6.141:
Robotics systems and science
Lecture 14: Grasping and Manipulation

Lecture Notes Prepared by Daniela Rus

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EECS/MIT

Spring 2012

Reading: Chapter3, Craig: Robotics

http://courses.csail.mit.edu/6.141/

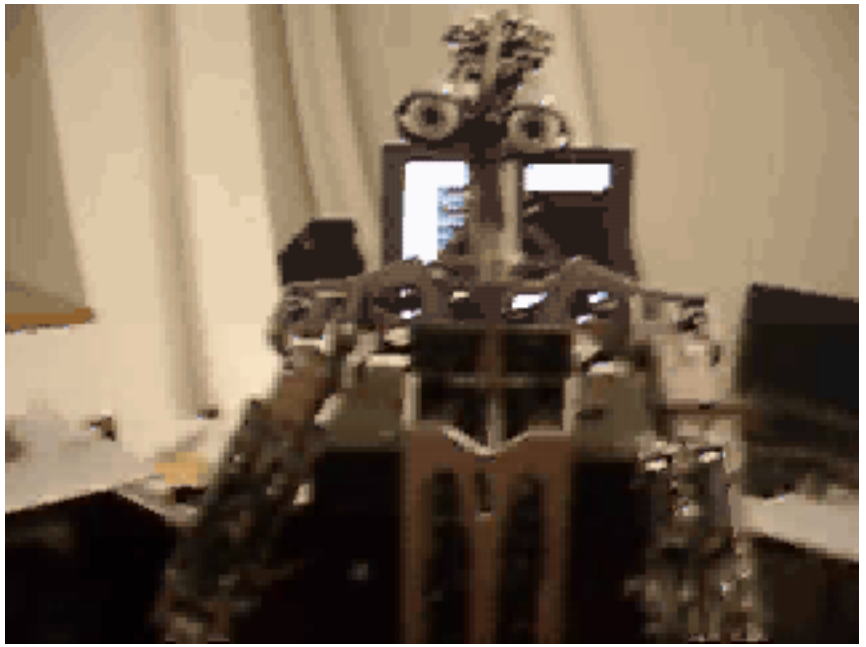
Challenge: Build a Shelter on Mars

Last 2 modules were about

- High-level planning
- Localization
- Challenge

Today

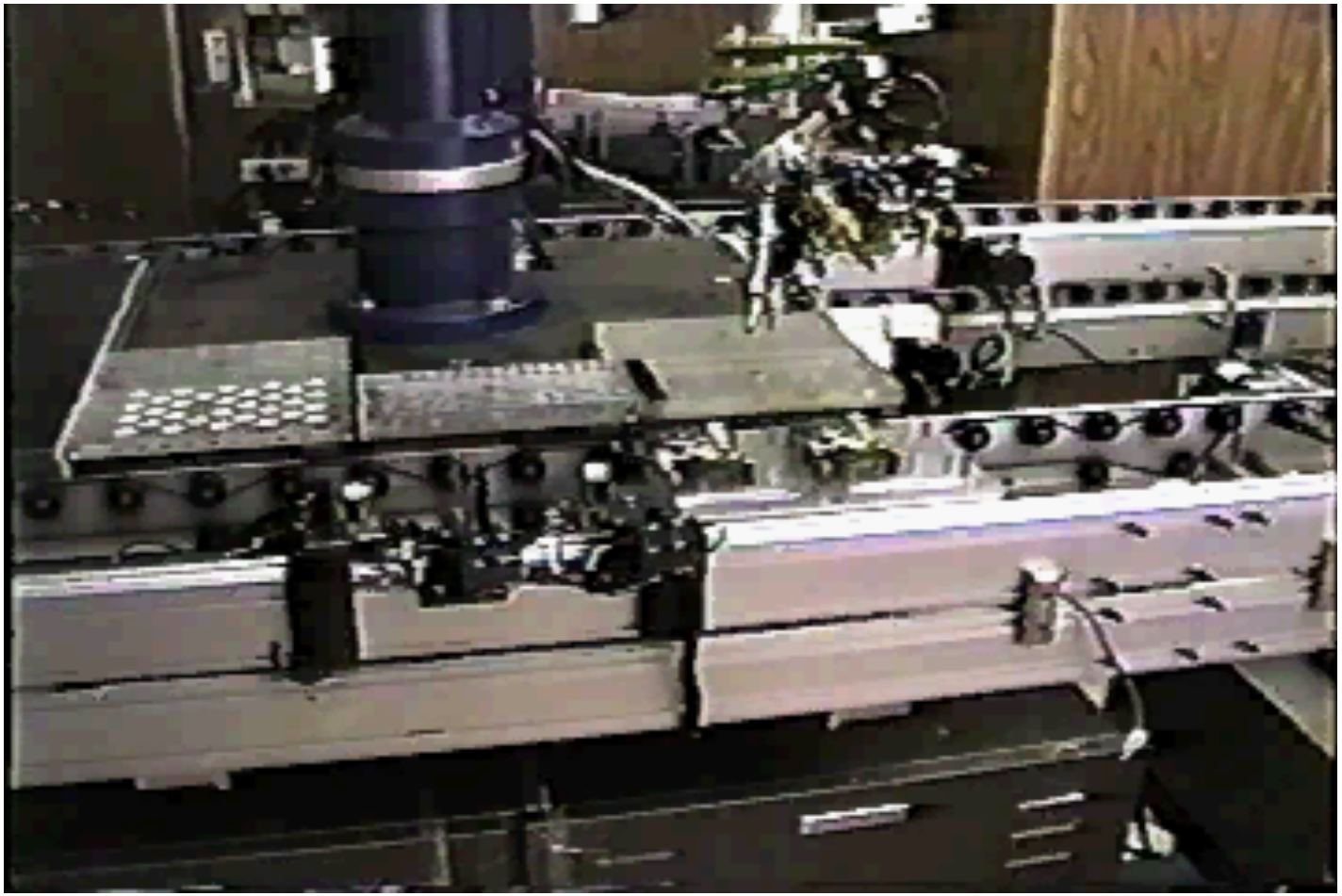
- Intro to debates
- Robot grasping
- Reading: chapters 3, 6



Debates

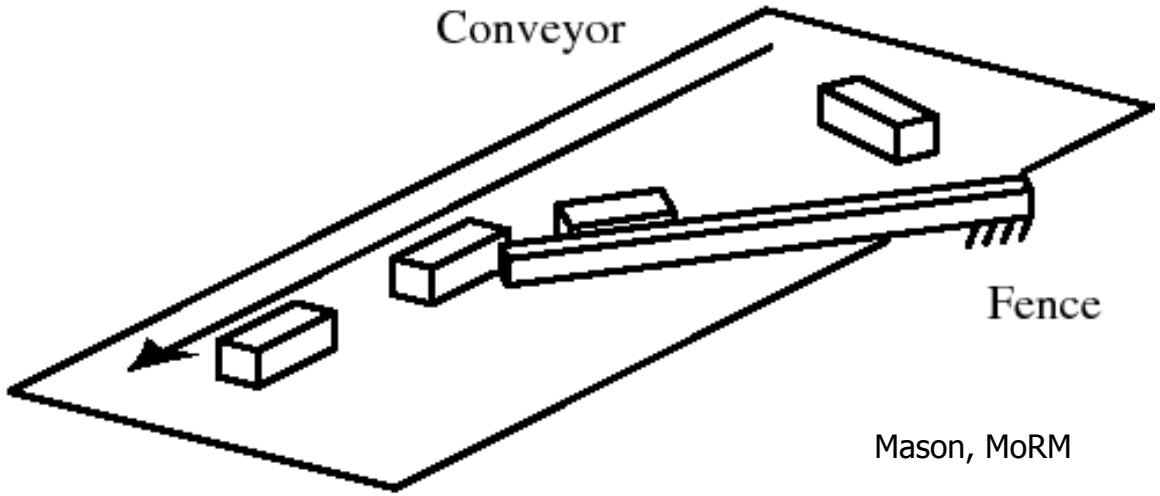
- Posted on the Web,
- Pick topic by emailing kbates@csail.mit.edu by Friday April 6
- Debates shall be organized as follows:
  - **Constructive Speeches:** Affirmative: 7 min Negative: 7 min
  - **Rebuttal Speeches:** Affirmative: 3 min Negative: 3 min
  - **Discussion and Cross-Examination (4 minutes).**
    - When debating in teams, the constructive and rebuttal presentations may be shared by the team members.
    - Time will be kept using the briefing timer.
- Do not argue by authority, use technical arguments
- Rules of Evidence
  In debate, source citations of evidence must be stated the first time a source is used.
- Rules of Evidence Authenticity
  - Evidence must not be fabricated or distorted.
    - Fabrication means falsely representing a cited fact or statement of opinion as evidence; or intentional omission/addition of information within quoted material.
    - Distortion means misrepresentation of evidence or of citation which significantly alters meaning.

Grasping and Manipulation



Fixturing

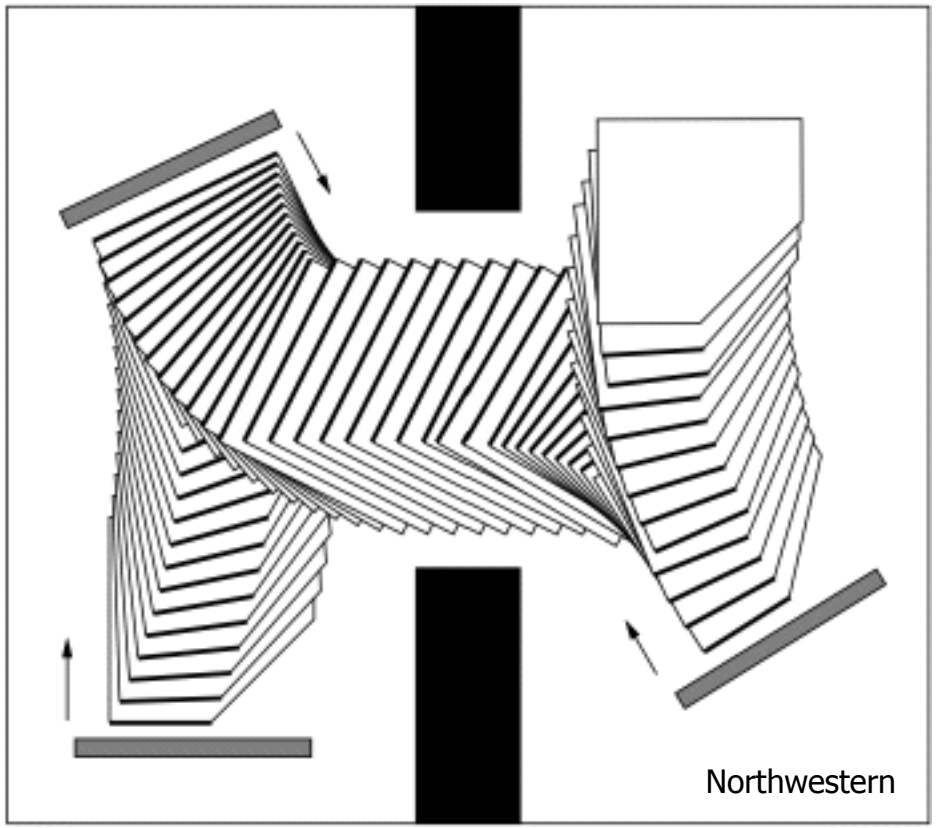
- Use of designed pegs, surfaces, prior knowledge of manipuland geometry to achieve desired pose



Mason, MoRM

Manipulation by Pushing

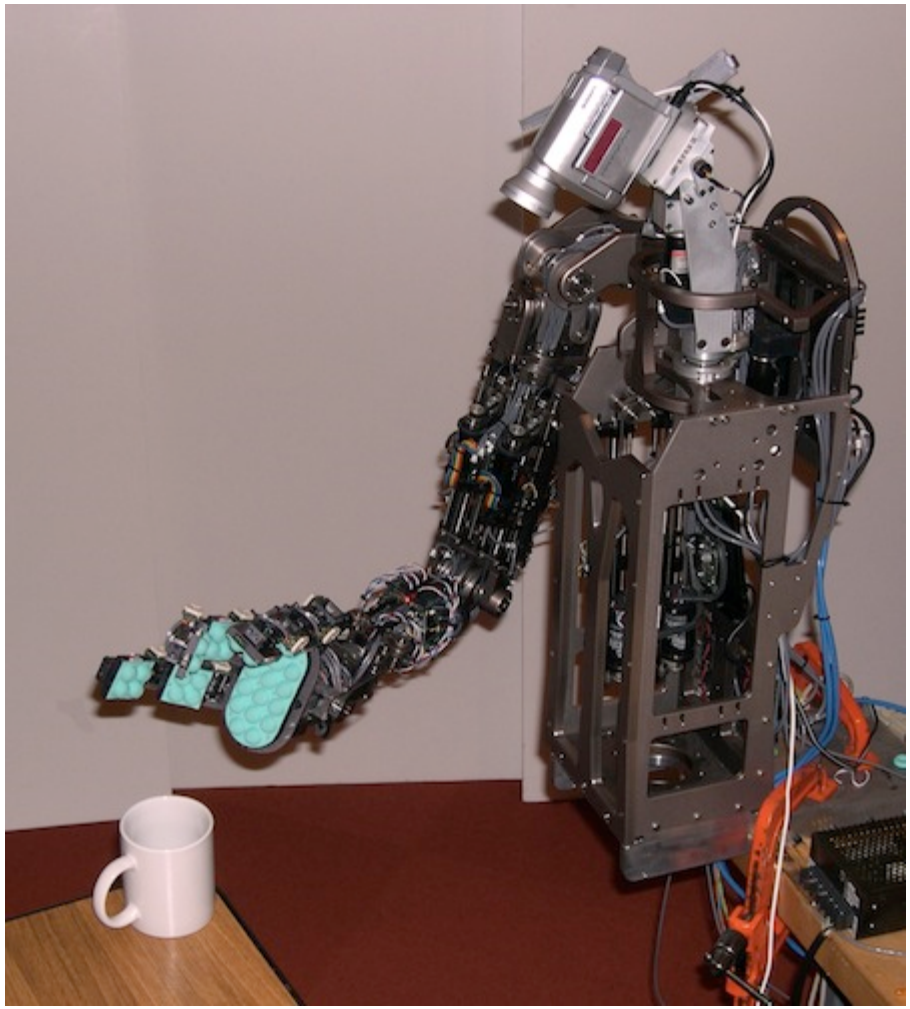
- Stable push:
  - Motions that keep object in line contact w/ manipulator



  - Motion planning, but with additional constraints

Soft-finger Manipulation

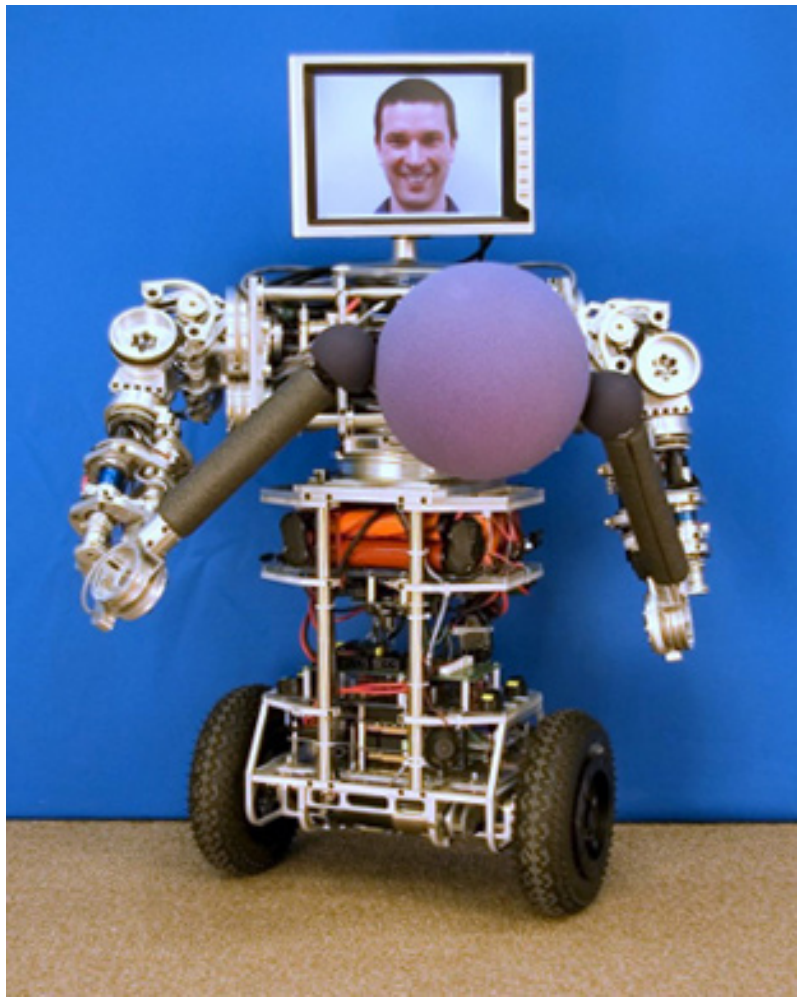
- Can exploit visual/tactile sensing & feedback



