Robot Actions: Locomotion & Manipulation

SS-3406 Introduction to Robotics

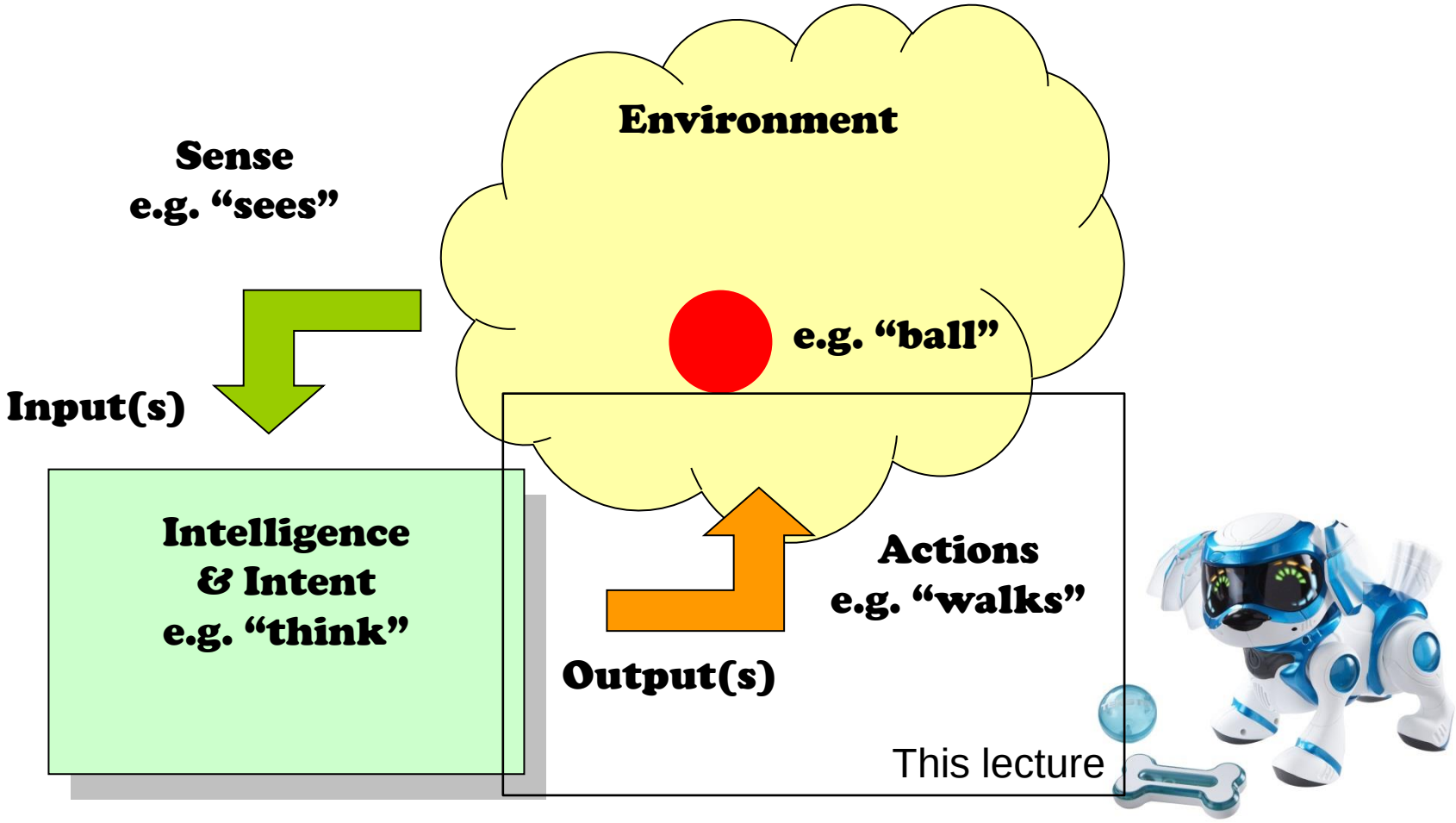
RECAP

Summary of Prev Lecture

- We ventured into looking at various aspects pertaining to robot actions.
- Three types of actions:

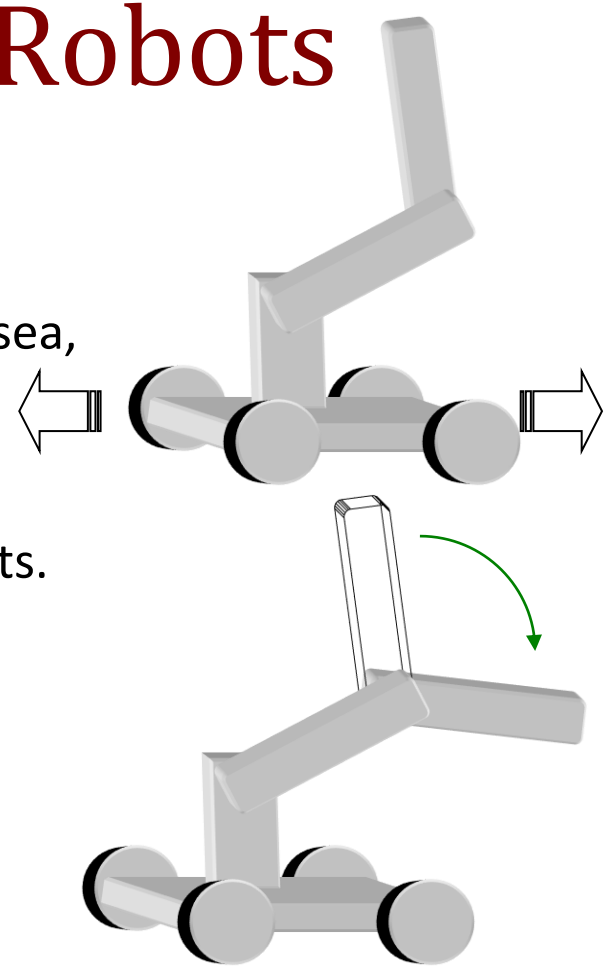
- Effectors: the parts of a robot that interact with the environment and have an effect on the environment.
- Actuators: mechanisms or devices that drives the effectors to produce their effect in the environment.
  - Characteristics of actuators
  - Two types:
  - Active (3 main types): motors, hydraulic, pneumatic.
  - DC Motor, Servos, Stepper Motors.
    - Torque, Gearing

Properties of a Robot



Types of Actions in Robots

- **Locomotion** (interact with own body)
  - Going from one place to another, e.g. ground, sea, air.
- **Manipulation** (interact with environment)
  - Changing the environment, e.g. handling objects.
- **Information Presentation** (perception, communication)
  - Non-physical changes to the environment, e.g. sound, display.



