Robot Actions: Effectors & Actuators

SS-3406 Introduction to Robotics

RECAP

Summary of Prev Lecture

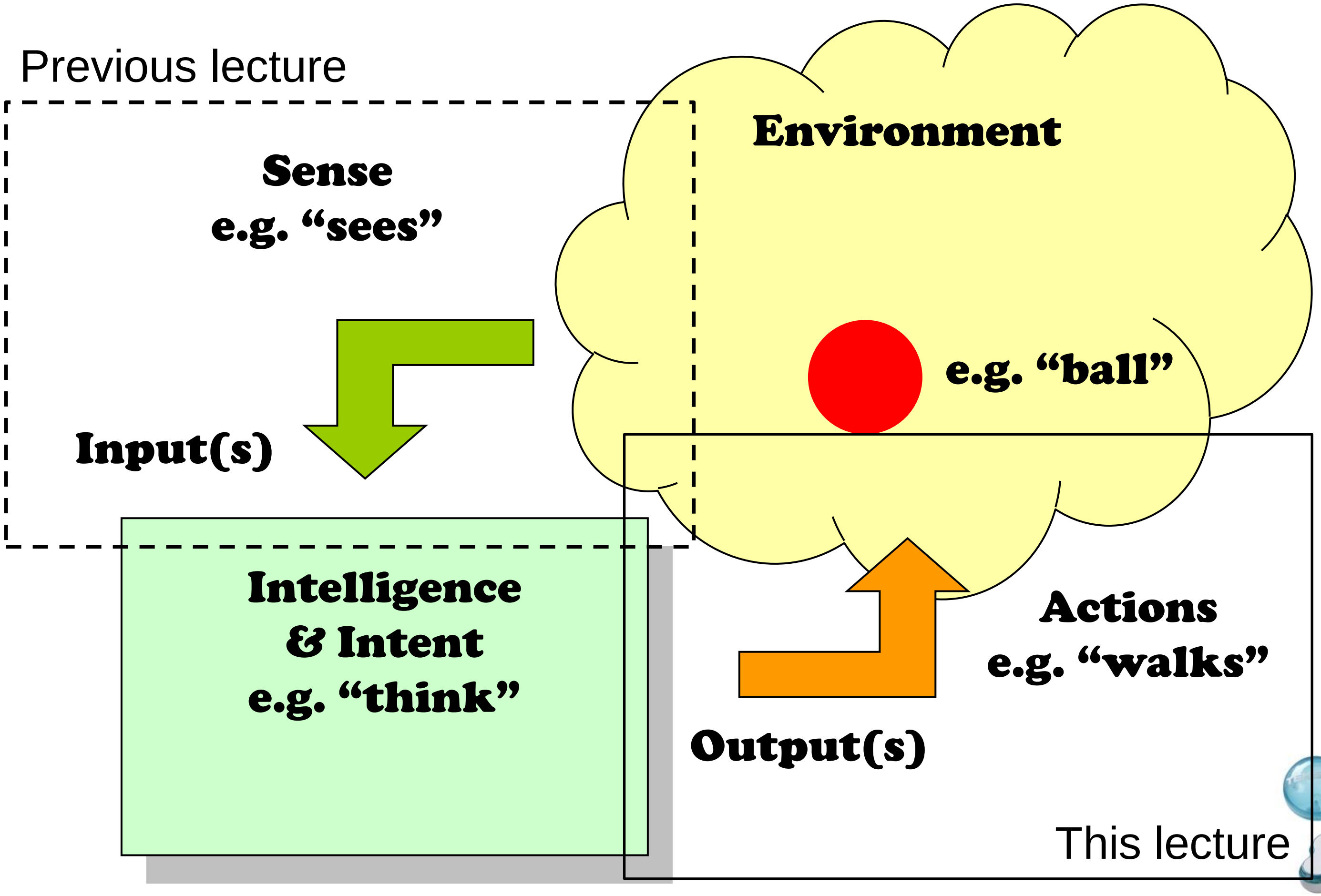
- Met My KeepON and iRobot
- Robot States:
  - Observability:
  - State space, Sensor space
- Sensors
  - Types: Proprioceptive, Exteroceptive
  - Types:
  - Challenges: low-level to high-level, uncertainty
  - Looked at a few sensors:

Today's Menu

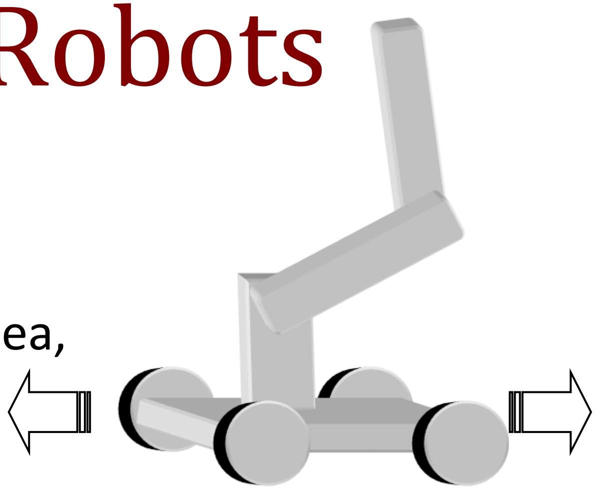
- Actions
- Effectors & Actuators
- Motors
  - DC Motor
  - Gearing
  - Servos
  - Stepper Motors

ACTIONS

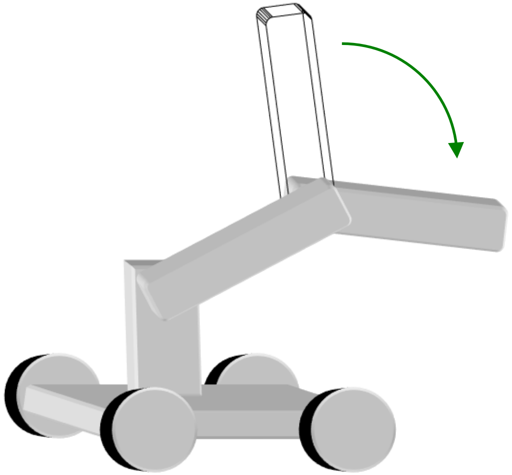
Properties of a Robot



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.

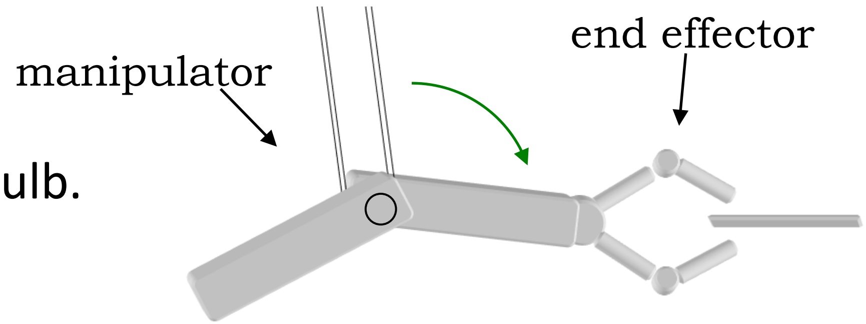


- **Information Presentation** (perception, communication)
  - Non-physical changes to the environment, e.g. sound, display.

EFFECTORS & ACTUATORS

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.

Wheels

- **Standard** wheels
  - 2-DOF, forward & reverse.
  - Usually driven (actuated).
- **Orientable** wheels: forces the direction.
  - Centered: non swivel.
  - Off-centered (castor): swivel.

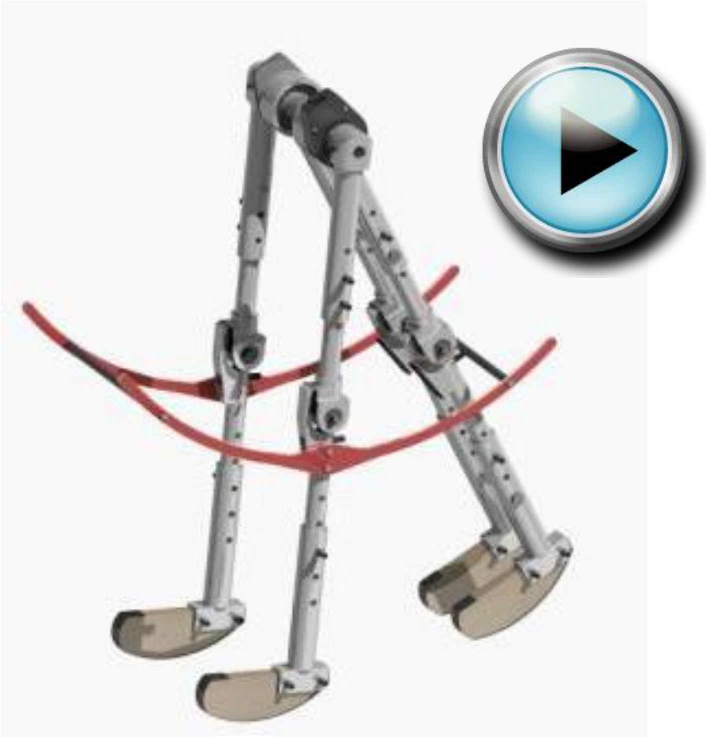
- **Ball** wheel: all direction.
  - More friction than orientable.
- **Omni** wheels: multi direction.
  - Usually driven (actuated).