Obrero / MIT

Mobile, Two-handed Manipulation

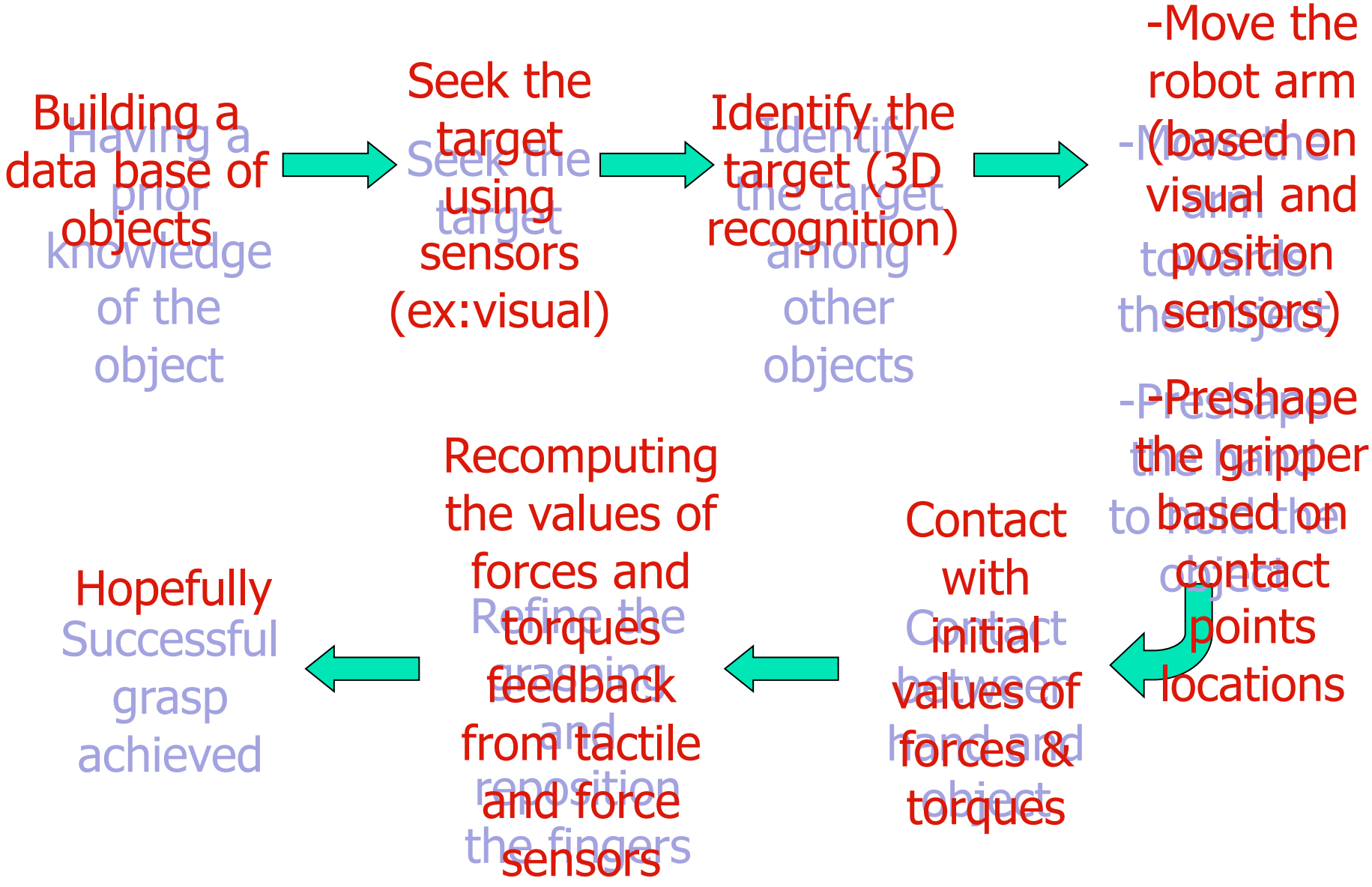
- Challenges: mass distribution; uncertainty



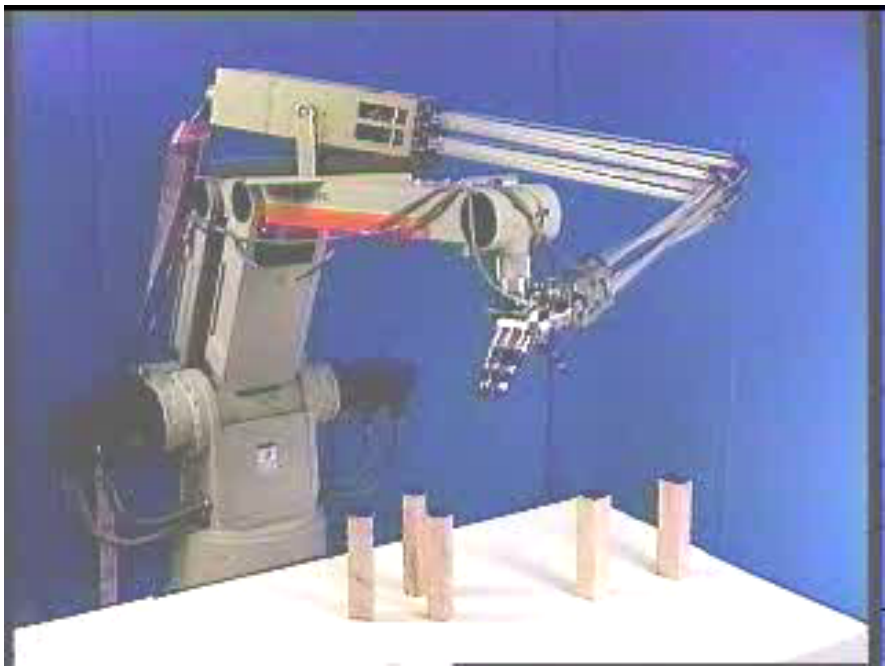
uBot / UMass Amherst

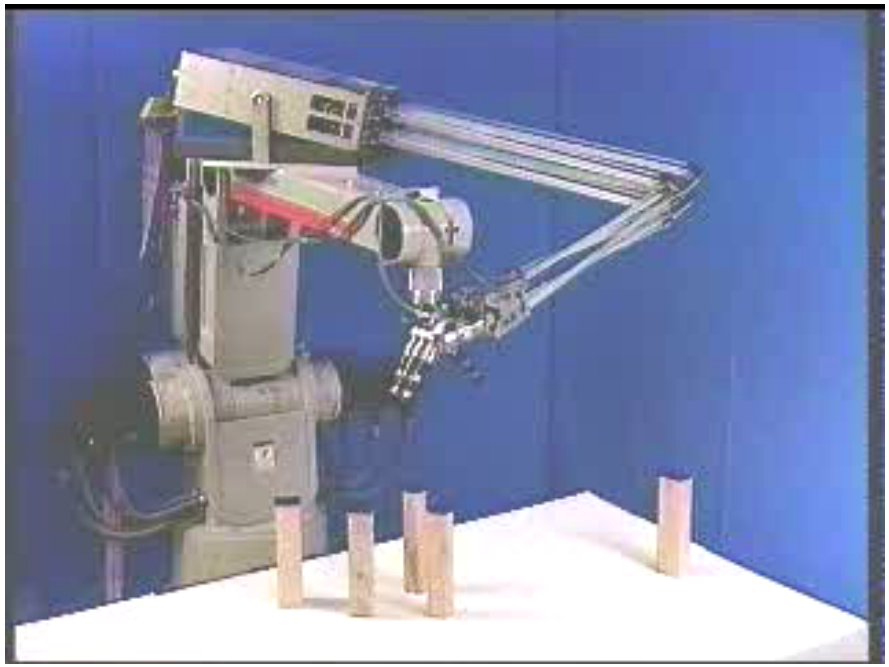
What is the equivalent sequence of grasping for a Robot

How human achieves grasping



Problems

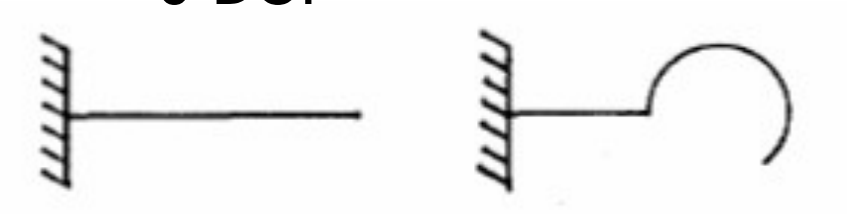




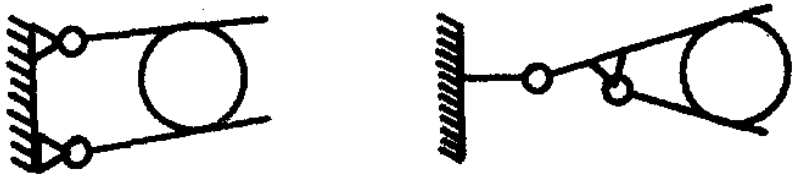
How does the robot reach for the object?
How does the robot grab the object?
How does the robot move the object?

Different Grasping Models

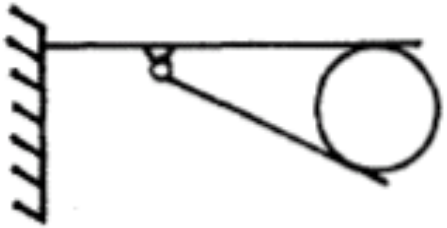
0 DOF



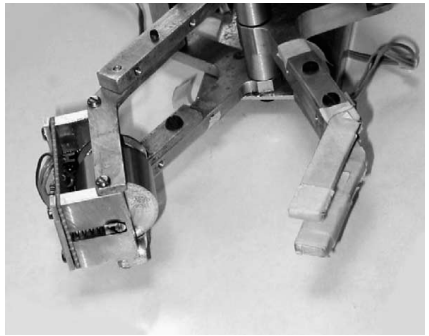
2 DOF

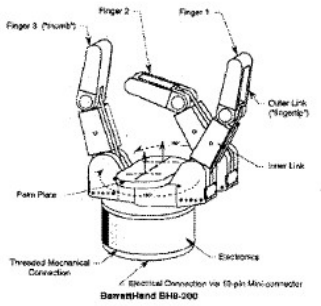


1 DOF



Many DOF

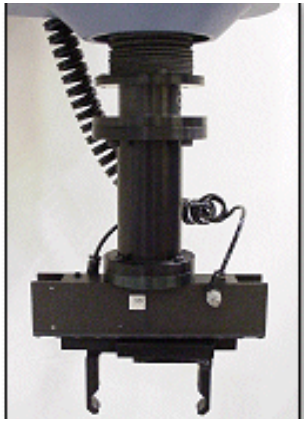




Grippers vs. Hands

- Structured environments
- Reliable
- Simple
- Low cost





- Unstructured environments
- Adaptable
- Complex
- Expensive



Grasping Elements

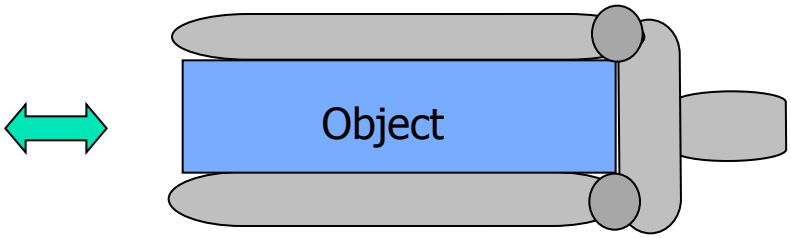
Human Arm Hand

Robot

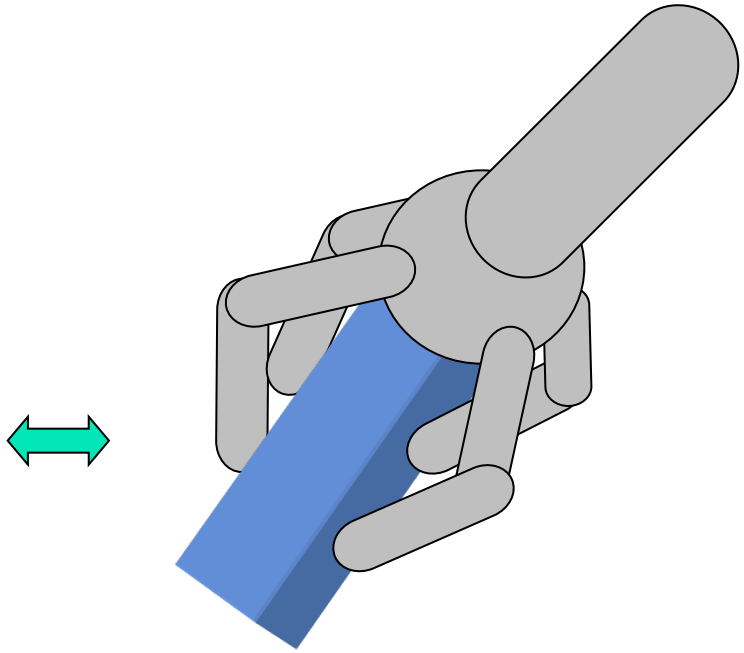
- Elements — Finger links, sensors, actuators → Design
- Function — Grasp, Manipulation → Mechanical analysis, Motion planning
- Control — Motion, Force → Mechanism control

Using a Gripper

- Simple tasks such as welding, carrying etc.