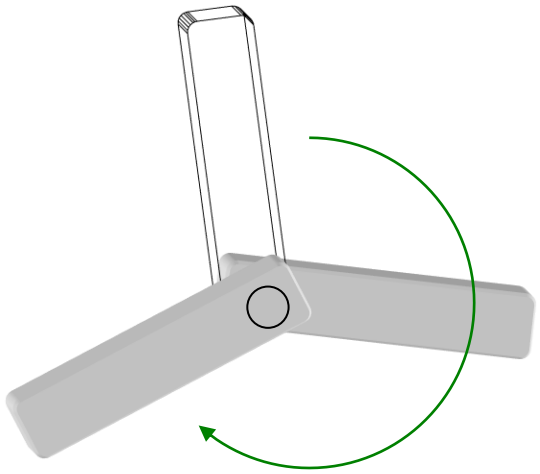
Today's Menu

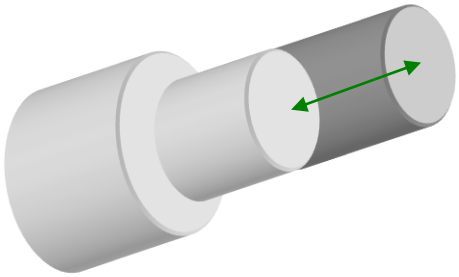
- Robot Motion
  - Degree of Freedom
  - Holonomic System
  - Kinematics & Dynamics
  - Trajectory
- Locomotion
  - Gait
  - Stability
    - Legged, Wheeled
- Manipulation
  - Forward & Inverse Kinematics
  - Gripper

ROBOT MOTIONS

Robot Motion

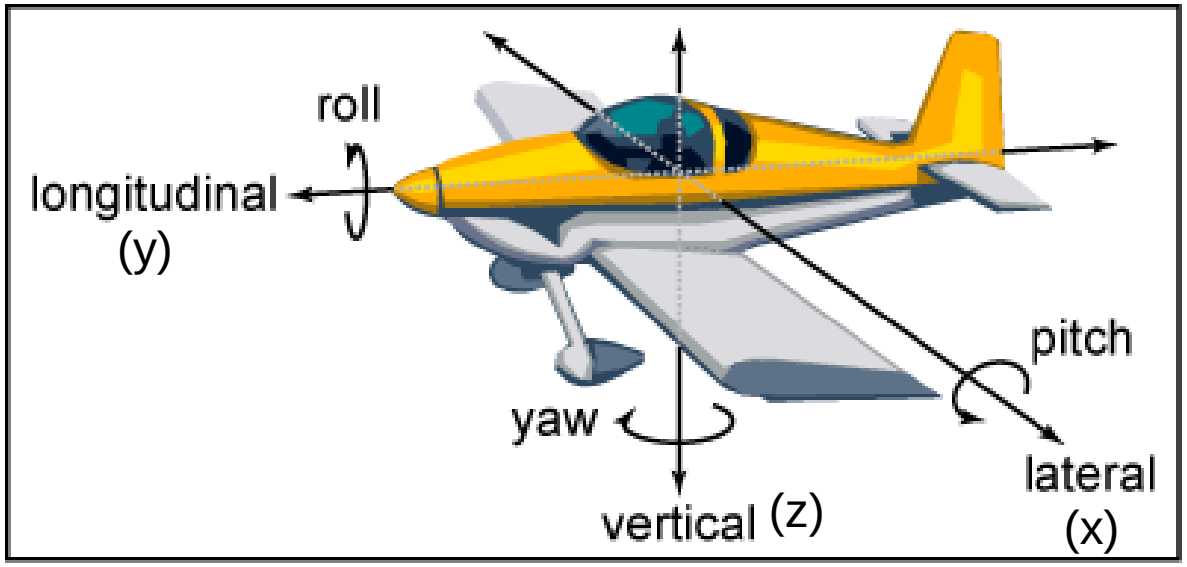
- **Rotational** – also called **revolute**; about a pivot (R)
- **Translational** – also called **prismatic**; also called **linear**; along a line (P)



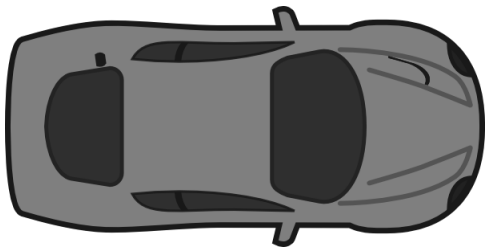


Degree of Freedom (DOF)

- Also called **Mobility**
  - The number of independent motions a body or effector can made
- A body in space (3D) has **6** DOF
  - 3 **translational** (for position): x, y, z
  - 3 **rotational** (for orientation): Yaw, Roll, Pitch.

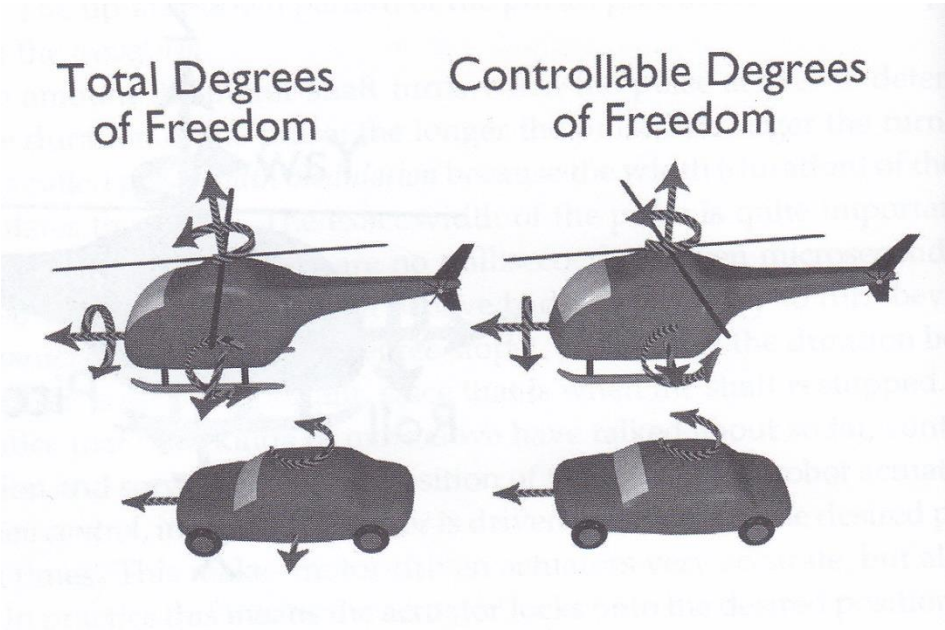


DOF on plane (2D)?



Controllable DOF

- One actuator gives one **controllable DOF** (**CDOF**).
  - Not all DOF are controllable.
- Uncontrollable DOF makes motion complex – it has to take a series of controllable DOF to achieve a desired motion.
  - That series of moving the body or effector is called the **trajectory**.