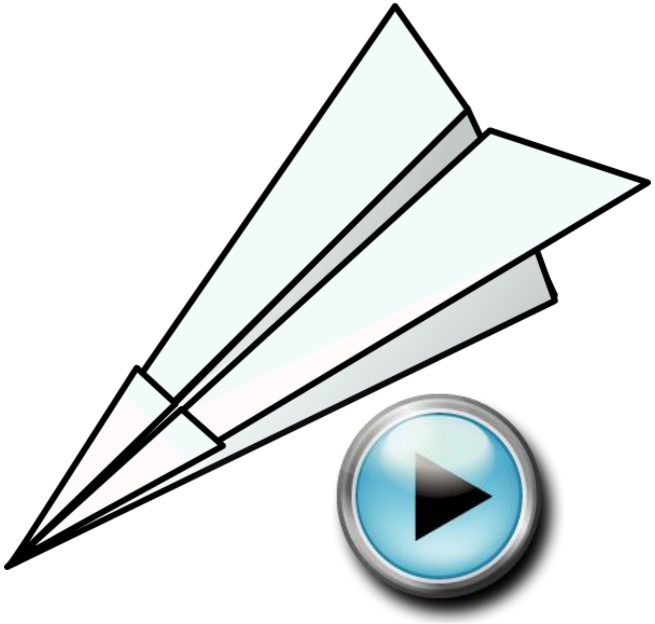
Actuators

- Actuators
  - Mechanisms or devices that **drives the effectors** to produce their effect in the environment, e.g. motors, spring, artificial muscle.
- Two types
  - **Passive**: uses potential energy in the effectors, and its interaction with the environment without active power consumption.
  - **Active**: consumes energy from power source. Most commonly used.
  - E.g. gliding (passive) vs jet engine (activte).

Passive Actuators

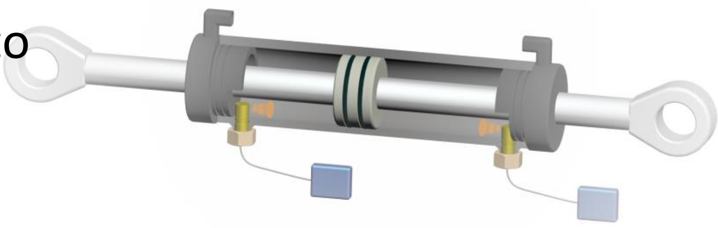
- Not easy. Not common.

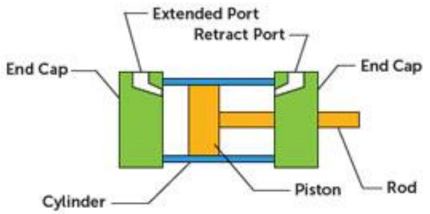


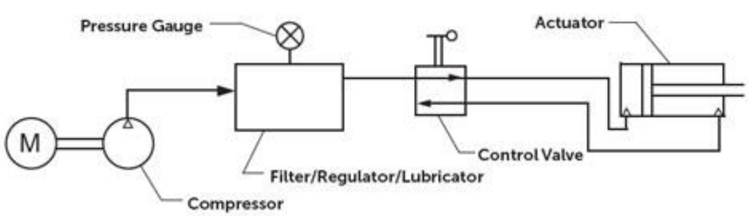


Active Actuators

- **Electric motors** – use electricity.
  - Cheap, simple to use.
- **Hydraulics** – use fluid pressure.
  - Powerful, fast, large, require much care to use.
- **Pneumatics** – use air pressure.
  - Powerful, fast, large, require much care to use.
- **Others**: Photo-reactive materials, Chemically reactive materials, Thermally reactive materials, Piezoelectric materials.







Choosing Actuators

- **Load** (e.g. torque to overcome own inertia)
- **Speed** (fast enough but not too fast)
- **Accuracy** (will it move to where you want?)
- **Resolution** (can you specify exactly where?)
- **Repeatability** (will it do this every time?)
- **Reliability** (mean time between failures)
- **Power consumption** (how to feed it)
- Energy supply, weight, physical design, controllability

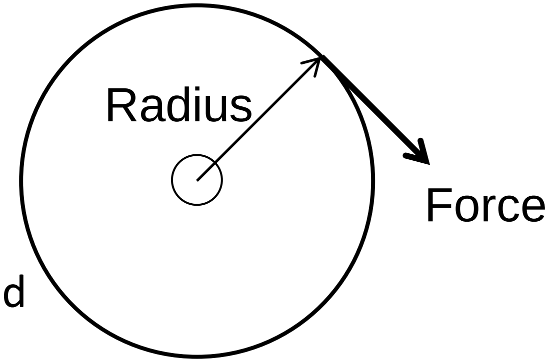
DC MOTOR

Electric Motors

- Two general categories:
  - **AC motor** – runs on mains power supply.
  - **DC motor** – runs on battery, or similar source.
- Power sources terminology:
  - **AC**: Alternating Current – changing direction.
  - **DC**: Direct Current – one direction.
- Mobile robots mostly use DC motors. Why?

Motor Characteristics

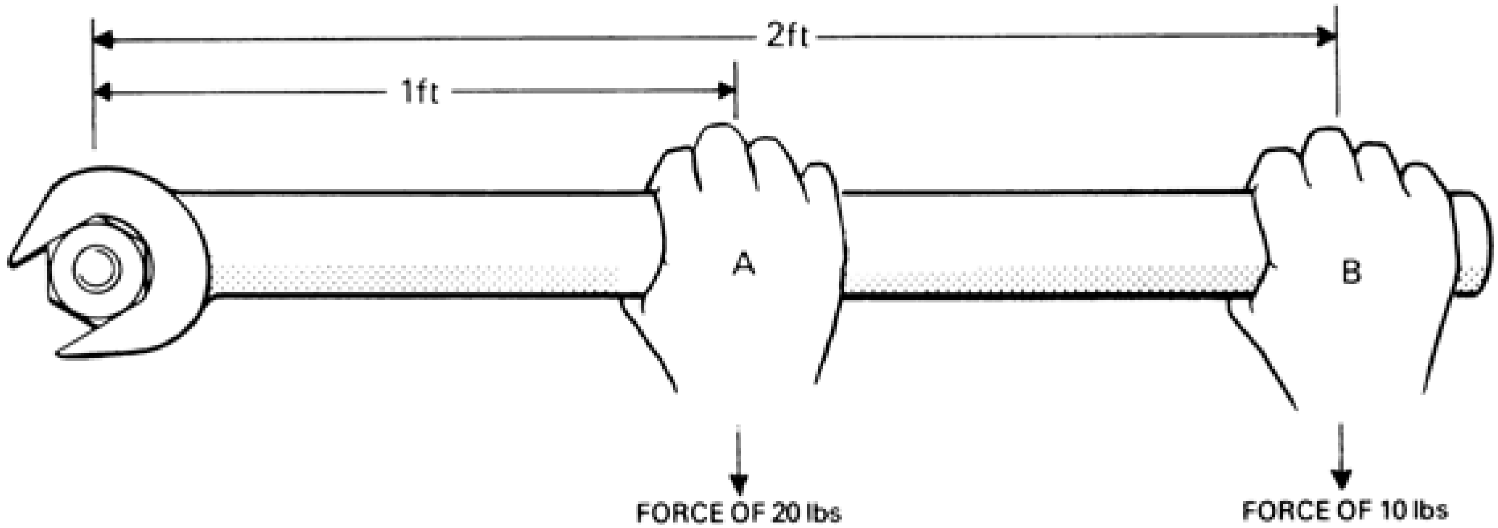
- (1) **Speed** (**Velocity**; we will be loose with the definition at this point)
  - How fast it can rotate, usually specified in revolutions per minute (rpm).
- (2) **Torque** (Max, Stall)
  - Also called **moment** or moment of force, or “turning force”.
  - The measure of how much a force will rotate an object about an axis, fulcrum, or pivot.
  - Torque = Force × Radius



- (3) **Power**
  - The amount of work that can be done in a certain amount of time.
  - (3) Power = (2) Torque × (1) Rotational Speed
  - Maximum power of a motor is fixed.
  - Tradeoff between torque and speed.

