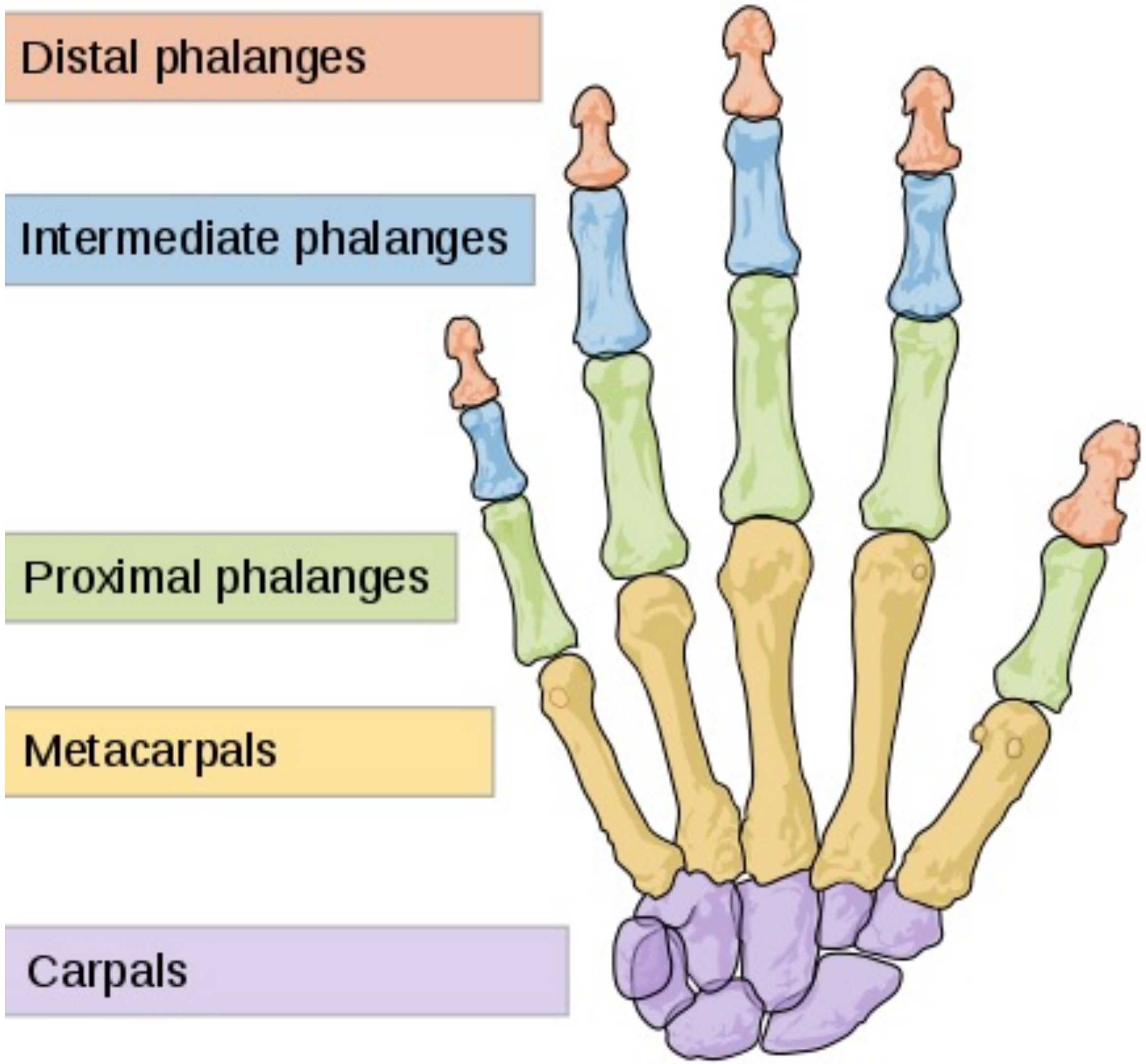
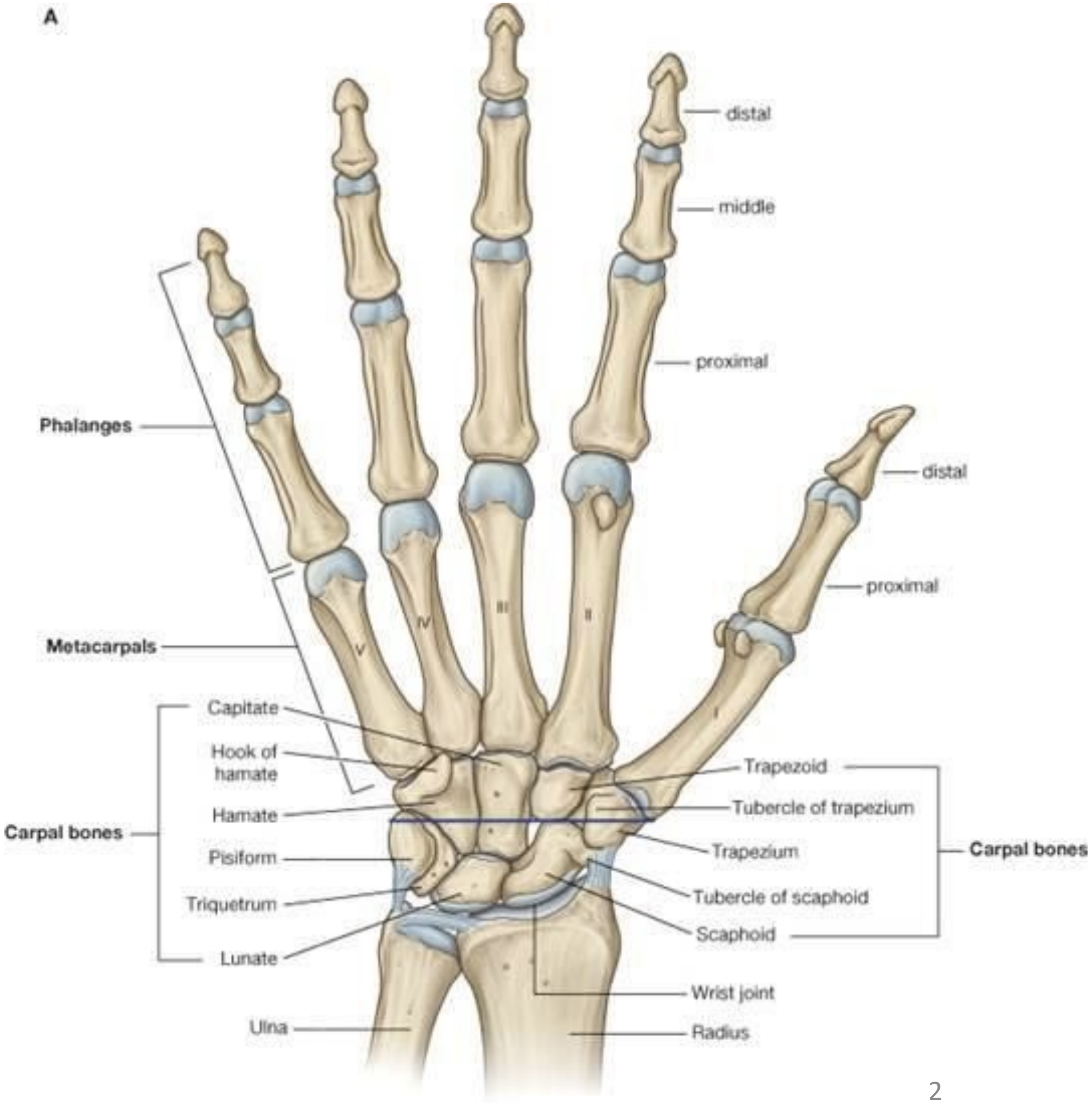
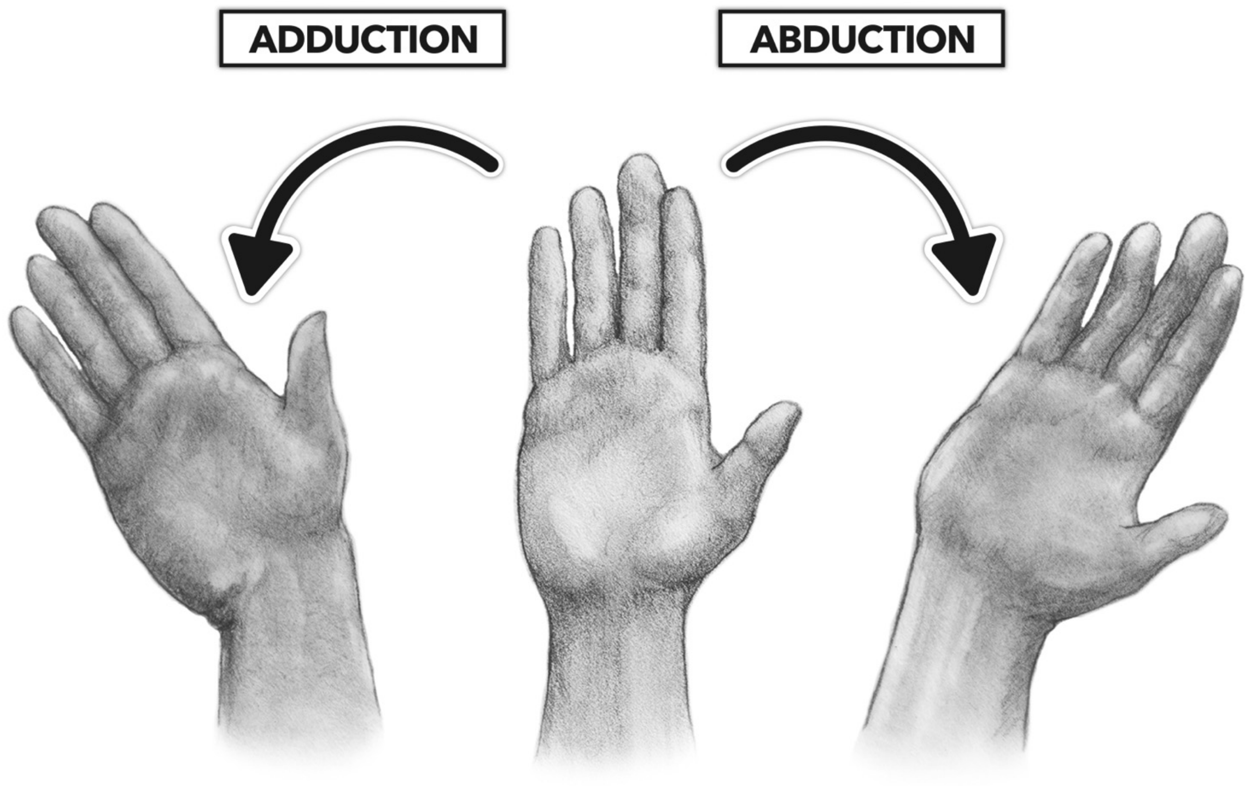
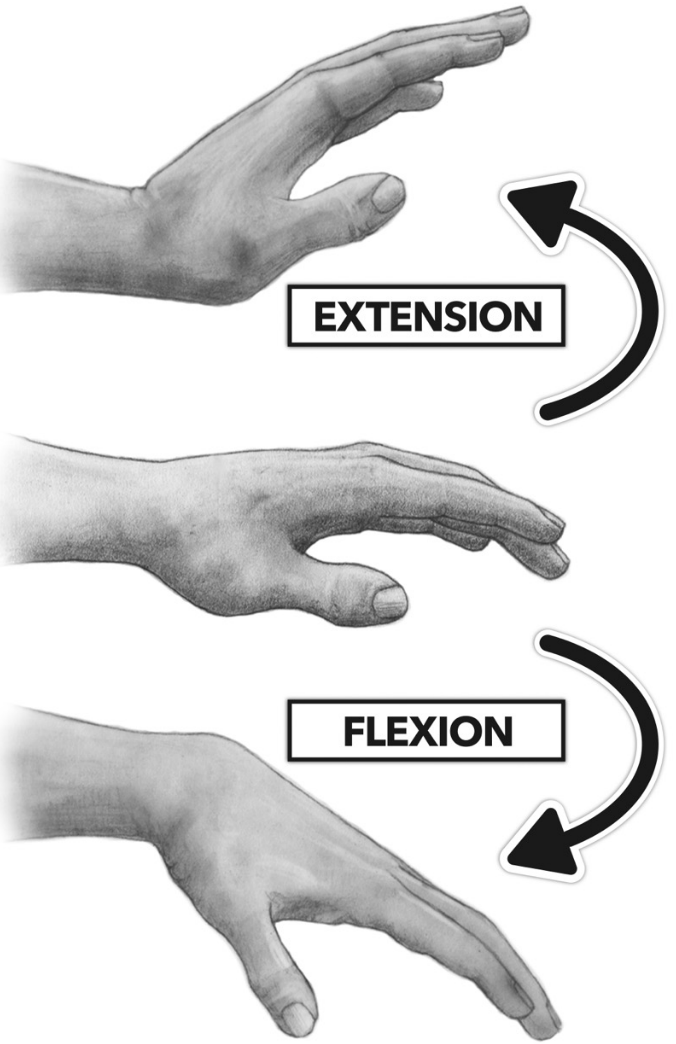
Intro to Robotics