- Dexterous and fine manipulation tasks such as assembling



Methodologies and sensors

Slip Detection

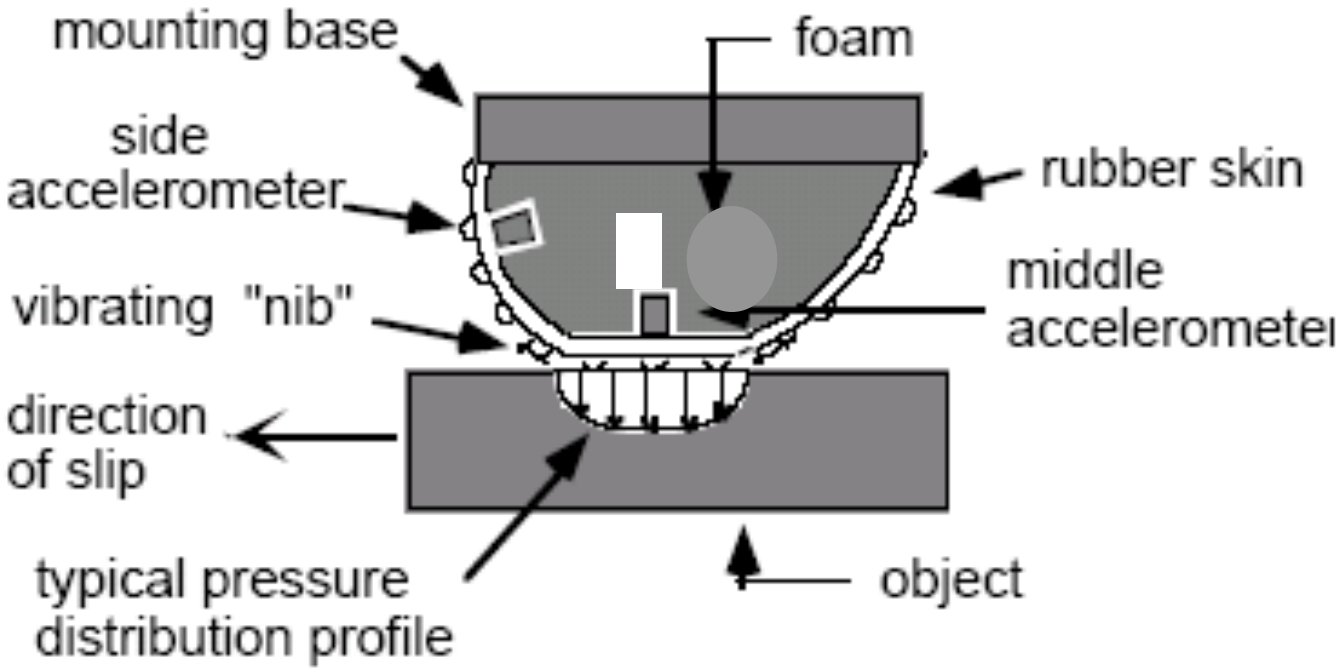
- By detecting local vibration using accelerometer
- By detecting secondary slip between rubber and gripper
- By studying the change in normal & shear stress curves using ANN

Closure Grasps

Selecting the contact point location that can resist any external force or torque

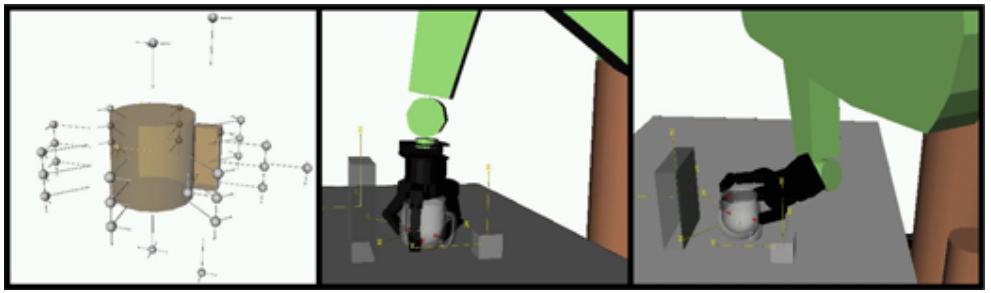
- Heuristic approach
- Synthesis approach
- Grasp Eigenvalues

Slip Detection: local vibration w/ accelerometers



Grasping Synthesis

- Using end-effectors (fingers) to immobilize something relative to the hand
- Issues:



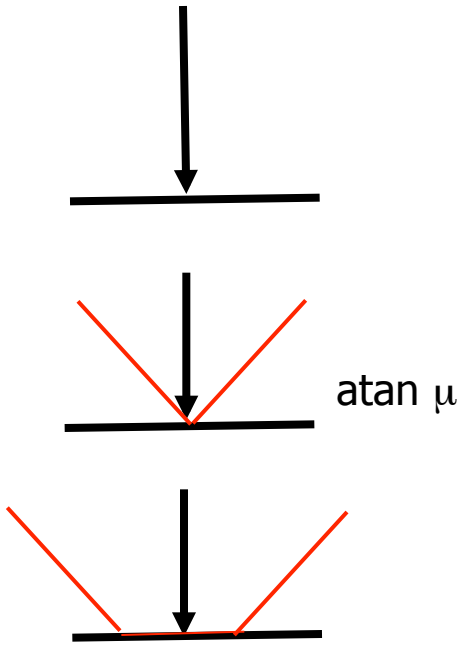
- What contacts?
- Where to place the contact points?
- What grasp properties?

Grasp Types

- 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

Finger types

- Point contact with friction
- Hardfinger Contact
- Softfinger Contact

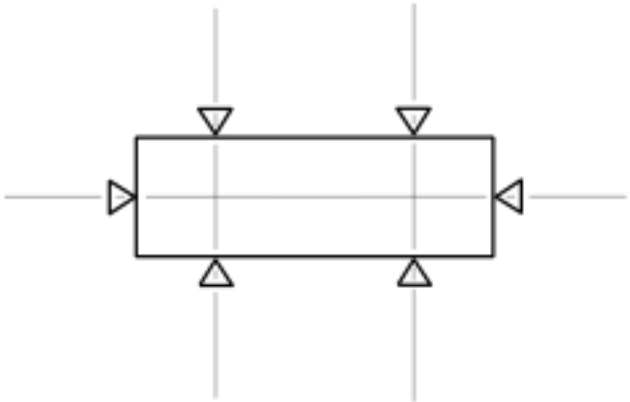


Issues in Grasp Design

- 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

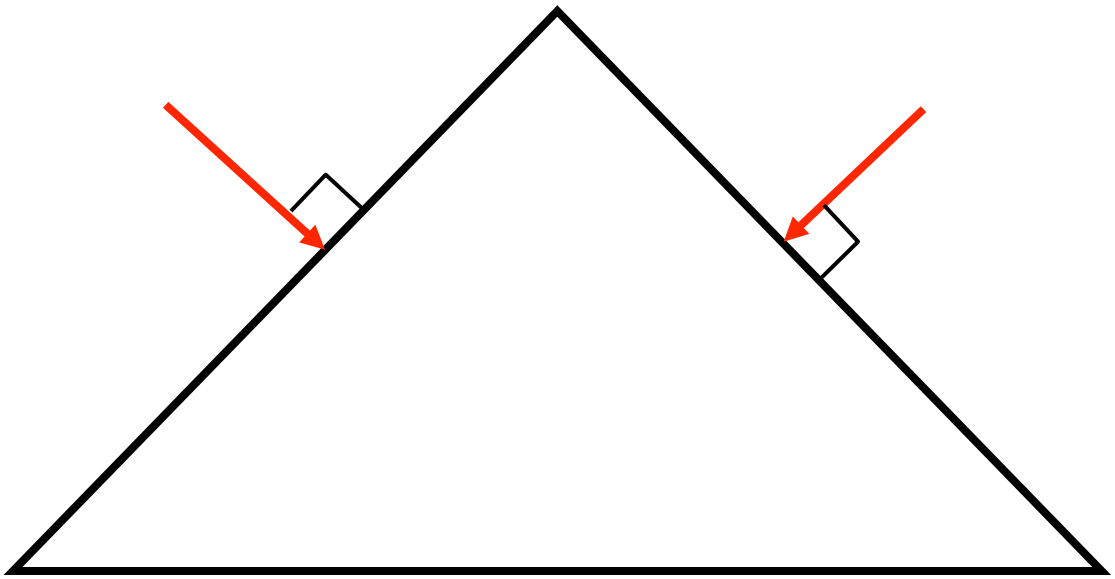
Existence

- Given an object, does it have a force-closure grasp?
- Theorem1 (Mishra, Schwartz, Sharir): for any bounded object that is not a surface of revolution a force closure grasp exists
- Theorem2 (Mishra, Schwartz, Sharir): at most 6 fingers in 2d, 12 fingers in 3d



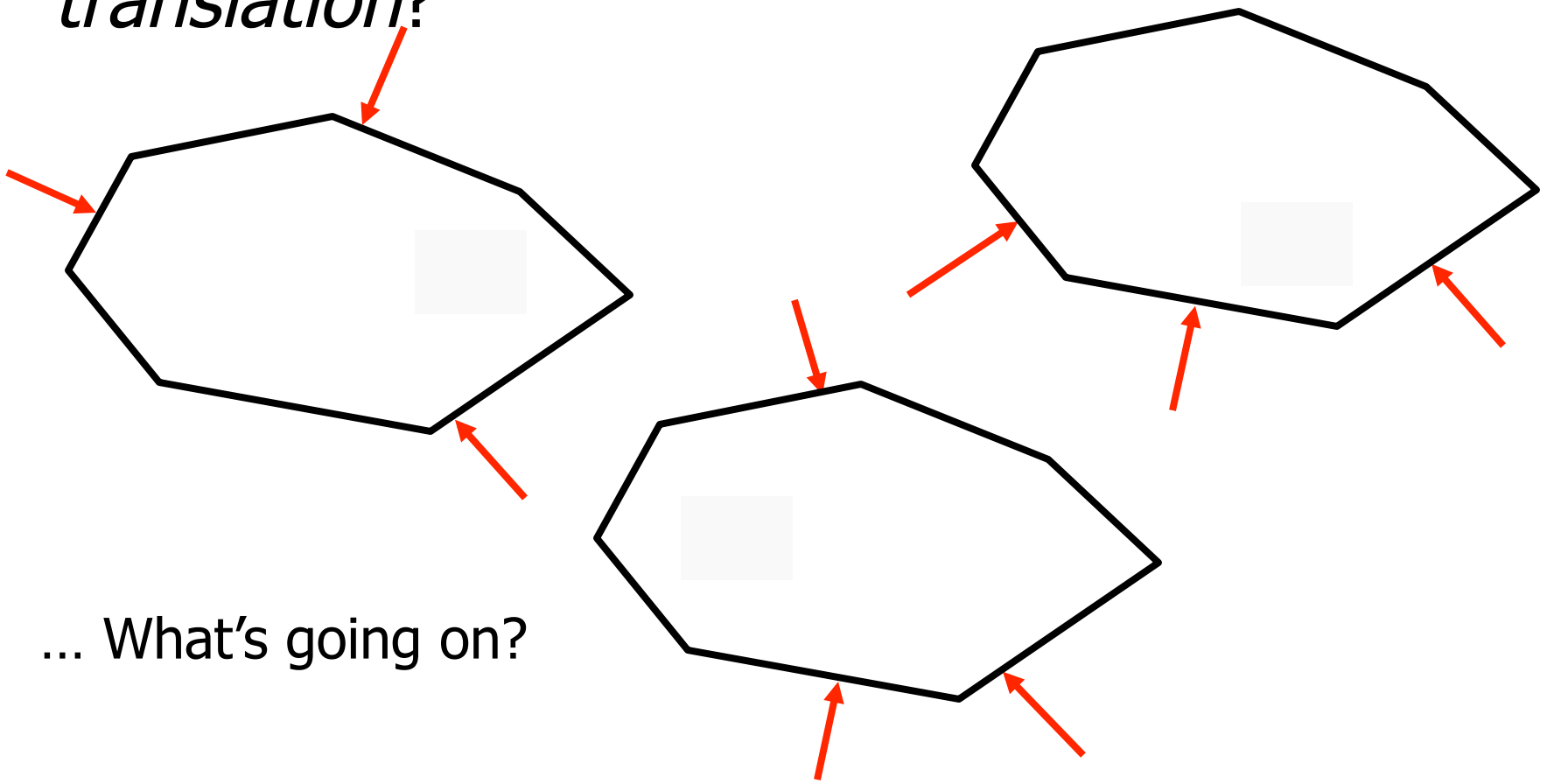
Frictionless Point Contacts

- Force must be normal to object boundary (why?)
- Force must point into object's interior



Force-Direction Closure

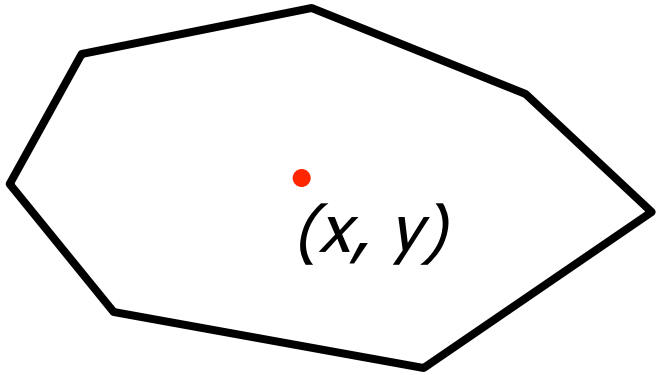
- Under what conditions will a set of point contact forces resist arbitrary planar *translation*?



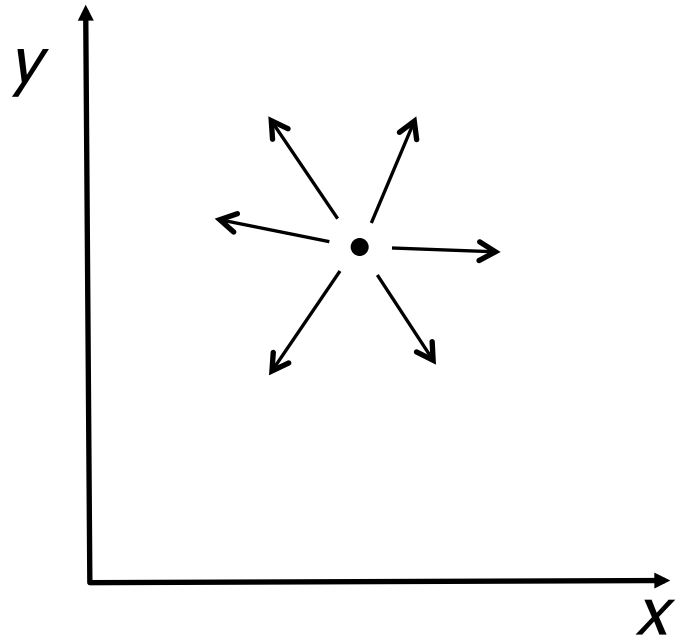
… What's going on?

How many contacts are needed?

- Analyze situation in c-space with DOF argument
  - First: how many c-space DOFs for object origin?



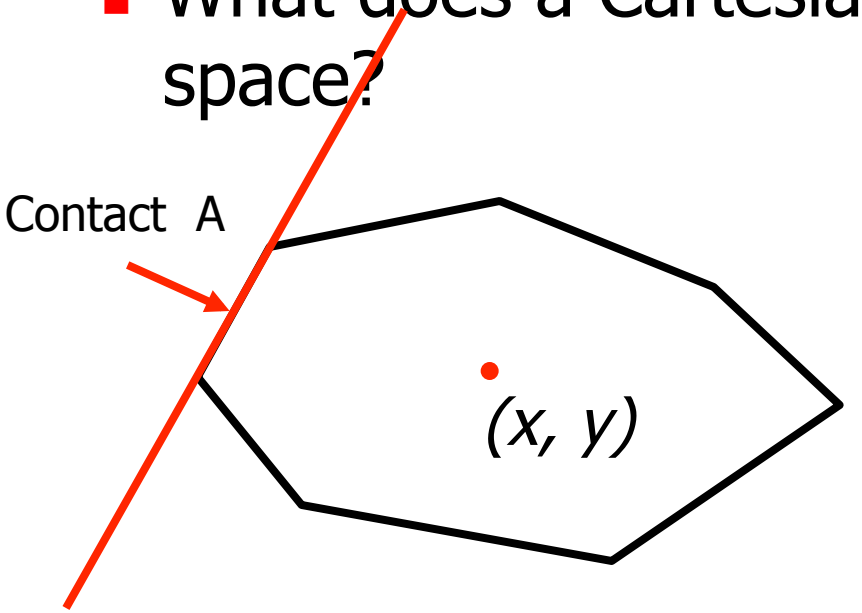
Cartesian space



Configuration space

How many contacts are needed?

- Analyze situation in c-space with DOF argument
  - What does a Cartesian point contact imply in c-space?



