Introduction to Robotics

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THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

Robotics Background Outline

Introduction, Concepts
this presentation

Motion Planning
Alan's presentation

Control
Dhruv's presentation

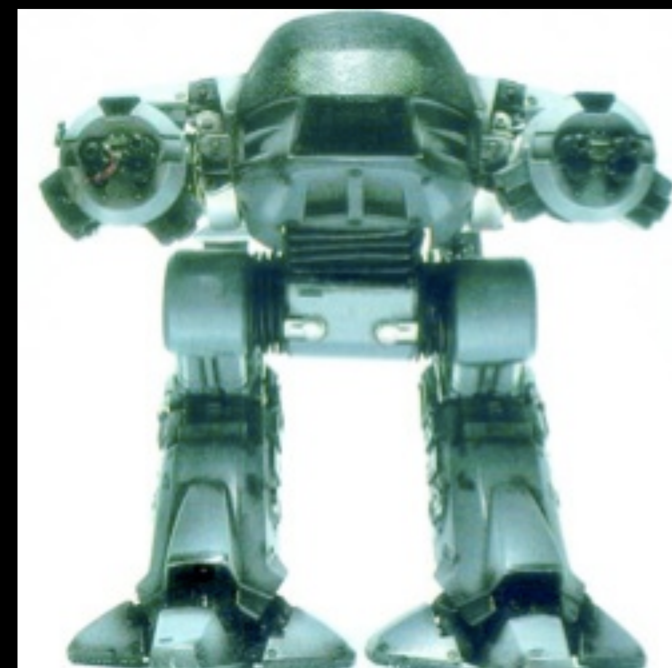
Case-study
Hannah's presentation

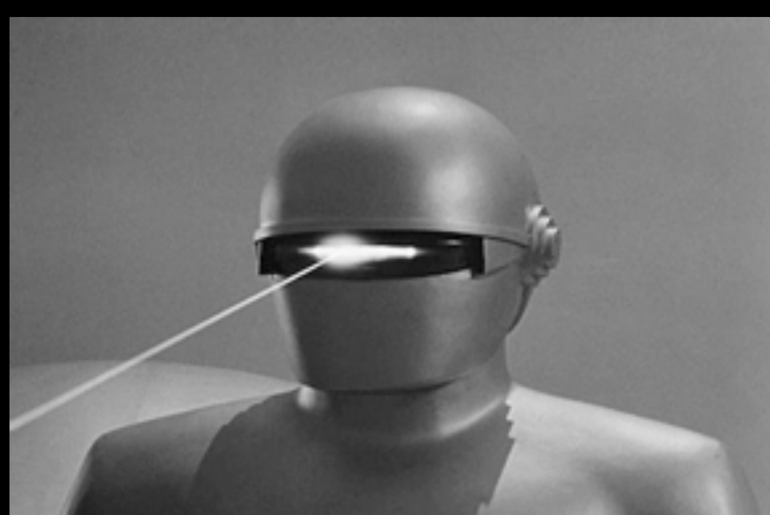
Robotics Research Areas
Andrew's presentation

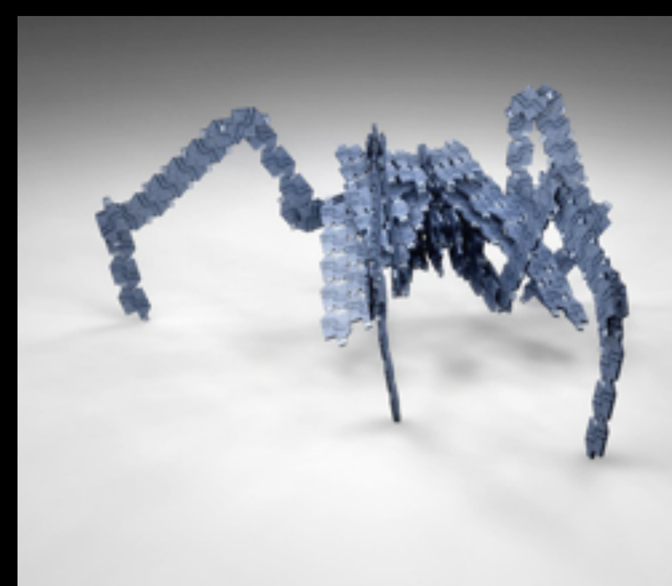
What is a robot?

