Lecture 1_1: Introduction

Industrial Robots, Mechanical System

Robotics

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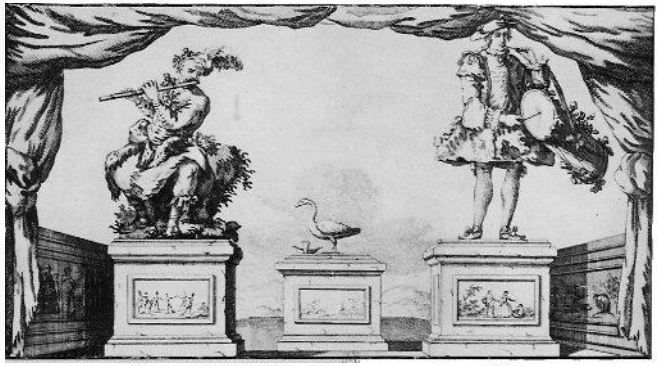
Outlines

- History
- Different Types
- Industrial Robot
- Mechanical System

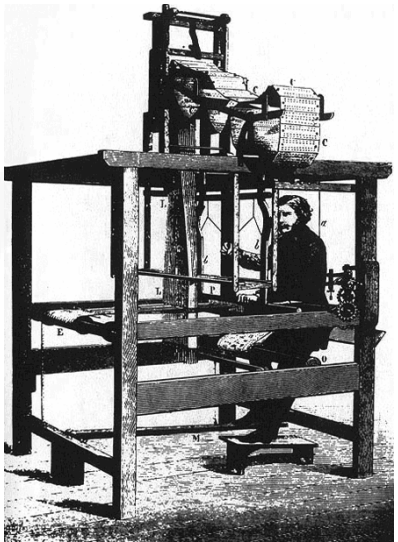
History

Initiation of Robotics

- 1750 (ca): J. de Vaucanson builds several mechanical dolls, with dimensions similar to the human ones and able to play music.



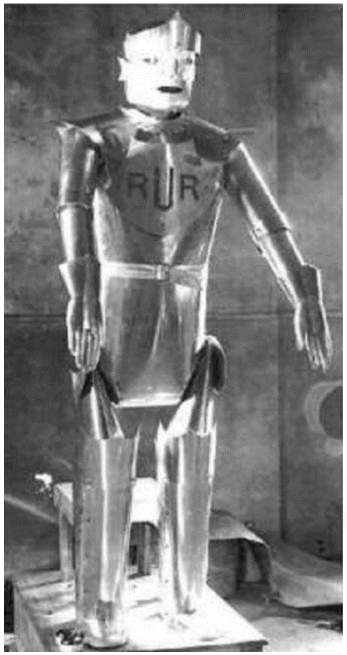
- 1801: J. Jacquard fabricates the 'Jacquard loom', a programmable machine used to weave cloths.

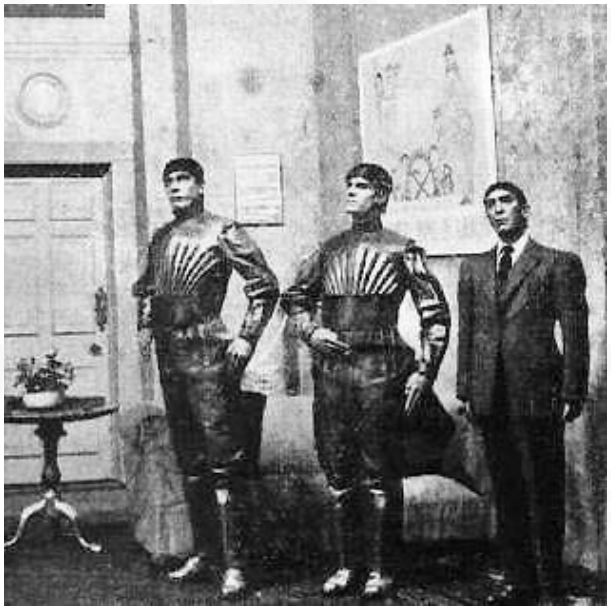


← Outline

History

- **Humanoid Robot**
  - **Robot:**
  - The name derives from the slavic word **robota** (“work”), used to indicate artificial humanlike creatures built for being inexpensive workers in the theater play Rossum’s Universal Robots (R.U.R.) written by Karel Capek in 1920 and translated in English.

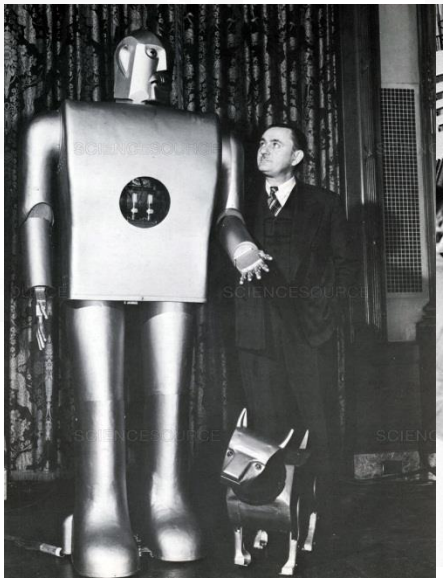




History

- **Humanoid Robot**
  - Metropolis (1926):
  - first movie with robots (Fritz Lang, Germany)

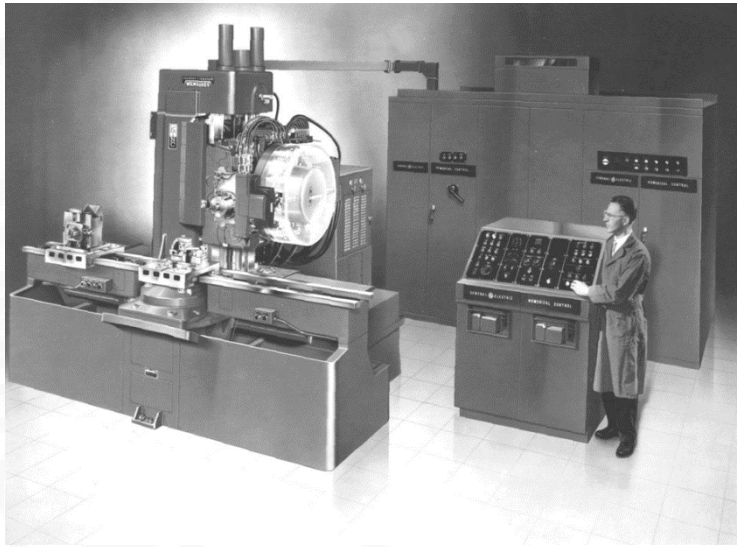
  - Electro and Sparko (1939):
  - New York World Fair,
  - the robot could walk and talk



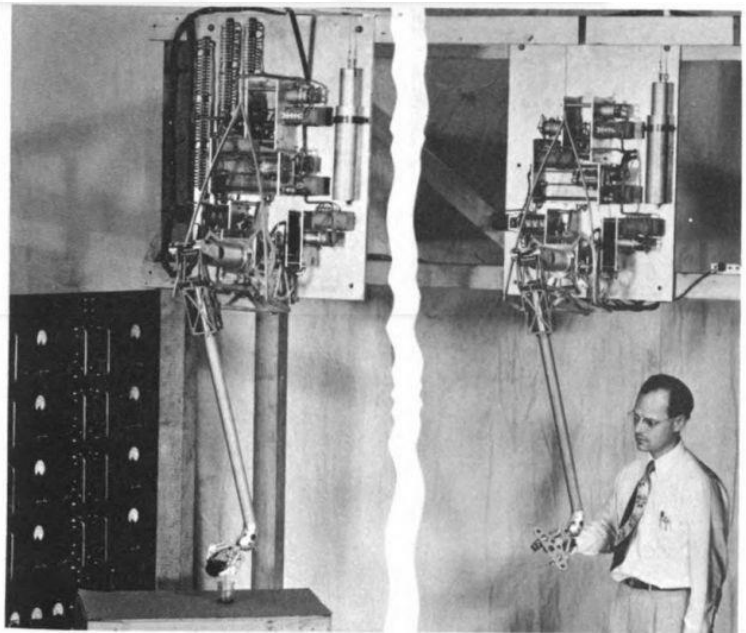
History

❑ Industrial Robot

- The initiation was from 1949 by MIT Servo Lab. (Numerical Control Machines).



- The first "modern" robots have been developed for teleoperation (radioactive material, in the 50's) and prosthetic applications. (Ray Goertz)



History

❑ Industrial Robot

- Robots have been used in production plants since the 70's.

- Initially, they have been almost exclusively used in industrial environments in tasks such as painting, welding, manipulation, assembly, and so on.

- More recently, they are more and more often used also in other fields:
  - ➢ Medicine
  - ➢ Entertainment
  - ➢ Training & Education
  - ➢ Social services
  - ➢ Surveillance
  - ➢ Military applications
  - ➢ Space & Underwater tasks
  - ➢ Construction
  - ➢ Agriculture
  - ➢ ….

