ELEC1100: Introduction to Electro-Robot Design

Lecture 1: Course Introduction + Basic Electronics + Energy

CHEN Wei, Dept. of ECE, HKUST

COURSE DESCRIPTION

- ELEC1100 is designed to provide the fundamental knowledge on the basic electrical engineering, components design and skills needed for the design, implementation and evaluation of a robot and its subsystems.
- It will cover the basic electronic engineering principle and techniques.
- Hands-on laboratory sessions, complemented with lectures and tutorials, are provided to allow students to have a systematic view of the electronic engineering principles.
- Students will apply the knowledge and principles learnt to design and build a functional robot by themselves.

INTENDED LEARNING OUTCOME

- Through hands-on labs and term project, complemented with lectures and tutorials, you will be able to:
  - *Analyze* and *design* simple analog **circuits**, combinatorial and sequential logic circuits, and *design* and *implement* simple feedback control strategies.
  - *Build* and *debug* real engineering system following a **hierarchical** design principle.
  - *Work* in a **team** environment: learn and practice effective project and time management.
  - *Execute* a complete **project** from problem formulation, design/implementation, up to verification and documentation.

TEACHING METHODOLOGY

- Problem with conventional teaching:
  - Current education system was developed in the industrial revolution and does not evolve to the information era
  - Teaching knowledge, but not how to apply the knowledge
  - School never tells students that the taught knowledge may become obsolete upon graduation
- Question to think about:
  - One month after taking a class, how much material can you still recall?

REVERSE ENGINEERING APPROACH

- Conventional approach:
  - Mathematics ➔ Physics ➔ Engineering
- Reverse engineering approach:
  - Engineering ➔ Physics ➔ Mathematics
  - Many things can be learned, but not taught
  - Learning requires an objective, which is usually from needs and experience

Tell me and I forget. Teach me and I remember. Involve me and I learn.

WHAT IS THIS CLASS ABOUT?

- It is NOT a LEGO robot programming class
- We start from the most basic and construct a robot from the primary components
- You will learn the following
  - managing power supply
  - driving motors
  - reading sensor output
  - logic control and decision making
- You will construct an autonomous “robot” to finish a task

CLASS SCHEDULE

- Lectures:
  - L1: Wed/Fri 10:00-12:50 at Rm 6591 by Prof. CHEN, Wei
- Labs:
  - LA1: Thu (every week) 14:00-16:50 + Wed (Week 2 & 3) 10:00-12:50 at Rm 2134
- Tutorials:
  - T1: Wed/Fri 15:00-15:50 at Rm 6591 by TANG, Yimeng

Check the Full Schedule on Canvas

TENTATIVE COURSE SCHEDULE

Week	Start (Wed)	Lecture 1 (Wed)	Tutorial 1 (Wed)	Thursday Lab	Lecture 2 (Fri)	Tutorial 2 (Fri)
1	20-Jun	01: Intro + Basic Comp. + Energy	T01: Intro. to Lab1	Lab#1: Equipment	02: DC + Pulse +PWM	T02: Intro. to Lab2
2	27-Jun	Lab#2: DC Regulator &Pulse Generation	T03: Intro. to Lab3	Lab#3: PWM Control	03: Transistor + H-bridge + Sensor	T04: Intro. to Lab4
3	04-Jul	Lab#4: Transistor & H-bridge	T05: Intro. to Lab5	Lab#5: Assembly of Navidroid	04: Logic + K-Map + Midterm Review	T06: Written Midterm Review
4	11-Jul	Written Midterm (Rm6591)	T07: Lab Midterm Review	Lab Practice Session	05: Seq. Logic + Embedded system+ MCU & Arduino	Lab Midterm (Rm2134)
5	18-Jul	06: Arduino Hardware & Software + Programming Language (part I-II)	T08: Intro. to Lab 6	Lab#6: Sensors & MCU	07: Programming Language (part III-IV) + Final Project	T09: Intro. to Project
6	25-Jul	Project Period				
7	01-Aug	Project Period	Project Demo			

Written Midterm: **July 11 (Wed), 10:10-11:50, Rm6591**
Lab Midterm: **July 13 (Fri), 15:00-15:50, Rm2134**

*****Project Demo:*** **Aug 1 (Wed), 15:00-15:50, Rm2134**

TEXT AND REFERENCE BOOKS

- Major Text: No major text, mainly use hand-outs provided by the instructors

- Major Reference:
  - L. Richard Carley and Pradeep Khosla, "Introduction to Electrical and Computer Engineering- taught in Context", The McGraw-Hill Companies, Inc.
  - G. Rizzoni "Principles and Applications of Electrical Engineering," 5th edition, McGraw Hill, 2007
  - D. V. Kerns and J.D. Irwin, "Essentials of Electrical and Computer Engineering", Pearson, 2004
  - M. M. Mano, C.R. Kime, "Logic and Computer Design fundamentals", 3rd edition, Prentice-hall, 2004

COURSE GRADING

- Exams: 1 written (20%) and lab (15%) mid-term; no final exam
- Quiz: a few pop-up in-class quizzes (open book) (6% total)
- Labs: 6 lab assignments (4% each, 24% total); minimum 4 labs' attendance to be eligible for final project demo
  - Go to the lab on time
- Final project (35% total): Project Demo (25%), Post-demo Interview (5%), Project Report (5%)

COURSE GRADING

- In general, there is no make-up session for all grading components.
- If due to a justified reason, you missed one grading component, please submit your proof to Yimeng (eetangy@ust.hk) within one week for arrangement of a make-up session.

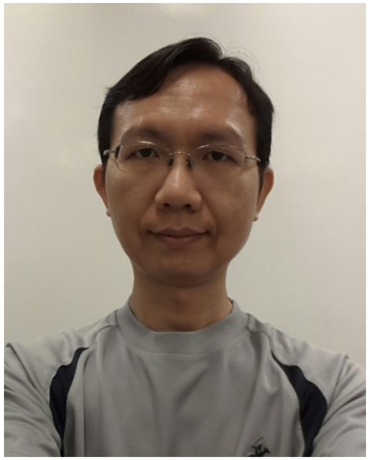
TEACHING TEAM (I)

- Instructor
  - Prof. CHEN, Wei
  - Office: Room 2412
  - E-mail: eeweichen@ust.hk
  - Office hour: by appointment

TEACHING TEAM (II)

- Instructional Assistant (Tutorials, Administrative matters)
  - TANG Yimeng
  - Office: Room 2395
  - E-mail: eetangy@ust.hk

- Technical Officer:
  - NG Allen eeallen@ust.hk
  - CHENG Joseph cscheng@ust.hk



CLASS EXPECTATION

- Attend lectures/labs/tutorials on time
- Be active during lectures: ask questions
- Form teams for the labs and the final project (2 students per group)
- Enjoy the experience and have a good time!

CHEATING POLICY

- Cheating is guilty when you are being caught

- Following the honor code

What makes a good engineer?

1. Technical Competence
2. Interpersonal Skills (Communication, teamwork)
3. Work Ethic (Diligent..)
4. Moral Standards (Honesty, integrity)

WHAT IS A ROBOT?

Robots in the Movies

ORIGIN OF ROBOTS

- The word “robot” was first introduced in Czech playwriter Karel Capek’s play R.U.R. (Rossum’s Universal Robots) in 1921.
- The word “robotic” was first used in Runaround, a short story published by Issac Asimov in 1942.
- These were way before modern ECE technologies, such as computer, IC, transistors, and AI, became well-developed and impacted on our daily life.

FEATURES OF A ROBOT

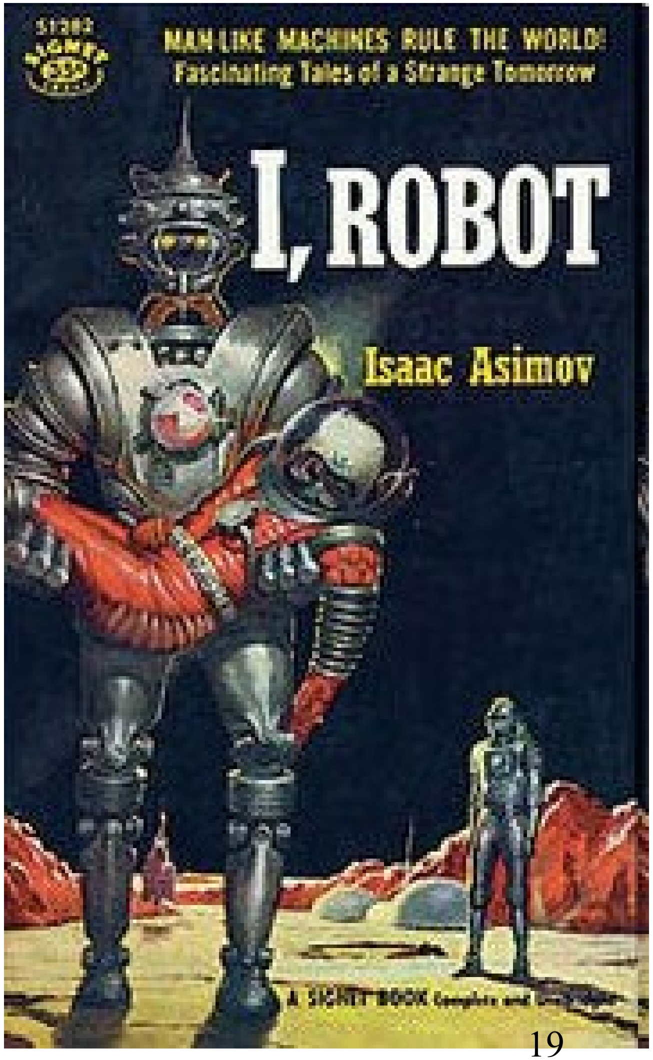
- It is artificially created and programmable
  - Q: are animals robots?
- It can sense its environment, and manipulate or interact with things in it
  - Q: is a motorcycle a robot?
- It has some abilities to make choice based on the environment, often using automatic control or preprogrammed sequence
- It moves without direct human interaction
  - Q: is a helicopter a robot?
- Can you list some other features?

THE THREE LAWS OF ROBOTIC (1950)

- Defined by Isaac Asimov in 1950
- A robot may not injure a human being or, through inaction, allow a human being to come to harm.
- A robot must obey any orders given to it by human beings,

  except where such orders would conflict with the First Law.
- A robot must protect its own existence

  as long as such protection does not conflict with the First or Second Laws.