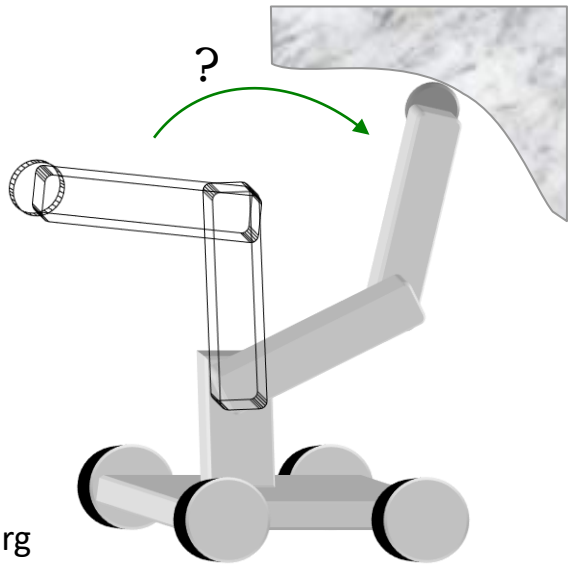


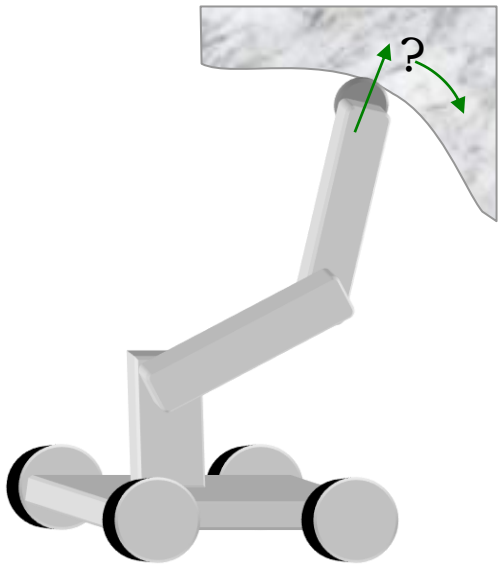
Holonomic System

- **Holonomic** System
  - CDOF = TDOF
  - E.g. Helicopter.
- **Nonholonomic** System
  - CDOF < TDOF
  - E.g. Car.
- **Redundant** System
  - CDOF > TDOF
  - E.g. Human arm.
  - Improves reliability.
- Note: **TDOF** = Total (available) DOF

Kinematics & Kinetics

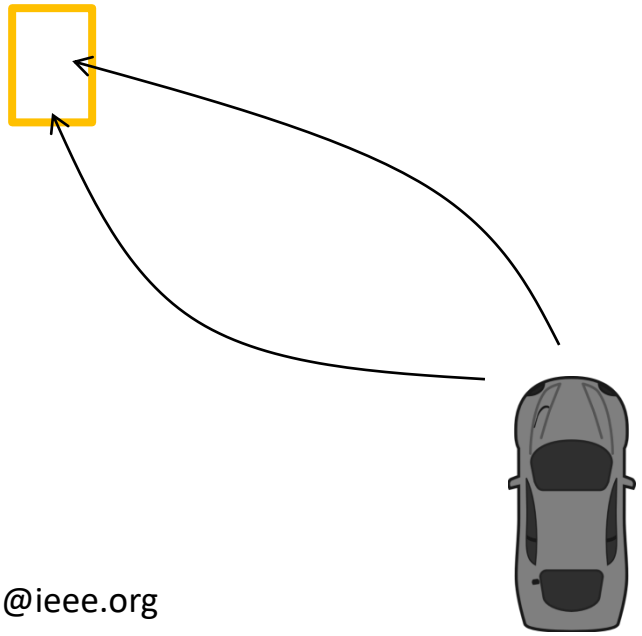
- **Kinematics** – is the study of motion without regard to forces.
  - Study of correspondence between actuator mechanisms and resulting motion of effectors.
- **Kinetics** – also called **Dynamics**, is the study of motion with regard to forces

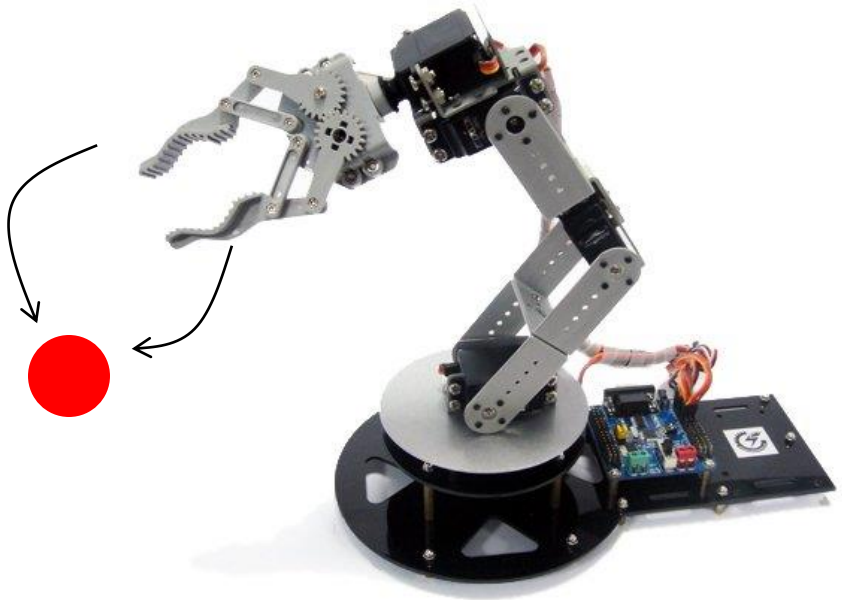




Trajectory of Motion

- The **path** of transverse from starting position or location to destination position or location, or an effector or a body.
- Not all trajectory are possible – depends on **holonomic constraints** of a robot.





