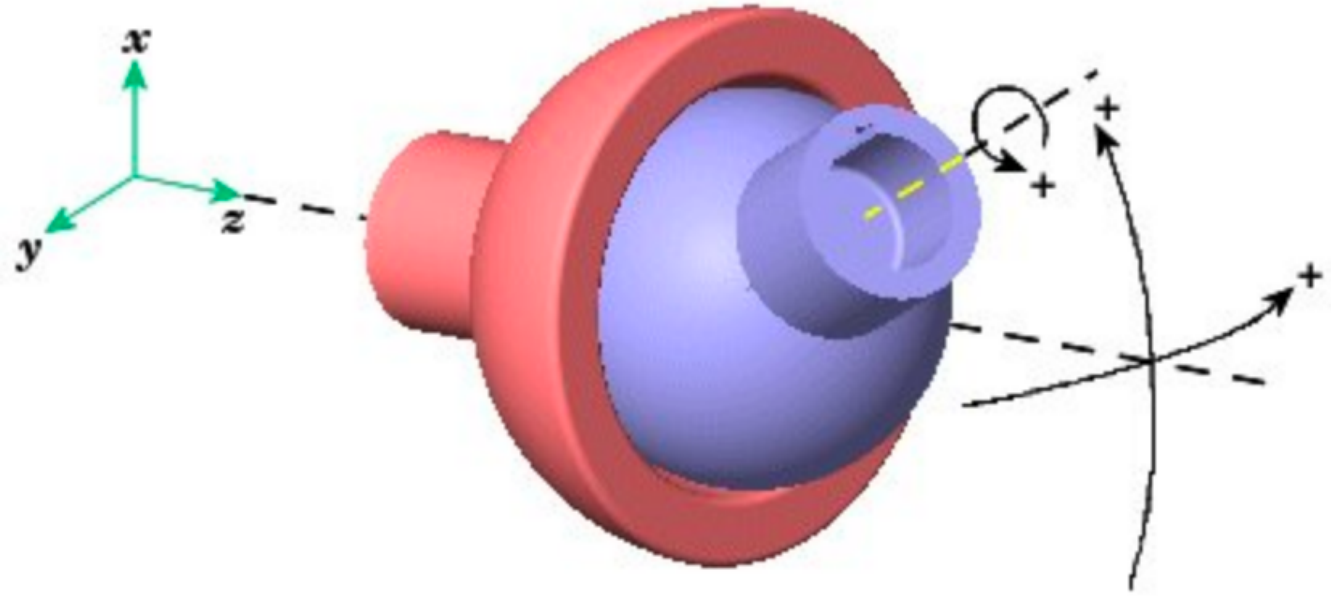


A universal joint may also known as a universal coupling, a

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. = $\Sigma\,(freedom\ of\ body\ parts)\ -$ $\#\ of\ independt\ constraints$

- $N = \#\ of\ bodies, including\ ground$
- $J =\ \ \#\ of\ joints$
- $m = 6\ for\ spatial\ bodies, 3\ for\ planar$

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


QUESTIONS

Robot's D.O.F.

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

- $N = \#\ of\ bodies, including\ ground$
- $J =\ \ \#\ of\ joints$
- $m = 6\ for\ spatial\ bodies, 3\ for\ planar$

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

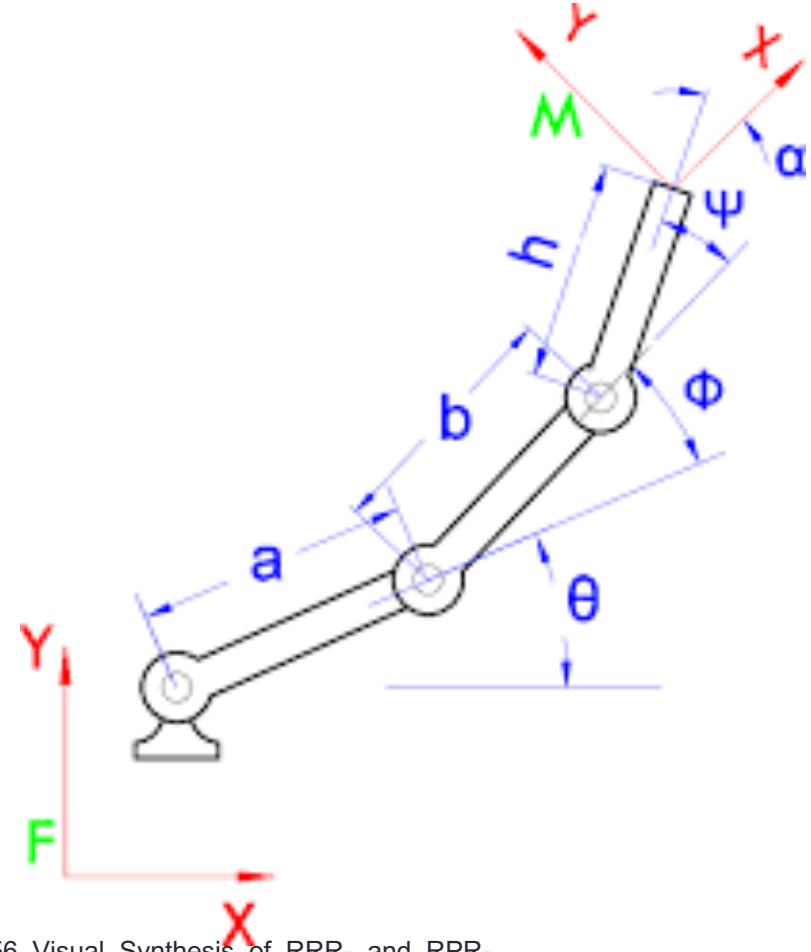
Grubler's formula

- Assuming all constraints are independent:
- $$D.O.F. = m * (N-1) - \Sigma_{i=1}^{J} c_i =$$
$$m * (N-1) - \Sigma_{i=1}^{J} (m - f_i) =$$
$$m * (N-1-J) + \Sigma_{i=1}^{J} f_i$$

  - $N = \#\ of\ bodies\ (links), including\ ground\ (frame)$
  - $J = \ \#\ of\ joints$
  - $m = 6\ for\ spatial\ bodies, 3\ for\ planar$
  - $f_i = degrees\ of\ freedom\ of\ joint\ _i$

3R serial “open-chain” robot

- Planar robot with 3 Revolute joints



https://www.researchgate.net/publication/267489856_Visual_Synthesis_of_RRR-_and_RPR-Legged_Planar_Parallel_Manipulators_Using_Constraint_Manifold_Geometry

3R serial “open-chain” robot

- This is a planar robot:
  - $m = 3,$
  - $N = 4,\ J = 3,$

- $D.O.F. = m * (N - 1 - J) + \Sigma_{i=1}^{J} f_i =$
  $(3 * (4 - 1 - 3) + 3 = 3$

Degrees of Freedom

- Degrees of freedom


QUESTIONS