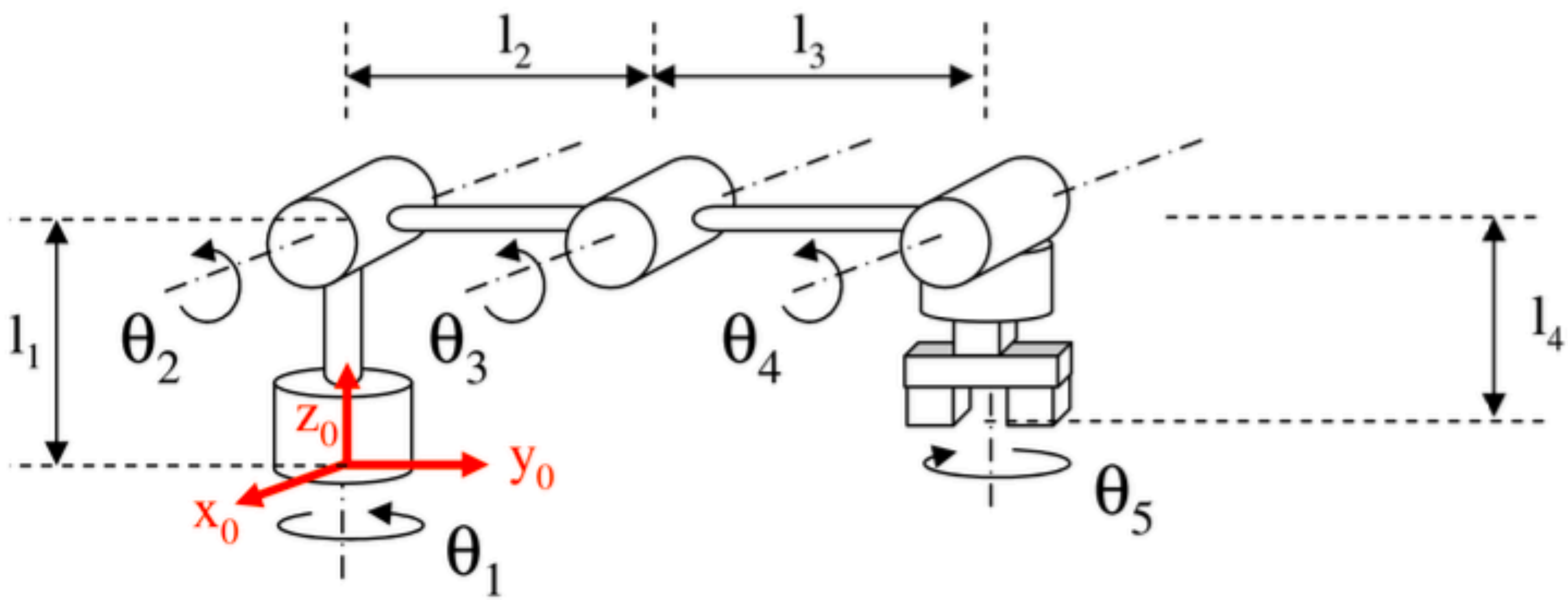
Midterm Material

- **Rotation Matrices and Orientation Kinematics**
- **Homogenous Transformation**
- **Devanit-Hartenberg Notation and Forward Kinematics**
- **Inverse Kinematics**
- **Jacobian Basic Concepts**