MORE RECENT DEFINITIONS OF ROBOTS

❖ According to the Robot Institute of America (1979), a robot is:

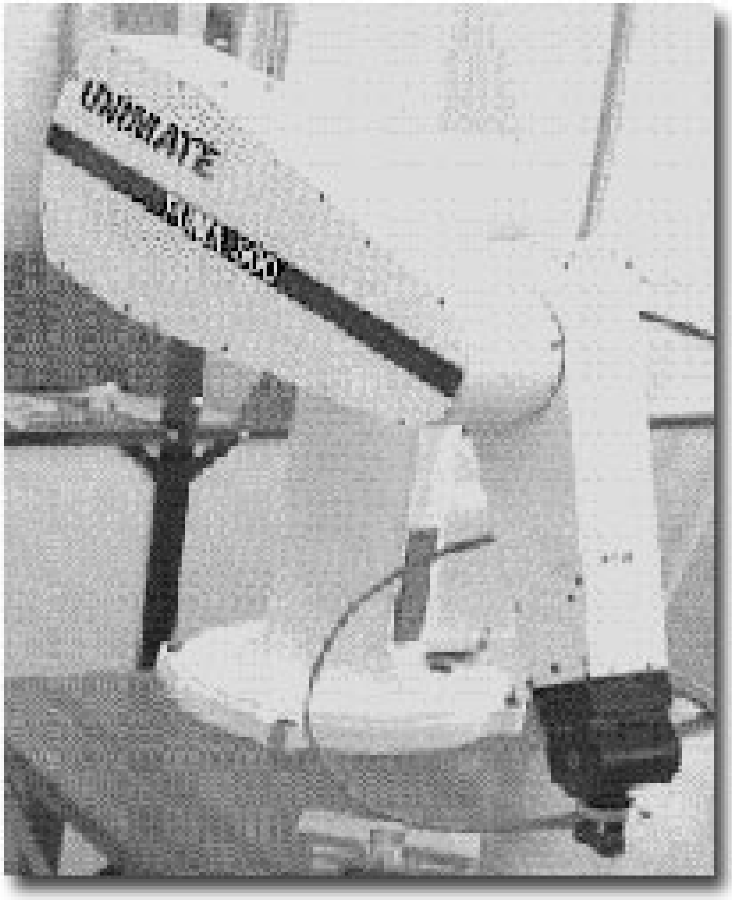
"*A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks*"

❖ A more inspiring definition can be found in Webster:

"*An automatic device that performs functions normally ascribed to humans or a machine in the form of a human*"

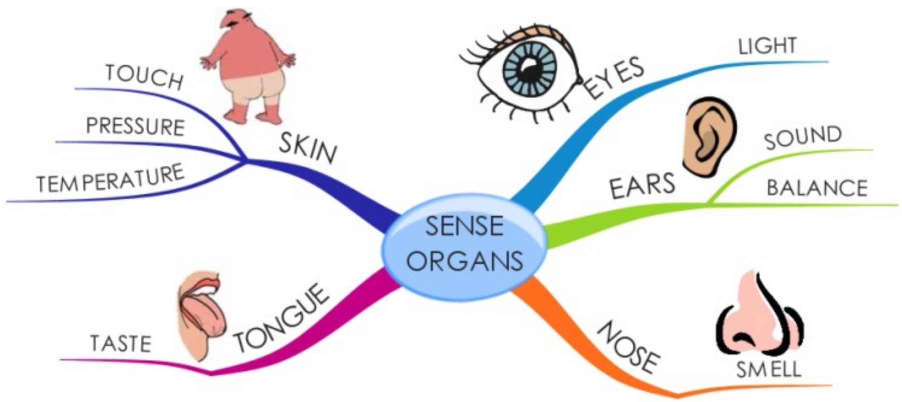
FIRST REAL ROBOT

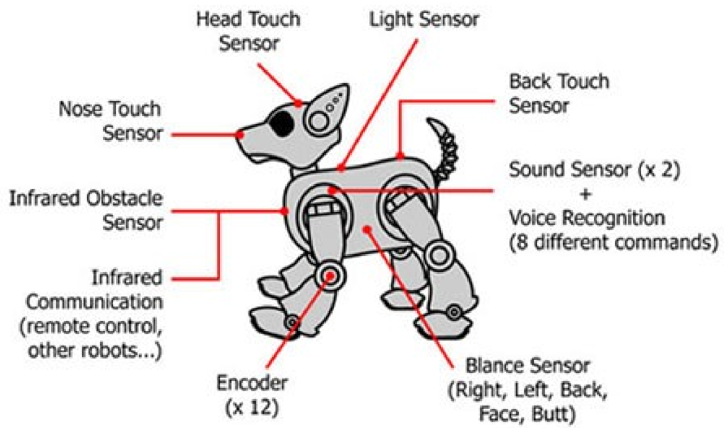
- Inspired by Issac Asimov's, Joseph F. Engelberger (also known as the father of robotics) started working on real robot in 1956 with G. C. Deveol.
- In 1961, first commercial robot "Unimate" was deployed in GM car manufacturing plant to work with heated die-casting machines.
- From then onwards, more robotics were being designed and developed with the help of micro-electronics.



- Robotics: the science of perceiving and manipulating the physical world through computer-controlled mechanical devices.

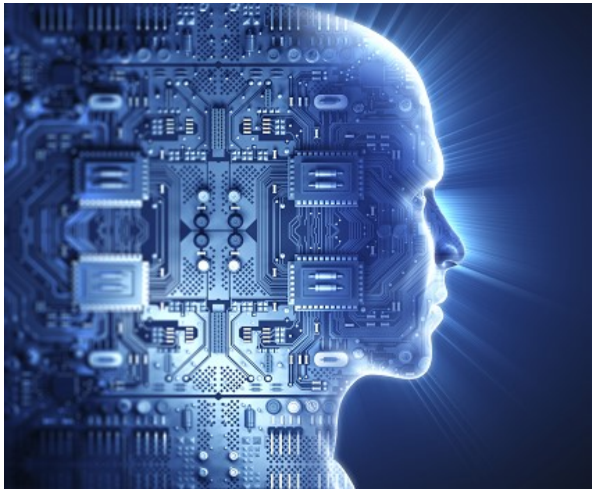
Human Functions vs. Technology: Perceiving





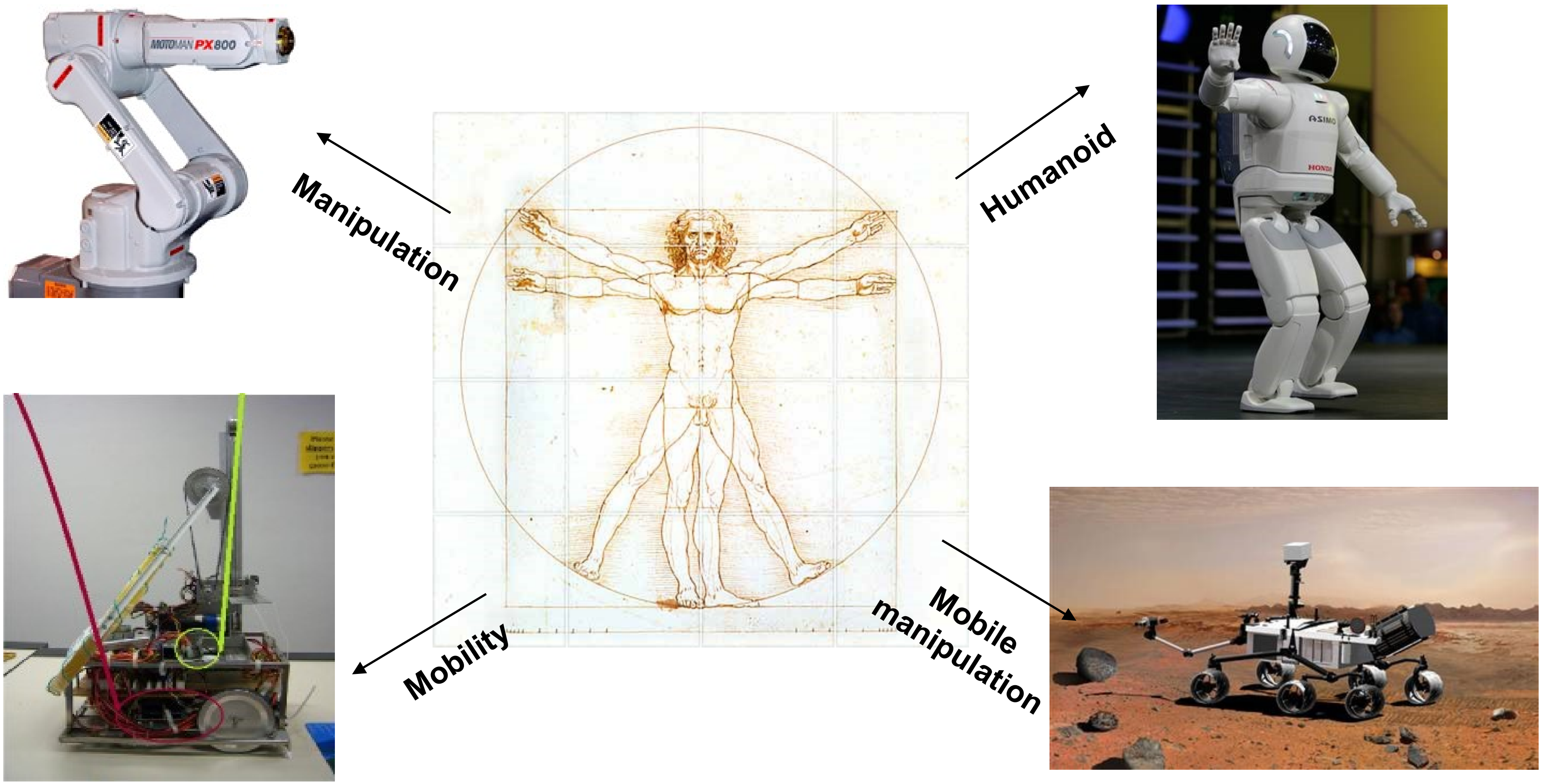
Human Functions vs. Technology: Manipulation

Human Functions vs. Technology: Computation



ANALOGUE OF ROBOT WITH HUMAN BODY

	Human	Robot
Sensing	eyes, ears, nose, tongue, skin	light sensor, microphone, temperature sensor, chemical sensor, motion detector
Structure	head, body, arm leg …	motion parts, joints
Motion	muscles, bones	motors, actuators, relays
Fuel	food, oxygen	battery, natural gases, solar cells
Control	brain	logic unit, micro-controller
Internal communication	nerve	wires, optical links
External communication	speech, actions	signal lines, sensor signals, wireless


MOTOMAN PX800
Manipulation
Humanoid
ASIMO
HONDA
Mobility
Mobile manipulation

MANIPULATORS

- **Sensing**
  - Vision, Force/ Torque
- **Controller**
  - Signal Processing, Trajectory, Logic, Control Algorithm
- **Power**
  - AC Power for servo motor
  - DC Power for analog & digital circuits and sensors
- **Mechanical motion**
  - Joints/ links, open & closed chain

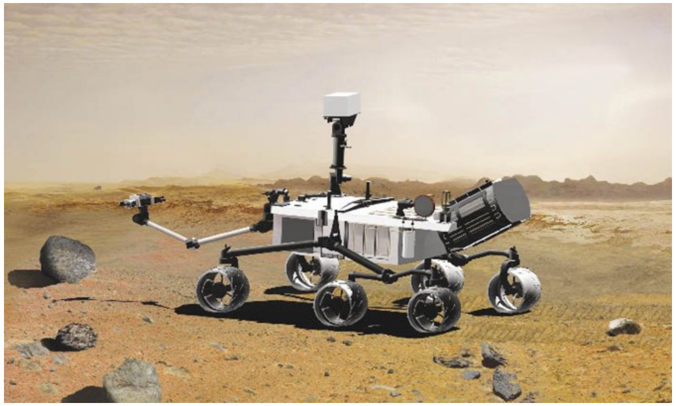
Arc welding | Assembly | Clean room | Coating/ dispensing | Material cutting | Material removal | Material handling | Surgery

MOBILE ROBOTS

- Sensing
  - Vision, Sonar, GPS, Gyro Compass
- Controller
  - Signal processing, map in memory, planned motion command, control algorithm
- Power
  - DC Power for analog & digital circuits
  - Solar and portable energy source
- Mechanical motion
  - Wheels/ axles, structures

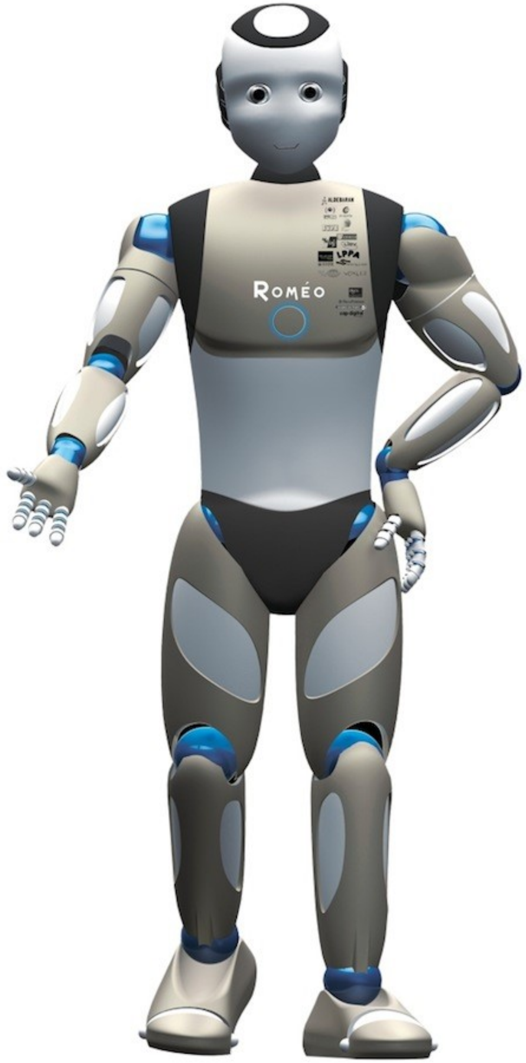
MOBILE MANIPULATORS

- Sensing
  - Vision, Sonar, GPS, Gyro Compass
- Controller
  - Signal processing, map in memory, planned motion command, control algorithm
- Power
  - DC Power for analog & digital circuits
  - Solar and portable energy source
- Mechanical motion
  - Wheels/ axles, structures, manipulator



