Principle and Automated Application of Industrial Robot

Course number: ME4202
Class schedule: Thursday, 9am-12pm
Venue: E2-414

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Content

History of robots

Chapter 1: History of robots

- **Etymology of “robot”**

Slavic countries languages : “worker, slave”

Russian: “работа” (work), “раб” (slave)

Polish: “robotnik” (worker)

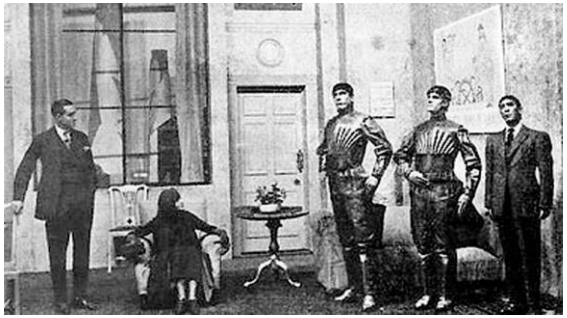
Byelorussian: “работнік” (worker)

Czech: “pracovník” (worker)

Chapter 1: History of robots

- **First instances of "mechatronic" humanoid**

1809: "The Pin Man", Hermann Mac Coolish Rotenberg Caistria
1818: "The Sandman", Ernst Theodor Amadeus Hoffmann
1885: "The electric man", Luis Senarens



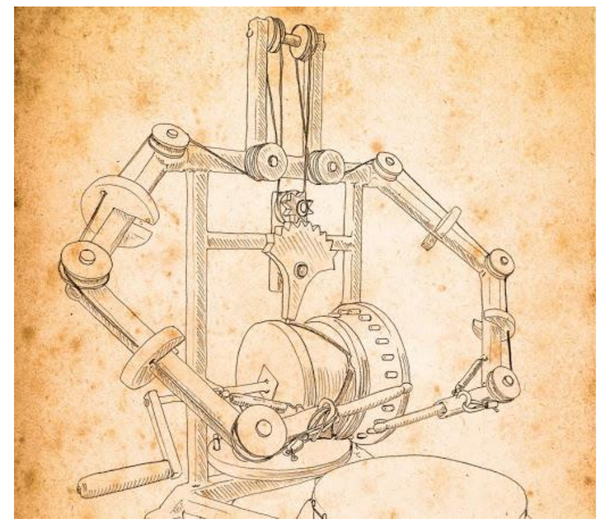
- **First mention of "robots"**

1921: Karel Čapek, Rossum's Universal Robots
1927: "Metropolis" movie, Thea von Harbou, Fritz Lang's novel
1942: Isaac Asimov

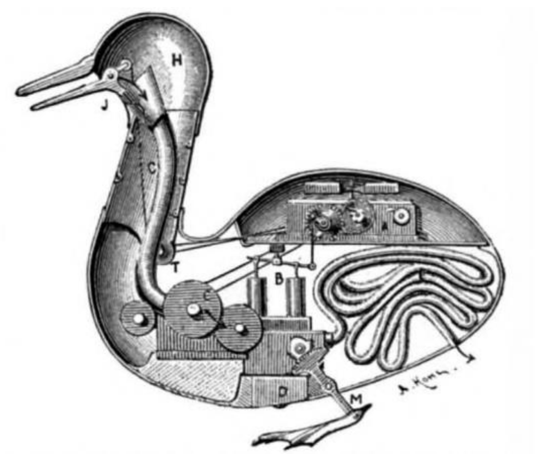
I, Robot (1950) and later collections: The Complete Robot (1982), Robot Dreams (1986), and Robot Visions (1990)
"The Bicentennial Man" (1976) or The Positronic Man (1992) - short story later developed into a complete novel
"Mother Earth" (1948) - short story, in which no individual robots appear, but positronic robots are part of the background
The Caves of Steel (1954) - first Robot series/R. Daneel Olivaw novel
The Naked Sun (1957) - second Robot series/R. Daneel Olivaw novel
"Mirror Image" (1972) - short story about R. Daneel Olivaw and detective Elijah Baley
The Robots of Dawn (1983) - third Robot series/R. Daneel Olivaw novel
Robots and Empire (1985) - fourth Robot series/R. Daneel Olivaw novel

- **First instances of automaton**

1495: Leonard Da Vinci
Technical sketch of a horseman, able to move on its own



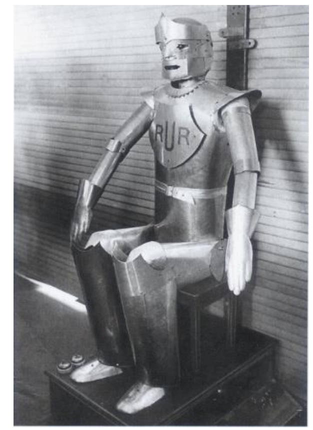
1738: Jacques de Vaucanson
Human doll playing music instrument
Duck doll eating food

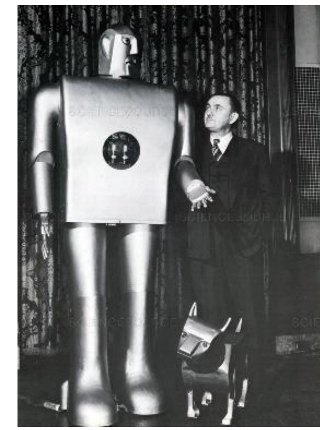


INTERIOR OF VAUCANSON'S AUTOMATIC DUCK.
A, clockwork; *B*, pump; *C*, mill for grinding grain; *F*, intestinal tube; *J*, bill; *H*, head; *M*, feet.

- **First humanoid robots**

1928: Eric humanoid robot, annual exhibition of the Model Engineers Society, London
1937: Elektro humanoid robot, Westinghouse Electric Corporation





- **First robotic manipulators**

1948: first electronic autonomous robots
1954: first digital and programmable robot, Unimate
1961: first use of a robot by General Motors (Unimate)