Good

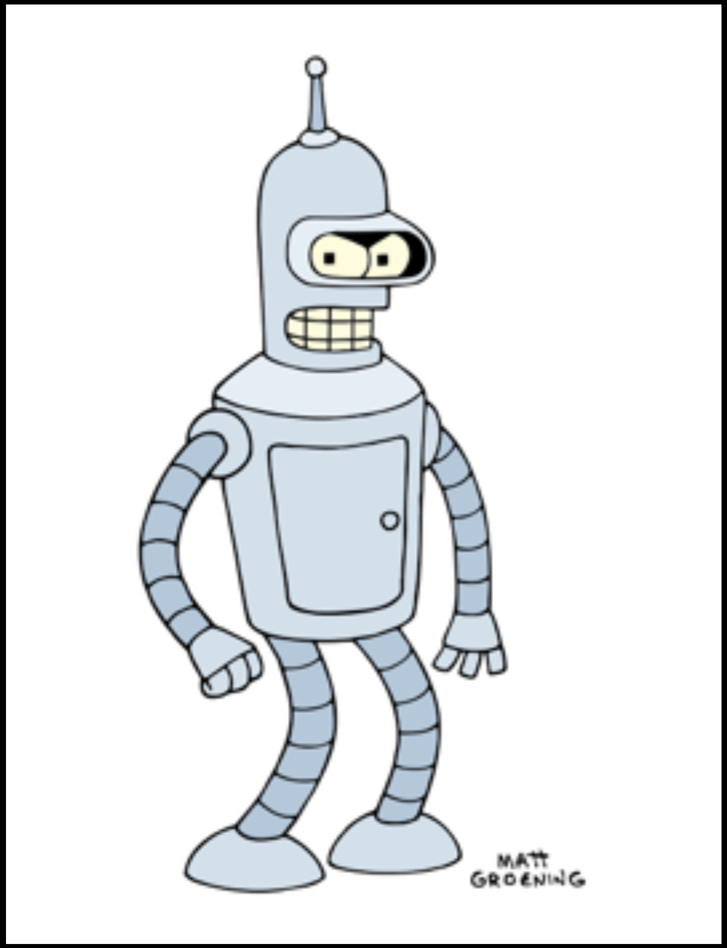
Bad

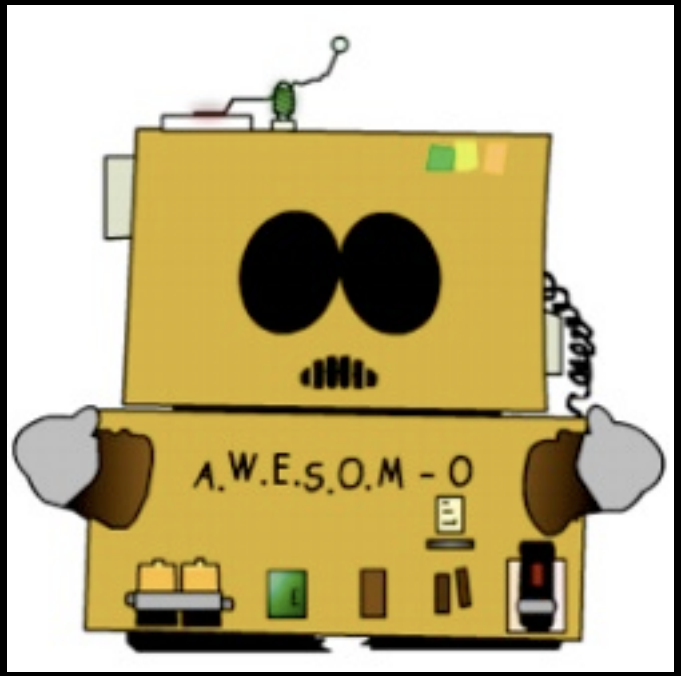






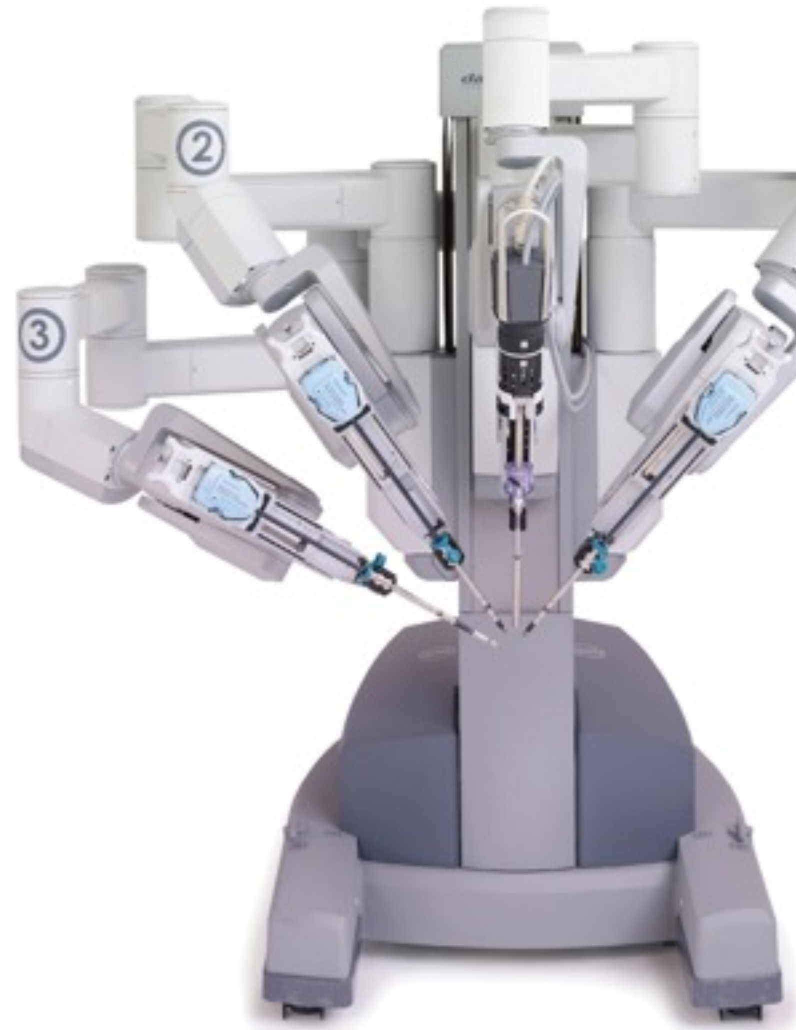
Useless





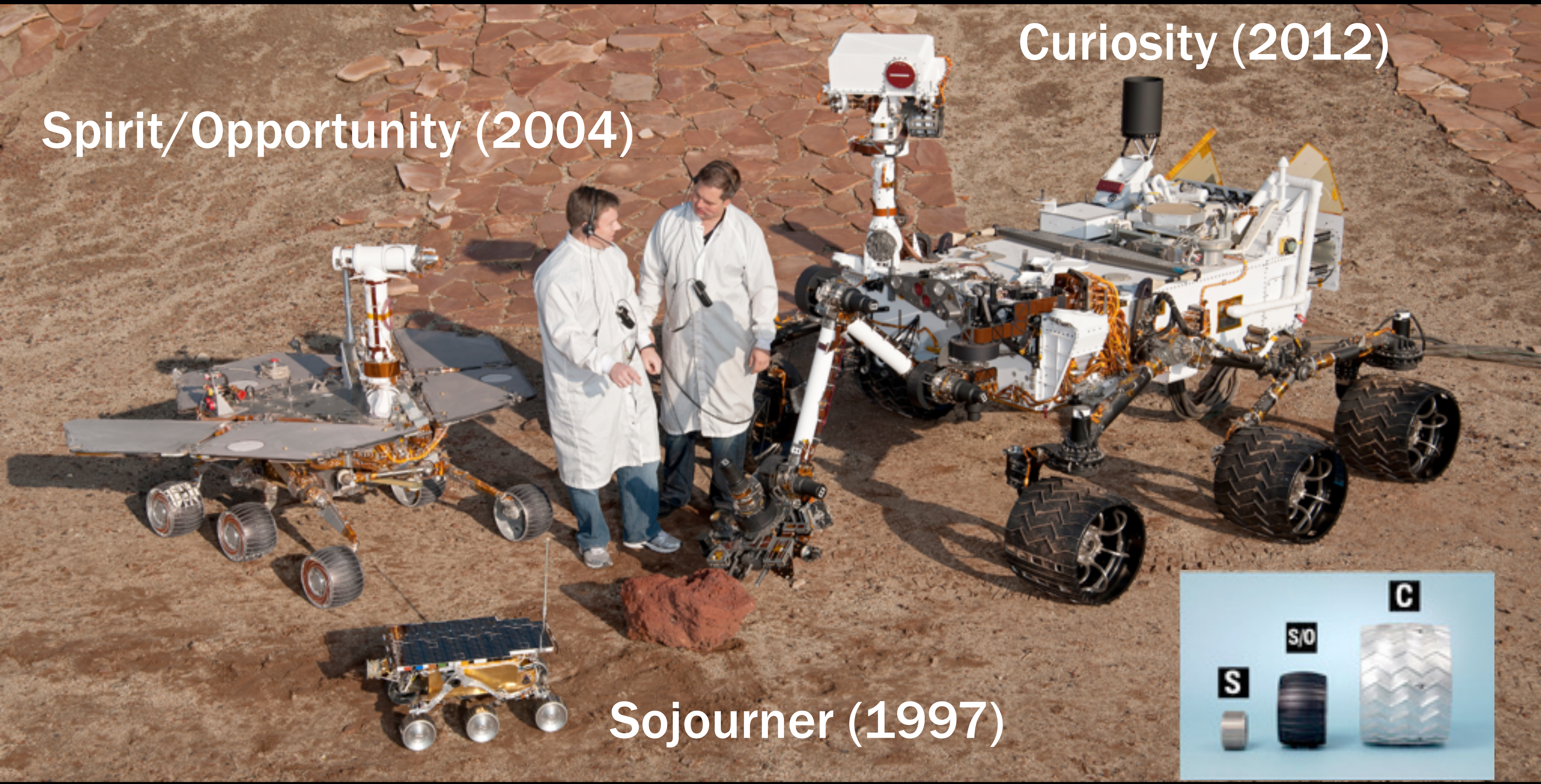
Manufacturing

Aldebaran Nao

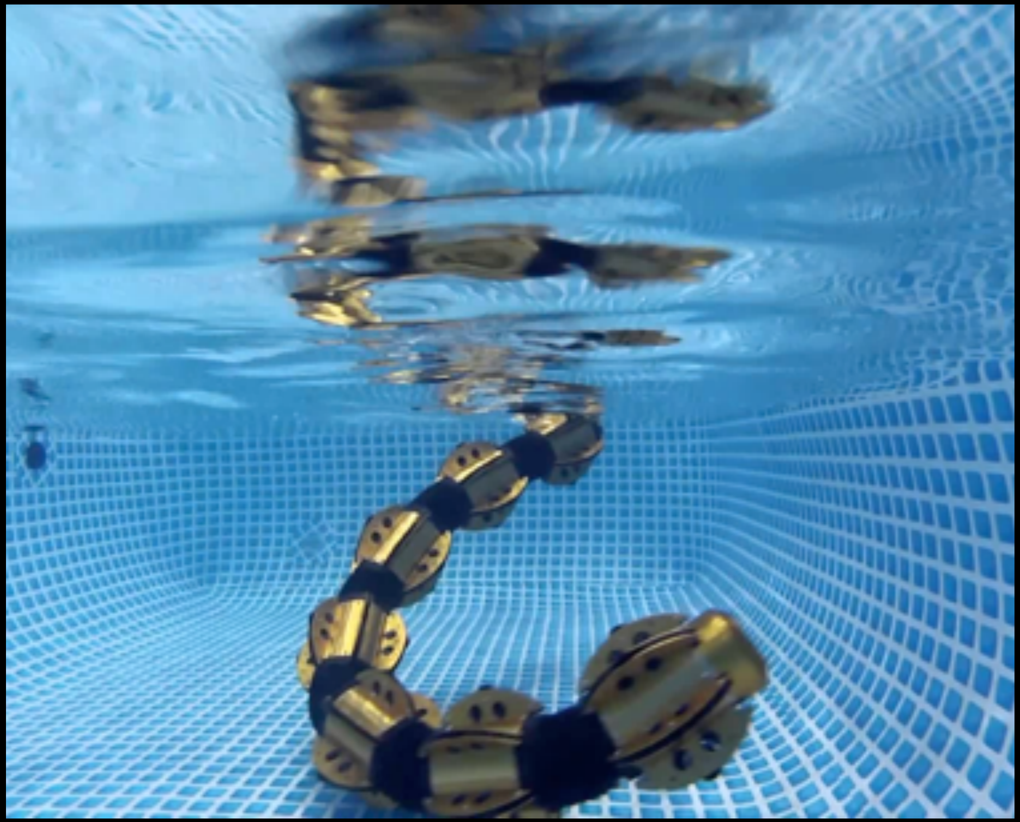


da Vinci
Surgical Robot

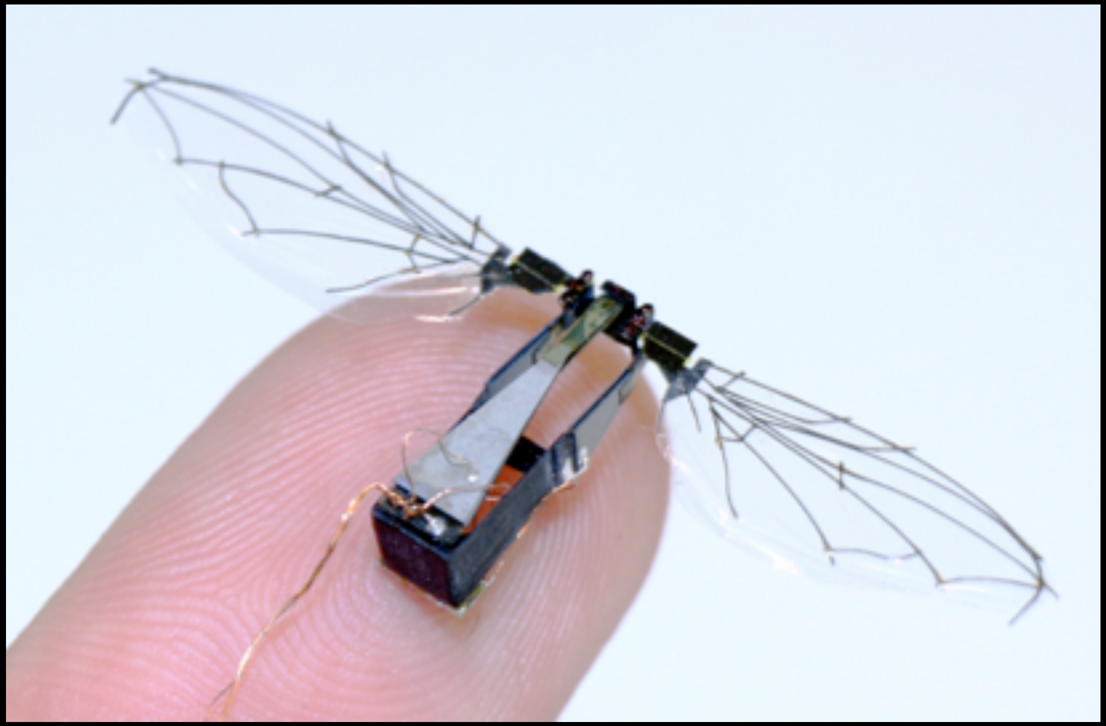
Roomba


Curiosity (2012)
Spirit/Opportunity (2004)
Sojourner (1997)
S
S/O
C

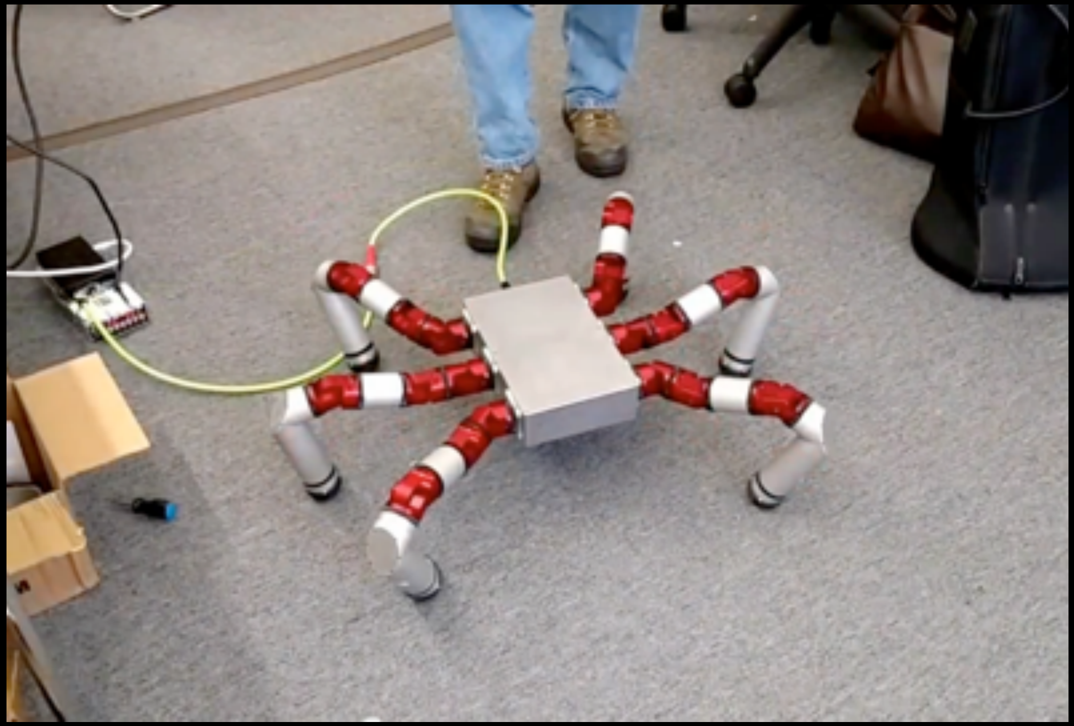
Boston Dynamics WildCat



HiBot ACM-R5H Snake Robot



Harvard Microrobotic Fly



CMU “Snake Monster” Hexapod

What is a robot?

“I can't define a robot,
but I know one when I see one.”

–Joseph Engelberger,
developer of the Unimate, the first deployed industrial robot

Where are robots?

Home
Hospital
Rehabilitation
Manufacturing
Disaster
War
Transportation
Delivery
Education/Entertainment
…

What is *Robotics*?

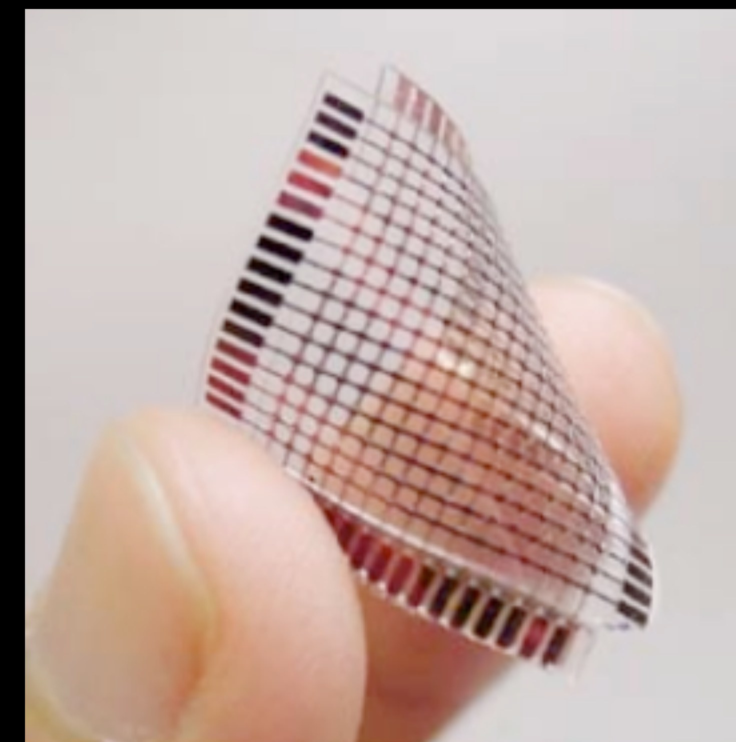
- Sensing
- Artificial Intelligence: knowledge representation/ontologies, recognition, classification, identification
- Machine Learning: control learning, task learning
- Robot design: task oriented, biologically inspired,
- Task Planning
- Motion Planning
- Moving
  - Control, Contact
  - Walking, slithering, flying, swimming, driving
- Multiple robots, parallel robots
- Differing scale: from extremely large to nanoparticle
- Grasping
- Manipulation
- Localization, SLAM
- Software architecture, programming
- Human interaction
  - Human-robot interface
  - Force and tactile sensing and control
  - Haptics
  - Safety, compliance
  - Teleoperation
  - Performance augmentation
- Fault handling and recovery

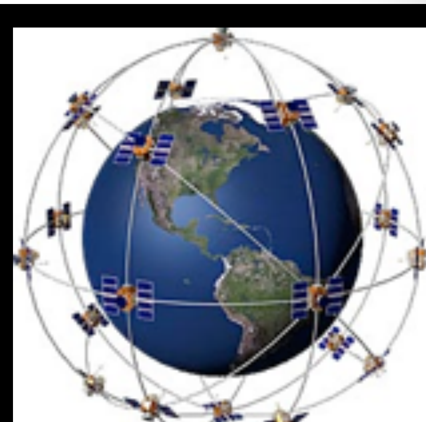
…

partial list from IROS conference schedule


sense
plan
move

Sense



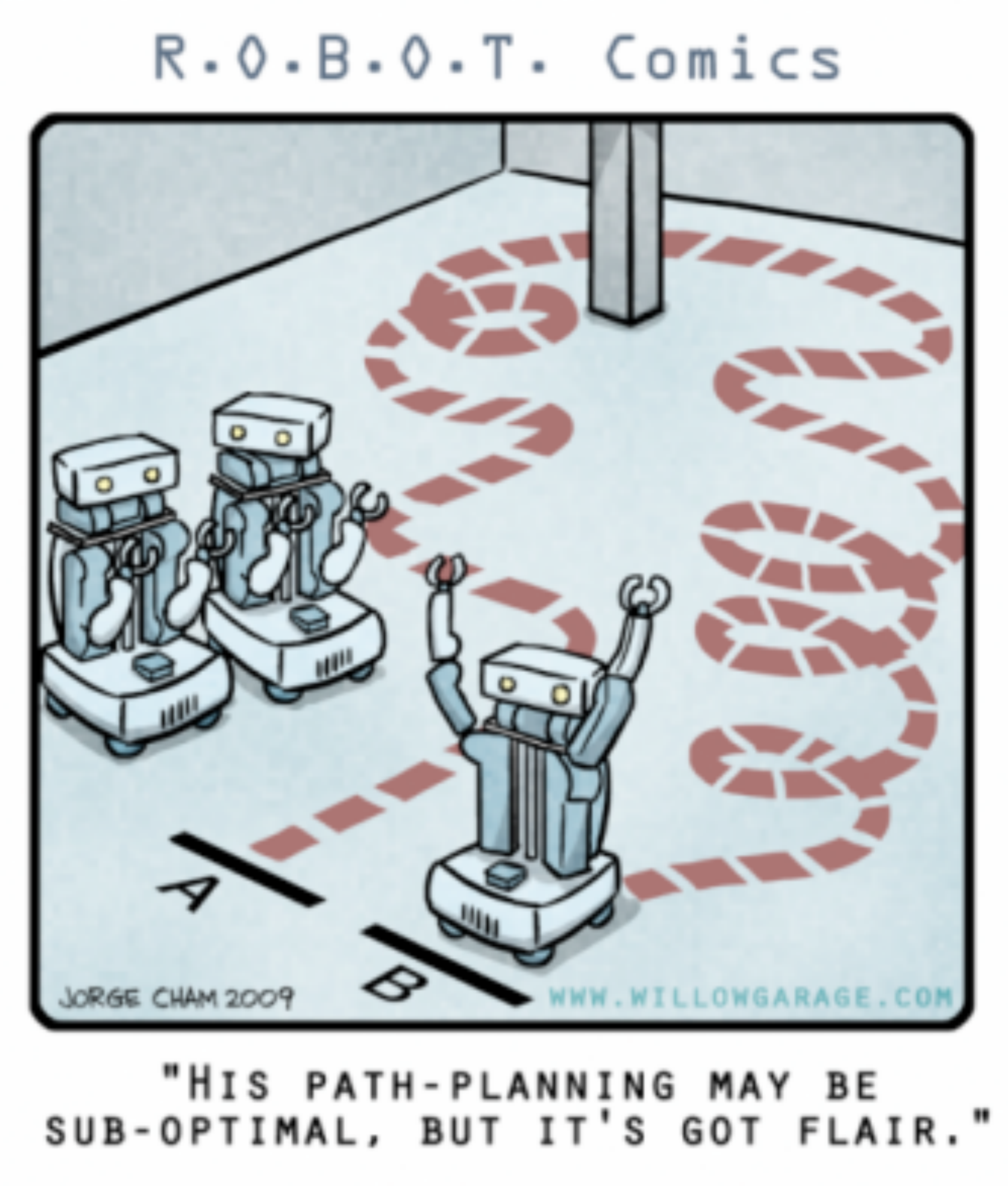


Plan

Alan's presentation

"Plan a motion from point A to point B."

