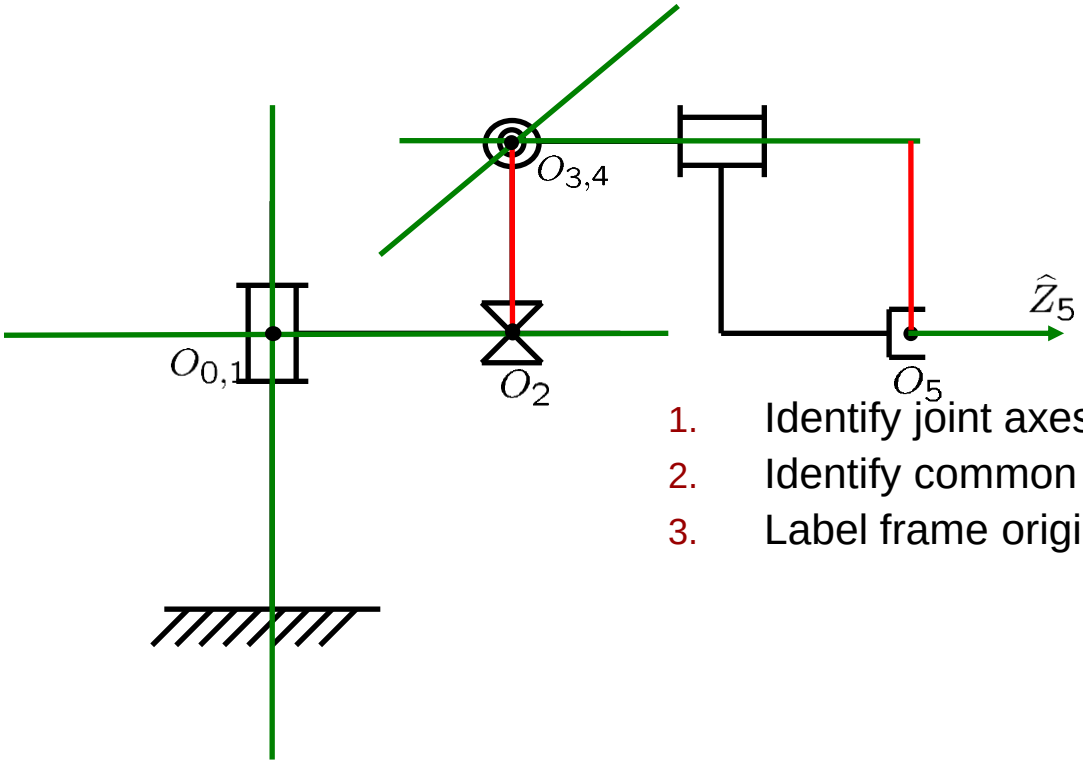
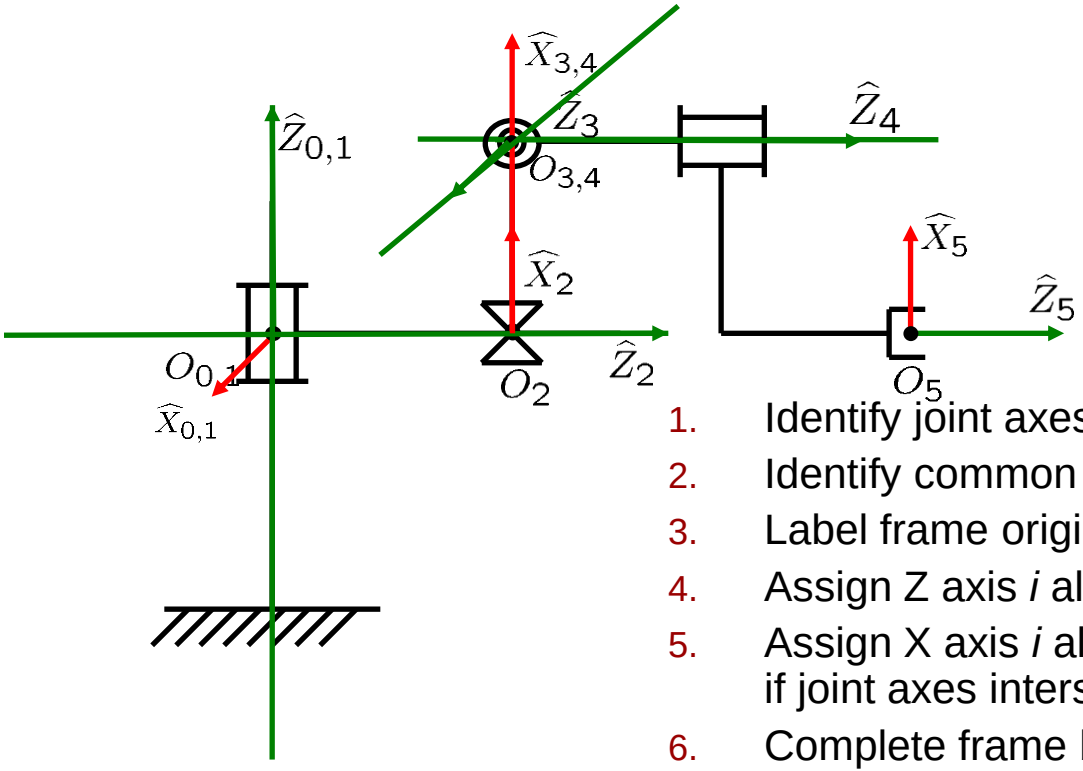
Example with n=5