Different Types

❑ Classification

- Two main classes of Robots:
  - ➢ Mobile Robots
  - ➢ Manipulator Based Robots

← Outline

Different Types

- **Categories:**
  - Humanoid Robots
  - Legged Robots
  - Load Carrying Robots
  - Military Robots
  - Fighting Robots
  - Rescue Robots
  - Swarm Robots
  - Snake Robots
  - Soccer Robots
  - Line Following Robots
  - Vaccum Cleaner Robots
  - Sphere Robots
  - Underwater Robots
  - Flying Robots
  - …

← Outline

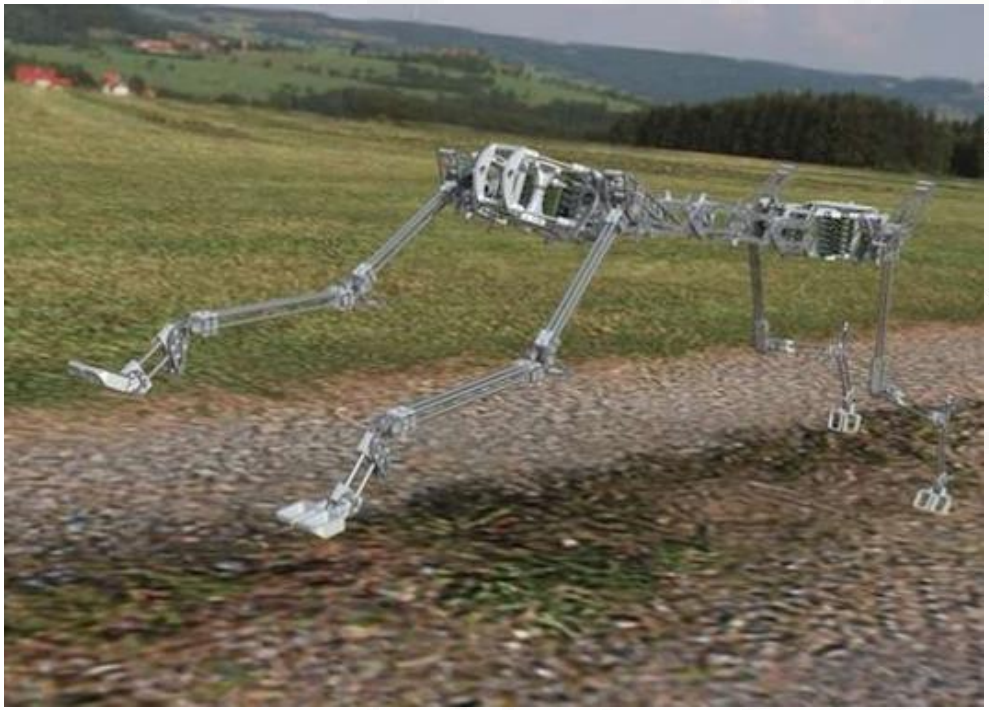
Different Types

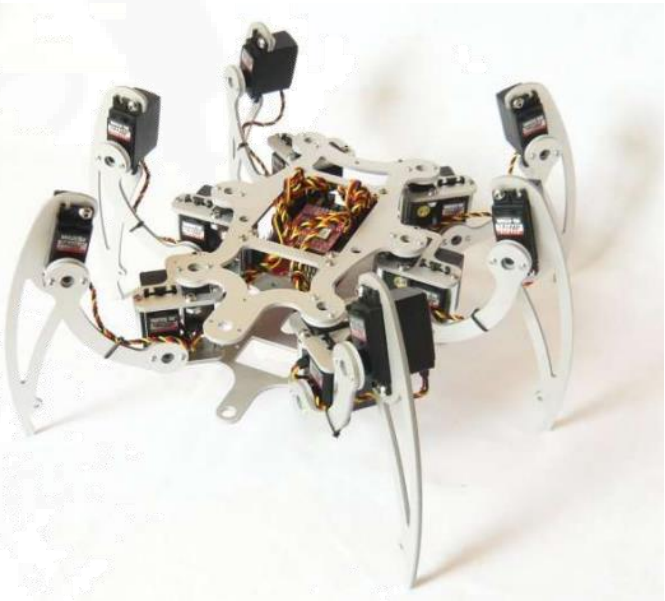
- **Humanoid Robots**

← Outline

Different Types

- **Legged Robots**





← Outline

Different Types

- **Load Carrying Robots**

← Outline

Different Types

- **Military Robots**

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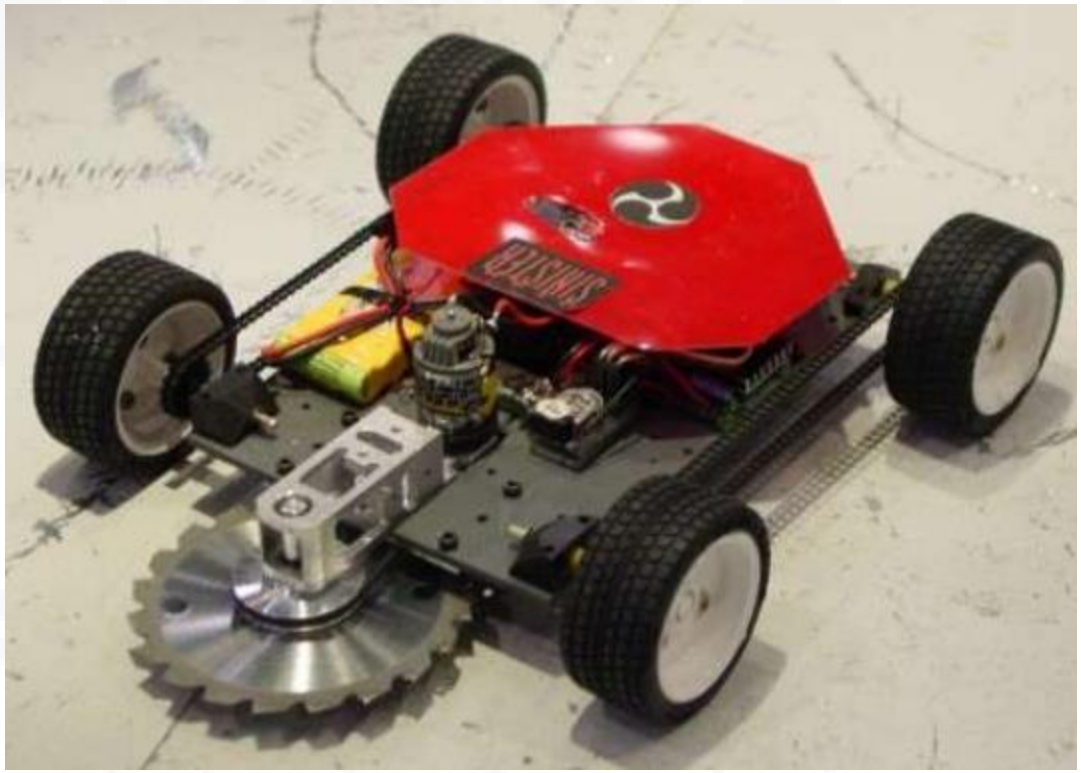
Different Types

- **Fighting Robots**



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Different Types

- **Rescue Robots**

← Outline

Different Types

- **Rescue Robots**

← Outline

Different Types

- **Swarm Robots**

← Outline

Different Types

- **Snake Robots**

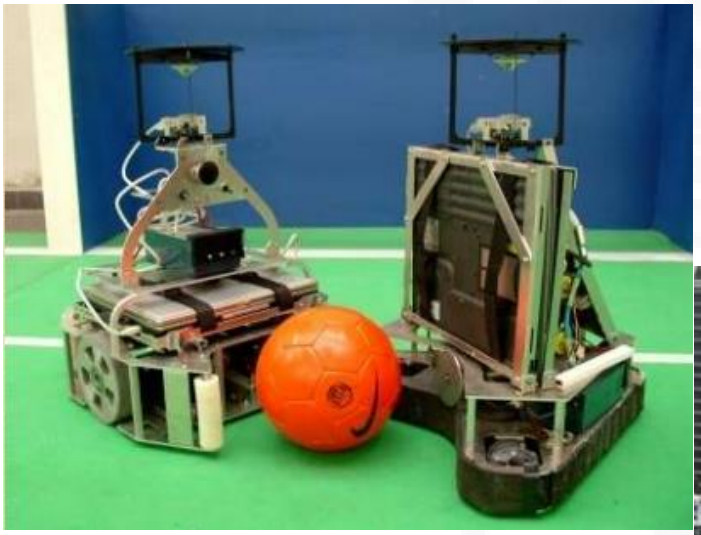
Different Types

- **Soccer Robots**
  - Small size soccer league

← Outline

Different Types

- **Soccer Robots**
  - Middle size soccer league



← Outline

Different Types

- **Soccer Robots**
  - Humanoid soccer league

← Outline

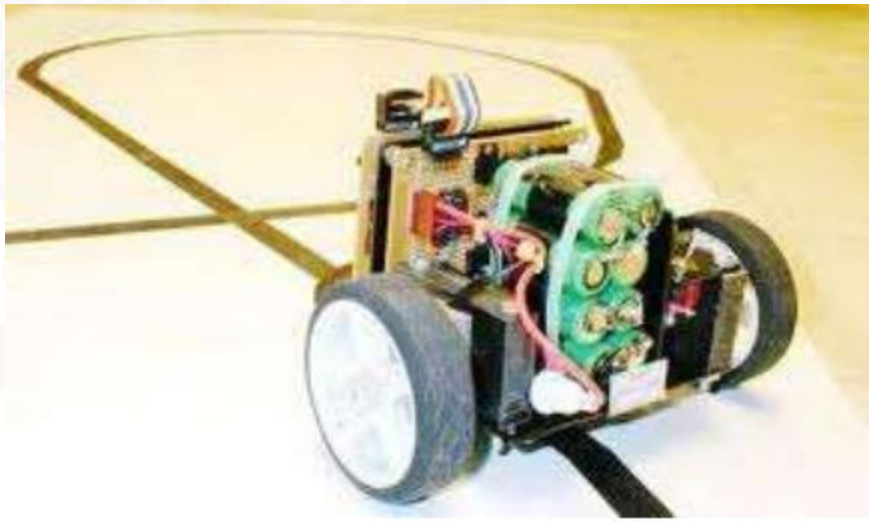
Different Types

- **Soccer Robots**
  - Four legged robots soccer league

← Outline

Different Types

- **Line Following Robots**



Different Types

- **Vaccum Cleaner Robots**

Different Types

- **Sphere Robots**

← Outline

Different Types

- **Underwater Robots**

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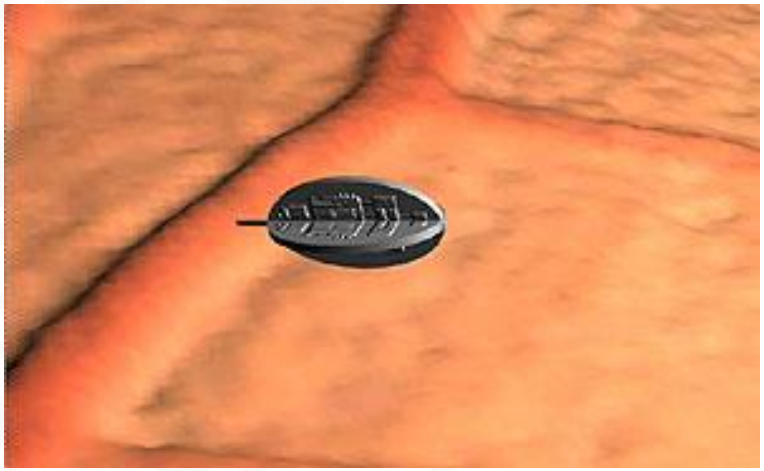
Different Types