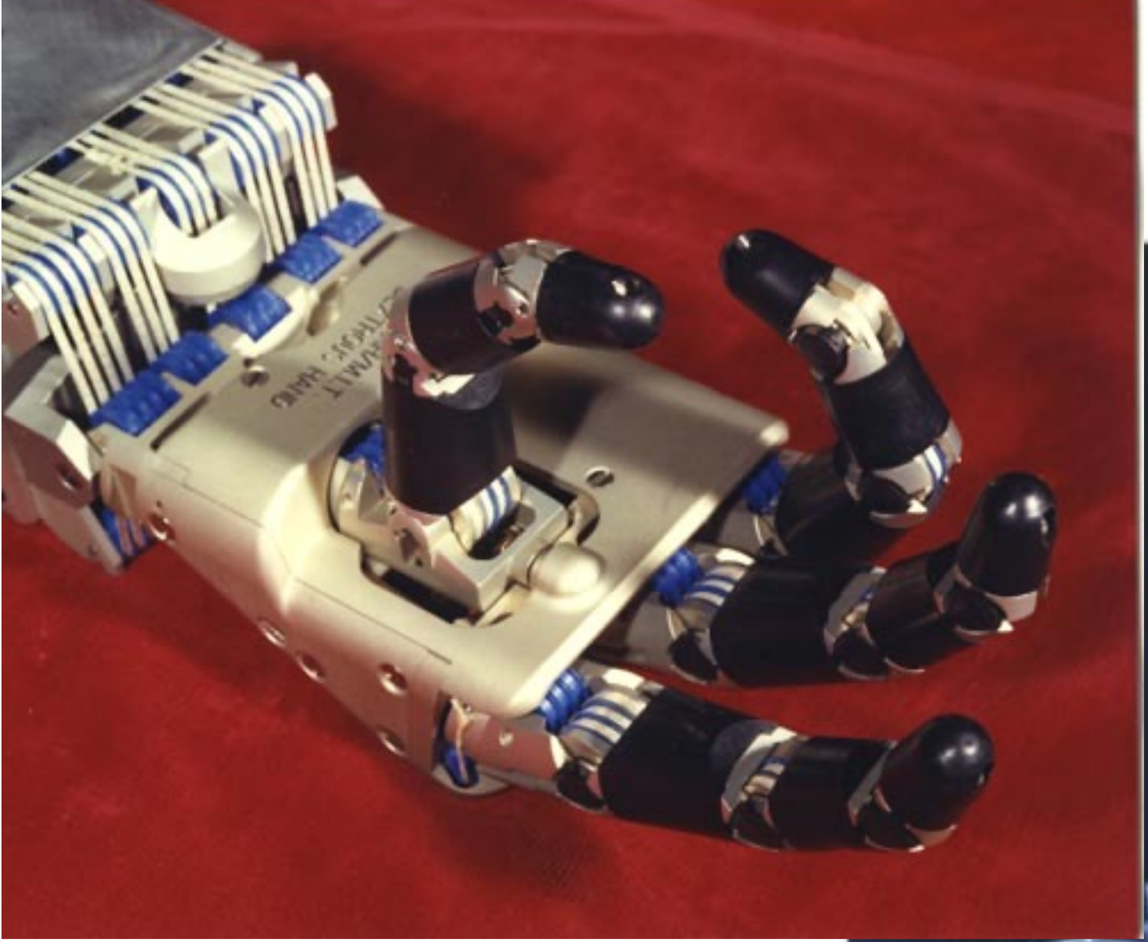
Lecture 14 Robotic Hand and Grasping

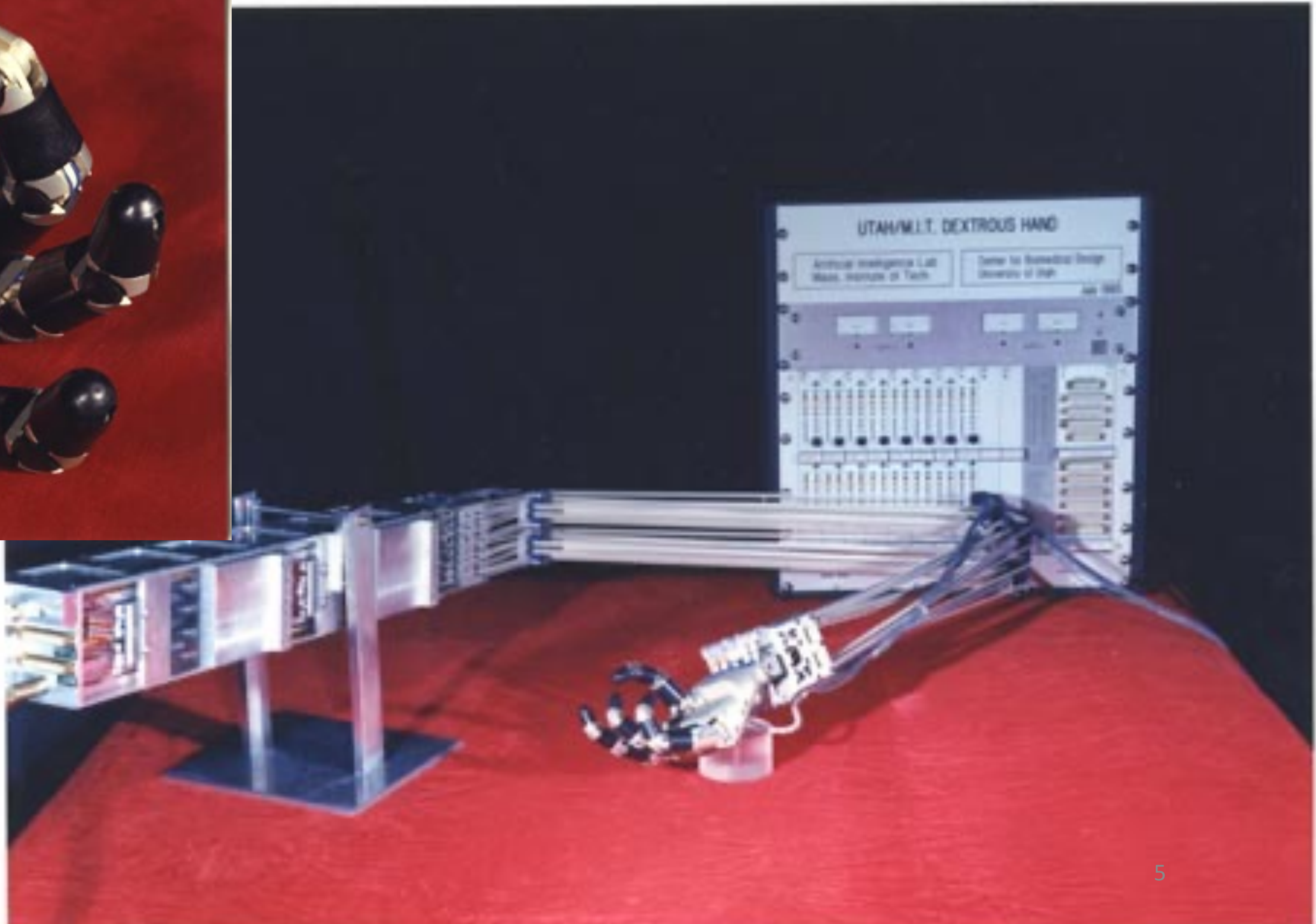

Distal phalanges
Intermediate phalanges
Proximal phalanges
Metacarpals
Carpals


A
distal
middle
proximal
Phalanges
distal
proximal
Metacarpals
Capitate
Hook of hamate
Hamate
Carpal bones
Pisiform
Triquetrum
Lunate
Ulna
Trapezoid
Tubercle of trapezium
Trapezium
Carpal bones
Tubercle of scaphoid
Scaphoid
Wrist joint
Radius


