Grasping

Outline for the next many lectures.

MANIPULATION PLANNING

ARM PLANNING $\rightleftharpoons$ GRASP PLANNING

Producing collision-free motions of arm and hand

Producing a stable grasp of the object.

Heavily Interconnected.

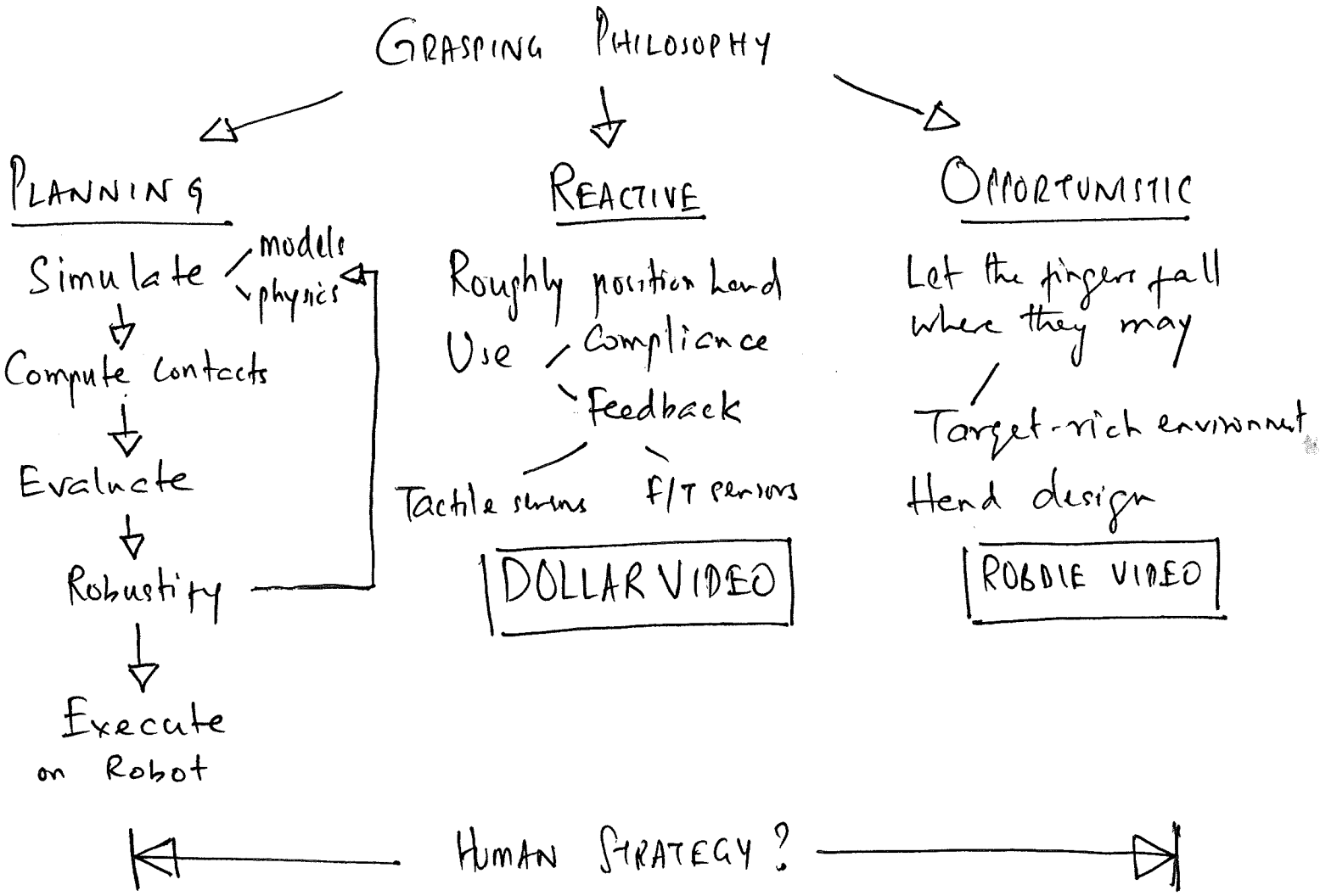
Can't grasp something unless the arm can get there.
Arm needs to know where to go.