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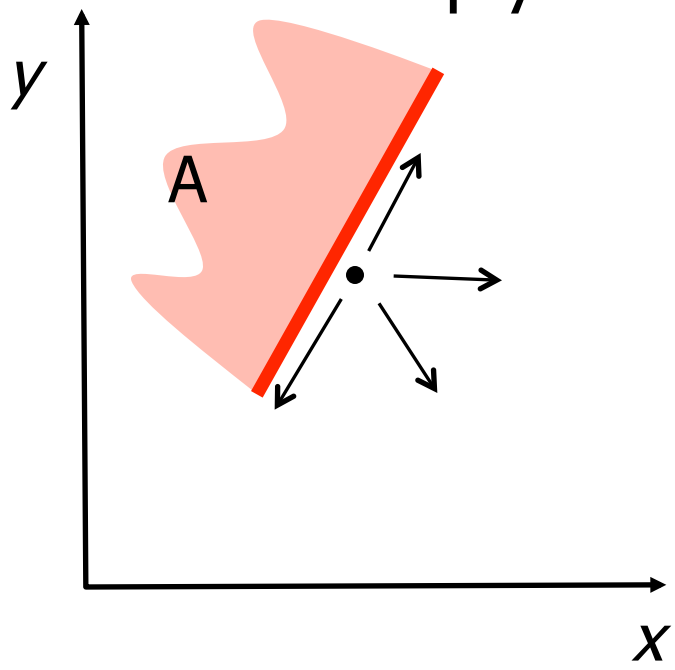

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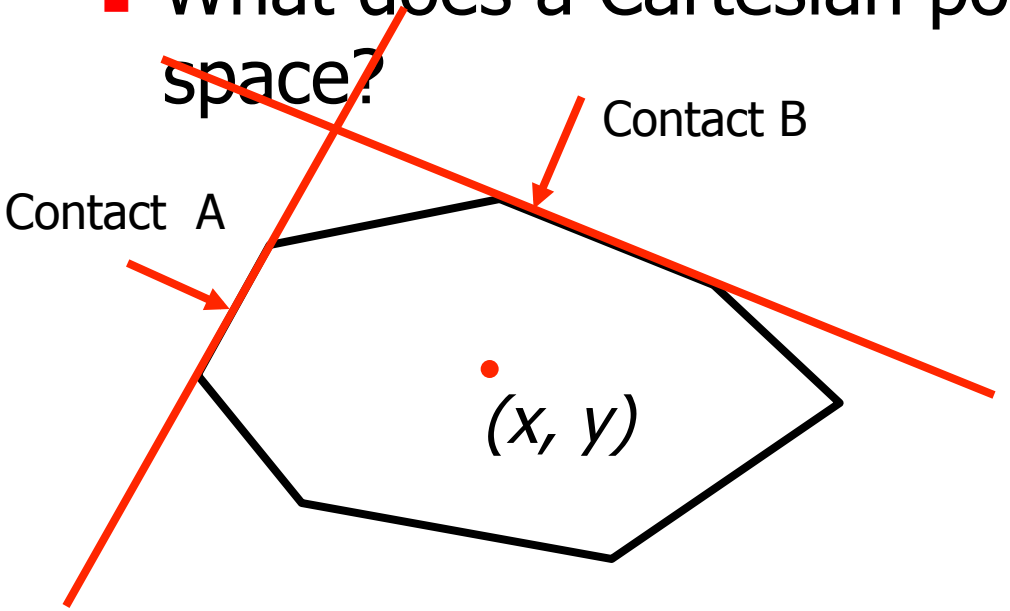

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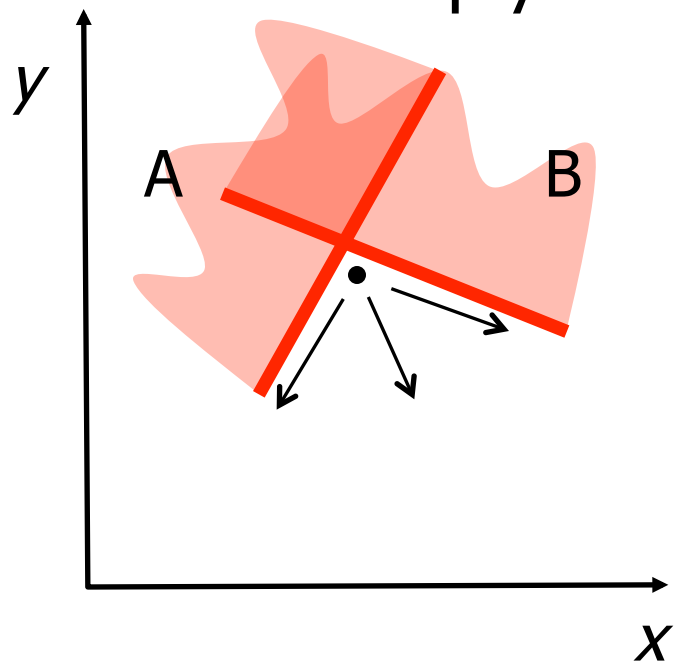

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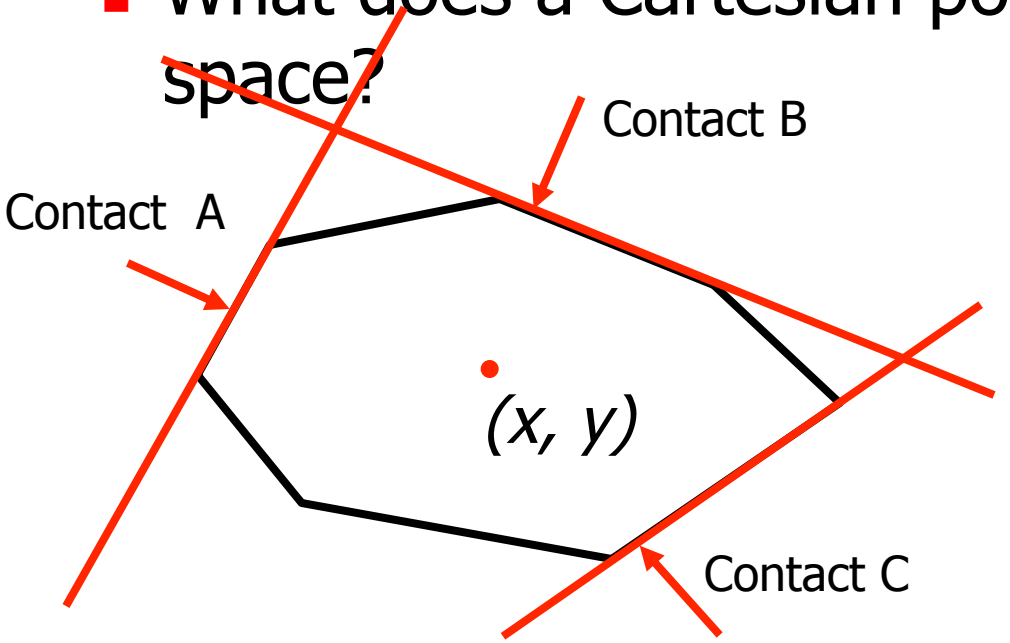

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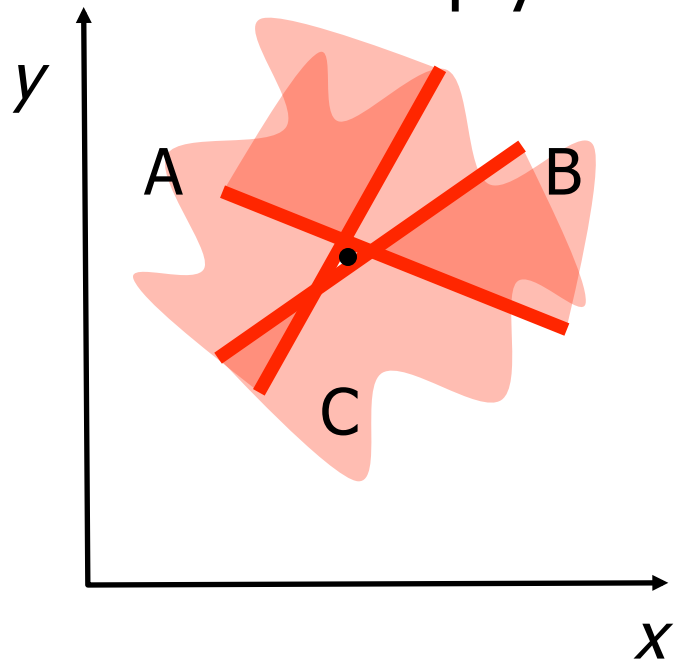
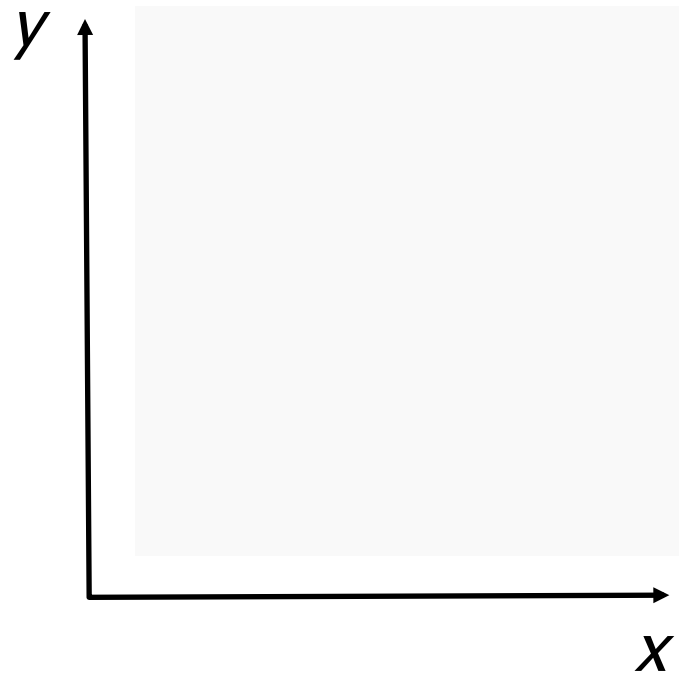


Configuration space

DOF Counting for Translation

- Conclude that contacts are needed in general
  - Are there situations in which more are required?



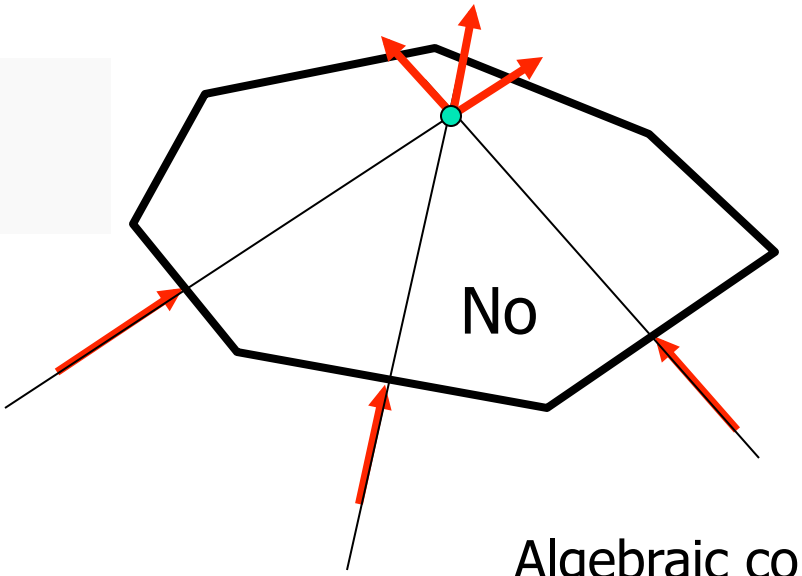
Cartesian space

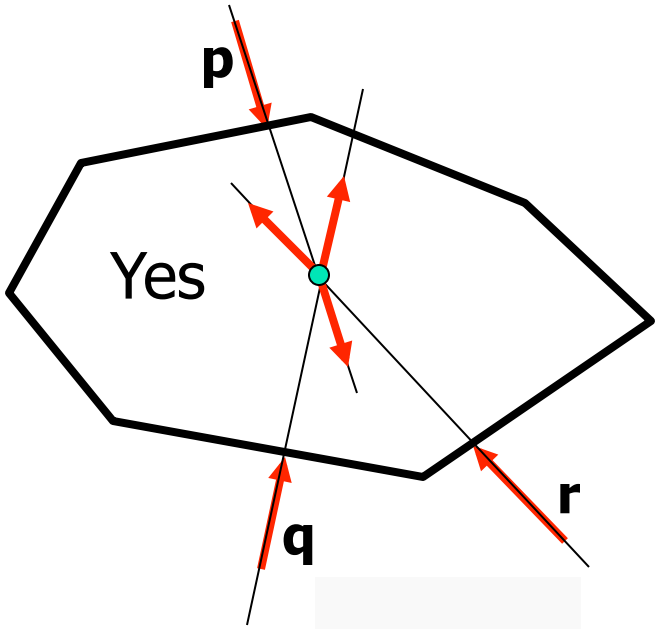
Configuration space

- Example of geometric

Conditions for Force-Direction Closure

- Force vectors must
- Some positive combination of forces

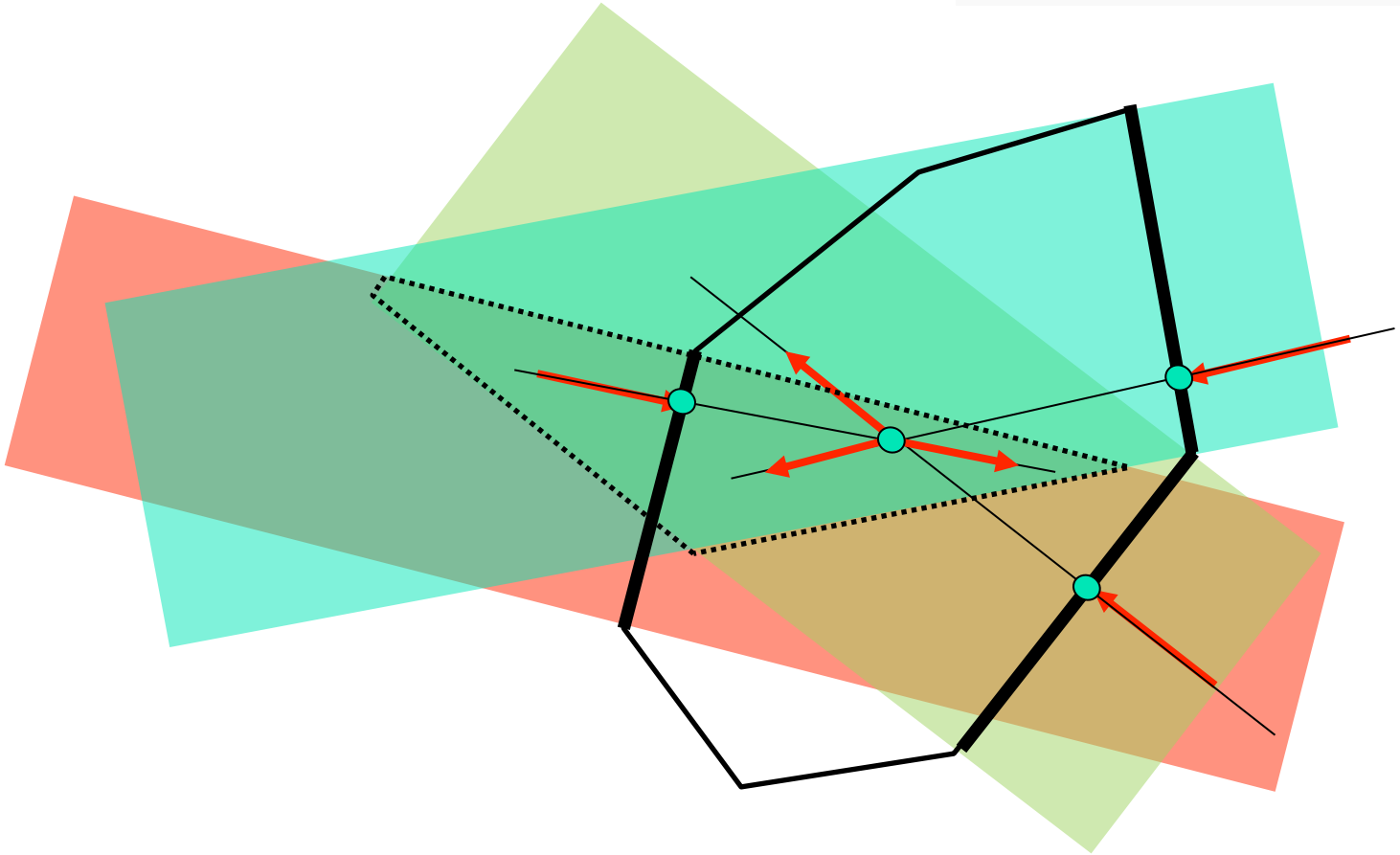




Algebraic condition?
For force vectors **p**, **q**, **r**,
there must exist $\alpha, \beta, \gamma > 0$
s.t. **0**