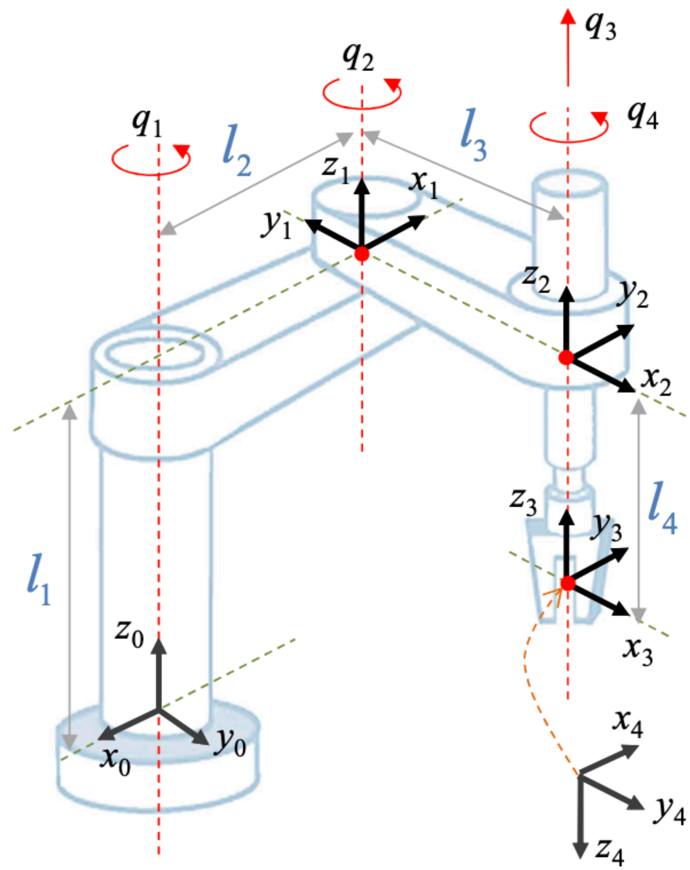
DH-Example



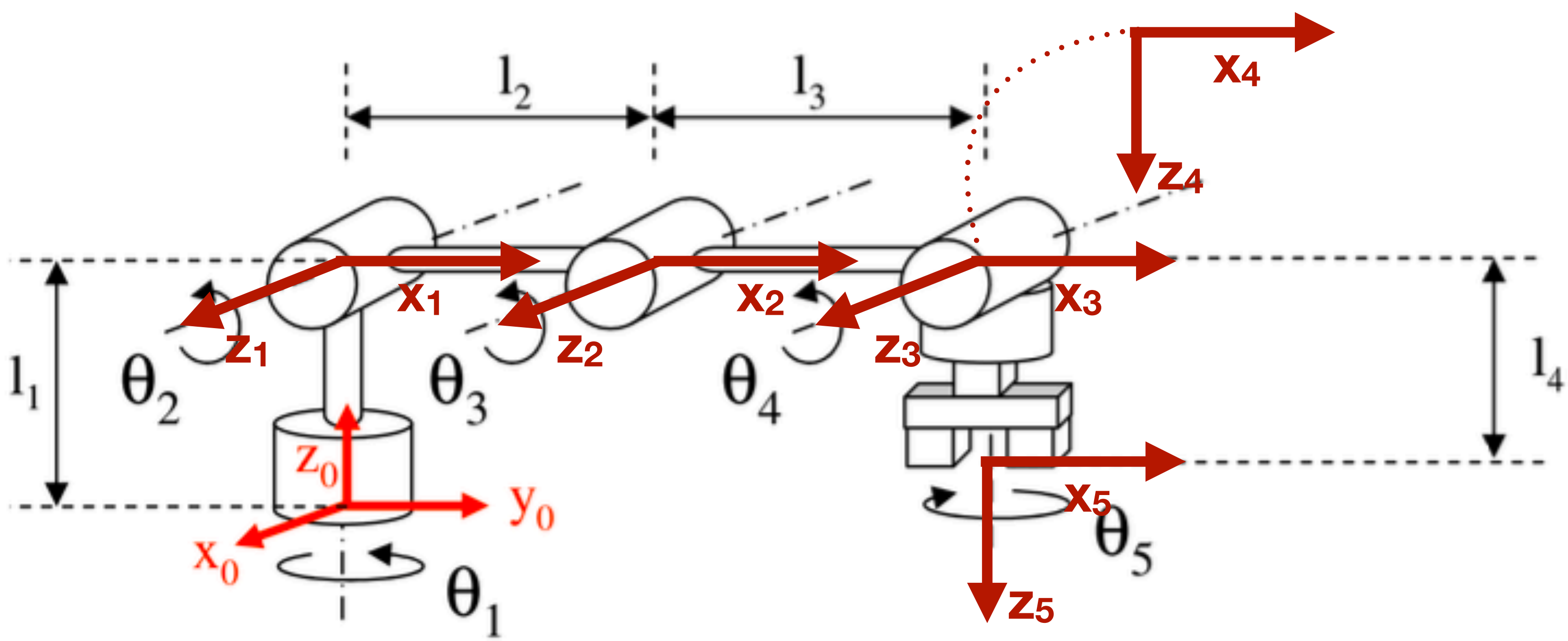
a. Assign reference frames according to DH-method
b. Find the DH-table