ADDUCTION
ABDUCTION


EXTENSION
FLEXION

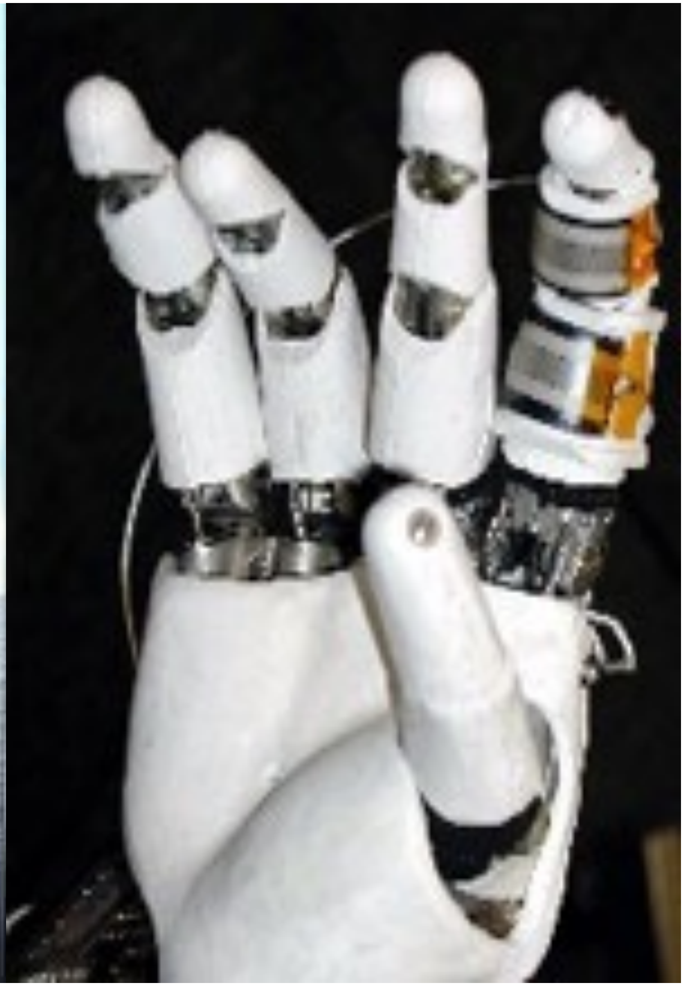




Utah/MIT Hand, 1983

Anthropomorphic Hands

DLR/HIT Hand



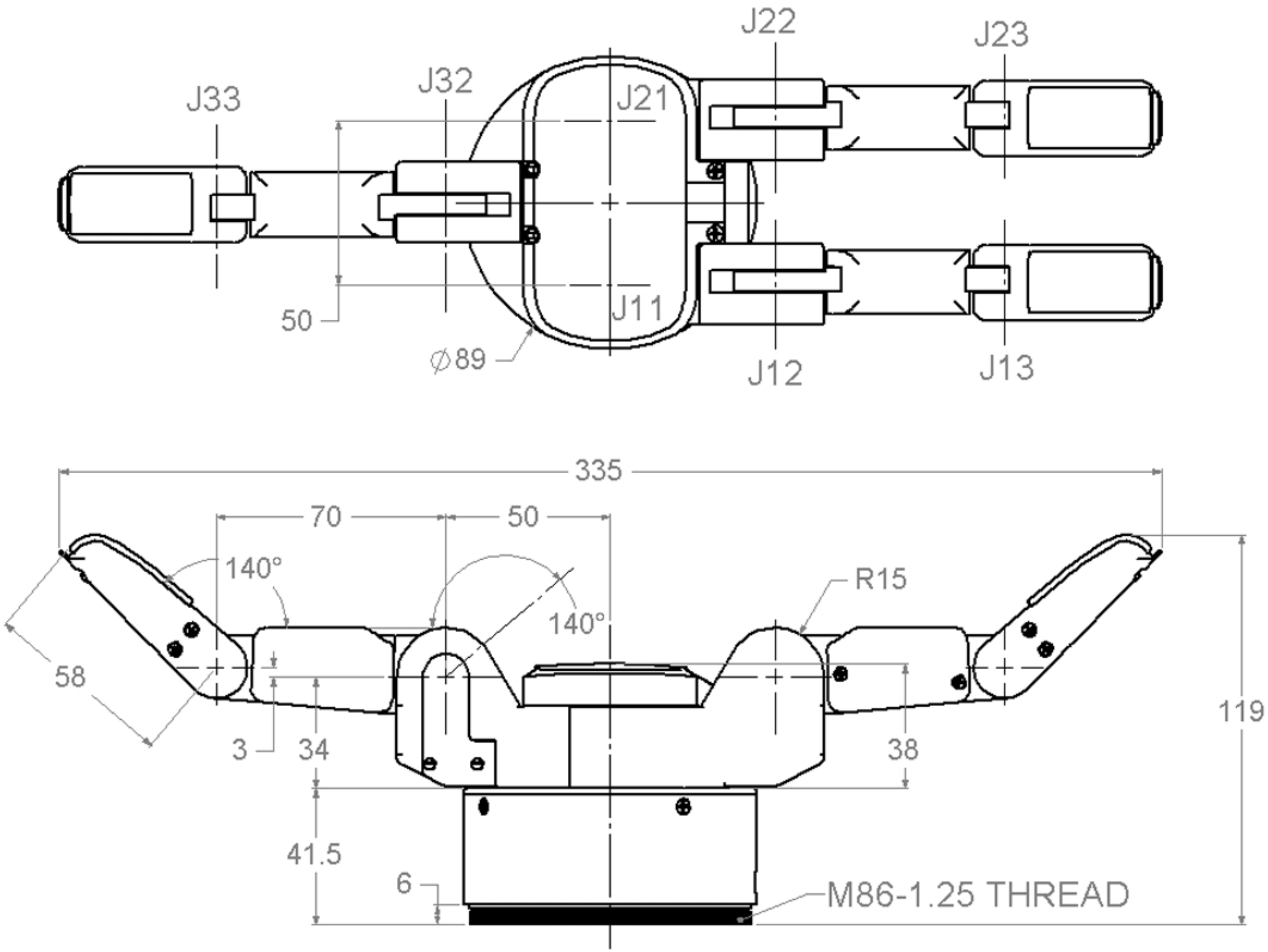
NASA Hand

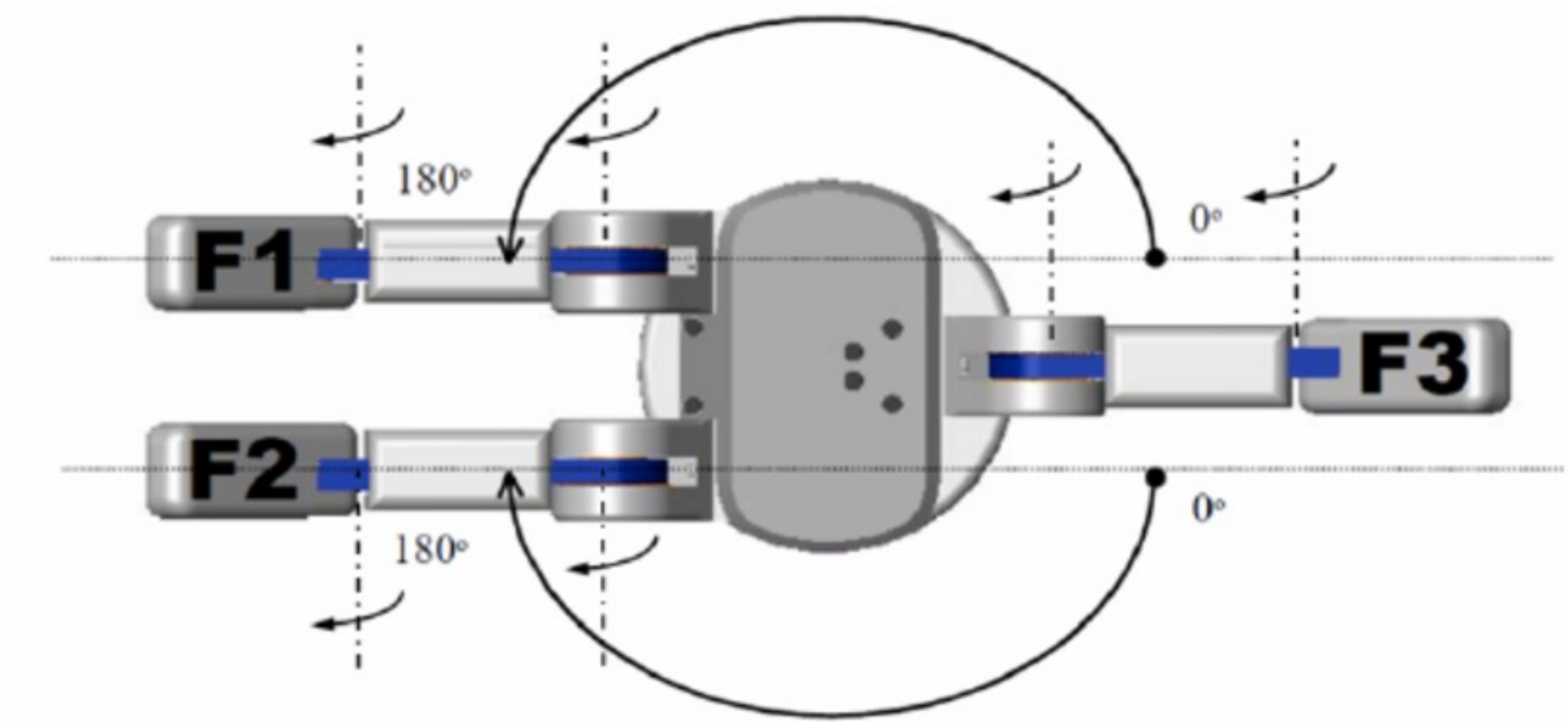
Bionic Hand

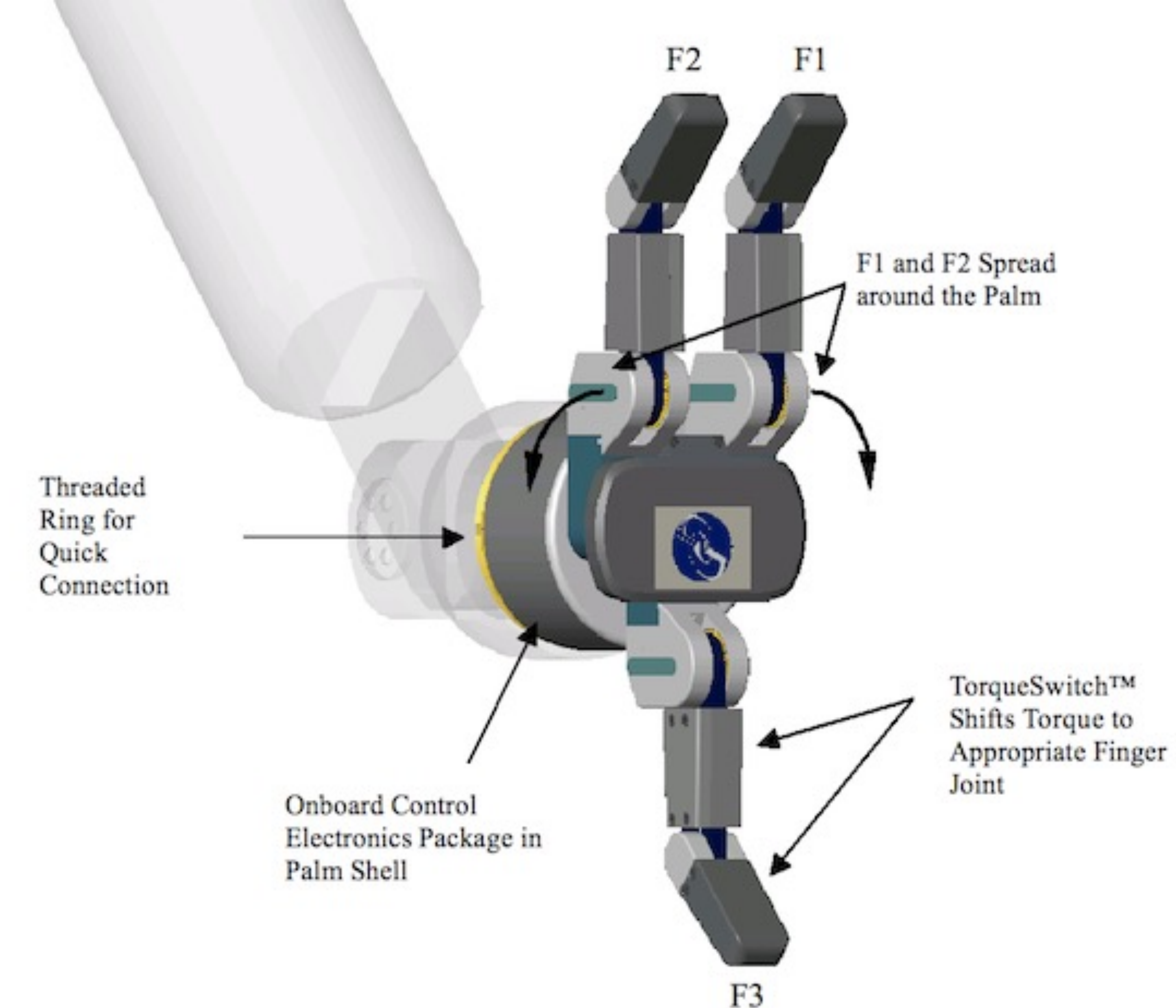
Shadow Hand

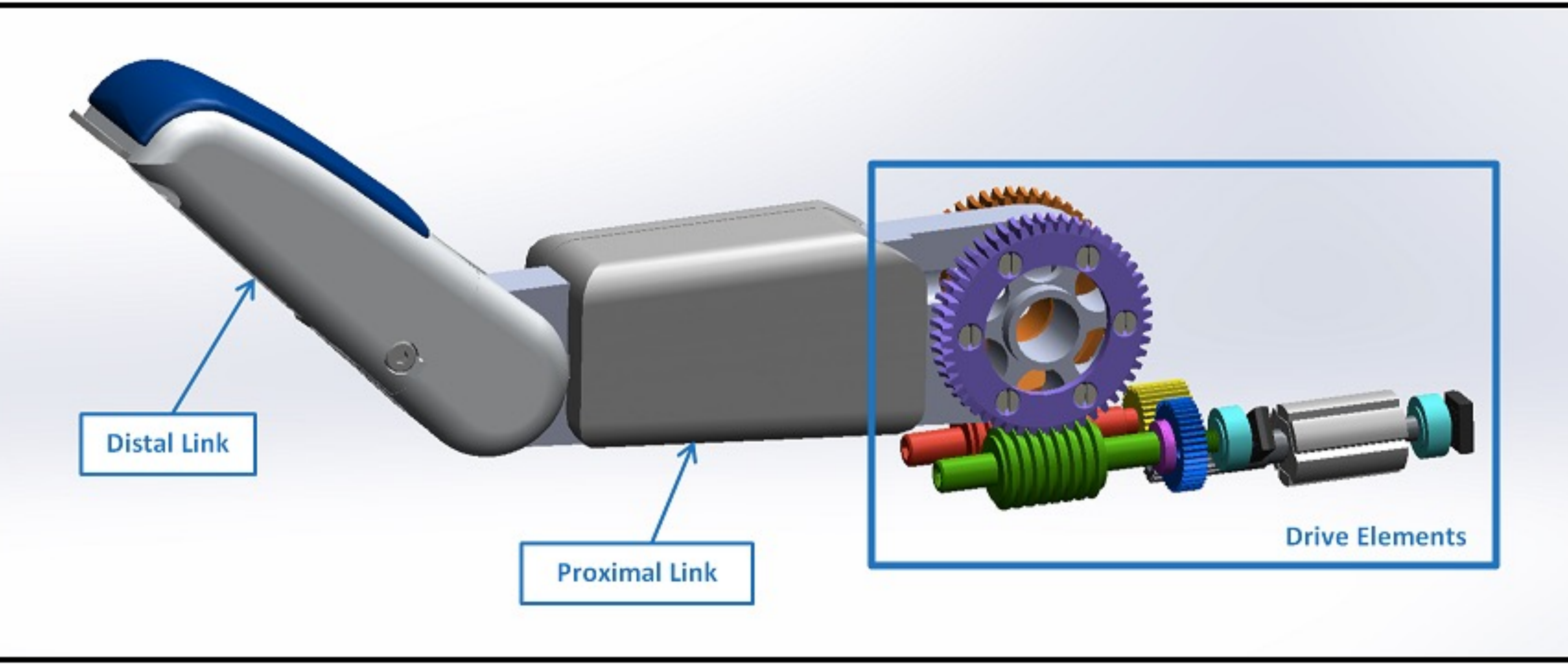
BarrettHand

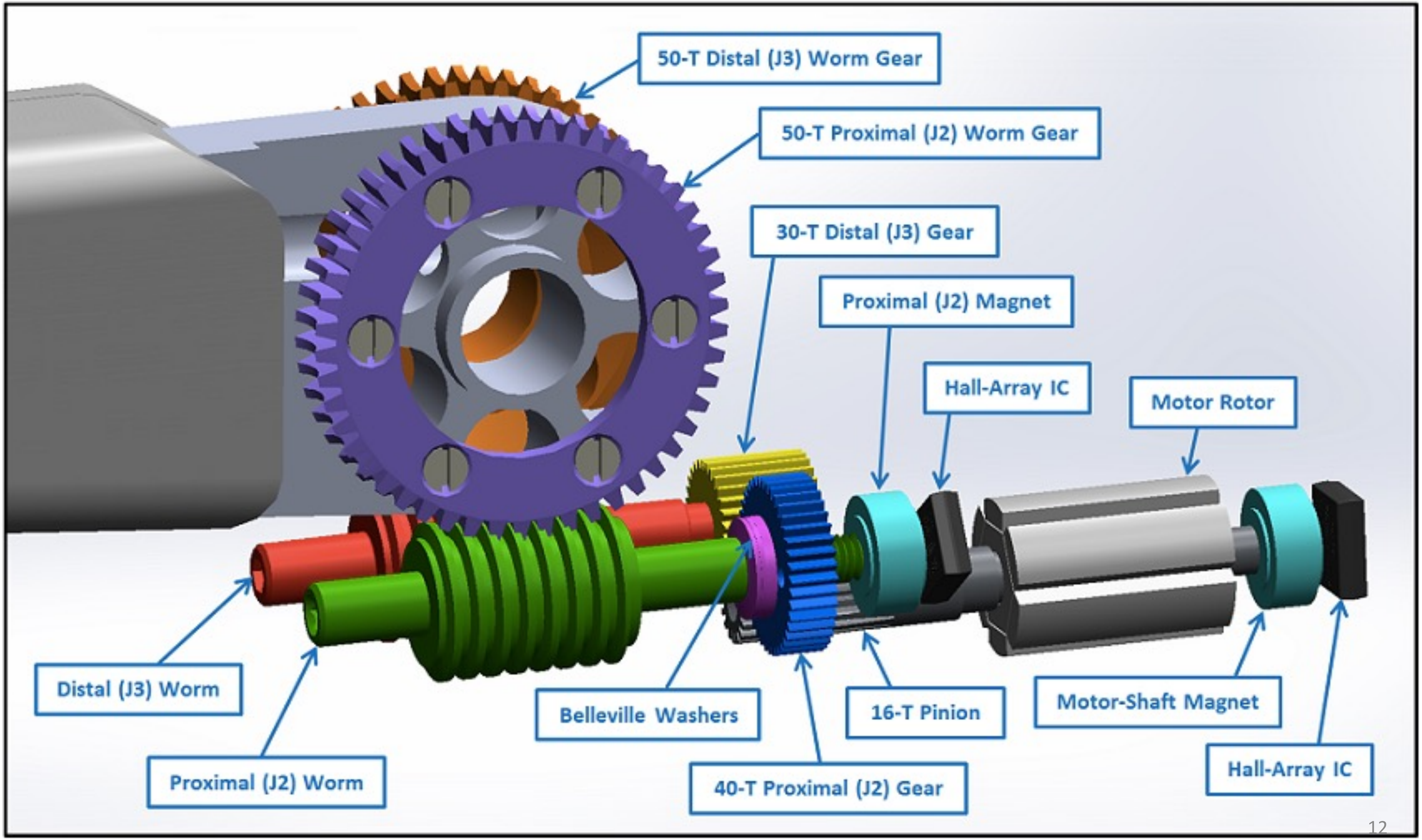
Kinematics	Total fingers: 3 Fingers which spread: 2 Joints per finger: 2 Motors per finger: 1 Axes of palm spread motion: 2 Motors for palm spread motion: 1 Total hand axes: 8 Total hand motors: 4
Range of Motion	Finger base joint: 140° Fingertip: 45° Finger spread: 180°
Finger Speed	Finger fully open to fully closed:1.0 sec Full 180° finger spread: 0.5 sec