LOCOMOTION

Locomotion

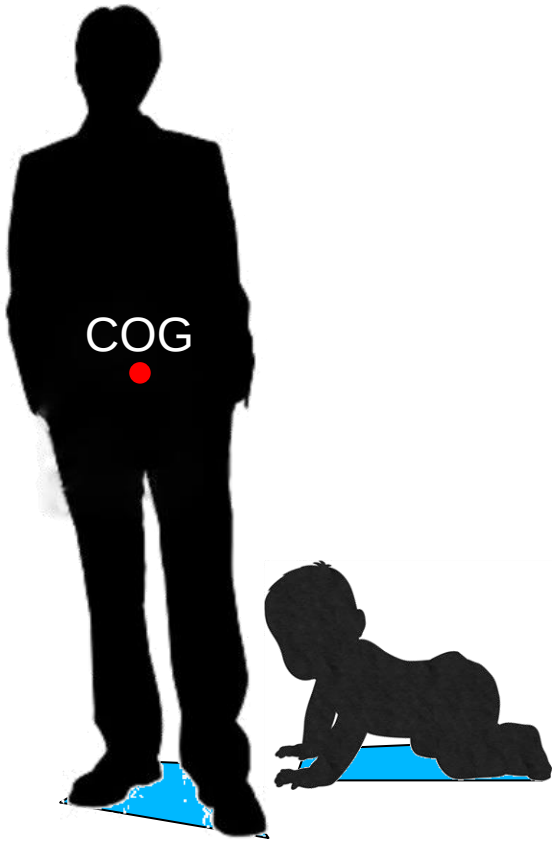
- The method to **move between places**, i.e. moving location.
- Effectors – types of locomotion:
  - Legs – walking, crawling, climbing, jumping, hopping.
  - Wheels – rolling.
  - Arms – swinging, crawling, climbing.
  - Wings – flying.
  - Flippers – swimming.

Gait

- The way a robot moves by using a particular **pattern** of footfall
  - 2 legged: alternating swing and stance phases.
  - 4 legged: lateral walking vs. diagonal walking
  - 6 legged: alternating tripod gait vs. ripple gait.
- Consideration for desirable robot gaits
  - Stability, speed, energy
  - robustness, simplicity

Stability

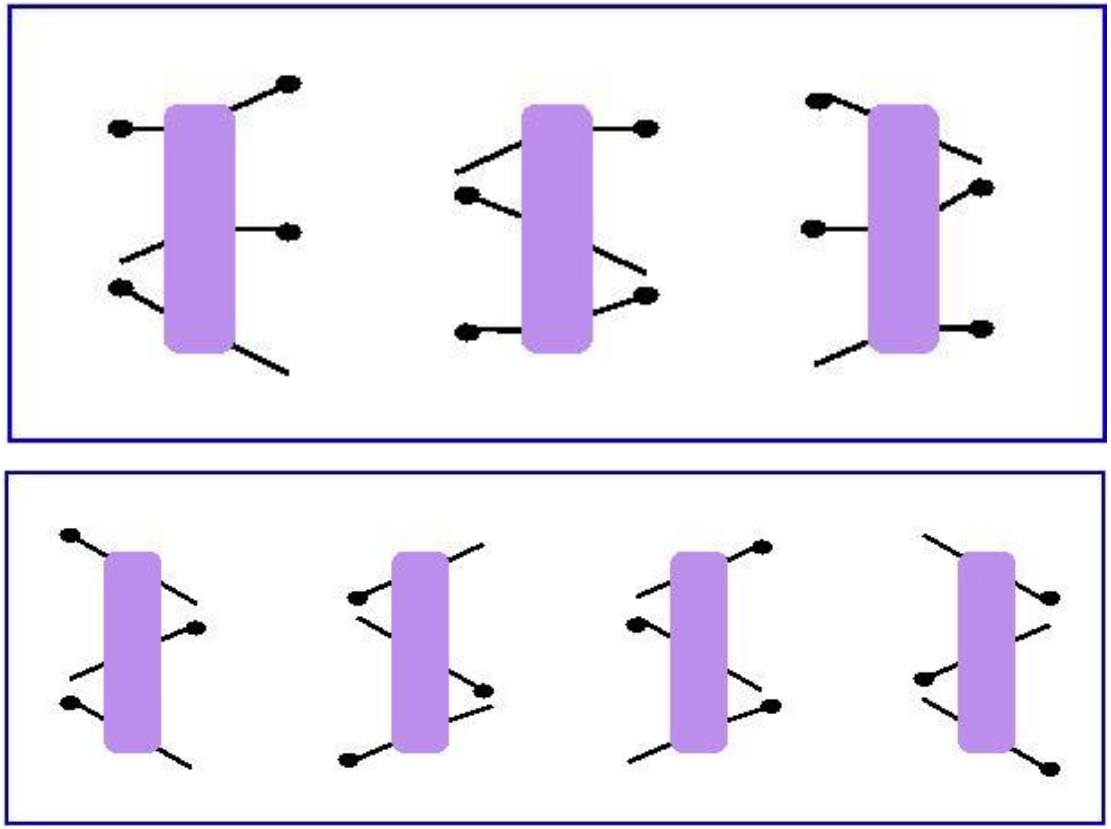
- Being **stable**: without wobble, lean, fall.
- Two kinds:
  - **Statically** Stable – e.g. car with four wheels.
    - Stable without making effort.
    - Require sufficient wheels, legs.
  - **Dynamically** Stable – e.g. standing.
    - Maintaining stable with effort.
- Center of Gravity (COG) to be within the polygon of support.
  - The area covered by the ground points (legs or wheels) is called polygon of support.



Polygon of Support

Statically Stable Locomotion

- Being stable while **not moving**.
  - Easy, safe but slow. E.g. tripod gait, ripple gait of six legged robot.



Dynamically Stable Locomotion

- Being stable while **moving**.
  - Complex but fast.

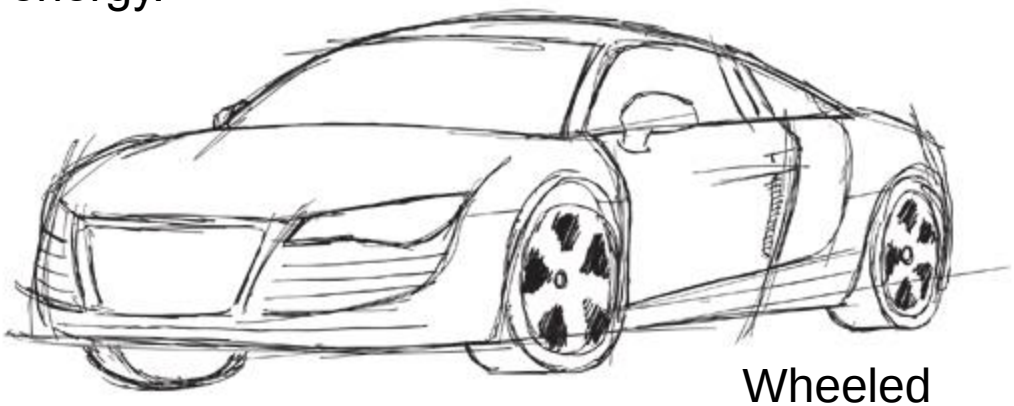
Legs are Difficult

- Animals use legs, but legs are difficult to control.
  - High DOF. Complex to control.
  - Difficult to stay stable.

Easy to fall if can't balance.
"Stand" requires energy.

Legged

"Stand" without using energy.



