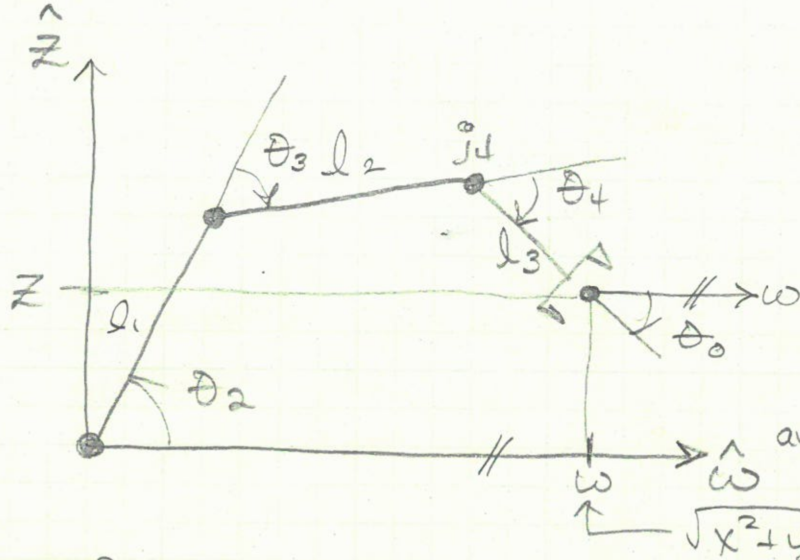
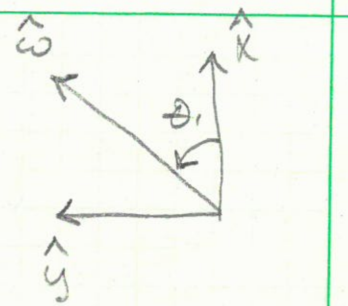




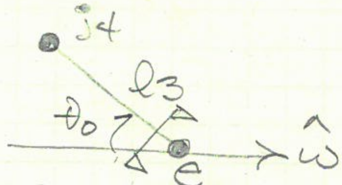
$\theta_1 = \text{atan2}(y, x)$

angle = cosine_law(left, right, opp)
triangle sides

$\theta_0 \equiv$ end effector orientation

- typically you define 2 things:
  - end effector location (x_e, y_e, z_e)
  - end effector orientation ... why?

- we can find joint 4's location based off these 2 pieces of information

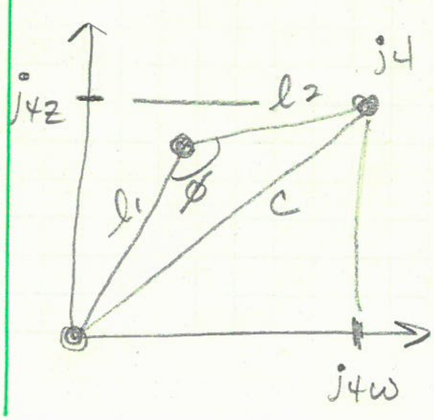


e ≡ end effector loc

$$j4 = [w_e - l_3 \cos(\theta_0)]\hat{w} + [z_e + l_3 \sin(\theta_0)]\hat{z}$$

remember: this is a combination of $\hat{x}$ and $\hat{y}$ axes

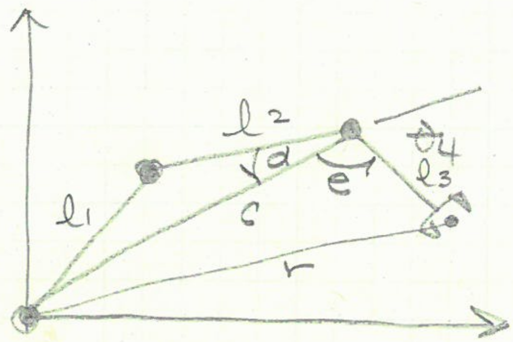
Now we know where the 4th joint is located.



$$c = \sqrt{j4_w^2 + j4_z^2}$$

$$\phi = \text{cosine\_law}(l_1, l_2, c)$$

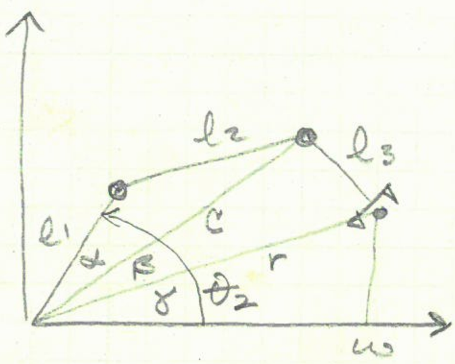
$$\theta_3 = \pi - \phi$$



$d = \text{cosine\_law}(l_2\ c\ l_1)$

$e = \text{cosine\_law}(c, l_3, r)$

$\theta_4 = \pi - (d+e)$



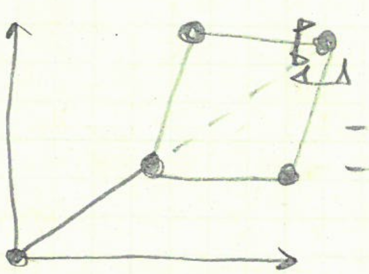
$\gamma = \text{atan2}(z, w)$

$\beta = \text{cosine\_law}(c, r, l_3)$

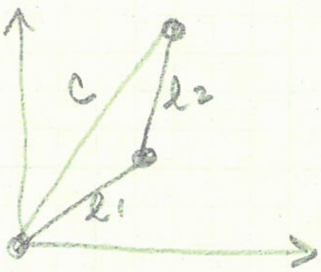
$\alpha = \text{cosine\_law}(c\ l_1\ l_2)$

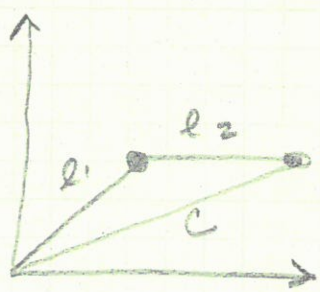
$\theta_2 = \alpha + \beta + \gamma$

- now you have: $\theta_1\ \theta_2\ \theta_3\ \theta_4$
- you just need to keep an eye out for uniqueness issues:



- which one is it?
- how can you figure it out?
  - maybe use forward kinematics to see if you get to the correct point?





from a cosine law stand point, these are the same!