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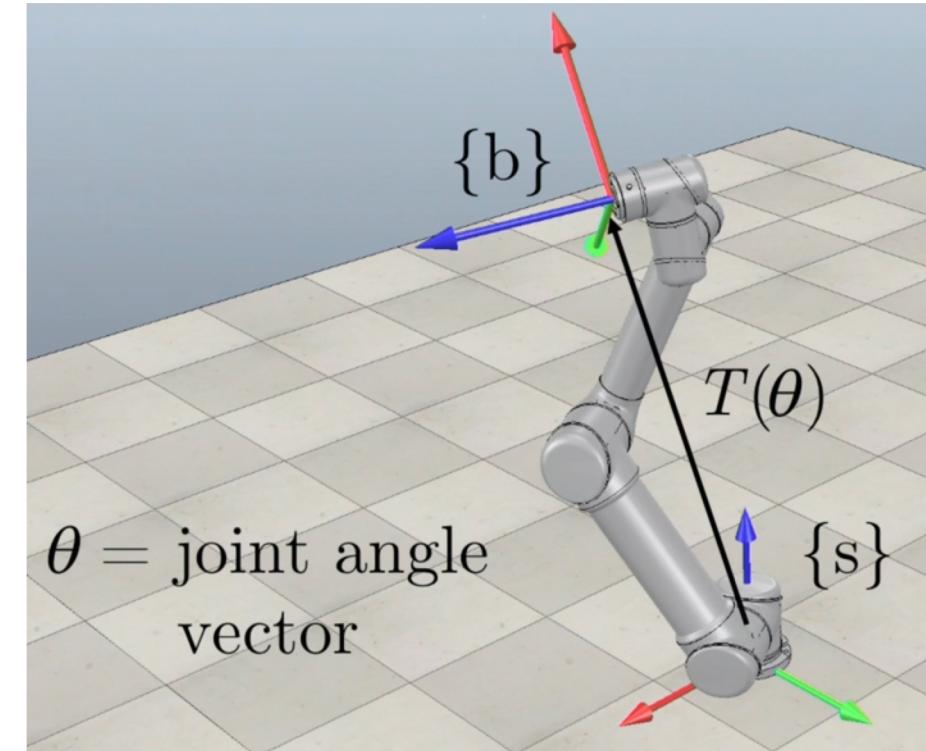
## Important concepts, symbols, and equations

**Forward kinematics** of a serial chain:

Given

- $M = T_{sb}(0) \in SE(3)$ , the configuration of the end-effector frame  $\{b\}$  at the home configuration  $\theta = 0$ ,
- the screw axes for each joint at  $\theta = 0$ , and
- the joint vector  $\theta$ ,

find  $T_{sb}(\theta) \in SE(3)$ .



## Important concepts, symbols, and equations (cont.)

- For screw axes  $S$  expressed in  $\{s\}$ , the **product of exponentials** (PoE) in the space frame is

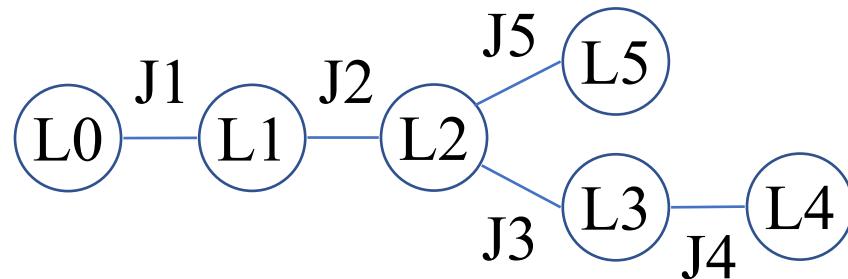
$$T(\theta) = e^{[S_1]\theta_1} \dots e^{[S_n]\theta_n} M$$

- For screw axes  $\mathcal{B}$  expressed in  $\{b\}$ , the PoE is

$$T(\theta) = M e^{[\mathcal{B}_1]\theta_1} \dots e^{[\mathcal{B}_n]\theta_n}$$

## Important concepts, symbols, and equations (cont.)

The **Universal Robot Description Format (URDF)** is an XML file describing the kinematics, inertial properties, and geometry of a tree-structured robot.

