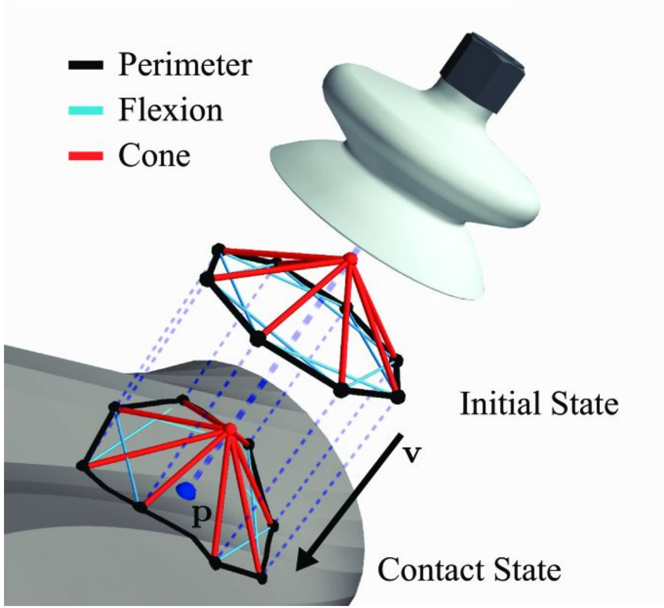
EECS 106B/206B
Robotic Manipulation and Interaction

Prof. Ruzena Bajcsy

INTRO TO GRASPING


baxter
CHEEZ-IT
ARE THESE CHEESES READY?
SPAM

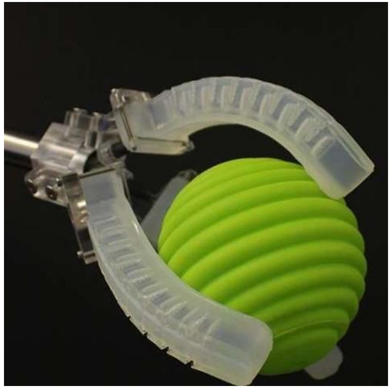

Perimeter
Flexion
Cone
Initial State
v
p
Contact State

Types of Grippers

Suction

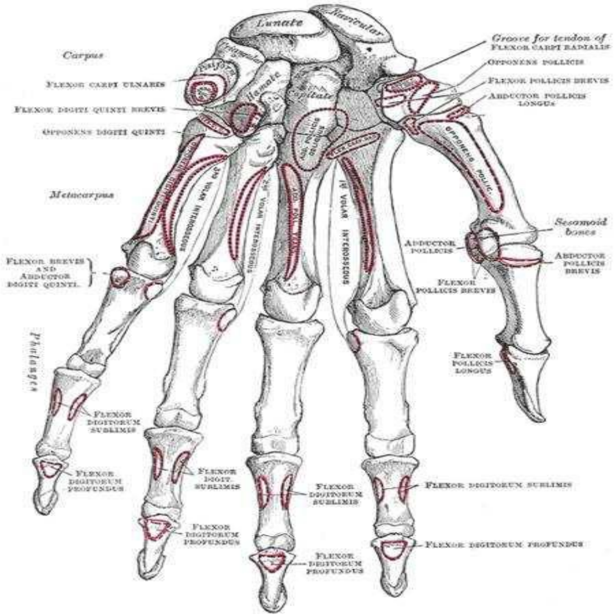
Parallel

Multi-Finger



Soft-Finger

Hand Function



Hand function:

- Interface with external world

Hand operation:

- Grasping
- Dextrous manipulation
- Fine manipulation
- Exploration

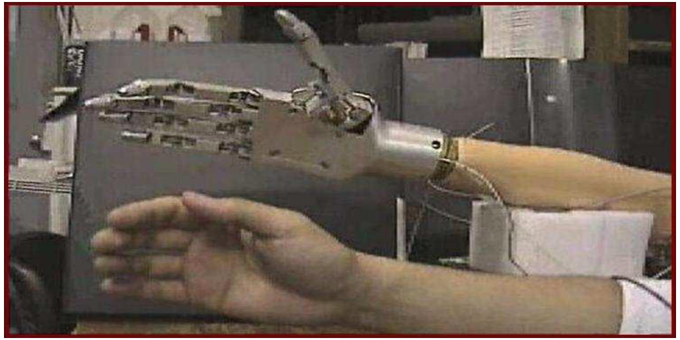
History of Hand Design

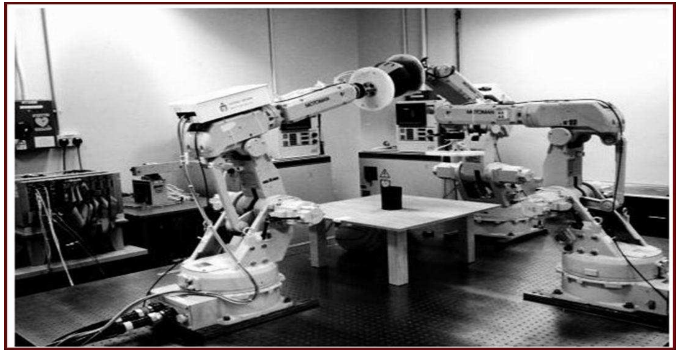
Prosthetic devices (1509)

Dextrous end-effectors

Multiple manipulator/agents coordination

Human hand study

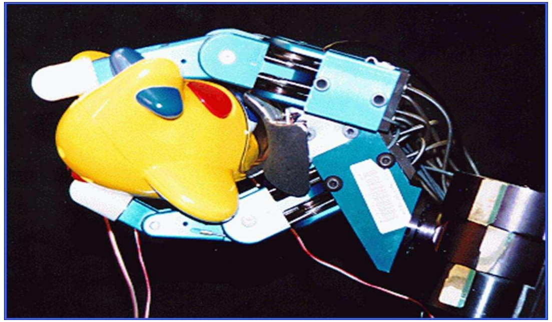




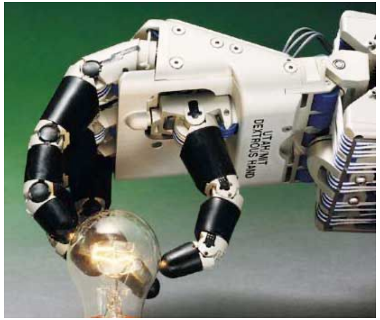
Hand Design Issues

- Mechanical systems
- Sensor/actuators
- Control hardware

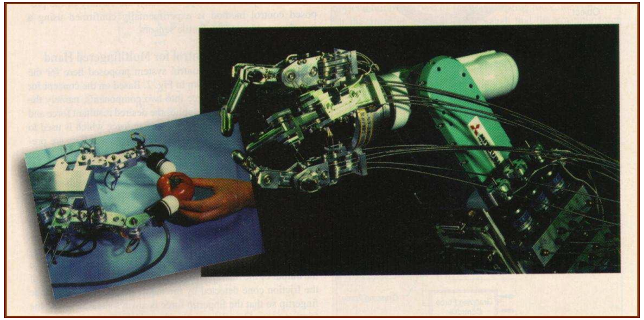
Example Hand Prototypes



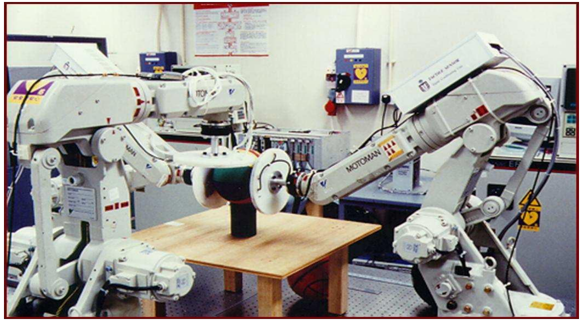
Salisbury



Utah-MIT

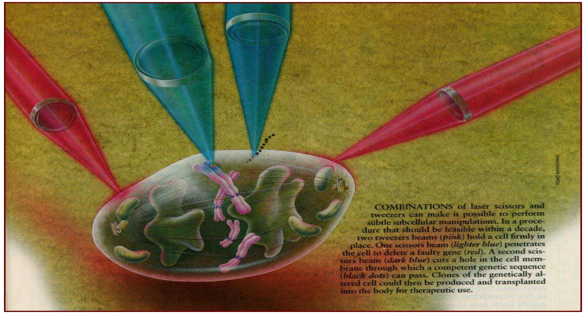


Toshiba



HKUST

DLR



Micro/Nano

Grasp Planning

A **contact** between a finger and an object can be described as a mapping between forces exerted by the finger at the point of contact and the resultant wrenches at some reference point on the object.