Position Sensing	12-bit absolute sensing at each motor with array of Hall sensors
Weight	Hand: 980 grams
Payload	6.0 kg
Finger Forces (at tip)	Active: 15 N Passive: 20 N
Motor Type	Rare-Earth brushless-DC servo motors
Mechanisms	Worm drives integrated with proprietary cable drive and breakaway clutch

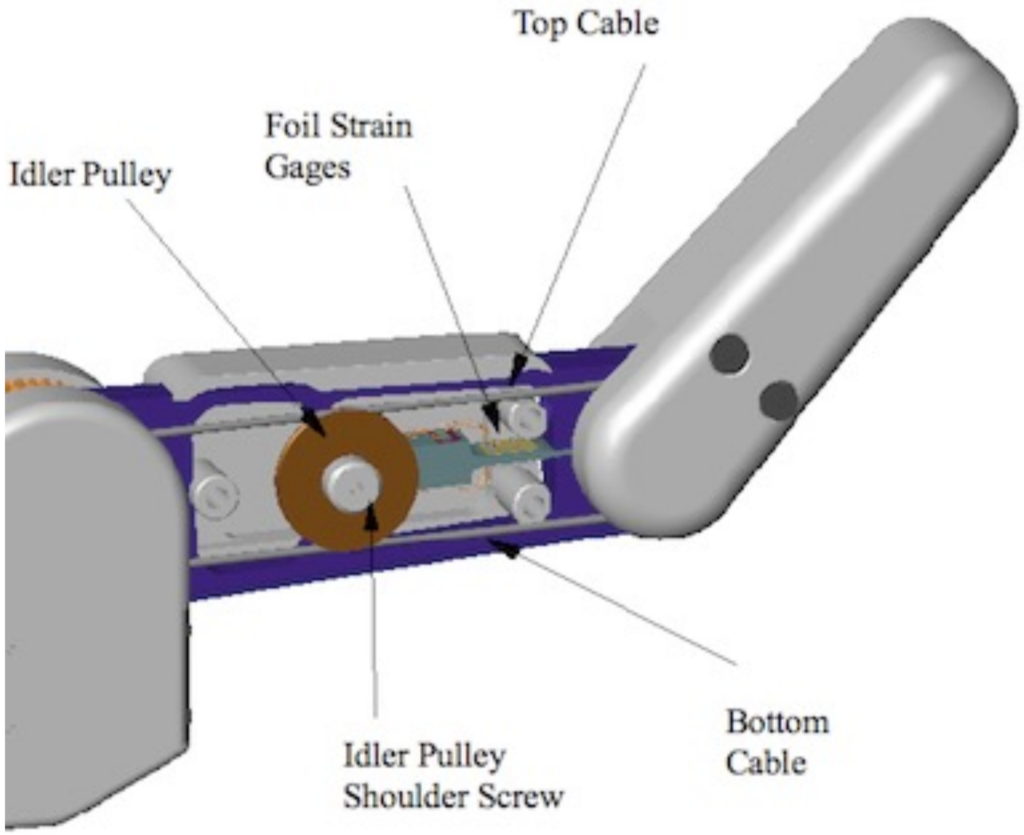

J33
J32
J21
J22
J23
50
⌀89
J11
J12
J13
335
70
50
140°
140°
R15
58
3
34
38
119
41.5
6
M86-1.25 THREAD

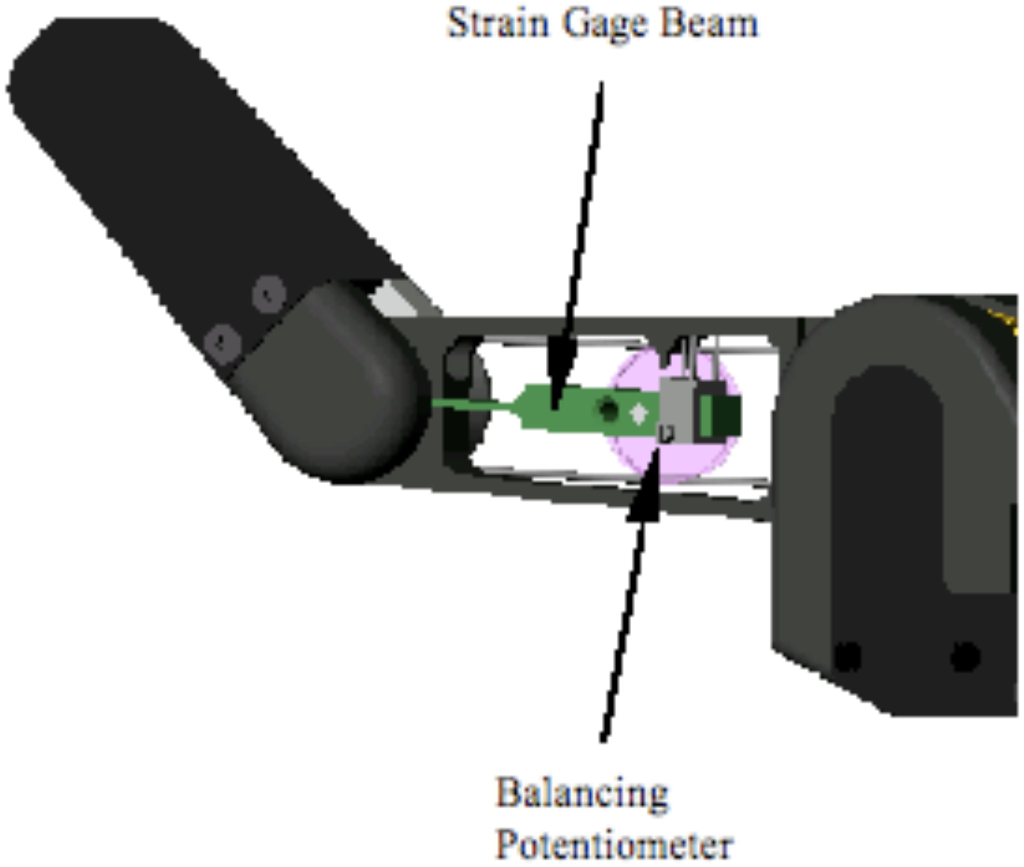

180°
0°
F1
F3
F2
0°
180°


F2
F1
F1 and F2 Spread around the Palm
Threaded Ring for Quick Connection
Onboard Control Electronics Package in Palm Shell
TorqueSwitch™ Shifts Torque to Appropriate Finger Joint
F3