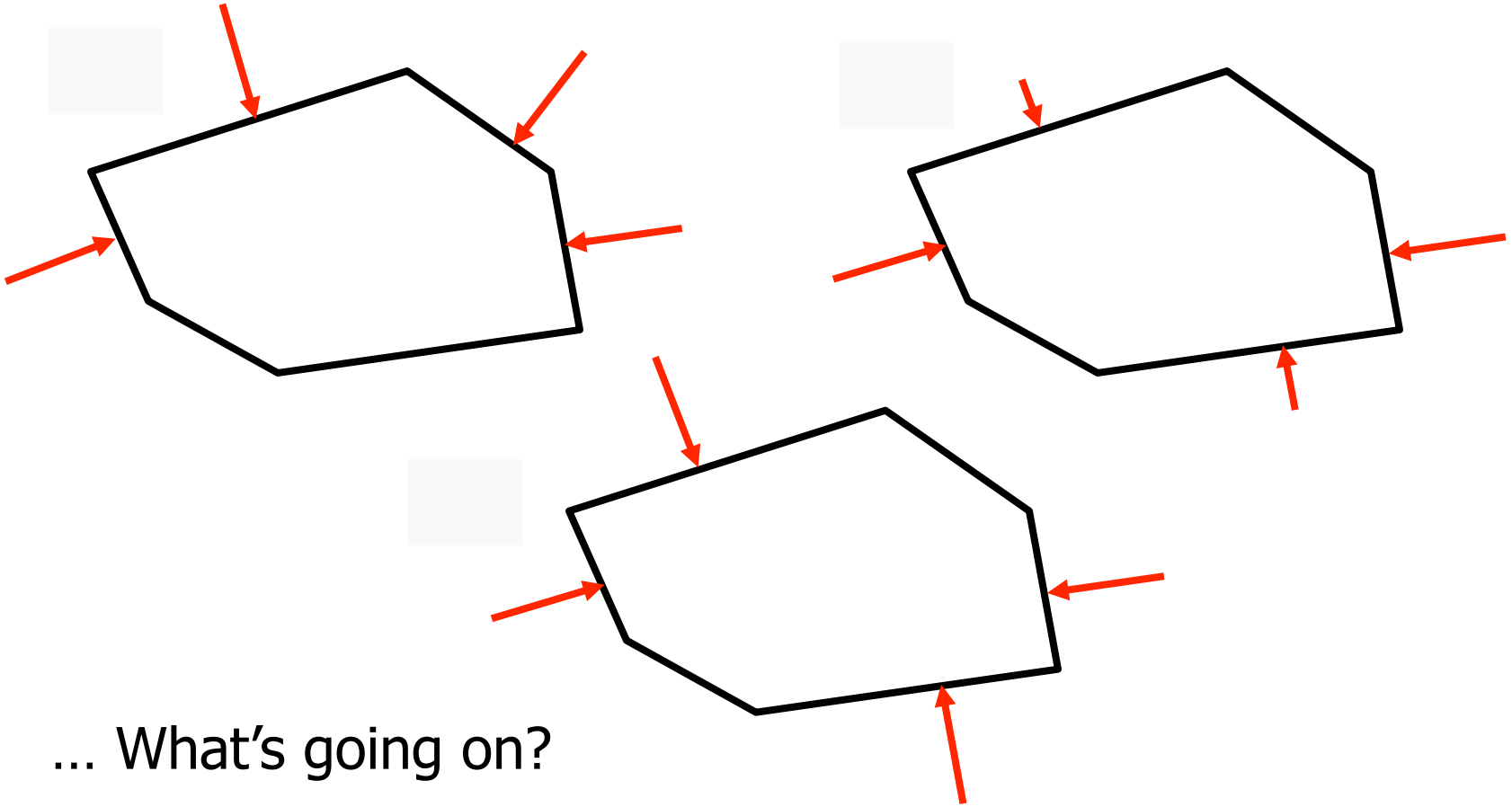
Synthesizing a Force-Direction Grasp

1. Choose admitting a
2. Project onto each contact edge
3. Scale force magnitudes to produce



Torque Closure

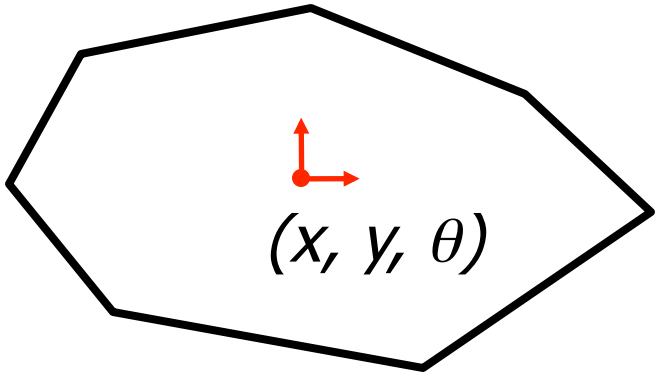
- Under what conditions will a set of point contact forces resist arbitrary planar *rotations*?



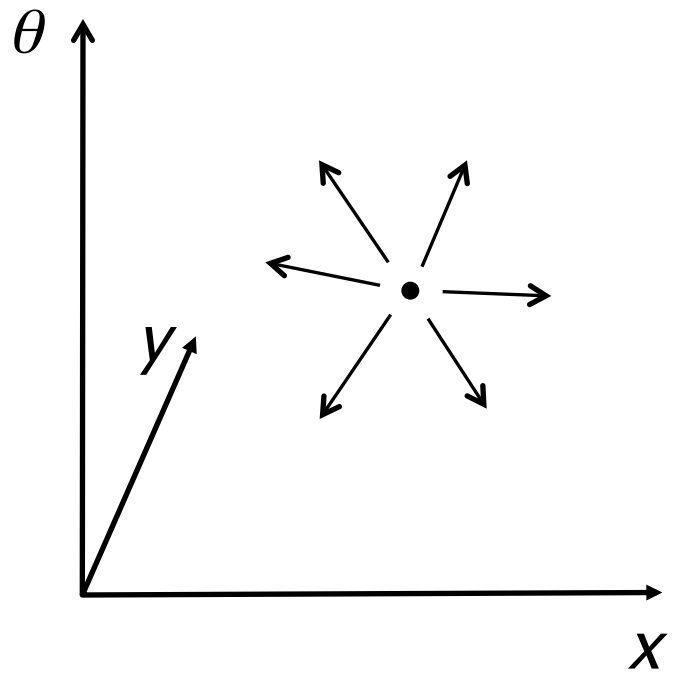
… What's going on?

How many contacts to pin rotation?

- Use analogous DOF argument in c-space
  - First: how many c-space DOFs for object pose?



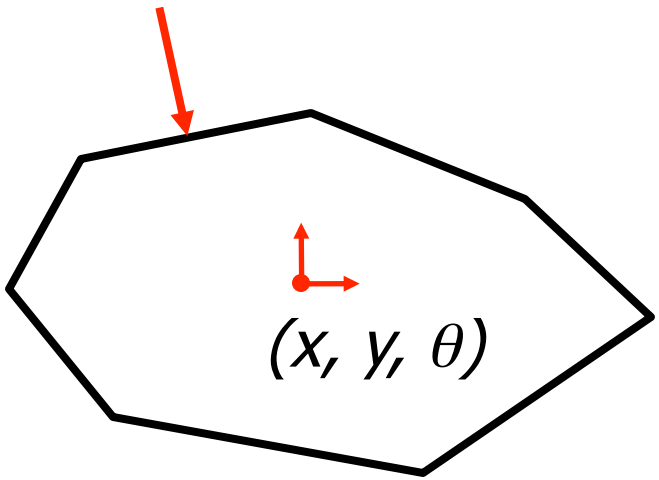
Cartesian space



Configuration space

How many contacts to pin rotation?

- Introduce point contact in Cartesian space
  - Implies c-space constraint with 2D manifold boundary



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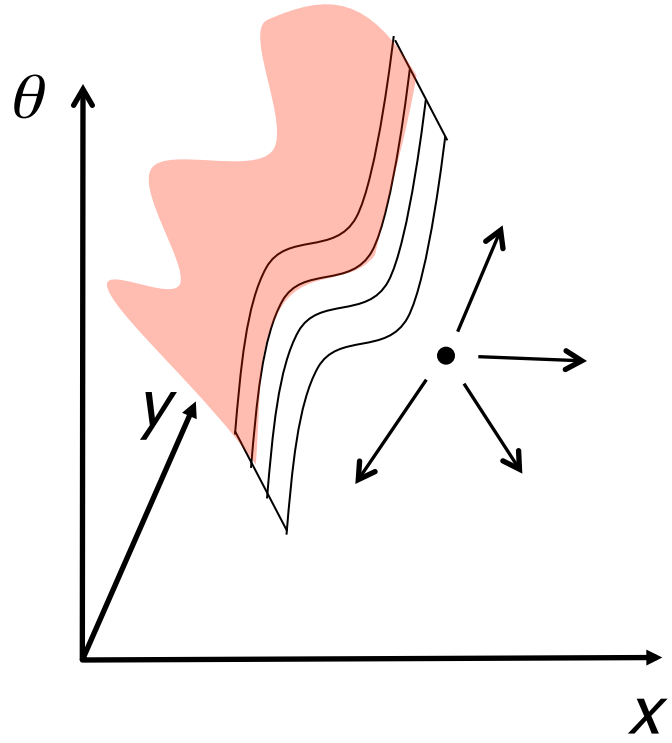

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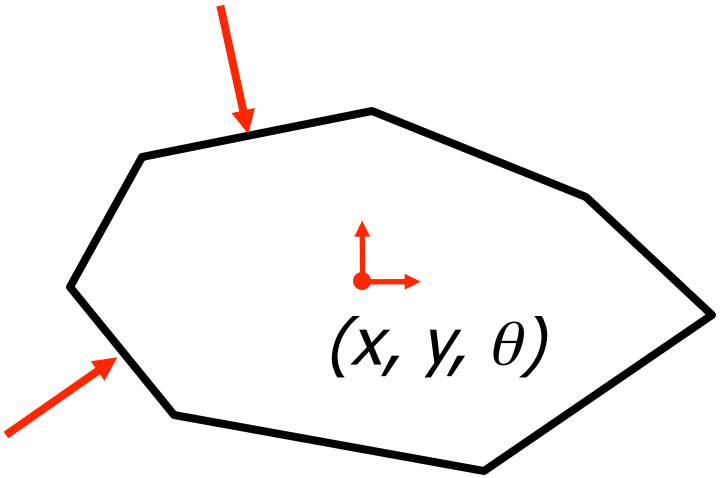
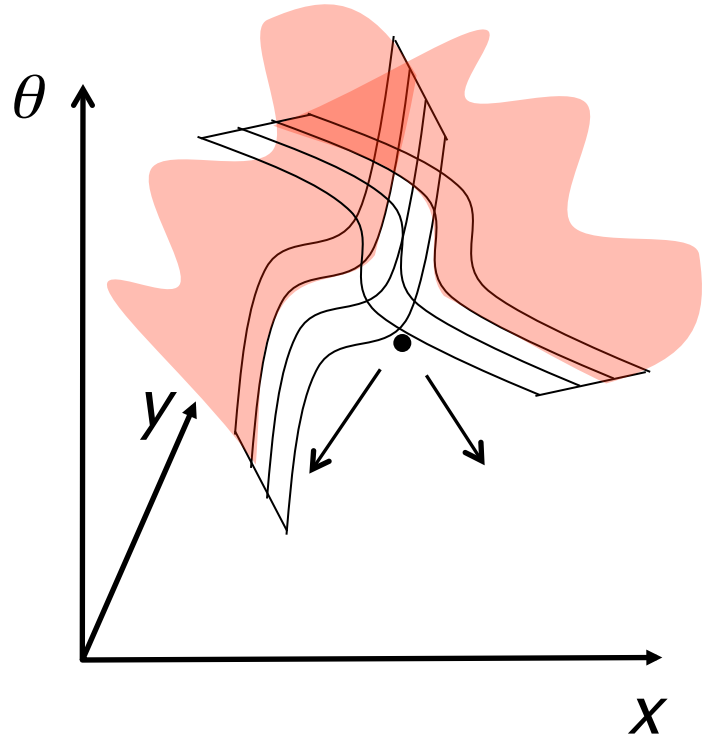


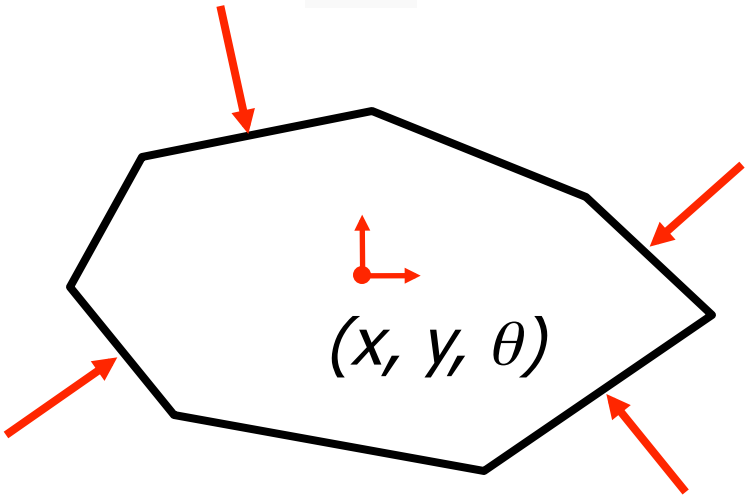
Cartesian space



Configuration space

How many contacts to pin rotation?

- Locally, each constraint has a planar boundary
  - … So, how many *halfspaces* needed to pin point?