Wheeled

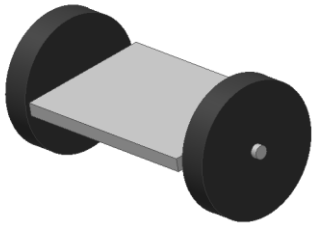
Wheels are Preferred

- Now you know why …

Wheeled Robots

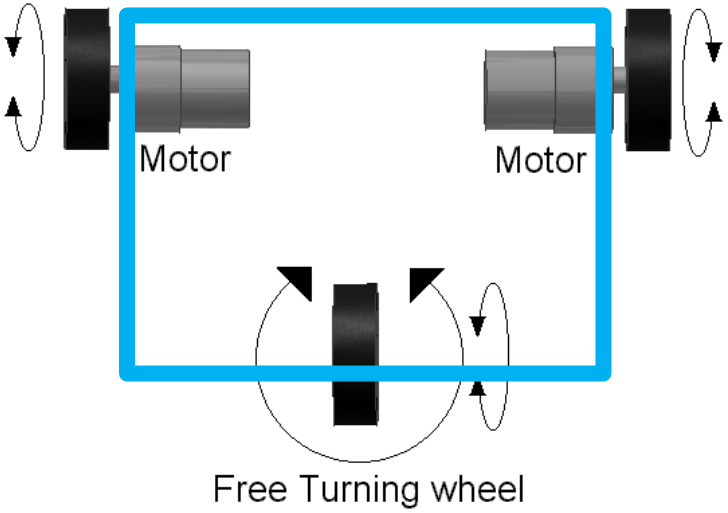
- Single wheel
  - Not possible without additional actuator or effector, or non-standard wheels.
- Two wheeled
  - Statically stable in one plane, unless with addition effector.
  - Difficult inverted pendulum balancing in another plane.
- Three wheeled
  - Minimum wheels to be statically stable.
  - Focus on locomotion, may not require balancing.
- Four wheeled
  - Ideal configuration for stability.
- More than four wheel
  - For uneven terrain, e.g. space.

Wheel Configurations

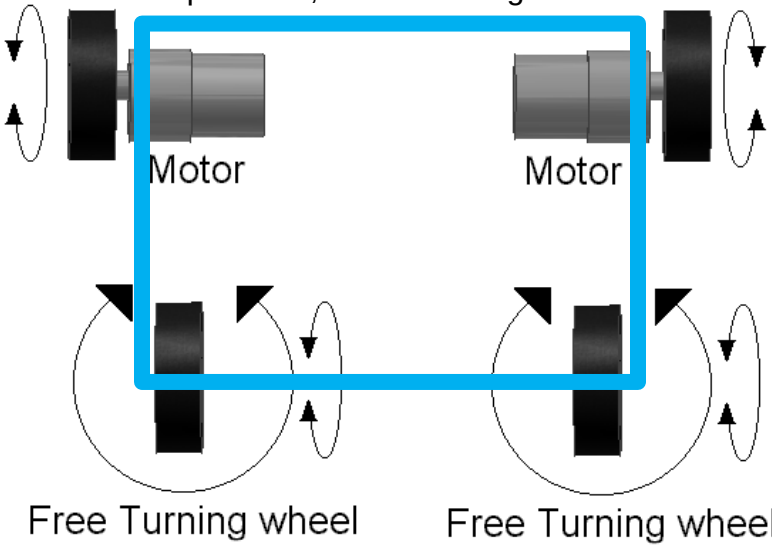


Swing-type

Differential steered 3 wheeled



2 powered, 2 free rotating

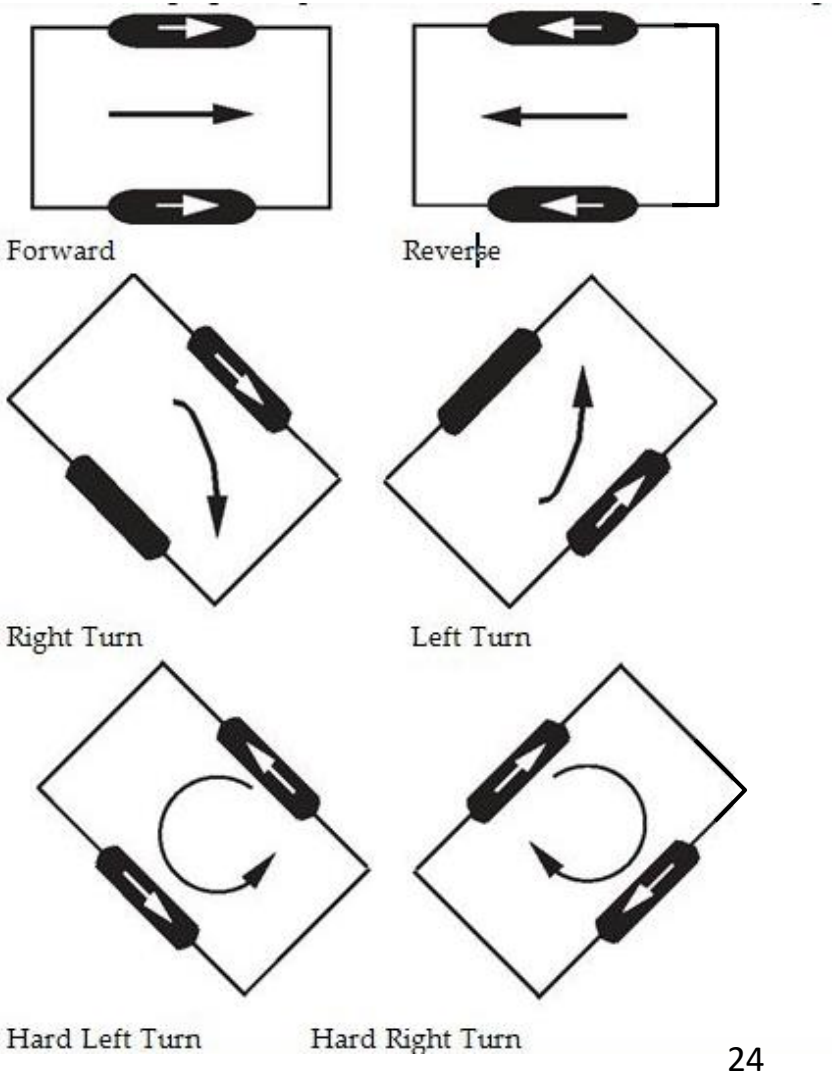


Source: http://en.wikibooks.org/wiki/Robotics/Types_of_Robots/Wheeled

Two Wheeled Kinematics

- How many TDOF?
- How many CDOF

- Differential drive – independent control of each wheel.
  - Steering by controlling differential drive is called differential steering.