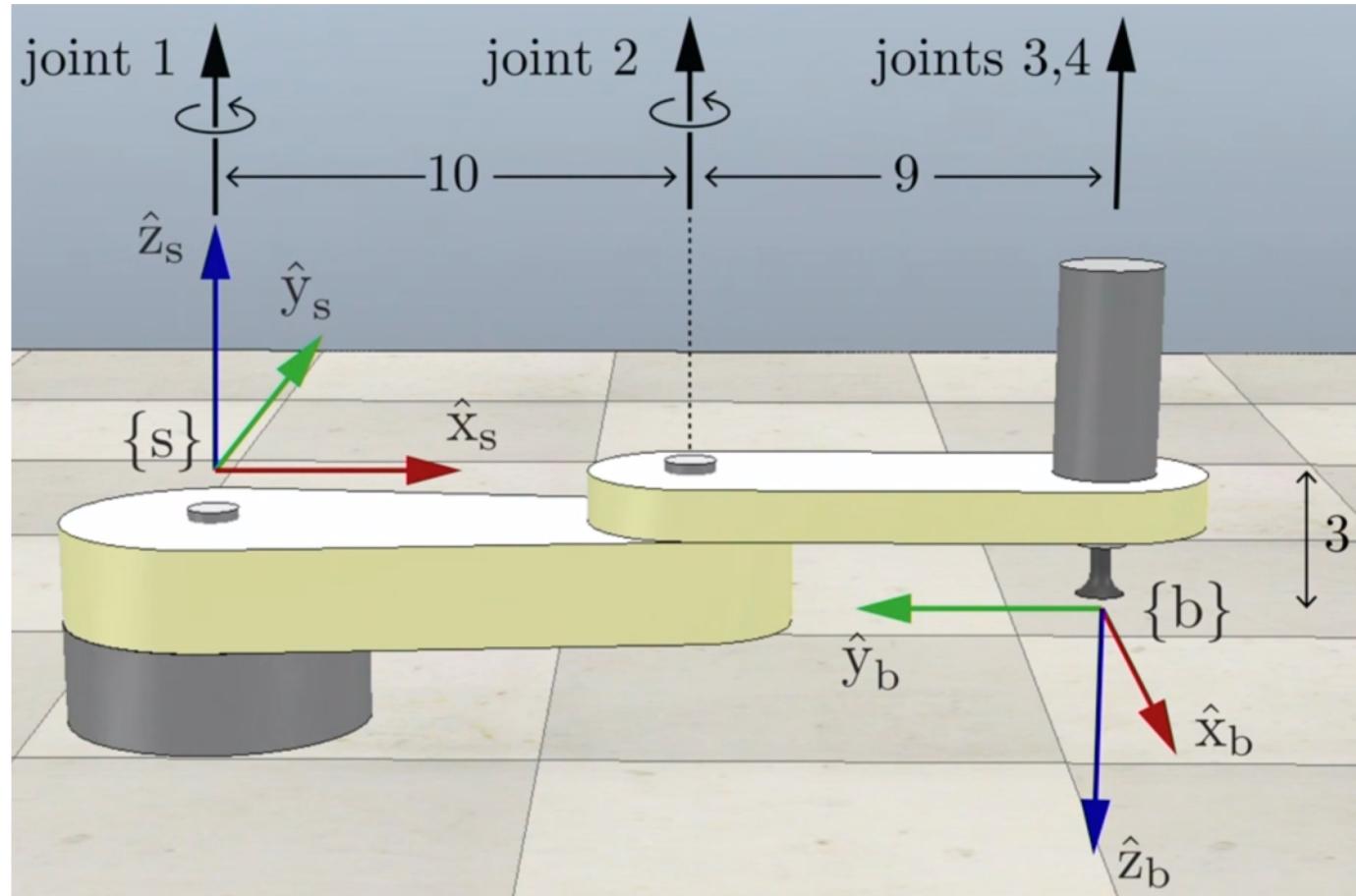


the **joint** element (kinematics)