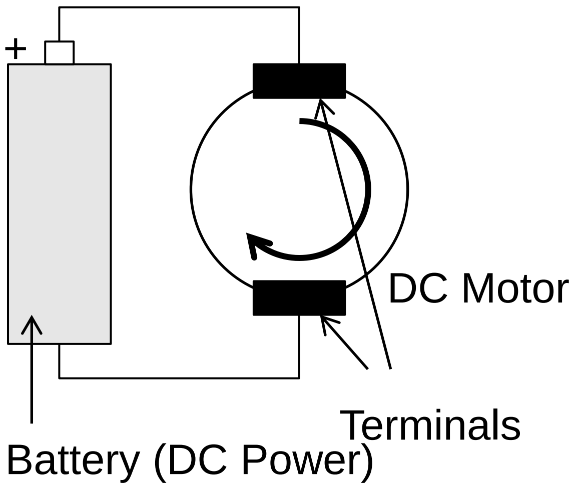
Torque at Work

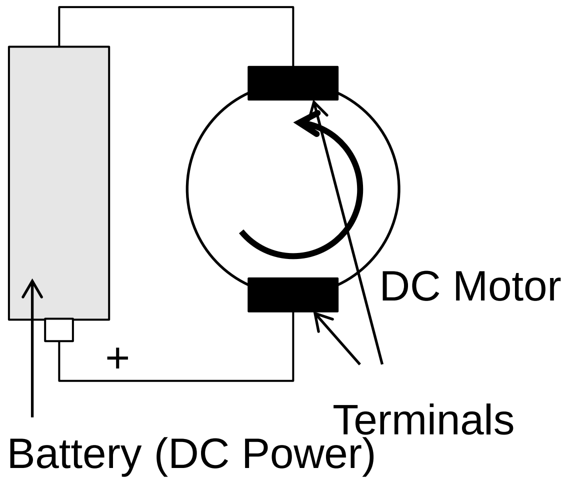
- ***Torque** = Force × Radius (Distance)*
- The nut requires a fixed amount of torque (to overcome the friction) to turn.
- However, we require different amount of force at different distances to turn the nut.

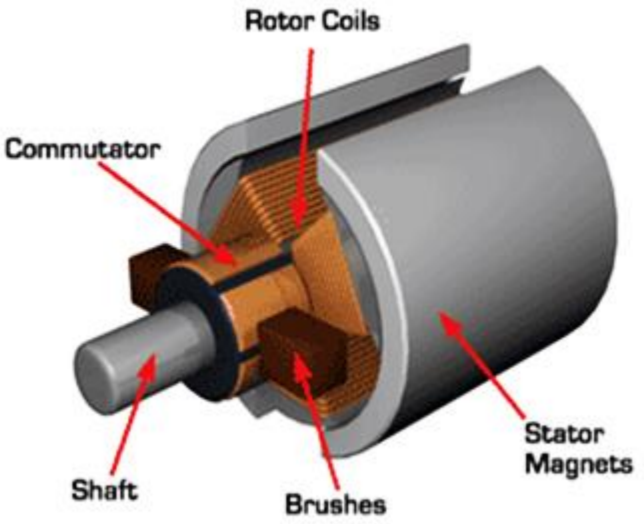


DC Motors

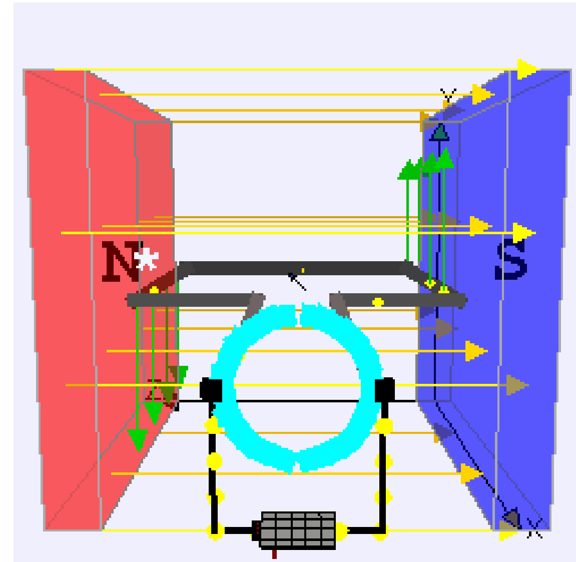
- Rotate when given **DC voltage**. Direction of rotation depends on direction of DC voltage.
- Generally used for locomotion.
  - Fast, continuous rotation.



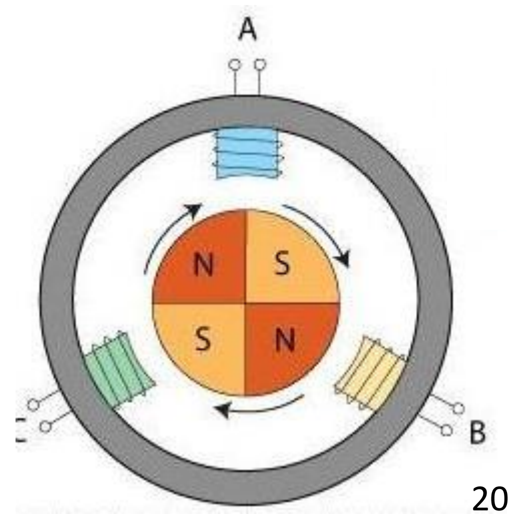




Types of DC Motors

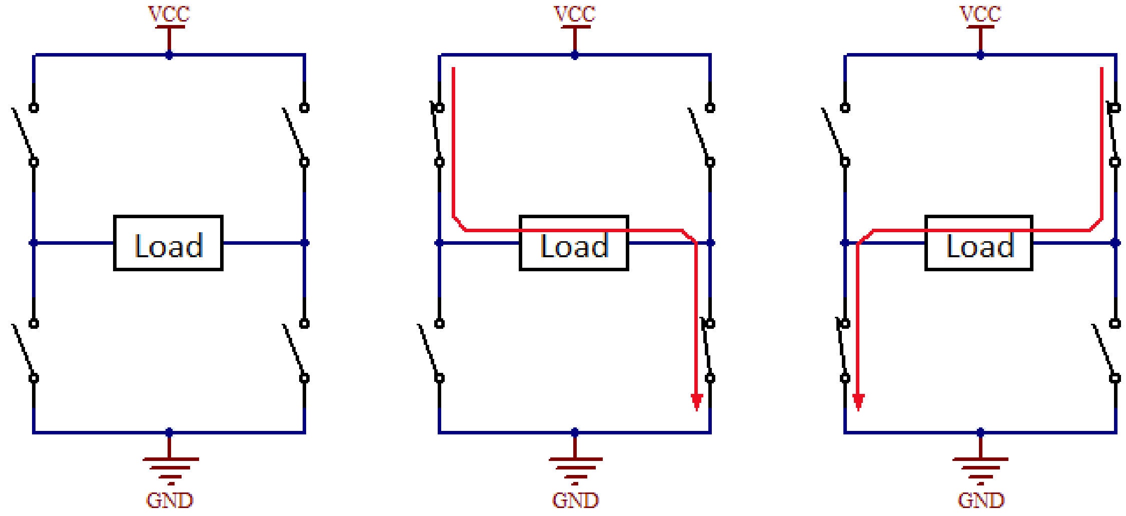


- **Brushed**
  - Uses brushes, usually carbon brush, to connect to external wiring such that it maintains its direction of rotation.
  - Low cost, simple control, however short lifespan (brush maintenance).
- **Brushless**
  - Converts DC to AC, and moves motor coils to stator (body) to avoid using the brushes.
  - Higher cost, not simple control, however long lifespan (no brush maintenance).

