Manipulation

15-494 Cognitive Robotics
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Manipulation with Cozmo

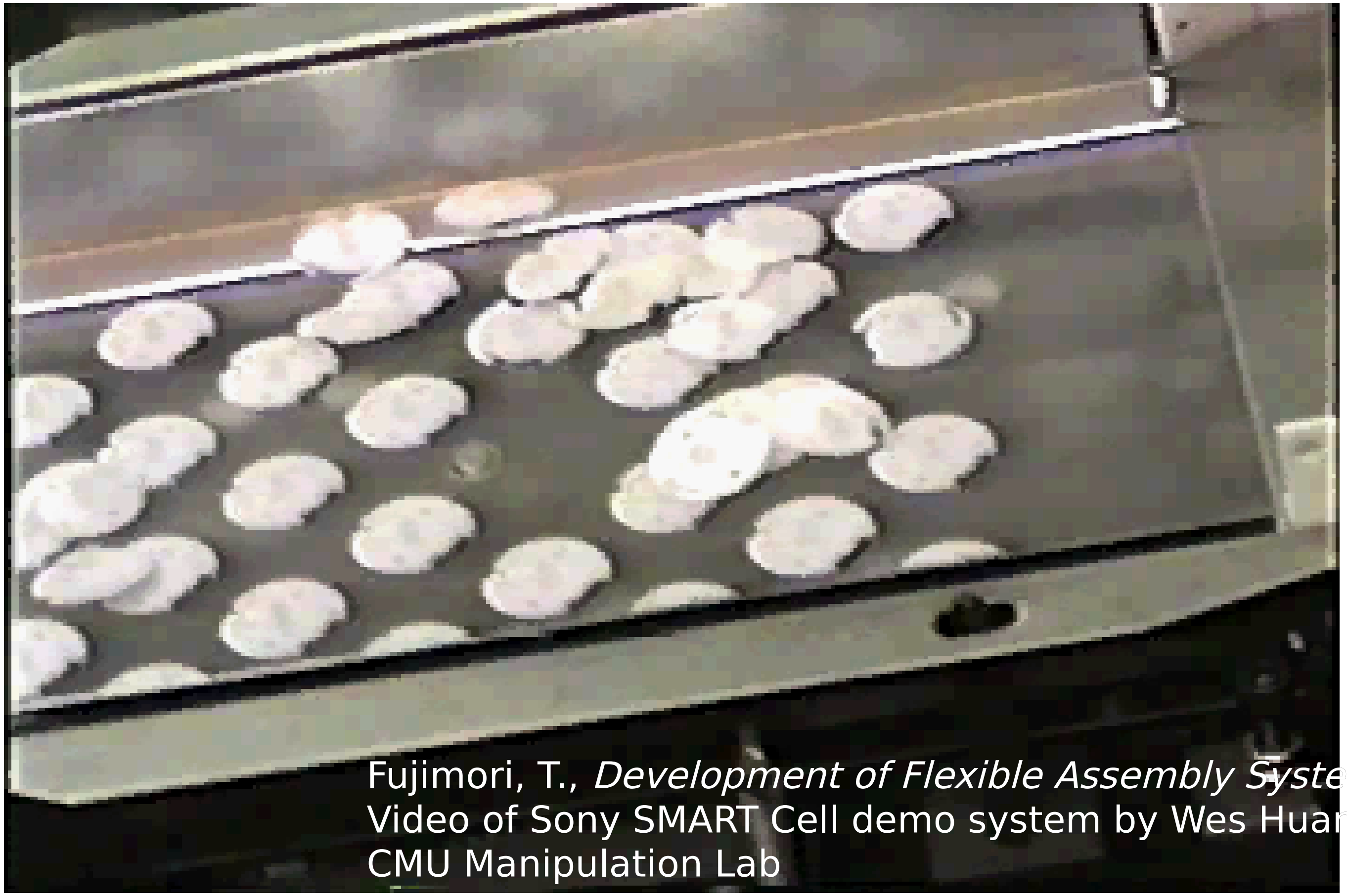
- No hands → No grasping.
- What can we do?
  - Exploit constraints in the environment.
  - Use the environment to supply additional contact points (e.g. walls).
  - Use a second robot to provide a second contact point.
  - Specialized lift attachments.

Constraints

- Constraints can be your friend!
  - Upside: Use the environment and the object itself to your advantage.
  - Downside: Requires planning and *accurate* modeling
- Example: Part Orientation
  - Can position/orient an ‘L’ shaped part with unknown initial configuration using nothing more than an actuated tray — no sensors!