Imagine the 3 point contacts (in Figure A) to be the fingertips of a hand grasping an object, this arrangement will be referred to as a grasp.

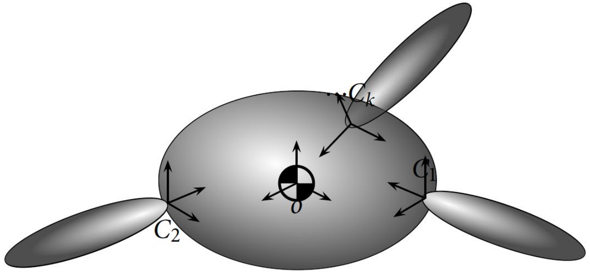


Figure A

Grasp Planning

Desirable Properties of a Grasp

- Ability to resist external forces
- Ability to dexterously manipulate the object

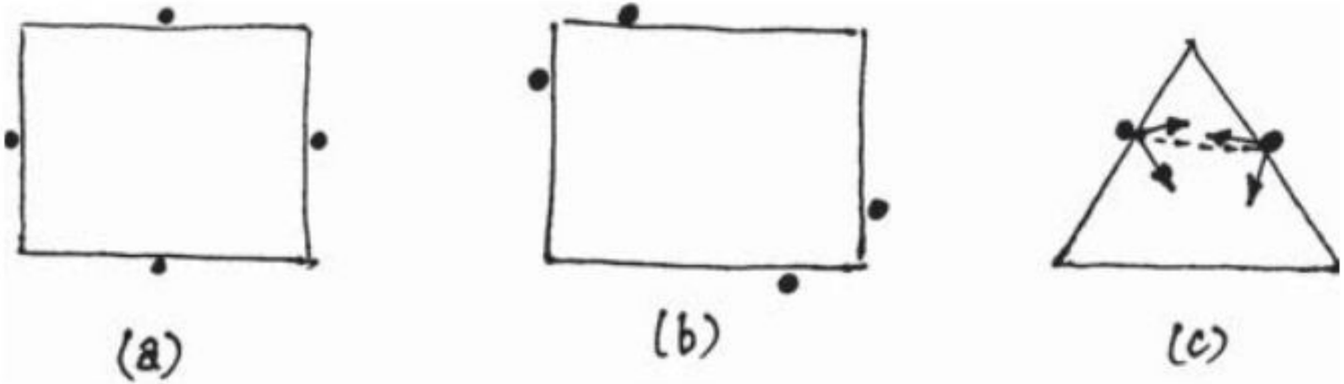
Assumptions for this lecture:

- Object is a rigid body
- Accurate models of the finger and object are given

Problems with Grasping

- Perceiving and identifying objects
- Designing end effectors
- Grasp planning (will the grasp work?)
  - Shape
  - Density
  - Material
- Grasp execution (how do we know it worked?)
  - Applying forces
  - Manipulating objects
  - Regrasping

2D Contact Models



a&b) A planar rigid body constrained by four frictionless point contact

c) A rigid body constrained by two point contacts with friction. Gravity acts downward