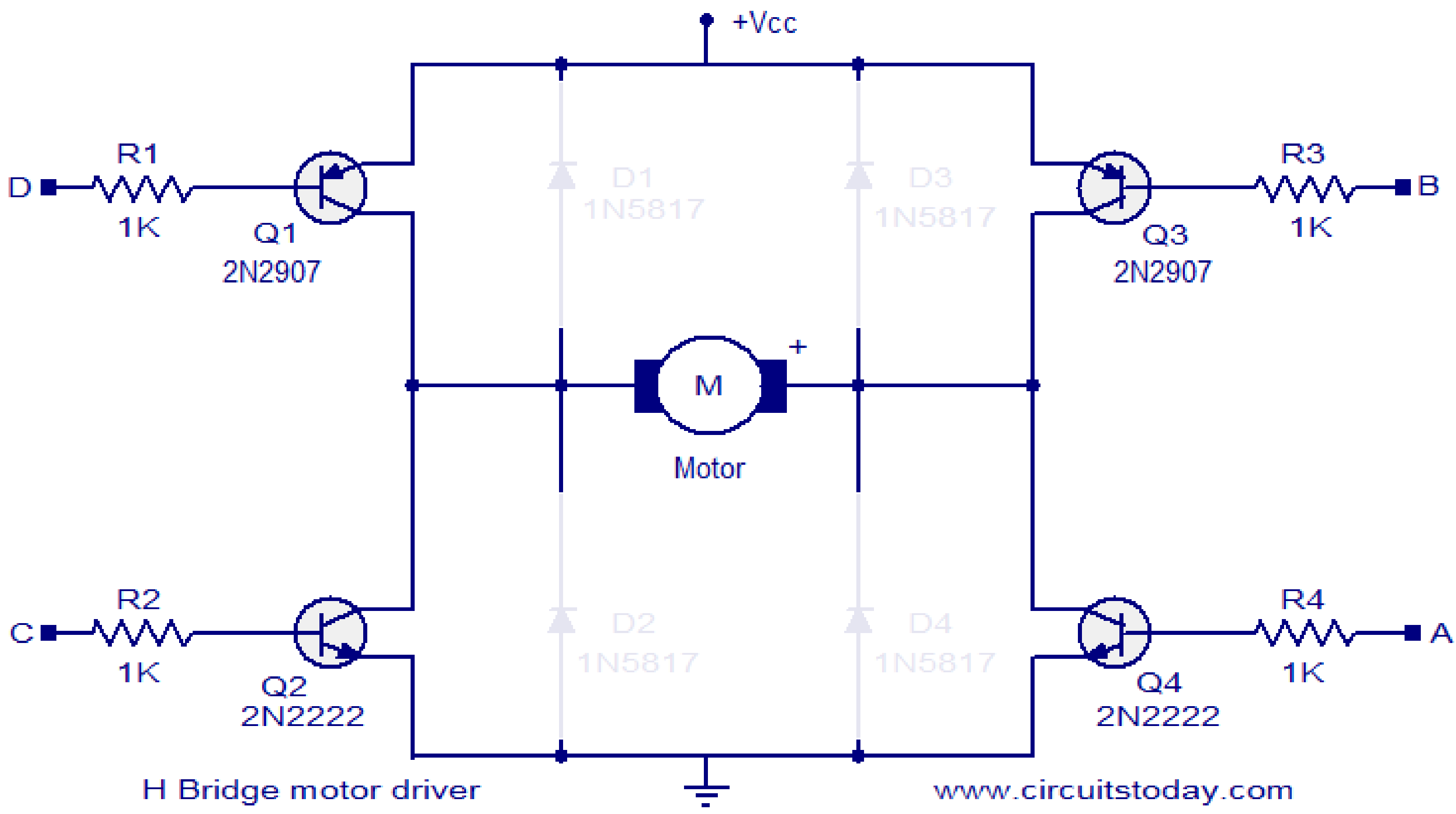


Motor Driver

- Motors require **higher current** than what the controller (control circuit) can supply.
- Motor driver circuit receives signal from the controller and switches the motor using its own power supply – in desired direction.



Motor Driver: H-Bridge



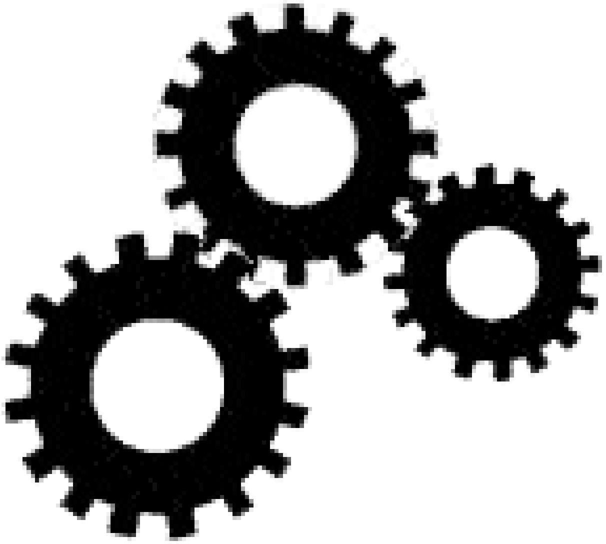
GEARING

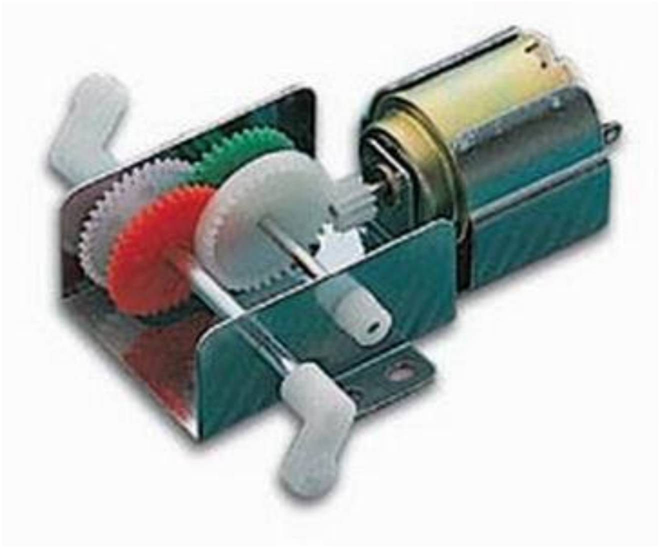
Changing Speed of a Motor

- Use **gear**: change gear ratio.
  - To be discussed in next section.
- Change driving **power** to the motor.
  - The power through the H-Bridge

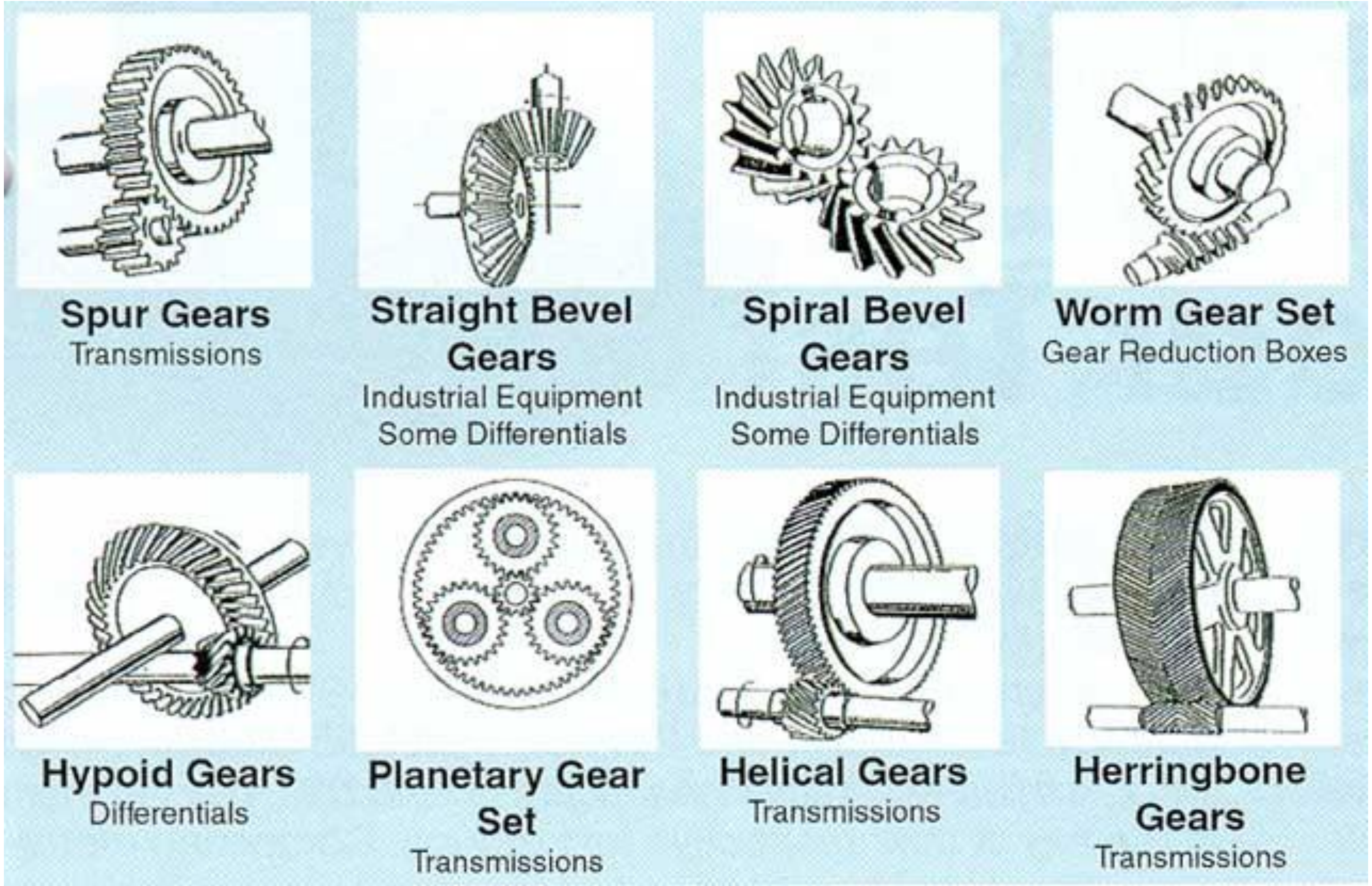
Gears

- A **gear** or cogwheel is a rotating machine part having cut **teeth**, or cogs, which **mesh** with another toothed part in order to **transmit torque**.