Distal Link
Proximal Link
Drive Elements


50-T Distal (J3) Worm Gear
50-T Proximal (J2) Worm Gear
30-T Distal (J3) Gear
Proximal (J2) Magnet
Hall-Array IC
Motor Rotor
Distal (J3) Worm
Proximal (J2) Worm
Belleville Washers
40-T Proximal (J2) Gear
16-T Pinion
Motor-Shaft Magnet
Hall-Array IC


Top Cable
Foil Strain Gages
Idler Pulley
Idler Pulley Shoulder Screw
Bottom Cable

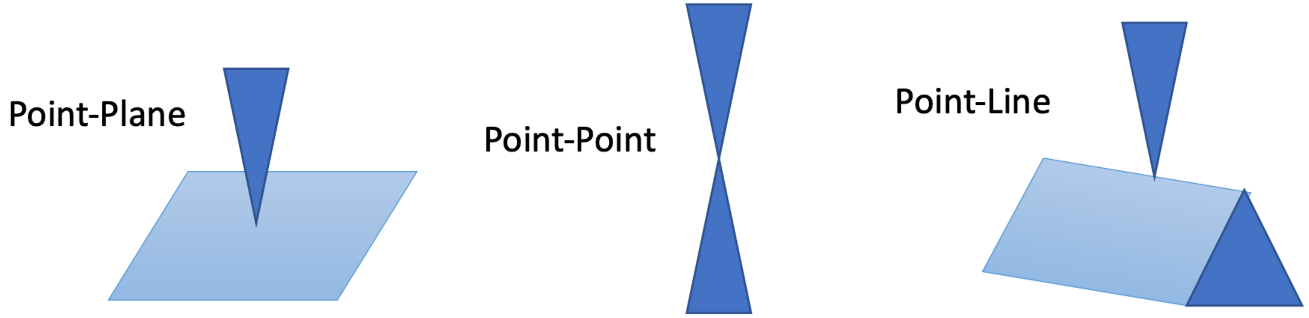

Strain Gage Beam
Balancing Potentiometer

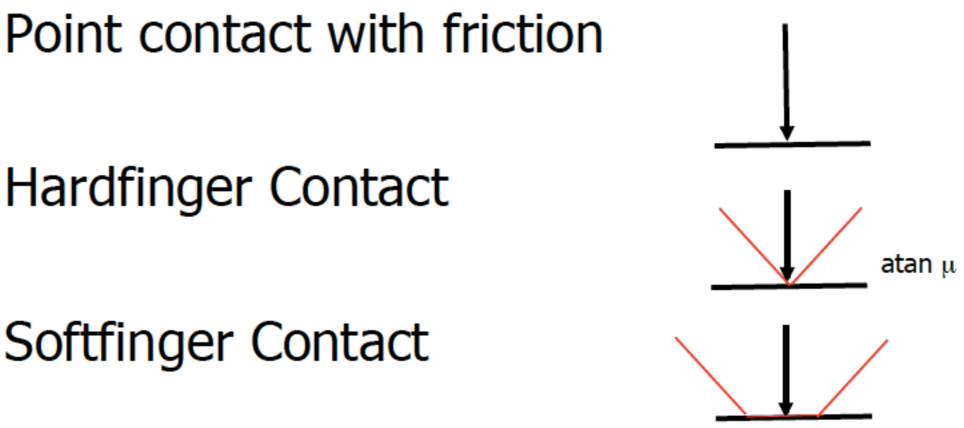
Mechanic of Contact

- Contact forces
- Quasistatic
- What will have form closure, sliding, rolling
- Contact kinematics
- Velocity from finger (moving direction) will allow sliding, rolling

Contact Types

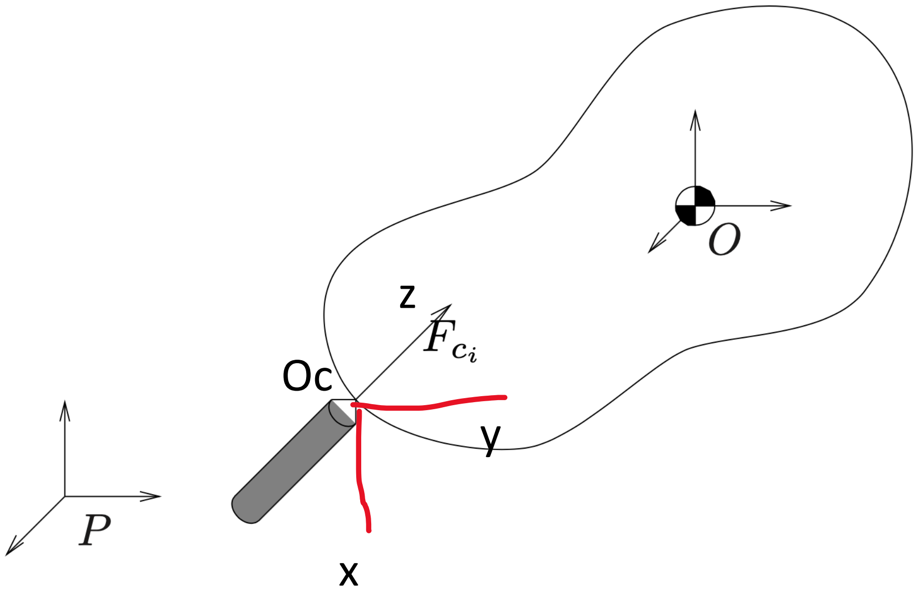
- Point: point on plane (stable), point on point or line (unstable)
- Line: line on plane or nonparallel line (stable), line on parallel line (unstable)
- Plane: plane on plane





Frictionless point contact

- No friction between the fingertip and the object
- Forces can only be applied in the direction normal to the surface of the object
- Can push on an object, but it cannot pull on the object.



$$F_{c_i} = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} f_{c_i} \quad f_{c_i} \geq 0,$$

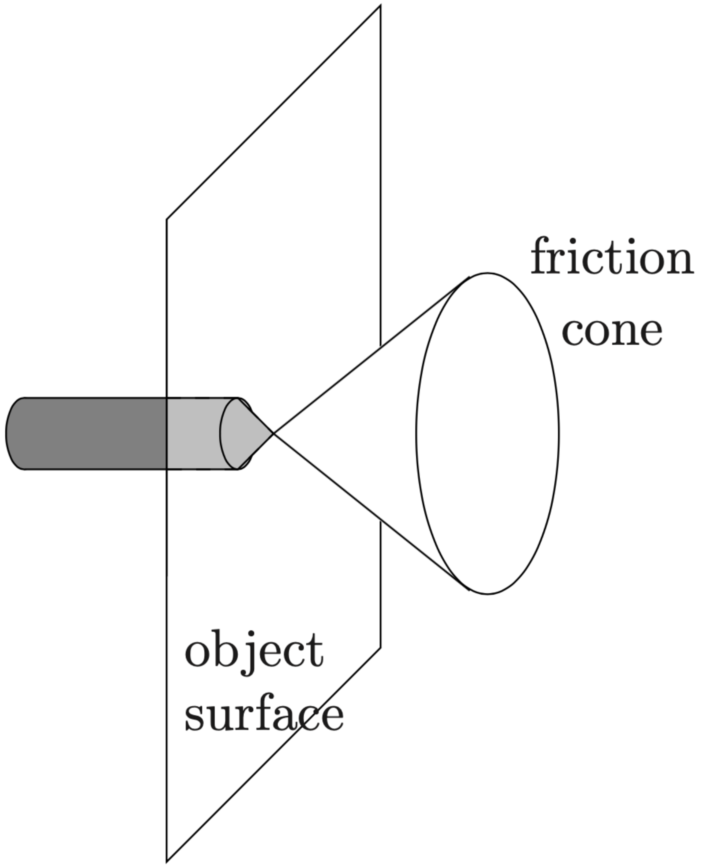
Coulomb Friction Model

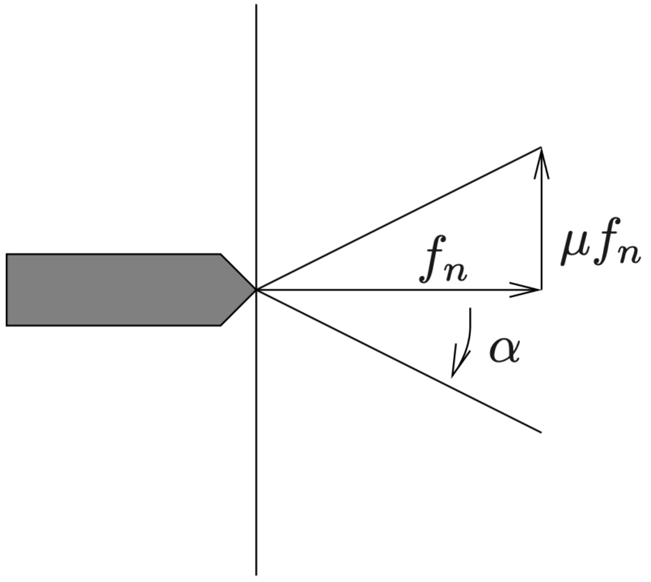
- How much force a contact can apply in the tangent directions to a surface as a function of the applied normal force.
- Empirical model which asserts that the allowed tangential force is proportional to the applied normal force, and the constant of proportionality is a function of the materials which are in contact.
- If we let $f_t \in R$ denote the magnitude of the tangential force and $f_n \in R$ denote the magnitude of the normal force, Coulomb's law states that slipping begins when

$$| f_t | > \mu f_n, \text{ where } \mu > 0 \text{ is the (static) coefficient of friction}$$

Friction cone

$\alpha = \tan^{-1} \mu.$





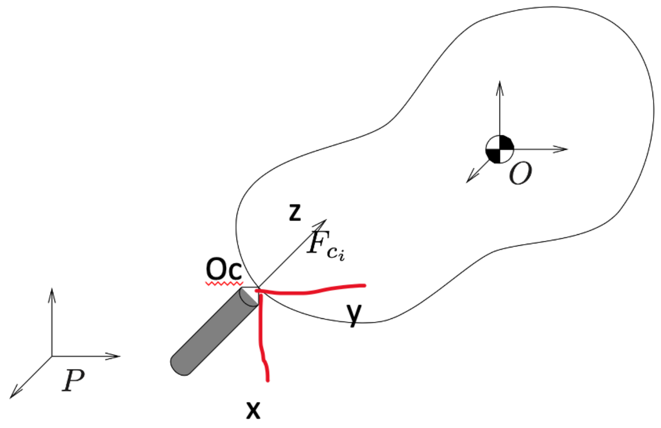
side view

Static Friction Coefficients for Some Common Materials

Steel on steel	0.58	Wood on wood	0.25-0.5
Polyethylene on steel	0.3–0.35	Wood on metals	0.2-0.6
Polyethylene on self	0.5	Wood on leather	0.3–0.4
Rubber on solids	1–4	Leather on metal	0.6

Point Contact with Friction Model

- Friction between fingertip and the object
- Wrench (force and torque) applied to the object with respect to a basis of directions



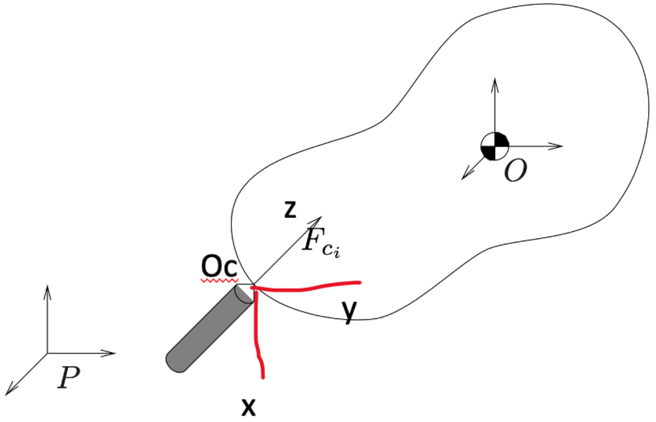
$$F_{c_i} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} f_{c_i} \qquad f_{c_i} \in FC_{c_i},$$

where

$$FC_{c_i} = \{f \in \mathbb{R}^3 : \sqrt{f_1^2 + f_2^2} \leq \mu f_3,\ f_3 \geq 0\}.$$