Finger Contacts

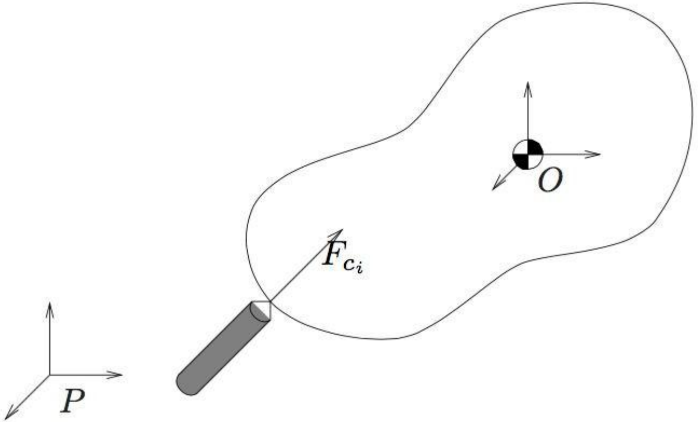
- How do we measure the effect of a multifingered grasp?

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

Force

Wrench Basis (B)

Weights

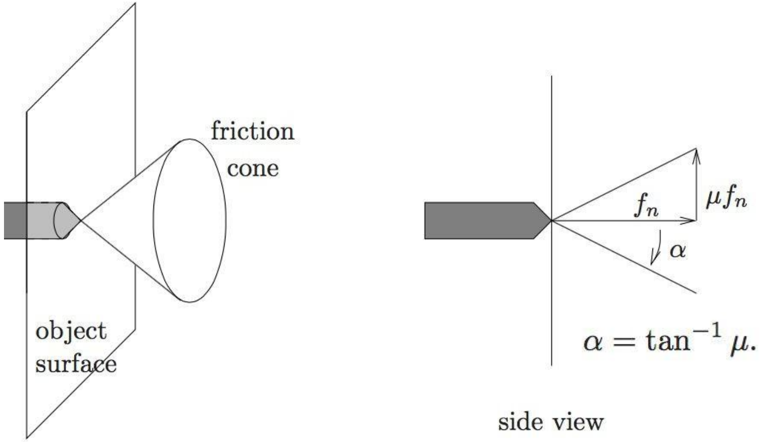


$$\boxed{F_{c_i} = B_{c_i} f_{c_i} \qquad f_{c_i} \in FC_{c_i}.}$$

Grasps with Friction

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

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



Torsional Friction

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

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

Multiple Fingers: Grasp Maps

Having multiple fingers means we should use the world frame, rather than individual contact frames. So we use the Adjoint:

$$F_o = \mathrm{Ad}^T_{g^{-1}_{oc_i}} F_{c_i} = \begin{bmatrix} R_{oc_i} & 0 \\ \widehat{p}_{oc_i} R_{oc_i} & R_{oc_i} \end{bmatrix} B_{c_i} f_{c_i}, \qquad f_{c_i} \in FC_{c_i}.$$

First, we define a contact map G:

$$G_i := \mathrm{Ad}^T_{g^{-1}_{oc_i}} B_{c_i}.$$

This maps the contact basis to a wrench in the world frame.

Combining multiple fingers

The net force on the object is:

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

We can redefine the array $\begin{bmatrix} G_1 & \cdots & G_k \end{bmatrix}$ as a new mapping:

$$G = \begin{bmatrix} \mathrm{Ad}^T_{g^{-1}_{oc_1}} B_{c_1} & \cdots & \mathrm{Ad}^T_{g^{-1}_{oc_k}} B_{c_k} \end{bmatrix} \qquad F_o = G f_c \qquad f_c \in FC$$

This is the grasp map, which maps an entire hand to a wrench in the world frame.

Force Closure

If a grasp can resist any applied wrench, we say that such a grasp is Force-closure. Formally,

Definition 5.2. Force-closure grasp
A grasp is a *force-closure* grasp if given any external wrench $F_e \in \mathbb{R}^p$ applied to the object, there exist contact forces $f_c \in FC$ such that

$$G f_c = -F_e.$$

Proposition 5.2. Necessity of internal forces
A grasp is force-closure if and only if G is surjective and there exists a vector of contact forces $f_N \in \mathcal{N}(G)$ such that $f_N \in \operatorname{int}(FC)$.