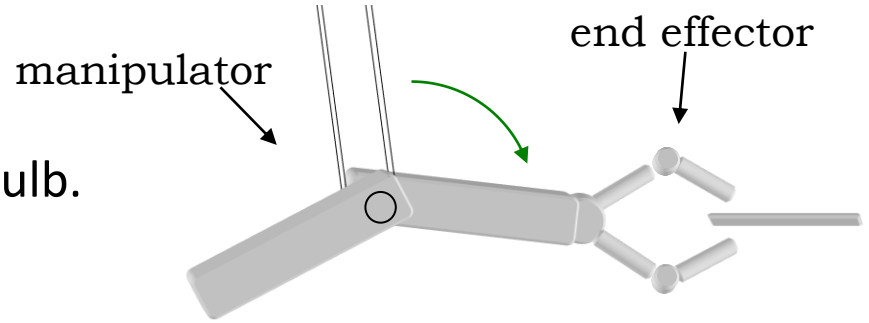
Locomotion Challenges

- For a mobile robot moving on the ground, locomotion requires:
  - Maintaining **stability** while moving and stationary.
  - Ability to **navigate** from starting point to destination point.
    - Avoid colliding into another object.
    - Avoid being collided by another object.
    - Control movement based on the kinematics of the robot.
    - Planning the trajectory of the path of travel.

MANIPULATION

Recap: Effectors

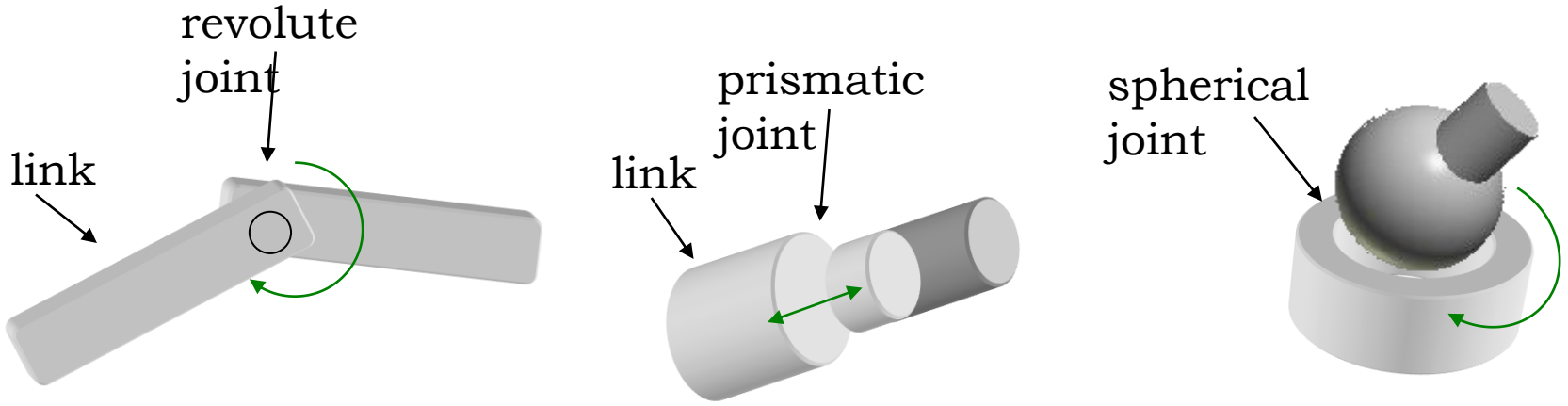
- Effectors
  - The parts of a robot that interact with the environment and have an **effect** on the environment.
  - Three types:
    - Physical effects (main focus in robotics):
      - **Manipulators**, e.g. arms.
      - **Mobile**, e.g. wheels, legs.
    - **Perceptual**, e.g. speaker, light bulb.



- End-effectors
  - The tool, gripper or other device mounted **at the end** of a manipulator or mobile effector.

Manipulators

- Manipulators are usually made of links and joints:
  - **Link** – rigid piece of material connecting joints in a robot
  - **Joint** – device which allows relative motion between two links in a robot; joint can be **revolute** (R), **prismatic** (P), **spherical** (S) or **universal** (U)
    - Each joint provides one DOF

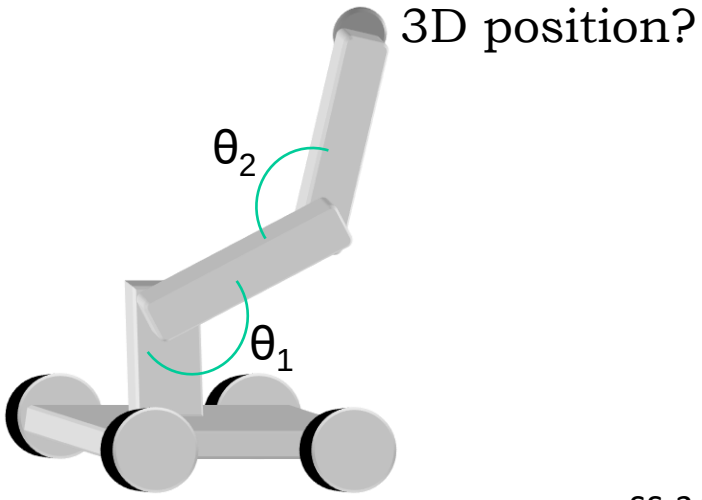


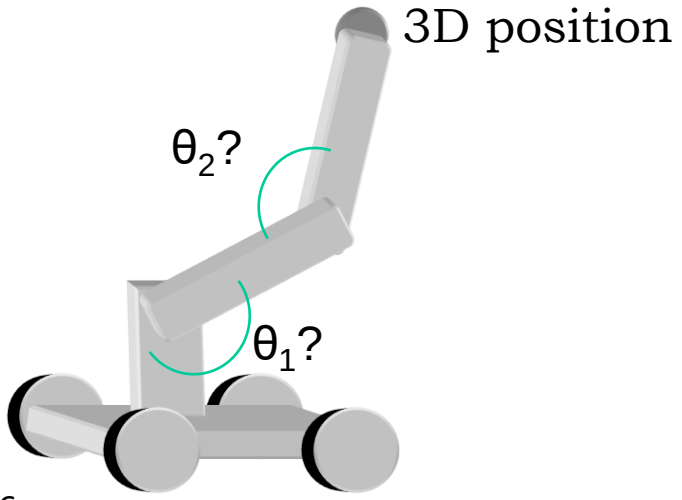
Manipulation

- **Manipulation** involves at least two things
  - Bringing the **end-effector** to the **position** through the movement of the complete manipulator, e.g. moving the arm.
  - Controlling the end-effector to do its **work**, e.g. gripping.
- Manipulation is not easy
  - The manipulator is linked to a body, i.e. its movement is constrained.
  - Involves moving every parts of the manipulator and end-effector, i.e. control high DOF.