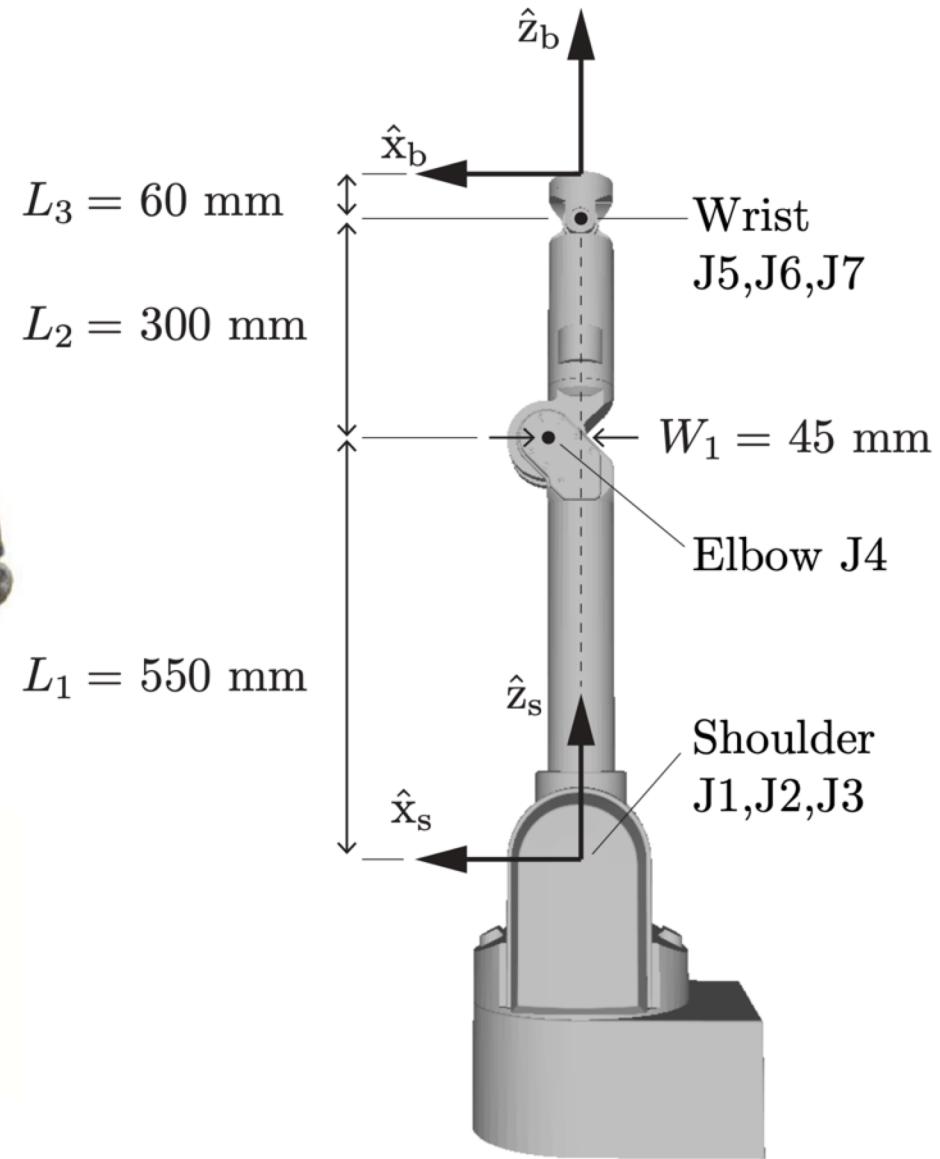
```
<joint name="joint2" type="revolute">
  <parent link="link1"/>
  <child link="link2"/>
  <origin rpy="0 1.5708 0" xyz="0 0.5 0">
  <axis xyz="0 1 0">
  <limit lower="-3.0" upper="3.0">
</joint>
```

the **link** element (inertial properties)