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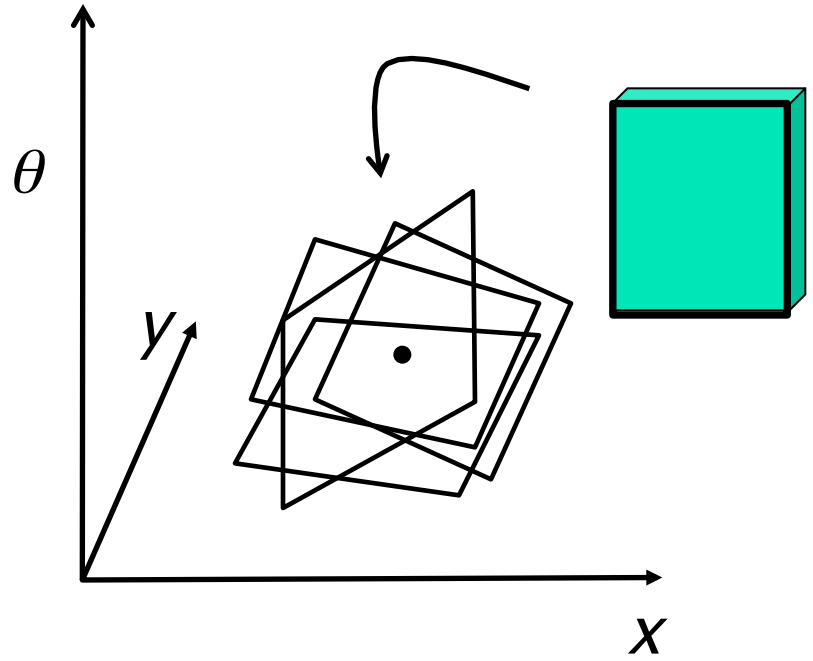
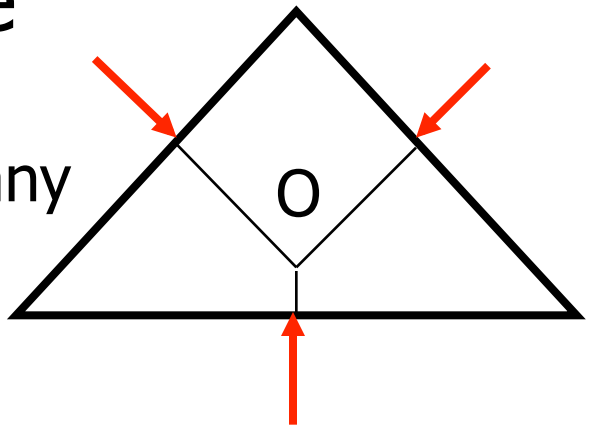


Configuration space

Grasp Analysis (no friction)

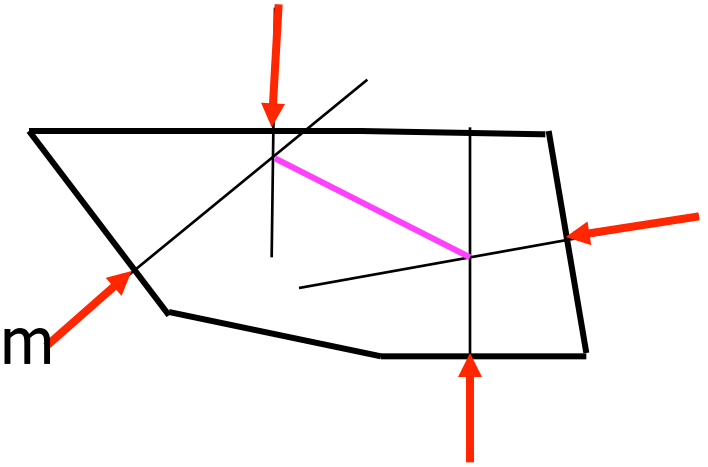
- Force-direction closure

  Translate forces to O;
  they compose to generate any
  desired resultant force



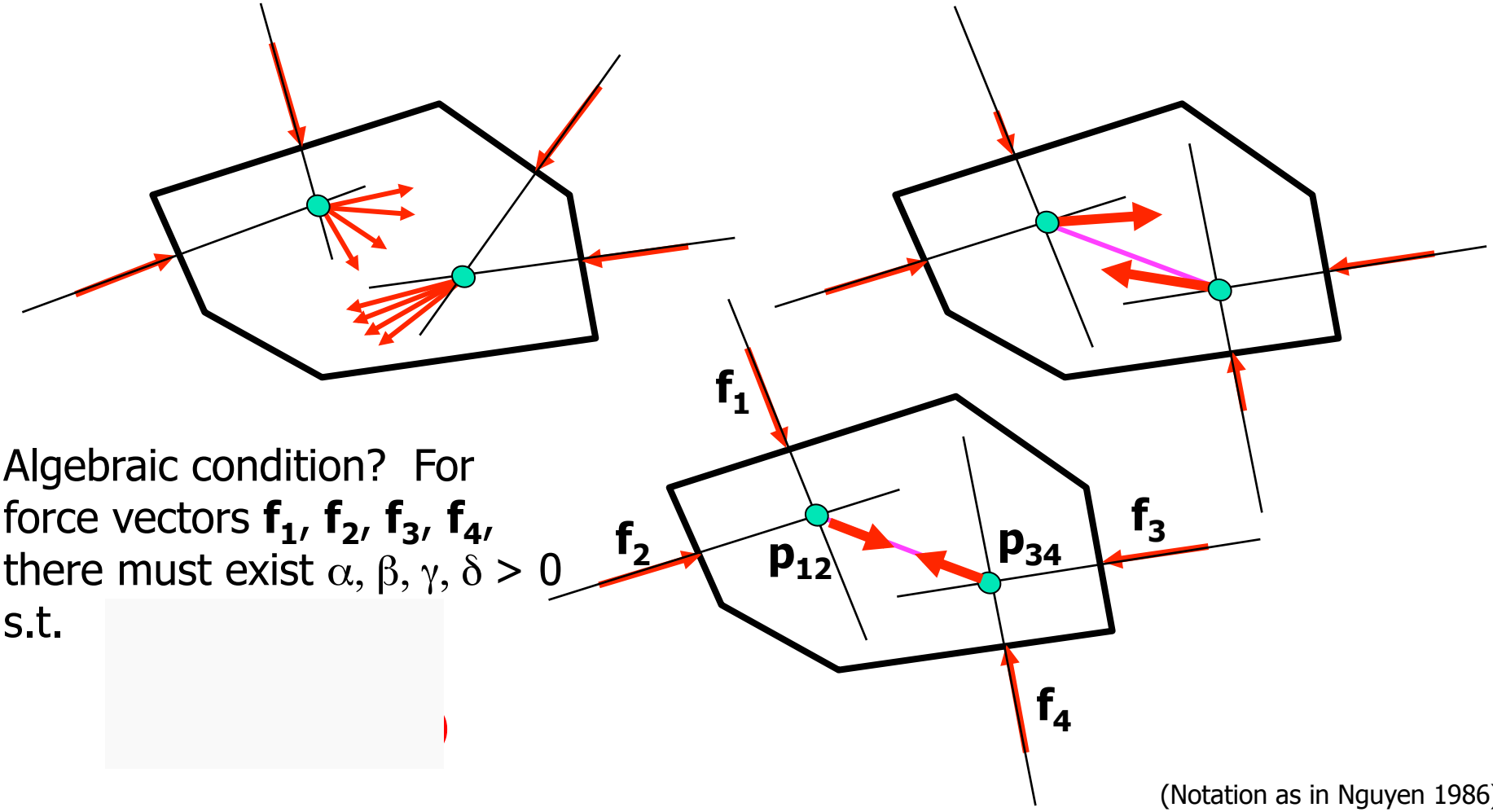
- Torque closure

Translate forces to intersection Points; they can be adjusted to point at each other and away from each other to generate torque



Geometric Conditions for Torque Closure

- Each normal cone must contain the other's apex
- Pairwise effective forces must cancel each other

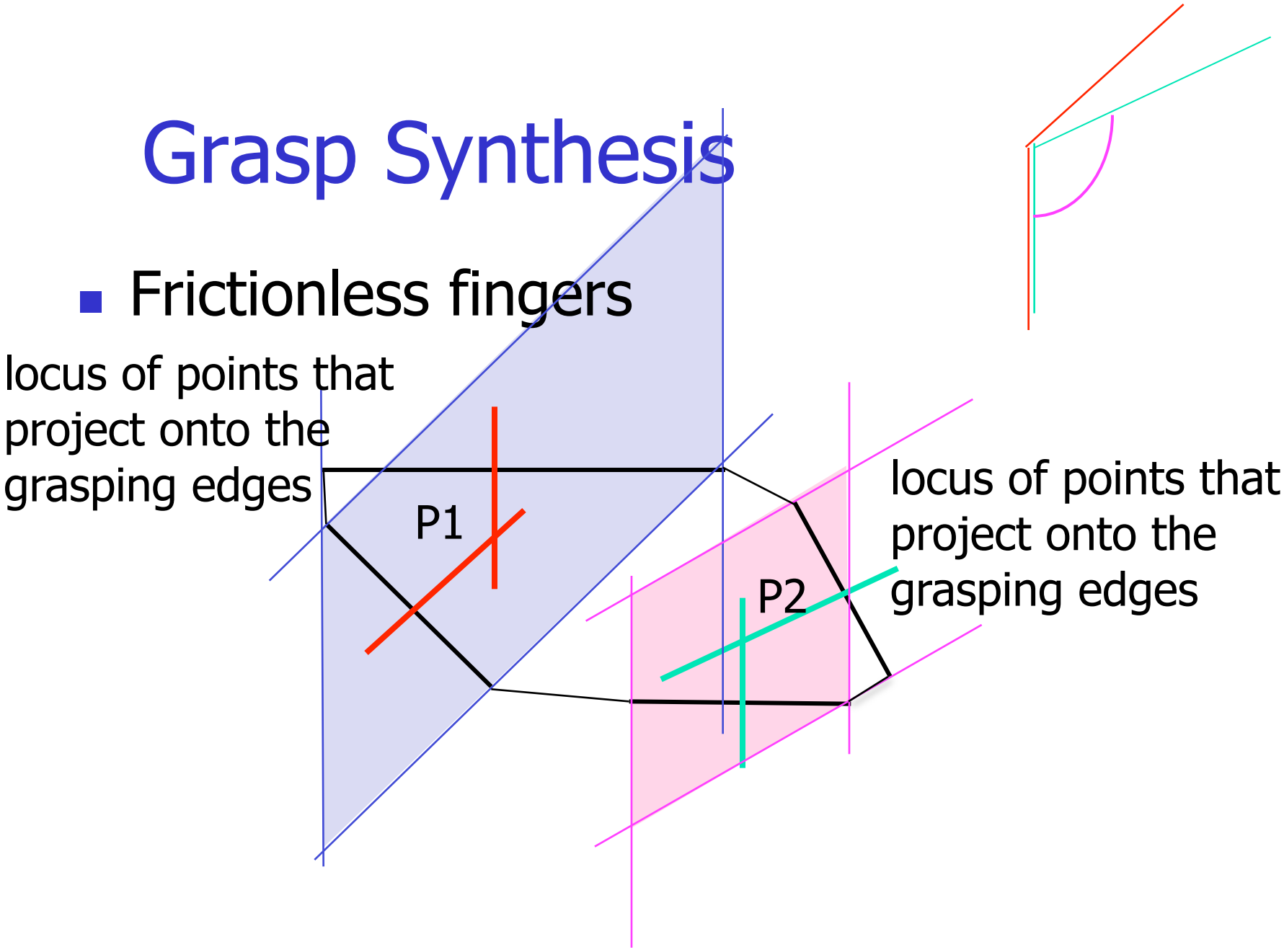


Algebraic condition? For force vectors $\mathbf{f_1}$, $\mathbf{f_2}$, $\mathbf{f_3}$, $\mathbf{f_4}$, there must exist $\alpha, \beta, \gamma, \delta > 0$ s.t.

(Notation as in Nguyen 1986)

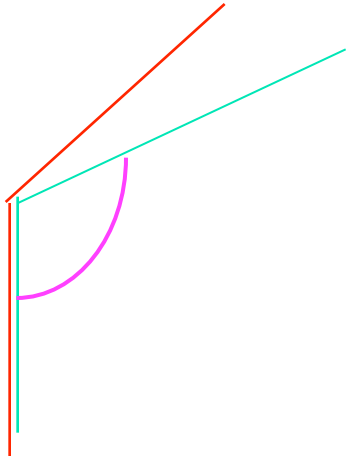
Grasp Synthesis

- Frictionless fingers



Grasp Synthesis

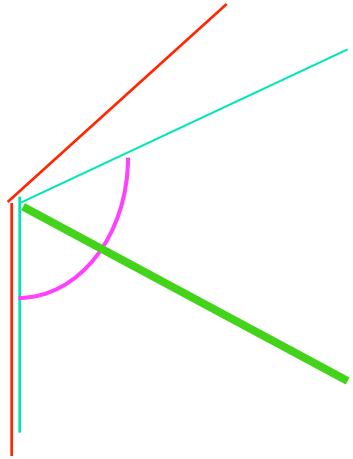
- Frictionless fingers

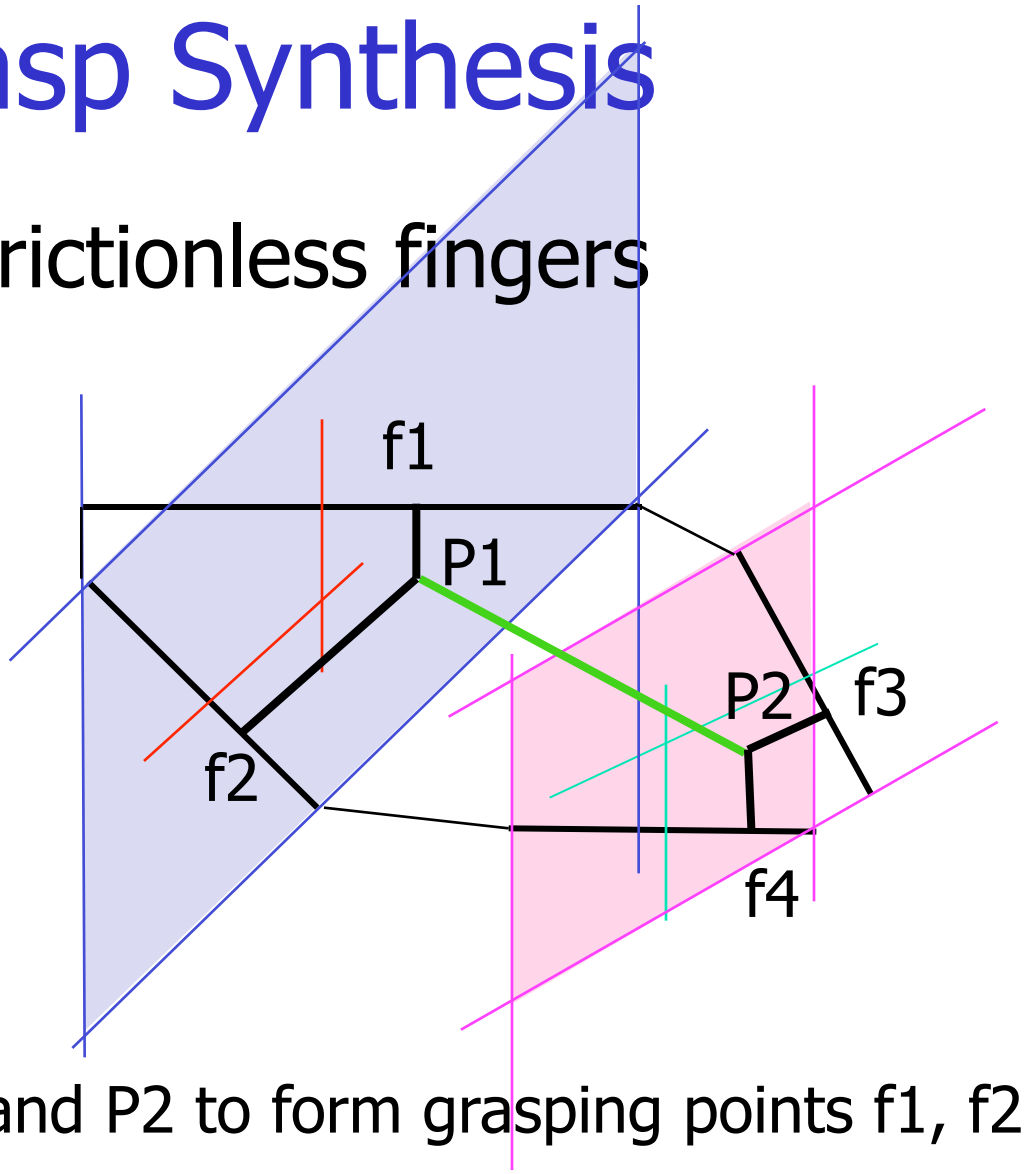


Pick P1 in blue region and P2 in pink region so that the line P1P2 has direction contained in the intersecting normal cones