Nature of robots

- **Robotics manipulators**

Manipulation of object in space
End effector for grasping and/or interaction

- **Mobile robots**

Free navigation in an environment
Locomotion method: legs or wheel

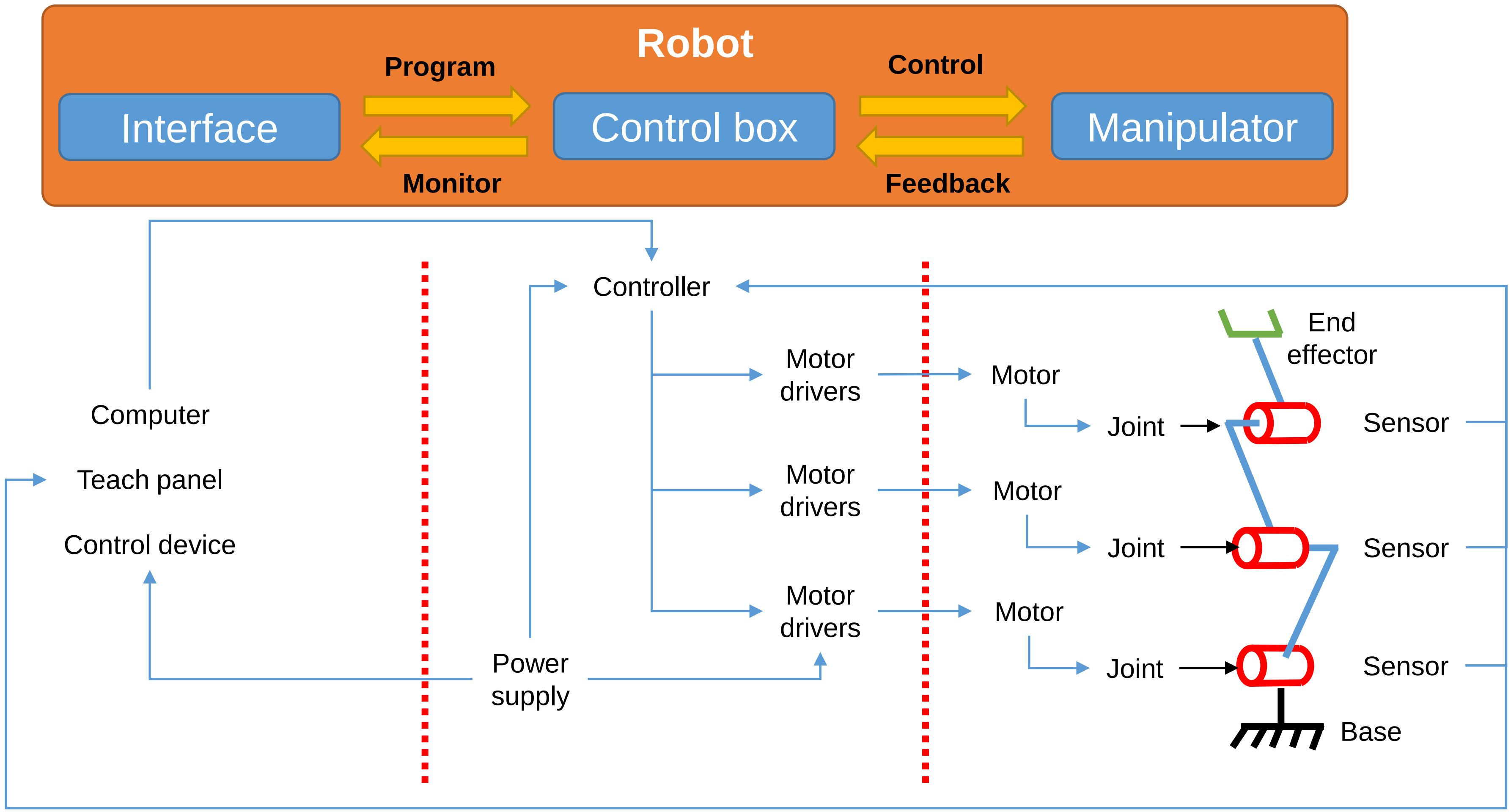
Chapter 2: Nature of robots

- **Humanoid robots**

Human-like robots (not cyborg!)
Often with locomotion system

Robotic manipulators

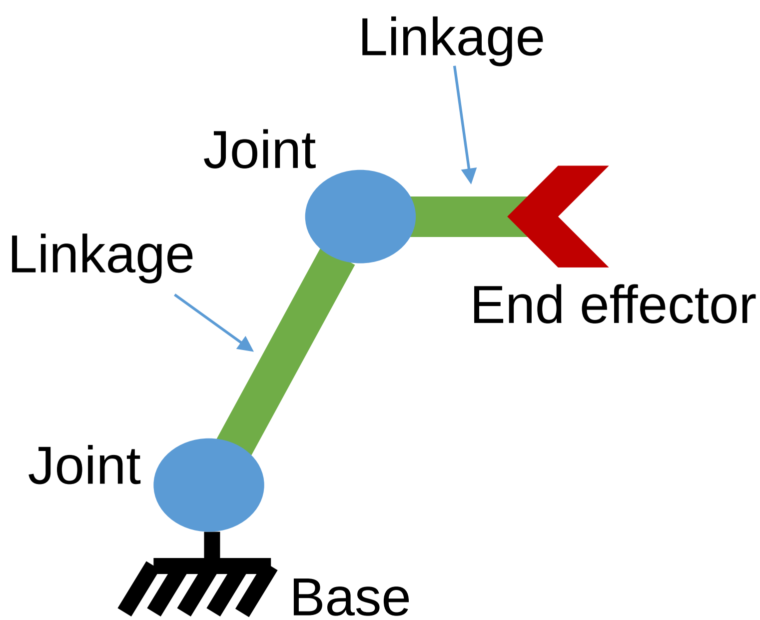
- Composition of a robotic system

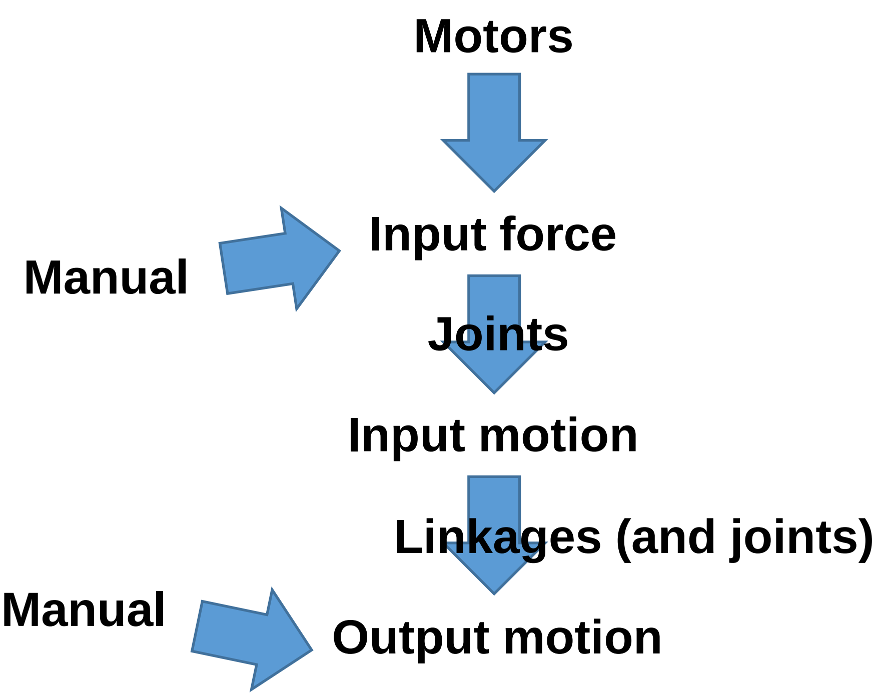


Chapter 3: Robotic manipulators

- **Mechanical part of robots**

Mechanism: device transmitting or transforming motion/force

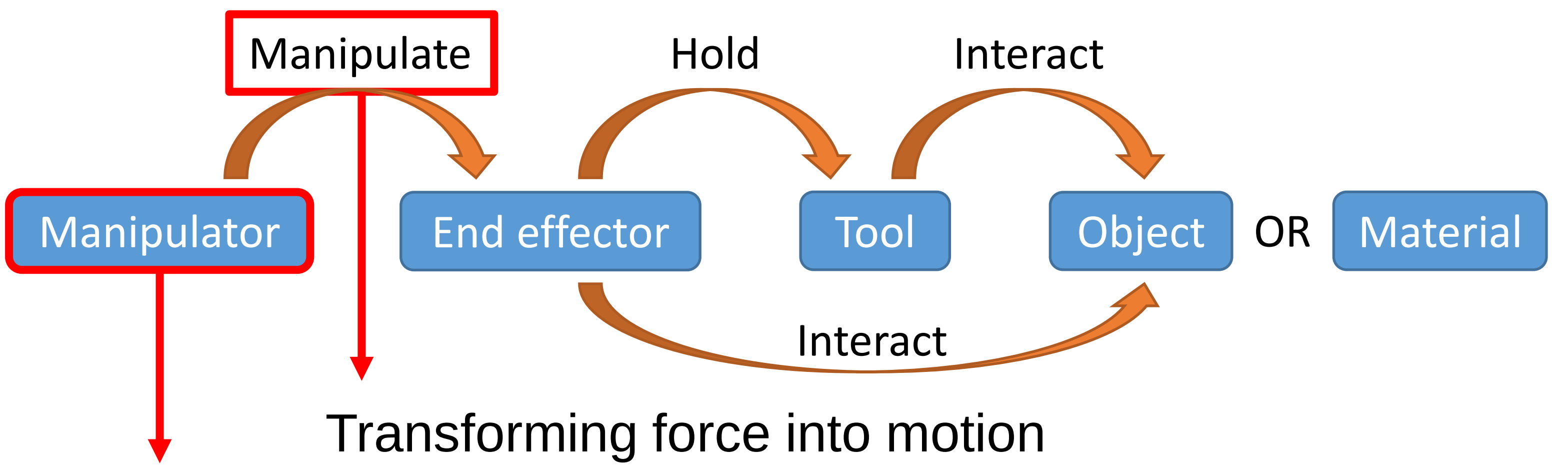




Chapter 3: Robotic manipulators

- **Mechanical part of robots**

Manipulator: manipulate objects in space
End effector: hold object or interact with object/environment



Transforming force into motion

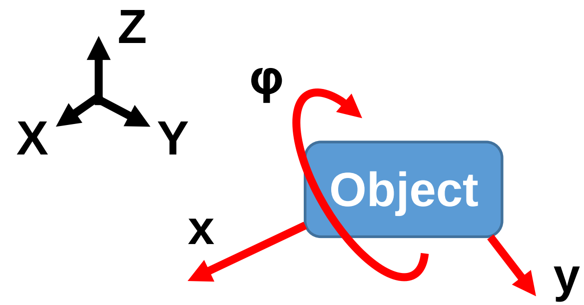
Instrumented mechanism

Architecture of robots

Chapter 4: Architecture of robots

- **Degrees of freedom (DoF)**