Soft-Finger Contact

- Forces and torques about that normal



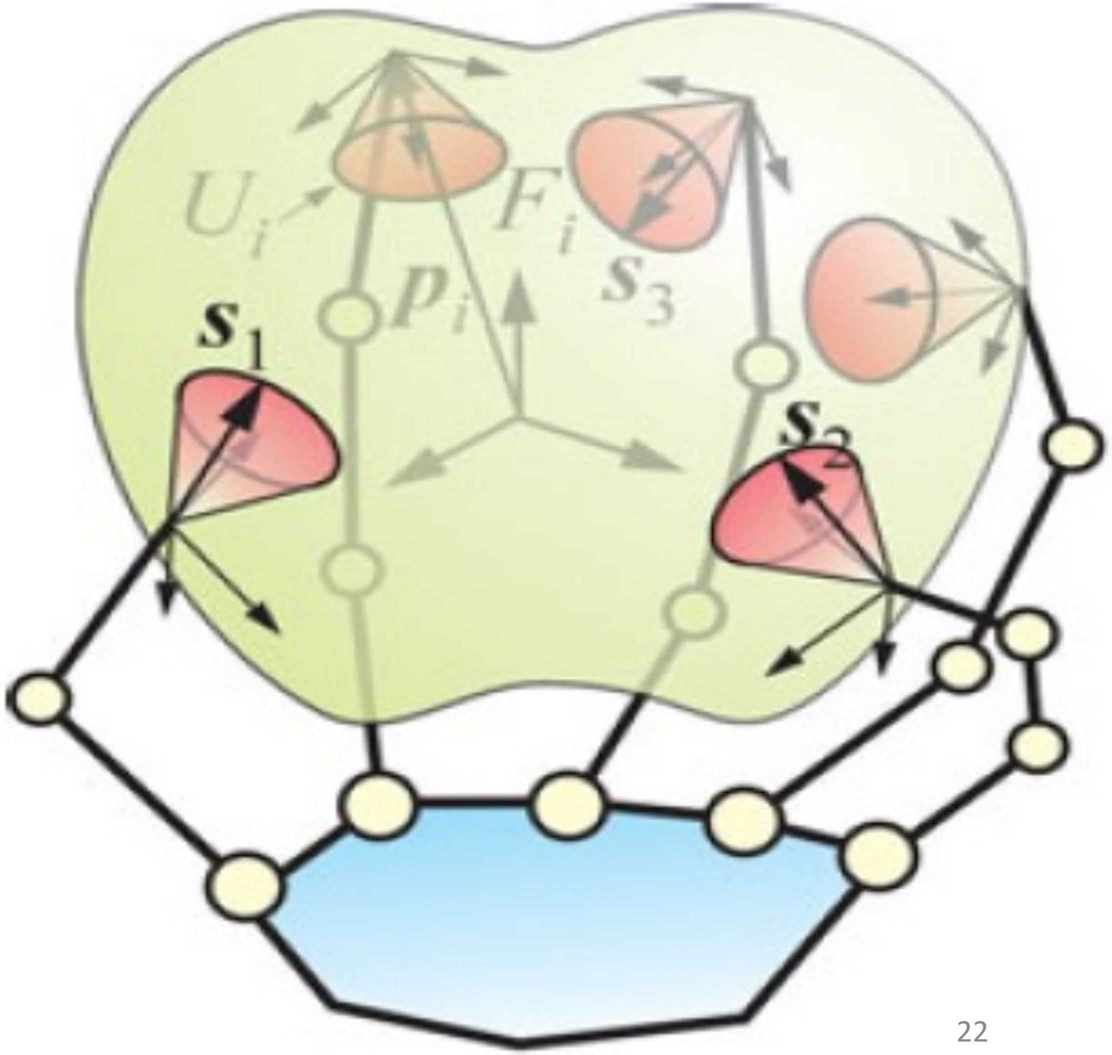
$$\cdots_i = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} f_{c_i} \qquad f_{c_i} \in FC_{c_i}$$

- Friction cone becomes (where γ > 0 is the coefficient of torsional friction)

$$FC_{c_i} = \{f \in \mathbb{R}^4 : \sqrt{f_1^2 + f_2^2} \leq \mu f_3,\ f_3 \geq 0,\ |f_4| \leq \gamma f_3\}$$

Grasping Problem with Multiple Fingers

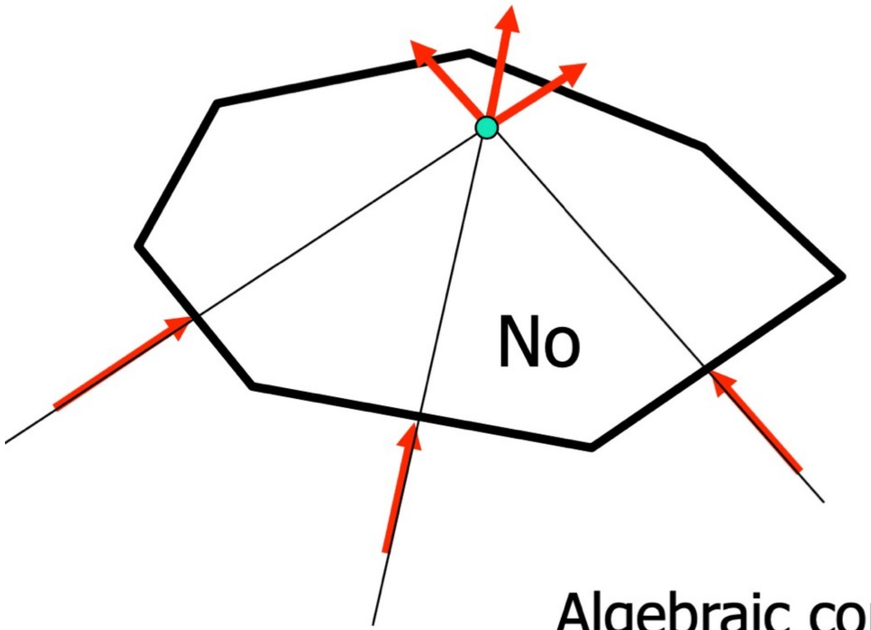
- Existence: given an object and constraints determine if closure exist
- Analysis: given an object and contacts determine if closure applies
- Synthesis: given an object, find contacts that result in closure

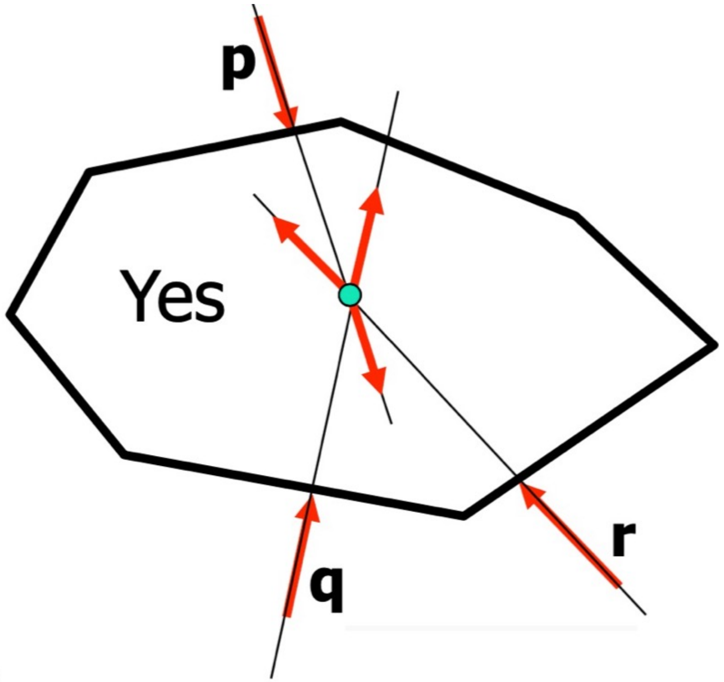


Grasping Problem with Multiple Contact Points

- Force closure: fingers resist any external force
- Torque closure: fingers resist any external torque
- Equilibrium: the contact forces can balance the object weight and external forces

Frictionless Point Contacts

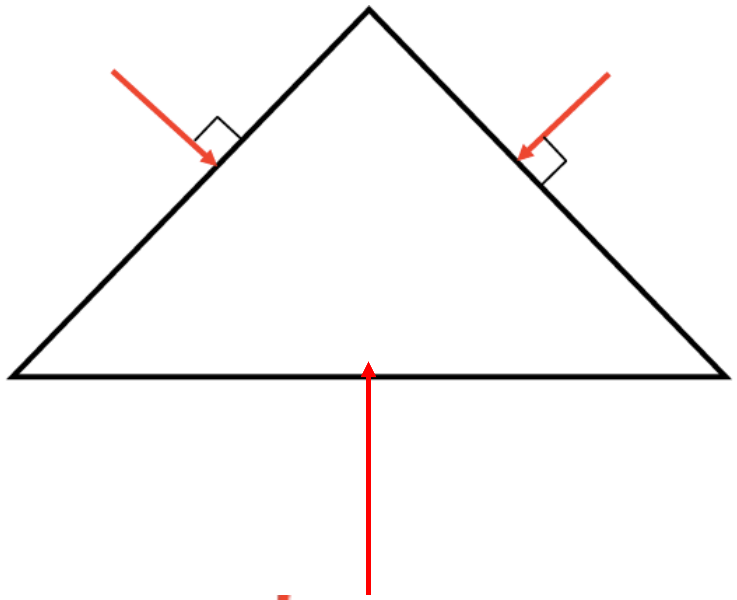


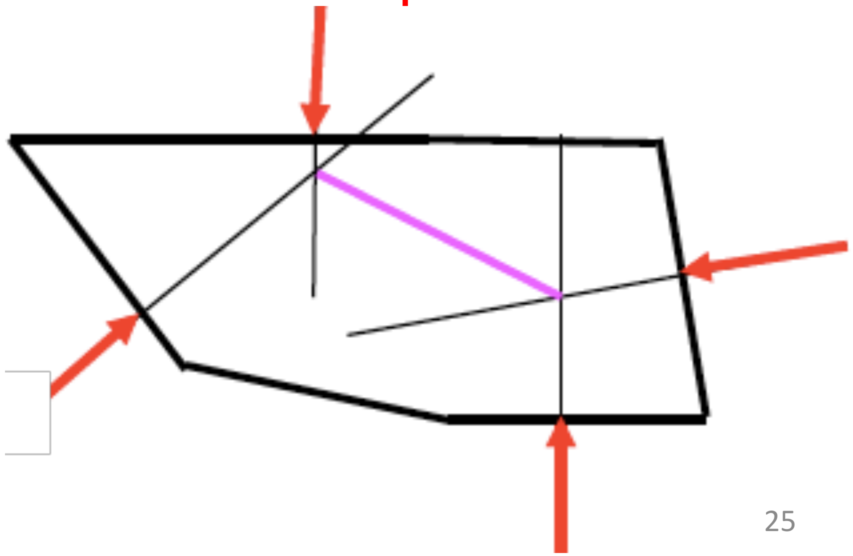


Algebraic condition?
For force vectors **p**, **q**, **r**,
there must exist $\alpha, \beta, \gamma > 0$
s.t. $\alpha\mathbf{p} + \beta\mathbf{q} + \gamma\mathbf{r} = 0$