"Compute an obstacle-free sequence of configurations through the robot's configuration space that reaches a goal region while satisfying the robot's kinematic constraints and problem-specific constraints."



Plan

Alan's presentation

"Plan a motion from configuration A to configuration B."

Typically not concerned with differential constraints (e.g., dynamics).

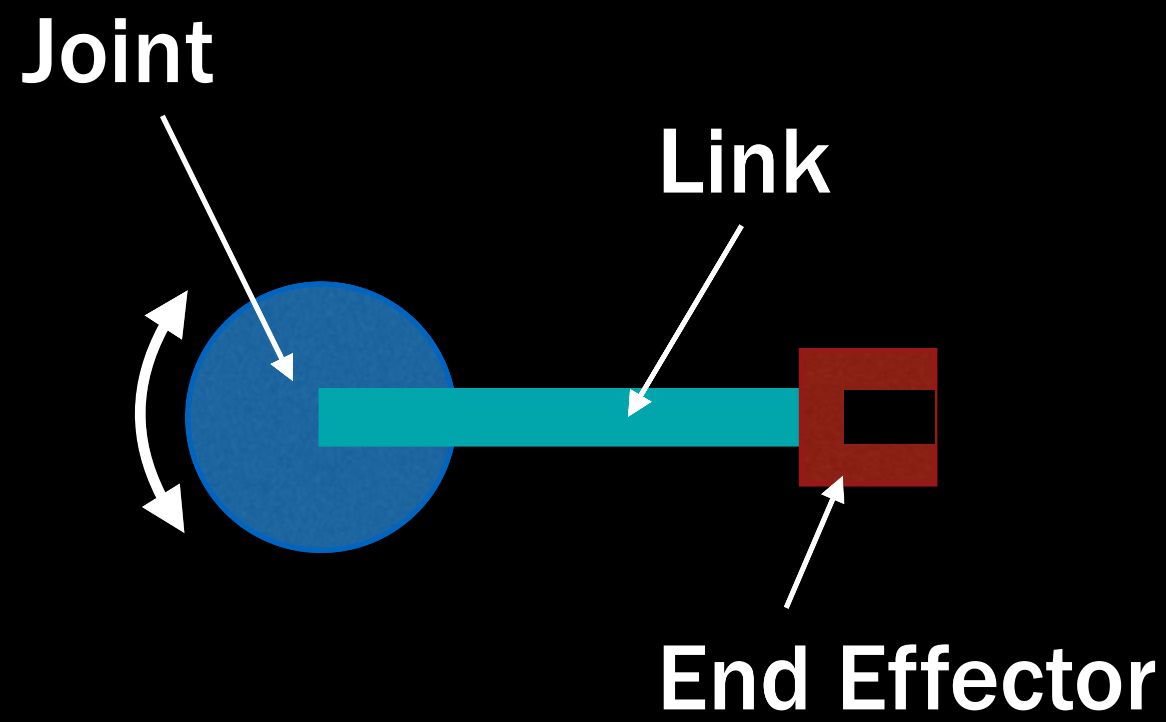
More recent research starting to include optimality, uncertainties, modeling errors, differential constraints

Move

Dhruv's presentation

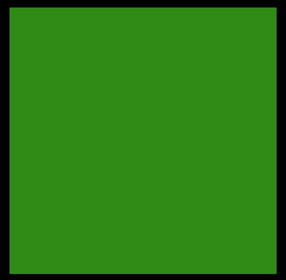
Control theory:
feedback policies,
adaptive execution, stability