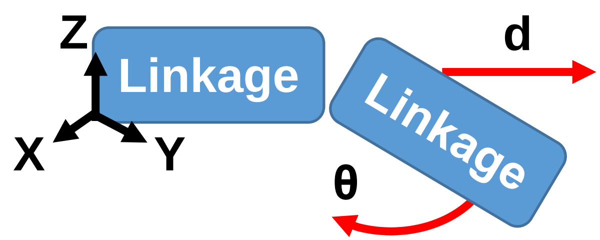
Independent position variables
required to locate an object

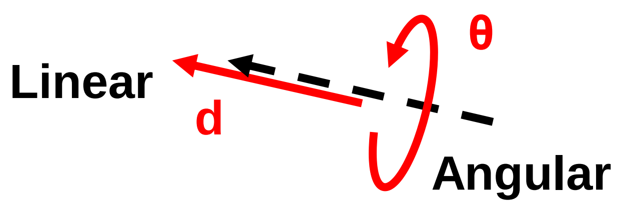


Independent motion ability between two successive solids

Linear or angular DoF

- One axis (direction) of motion
- One position variable





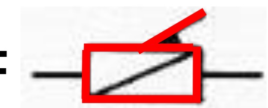
Chapter 4: Architecture of robots

- Kinematic pairs (joints)

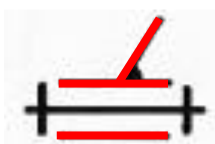
Allow motion(s) between two successive solids

Non-exclusive list of joints:

Rigid: no DoF 

Helical: 1 combined DoF 

Revolute: 1 angular DoF



Cylindrical: 1 angular and 1 linear DoF

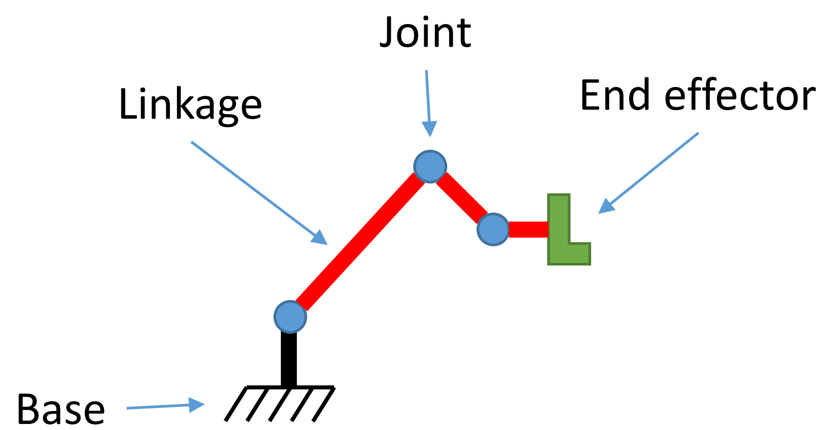
Prismatic: 1 linear DoF

Spherical: 3 angular DoF

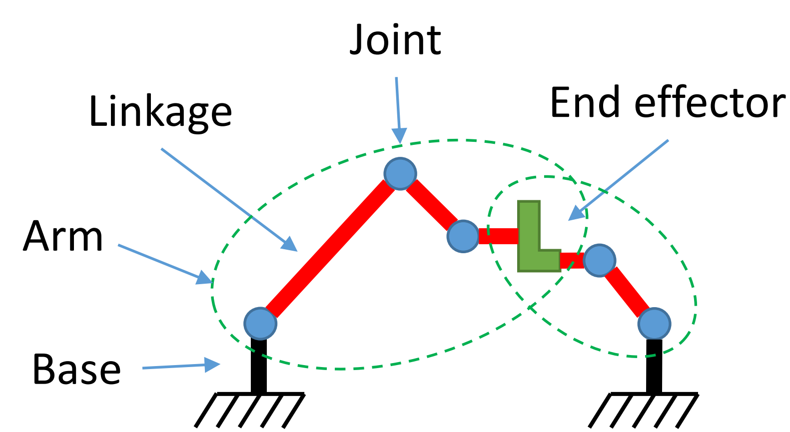
- **Serial vs. parallel**

- Serial mechanism
One series of linkage

- Parallel mechanism
Close kinematic loop



Manipulators	Serial	Parallel
Workspace	Larger	Smaller
Rigidity	Lower	Higher
Accuracy	Lower	Higher
Active joints	All	Some
Fwd kinematic	Simple	Very complex
Inv kinematic	Complex	Accessible