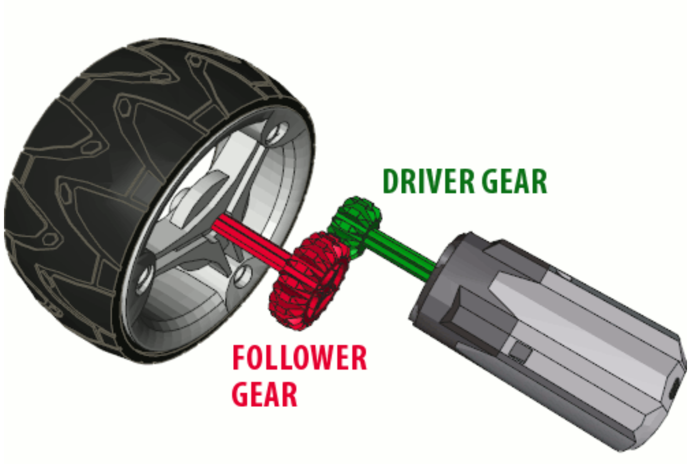


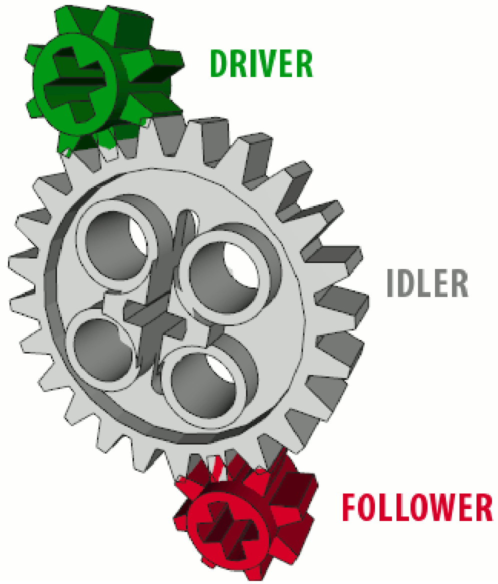
Types of Gears



Driver, Follower and Idler

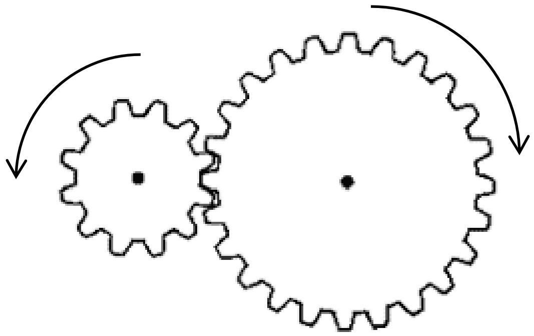
- **Driver** (input) gear
  - The gear turned by an actuator (e.g., attached to the motor)
- **Follower** (**driven**, output) gear
  - The gear turned by the driver (e.g., attached to the wheel)
- **Idler** gear
  - Between driver and follower.
  - Does not effect the ratio.
  - Changes direction.





Functions of Gears

- Change planes of rotation
- Transfer motion
- Change speed of rotation
- Change torque
- Change direction

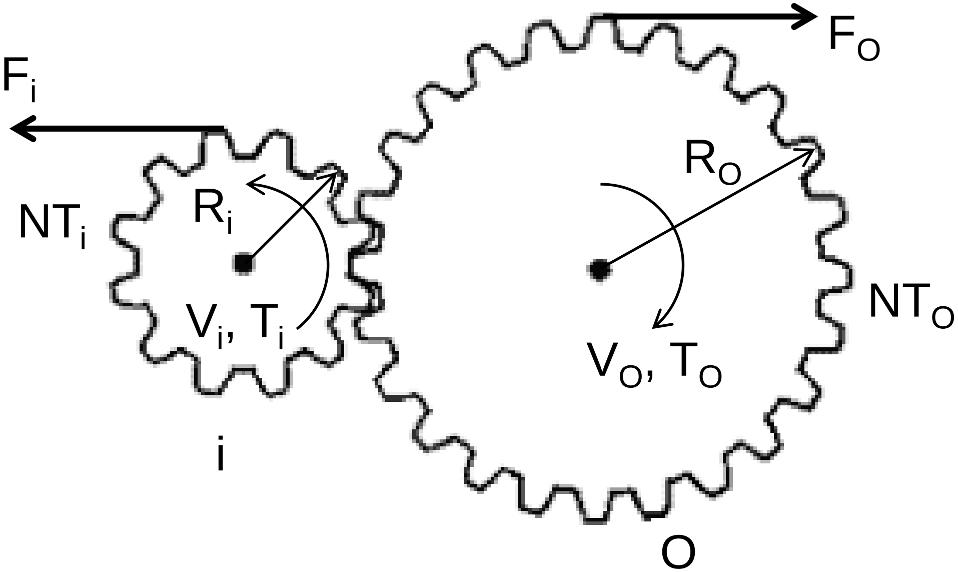


Gear Ratios

- ***Gear ratio** = no. of follower teeth / no. of driver teeth*.
  - E.g. 24/8 or 3:1 if driver has 8T and follower has 24T.
- Bigger gear => more teeth. Smaller gear => less teeth.
- Based on the torque equation: Torque = Force × Radius.