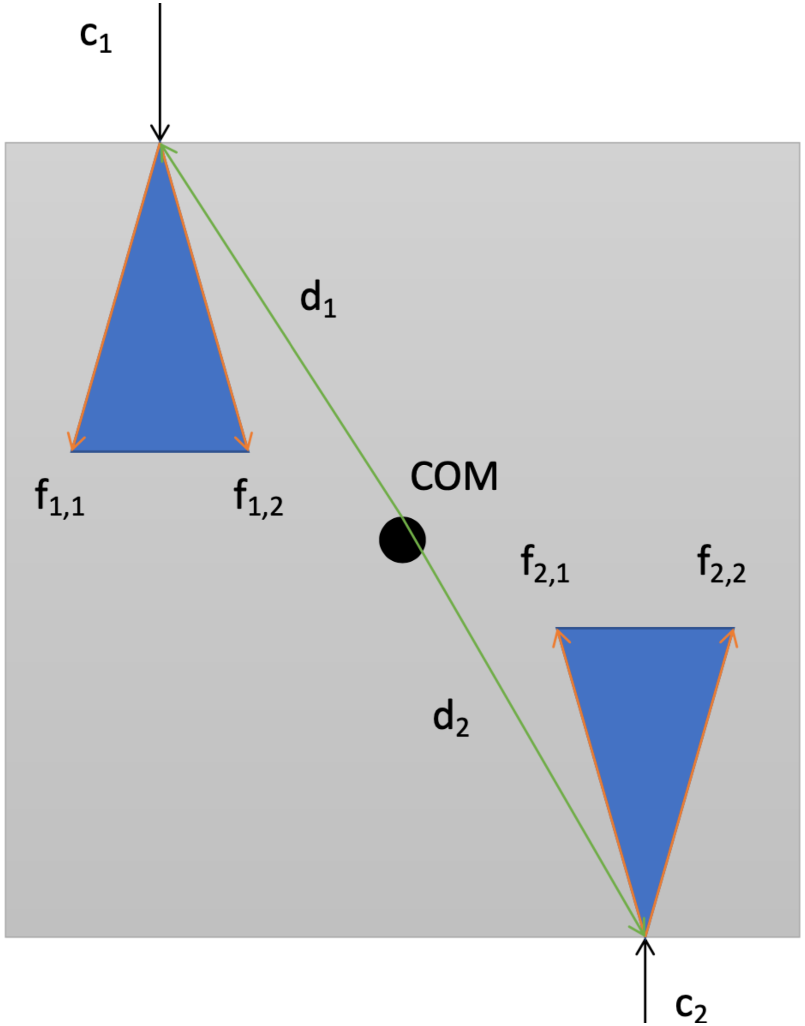
Frictionless Point Contacts

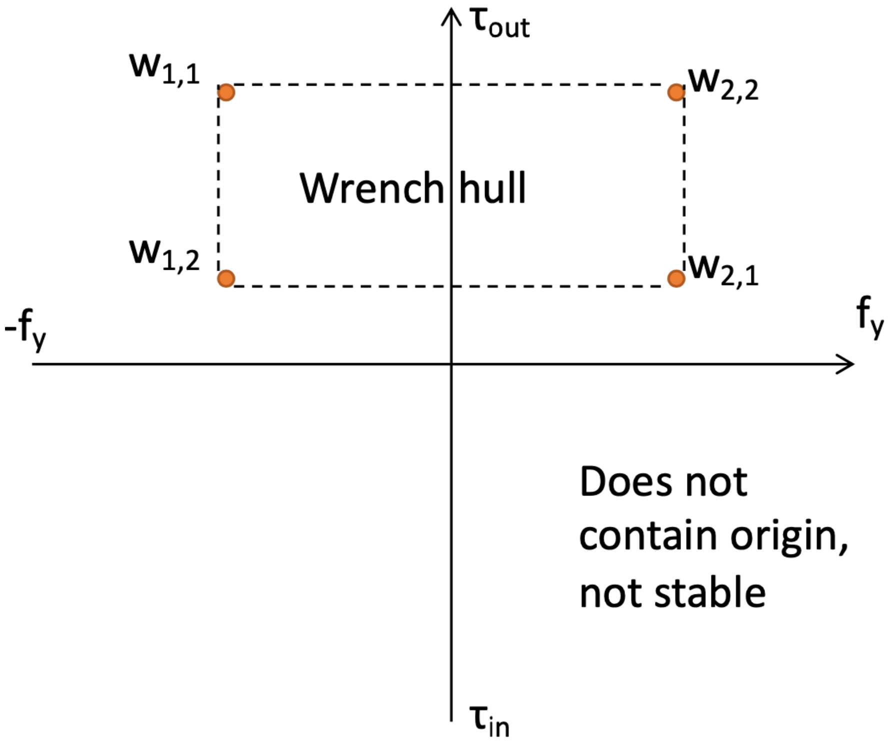
- Force must be normal to object boundary
- Force must point into object's interior
- Force-direction closure
  - Translate forces to center
  - They compose to generate any desired resultant force
- Torque closure
  - Translate forces to intersection points; they can be adjusted to point at each other and away from each other to generate torque