- **Architecture of robots**

Common industrial architecture

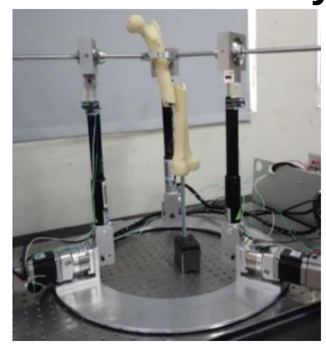
Cartesian

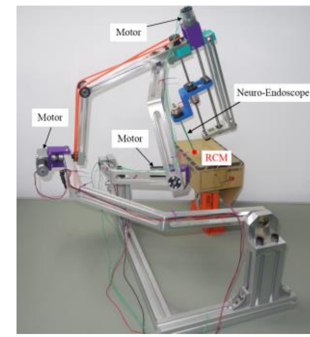
Anthropomorphic

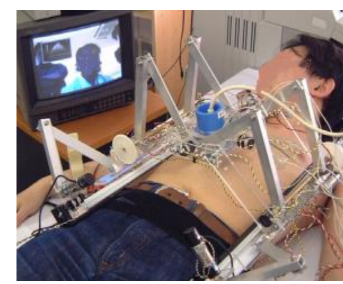
Delta

SCARA

And many other types







Operation of robots

Chapter 5: Operation of robots

- Degree of autonomy

Automatic: the task is (planed and) automatically provided by the system
Controlled: the system is controlled by a direct or remote control
Semi-automatic: both characteristics combined

- Positioning method

Passive: No actuator, require manual intervention → just a mechanism
Semi-active: Motion by both actuators and manual intervention (power is cut in passive mode) or motion partly active (passive and active parts)
Fully active: motion using actuator exclusively

- Programming method

Offline: use of computer software with realistic graphics to plan and program tasks without use of robot hardware.
Lead-Through: end-effector physically guided by human operator through desired position for memorization.
Teach: use of integrated interface for motion control and task programming.

Kinematic model

- **Definitions**

Relationship between joint coordinates and end effector coordinates

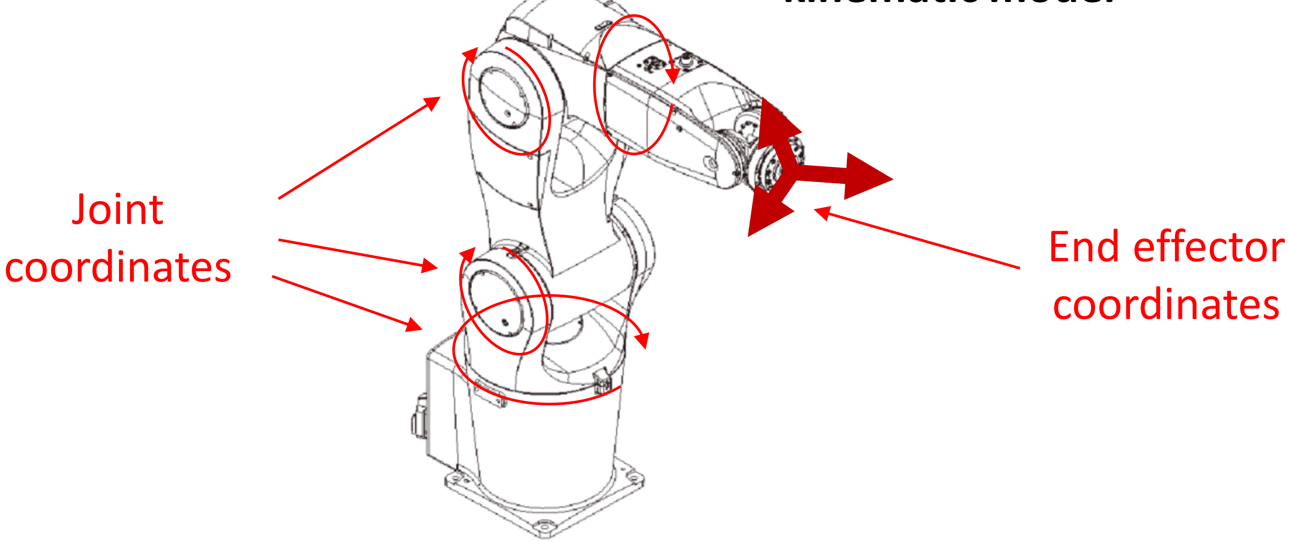
Inverse kinematic model

Mechanism

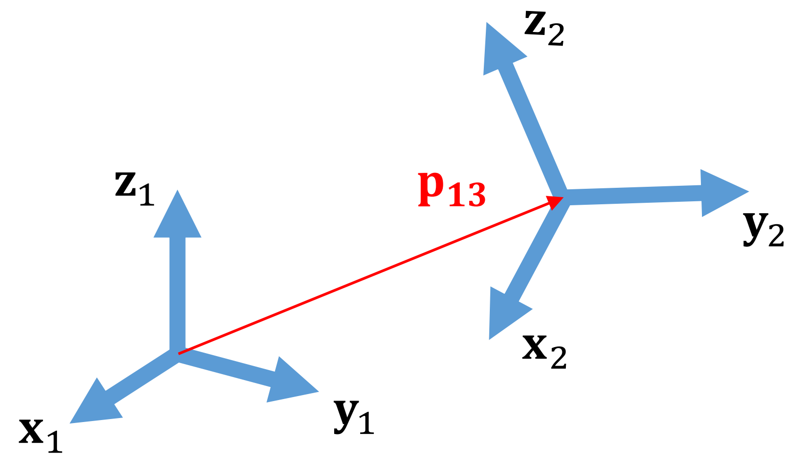
Design variables | Joint coordinates

End effector coordinates

Forward kinematic model



- **Transformation matrix**



Coordinates of reference frame
Rotation matrix and position vector

$$\mathbf{T}_{12} = \begin{bmatrix} \mathbf{R}_{12} & \mathbf{p}_{12} \\ \mathbf{0}_{3\times1} & 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Classical rotation matrices

x axis

$$\mathbf{R}_{12} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & C\alpha & -S\alpha \\ 0 & S\alpha & C\alpha \end{bmatrix}$$

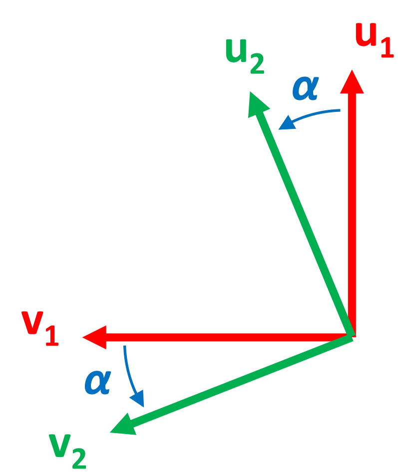
y axis

$$\mathbf{R}_{12} = \begin{bmatrix} C\alpha & 0 & S\alpha \\ 0 & 1 & 0 \\ -S\alpha & 0 & C\alpha \end{bmatrix}$$

z axis

$$\mathbf{R}_{12} = \begin{bmatrix} C\alpha & -S\alpha & 0 \\ S\alpha & C\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