DH-Example - Frame assignment rules

- assign axis x_i in the direction of $z_{i-1} \times z_i$. If they are parallel assign along common normal between z_{i-1} & z_i
- assign axis y_i to complete the frame following right hand rule
- tool frame (end effector frame)
  - x_n orthogonal to z_{n-1}
  - z_n pointing outwards

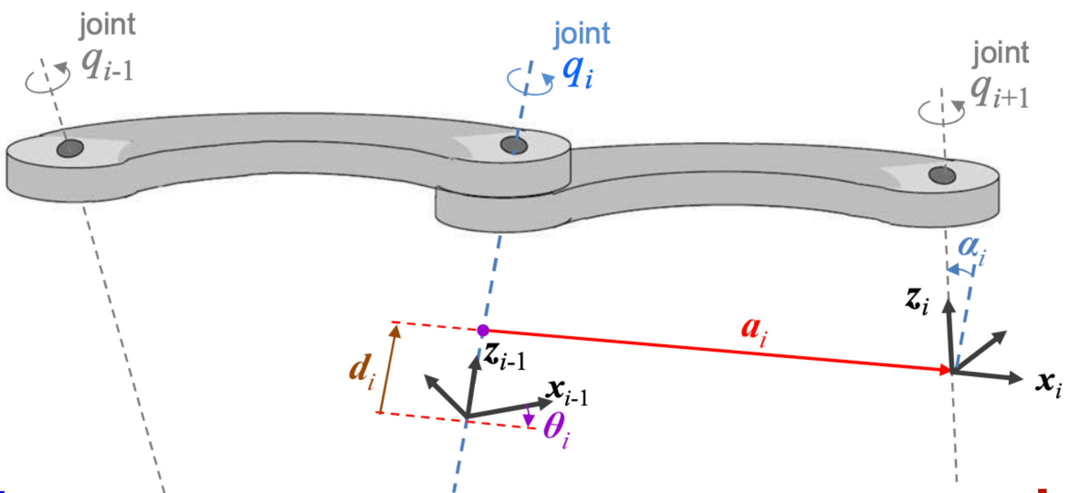


DH-Example



a. Assign reference frames according to DH-method (solution)