$$V_O = V_i \frac{R_i}{R_O} =$$

$$T_O = T_i \frac{R_O}{R_i} =$$

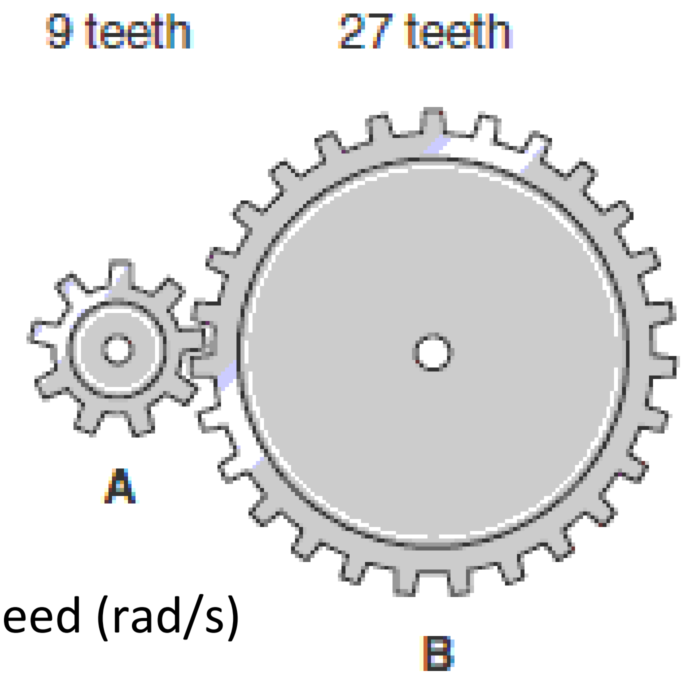


R = Radius, T = Torque, F = Force
V = Velocity, NT = No. of teeth

Gear Ratios Exercise

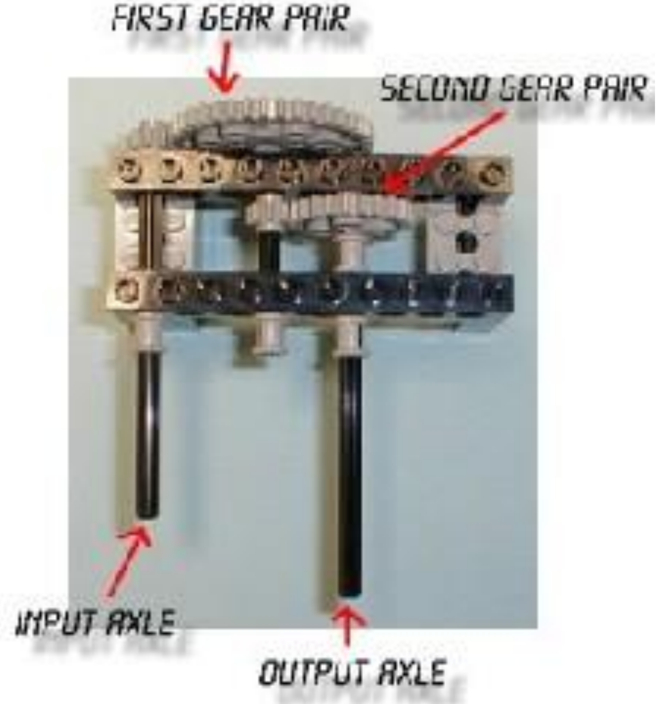
- The **spec** of a DC brushed motor RS441-5361:
  - Supply Voltage: 12V
  - Max Output Torque: 5.4mNm
  - Output Speed: 8700rpm
  - Shaft Diameter: 1.5mm
- **Calculate**:
  - Power of the motor.
  - Output torque and speed if A is driver.
- Recall
  - Power (W) = Torque (Nm) × Rotational Speed (rad/s)
  - With units:

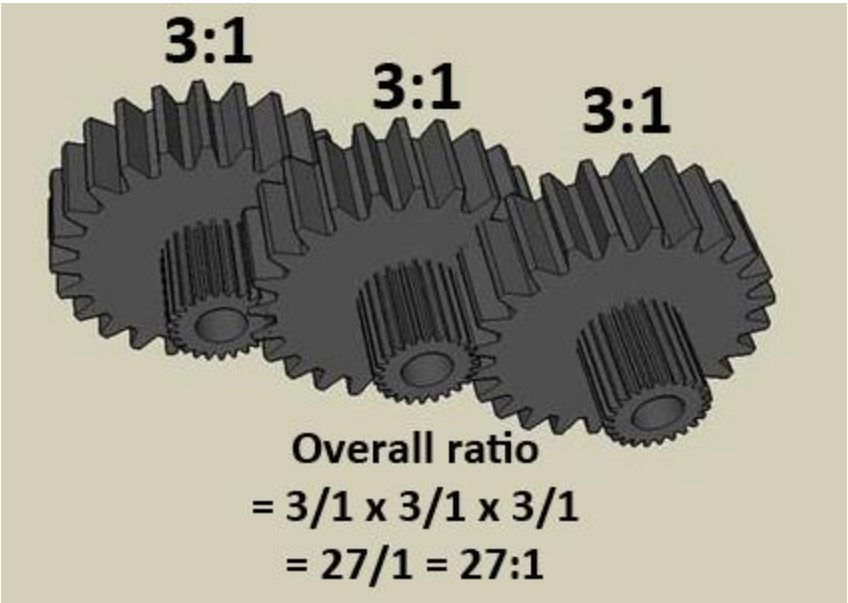
$$P(W) = \tau(Nm) \times \frac{2\pi \times \omega(rpm)}{60}$$



Ganged Gears

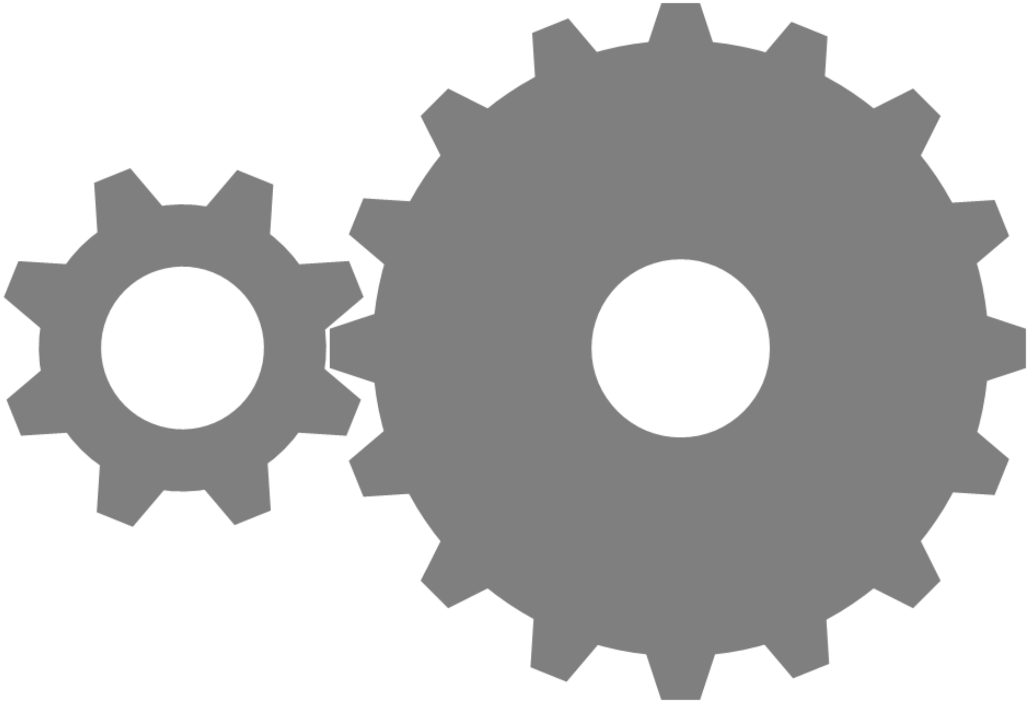
- Gears in series.
- Gear ratios multiply.





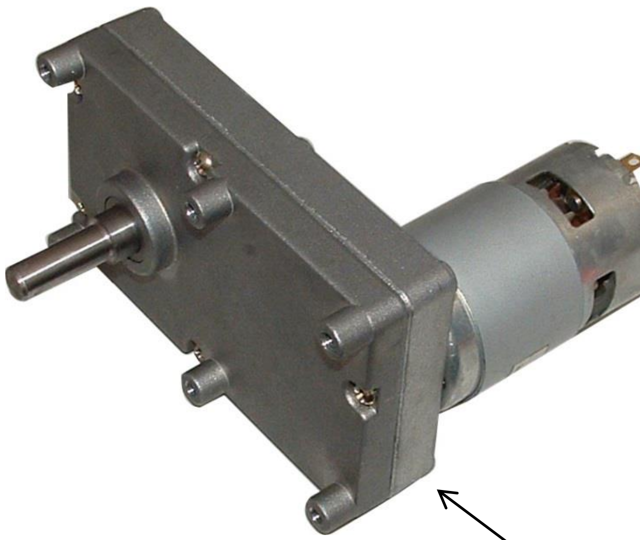
Gears are Precisely Machined

- **Backlash** – too loose.
- High resistance, or **jam** – too tight.



Geared DC Motors

No Gear



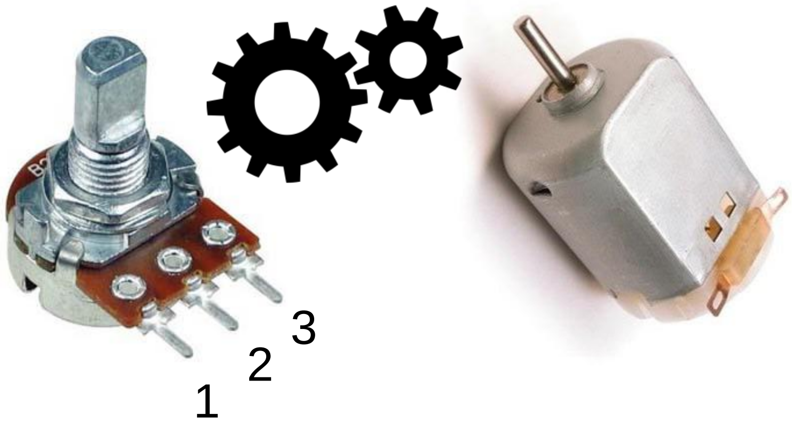
Gear Box

SERVOS

Servo Motor (Servo)