Next few lectures / and HW1

GRASP PLANNING

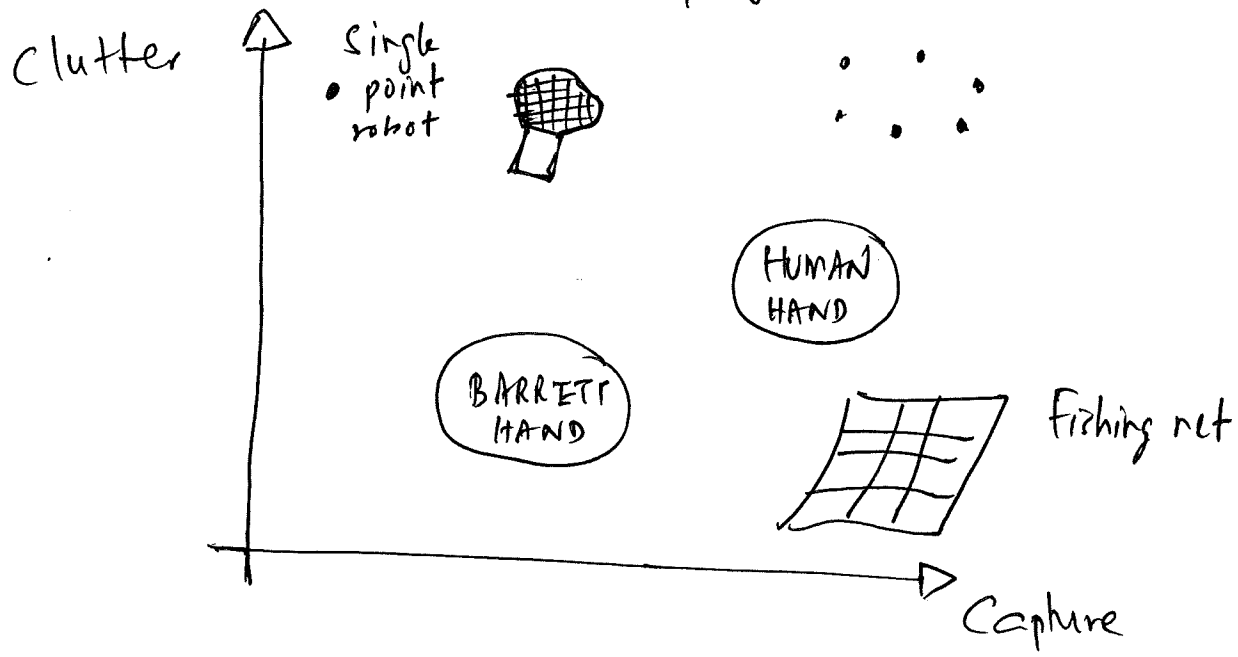
Today's lecture

VERIFICATION: Given a grasp of an object by a hand, is it STABLE?


GRASPING PHILOSOPHY
PLANNING
Simulate
models
physics
Compute contacts
Evaluate
Robustify
Execute
on Robot
REACTIVE
Roughly position hand
Use
Compliance
Feedback
Tactile sensors
F/T sensors
DOLLAR VIDEO
OPPORTUNISTIC
Let the fingers fall
where they may
Target-rich environment
Hand design
ROBBIE VIDEO
HUMAN STRATEGY ?

HAND DESIGN

Does more DOFs ~~mean~~ imply greater GENERALITY?