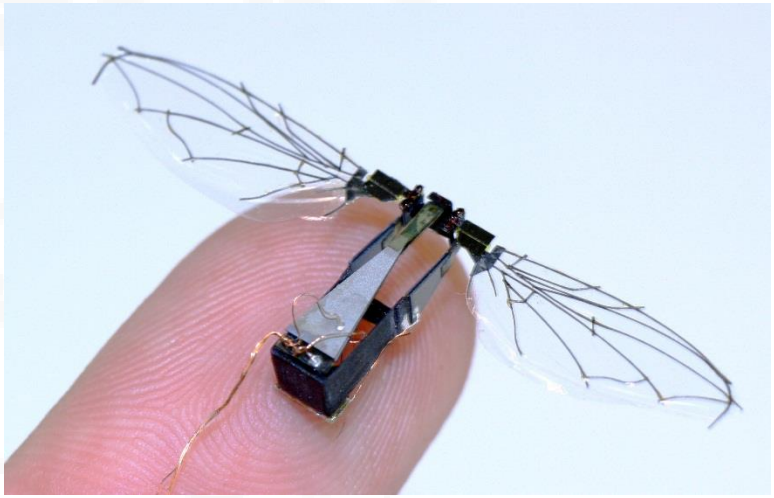
- **Flying Robots**

← Outline

Different Types

- **Micro/Nano Robots**





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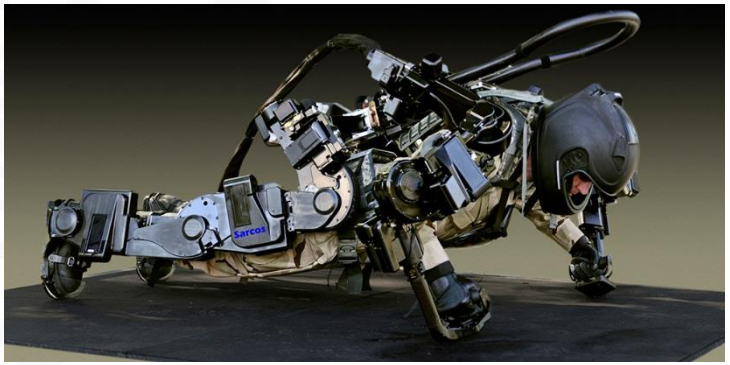
Different Types

- **Exoskeleton**
  - Power amplifiers



← Outline

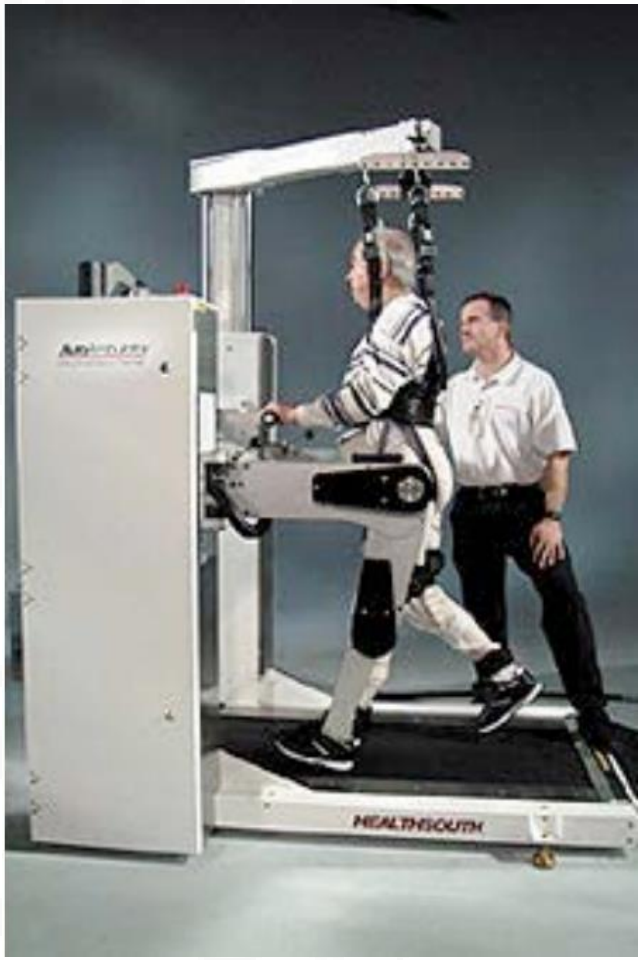
Different Types

- **Medicine**
  - Prosthetics

← Outline

Different Types

- **Medicine**
  - Rehabilitation



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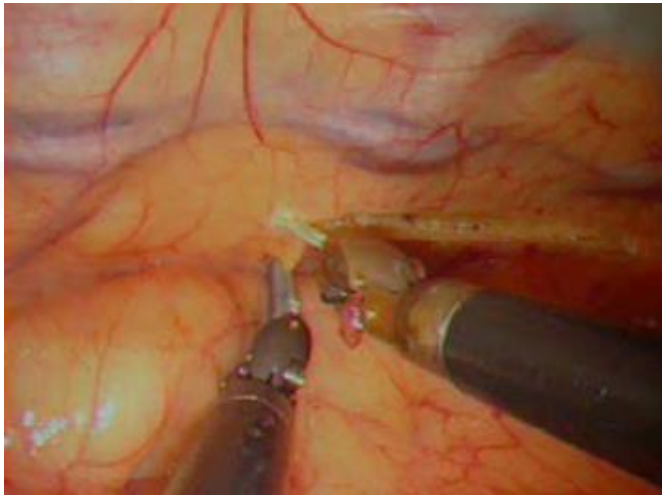
Different Types

- **Medicine**
  - Surgery



← Outline

Different Types

- **Articulated hands**

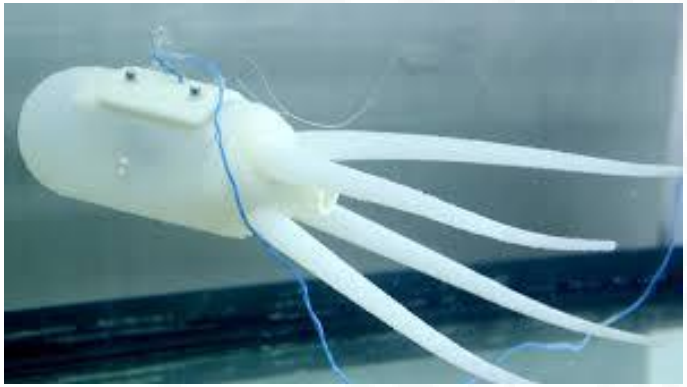
← Outline

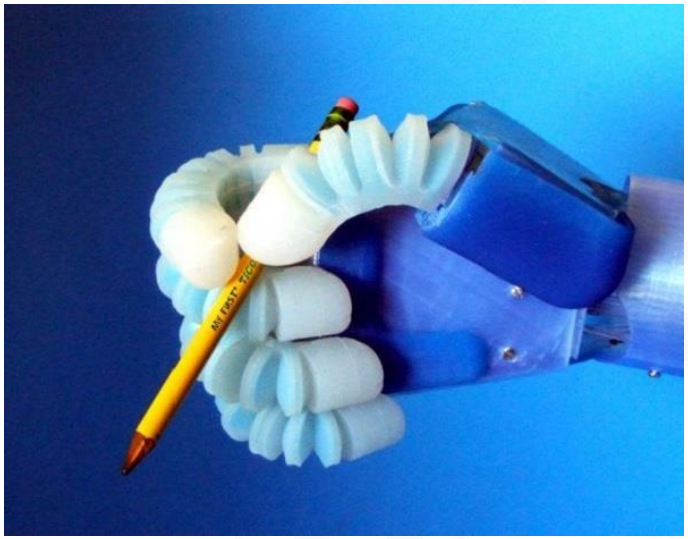
Different Types

- **Teleoperation Systems**

Different Types

- **Soft Robots**





← Outline

Industrial Robot

Industrial Robot

- **Definition:**
- Re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks, which also acquire information from the environment and move intelligently in response.
- Definition by RIA (*Robotic Institute of America*)

← Outline

Industrial Robot

❑ Robotics

- Inter-disciplinary "science", with competencies in the fields of:
  - ➢ Mechanics
  - ➢ Electronics
  - ➢ Computer Science
  - ➢ Automatic Control
  - ➢ Sensors
  - ➢ Actuators
  - ➢ Materials

← Outline

Industrial Robot

- **Robot Components**

1) **Mechanical system:** for interacting with the environment
2) **Control system:** for the run-time control and programming
3) **Actuation system:** for task execution
4) **Sensory system:** for getting proper information

← Outline

Mechanical System

1) Manipulator
2) Components
3) Kinematic Chain
4) Geometric Configuration
5) Degrees of Freedom (DoF)
6) Nomination

← Outline

Mechanical System

1) Manipulator

- The mechanical system of a robot is called "**manipulator**".
- It has different complexity and kinematic configurations.
- It comprises:
  1) Chain of rigid bodies: links
  2) Actuated connections: joints

← Outline

Mechanical System

2) Components

- 2-1) Base
- 2-2) End Effector
- 2-3) Wrist
- 2-4) Links
- 2-5) Joints

← Outline

Mechanical System

2) Components

2-1) Base

- An extremity of the manipulator, the BASE, can be either fixed in the work environment or placed on a mobile platform.