Articulated Robot Parts



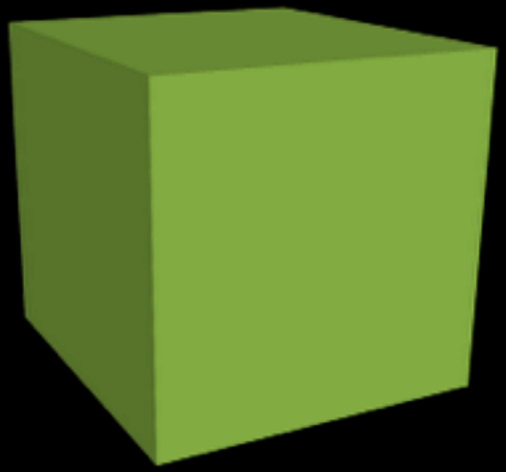
Workspace

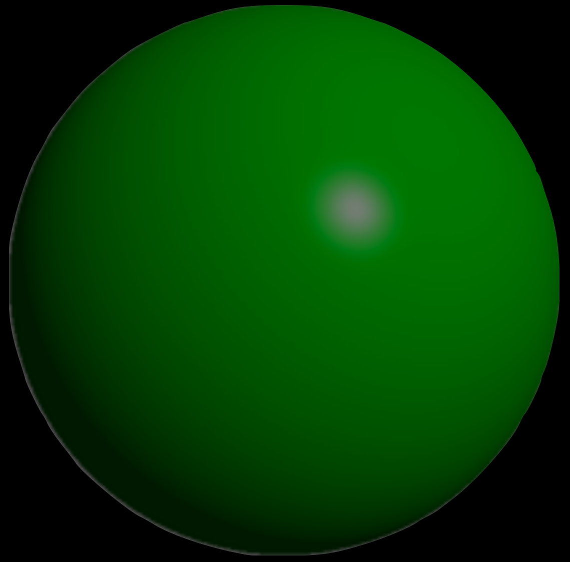
Space in which the robot operates



2D = $\mathbb{R}^2$

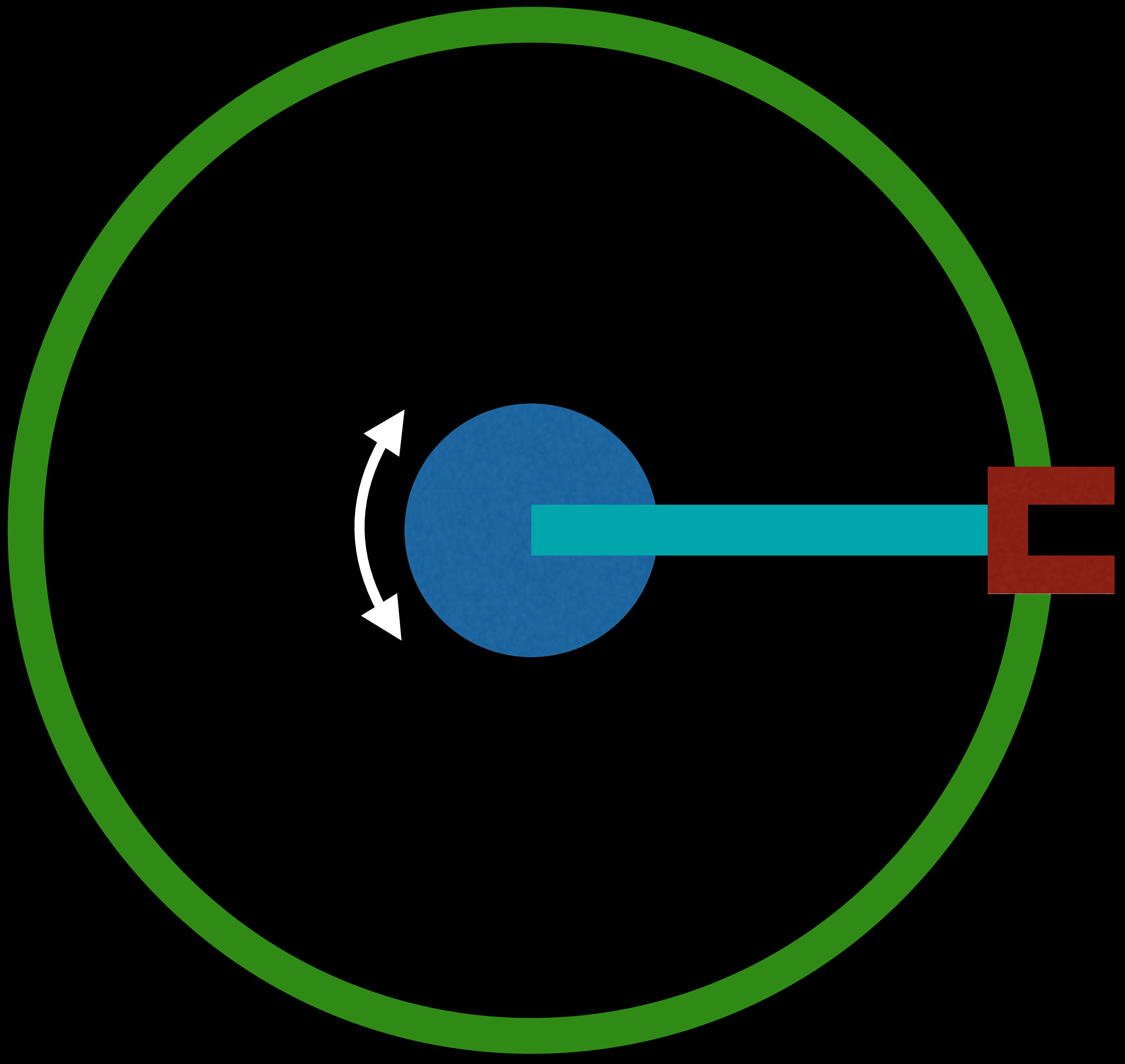
3D = $\mathbb{R}^3$





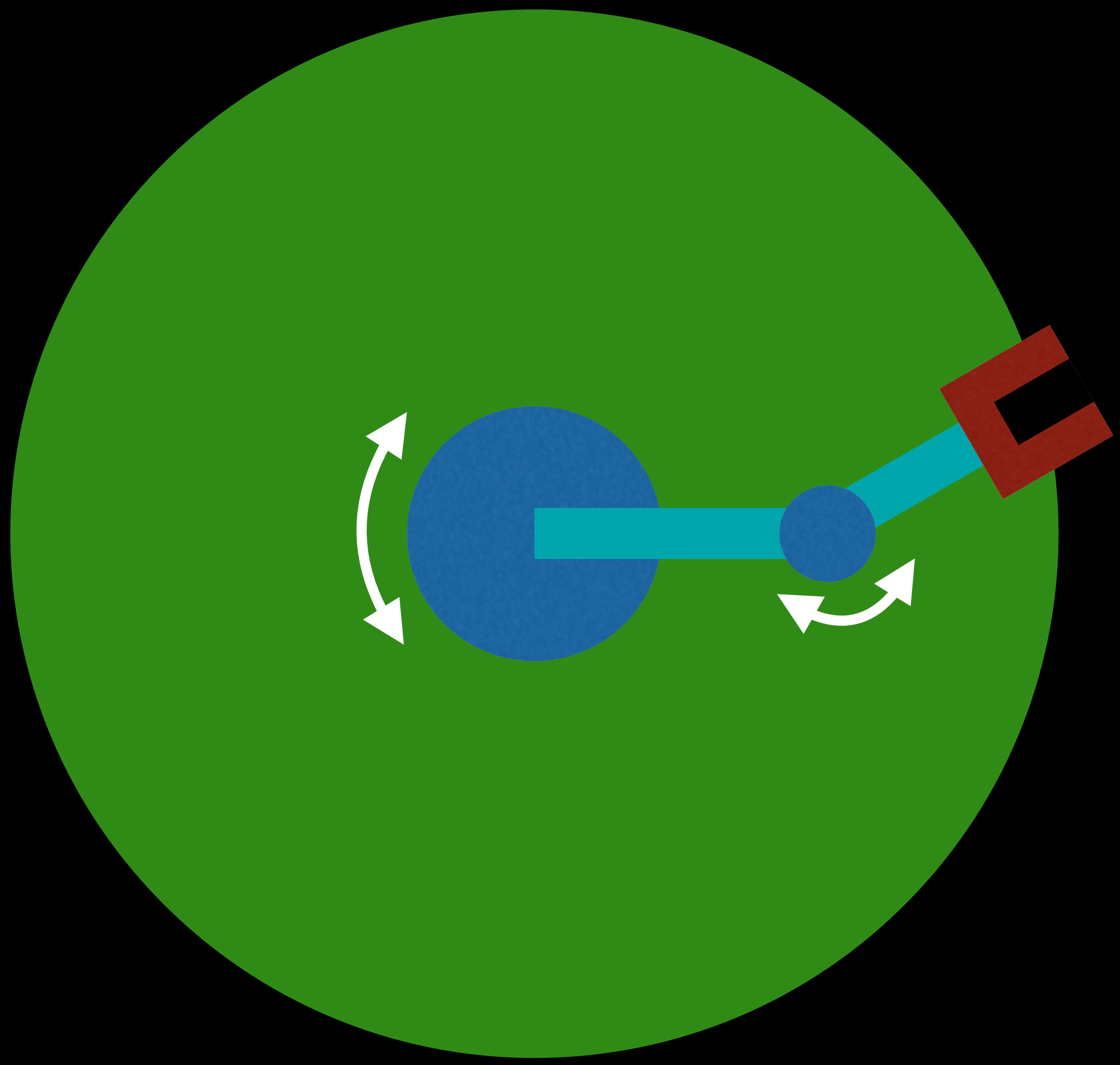
Surface of Sphere

Workspace



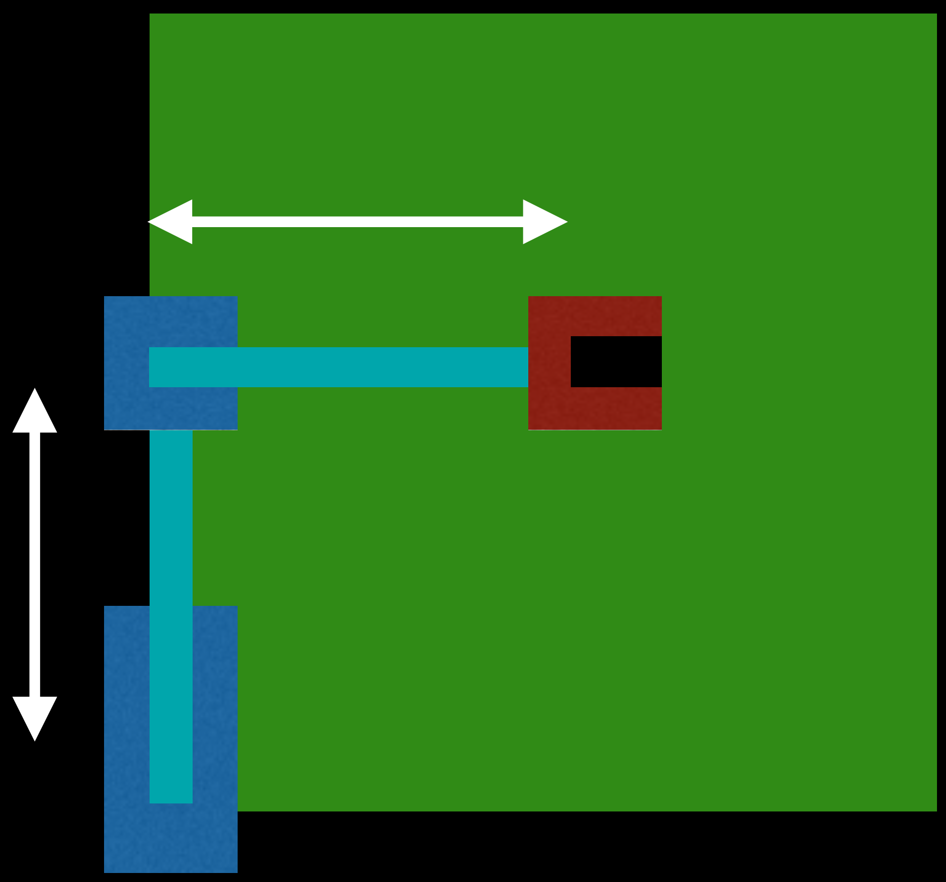
1 Link Robot

Workspace



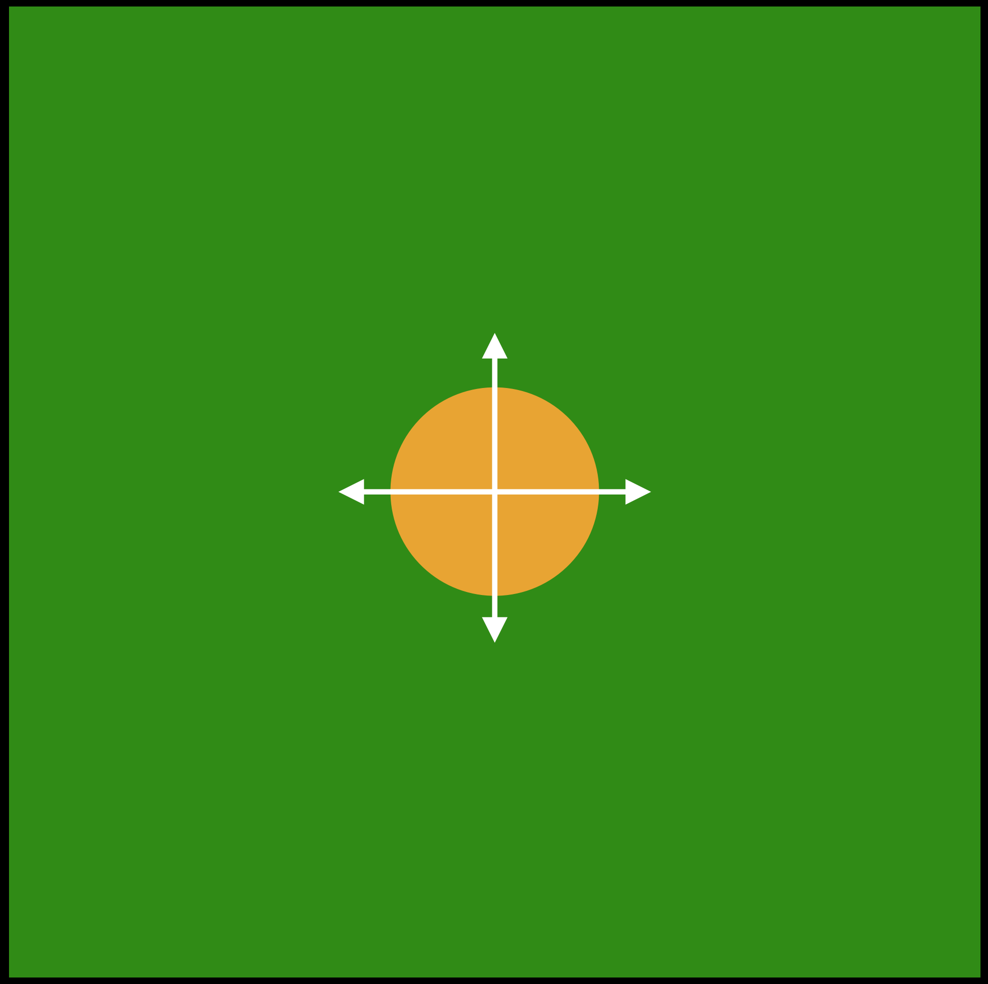
2 Link Robot

Workspace



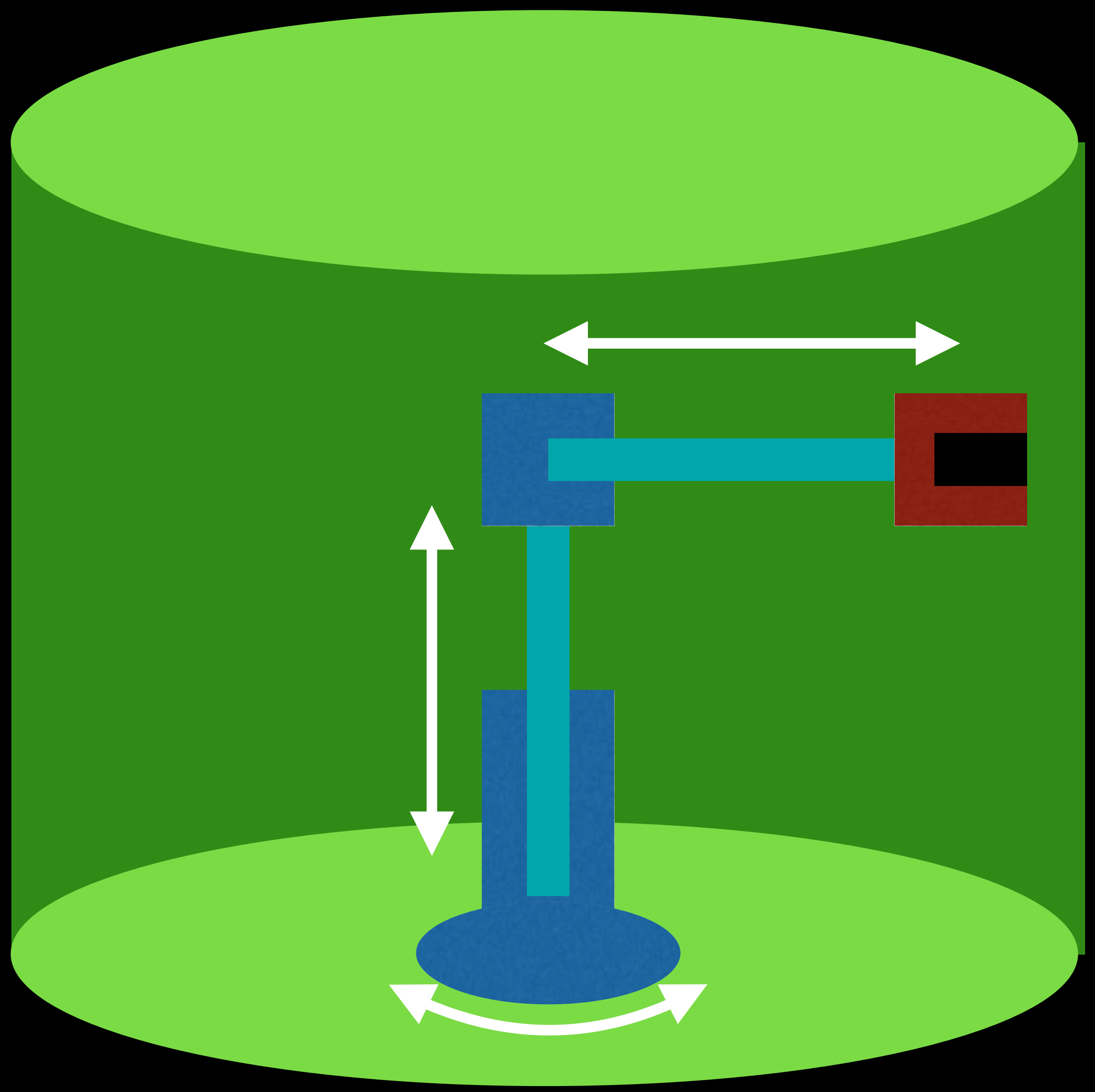
2 Prismatic Joints

Workspace



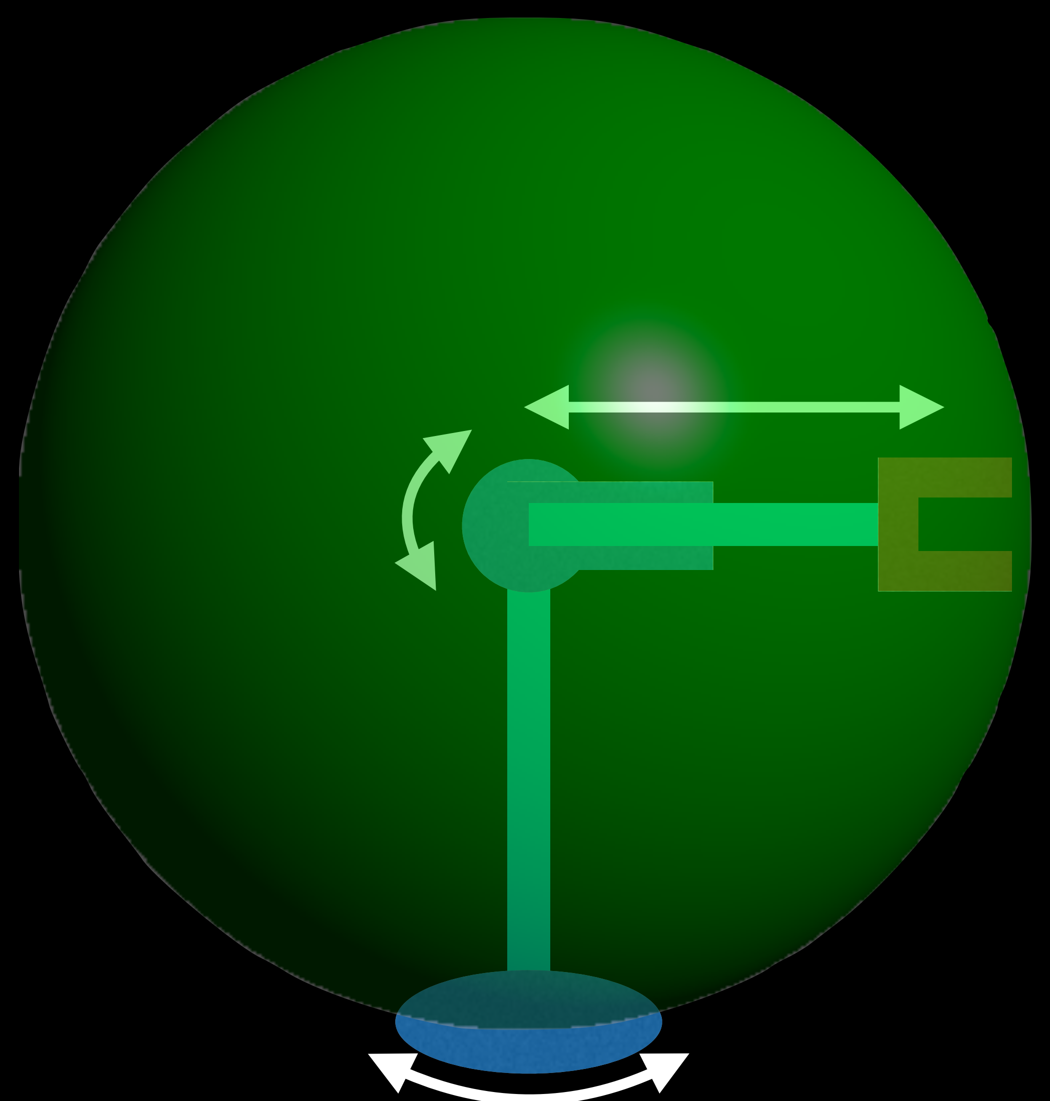
2D Point/Disc Robot (e.g., Roomba)