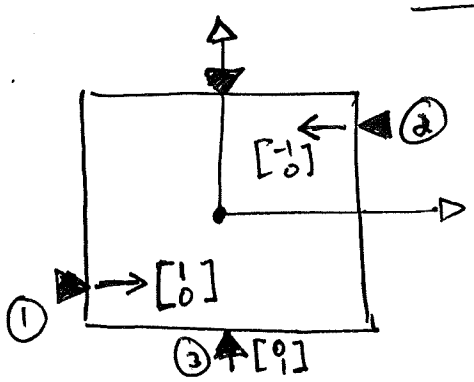


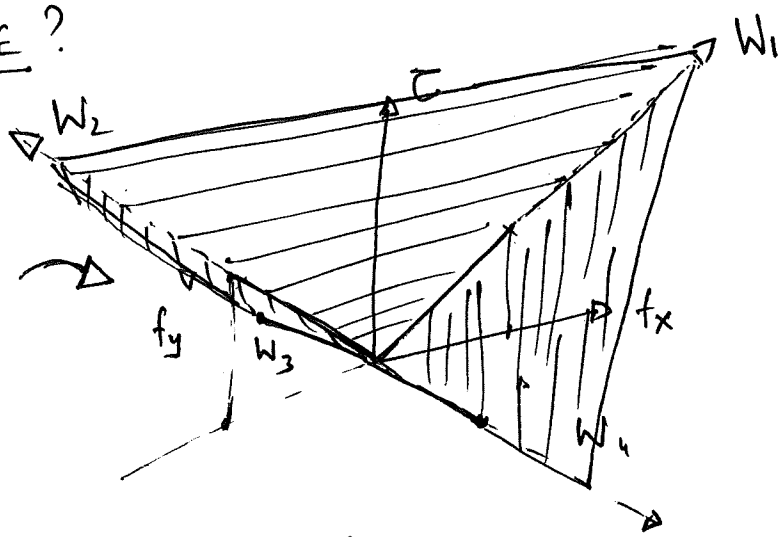
GRASP VERIFICATION

Given: ① Object Geometry

② Contact points and normals on the object.

IS THE GRASP STABLE?





Assume frictionless point contact

$\hat{n}_1 = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ $\hat{n}_2 = \begin{bmatrix} -1 \\ 0 \end{bmatrix}$ $\hat{n}_3 = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ $\hat{n}_4 = \begin{bmatrix} 0 \\ -1 \end{bmatrix}$

$\vec{r}_1 = \begin{bmatrix} -1 \\ -1 \end{bmatrix}$ $\vec{r}_2 = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ $\vec{r}_3 = \begin{bmatrix} 0 \\ -1 \end{bmatrix}$ $\vec{r}_4 = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

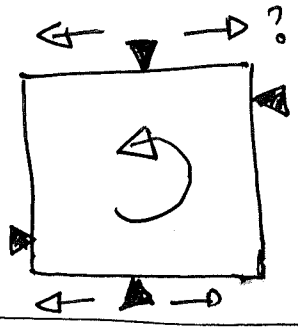
$w_1 = \begin{bmatrix} \hat{n}_1 \\ \vec{r}_1 \times \hat{n}_1 \end{bmatrix}$ $w_2 = \begin{bmatrix} \hat{n}_2 \\ \vec{r}_2 \times \hat{n}_2 \end{bmatrix}$ $w_3 = \begin{bmatrix} \hat{n}_3 \\ \vec{r}_3 \times \hat{n}_3 \end{bmatrix}$ $w_4 = \begin{bmatrix} \hat{n}_4 \\ \vec{r}_4 \times \hat{n}_4 \end{bmatrix}$

$= \begin{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \\ 1 \end{bmatrix}$ $= \begin{bmatrix} \begin{bmatrix} -1 \\ 0 \end{bmatrix} \\ 1 \end{bmatrix}$ $= \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$ $= \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix}$

$W_1 = w_1 f_1$ $f_1 \geq 0$ $W_2 = w_2 f_2$ $f_2 \geq 0$ $W_3 = w_3 f_3$ $f_3 \geq 0$ $W_4 = w_4 f_4$ $f_4 \geq 0$

UNILATERAL CONTACT

ARE WE DONE?



CANNOT RESIST A UNIT + TORQUE

SIDEBAR: Force Closure Vs Form Closure.

Instantaneous

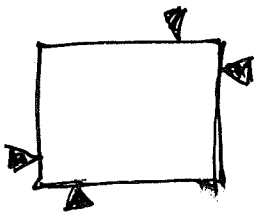
Non-instantaneous.

~~Allowable motion of object~~

Only non-penetrating in its grd. configuration of object is its current configuration.

Should the contacts move to the left or to the right?