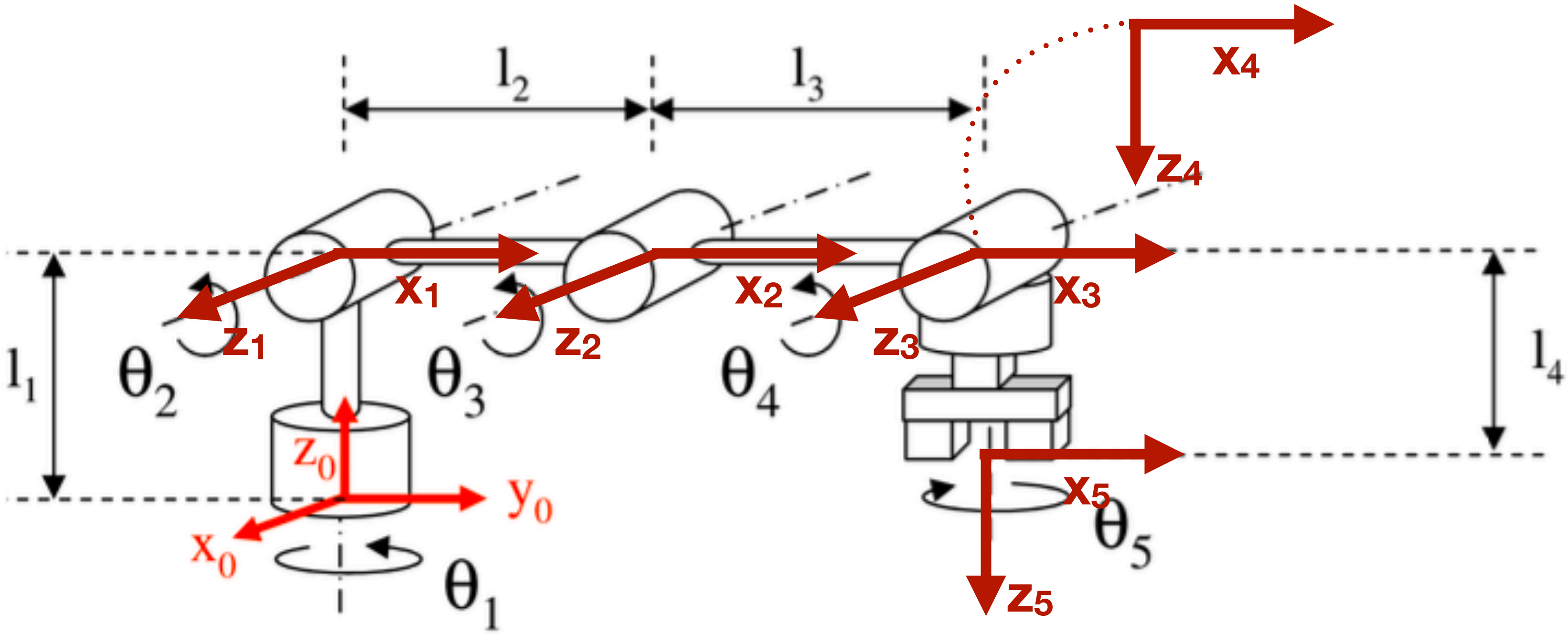
DH-Example - Parameter Rules



Joint Parameters

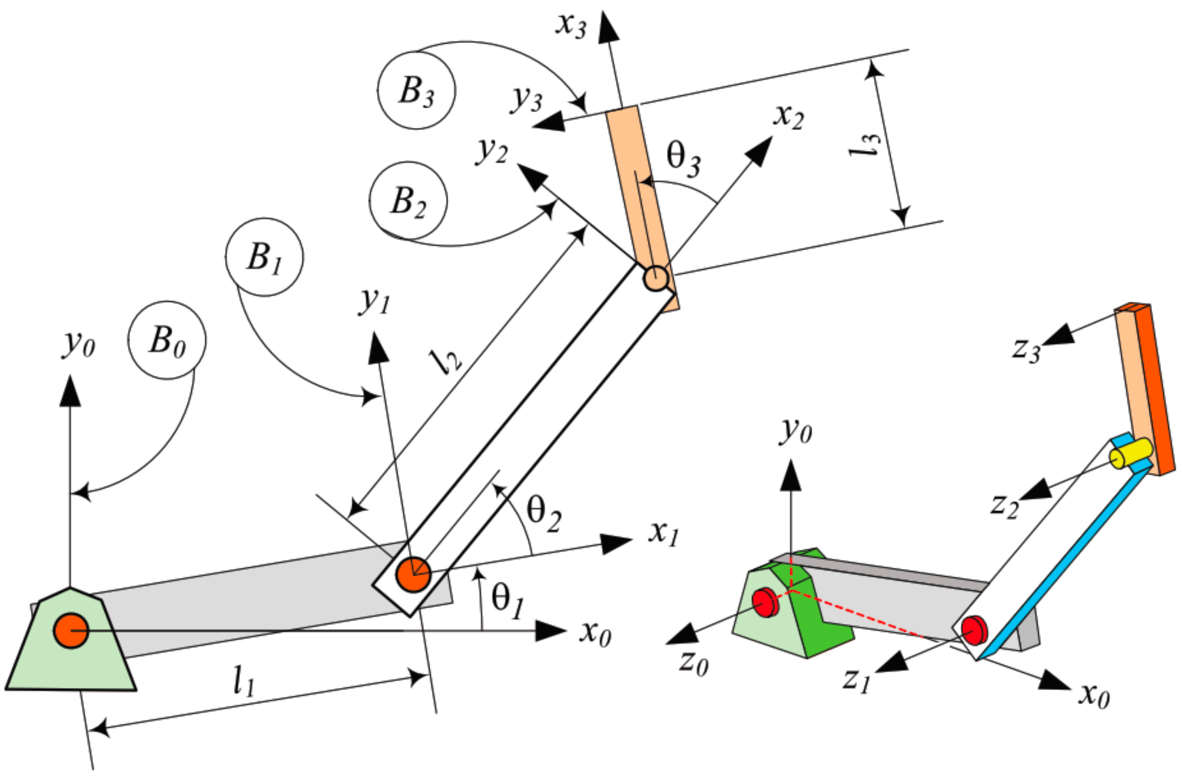
Link Parameters

- d_i: distance from the origin of {i-1} to the intersection of z_{i-1} with x_i along z_{i-1}