HUMANOID

- Sensing
  - Vision, Sonar, Gyro, microphone, pressure, temperature, chemical etc.
- Controller
  - Signal processing, control algorithm, motion pattern generation
- Power
  - DC Power for analog & digital circuits
  - Solar and portable energy source
- Mechanical motion
  - Motors and structure
  - Head, arm, body, legs

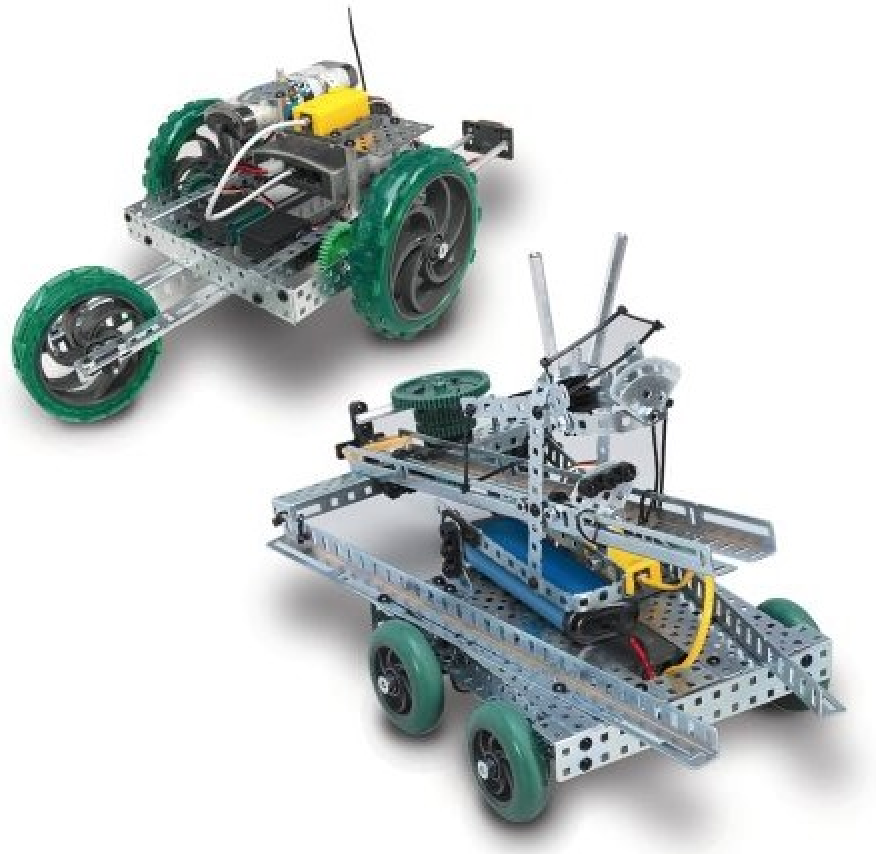


SUMMARY

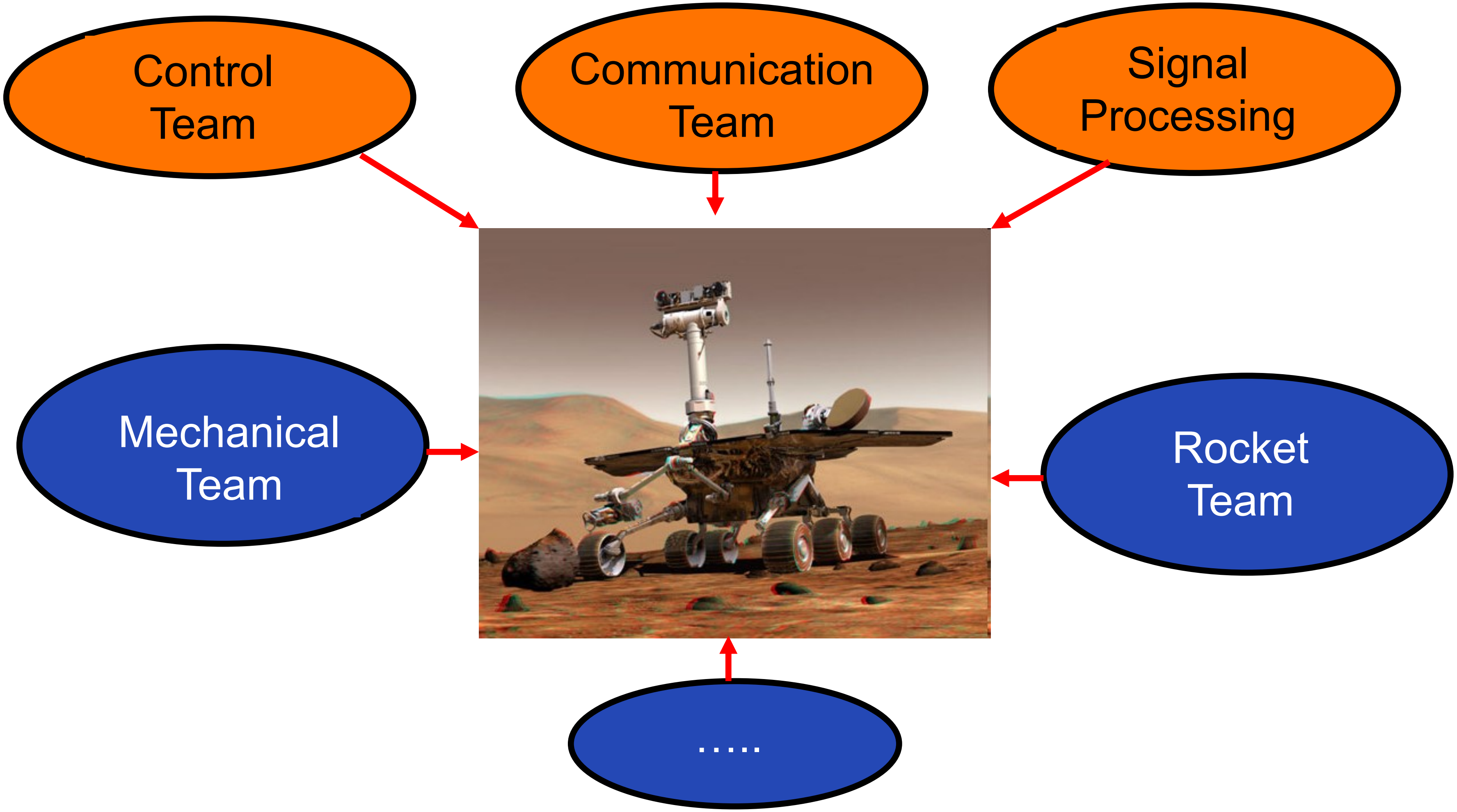
- Robots can be classified into 4 main types:
  - Manipulators
  - Mobile manipulators
  - Mobile robot
  - Humanoid
- Robot has some basic components:
  - Power subsystem
  - Sensors
  - Controller
  - Mechanical motion system

HIERARCHICAL DESIGN

- Complex systems (e.g. robot) are usually composed of numerous sub-systems
- To make the design more manageable, we usually use a “divide-and-conquer” approach for designing complex system
- The divide-and-conquer approach is also used in the sub-system design
- We call this hierarchical decomposition of designs