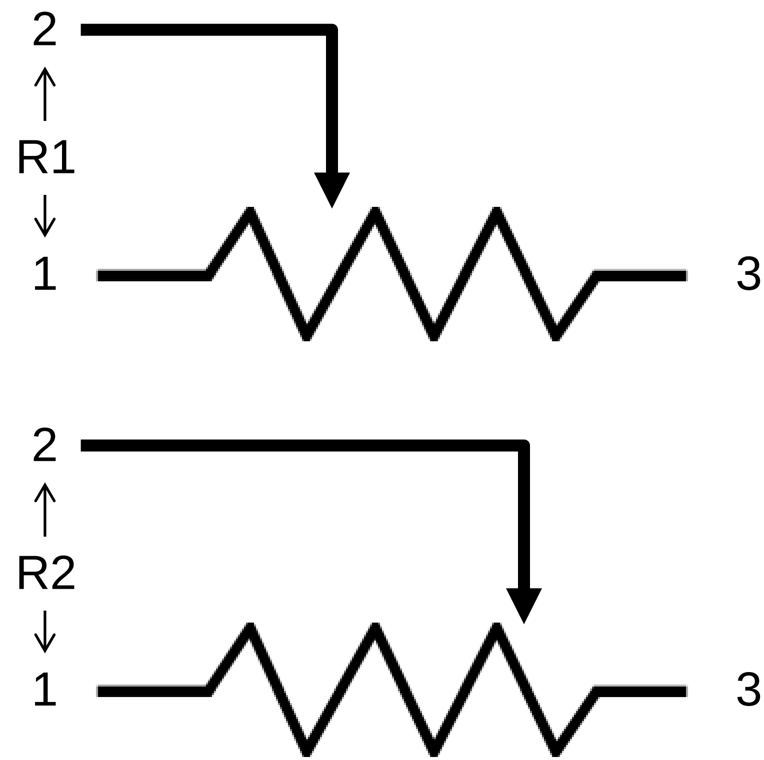
- **Servo** = DC Motor + Gear + Position Sensor + Position Control Circuit.
- Commonly used in robots.
  - Easy control of position.
- Two types:
  - Standard: **position**
  - Continuous: **rotation rate**
- Control of position (or speed) by
  - **Pulse Width Modulation** (PWM).
  - See next slide.

Potentiometer (Position Sensor)



Potentiometer
(Variable Resistance)

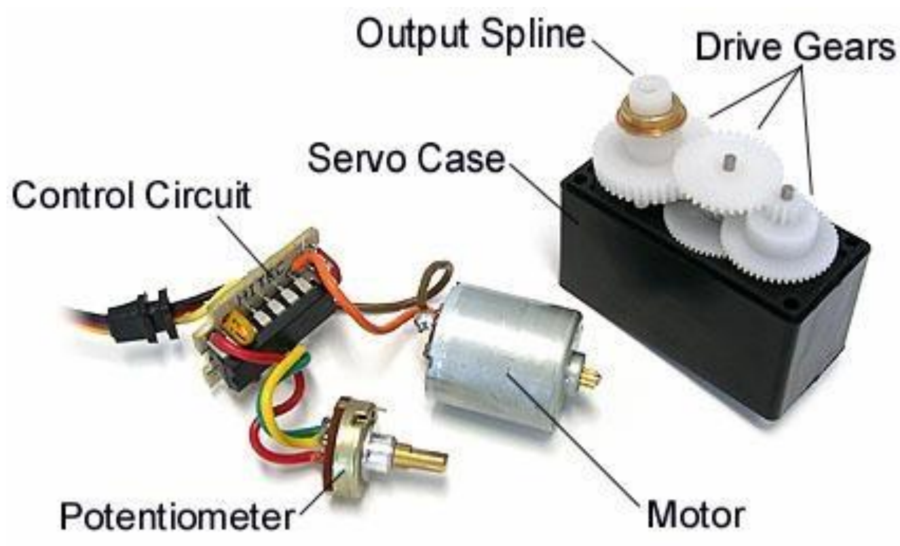
Translates motor shaft movement (position of the end-effector, e.g. wheel) into resistance.

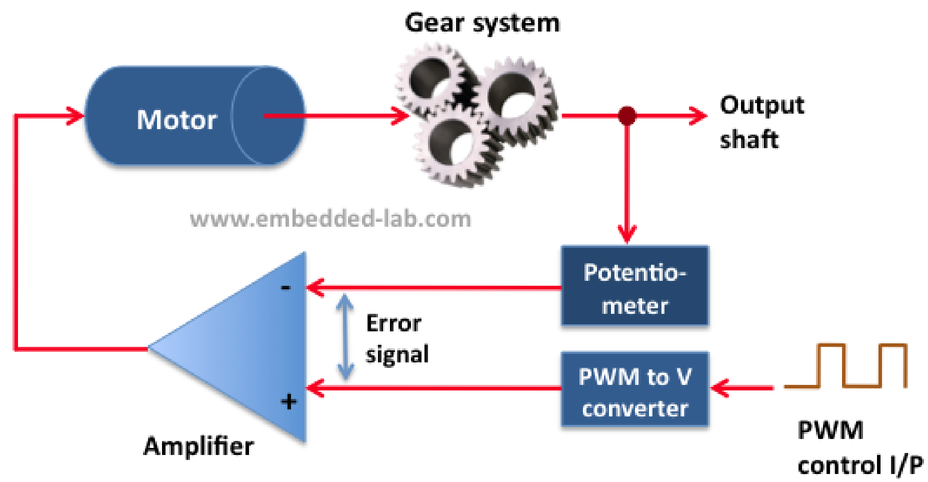


R2 > R1

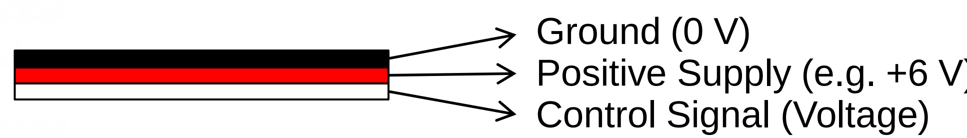
Changing resistance changes voltage and current: can be measured.

Servo Parts

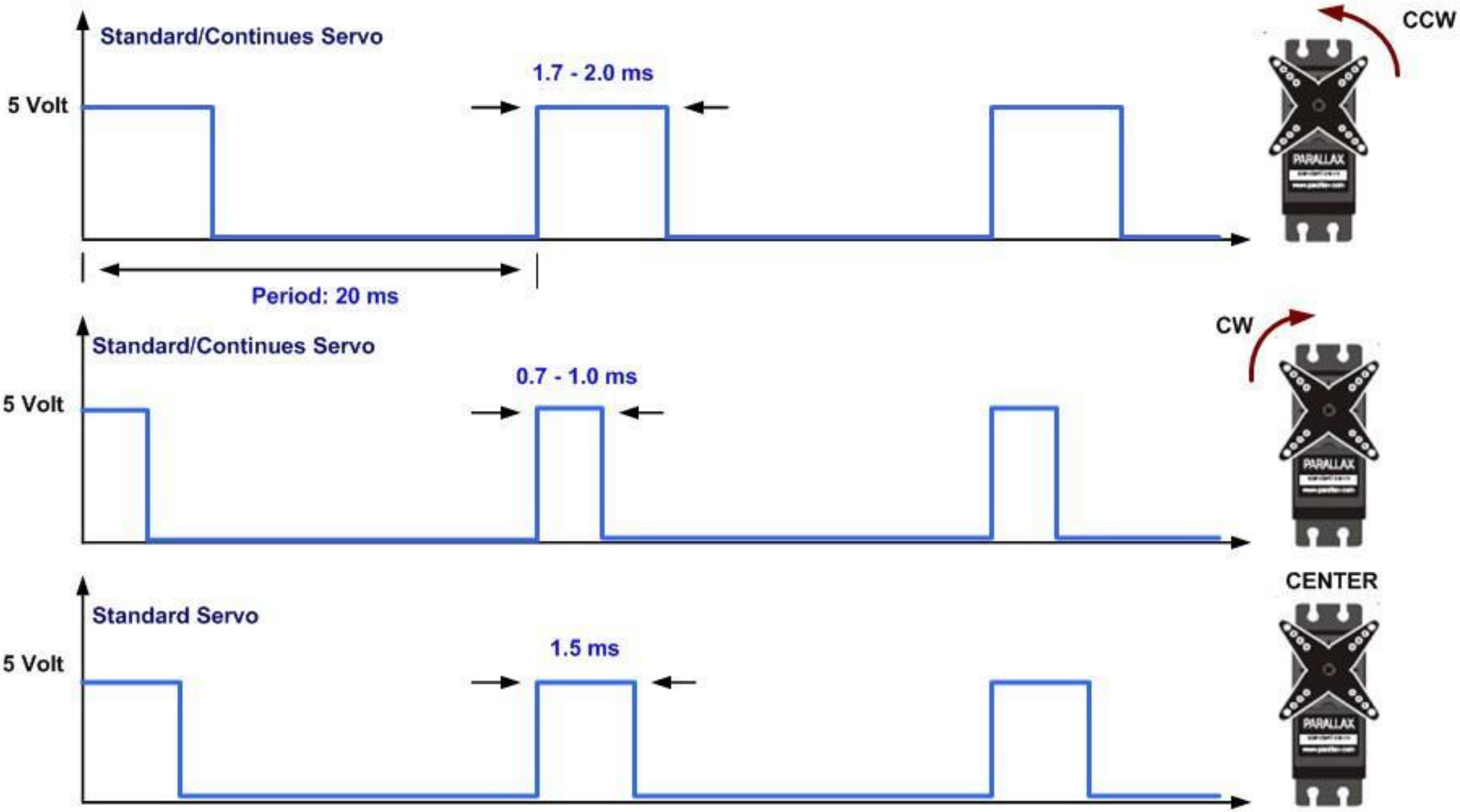




(Not all servos use potentiometer for position sensor, they may use encoder, for e.g.)