- θ_i: rotation angle from x_{i-1} with x_i about z_{i-1}
- a_i: distance from the intersection of z_{i-1} with x_i along x_i
- α_i: angle from z_{i-1} with z_i about x_i



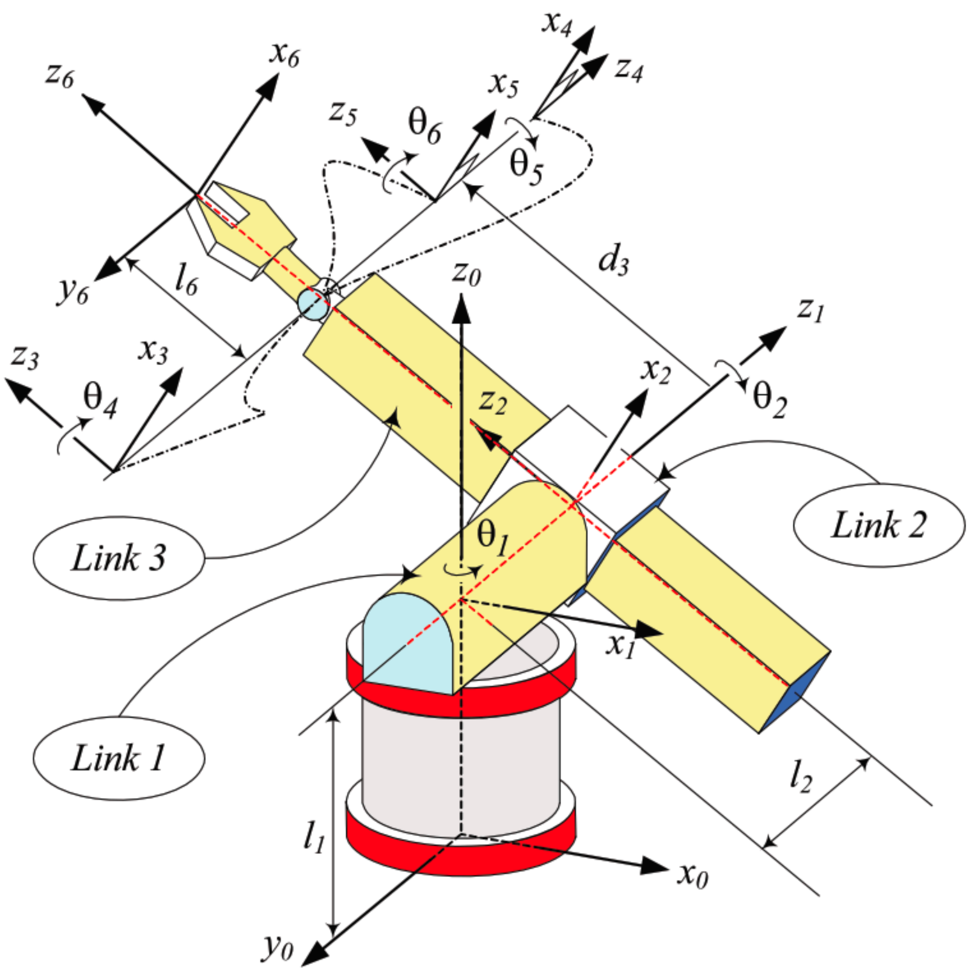
Joint i	d_i	theta_i	a_i	alpha_i
1				
2				
3				
4				
5				