Grasp Synthesis

- Frictionless fingers



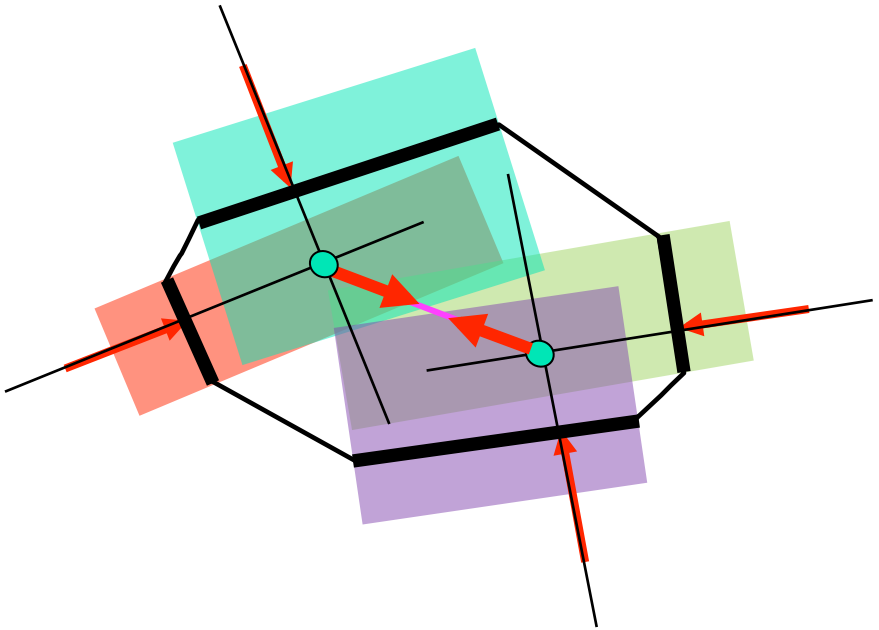


Project P1 and P2 to form grasping points f1, f2, f3, f4

Synthesizing a Torque-Closure Grasp

1. Choose two edge pairs* admitting force centers
2. Choose centers inducing mutual normal cones
3. Project centers to respective edge contact points
4. Scale forces to produce alignment, cancellation

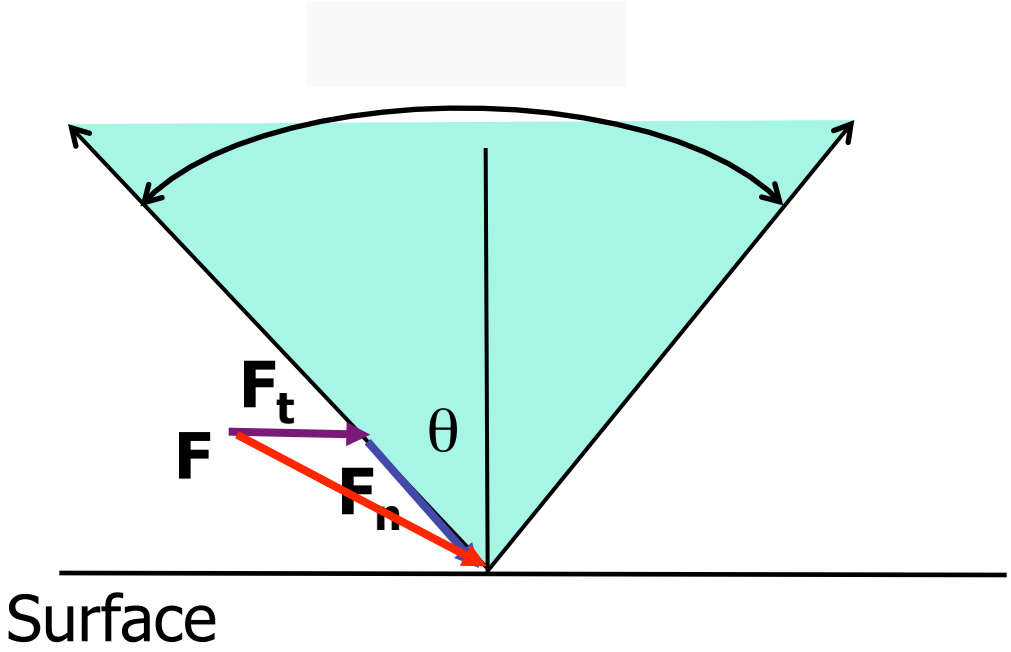
*Edge pairs need not be contiguous



Does rotation closure imply translation closure?

Point Contact with Friction

- Consider a point contact exerting force at some angle θ to the surface normal. What happens?

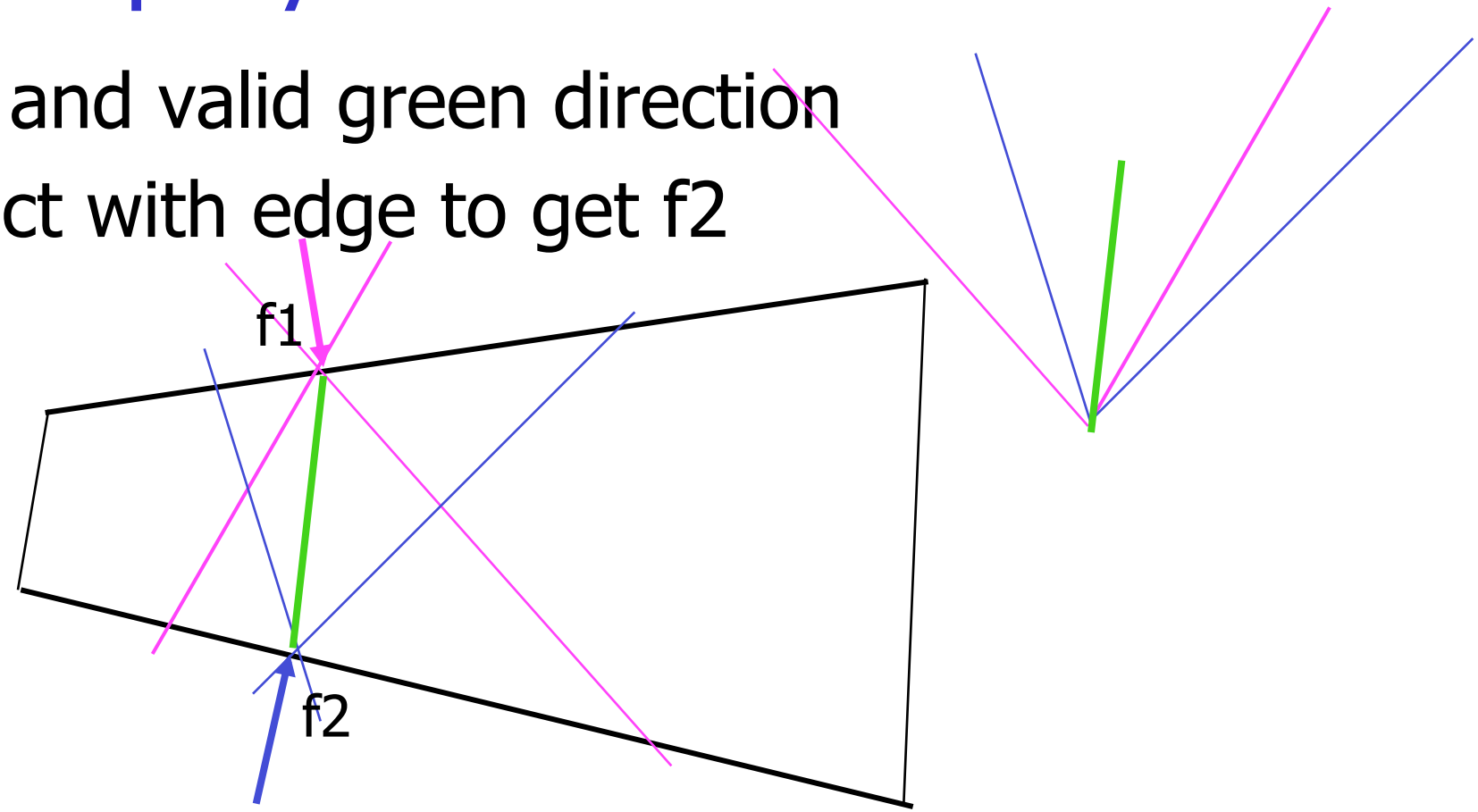


$\theta_{crit} = \tan^{-1} \mu$

- Produces a [redacted] of force directions

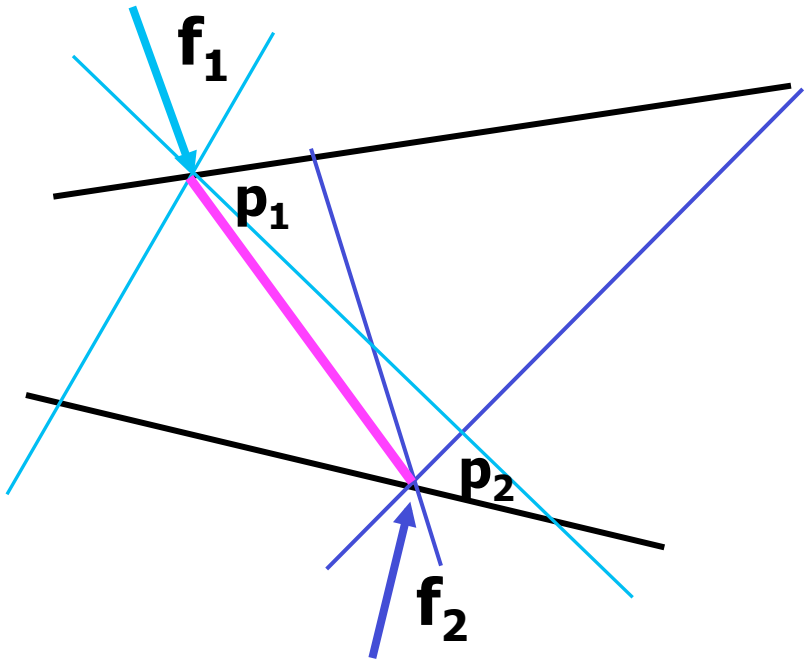
Grasp Synthesis with Friction

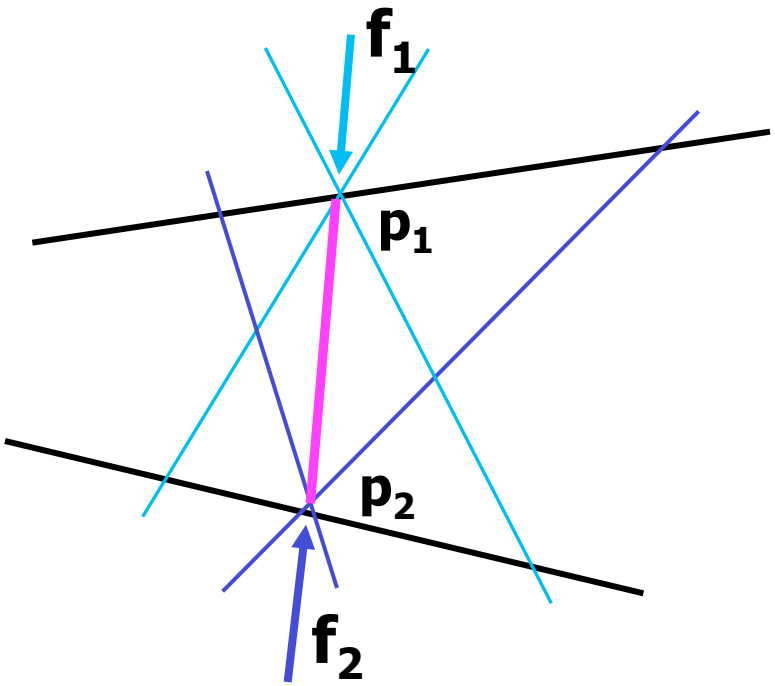
- Pick f1 and valid green direction
- Intersect with edge to get f2



Grasp Analysis With Friction

Consider forces $\mathbf{f_1}$, $\mathbf{f_2}$ at frictional contacts $\mathbf{p_1}$, $\mathbf{p_2}$





When can $\mathbf{f_1}$, $\mathbf{f_2}$ oppose one another without sliding?

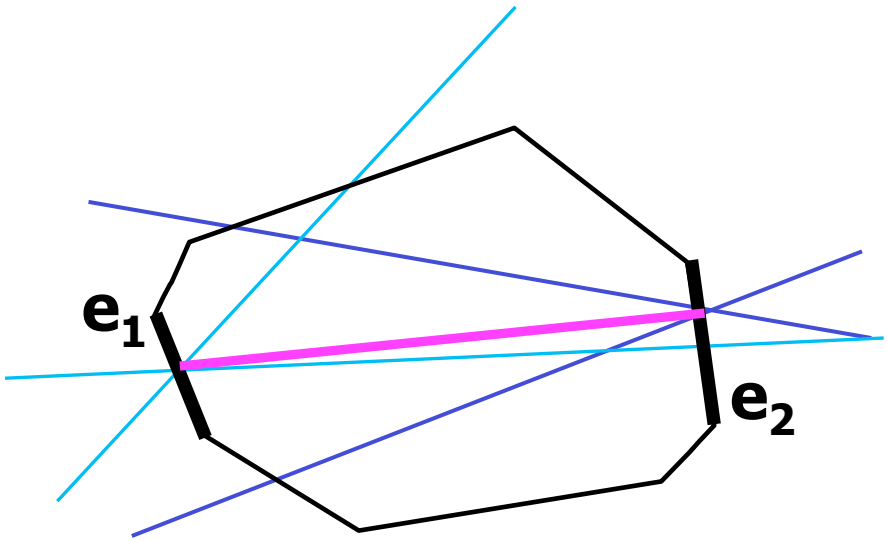
Each force must

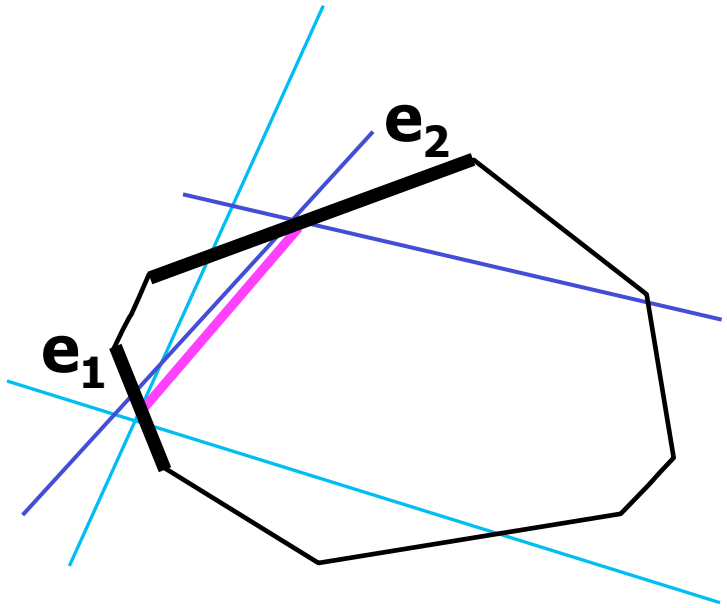
Point $\mathbf{p_1}$ (resp. $\mathbf{p_2}$) must