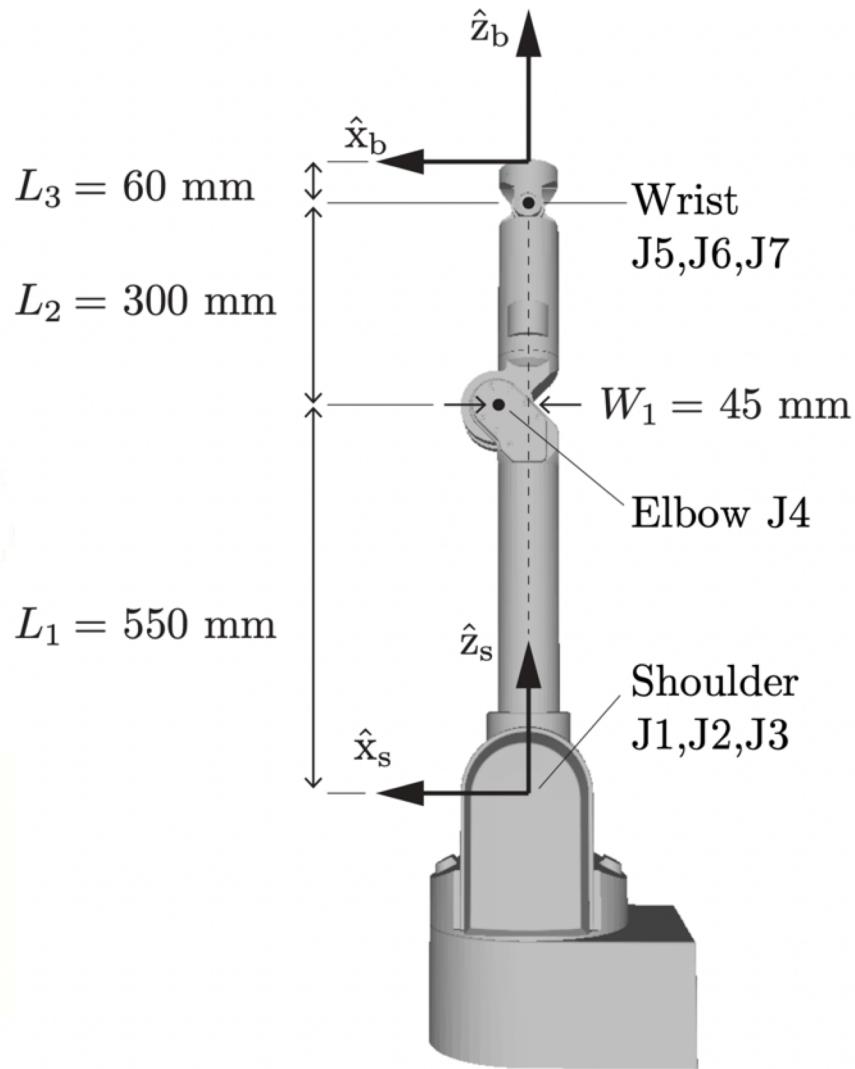
```
<link name="link2">
  <inertial>
    <origin rpy="0 0 0" xyz="0 0 0.5">
    <mass value="2.25">
      <inertia ixx="1.0" ixy="0" ixz="0"
               iyy="2.0" iyz="0" izz="3.0"/>
    </inertial>
  </link>
```