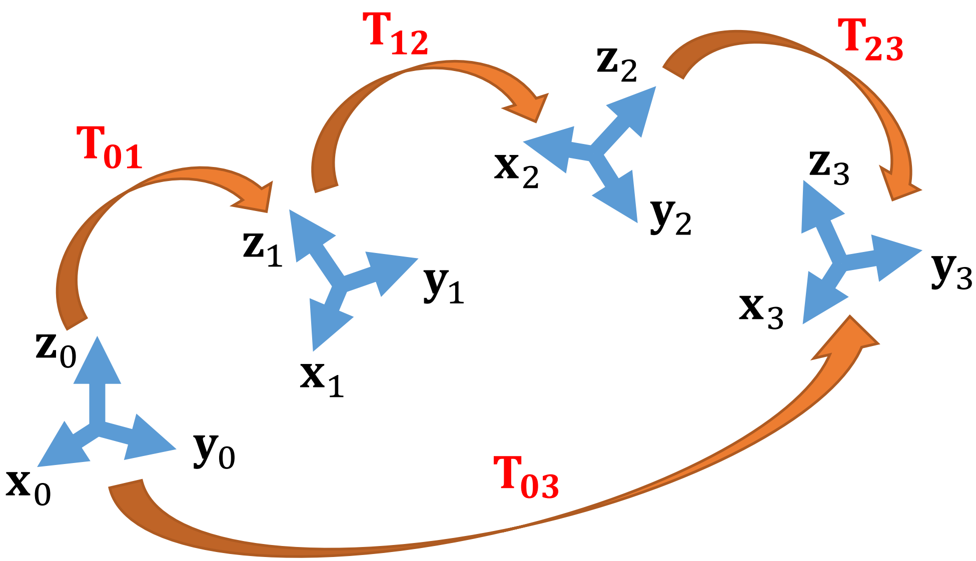
where $C\alpha = \cos\alpha\,, S\alpha = \sin\alpha$

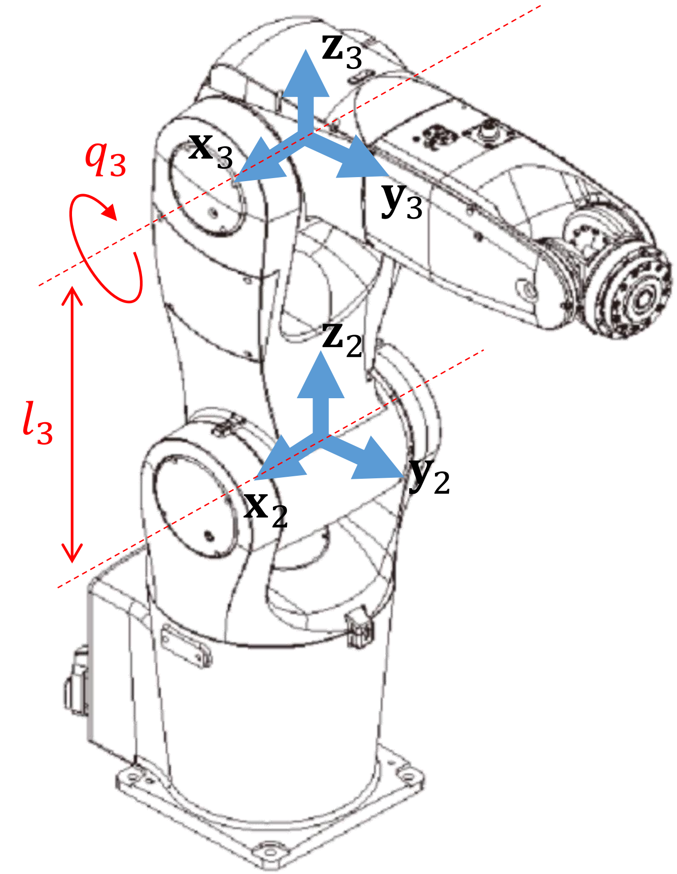


- **Product of transformation matrices**

General transformation matrix:

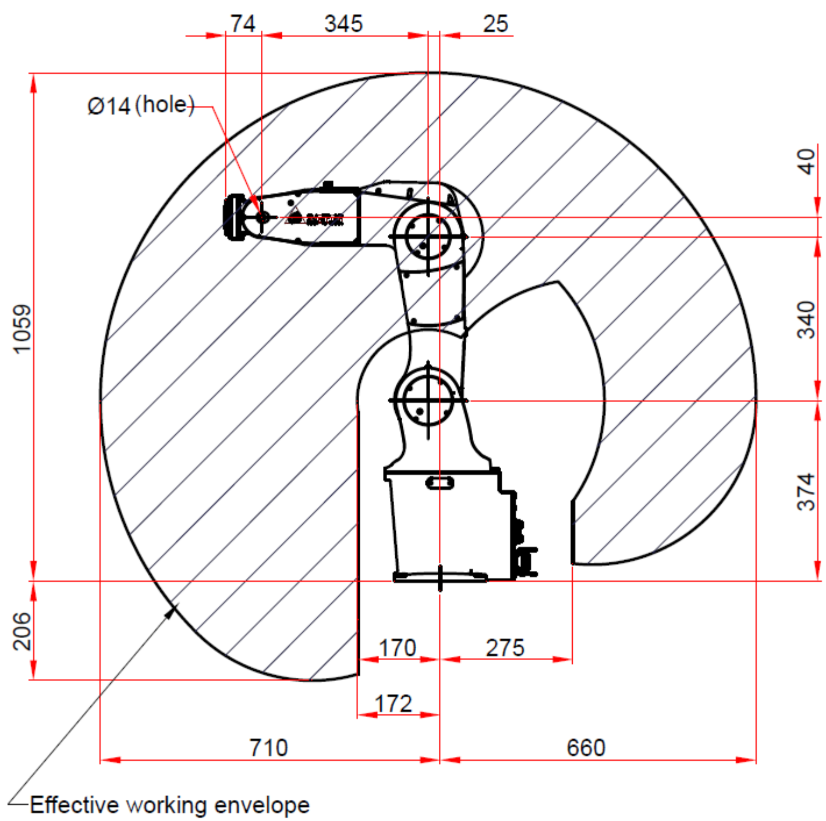
$$\mathbf{T}_{0n}(\mathbf{q}) = \prod_{i=1}^{n} \mathbf{T}_{i-1,i}(q_i) = \mathbf{T}_{01}\mathbf{T}_{12} \dots \mathbf{T}_{n-1,n}$$