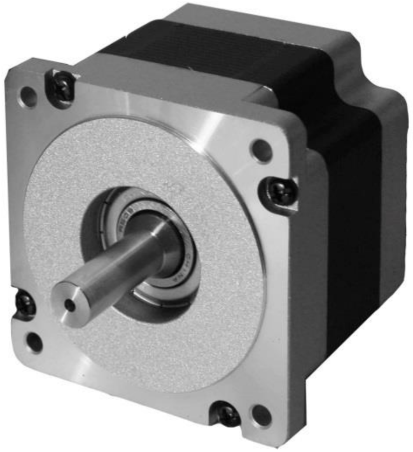
Pulse Width Modulation (PWM)

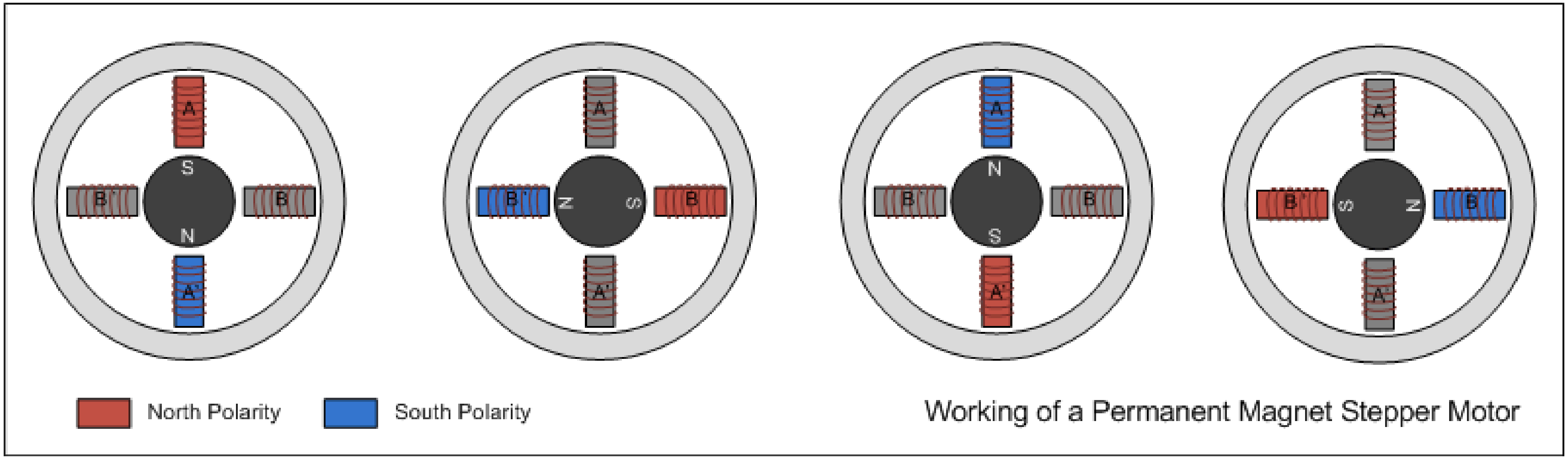


STEPPER MOTORS

Stepper Motor

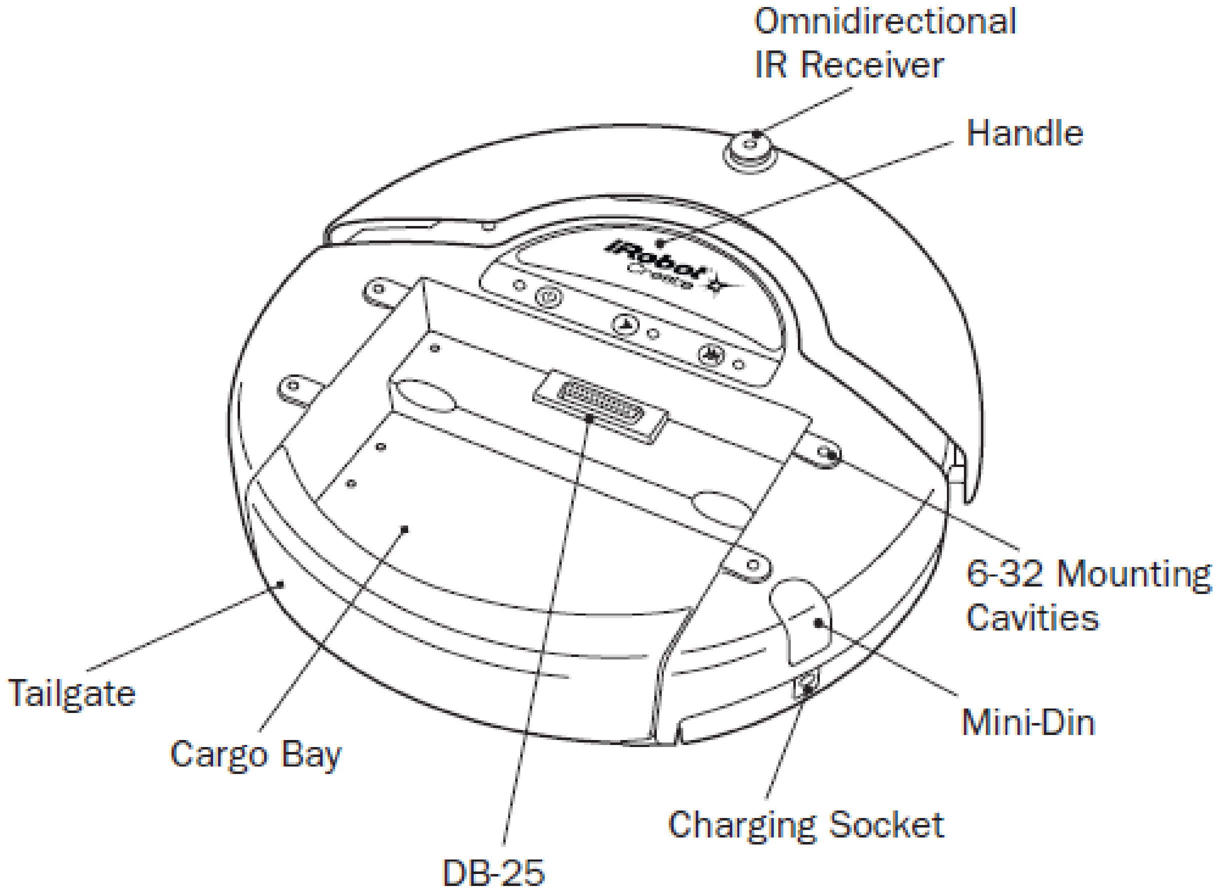
- Direct control of rotor position (no sensing needed).
- Low resolution. Slow, high precision.





Actions in My Keepon

Actions in iRobot Create



Reading List

- Then and Now Servos by Tom Carroll in Servo Magazine: http://www.robotshop.com/media/files/PDF/servo-magazine-then-now-0804.pdf

To Do List

- Give five examples, with diagrams or photos, of end-effectors.
- Make a comparison table between DC, servo and stepper motors. For each motor, state in what application one is chosen.

Summary

- Three **types of actions**: locomotion, manipulation and information presentation.
- Robots execute their actions through **effectors** and **actuators**.
- The actuators provide the moving energy to drive the effectors in order to interact with their environment.
- Example effector for mobile robot: **wheels**.
- Actuators can be **active** or **passive**.
- Example active actuators: **motors**.
- Motors: **DC**, **Servos**, **Stepper**.
- Motor speed control: **gearing**, driving **power**.

References

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