Forward & Inverse Kinematics

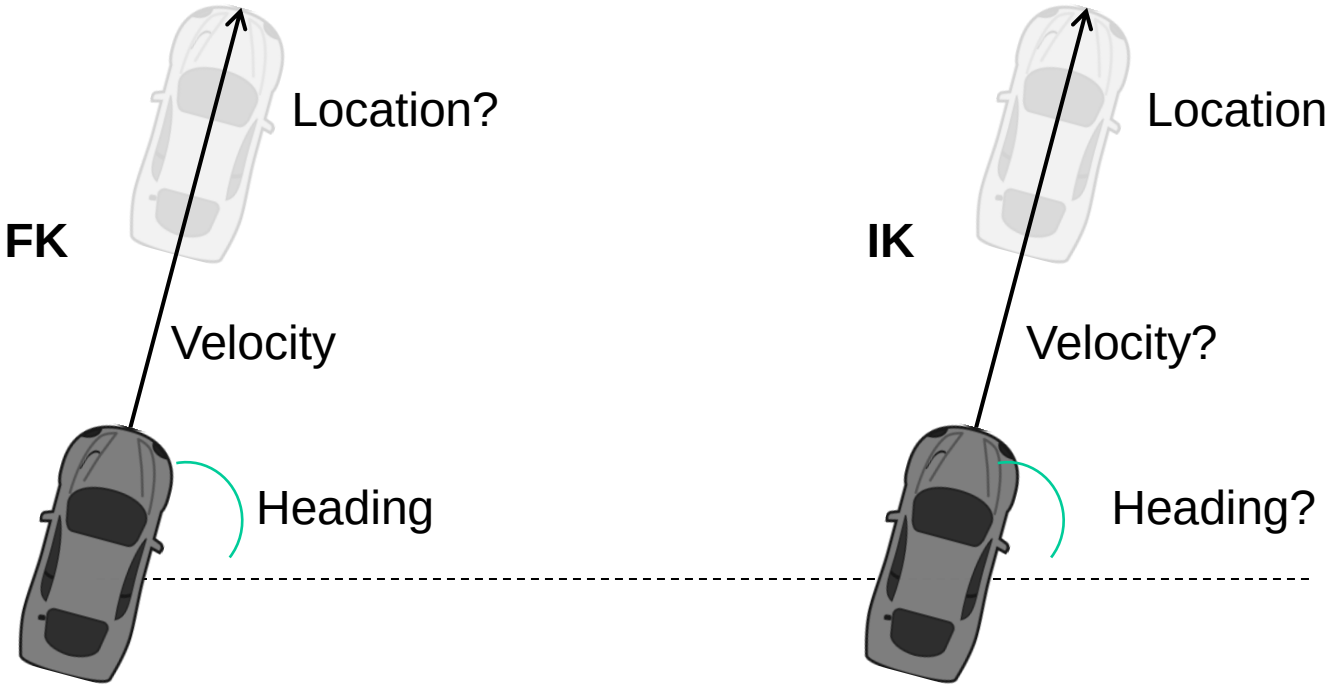
- **Kinematics** – is the study of motion without regard to forces.
  - Study of correspondence between actuator **mechanisms** and resulting **motion** of effectors.
- **Forward Kinematics** (FK): for the given angular movements at each joint, where will the end-effector reach?
- **Inverse Kinematics** (IK): for the desired position of the end-effector, how much should each joint move?





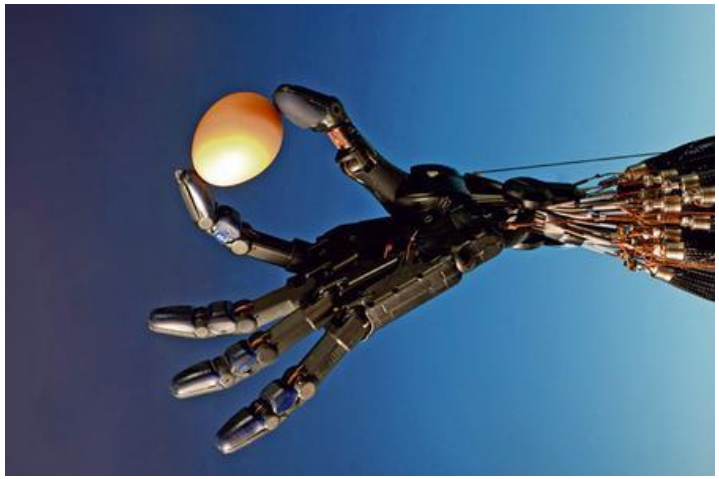
FK & IK for Wheeled Body

- **Forward Kinematics**: for a given wheel velocity (*v*), heading and time of travel, where the new location of the car?
- **Inverse Kinematics**: for a desired new location, what should be the wheel velocity (*v*), heading and time of travel?



Dynamics (Kinetics)

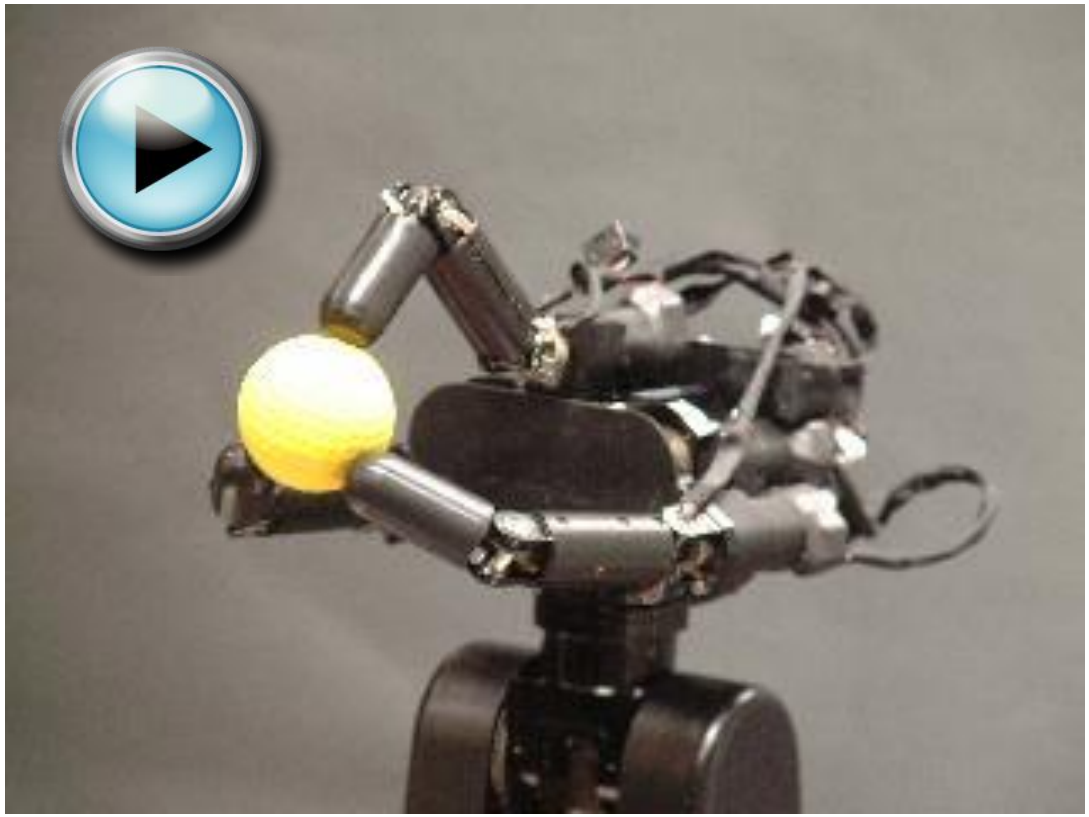
- **Kinetics** – also called **Dynamics**, is the study of motion with regard to forces.
  - Dynamics refers to the properties of **motion** and **energy** of a moving object.
- The faster an effector, or body, move, the more significant their dynamics.
- There are **direct** (forward) and **inverse** dynamics.
  - Much more complicated than kinematics.
- How much and how strongly should each finger of a gripper move to pick up an egg?