Workspace



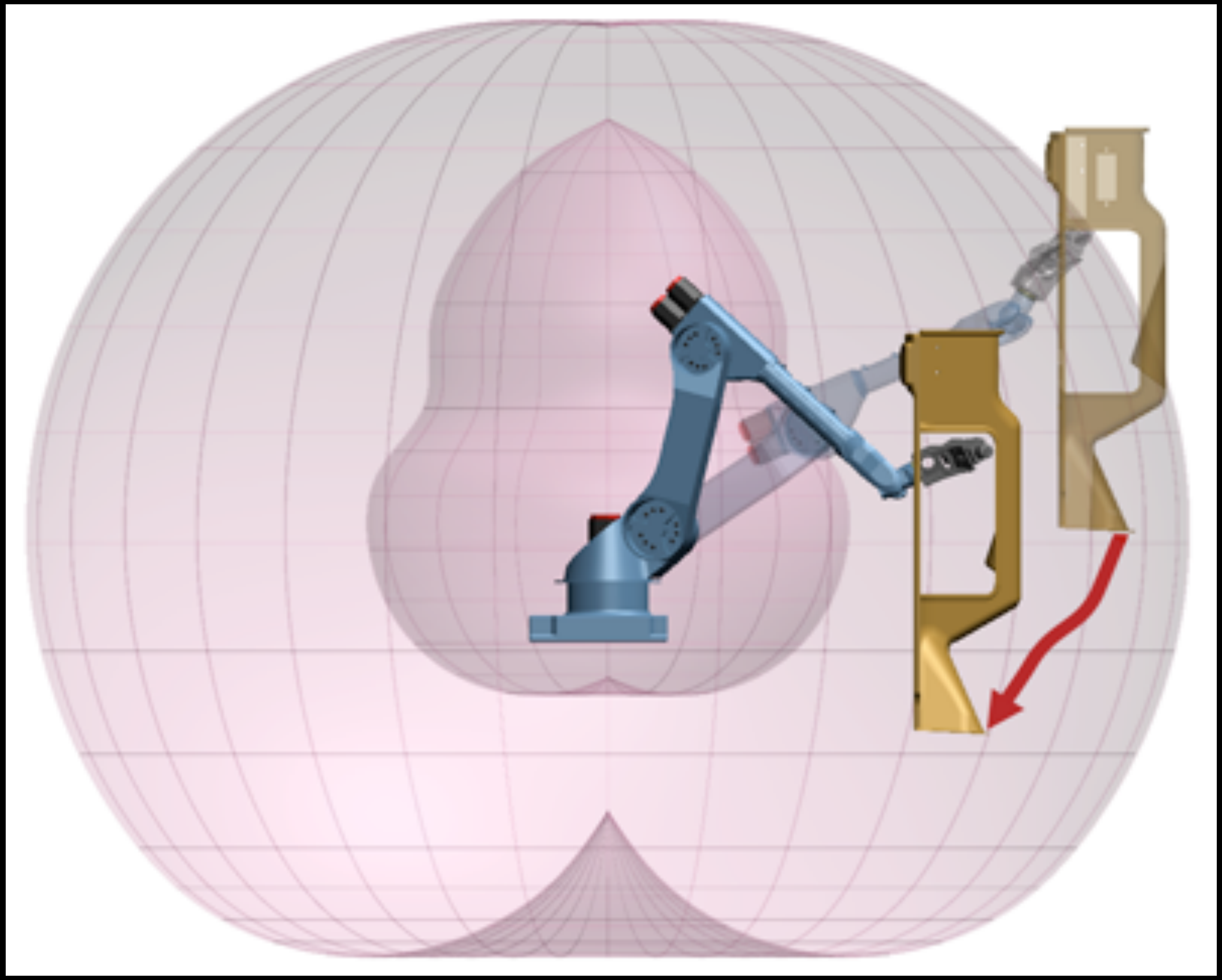
2 Prismatic + 1 Rotational Joint

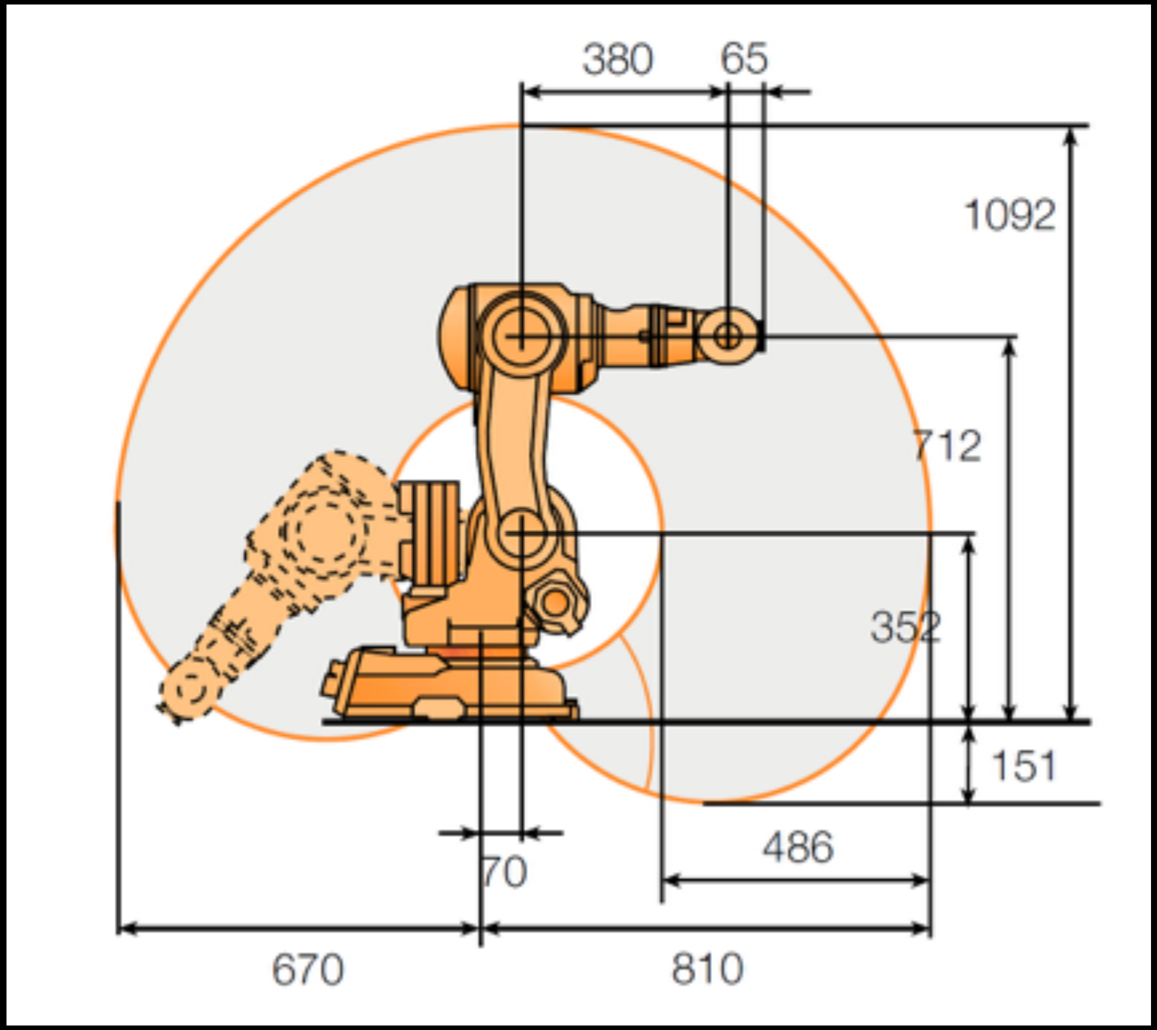
Workspace



1 Prismatic + 2 Rotational Joint

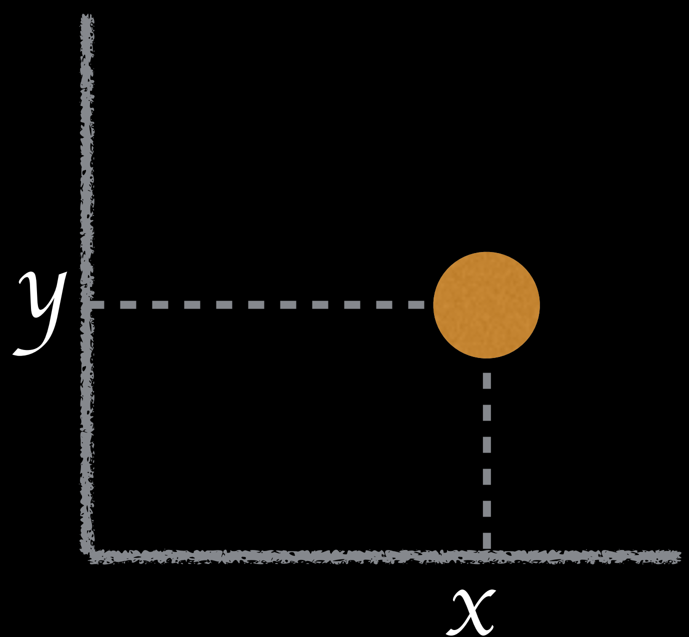
Workspace



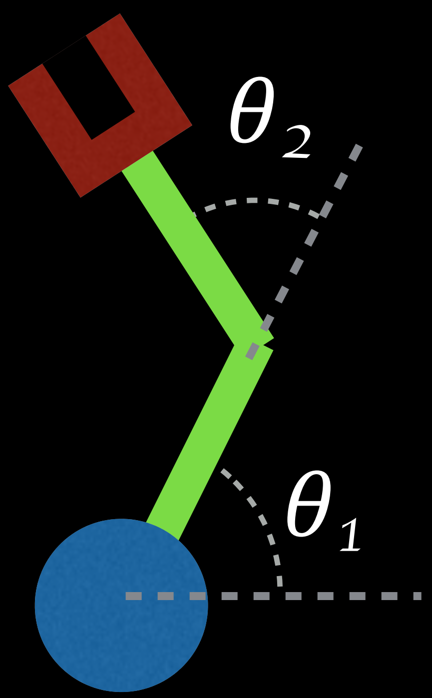


Robot Configuration

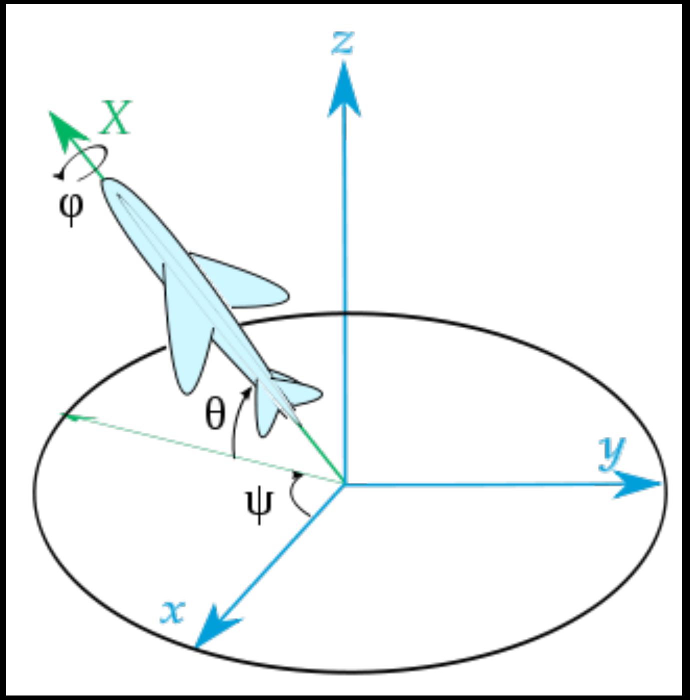
Configuration: The complete specification of a robot's pose, position, and orientation in space.



(x, y)



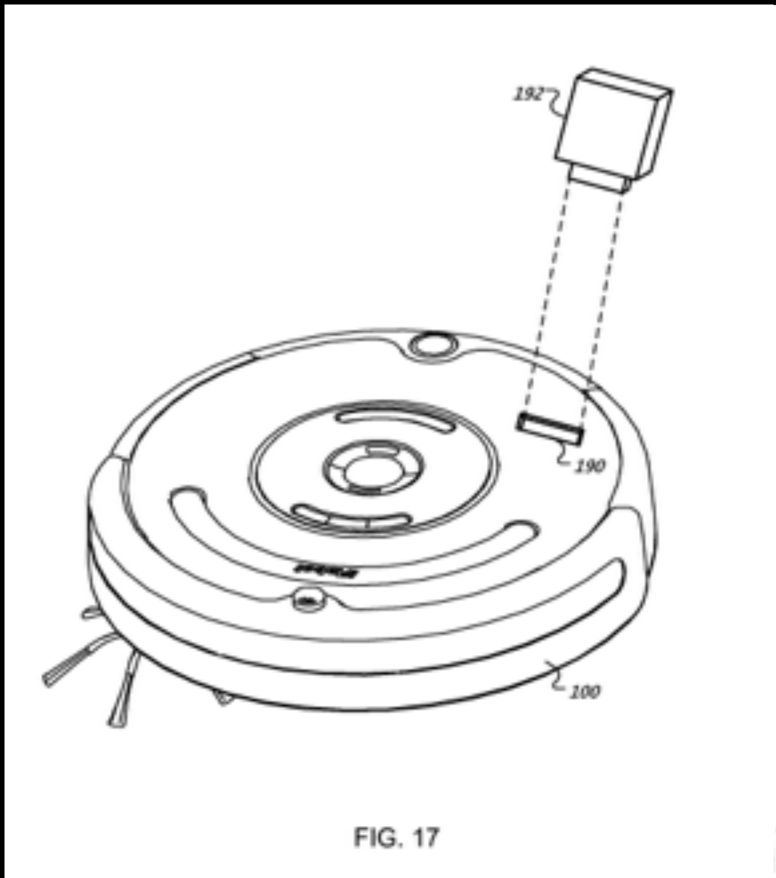
(θ_1, θ_2)

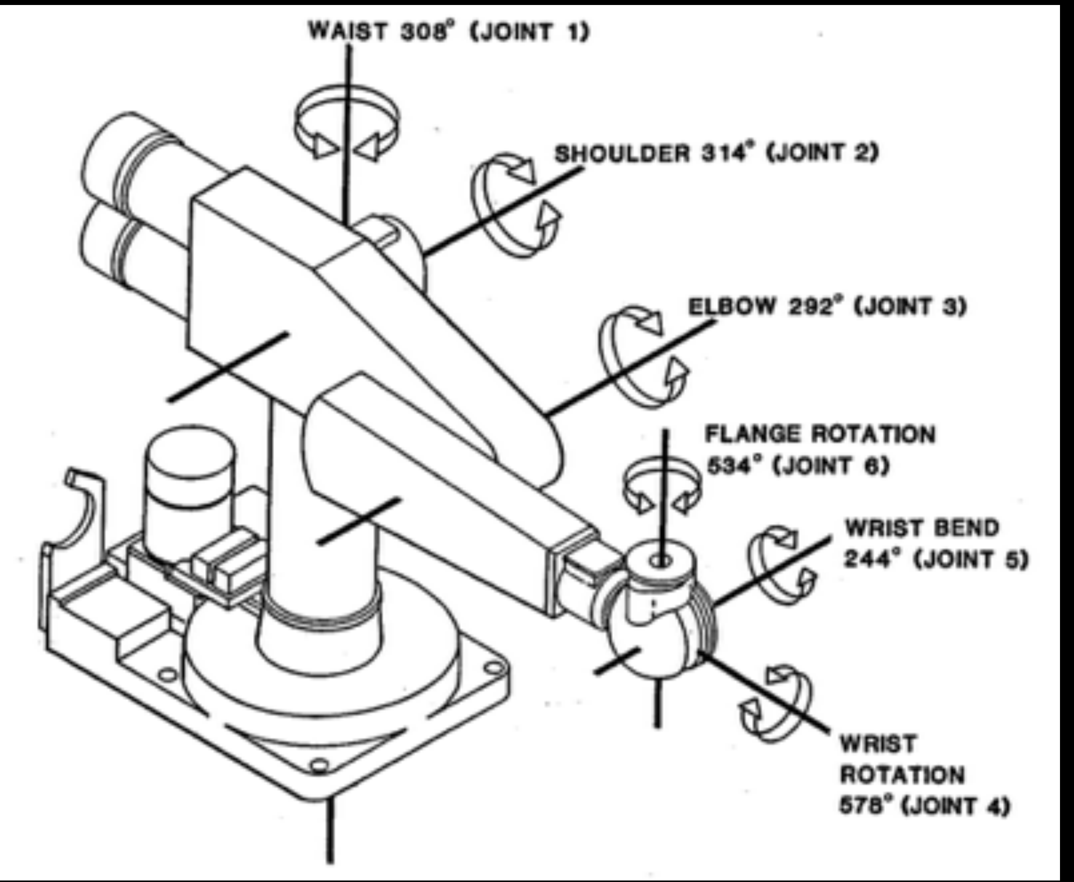


$(x, y, z, \psi, \theta, \varphi)$

Degrees of Freedom

DOF: the dimension of the configuration vector



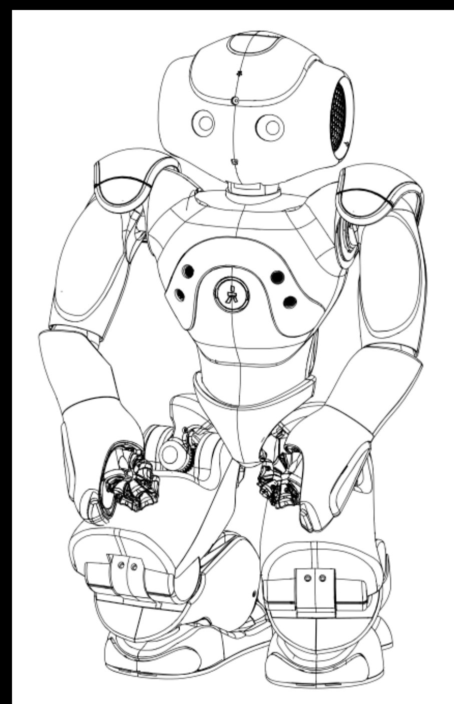


2 DOF (x, y)
3 DOF (x, y, θ)

6 DOF
$(x, y, z, \psi, \theta, \varphi)$

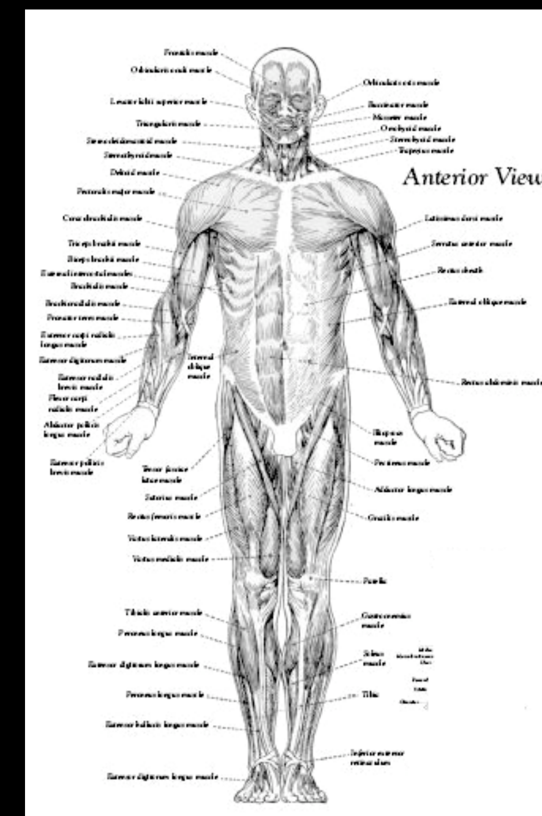
6 DOF
$(\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6)$