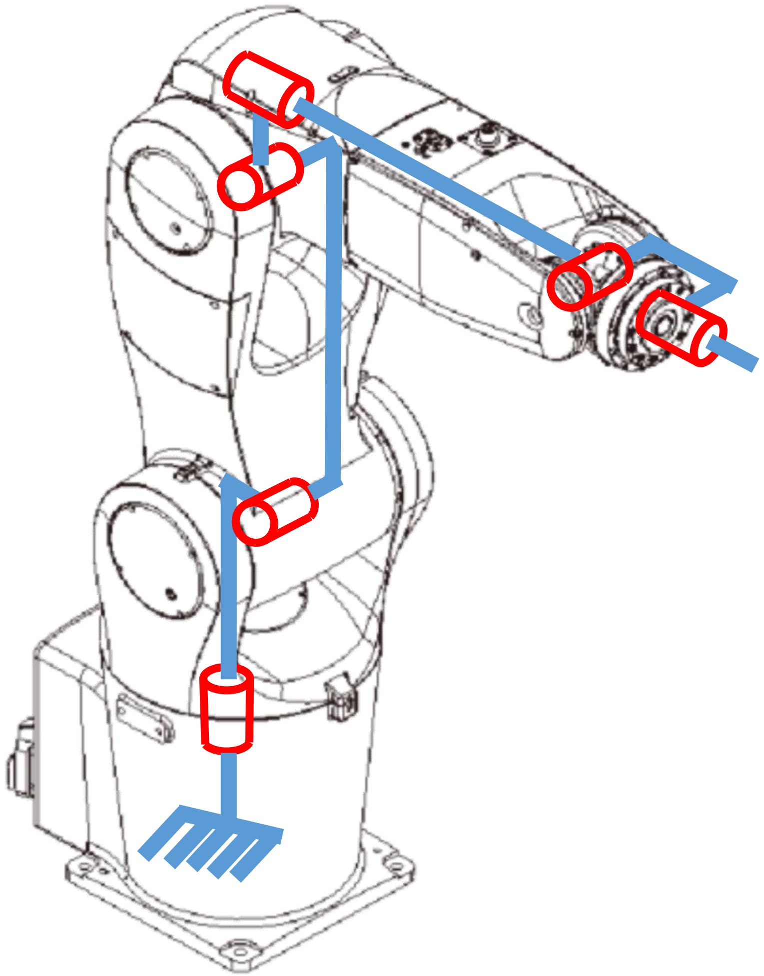




Application to DRV70L

- Kinematic drawing



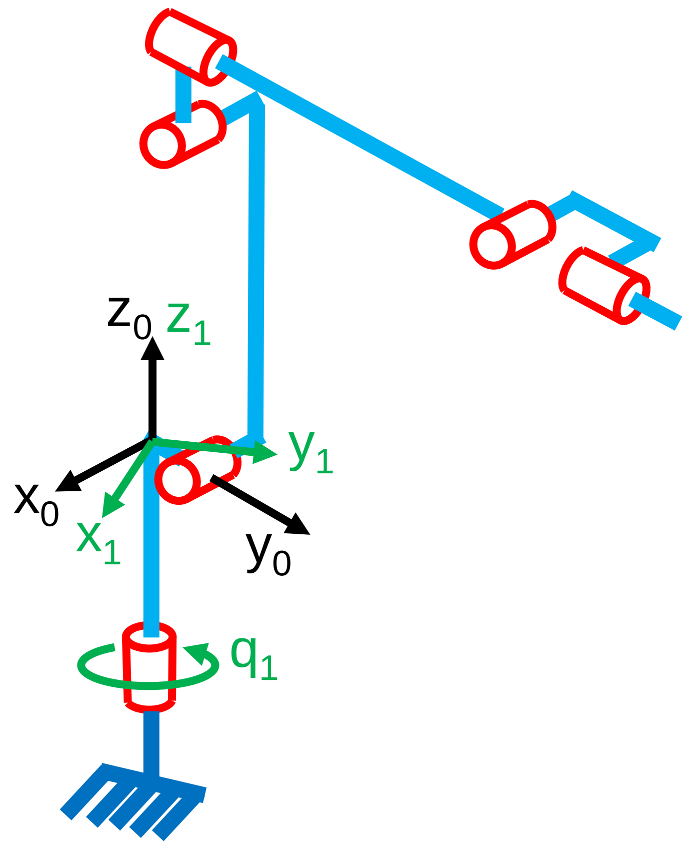


- **Transformation matrices:**

Revolute joint: axis $\mathbf{z_0}$
Linkage: ignored

Transformation matrix: $\mathbf{T_{01}}$

$$\mathbf{T_{01}} = \begin{bmatrix} \cos q_1 & -\sin q_1 & 0 & 0 \\ \sin q_1 & \cos q_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

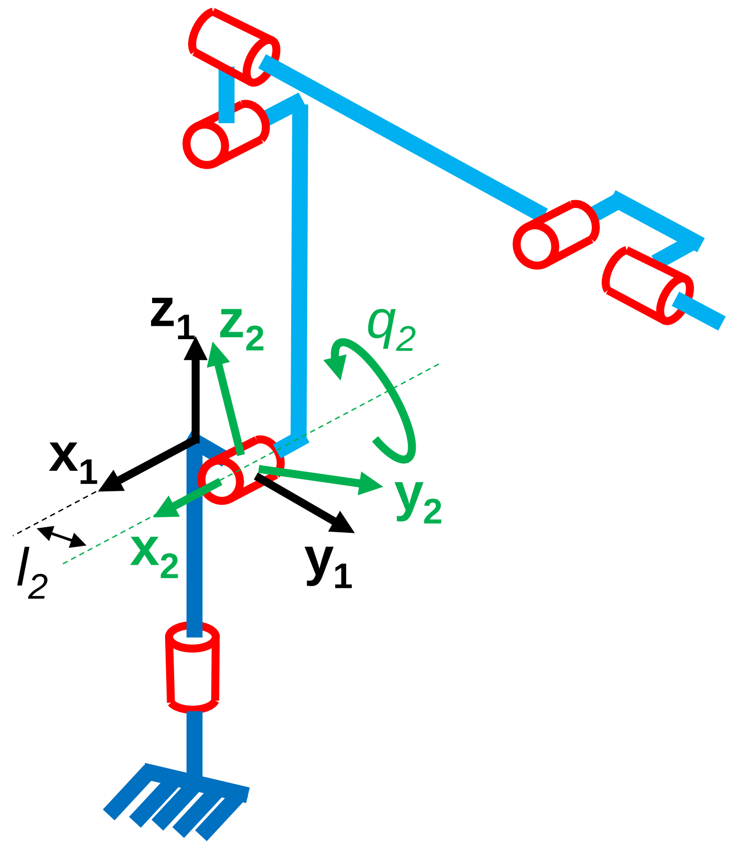


- **Transformation matrices:**

Revolute joint: axis $\mathbf{x}_2$
Linkage: $l_2\mathbf{y}_1$

Transformation matrix: $\mathbf{T}_{12}$

$$\mathbf{T}_{12} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos q_2 & -\sin q_2 & l_2 \\ 0 & \sin q_2 & \cos q_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



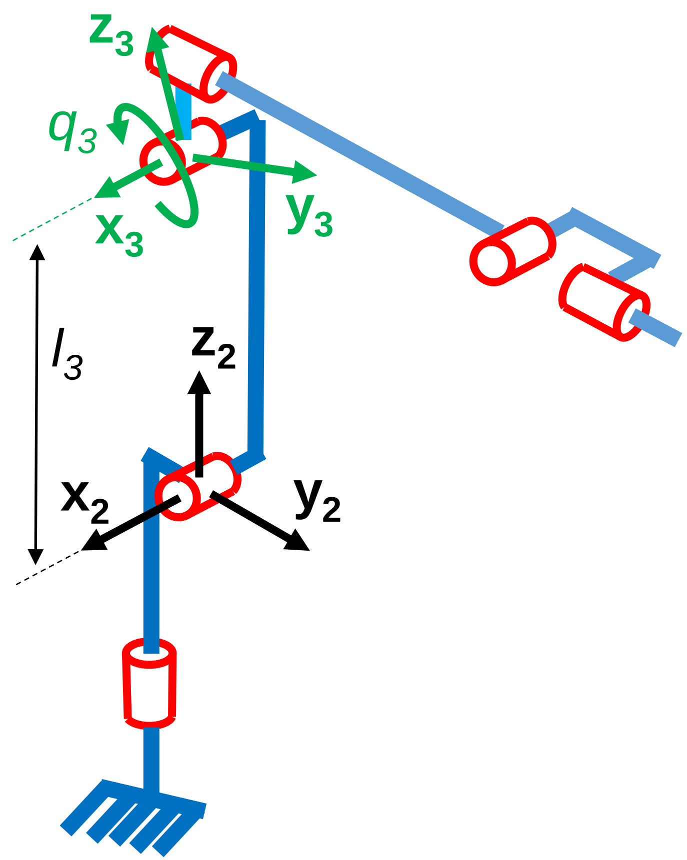
Chapter 7: Application to DRV70L

- **Transformation matrices:**

Revolute joint: axis $\mathbf{x_3}$
Linkage: $l_3\mathbf{z_2}$

Transformation matrix: $\mathbf{T_{23}}$

$$\mathbf{T_{23}} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos q_3 & -\sin q_3 & 0 \\ 0 & \sin q_3 & \cos q_3 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