Proof. (Sufficiency) Choose $F_o \in \mathbb{R}^p$ and let f_c' be any vector such that $F_o = Gf_c'$. Since G is surjective, such an f_c' must exist. We will show that there exists an α such that $f_c' + \alpha f_N \in \operatorname{int}(FC)$. Notice that

$$\lim_{\alpha \to \infty} \frac{f_c' + \alpha f_N}{\alpha} = f_N \in \operatorname{int}(FC);$$

therefore, there exists α' sufficiently large such that

$$\frac{f_c' + \alpha' f_N}{\alpha'} \in \operatorname{int}(FC) \subset FC.$$

From the properties of the friction cone, it follows that

$$f_c := f_c' + \alpha' f_N \in \operatorname{int}(FC)$$

and $Gf_c = Gf_c' = F_o$.

Force Closure

Proposition 5.3. Convexity conditions for force-closure grasps
Consider a fixed contact grasp which contains only frictionless point contacts. Let $G \in \mathbb{R}^{p \times m}$ be the associated grasp matrix and let $\{G_i\}$ denote the columns of G. The following statements are equivalent:

1. *The grasp is force-closure.*
2. *The columns of G positively span $\mathbb{R}^p$.*
3. *The convex hull of $\{G_i\}$ contains a neighborhood of the origin.*
4. *There does not exist a vector $v \in \mathbb{R}^p$, $v \neq 0$, such that for $i = 1, \ldots, m$, $v \cdot G_i \geq 0$.*

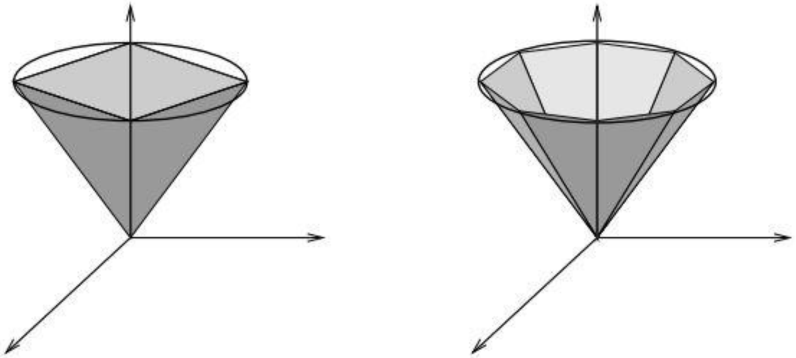
Limitations of Force Closure

- Assumes you can move fingers in any direction
- Assumes you can exert as much as infinite force
- Sometimes it’s better to execute suboptimal grasps

Approximating the Friction Cone

Why would you do this?

$$f_i = \begin{bmatrix} \mu \cos \frac{2\pi i}{n} \\ \mu \sin \frac{2\pi i}{n} \\ 1 \end{bmatrix}$$

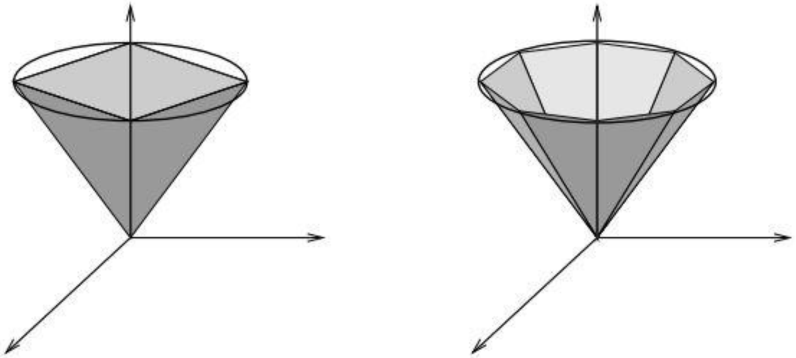


Approximating the Friction Cone

Why would you do this?

You can simplify the constraints to a **Positive** linear combination of facet vectors

$$f_i = \begin{bmatrix} \mu \cos \frac{2\pi i}{n} \\ \mu \sin \frac{2\pi i}{n} \\ 1 \end{bmatrix}$$



Sources

MLS Ch 3

Chapter 5 Lecture Notes for A Mathematical Introduction to Robotic Manipulation by Z.X. Li and Y.Q. Wu