RRRP robot



Barrett Technology's WAM 7R robot

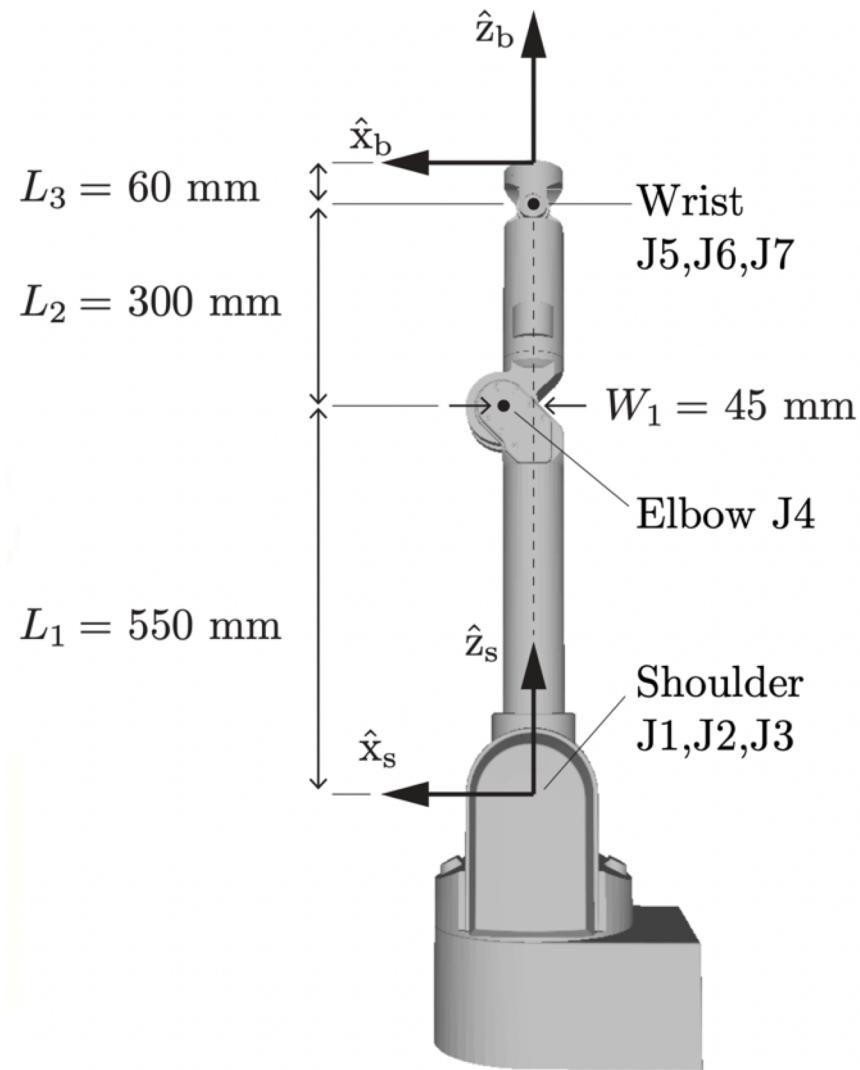


Joint axes 1, 3, 5, and 7 are aligned with  $\hat{z}_s$ .  
 Joint axes 2, 4, and 6 are out of the page.

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_1 + L_2 + L_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

screw axes  $\mathcal{B}_i$

$i$	$\omega_i$	$v_i$
1	$(0, 0, 1)$	$(0, 0, 0)$
2	$(0, 1, 0)$	$(L_1 + L_2 + L_3, 0, 0)$
3	$(0, 0, 1)$	$(0, 0, 0)$
4	$(0, 1, 0)$	$(L_2 + L_3, 0, W_1)$
5	$(0, 0, 1)$	$(0, 0, 0)$
6	$(0, 1, 0)$	$(L_3, 0, 0)$
7	$(0, 0, 1)$	$(0, 0, 0)$



screw axes  $S_i$

Joint axes 1, 3, 5, and 7 are aligned with  $\hat{z}_s$ .  
Joint axes 2, 4, and 6 are out of the page.