Grasp Synthesis With Friction

Choose a *compatible* pair of edges $\mathbf{e_1}$, $\mathbf{e_2}$

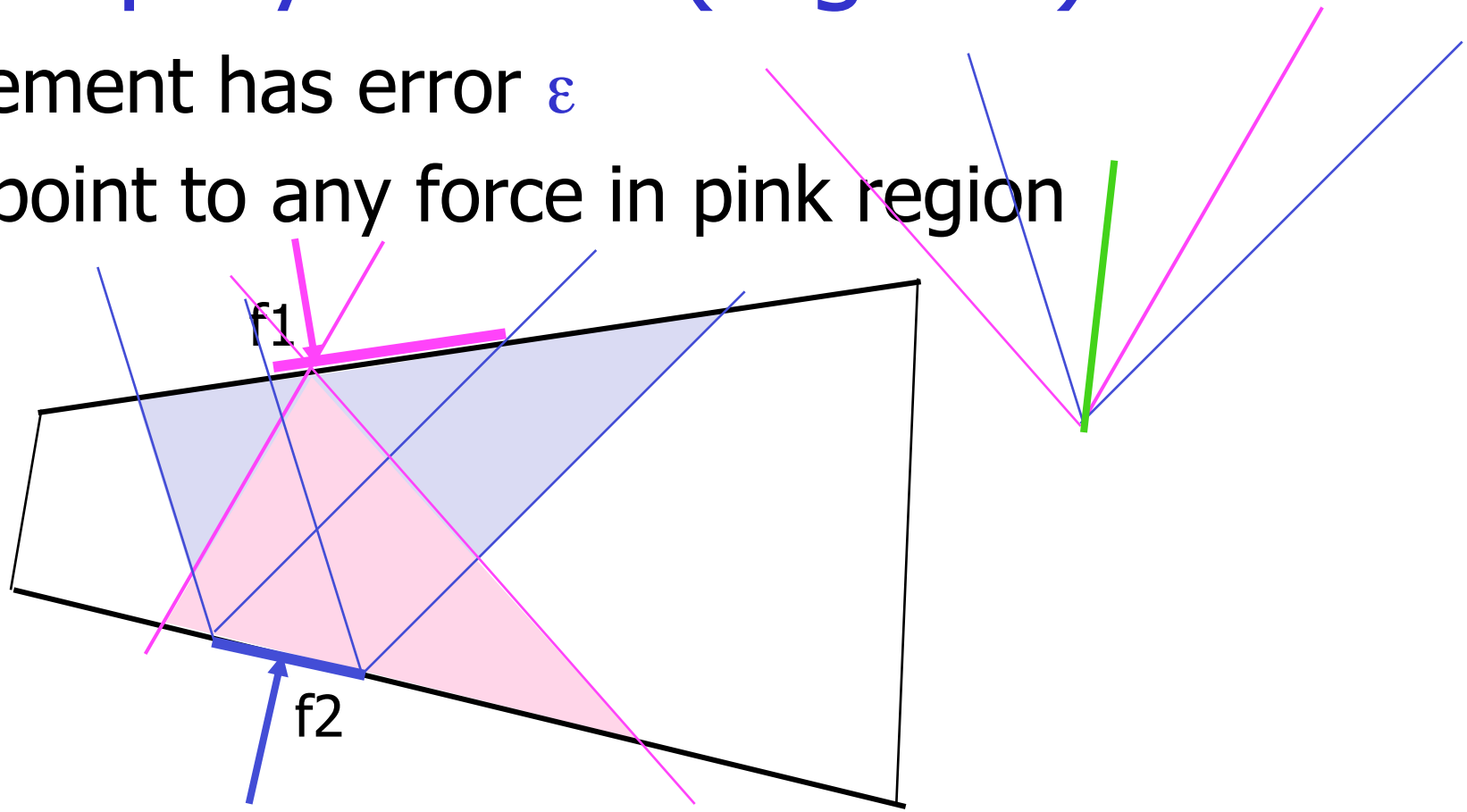
Intuition? Using what data? How to choose?





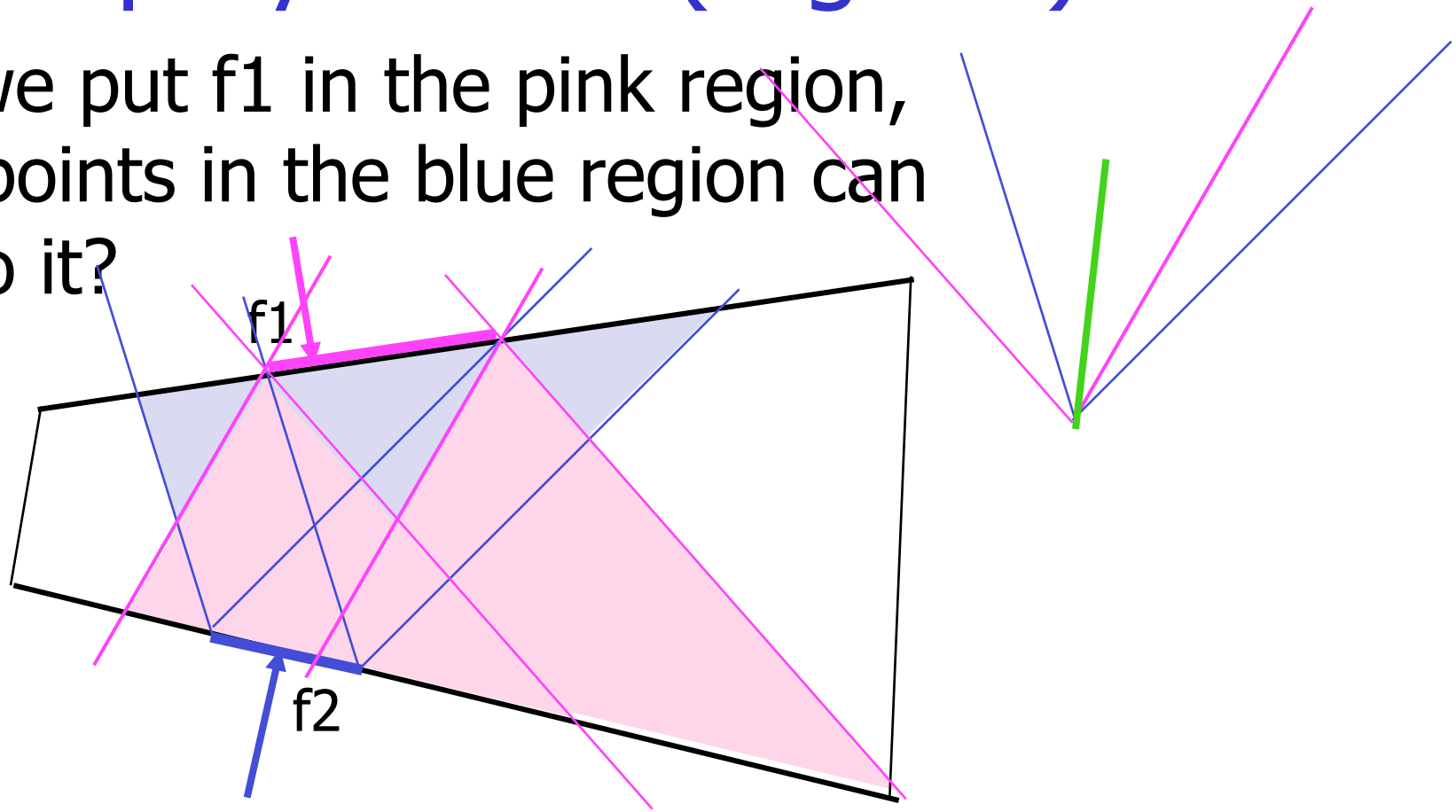
Grasp Synthesis (regions)

- f2 placement has error ε
- f2 can point to any force in pink region



Grasp Synthesis (regions)

- But if we put f1 in the pink region, which points in the blue region can point to it?



Grasp Synthesis (friction)

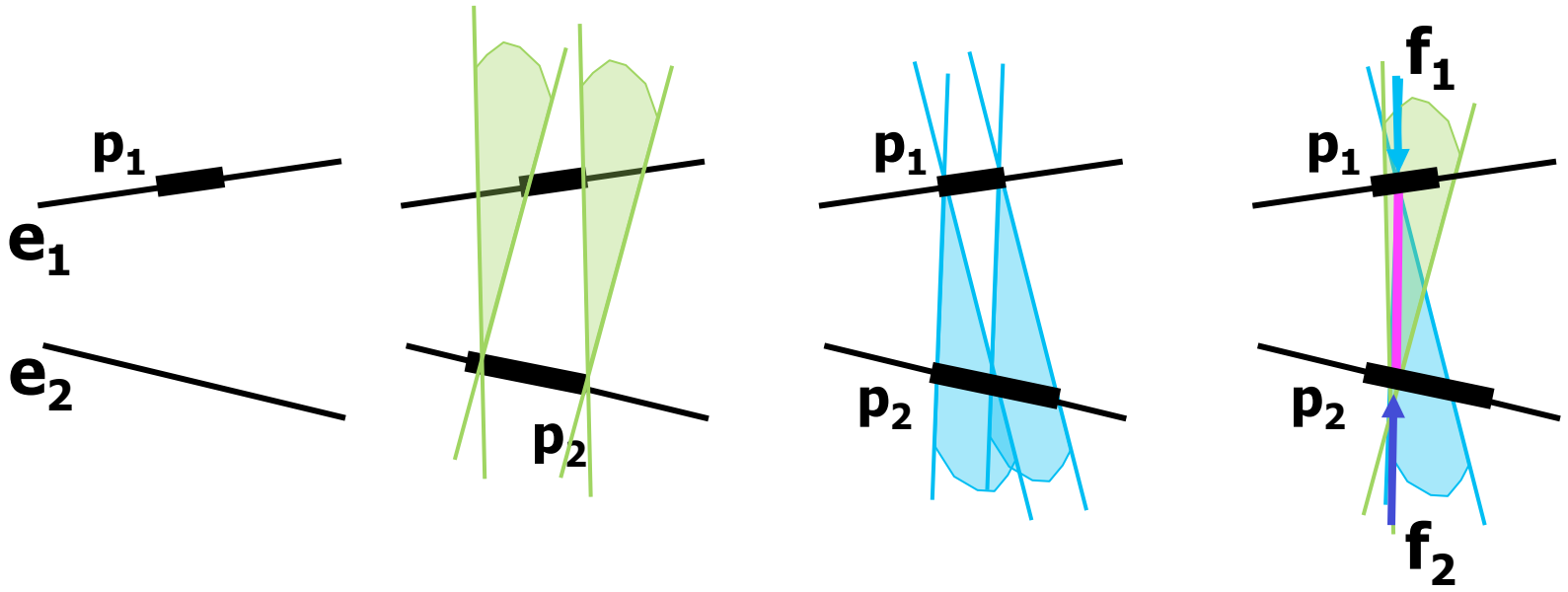
- 2 Finger Forces have to be within friction cones to stick
- 2 Finger Forces have to point at each other
- So…
- We need to find 2 edges with overlapping friction cones

Grasp Synthesis With Friction

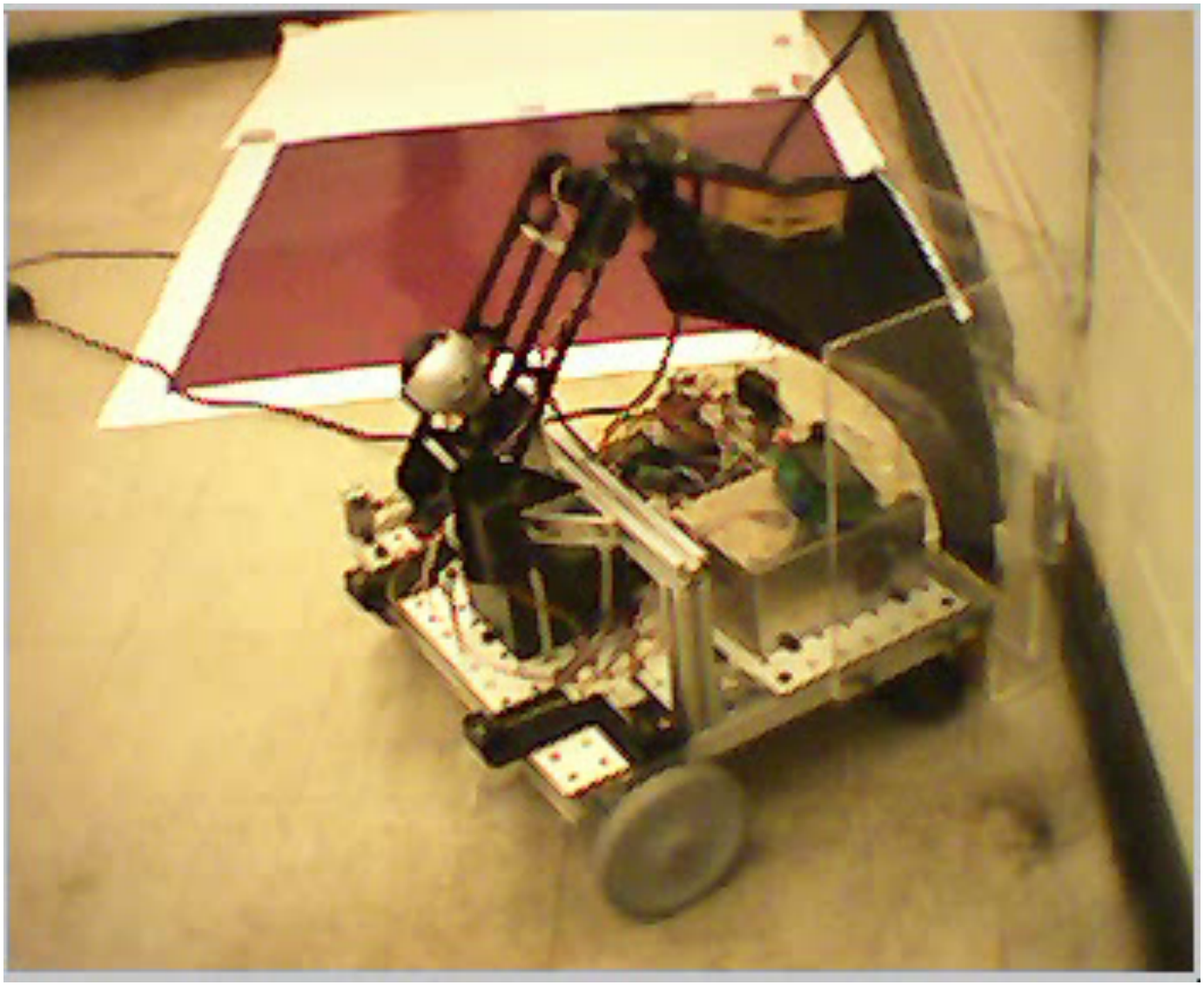
Choose target region for contact point $\mathbf{p_1}$

Determine feasible target region for contact $\mathbf{p_2}$

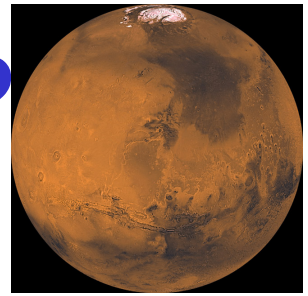
Orient and scale $\mathbf{f_1}$, $\mathbf{f_2}$ so as to cancel along $\overline{\mathbf{p_1 p_2}}$

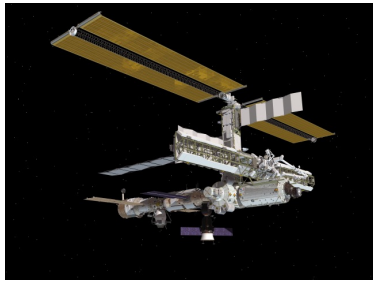


Example: 6.141 robot

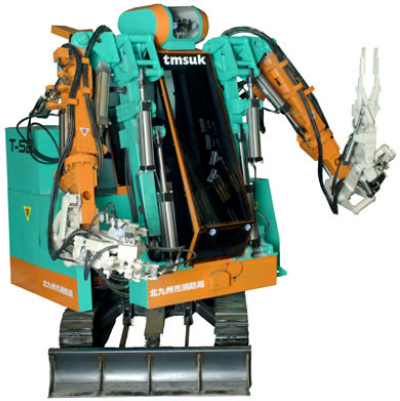


What is Robot Manipulation?

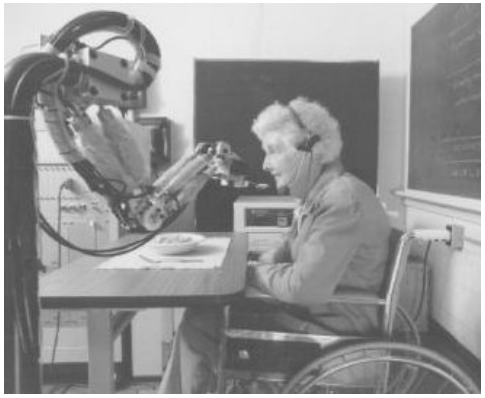




Space - in-orbit, repair and maintenance, planetary exploration anthropomorphic design facilitates collaboration with humans



Home - basic science - manufacturing, logistics, automated warehousing and distribution, computational models of cognitive systems, learning, human interfaces



Assistive - clinical applications, "aging-in-place," physical and cognitive prosthetics in assisted-living facilities

Military - supply chain and logistics support, re-fueling, bomb disposal