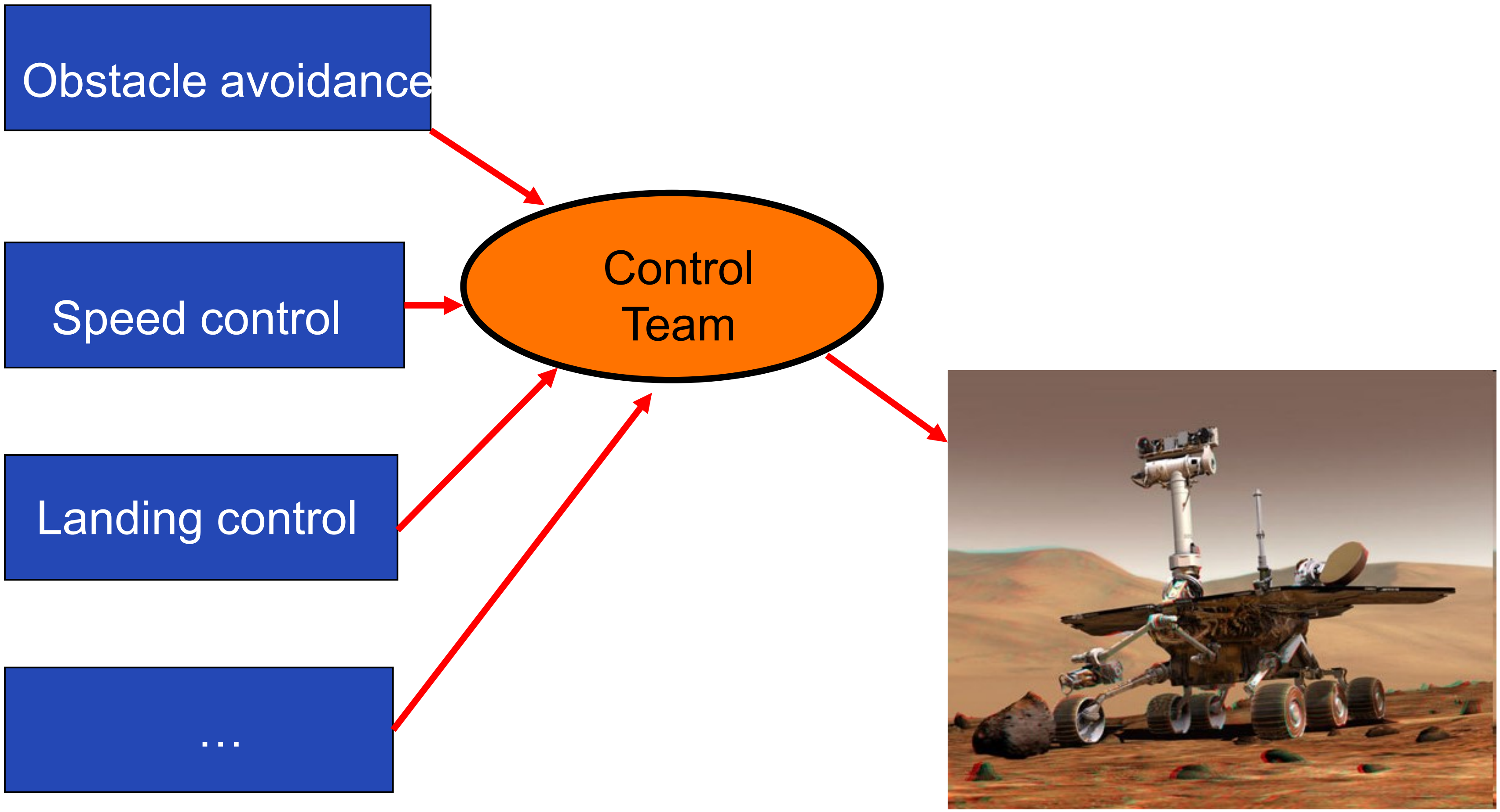


MARS ROVER

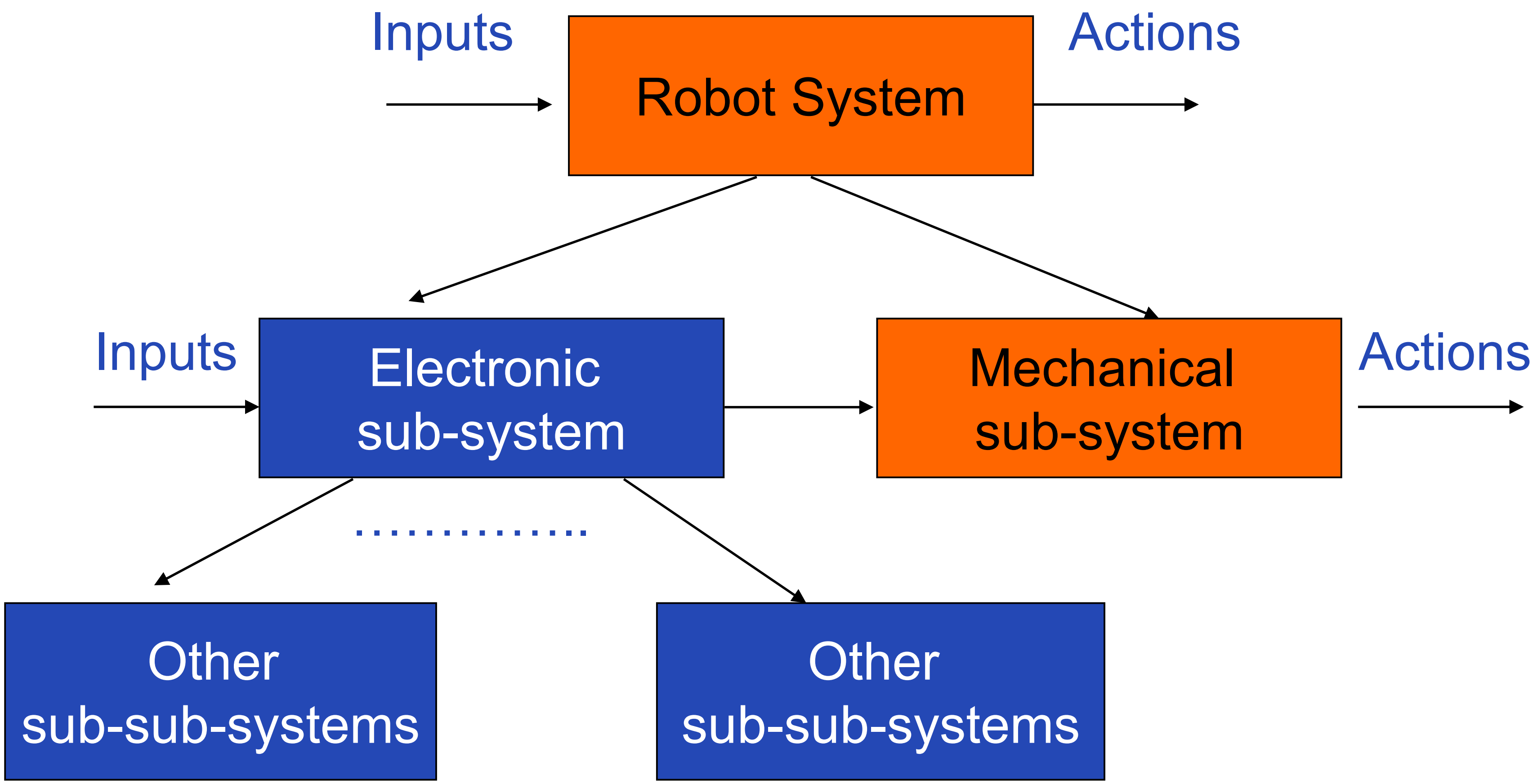


Department of Electronic and Computer Engineering, The Hong Kong University of Science & Technology

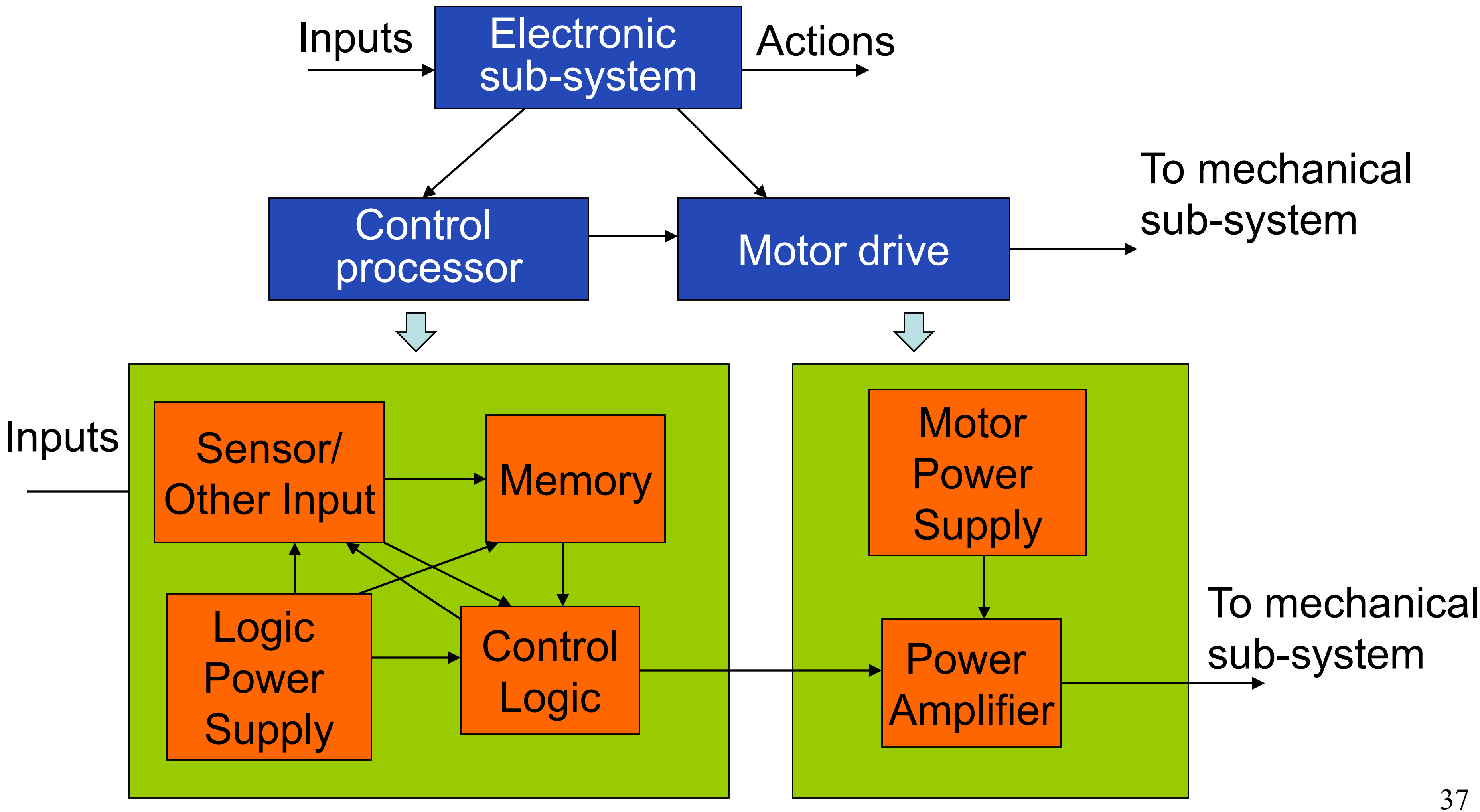
JOB OF SUBTEAM



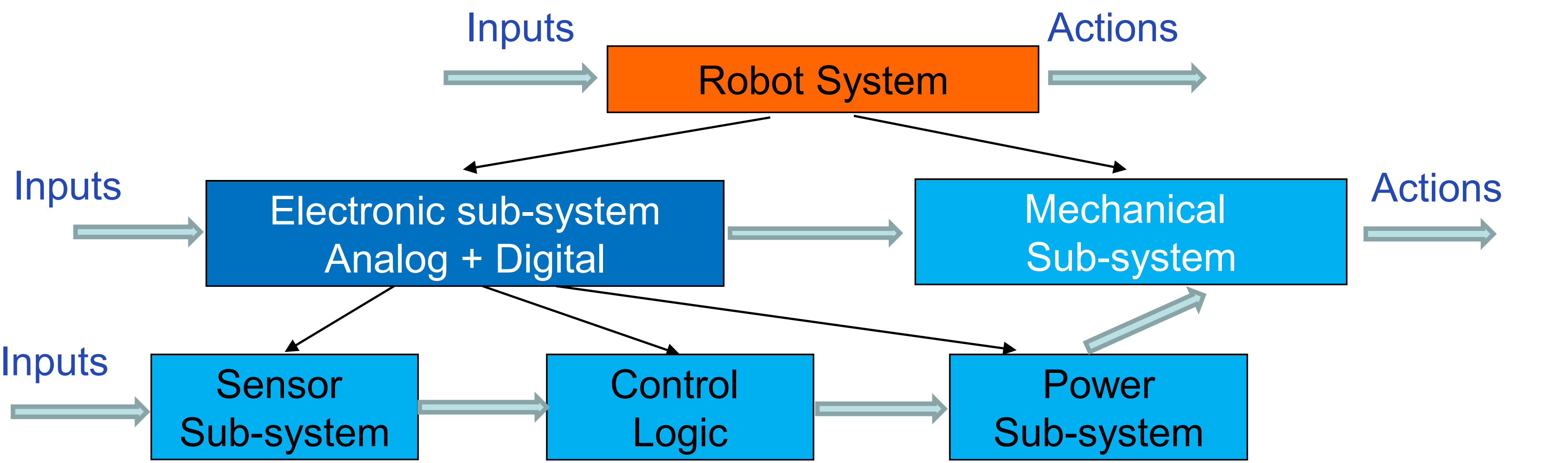
THE NAVIDROID VEHICLE



FURTHER DECOMPOSITION OF ELECTRONIC SUBSYSTEMS



ELEC1100 ROADMAP



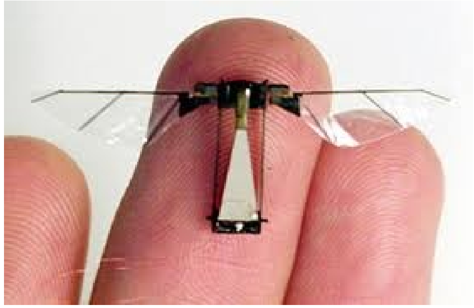
Sensor Basics:
Wk2: Sensor Basic

Combinational/Sequential Logic:
Wk3: Robot Brain: Logic Gate & Logic Operation
Wk4:Sequential Logic
Wk5:MCU & Programming Language

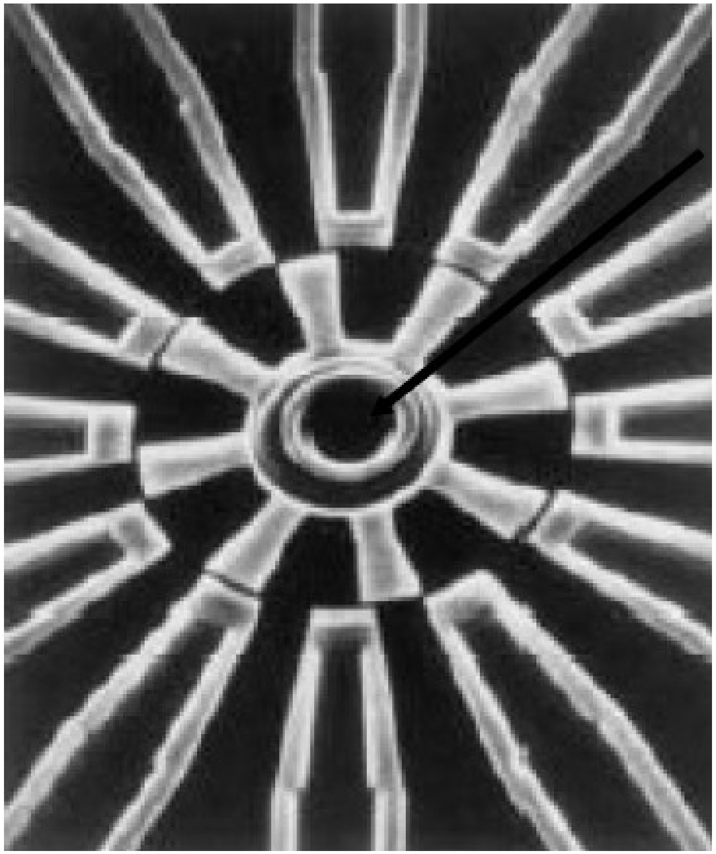
Basic electronics:
Wk1: Basic Electronics & DC Sources