Mechanical System

2) Components

2-2) End Effector

- On the other extremity, the manipulator is equipped with a tool used to execute the desired operations, the END-EFFECTOR:
  - Gripper
  - Specific tool

← Outline

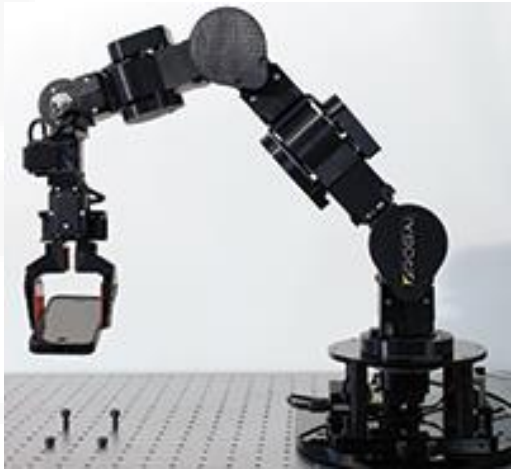
Mechanical System

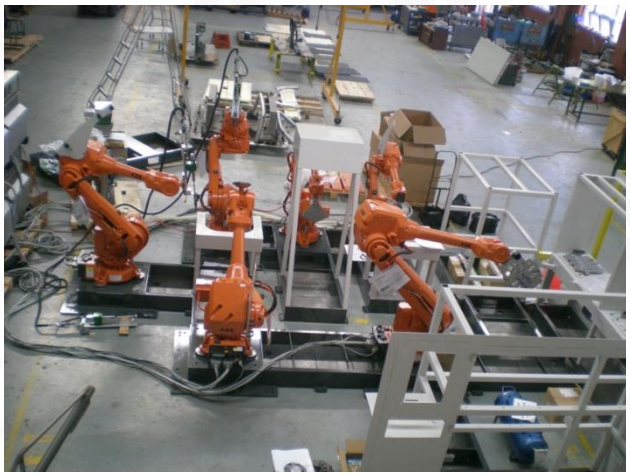
2) Components

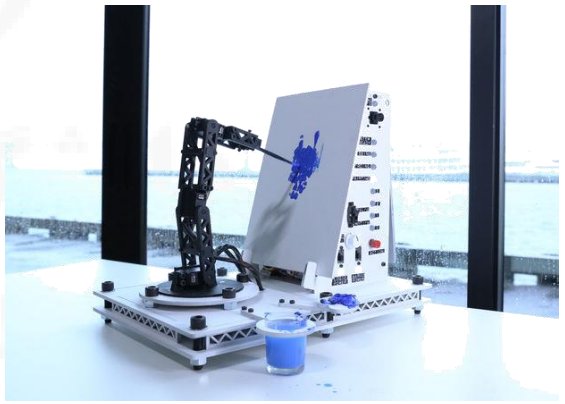
2-2) End Effector

- Manipulators interact with the environment through the end-effector.

- Some examples:
  - Grasp objects
  - Welding
  - Painting
  - Part assembly







Mechanical System

2) Components

2-2) End Effector

- Since the EE is a specialized device, it must be possible to change it in a simple manner if it is needed by the application.

- Sometimes, more EEs are available in a repository reachable by the robot, which automatically changes EE to execute different phases of a given task.

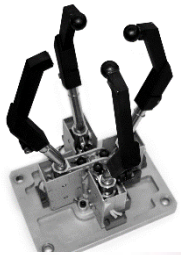
Mechanical System

2) Components

2-2) End Effector

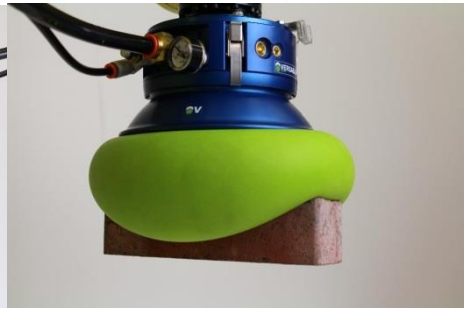
- Even restricting the interest to grippers, devices used to grasp objects, many different configurations and systems are available since these are usually designed on the basis of the objects to be grasped:
  - 2/3/4-fingered grippers
  - Inner grippers
  - Sucking grippers
  - Magnetic grippers
  - Universal grippers
  - ….









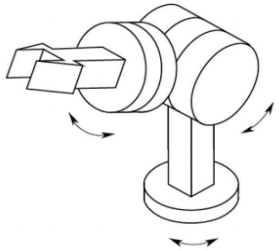


Mechanical System

2) Components

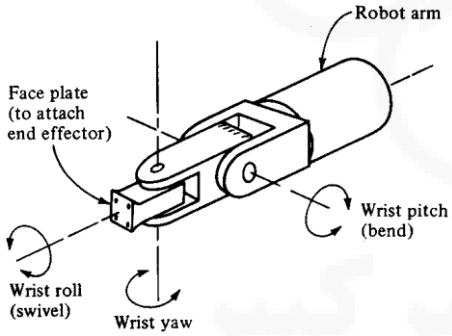
2-3) Wrist

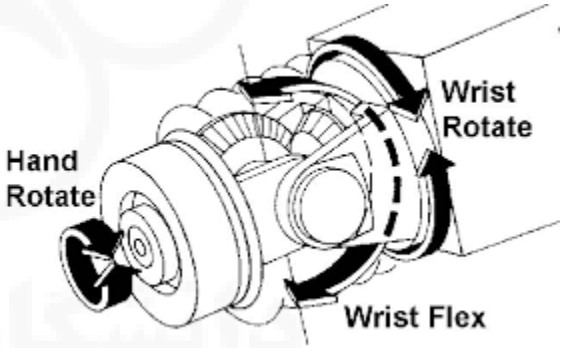
- The wrist is connected to the extremity of the arm to orient the end-effector in the workspace.



- It has at least three rotational DoF (Degree of Freedom).

- Many kinds of wrists are commercially available: different in terms of number of DoF and their kinematic configuration.





- Singular configurations: Configurations in which it is not possible to orient the EE along a particular direction.

← Outline

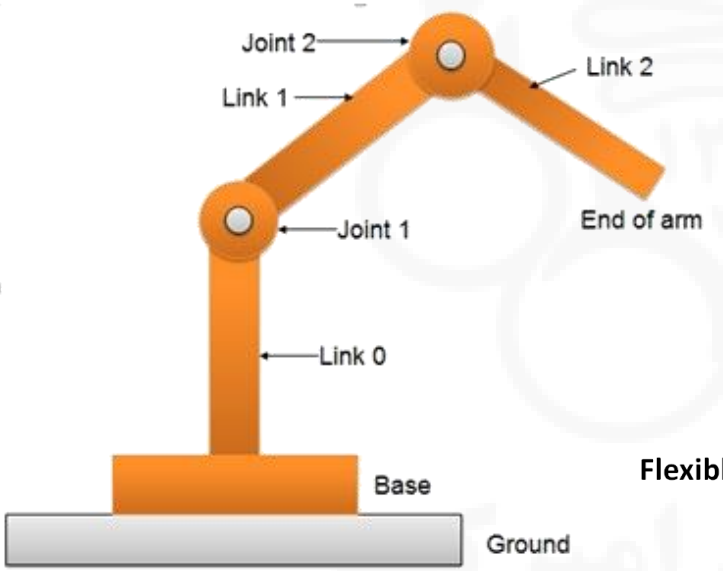
Mechanical System

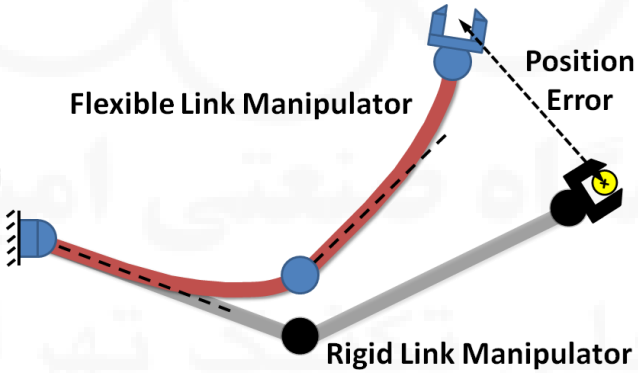
2) Components

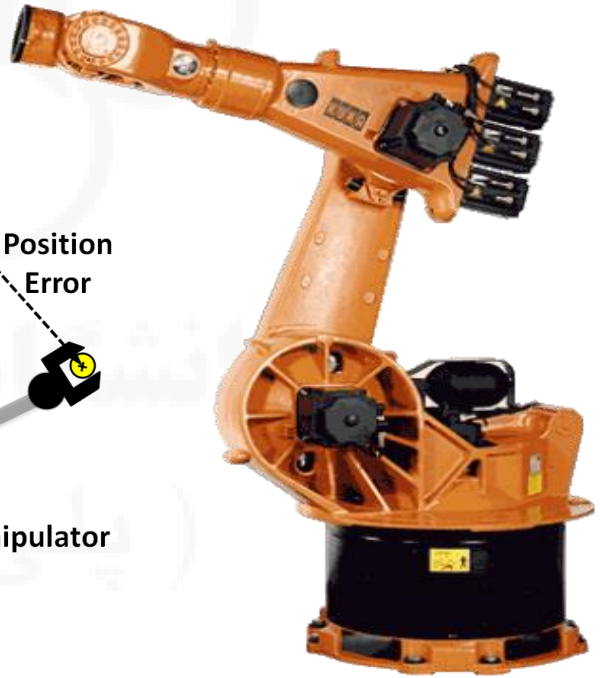
2-4) Links

- Manipulators consist of bodies which are utilized as its **arms**.

- It can be Rigid or Flexible.







Mechanical System

2) Components

2-5) Joints

- Manipulators links are connected by **joints** that allow **relative motion** of neighboring links.

- **Note:** Position sensors measure the **relative position** of neighboring links.