Gripper

- **Gripping** is not easy:
  - Finding the **grasping points** based on COG.
  - Determine the **strength** of grasps.
  - Overcome the constraint of the **environment**, e.g. slide along a surface to reach appropriate grasping points.
  - Deal with **dynamics** of moving object, e.g. catching.

Gripper Innovations

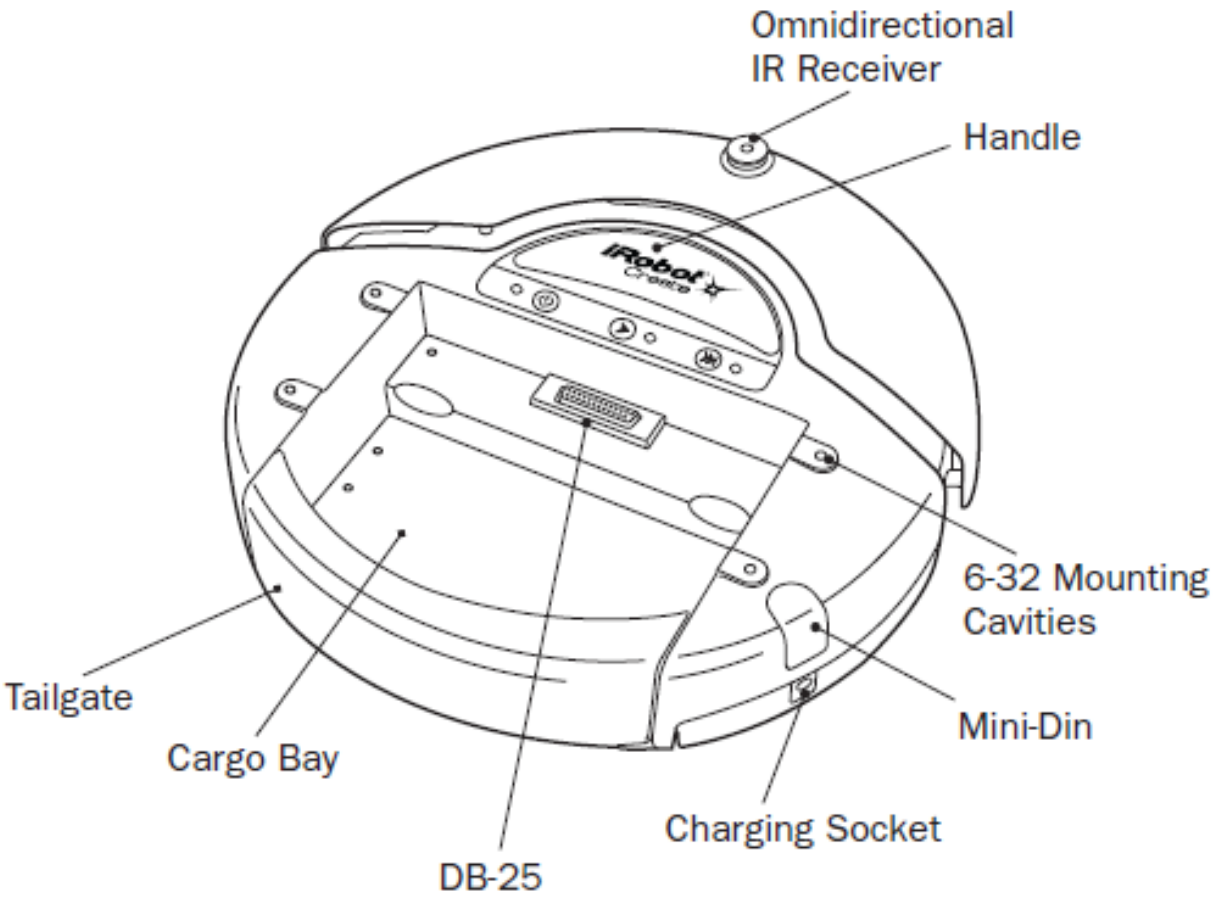


High Speed Robot Hand

Universal Gripper
(Doremon Hand!)

Actions in My Keepon

Actions in iRobot Create



Reading List

- Robot Arm on How It's Made:
  - https://www.youtube.com/watch?v=tkDbmWAyHYw
- Omid Jahanian & Ghasem Karimi, Locomotion Systems in Robotic Application, 2006
  - http://agents.sci.brooklyn.cuny.edu/corc3303/papers/c1-jahanian-icrb-2006.pdf

To Do List

- How many DOF does a human arm (up to the wrist) have?
- How many DOF does a human hand have?
- Give one example of an existing robot for each type of the wheeled robot given here: (1) Single wheel, (2) Two wheel, (3) Three wheel, (4) Four wheel, and (5) More than four wheel.

Summary

- Robot motion: **rotational**, **translation**.
- DOF: controllable DOF (**CDOF**), total DOF (**TDOF**).
- Holonomic Systems:
  - **Holonomic**: CDOF = TDOF
  - **Nonholonomic**: CDOF < TDOF
  - **Redundant**: CDOF > TDOF
- **Kinematics**: motion ignoring force.
- **Kinetics** (**dynamics**): motion with force.
- **Trajectory**: **path** of motion.
- **Locomotion**: **types**, **gait**, **stability**.

- **Stability**: COG within Region of Support.
  - Stability: **statically**, **dynamically**.
  - **Legs** are **difficult** to control stability.
  - **Wheels** are **easy** to control stability.
- **Effect** of actions: **manipulation**, **motion**, **perception**.
- **Manipulator**: system of effectors, with end-effector at the end.
- **FK**: where will we reach given series of actions.
- **IK**: what series of actions should we do given a desired destination.
- **Gripping**: concerns dynamic - motion with force.

References

- The Robotic Primer by Maja J Mataric
- Introduction to Robotics and Intelligent Systems by Ioannis Rekleitis of University of South Carolina.