Ex. 135 pg. 238



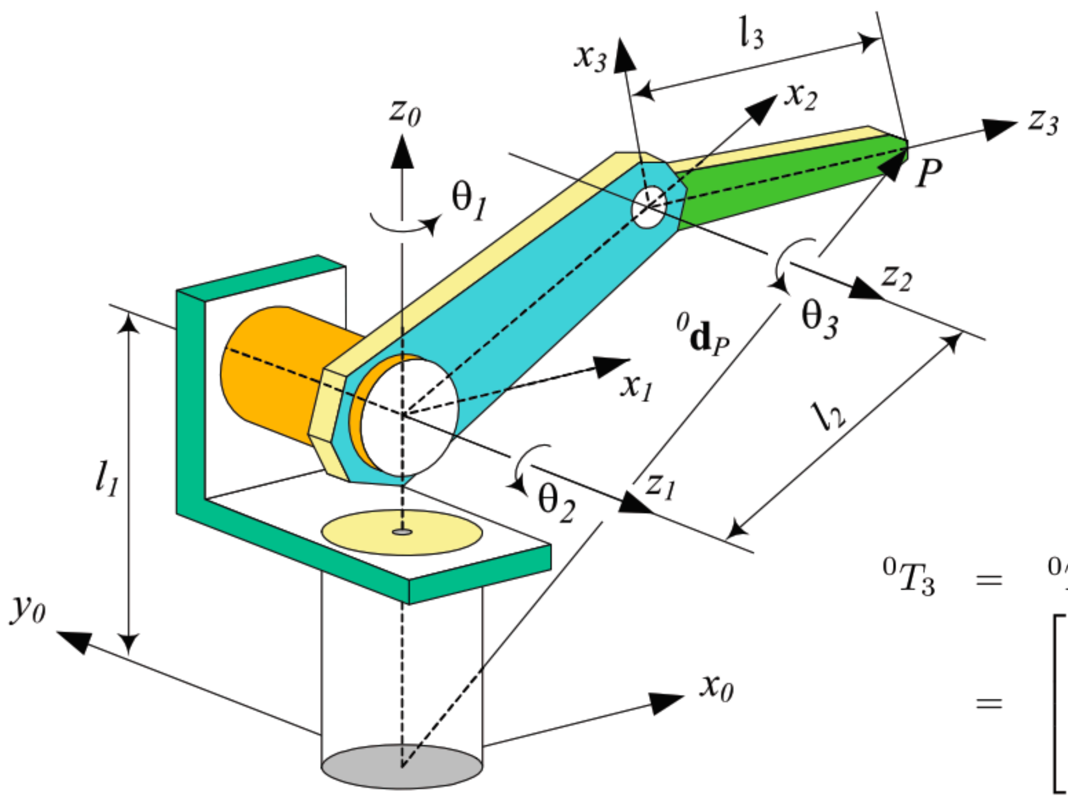
Frame No.	a_i	α_i	d_i	θ_i
1	l_1	0	0	θ_1
2	l_2	0	0	θ_2
3	l_3	0	0	θ_3

Ex.137 pg. 239



Frame No.	a_i	α_i	d_i	θ_i
1	0	-90 deg	l_1	θ_1
2	0	90 deg	l_2	θ_2
3	0	0	d_3	0
4	0	-90 deg	0	θ_4
5	0	90 deg	0	θ_5
6	0	0	l_6	θ_6

Ex. 182 pg. 328



Find an expression for the x,y,z tip of the end-effector?

What about the orientation of the tip?

How would you solve the IK problem?

$$
\begin{aligned}
{}^0T_3 &= {}^0T_1\,{}^1T_2\,{}^2T_3 \\
&= \begin{bmatrix} c\theta_1 c\left(\theta_2+\theta_3\right) & s\theta_1 & c\theta_1 s\left(\theta_2+\theta_3\right) & l_2 c\theta_1 c\theta_2 \\ s\theta_1 c\left(\theta_2+\theta_3\right) & -c\theta_1 & s\theta_1 s\left(\theta_2+\theta_3\right) & l_2 c\theta_2 s\theta_1 \\ s\left(\theta_2+\theta_3\right) & 0 & -c\left(\theta_2+\theta_3\right) & l_1+l_2 s\theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\end{aligned}
$$

Ex. 204 pg. 388

$$ {}^{B}R_{G} = R_{z,\psi} R_{x,\theta} R_{z,\varphi} $$

$$ {}_{B}\tilde{\omega}_{G} = \text{?} $$