DOF of Human/Humanoids



Nao Humanoid Robot

Head: 2
Arms: 5 x2
Hips: 1
Legs: 6 x2
= 25 DOF

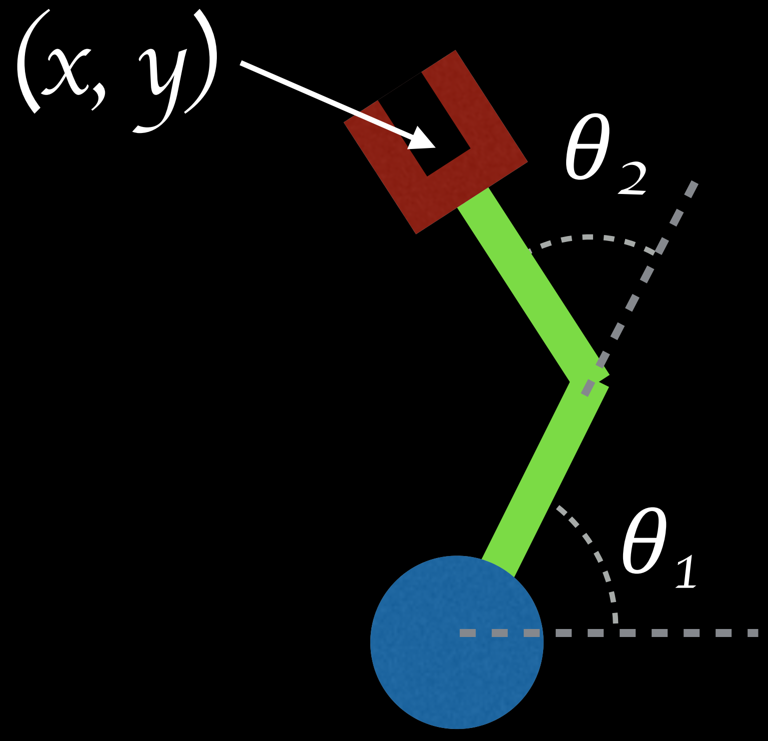


Human

~200 DOF

Kinematics

Forward Kinematics: computation of position and orientation of end effector as a function of the configuration.

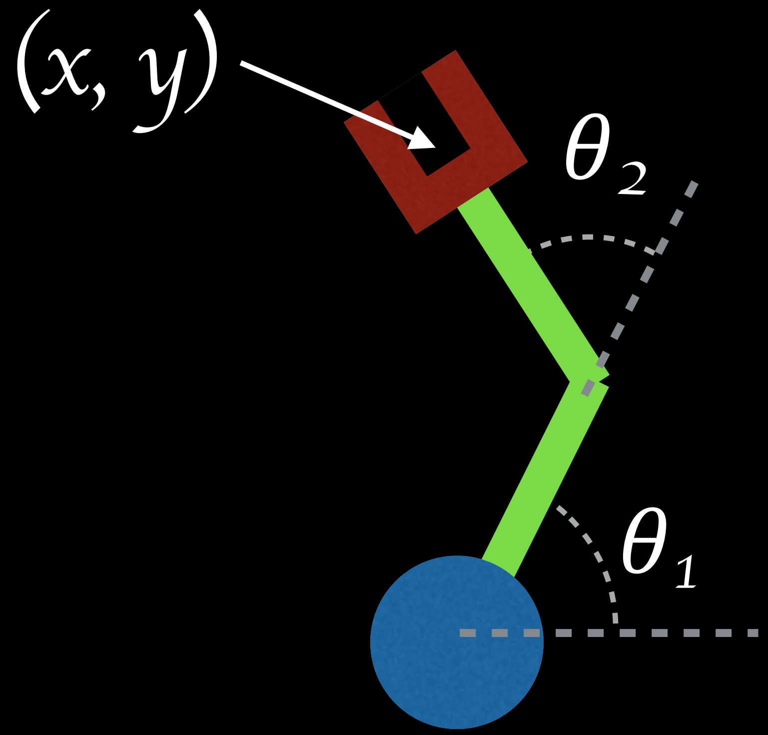


$$f(\theta_1, \theta_2) = (x, y)$$

Inverse Kinematics

Inverse Kinematics: computation of configuration vector given an end effector position and orientation.

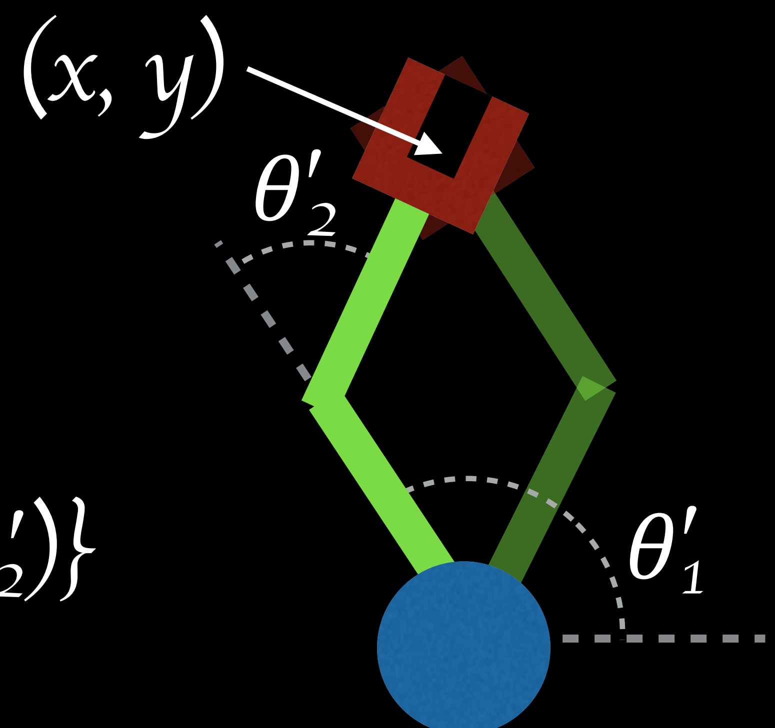
$$f^{-1}(x, y) = (\theta_1, \theta_2)$$



Inverse Kinematics

Problem: multiple solutions.
No closed form solution in many higher DOF robots.

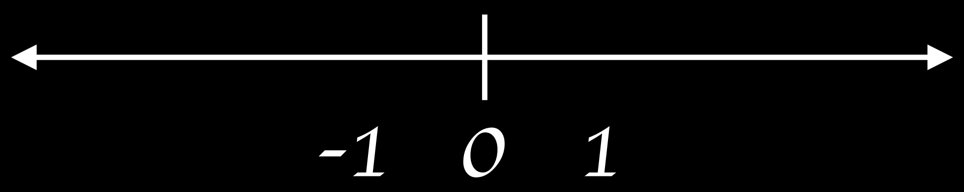
$$f^{-1}(x, y) = \{(\theta_1, \theta_2), (\theta'_1, \theta'_2)\}$$



C-Space

Configuration Space (C-Space): the set of possible configurations that can be applied to a robot.

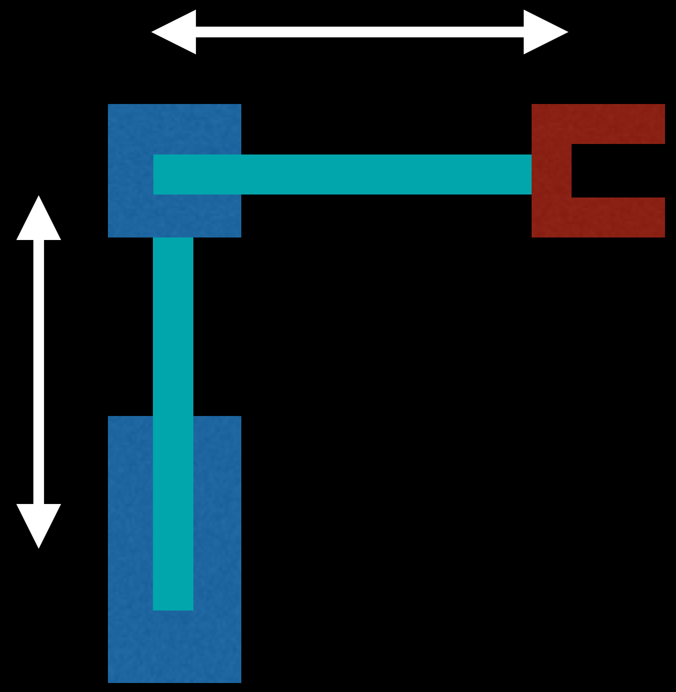
$\mathbb{R}^1$

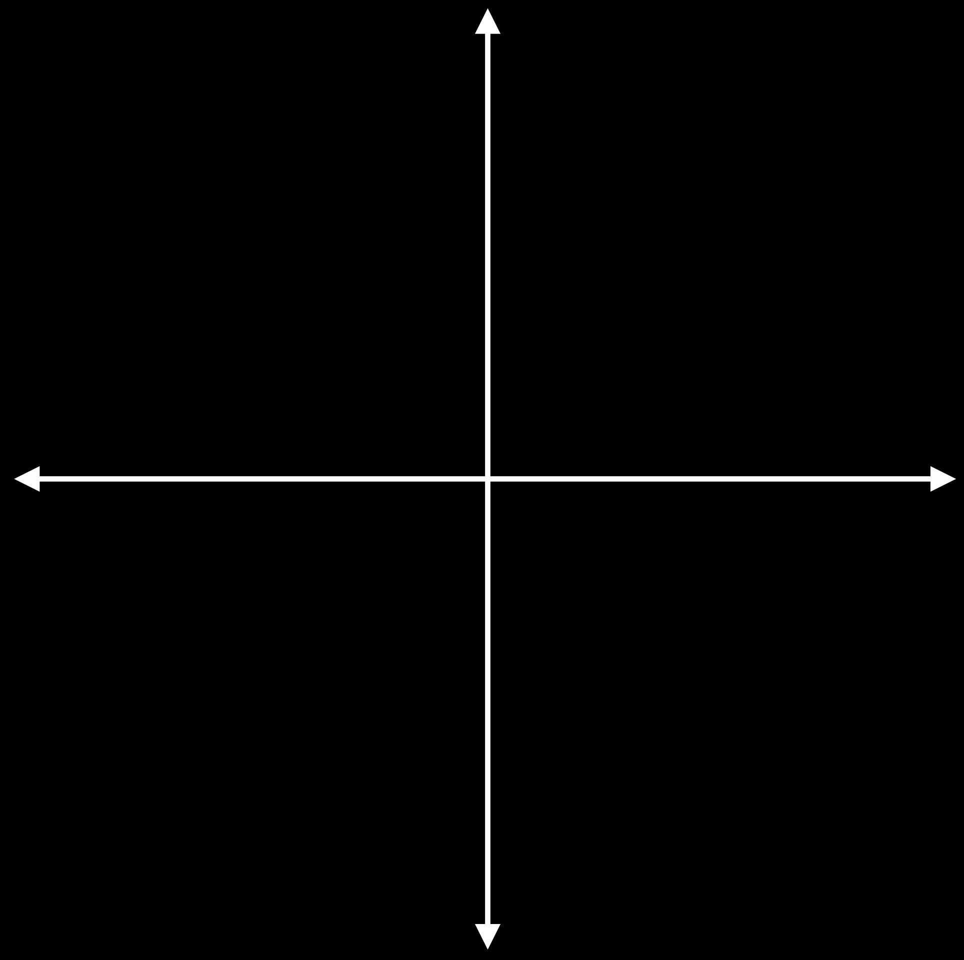


C-Space is where we do motion planning.