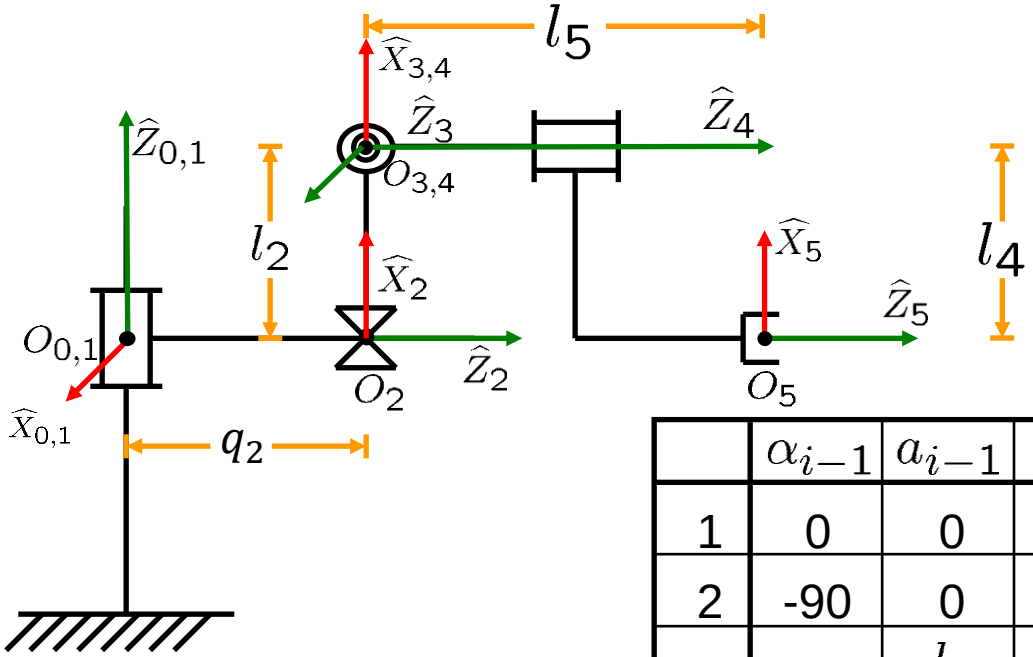
1. Identify joint axes; consider *i-1* and *i*
2. Identify common perpendicular
3. Label frame origin at perpendicular (or intersection)

Example with n=5



1. Identify joint axes; consider *i-1* and *i*
2. Identify common perpendicular
3. Label frame origin at perpendicular (or intersection)
4. Assign Z axis *i* along joint axis
5. Assign X axis *i* along perpendicular;
   if joint axes intersect, orthogonal to the axes plane
6. Complete frame by adding Y axis (right-hand-rule)
7. Assign {0} to match {1}
8. Choose end-effector frame {*n*}

Example with n=5



α_i = the angle between $\hat{Z}_i$ and $\hat{Z}_{i+1}$ measured about $\hat{X}_i$

a_i = the distance from $\hat{Z}_i$ to $\hat{Z}_{i+1}$ measured along $\hat{X}_i$

d_i = the distance from $\hat{X}_{i-1}$ to $\hat{X}_i$ measured along $\hat{Z}_i$

θ_i = the angle between $\hat{X}_{i-1}$ and $\hat{X}_i$ measured about $\hat{Z}_i$

	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	q_1
2	-90	0	q_2	-90
3	-90	l_2	0	q_3
4	90	0	0	q_4
5	0	$-l_4$	l_5	0

	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	q_1
2	-90	0	q_2	-90
3	-90	l_2	0	q_3
4	90	0	0	q_4
5	0	$-l_4$	l_5	0

$$
{}^{i-1}_{i}T = R_X(\alpha_{i-1})\, D_X(a_{i-1})\, R_Z(\theta_i)\, D_Z(d_i)
$$

$$
= \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{0}_{1}T = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\quad
{}^{1}_{2}T = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & q_2 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\quad
{}^{2}_{3}T = \begin{bmatrix} c_3 & -s_1 & 0 & l_2 \\ 0 & 0 & 1 & 0 \\ -s_3 & -c_3 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{3}_{4}T = \begin{bmatrix} c_4 & -s_4 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\qquad
{}^{4}_{5}T = \begin{bmatrix} 1 & 0 & 0 & -l_4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & l_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

Summary

- Homogoneous transformation:
  - Describing positions and orientations in space and how to map between them
- Forward kinematics:
  - Where is the robot`s i^{th} link or end-effector given the robots configuration
- Denavit-Hartenberg parameters
  - Uniform procedure for defining the robot`s kinematics in order to derive forward kinematics

Quiz time – DH params