Friction Point Contact

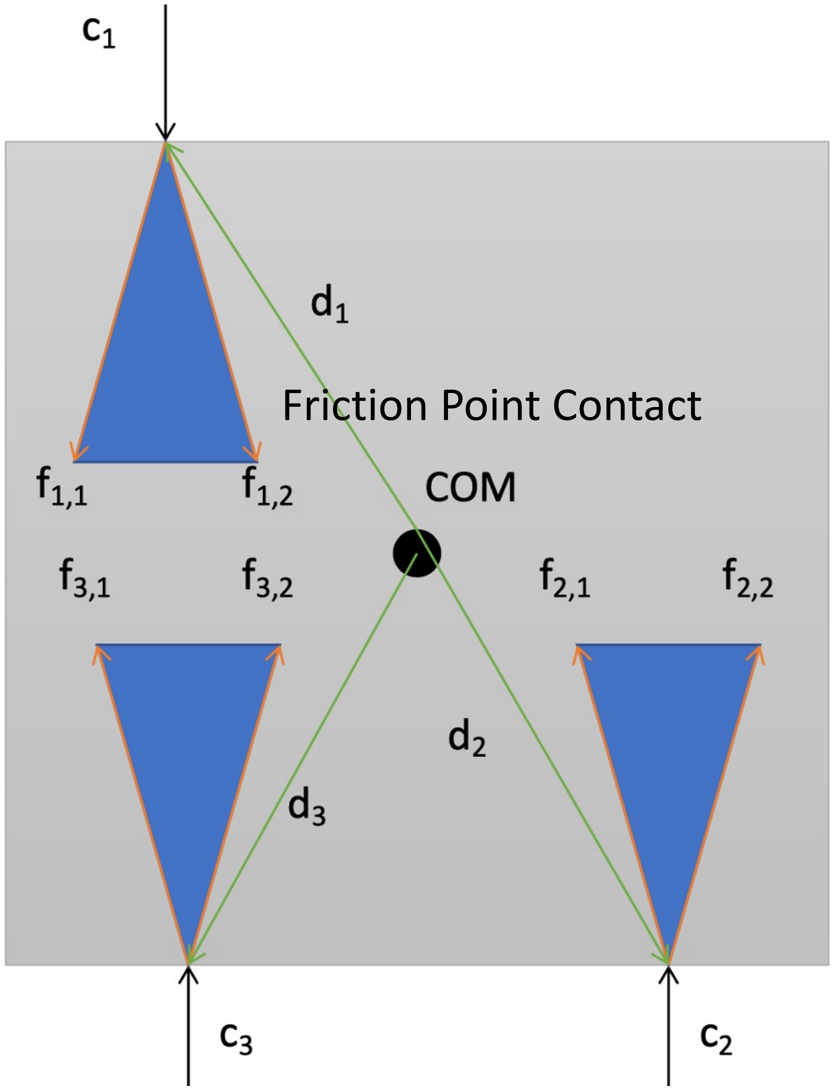


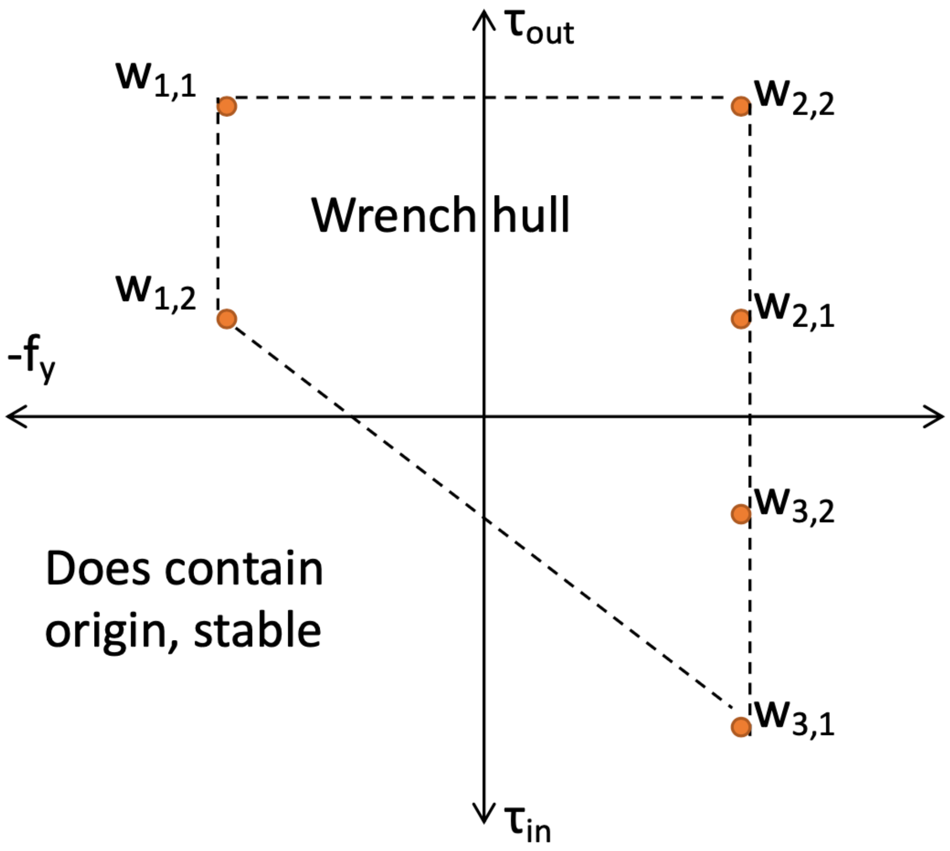


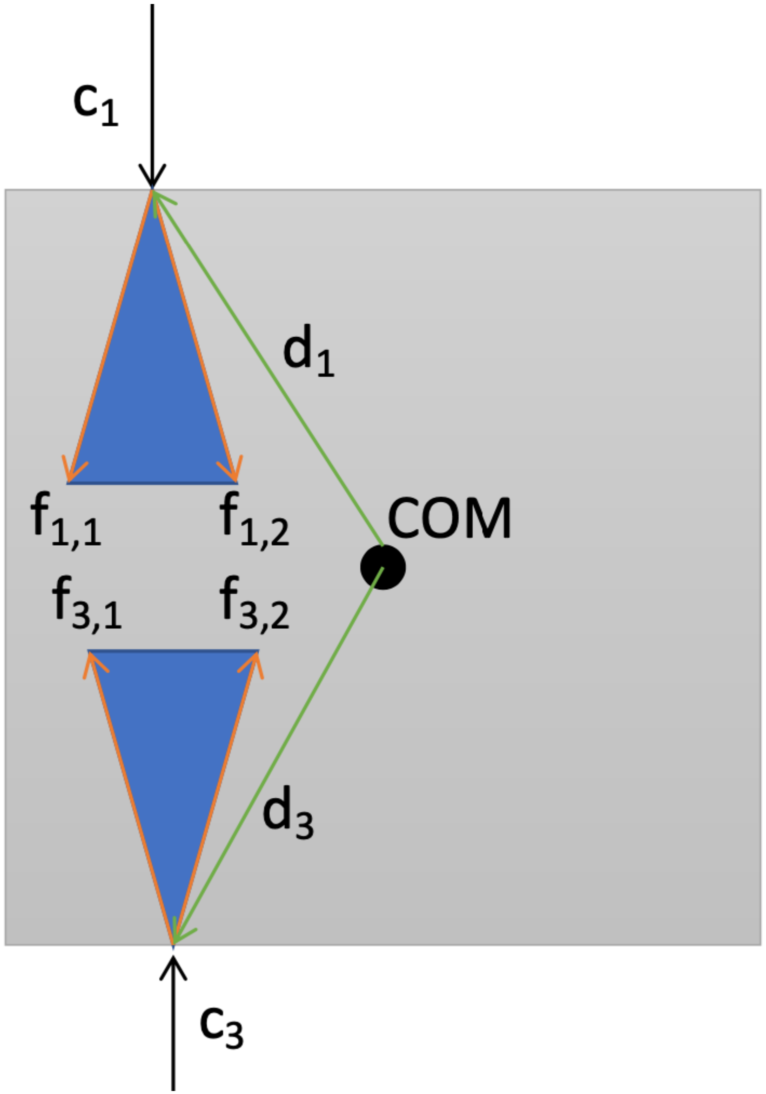
Does not contain origin, not stable

Fx is similar as f_y

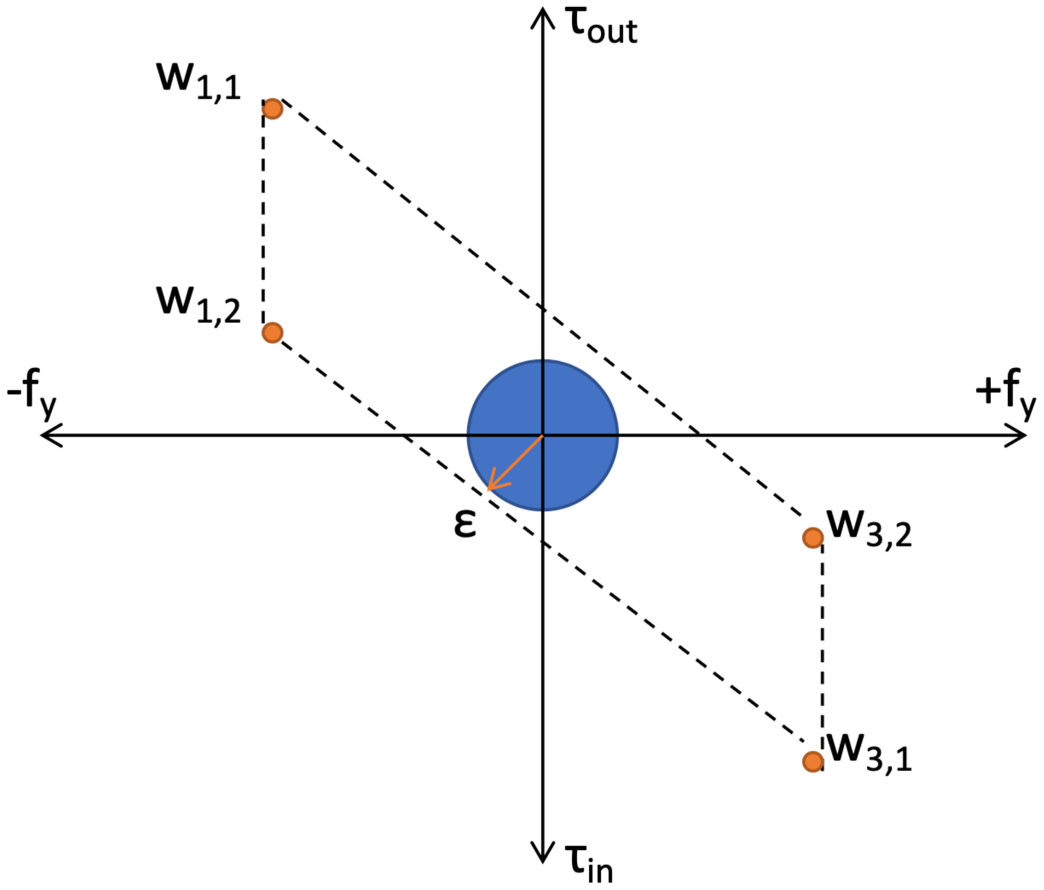
Friction Point Contact





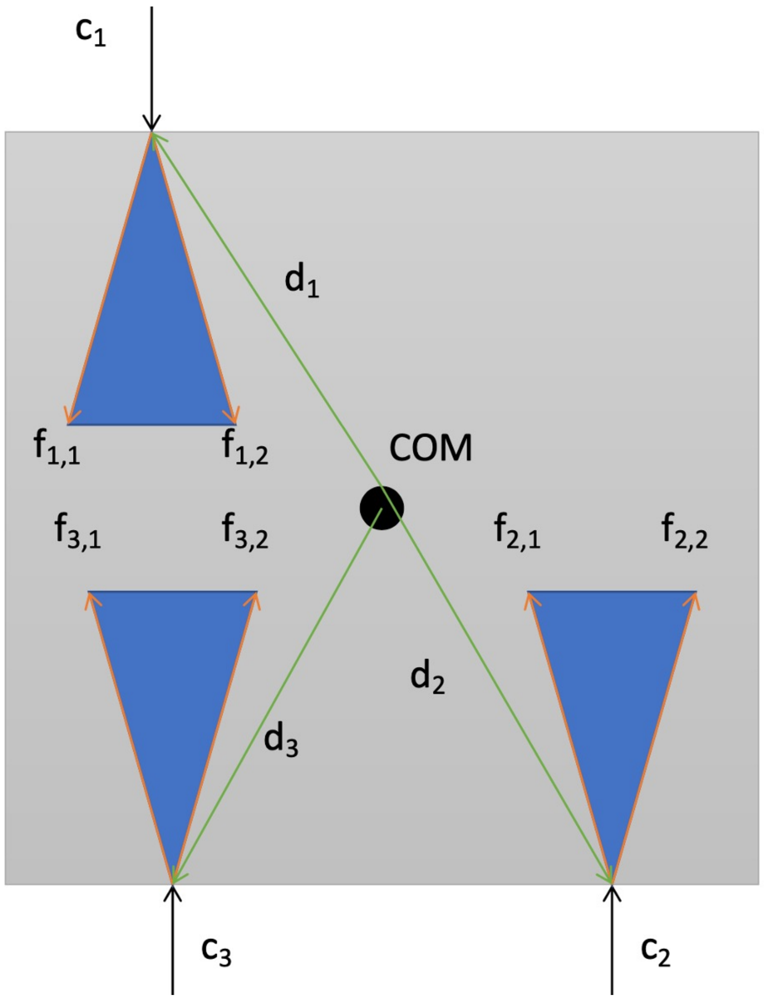


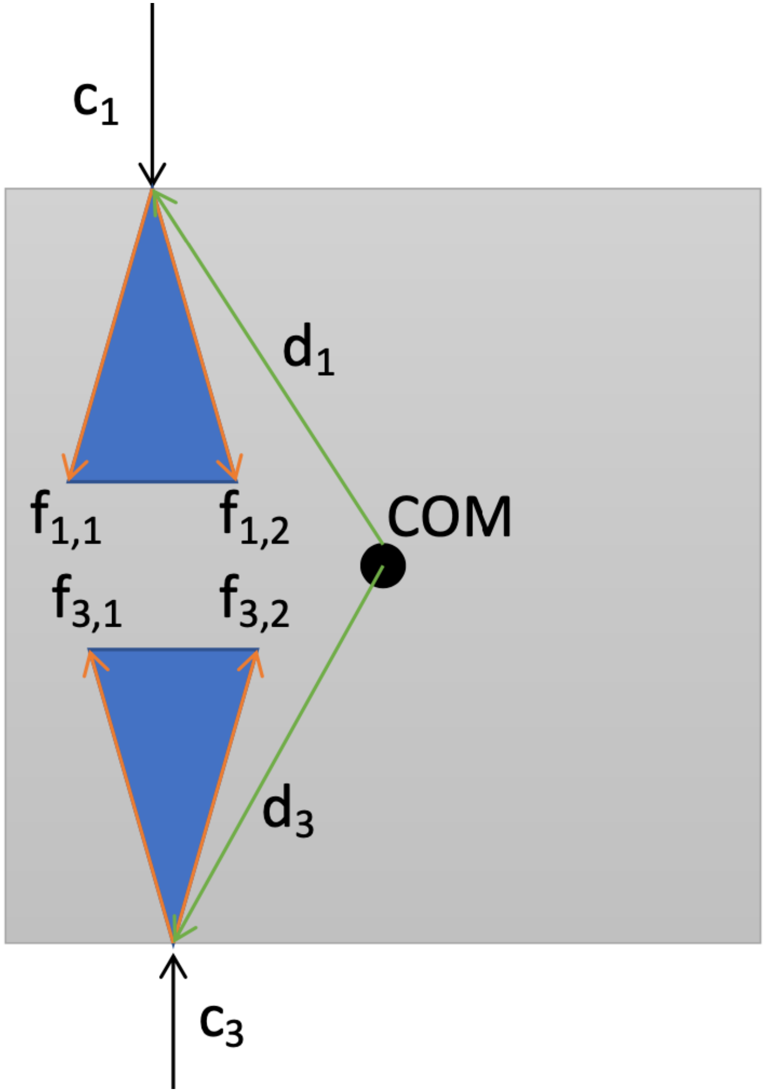
c_1
d_1
$f_{1,1}$
$f_{1,2}$
COM
$f_{3,1}$
$f_{3,2}$
d_3
c_3



τ_{out}
$w_{1,1}$
$w_{1,2}$
$-f_y$
$+f_y$
ε
$w_{3,2}$
$w_{3,1}$
τ_{in}

Comparing two grasps





Grasp

- A set of wrenches that can be achieved

$$F_o = G_1 f_{c_1} + \cdots + G_k f_{c_k} = \begin{bmatrix} G_1 & \cdots & G_k \end{bmatrix} \begin{bmatrix} f_{c_1} \\ \vdots \\ f_{c_k} \end{bmatrix}$$

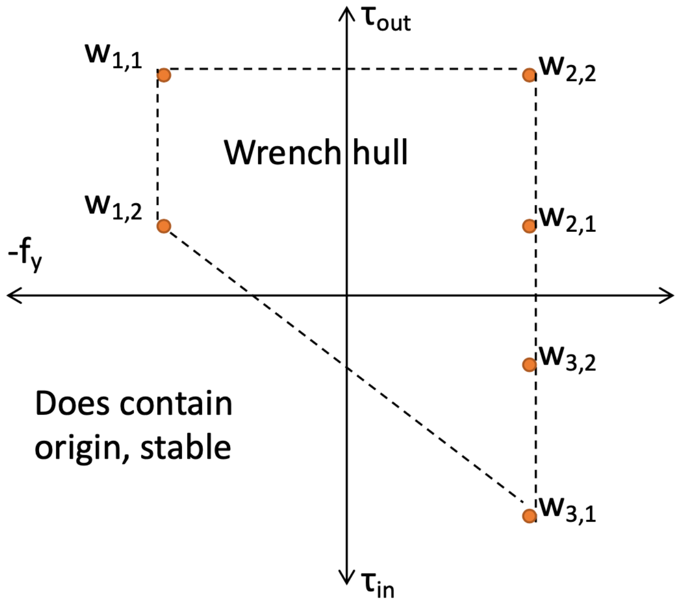
$$f_c \in FC$$

- G*i* = wrench basis matrix including transformation from local contact-reference frame to global object-centric reference frame
- *G*=[G*1* ...G*k*] =grasp map
  Transforming all applied forces and torques to achievable wrenches

Grasp Qualities - Force Closure

- Frictional properties of the object can be used to immobilize the object
- Test force closure

Input: Contact locations
Output: Is the grasp in Force-Closure? (Yes or No)
- Approximate the friction cone at each contact with a set of wrenches
- Combine wrenches from all cones into a set of points S in wrench space
- Compute the convex hull of S
- If the origin is inside the convex hull, return YES. If not, return NO.



- Intuition: the convex hull represents the positive linear combination of all the wrenches

Grasp Quality

- A grasp is a force-closure grasp IF for any external wrench W_t there exist contact forces $f_c \in F_c$ such that
- $G\,f_c = -W_t$
- i.e., if able to apply **sufficient force** at each contact, every external wrench can be compensated for.
- Quality is how well a grip can resist disturbances
- How little finger force you need to can resist disturbances

Grasp Quality

- Quality is how well a grip can resist disturbances
- Worst case scenario
  - How efficiently can a grip resist disturbance wrenches at its weakest point?
  - Weakest means the direction (in wrench space) at which the sum normal force is converted to the desired wrench least efficiently
- The point on the wrench hull that is closest to the origin is the weakest point
- Disturbances in the opposite direction are hardest to resist
- Metric ε = The radius of the largest ball that can be enclosed in the wrench hull
  - Varies from 0 to 1 due to normalization of wrenches