Motor Power Supply:
Wk1: Pulse Signal & PWM Control
Wk2: Transistor and H-Bridge

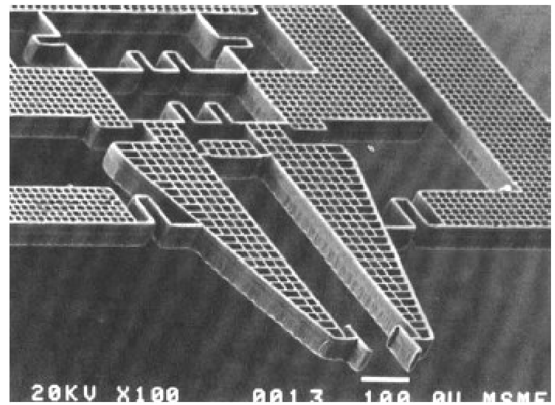
- Different areas of ECE relevant to Robotics
  - Nanoelectronics – fundamental hardware
  - Micro-electro-mechanical systems (MEMS) – micro-robots, sensors
  - Integrated-Circuit and Systems – control system
  - Photonics – sensors
  - Multimedia and signal processing – information processing
  - System and Automation – control system
  - Wireless communication and networking – robot communications
  - Computer Engineering – decision making

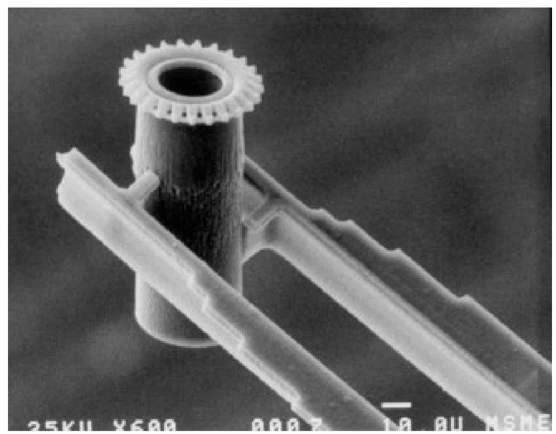




MICRO ROBOT EXAMPLES

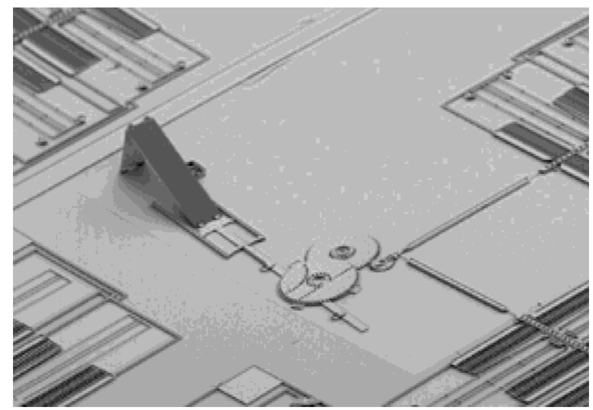


Electrostatic Micro Motor

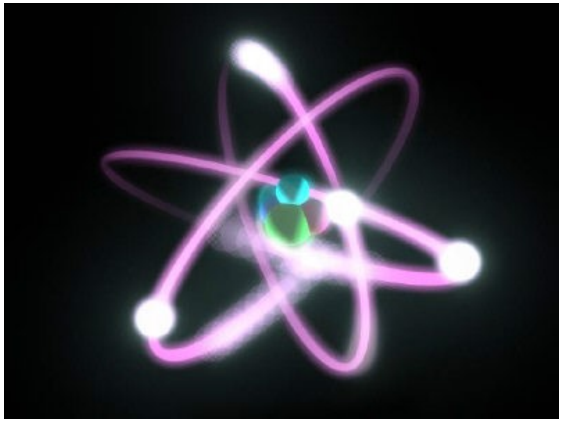




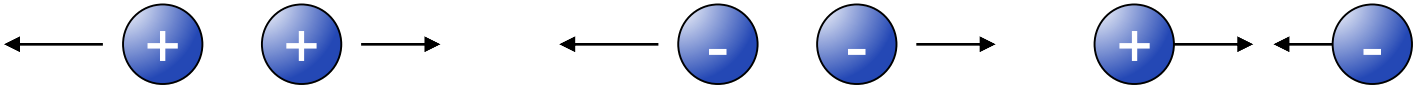
Micro Tweezers



Micro Manipulator



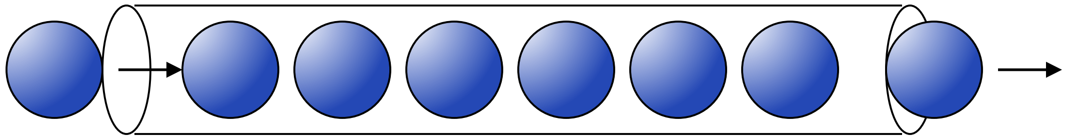
- **Atom structure**
  - fundamental element of matter
  - consists of protons, neutrons, and electrons
  - +ve charge (proton)
  - –ve charge (electron)
- **Opposite charges attract, like charges repel**



  - An atom is electrically neutral: same number of protons and electrons
  - Smallest amount of charge: q (charge for 1 electron) $-q = -1.6\text{x}10^{-19}\text{C}$
  - Electrons at the farthest orbit can be added and removed from the orbit easier than that in other orbits

CONDUCTORS AND INSULATORS

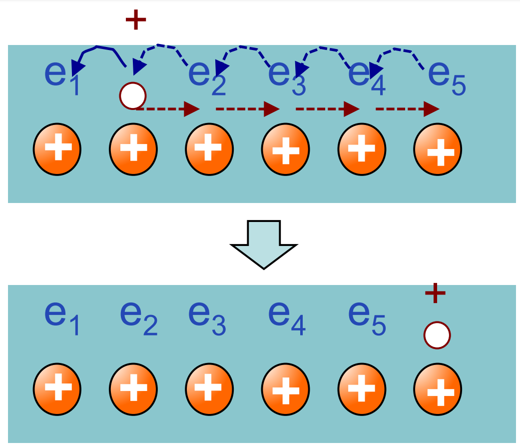
- Some atoms require less energy to remove the outer electrons for conduction – Conductors
  - Materials through which charge flows readily: low resistance
- Some atoms are difficult to lose electrons – Insulators
  - Materials that do not allow charge to move easily: high resistance
- Charges flow through a conductor:



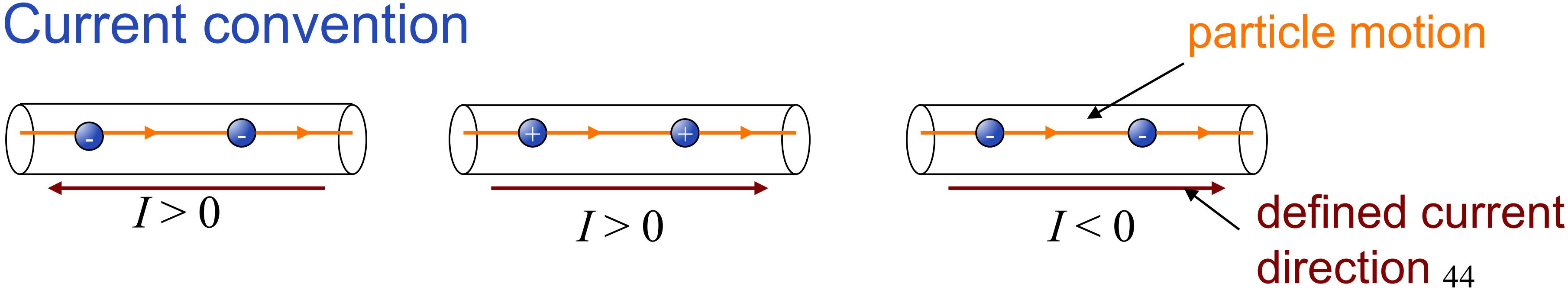
CURRENT

- Current is the orderly movement of charged particles and is equal to the rate of flow of charges
- Symbol: I
- Unit: ampere (A)
- 1 ampere = transfer of one coulomb in one second ($1\mathrm{C/s}$)
- Direction of current flow:
  - Electron is negative charge by definition
  - So positive current flow (i.e. $I > 0$) is opposing the flow of electrons

EXPLANATION OF CURRENT FLOW

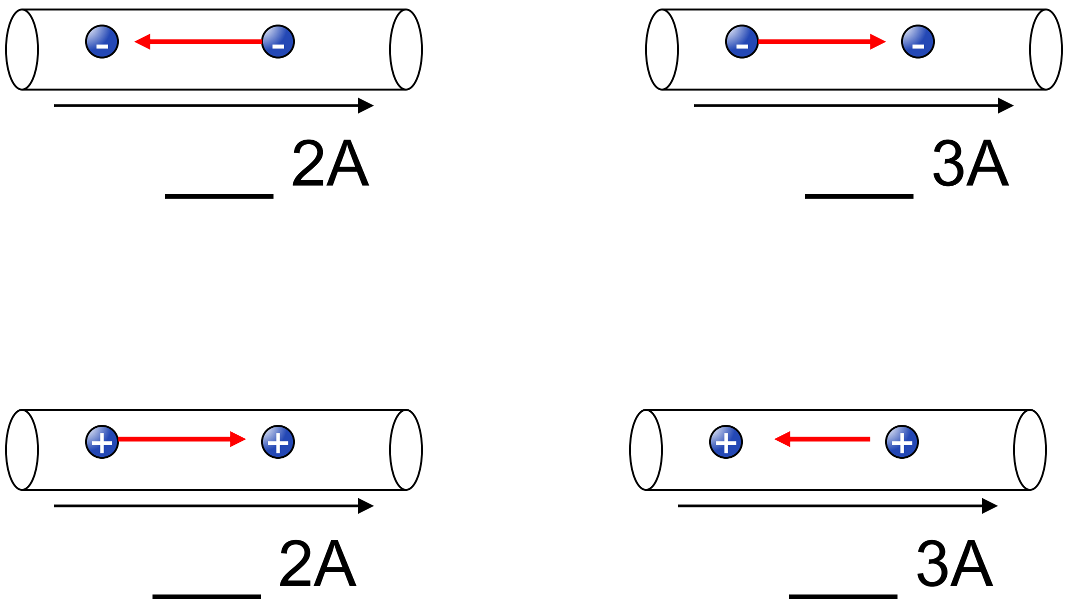


- The current generated by a negative charge moving to the left is equivalent to the current generated by a positive charge moving to the right.
- Current convention



CURRENT FLOW EXERCISE

- Indicate whether the current flow is positive or negative in the following diagram



- Current is the rate of flow of charge
  - Average current is given by $I = \dfrac{\Delta q}{\Delta t}$
- Examples
  - Q1: An electric heater operated from a dc source that provides $8.2\text{x}10^{21}$ electrons in 10 seconds. How much current in amperes is flowing through the heater?
  - Answer:

- Current is the rate of flow of charge
  - Average current is given by $I = \dfrac{\Delta q}{\Delta t}$
- Examples
  - Q1: An electric heater operated from a dc source that provides $8.2\text{x}10^{21}$ electrons in 10 seconds. How much current in amperes is flowing through the heater?
  - Answer: using the given equation

$$I = \frac{\Delta q}{\Delta t} = \frac{1.6 \times 10^{-19}\,\mathrm{C} \times 8.2 \times 10^{21}}{10\mathrm{s}} = 131.2A$$

CURRENT AND CHARGE [2]

- Current is the rate of flow of charge
  - Average current is given by $$I = \frac{\Delta q}{\Delta t}$$
- Examples
  - Q2: If a battery delivers a current of 50A when the car starts, and the starting time is 4 seconds, how many electrons flow out of the battery?
  - Answer:

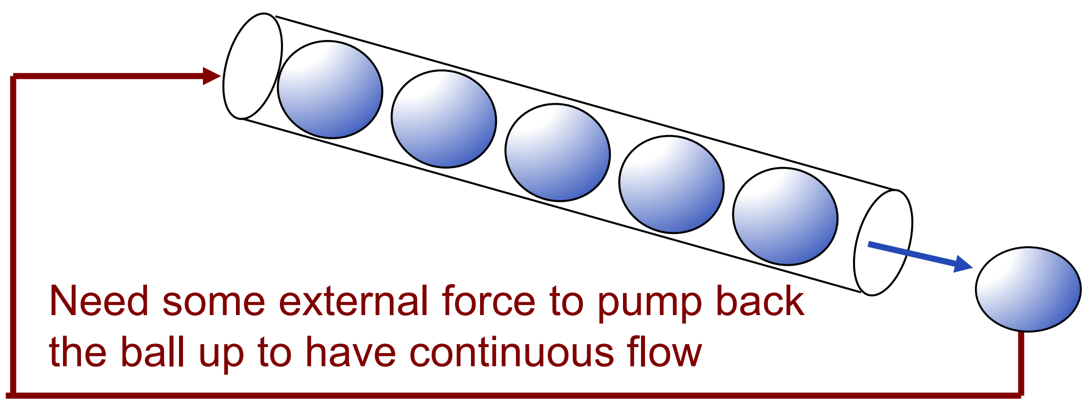
CURRENT AND CHARGE [2]

- Current is the rate of flow of charge
  - Average current is given by $I = \dfrac{\Delta q}{\Delta t}$
- Examples
  - Q2: If a battery delivers $50\mathrm{A}$ when the car is started, and the starting time takes 4 seconds, how many electrons flow out of the battery?
  - Answer:

$$I = \frac{\Delta q}{\Delta t} \Rightarrow 50\mathrm{A} = \frac{1.6\times 10^{-19}\mathrm{C}\times n}{4\mathrm{s}} \Rightarrow n = \frac{50\mathrm{A}\times 4\mathrm{s}}{1.6\times 10^{-19}\mathrm{C}} = 1.25\times 10^{21}$$

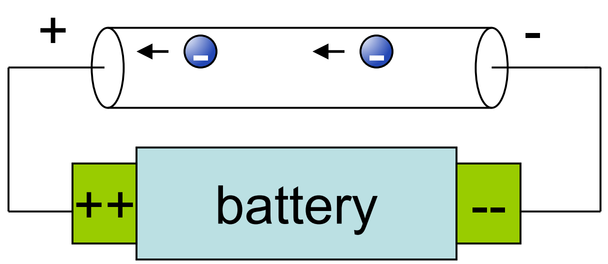
VOLTAGE [1]

- In order to have current flow between two points, we need to have a "voltage difference" between these two points
- Analogy to water flow or ball flow inside a tube
  - In order to have the balls flow, the tube needs to be tilted and the gravitational force will make the balls flow
  - The gravitational potential energy depends on the difference in the height of the two ends of the tube



VOLTAGE [2]

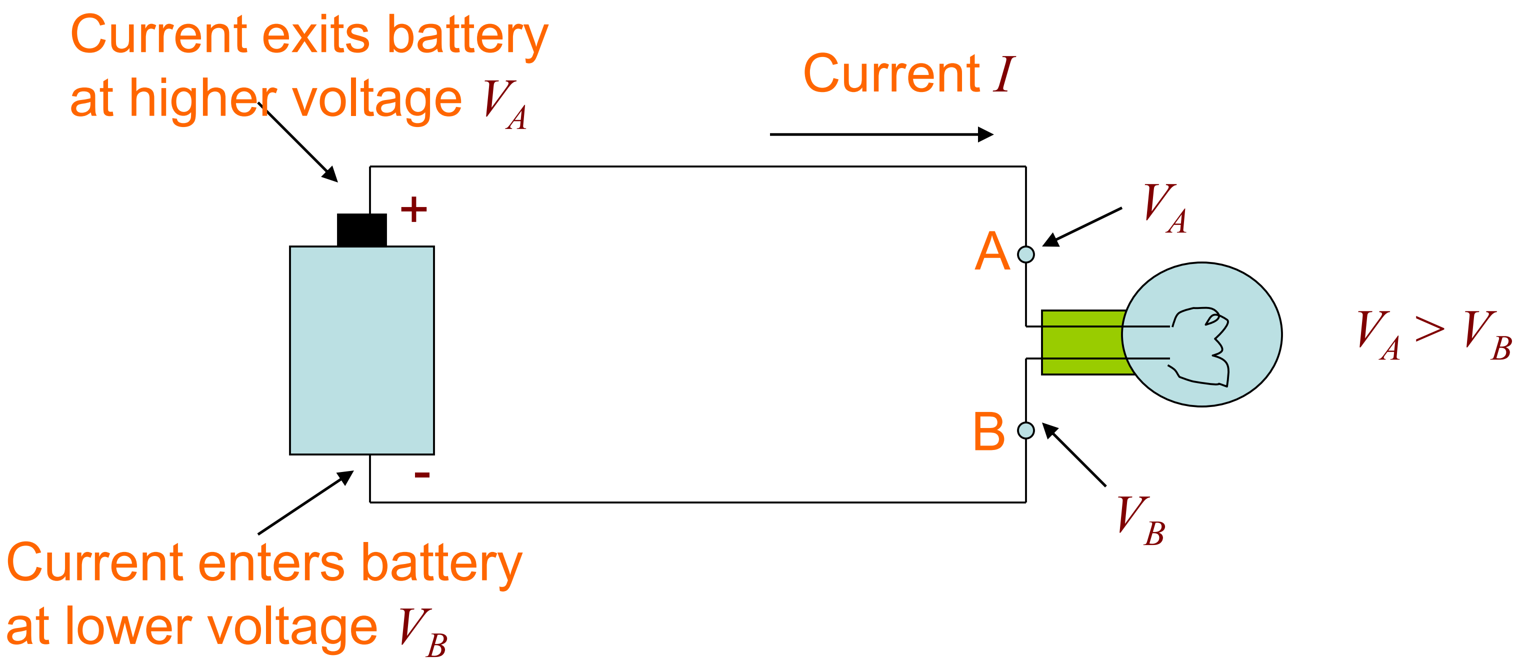
- To have current flow between two points, we need to have a connection (wire) and a voltage difference between them
- The two points have different polarity and hence have potential difference
  - We need some external source to move back the +ve charge from the –ve terminal to +ve terminal or –ve charge from the +ve terminal to –ve terminal in order to have continuous current flow
  - Example: a battery uses chemical energy to move the electrons



The voltage difference that a battery generates between its +ve and –ve terminals is a function of its internal chemistry, e.g., voltage of an AAA battery is about 1.5 Volt

VOLTAGE [3]

- Symbol: V;
- Unit: volt or V
- Voltage source example: a battery



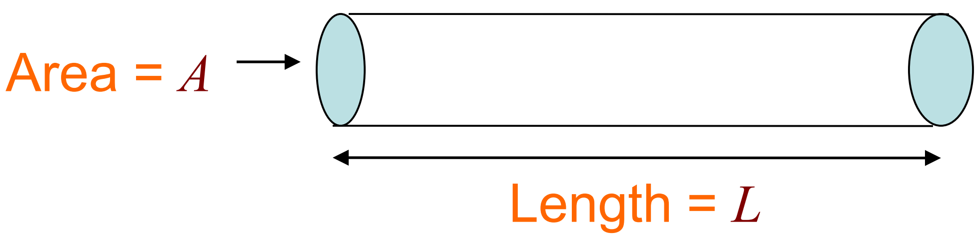
RESISTANCE [1]

- Resistance is the ability of a conducting material to resist the flow of charge (or current)
- For the same voltage difference between two points
  - Large resistance → small current
  - Small resistance → large current
- Ideal wire → ideal conductor → no resistance
- Ideal insulator → infinite resistance
- Real components → finite amount of resistance

- Effect of resistance

- Resistance can be added to avoid large current
- All loads (e.g. light bulbs, motors) and even wires have resistance

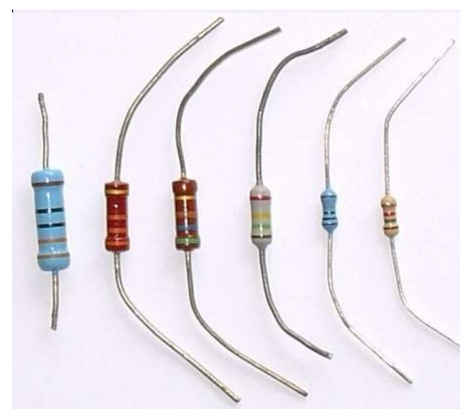
- Symbol: R;
- Unit: ohm or Ω
- Resistance of a wire



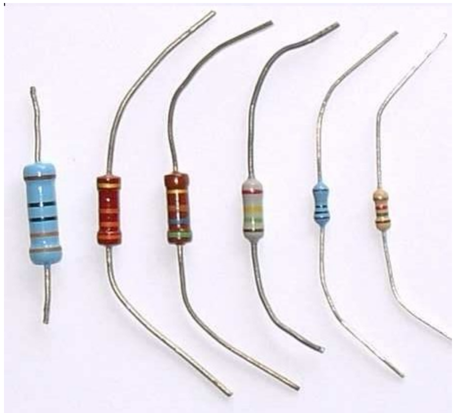
Resistivity (depends on material)

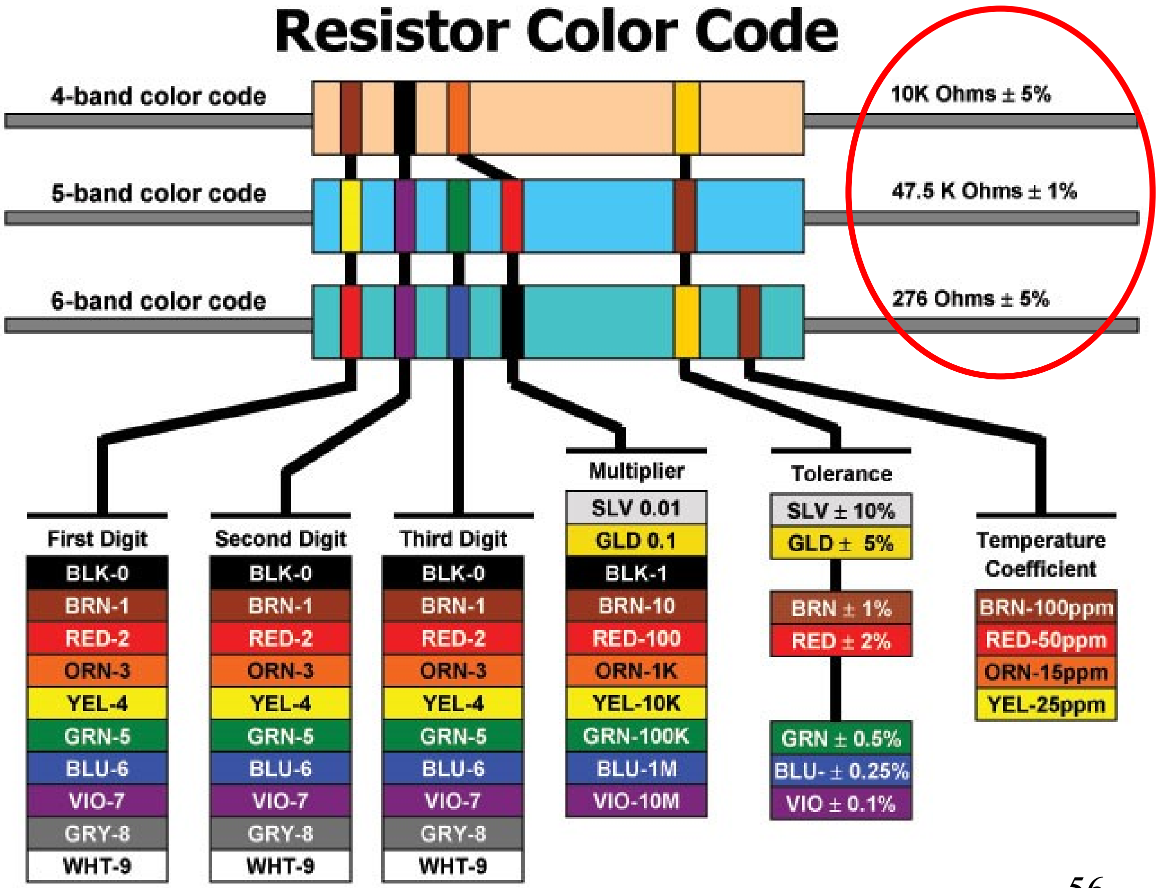
$$R = \rho \times \frac{L}{A}$$

- Resistors can be added to a circuit to limit current flow



❖ Color code for resistor values





METRIC PREFIX

- Can be used for volt, ampere and ohm

	atto = a = 10^{-18}
peta = P = 10^{15}	femto = f = 10^{-15}
tera = T= 10^{12}	pico = p = 10^{-12}
giga = G = 10^{9}	nano = n = 10^{-9}
mega = M = 10^{6}	micro = μ = 10^{-6}
kilo = k = 10^{3}	milli = m = 10^{-3}