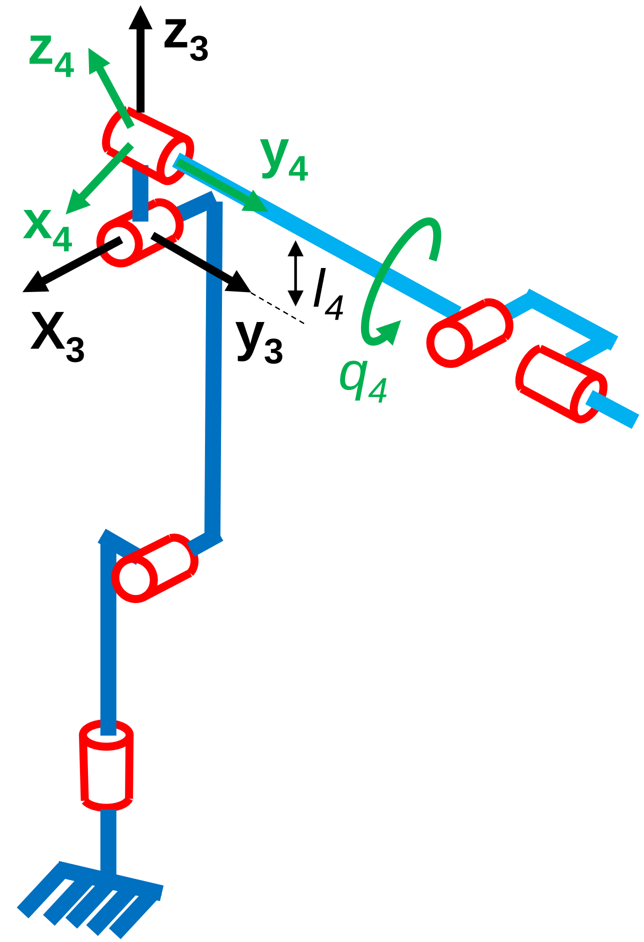


- **Transformation matrices:**

Revolute joint: axis $\mathbf{y_4}$
Linkage: $l_4\mathbf{z_3}$

Transformation matrix: $\mathbf{T_{34}}$

$$\mathbf{T_{34}} = \begin{bmatrix} \cos q_1 & 0 & \sin q_1 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin q_1 & 0 & \cos q_1 & l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

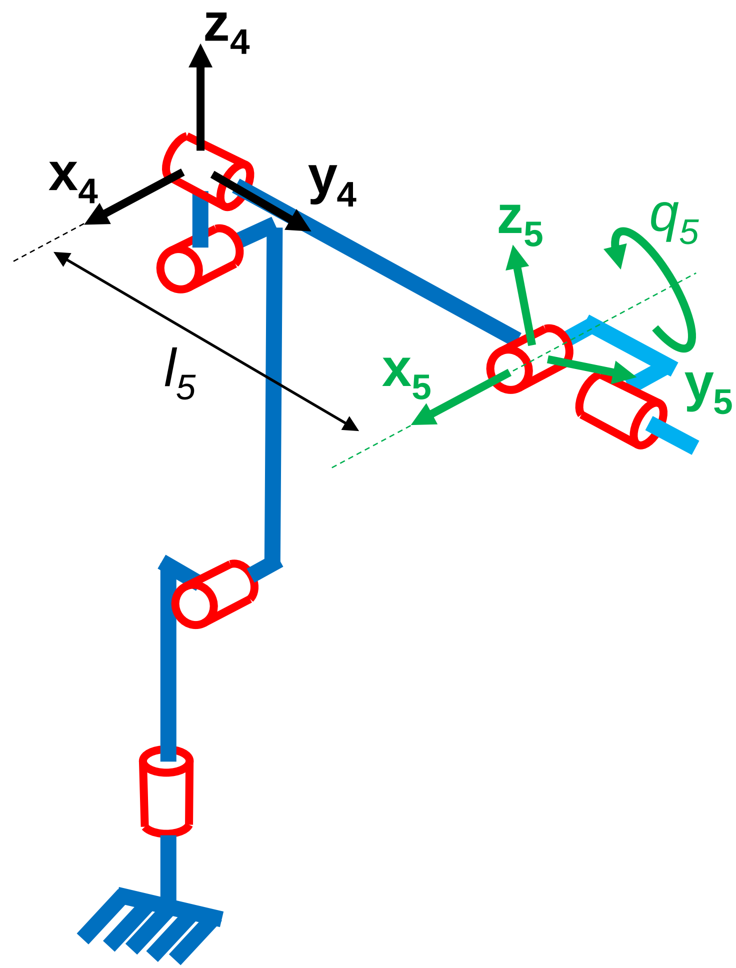


- **Transformation matrices:**

Revolute joint: axis $\mathbf{x}_5$
Linkage: $l_5\mathbf{y}_4$

Transformation matrix: $\mathbf{T}_{45}$

$$\mathbf{T}_{45} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos q_5 & -\sin q_5 & l_5 \\ 0 & \sin q_5 & \cos q_5 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

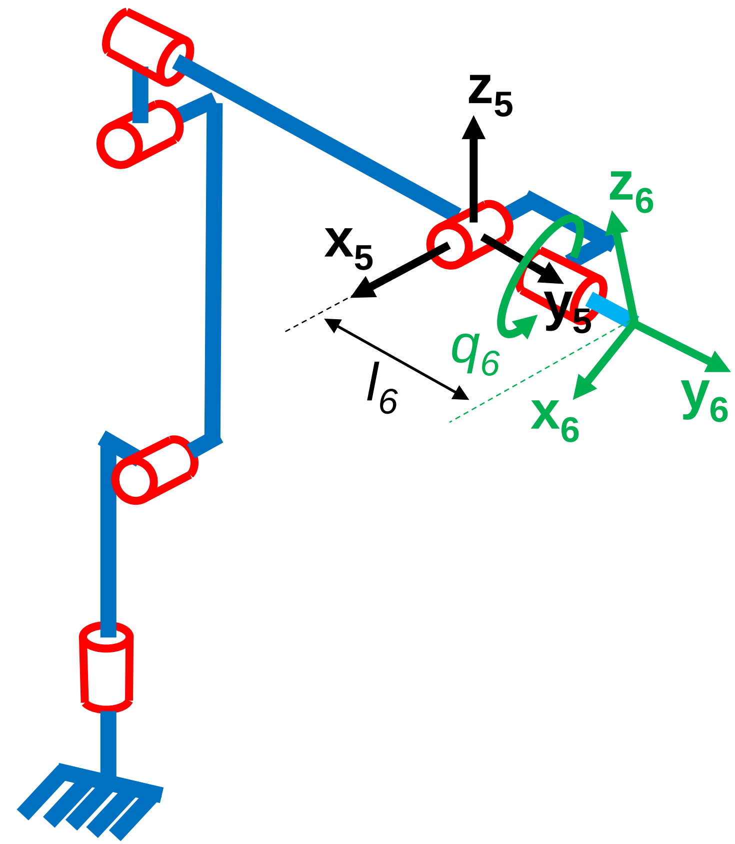


- **Transformation matrices:**

Revolute joint: axis $\mathbf{y_6}$
Linkage: $l_6\mathbf{y_5}$

Transformation matrix: $\mathbf{T_{56}}$

$$\mathbf{T_{56}} = \begin{bmatrix} \cos q_1 & 0 & \sin q_1 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin q_1 & 0 & \cos q_1 & l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