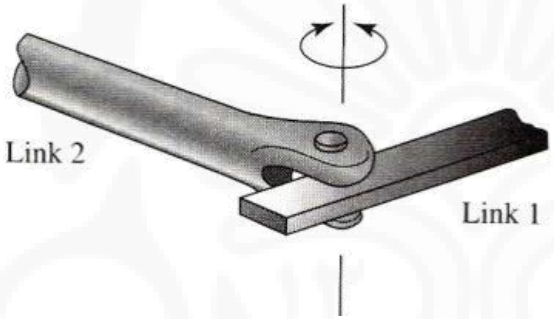
- Different types:
  1) Revolute (R)
  2) Prismatic (P)
  3) Universal (U)
  4) Spherical (S)

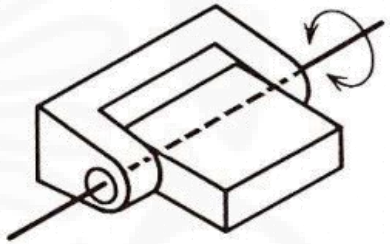
Mechanical System

2) Components

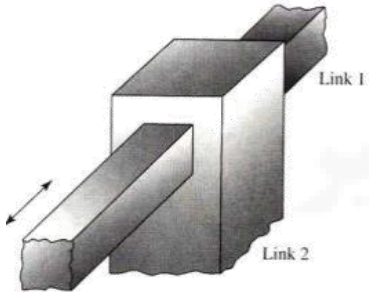
2-5) Joints

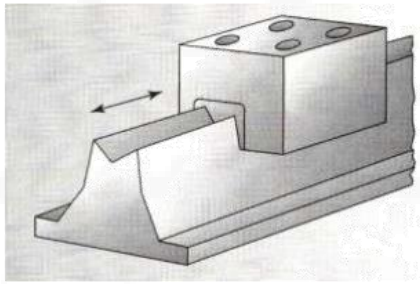
1) Revolute (R)

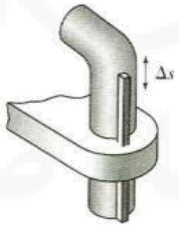


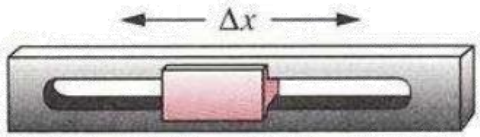


2) Prismatic (P)









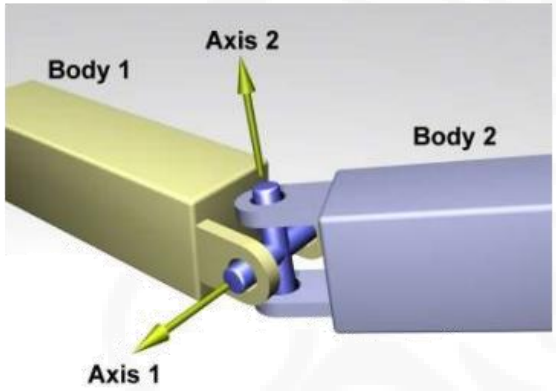
← Outline

Mechanical System

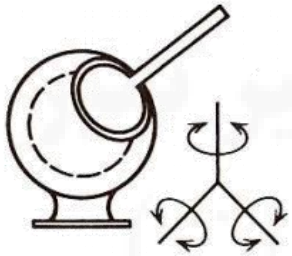
2) Components

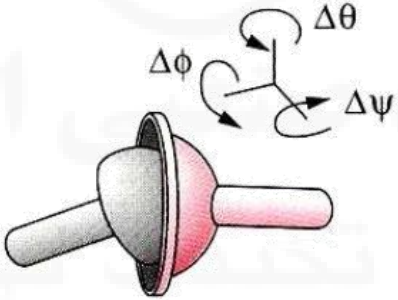
2-5) Joints

3) Universal (U)



4) Spherical (S)





Spherical (S) joint—3 *DOF*

Mechanical System

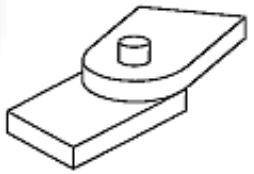
2) Components

2-5) Joints

- Two common joint types:

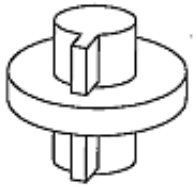
1) Revolute (R)
2) Prismatic (P)

1) Rotary or **Revolute** joints (**R**):
It has rotational motion.
The relative displacement is called **joint angle.**



Revolute

2) Sliding or **Prismatic** joints (**P**):
It has translation (linear) motion.
The relative displacement is called **joint offset.**



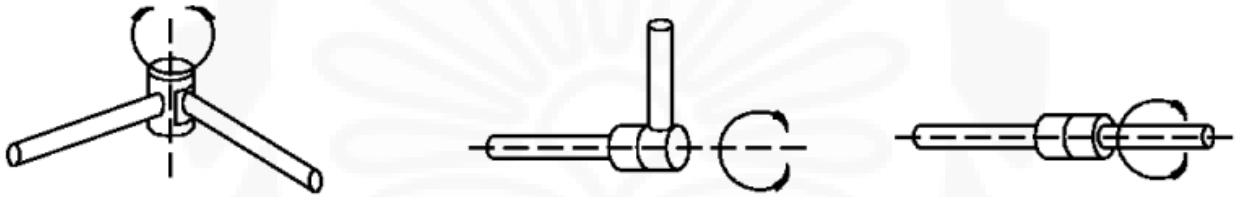
Prismatic

Mechanical System

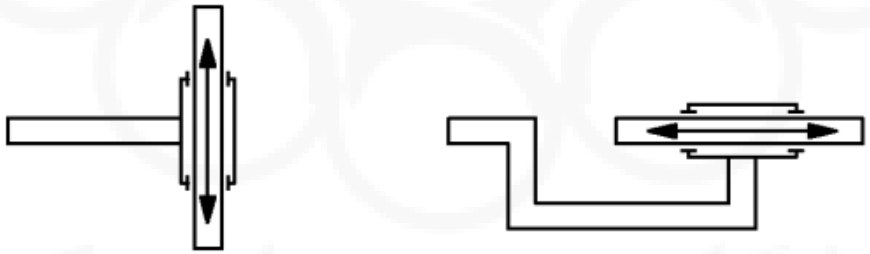
2) Components

2-5) Joints

- Revolute Joints:



- Prismatic Joints:



- **Note:** More complex joints, such as spherical or universal joints, can be considered as proper combination of prismatic and rotational joints.

← Outline

Mechanical System

3) Kinematic Chain

- Manipulators have two kinematic chains:
  1) Open Chain
  2) Closed Chain

- **Open Chain:**
- The robot links are in an open-chain structures.
- These manipulators are called **Serial Manipulator**.

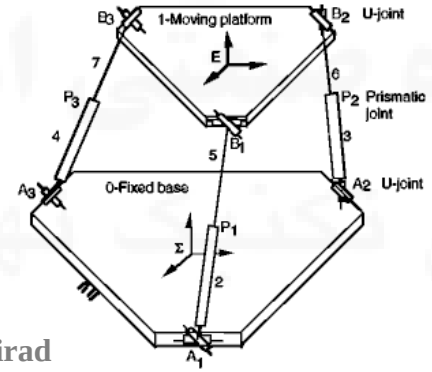
Mechanical System

3) Kinematic Chain

- **Closed Chain:**
- Other kinematic solutions exist, based on closed kinematic chains (**Parallel Manipulators**).

- Advantages:
  - Higher velocities
  - Higher precision
  - Higher "force"

- Disadvantages:
  - Reduced workspace
  - Increased space occupation

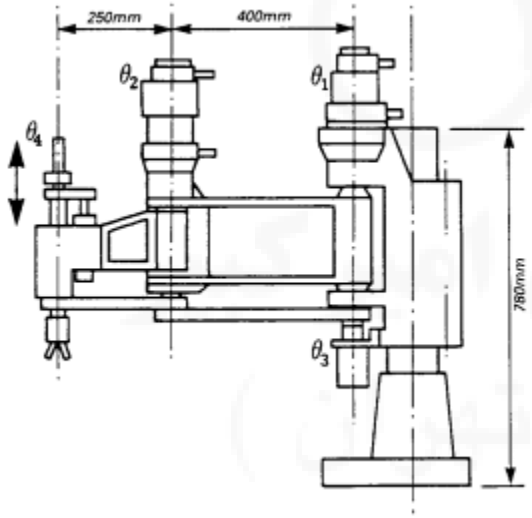


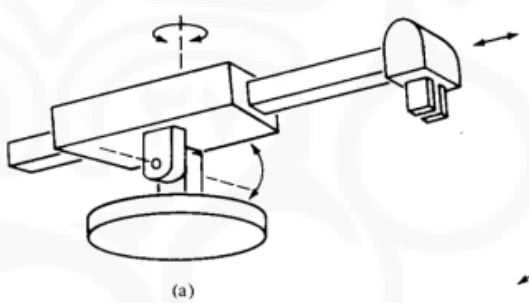
Mechanical System

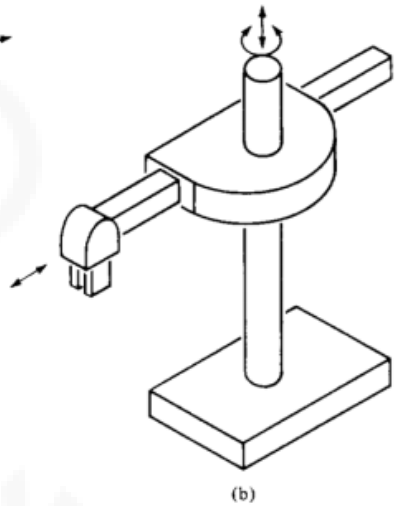
4) Geometric Configuration

- Different types of geometric configurations can be adopted an industrial robot for 2D & 3D spaces.

- Among the most common ones:
  - Spherical
  - Cylindrical
  - Cartesian
  - Anthropomorphic
  - SCARA




(a)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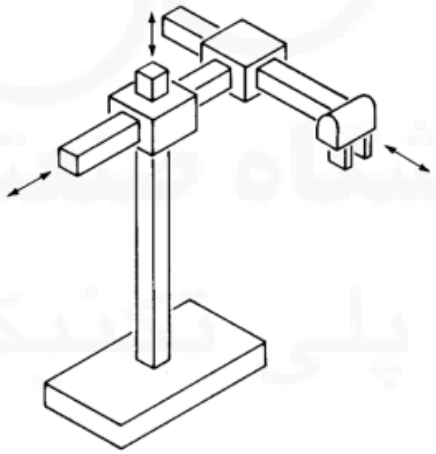
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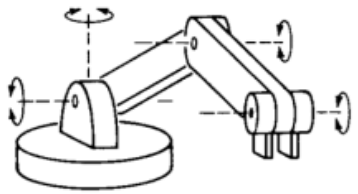
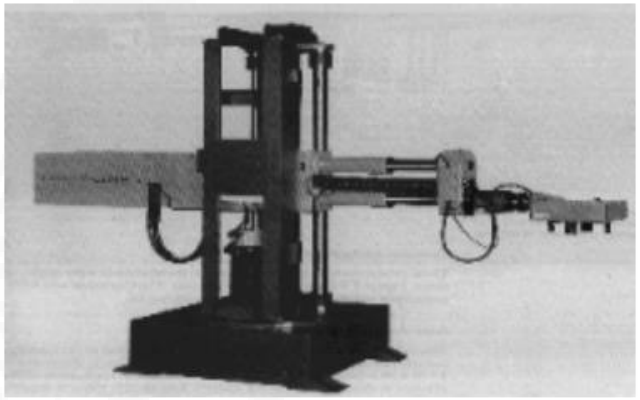

(d)

Mechanical System

4) Geometric Configuration

Polar

Cylindrical



Cartesian

SCARA:

Selective
Compliance
Arm for
Robotic
Assembly

Anthropomorphic

Mechanical System

5) Degrees of Freedom (DoF)

- Number of **independent position variables** that would have to be specified in order to locate all parts of the mechanism.