- e.g. 10 MΩ = 10000000 Ω; 5 μA = 0.000005 A

OHM'S LAW AND I-V CURVE

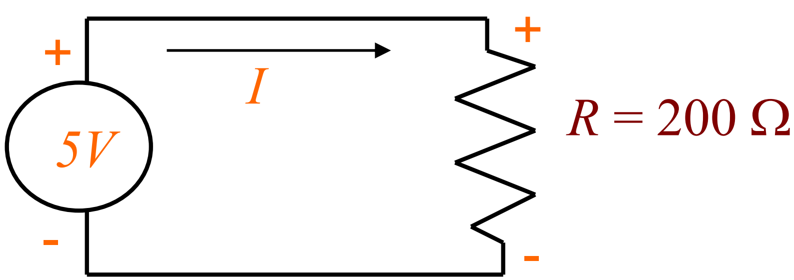
- Ohm's Law: current as a function of voltage

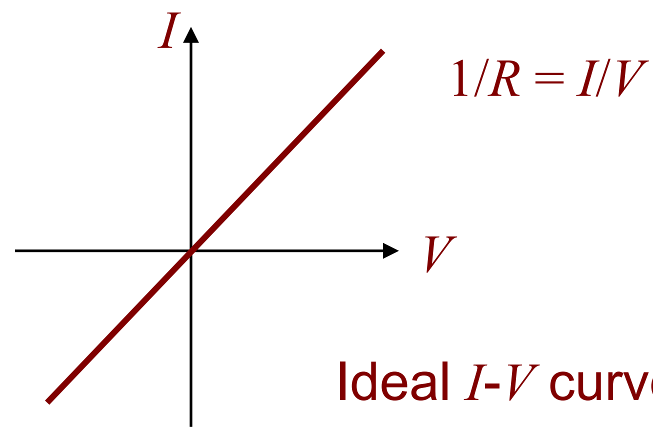
$V = V_A - V_B$

- Question: given V, what is I?

$\boxed{V = I \times R}$ or $\boxed{I = \dfrac{V}{R}}$

- I-V curve

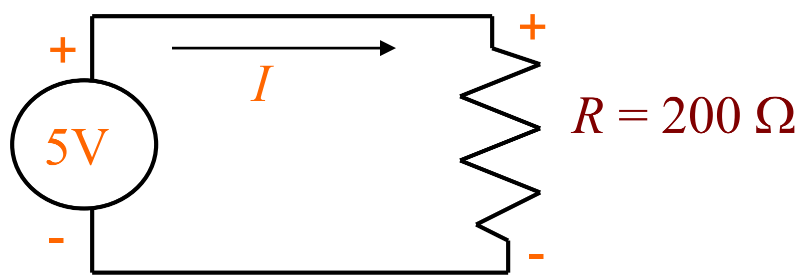




Ideal I-V curve

OHM'S LAW EXAMPLE

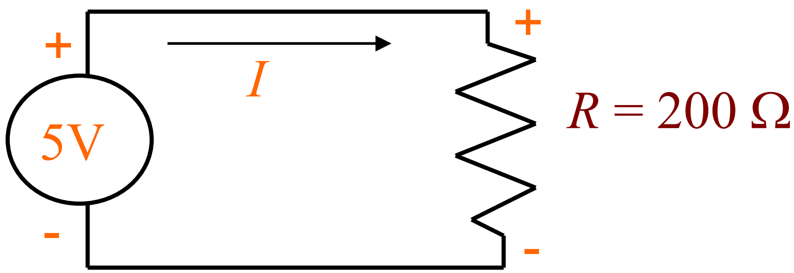
❖ For the following circuit, calculate the current



❖ Answer:

OHM'S LAW EXAMPLE

❖ For the following circuit, calculate the current



❖ Answer:

$$I = \frac{V}{R} = \frac{5\text{V}}{200\Omega} = 0.025\,\text{A} = 25\text{mA}$$

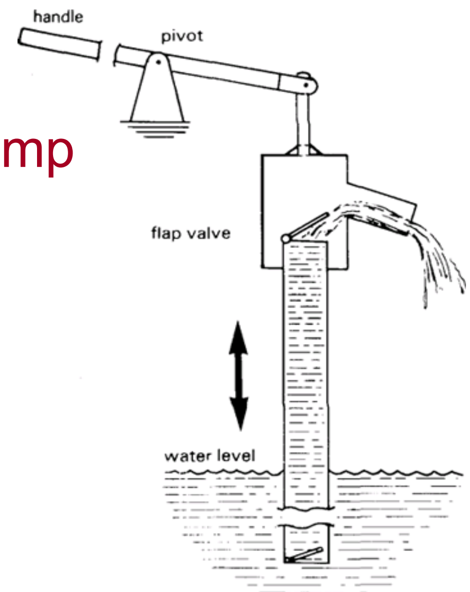
HOW DO WE GAIN ENERGY?

- How do a robot gain energy?

  Mostly, they rely on batteries.

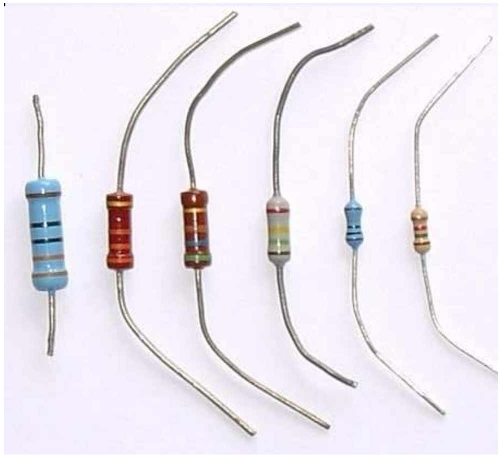
ANALOGIES: WATER SYSTEM AND CHARGE SYSTEM

Water Pump



Water Pipe

Battery



Resistor

ENERGY

- Energy is an attribute of objects and systems
- Symbol: E
- Unit: Joule or J
- Forms of Energy:
  - Mechanical: Kinetic and potential
  - Thermal
  - Electrical
  - Chemical
  - ……

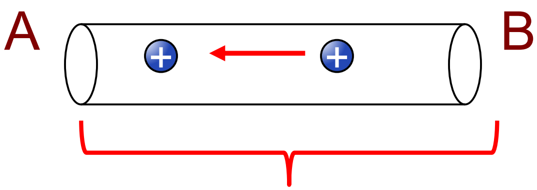
- Energy can be converted from one form to another, but the total energy is conserved

- Example:
  - a ball falling from the Leaning Tower of Pisa gets its kinetic energy from potential energy

- Revision exercise:
  - a Porsche's mass = 2 tons, velocity = 100 km/h, how much kinetic energy does it have?

- In order to have current flow between two points, we need to have a "voltage difference" between these two points

- A "positive charge" q gains energy when it moves from a point at lower voltage to a point with higher voltage



Voltage difference: V

$$E = q \times V \Rightarrow V = \frac{E}{q}$$

E in joule (J) with unit in electron-volt (eV)

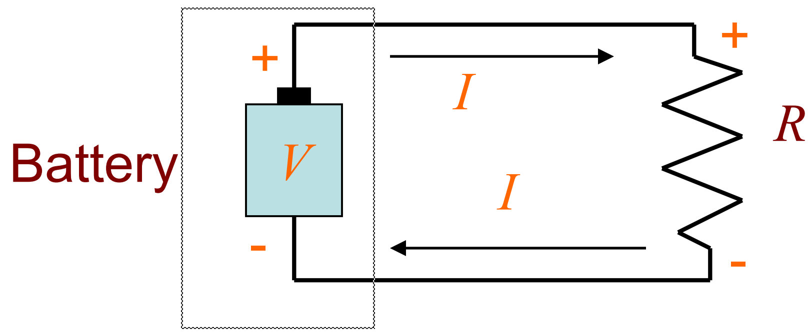
- Current is the rate of electron flow $$I = \frac{q}{t}$$

POWER

- Power is defined as the rate at which energy is produced/consumed/dissipated
- Symbol: P
- Unit: Watt or W or J/s

$$P = \frac{E}{t}$$

- Consider a battery supplying a voltage to drive the current through a resistor



$$P = \frac{E}{t} = \frac{E}{q}\frac{q}{t} = VI$$

$$P = I^2 R = \frac{V^2}{R}$$

POWER EXAMPLE

- A speaker converts electrical energy into vibration (sound energy)
- Power rating of a speaker is defined as the maximum power that can be delivered to it without damage
- Assume the internal resistance of a speaker is $16\ \Omega$ and the power rating is $100\ \mathrm{W}$. What is the maximum safe current that can be delivered to it?

POWER EXAMPLE

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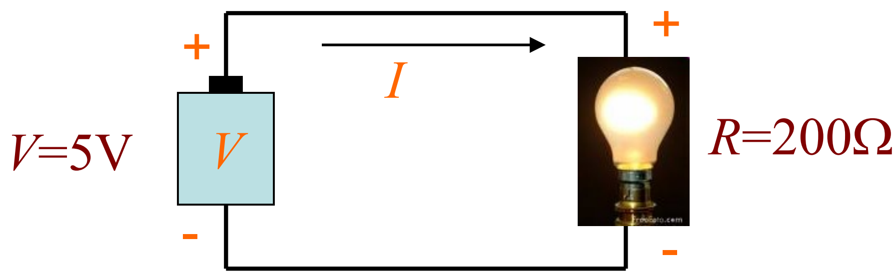
$$P = I^2 R$$

$$\Rightarrow I = \sqrt{\frac{P}{R}} = 2.5\mathrm{A}$$

ANOTHER EXAMPLE

- Consider the simple resistor network below. What's the power of the bulb?



- Answer:

ANOTHER EXAMPLE

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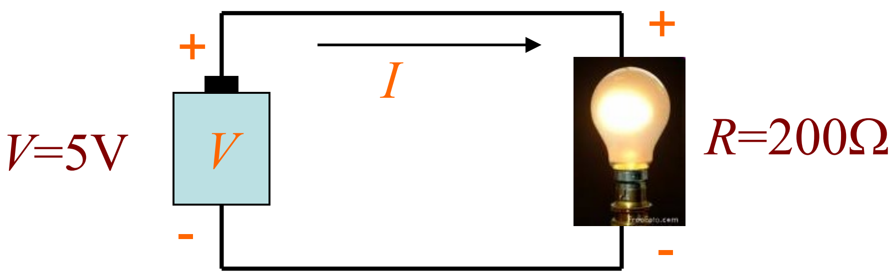
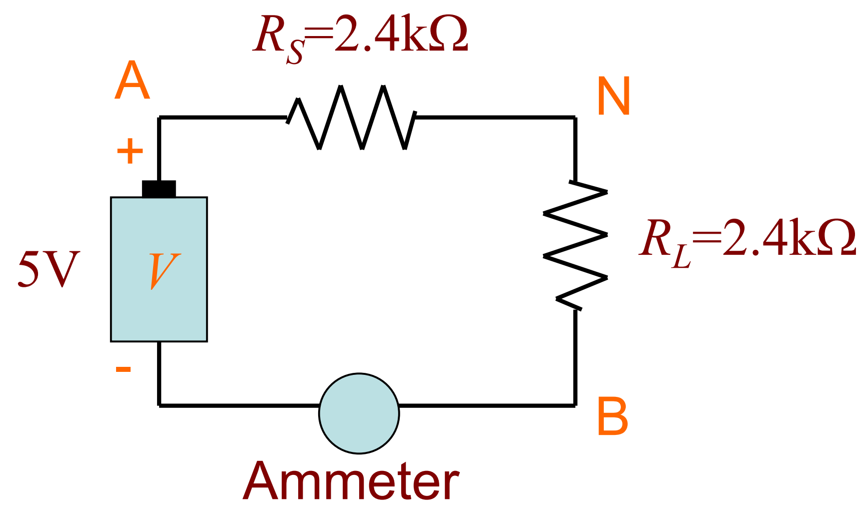


❖ Answer:

$$P = \frac{V^2}{R} = 0.125\text{W}$$

A LITTLE MORE CHALLENGING EXAMPLE

- Consider the simple resistor network below. What's the power of the R_L?