C-Space: Cartesian Products

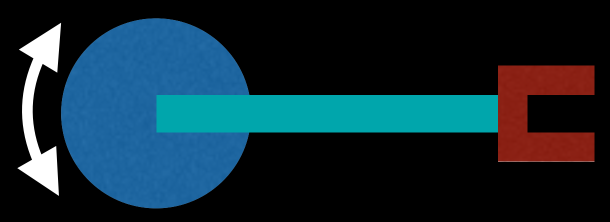
$$\mathbb{R}^1 \times \mathbb{R}^1 = \mathbb{R}^2$$

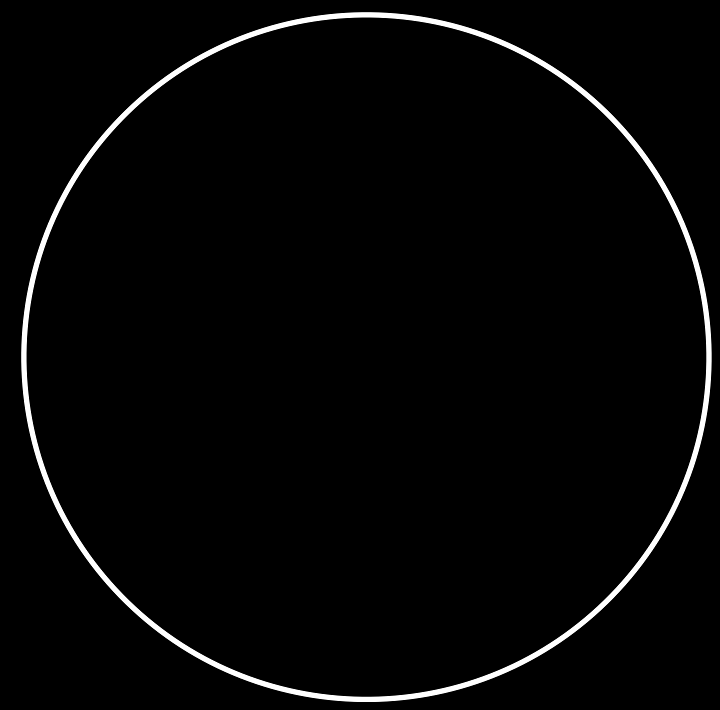




C-Space: Revolute Joints

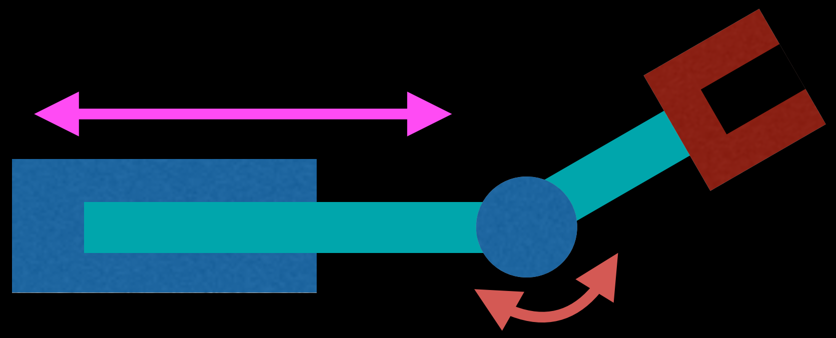
$$\mathbb{S}^1 = \{(x, y) \in \mathbb{R}^2 \mid x^2 + y^2 = 1\}$$

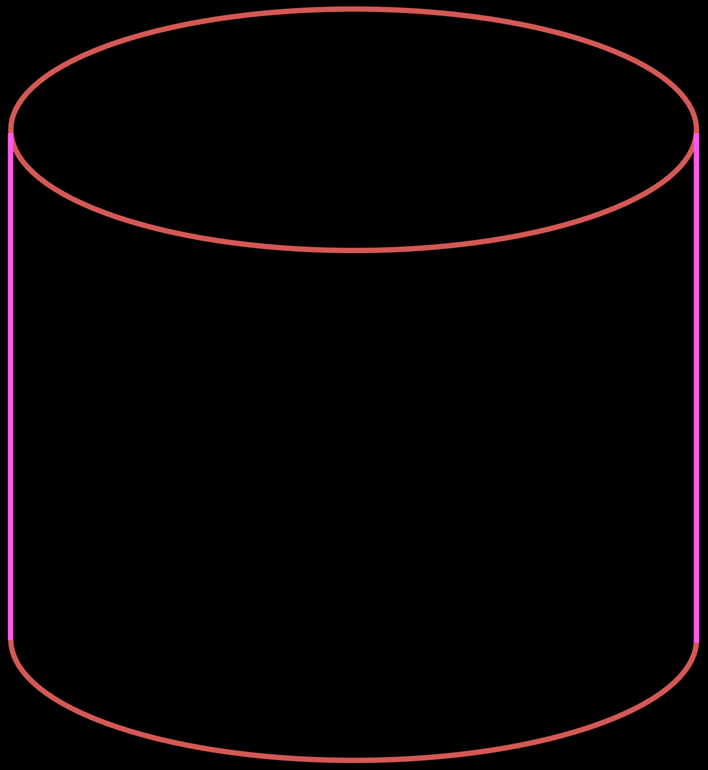




$\mathcal{C}$-Space: Revolute Joints

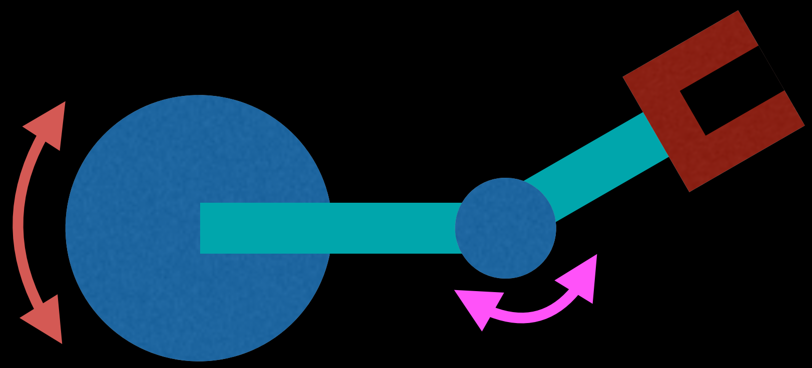
$$\mathbb{R}^1 \times \mathbb{S}^1$$

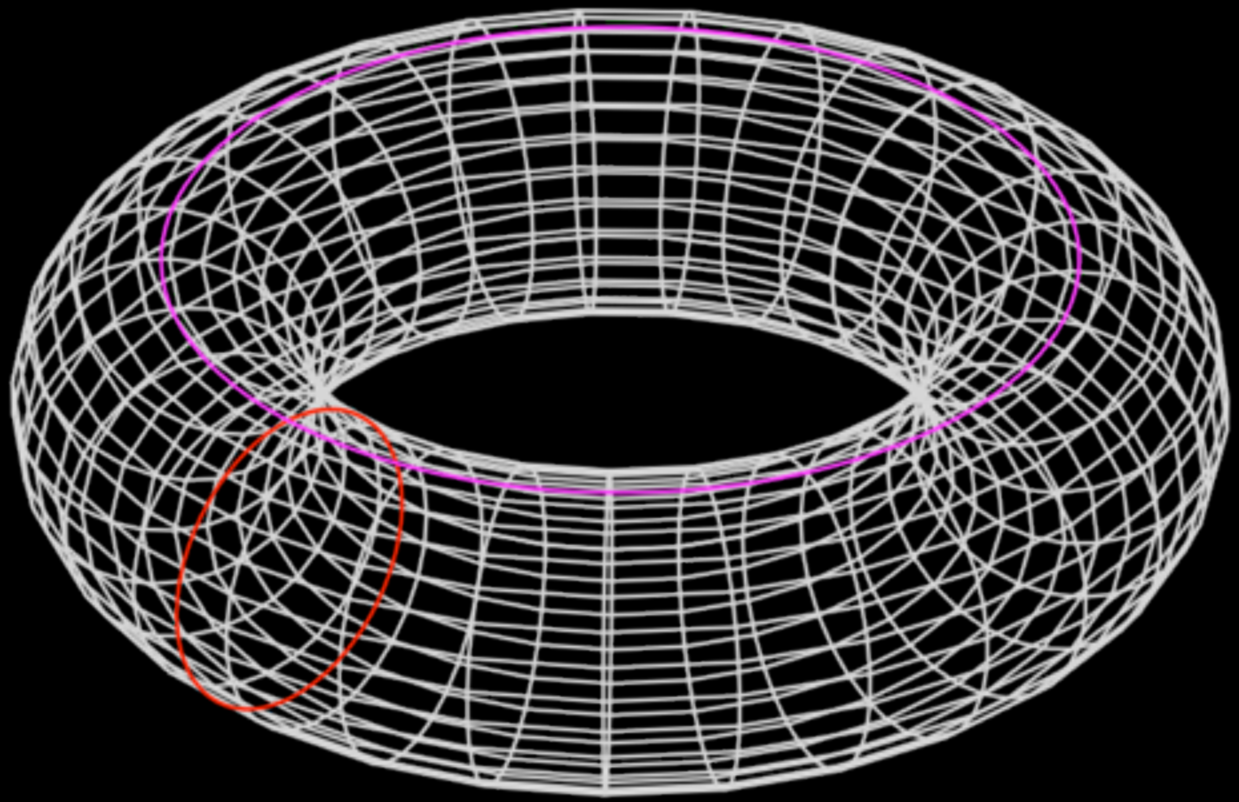




C-Space: Revolute Joints

$$\mathbb{S}^1 \times \mathbb{S}^1$$

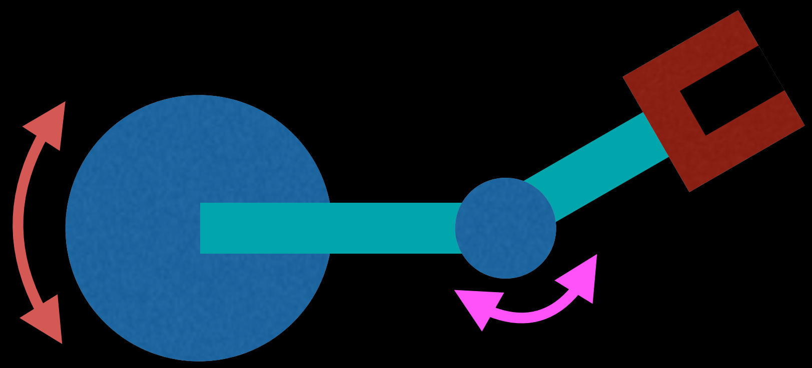


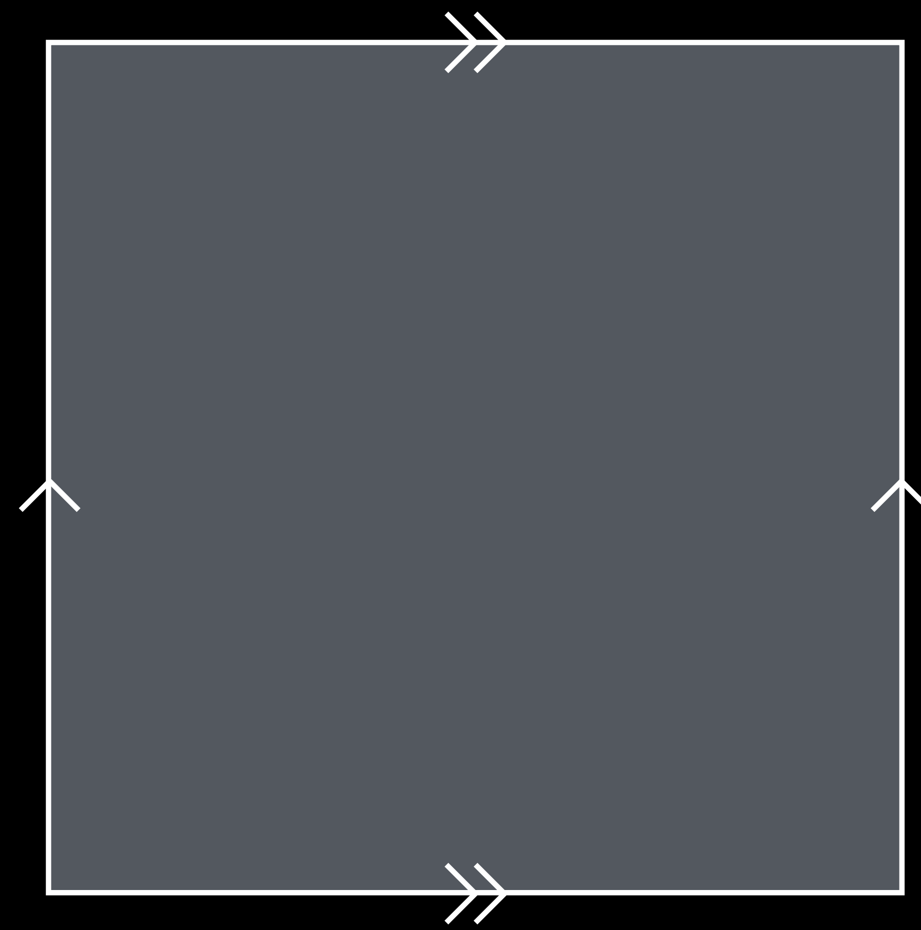


$$\mathbb{S}^1 \times \mathbb{S}^1 \neq \mathbb{S}^2$$

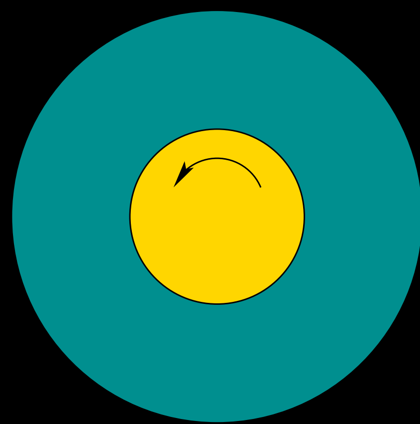
$\mathcal{C}$-Space "flattening"