- Degrees of Freedom can be analyzed for:
  - Manipulator (Mechanism) (n)
  - Operational Space (m)

❖ **Example:** DoF of four-bar linkage = ?

Mechanical System

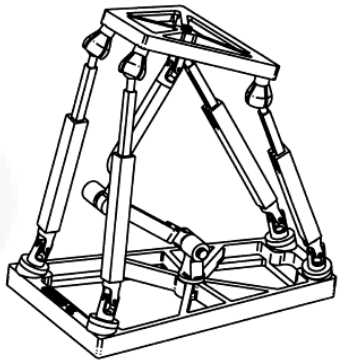
5) Degrees of Freedom (DoF)

❑ Manipulator

- Spatial Mechanism:

DoF=

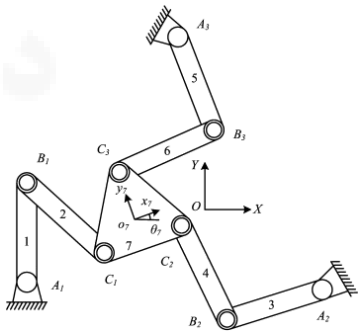
(No. of Elements * 6) – (No. of 1 DoF joints * 5) – (No. of 2 DoF joints * 4) – (No. of 3 DoF joints * 3) - …



- Planar Mechanism:

DoF=

(No. of Elements * 3) – (No. of 1 DoF joints * 2) – (No. of 2 DoF joints * 1)

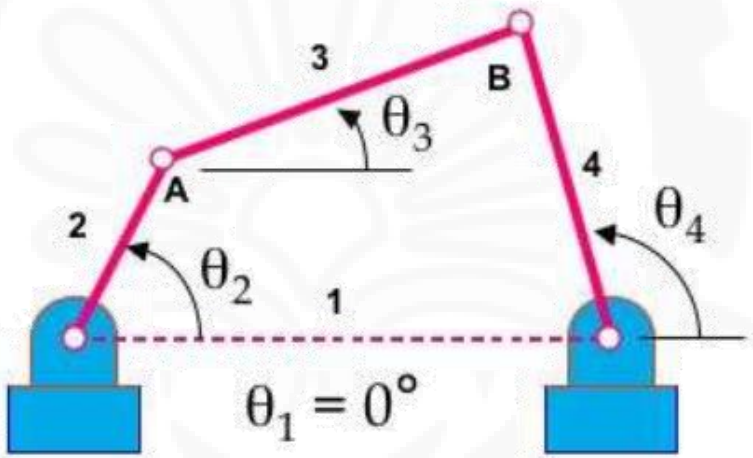


← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator

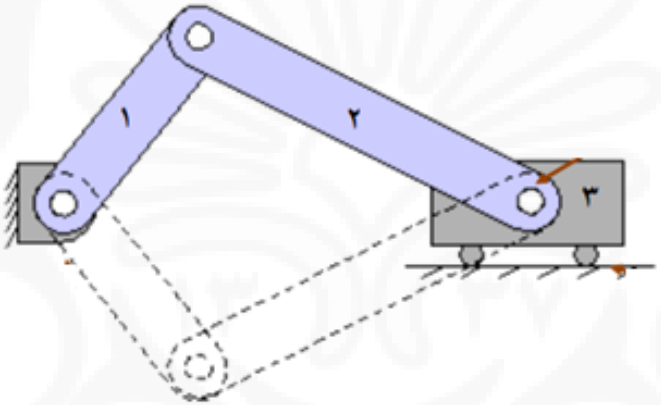


- No. of Elements = 3
- No. of 1 DoF joints = 4
- DoF = (3 * 3) – (4 * 2) = 1

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator

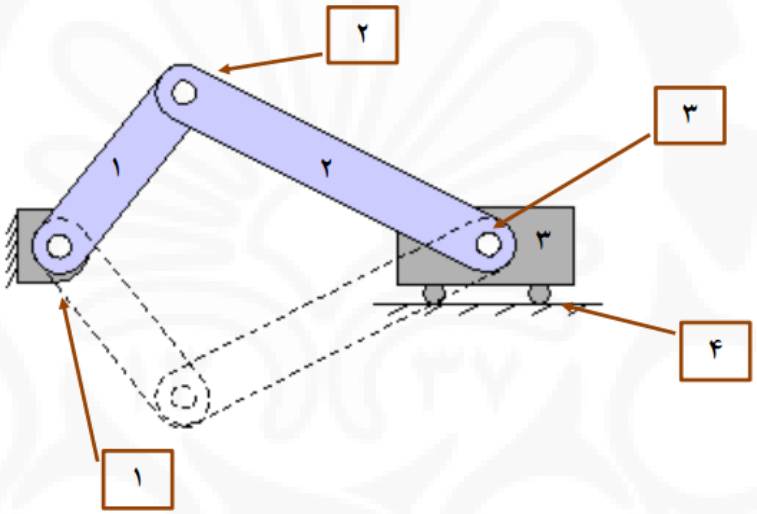


- No. of Elements = ?
- No. of 1 DoF joints = ?
- DoF = ?

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator



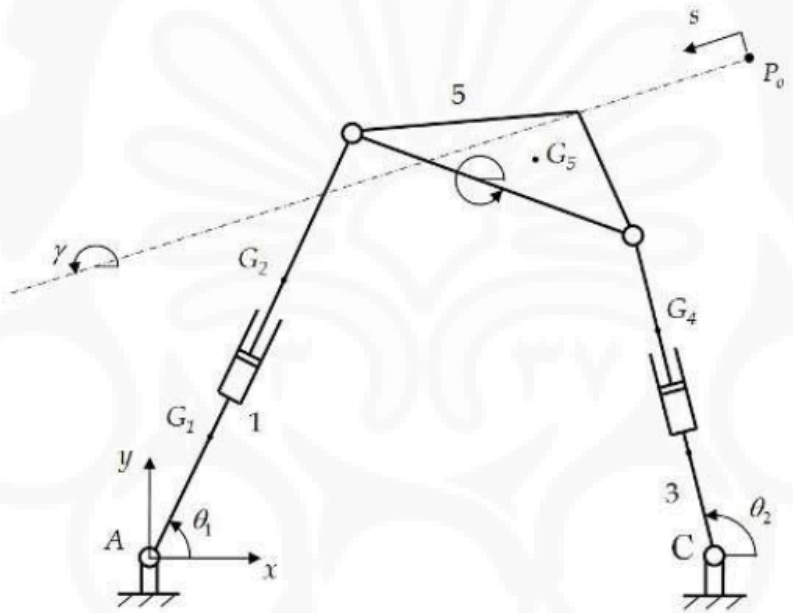
- No. of Elements = 3
- No. of 1 DoF joints = 4
- DoF = (3 * 3) – (4 * 2) = 1

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator



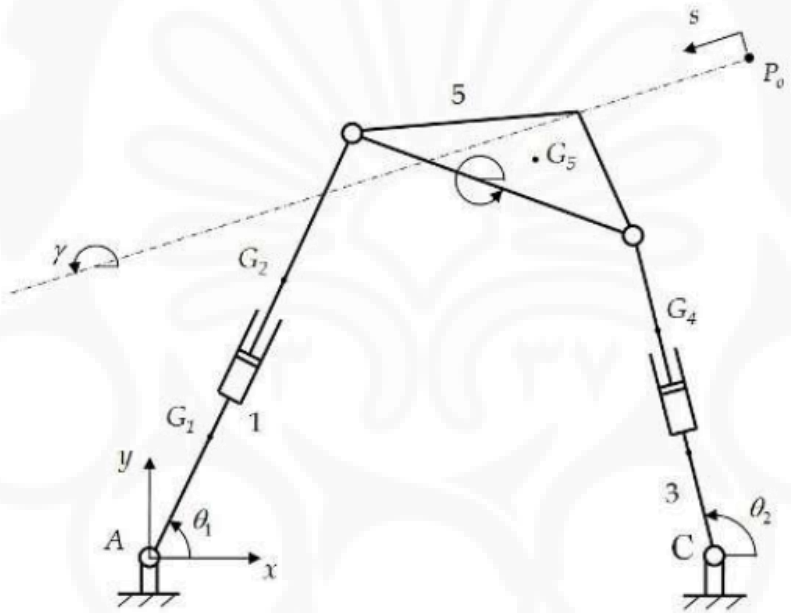
- No. of Elements = ?
- No. of 1 DoF joints = ?
- DoF = ?

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator



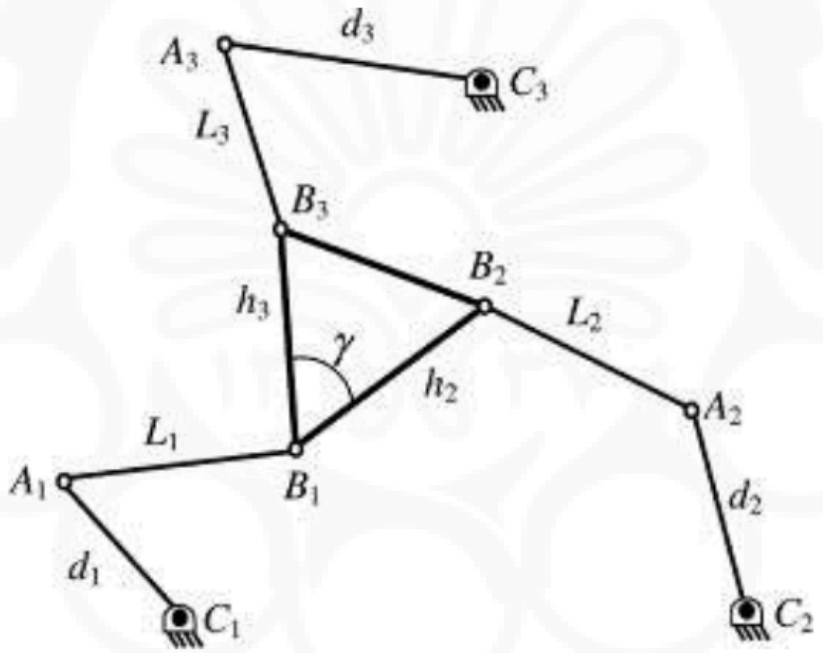
- No. of Elements = 5
- No. of 1 DoF joints = 6
- DoF = (5 * 3) – (6 * 2) = 3