- Answer:

A LITTLE MORE CHALLENGING EXAMPLE

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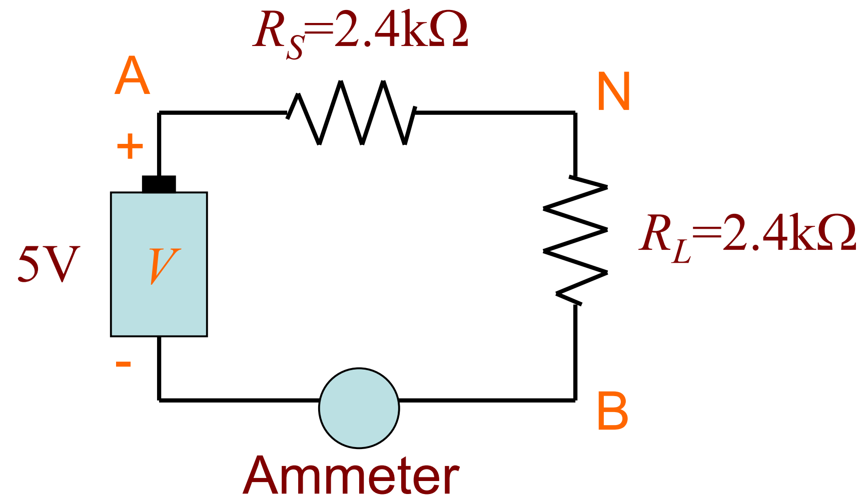
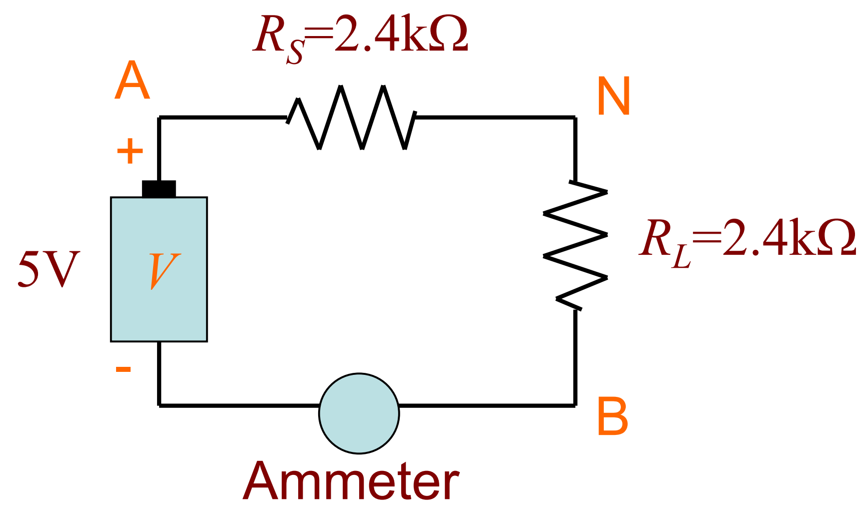


- Answer (method 1):

$$\text{total } R = 2.4\text{k}\Omega + 2.4\text{k}\Omega = 4.8\text{k}\Omega \qquad I = \frac{V}{R} = \frac{5V}{4.8\text{k}\Omega} = 1.04\,\text{mA}$$

$$P = I^2 R = 1.04\text{mA} \times 1.04\text{mA} \times 2.4\text{k}\Omega = 2.6\text{mW}$$

❖ Consider the simple resistor network below. What's the power of the R_L?



❖ Answer (method 2):

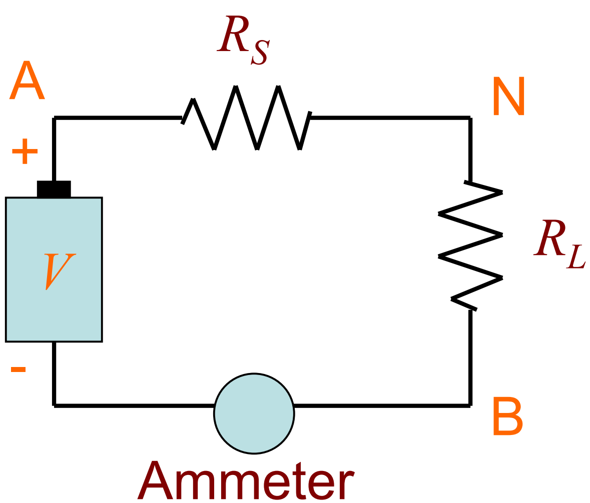
$$\text{total } R = 2.4\text{k}\Omega + 2.4\text{k}\Omega = 4.8\text{k}\Omega$$

$$\text{total } P = \frac{V^2}{R} = \frac{5^2}{4.8\text{k}\Omega} = 5.2\text{mW}$$

$$P_{RL} = \frac{5.2\text{mW}}{2} = 2.6\text{mW}$$

VOLTAGE DIVIDER

- What is the voltage at node *N* in the circuit below?



Q: What's implicitly assumed here?

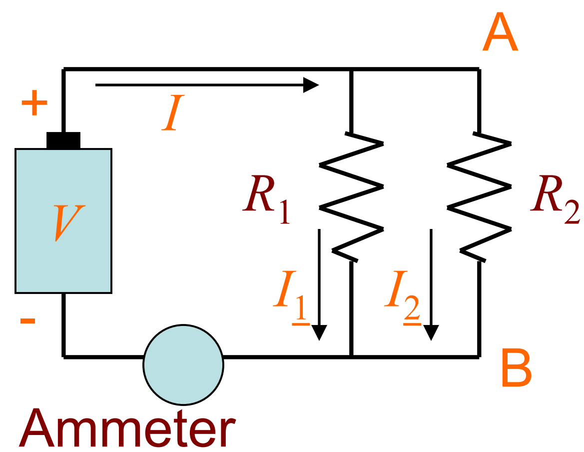
$$\text{Total}\, R = R_S + R_L$$

$$I = \frac{V}{R} = \frac{V}{R_S + R_L}$$

$$\therefore V_N = IR_L = \frac{R_L}{R_S + R_L} V$$

- Resistors in series partition the voltage according to the ratio of their resistances

- Consider the following circuit, what is the equivalent resistance given by R_1 and R_2?

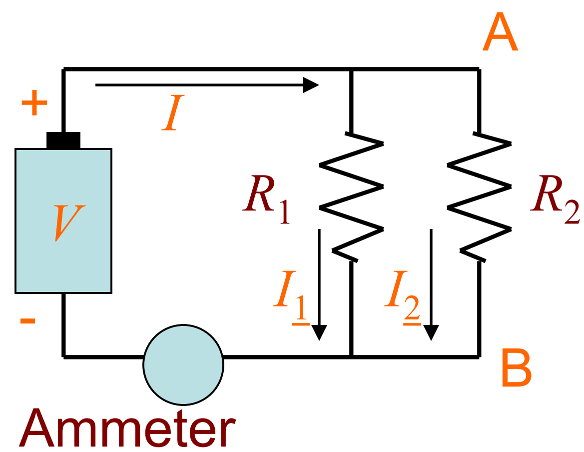


- Answer:

$$I_1 = \frac{V}{R_1} \qquad I_2 = \frac{V}{R_2}$$

$$I = I_1 + I_2 = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)V = \frac{R_1 + R_2}{R_1 R_2} V = \frac{V}{R_{eq}} \qquad \therefore R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

- The total resistance of two resistors in parallel becomes smaller than either one



- For more than 2 resistors in parallel

$$\frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} \cdots \frac{1}{R_n} \right)$$

- The quantity $1/R$ is denoted as conductance having the unit of Siemens (S)
- Other units of conductance include Ω^{-1}, mho, ℧ etc.

ENERGY SOURCES

AC

Power Plant

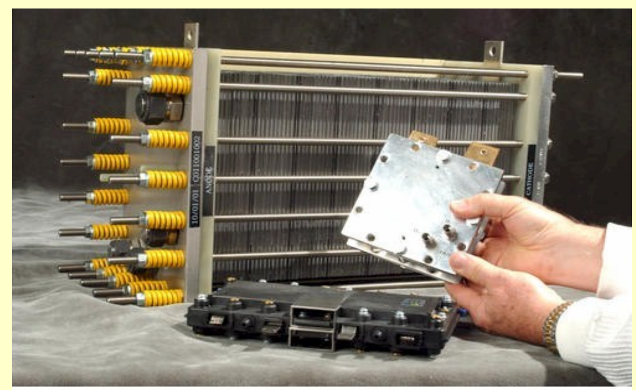
Power Generator

DC

Batteries

Energy Harvesting

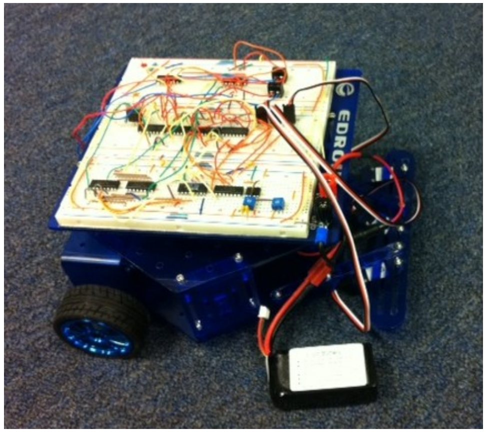
Solar Cell

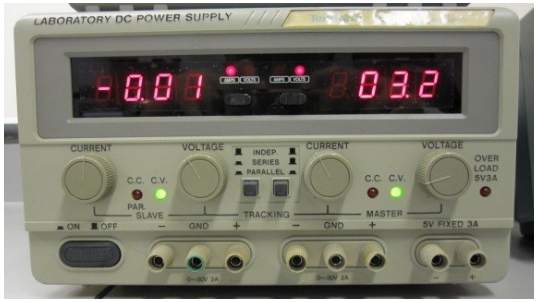


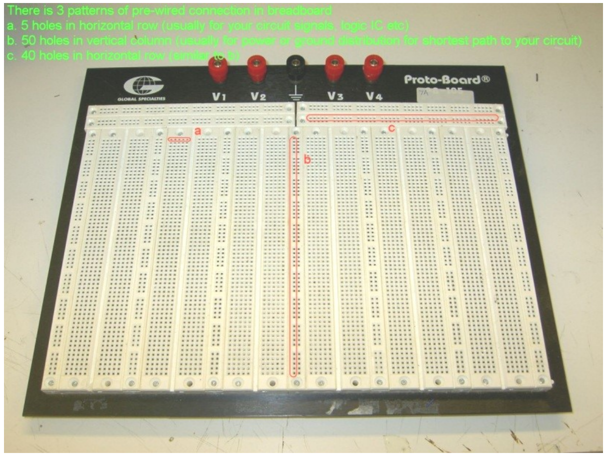
Courtesy of The National Renewable Energy Laboratory (NREL)

Fuel Cell

POWER SOURCES IN YOUR LAB







THIS WEEK'S ARRANGEMENT

- Tutorials (Lab briefing) start on Week 1 (Wed/Fri)
- Lab starts on Week 1 (Thu)
- Prelab
  - Read the lab manual and try the pre-lab questions (solution included) before the lab

NEXT LECTURE

- Battery characteristics
- DC sources
- Diodes and Voltage regulation
- Capacitors
- Pulse Generation
- PWM Control

Questions ?!