$\mathbb{S}^1 \times \mathbb{S}^1$

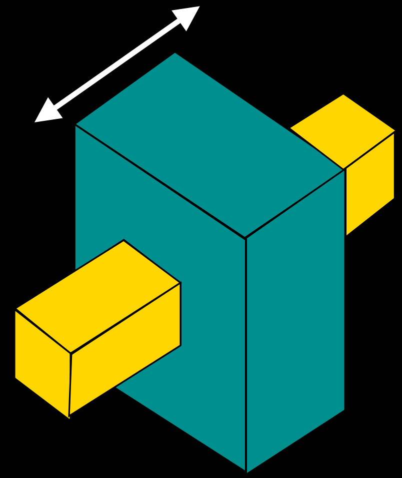




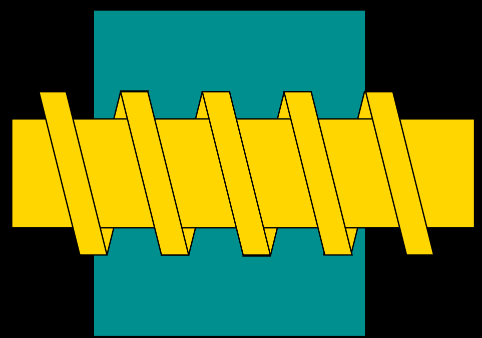
Additional Joints



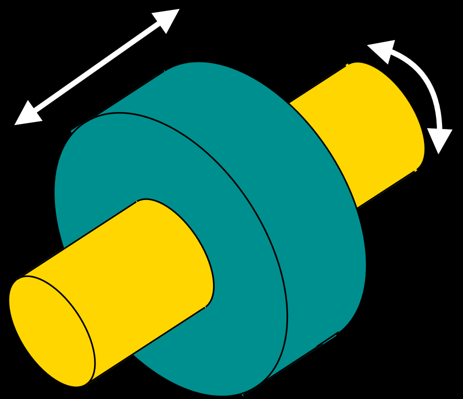
Revolute
1 DOF



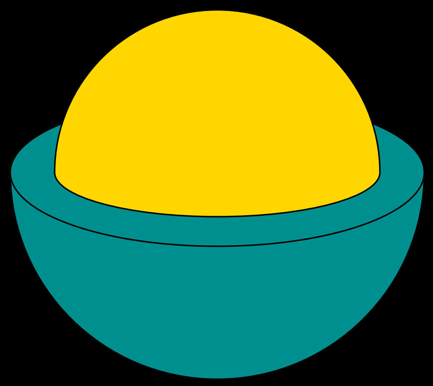
Prismatic
1 DOF



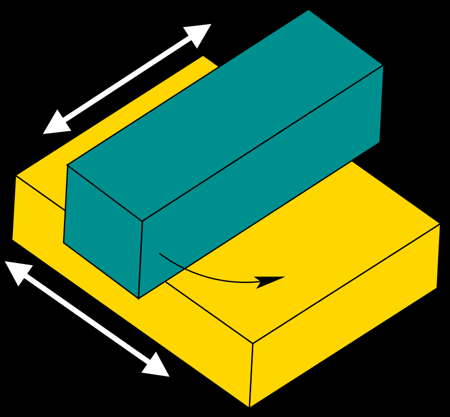
Screw
1 DOF



Cylindrical
2 DOF



Spherical
3 DOF

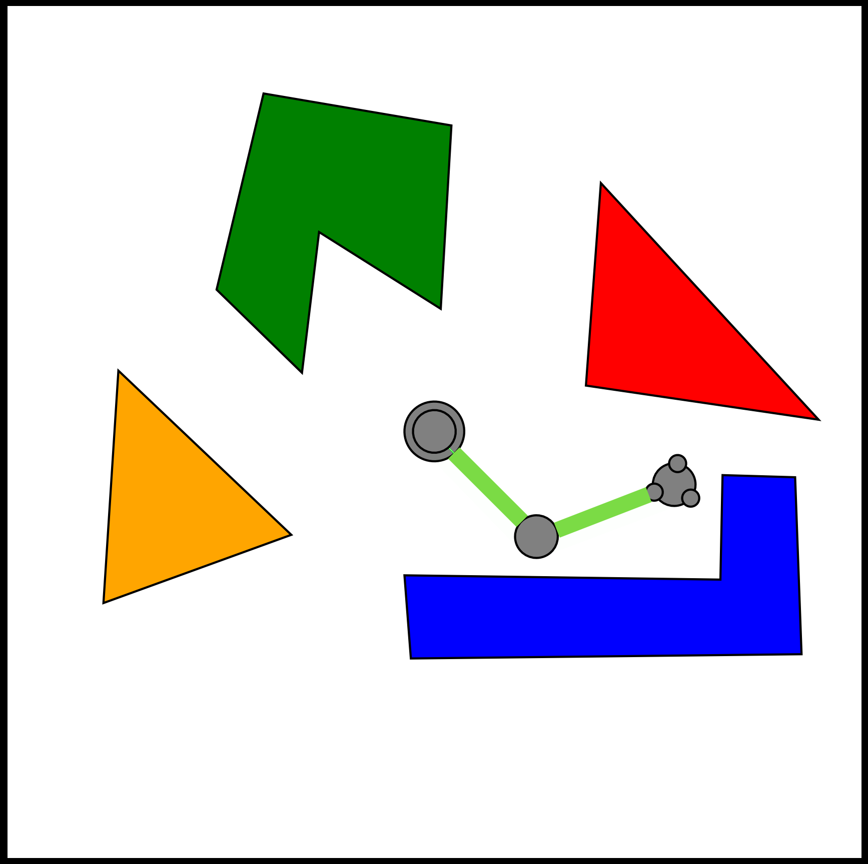


Planar
3 DOF

Source: LaValle, *Motion Planning*

C-Space and Obstacles

Robot with 2 revolute joints



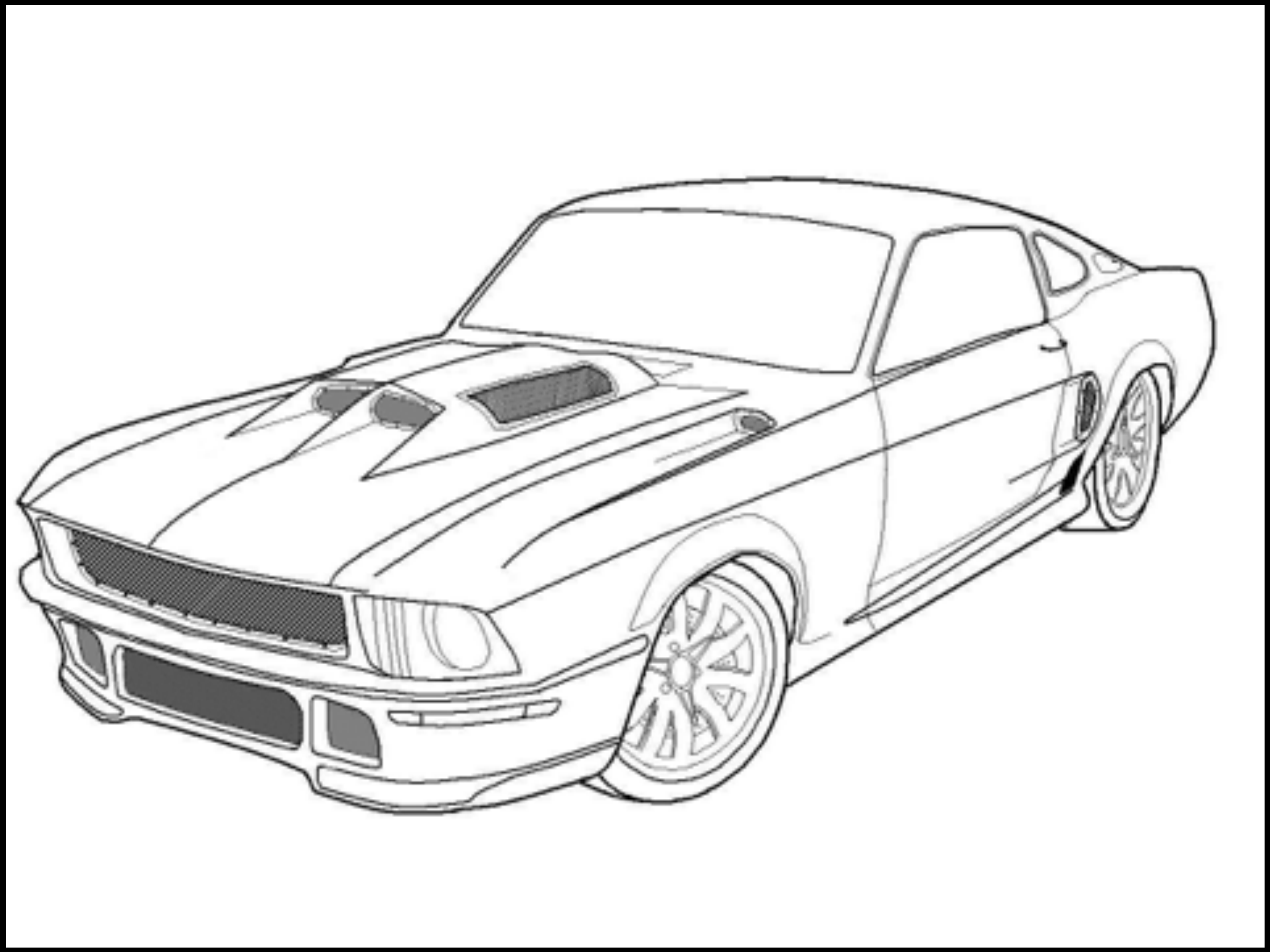
Workspace and Obstacles

C-Space and C-Obstacles

C-Space Obstacles demo

http://cs.unc.edu/~jeffi/c-space/robot.xhtml

DOF in a Car

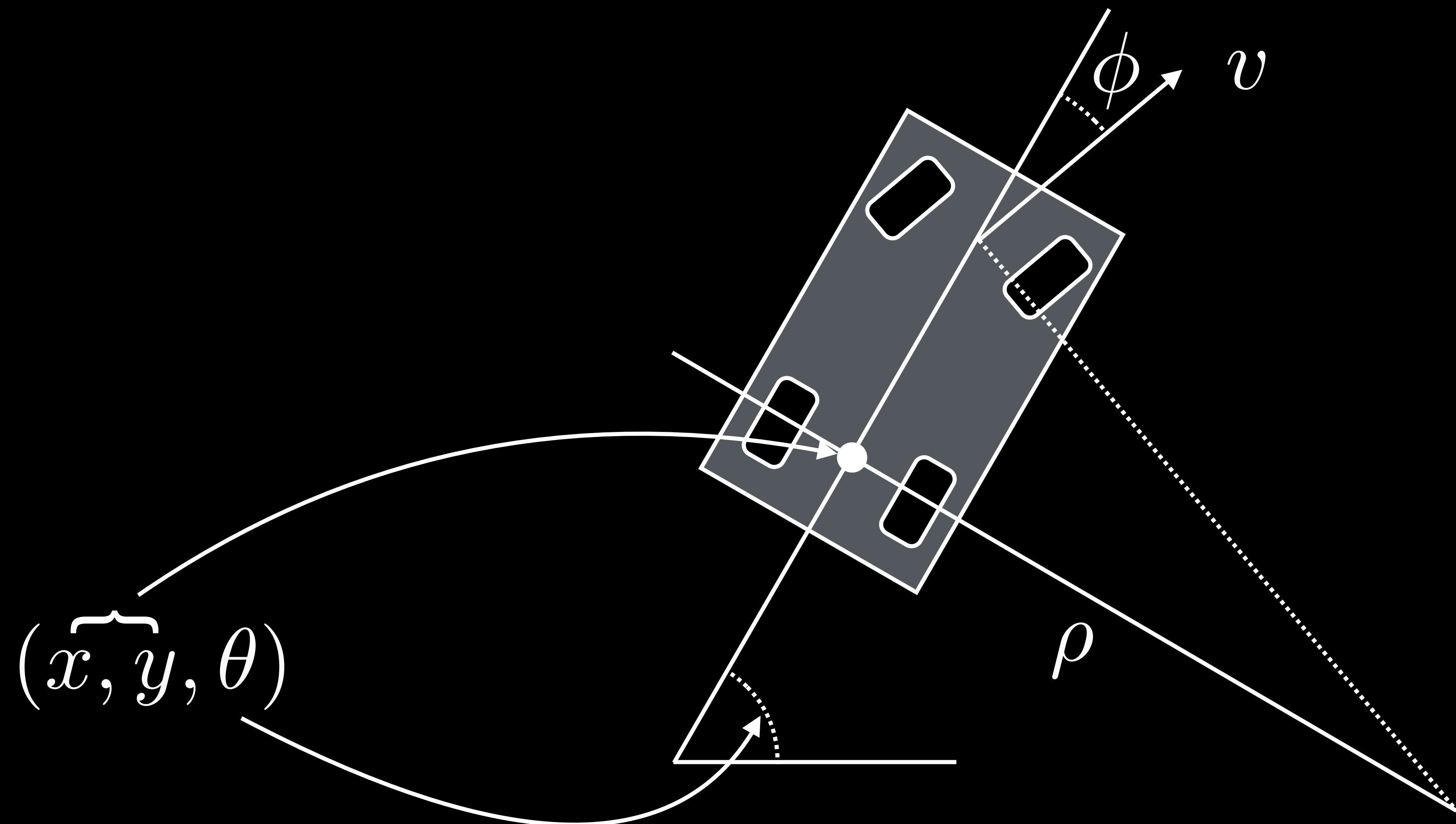


3 DOF (x, y, θ)

What about the control?

2 DOF (ϕ, v)

Holonomic / Nonholonomic



Holonomic: controllable DOF = total DOF.
(i.e., can instantaneously move any direction.
On car, cannot move sideways.)

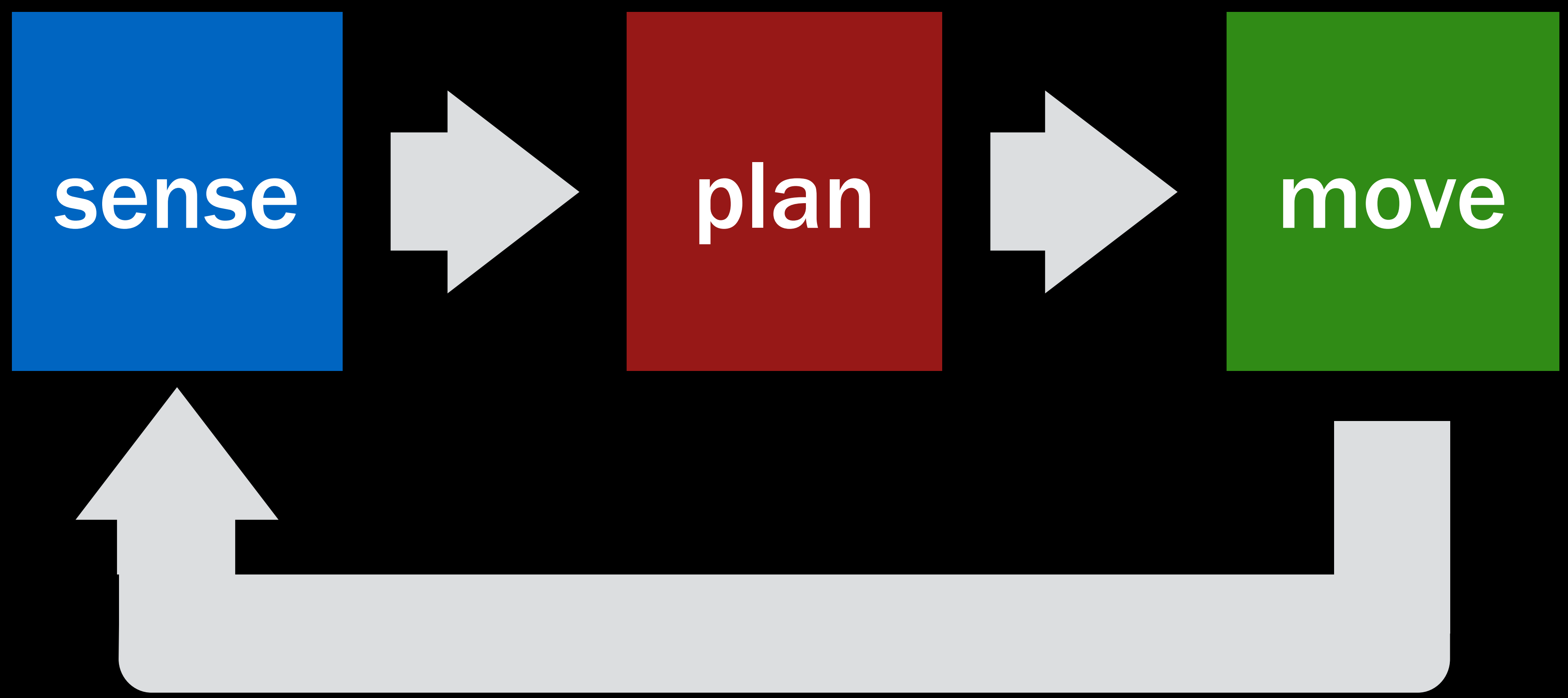
Geometric / Control

holonomic point/disc robot:
control & geometric are the same

car: position & orientation vs. steering & velocity
3 DOF (x, y, θ) **2 DOF** (ϕ, v)

In which space should we plan?

Open-Loop/Closed-Loop



Dealing with uncertainty and changing environments

Recap

Sense, Plan, Move

Configuration, DOF

Kinematics, Inverse Kinematics

Configuration Space

Obstacles

Holonomic / Nonholonomic

Geometric / Control