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator



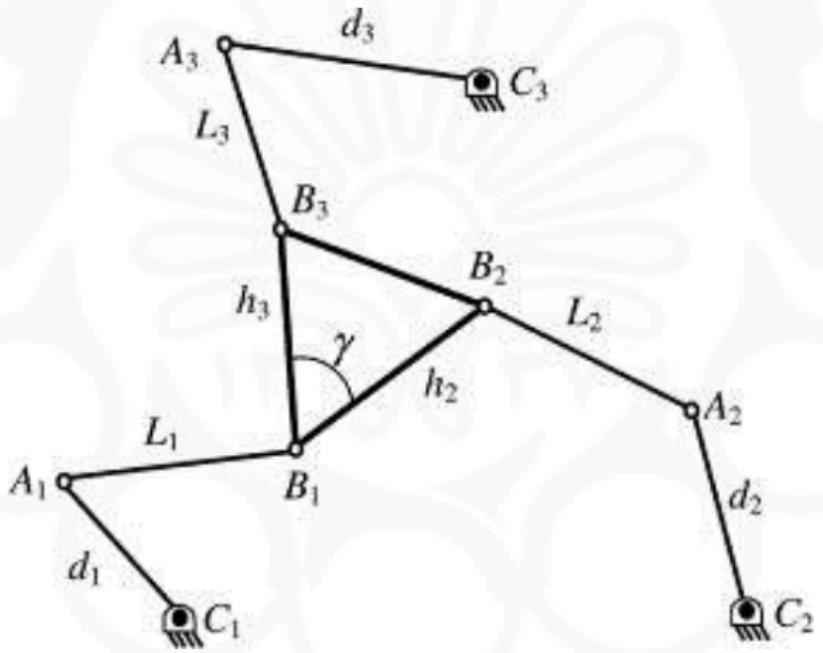
- No. of Elements = ?
- No. of 1 DoF joints = ?
- DoF = ?

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator



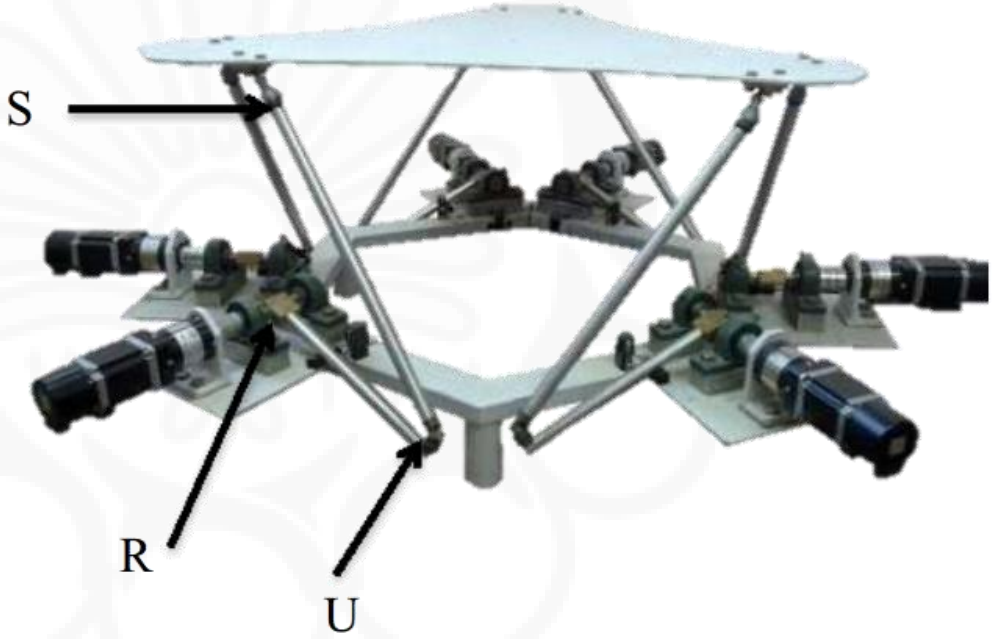
- No. of Elements = 7
- No. of 1 DoF joints = 9
- DoF = (7 * 3) – (9 * 2) = 3

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator

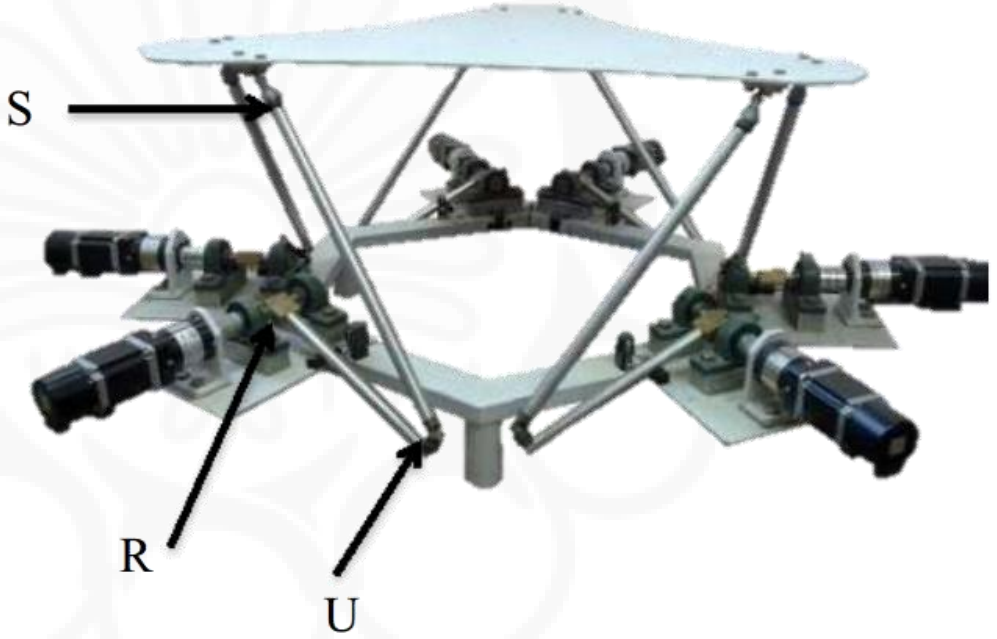


- No. of Elements = ?
- No. of 1 DoF joints = ?
- No. of 2 DoF joints = ?
- No. of 1 DoF joints = ?
- DoF = ?

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator



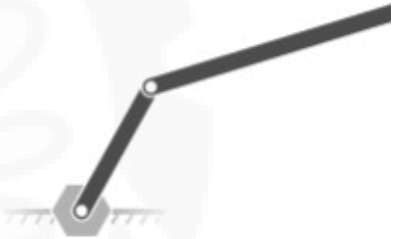
- No. of Elements = 13
- No. of 1 DoF joints = 6
- No. of 2 DoF joints = 6
- No. of 1 DoF joints = 6
- DoF = (13 * 6) – (6 * 5) – (6 * 4) – (6 * 3) = 6

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator

- **Serial Manipulators:**



- No. of Elements = ?
- No. of 1 DoF joints = ?
- DoF = ?

- No. of Elements = ?
- No. of 1 DoF joints = ?
- DoF = ?

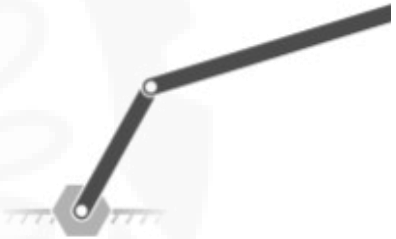
← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator

- **Serial Manipulators:**



- No. of Elements = 2
- No. of 1 DoF joints = 2
- DoF = (2 * 3) – (2 * 2) = 2

- No. of Elements = 3
- No. of 1 DoF joints = 3
- DoF = (3 * 3) – (3 * 2) = 3

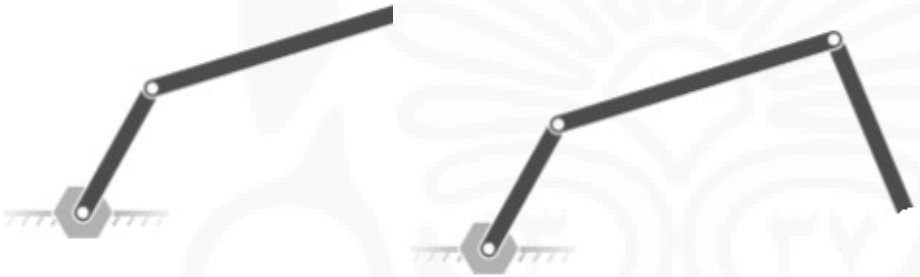
← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator

- **Serial Manipulators:**



- No. of Elements = n
- No. of 1 DoF joints = n
- DoF = (n * 3) – (n * 2) = n

- A serial manipulator is an **open kinematic chain**, and because each joint position is usually defined with a single variable, so …
  Number of joints = Number of degrees of freedom

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Operational Space:

- 2-D plane:
- 3 DOF: 2 translations and 1 rotation. $m = 3$

- 3-D Cartesian space:
- 6 DOF: 3 translations and 3 rotations. $m = 6$

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator-Operational Space Interaction:

- 2-D plane:

- 3-D Cartesian space:

← Outline

Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator-Operational Space Interaction:

- 2-D plane:
- Robot manipulator must have at least 3 DOF to cover the operational space completely.

- 3-D Cartesian space:
- Robot manipulator must have at least 6 DOF to cover the operational space completely.

- ***Q:*** Essential or Sufficient?

← Outline

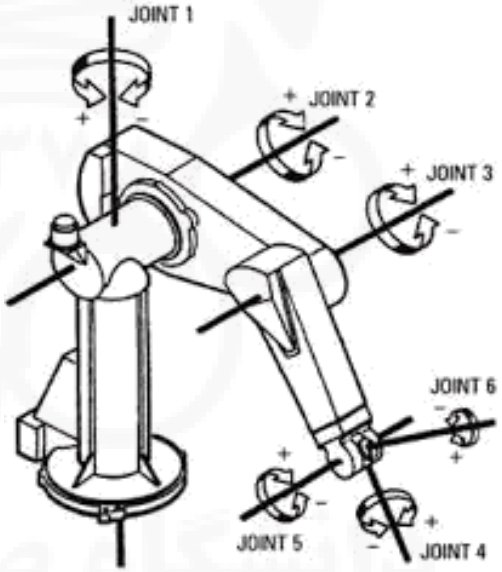
Mechanical System

5) Degrees of Freedom (DoF)

❑ Manipulator-Operational Space Interaction:

- A 6 DOF Robot:

  Robot Hand can move freely in operational space,
  along 3 translational axes and around 3 rotational axes.