Answer: LEFT does not resist torque.
RIGHT does!



Force closure = The ability to resist an arbitrary wrench.

$$W = \begin{bmatrix} w_1 f_1 + w_2 f_2 + w_3 f_3 + w_4 f_4 \end{bmatrix} = \begin{bmatrix} | & | & | & | \\ w_1 & w_2 & w_3 & w_4 \\ | & | & | & | \end{bmatrix} \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix}$$

$$= Gf$$

3×4 $\quad$ 4×1

G: Grasp Map

$\forall\, w_{ext}, \; \exists\, f \geq 0 \; : \; Gf = w_{ext}$

Constructive check

① Gf, $f \geq 0$ must span $\mathbb{R}^3$ or $\mathbb{R}^6$

② Origin O lies completely inside the unit wrench polyhedron.

INTUITION: $Gf = 0$ $f > 0$ is INTERNAL FORCE.

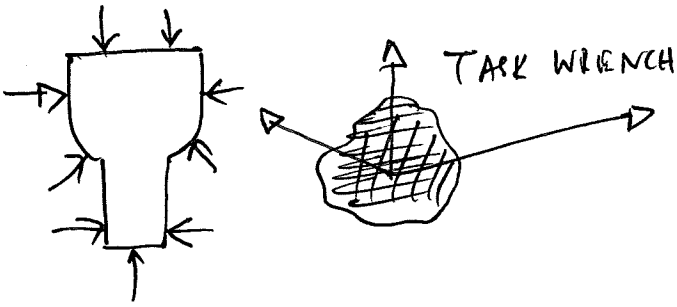
GRASP QUALITY METRICS.

① Radius of largest inscribed ball. ↑

② Volume of GWS $\propto \sqrt{\det(GG^T)}$ ↑

ISSUES

Very conservative. Blind to task.

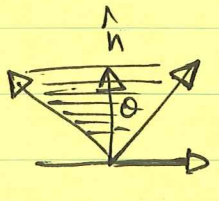


① Radius of largest TWS ↑

② $\frac{\text{Vol. TWS}}{\text{Vol. GWS}}$ ↓

WHAT HAPPENS WITH FRICTION?

IN 2D

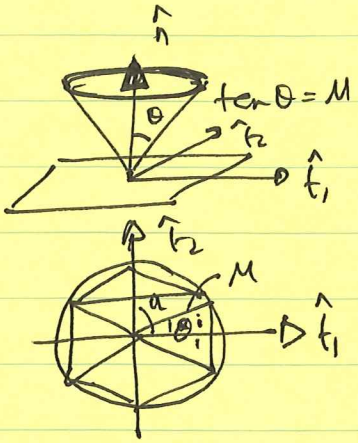


$\tan\theta = M$

$$f = \begin{bmatrix} f_L & f_R \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} \quad \alpha_1, \alpha_2 \geq 0$$

$$f_L = \begin{bmatrix} M & -M \\ 1 & 1 \end{bmatrix}$$

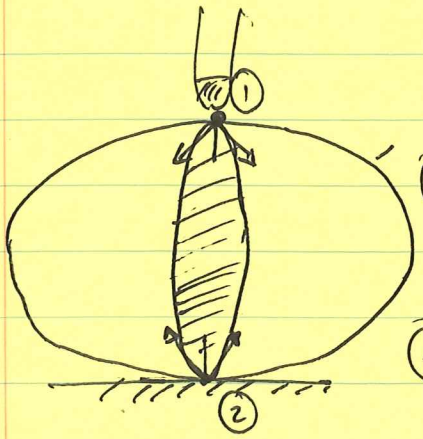
IN 3D



$$f_c = \begin{bmatrix} f_1 & f_2 & \cdots & f_K \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_K \end{bmatrix}$$

$$= \begin{bmatrix} M\cos\theta_1 & \cdots & M\cos\theta_K \\ M\sin\theta_1 & \cdots & M\sin\theta_K \\ 1 & & 1 \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_K \end{bmatrix}$$

Polyhedral approximation.



ISSUES

① Which one is more stable?
Uncertainty.

② How do we get to contacts?
Dynamics.