- **Result:**

Product of transformation matrices

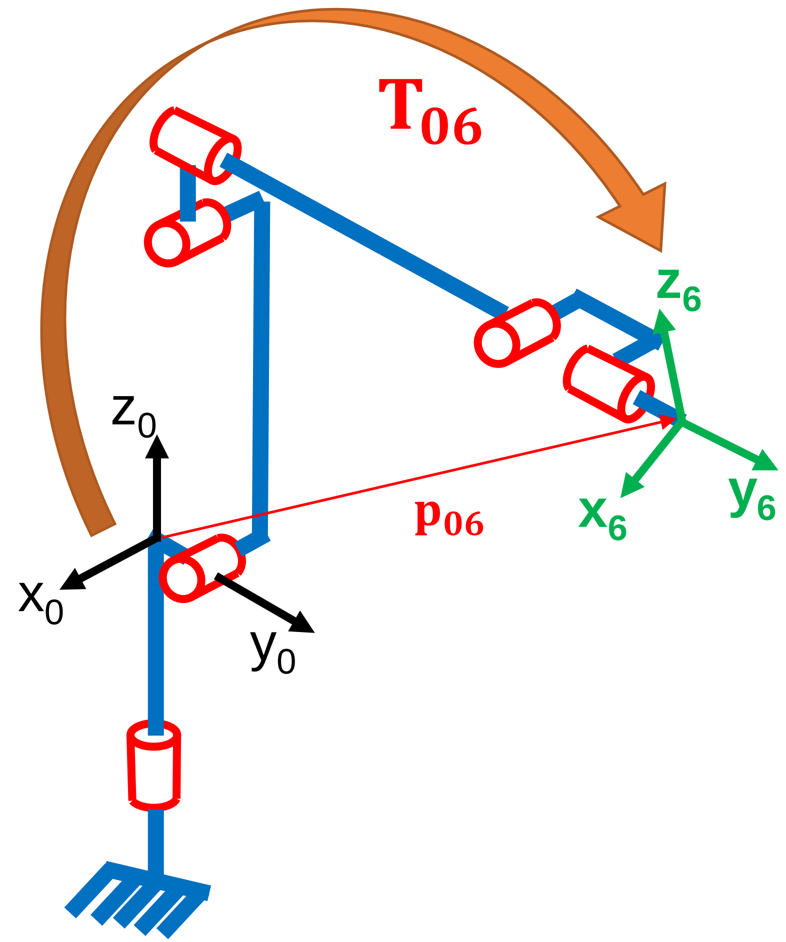
$$\mathbf{T_{06}}(\mathbf{q}) = \prod_{i=1}^{6} \mathbf{T}_{i-1,i}(q_i) = \mathbf{T_{01}}\mathbf{T_{12}}\mathbf{T_{23}}\mathbf{T_{34}}\mathbf{T_{45}}\mathbf{T_{56}}$$

Final transformation matrix: $\mathbf{T_{06}}$

$$\mathbf{T_{06}} = \begin{bmatrix} & \mathbf{R_{06}} & & \boxed{\begin{matrix} p_x \\ p_y \\ p_z \end{matrix}} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Linear coordinates:

$$\mathbf{p_{06}} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} p_x = f_x(q_1 \cdots q_n) \\ p_y = f_y(q_1 \cdots q_n) \\ p_z = f_z(q_1 \cdots q_n) \end{bmatrix}$$



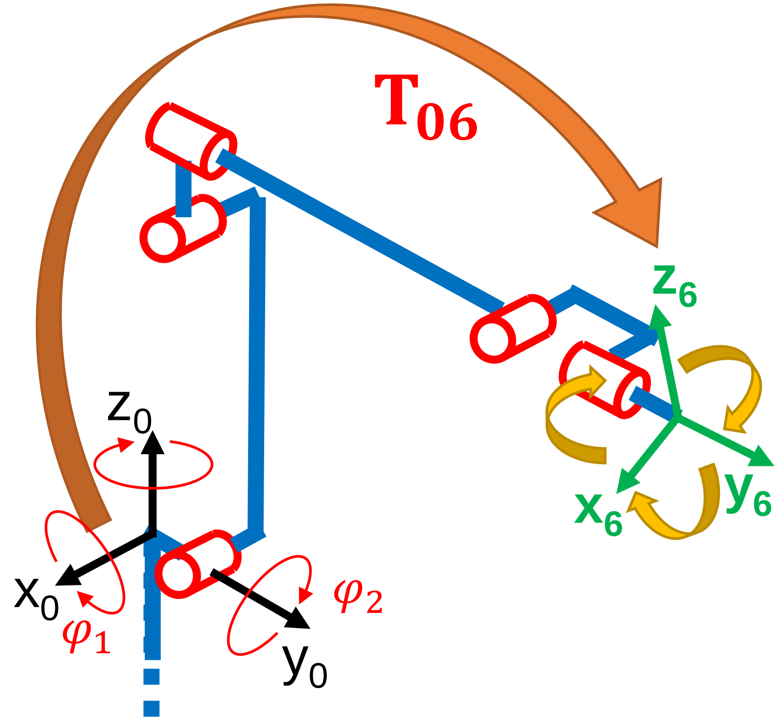
- **Result:**

Product of transformation matrices

$$\mathbf{T_{06}}(\mathbf{q}) = \prod_{i=1}^{6} \mathbf{T}_{\boldsymbol{i-1,i}}(q_i) = \mathbf{T_{01}T_{12}T_{23}T_{34}T_{45}T_{56}}$$

Final transformation matrix: $\mathbf{T_{06}}$

$$\mathbf{T_{06}} = \begin{bmatrix} & \boxed{\mathbf{R_{06}}} & & p_x \\ & & & p_y \\ & & & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Angular coordinates:

$$\mathbf{R_{06}} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} = \begin{bmatrix} C2C3 & -C2S3 & S2 \\ C1S3 + S1S2C3 & C1C3 - S1S2S3 & -S1C2 \\ S1S3 - C1S2C3 & S1C3 + C1S2S3 & C1C2 \end{bmatrix}$$

$$\varphi_2 = \sin^{-1} r_{13} \quad \varphi_1 = ATAN2\left(-\frac{r_{23}}{C2}, \frac{r_{33}}{C2}\right) \quad \varphi_3 = ATAN2\left(-\frac{r_{13}}{C2}, \frac{r_{11}}{C2}\right)$$