- A 8-DOF Robot:

  ????

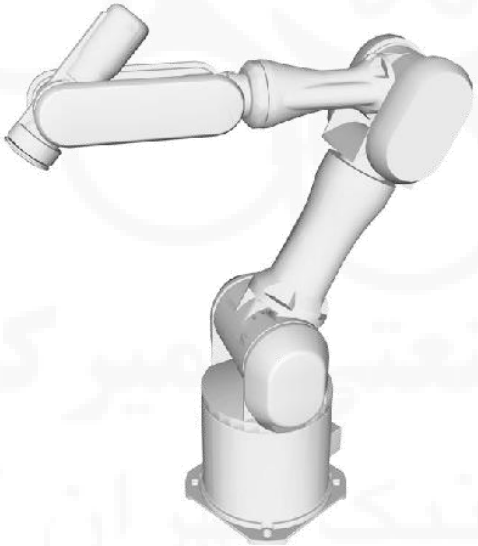
Mechanical System

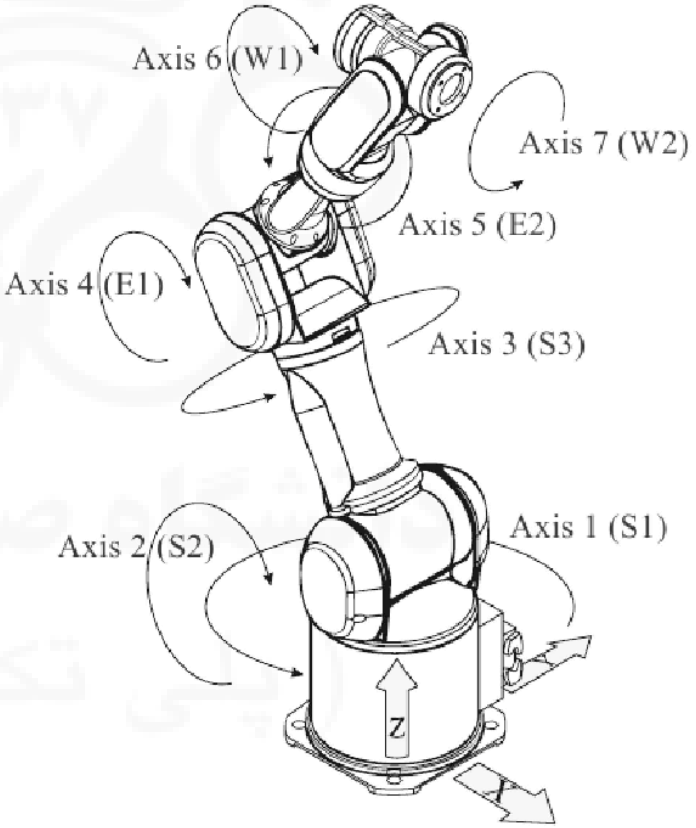
5) Degrees of Freedom (DoF)

- A 8-DOF Robot:
  This Robot has 8 DOF in actuator joint space and can have 6 motions in Robot operational space.

- This is a **redundant** Robot.

❖ ***Q:*** Why Redundancy?



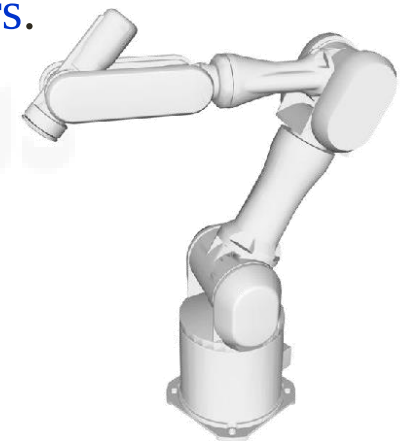


Mechanical System

5) Degrees of Freedom (DoF)

- **Defective manipulators:**
- $n < m$, e.g. $n = 4, 5$ and $m = 6$
- It is not possible to execute all the possible tasks in the workspace, but only those defined in a proper subspace
- (e.g. SCARA).

- **Redundant manipulators:**
- $n > m$, for example $n = 7, 8$, and $m = 6$
- A given task can be executed in infinite different manners.
- (e.g. Mitsubishi PA 10-7C).

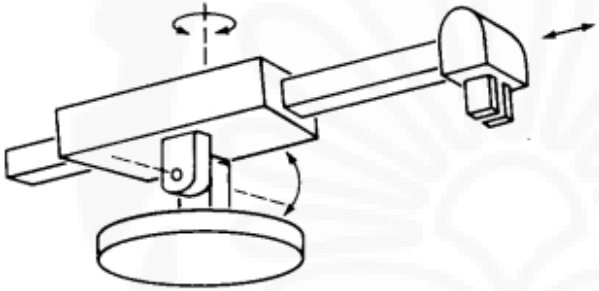


← Outline

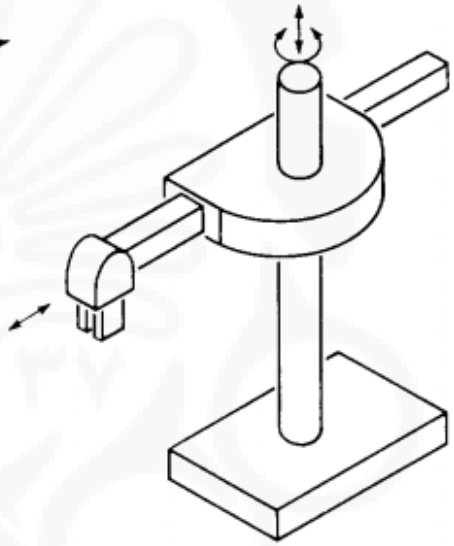
Mechanical System

6) Nomination

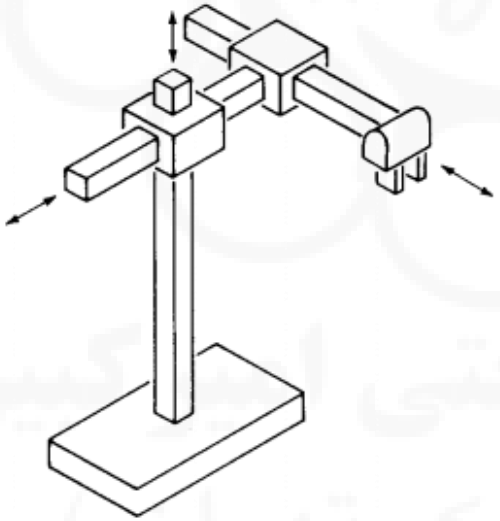
- It is usually done base on the configuration, number of DoF's & joint types.



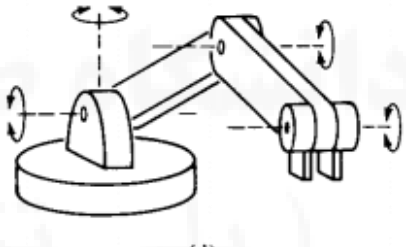
Spherical **RRP** Manipulator



Cylindrical **RPP** Manipulator



Cartesian **PPP** Manipulator

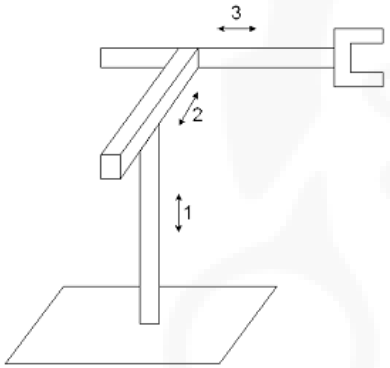


Anthropomorphic **RRR** Manipulator

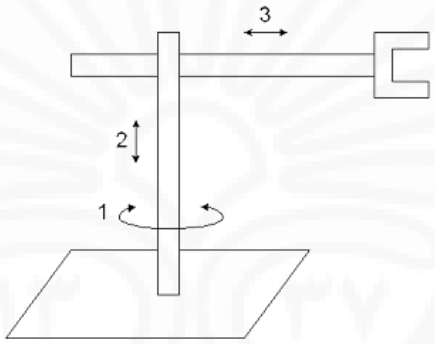
Mechanical System

6) Nomination

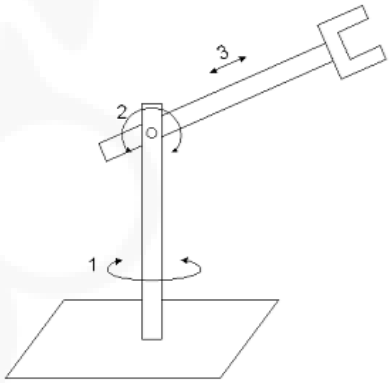
- It is usually done base on the configuration, number of DoF's & joint types.



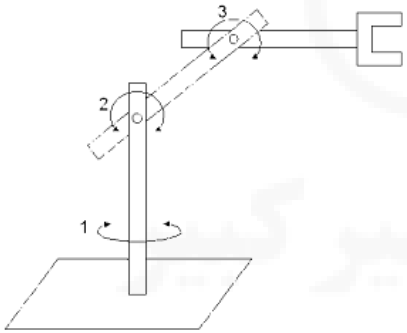
Cartesian: PPP



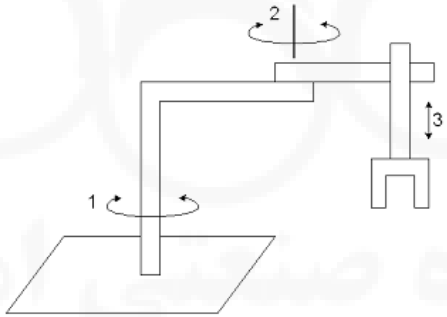
Cylindrical: RPP



Spherical: RRP



Articulated: RRR



SCARA: RRP

(Selective Compliance Assembly Robot Arm)

The END

- **References:**

1) .