Constraints Are Your Friend

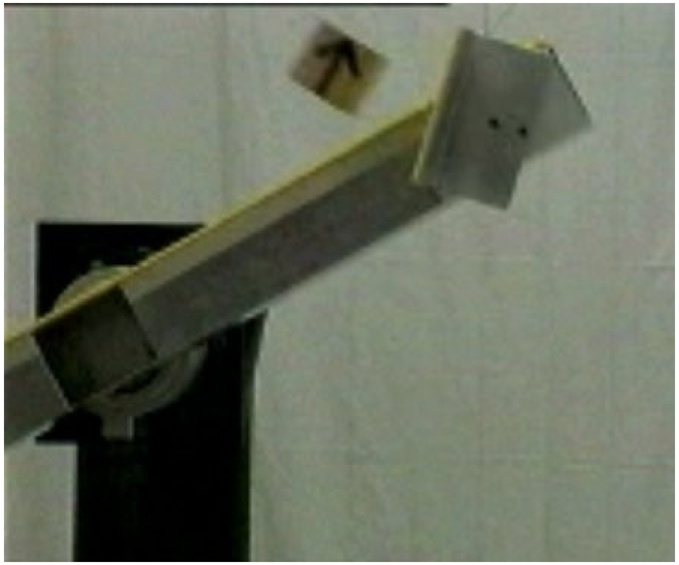
- Example: Part Orientation



Fujimori, T., *Development of Flexible Assembly System "SMART"*
Video of Sony SMART Cell demo system by Wes Huang
CMU Manipulation Lab

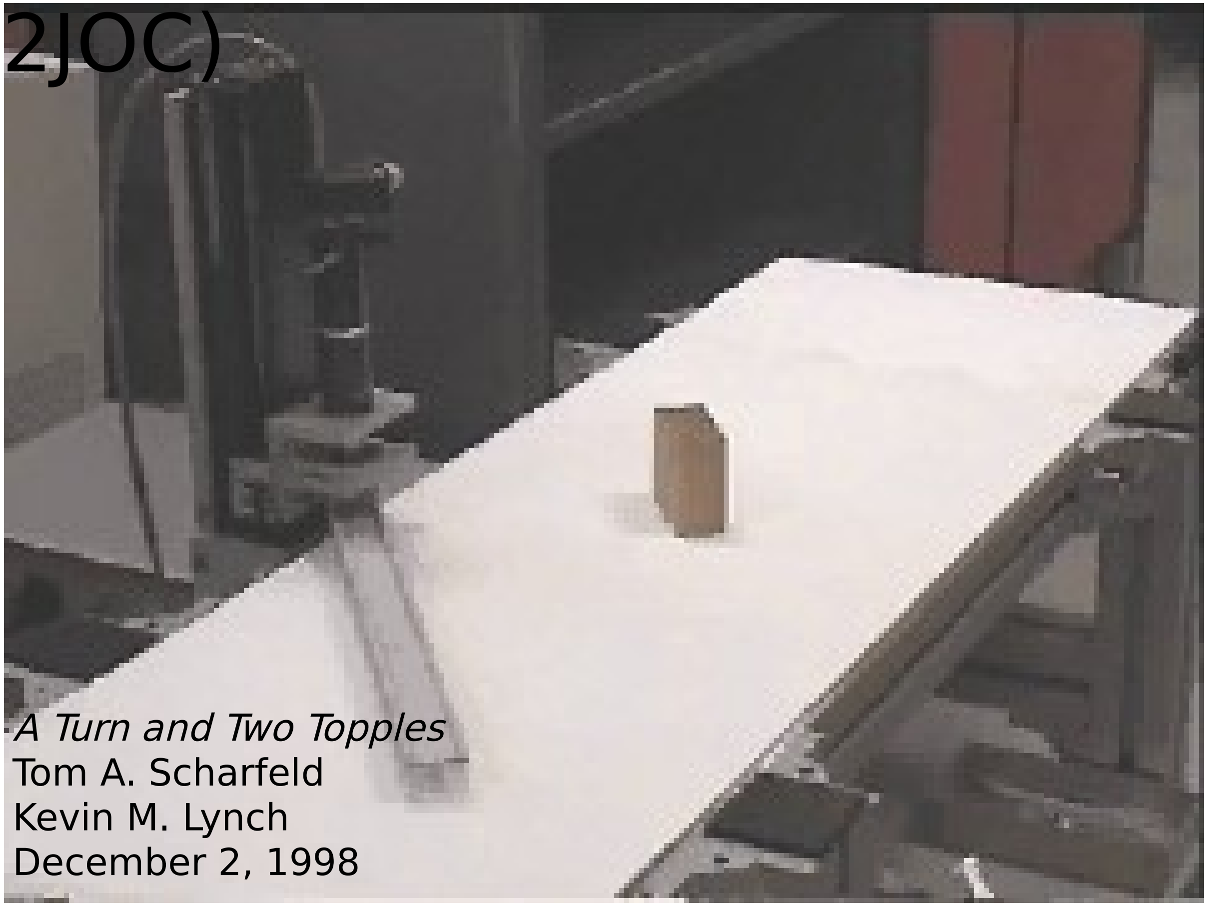
Constraints Are Your Friend

- Example: Throwing (Kevin Lynch)



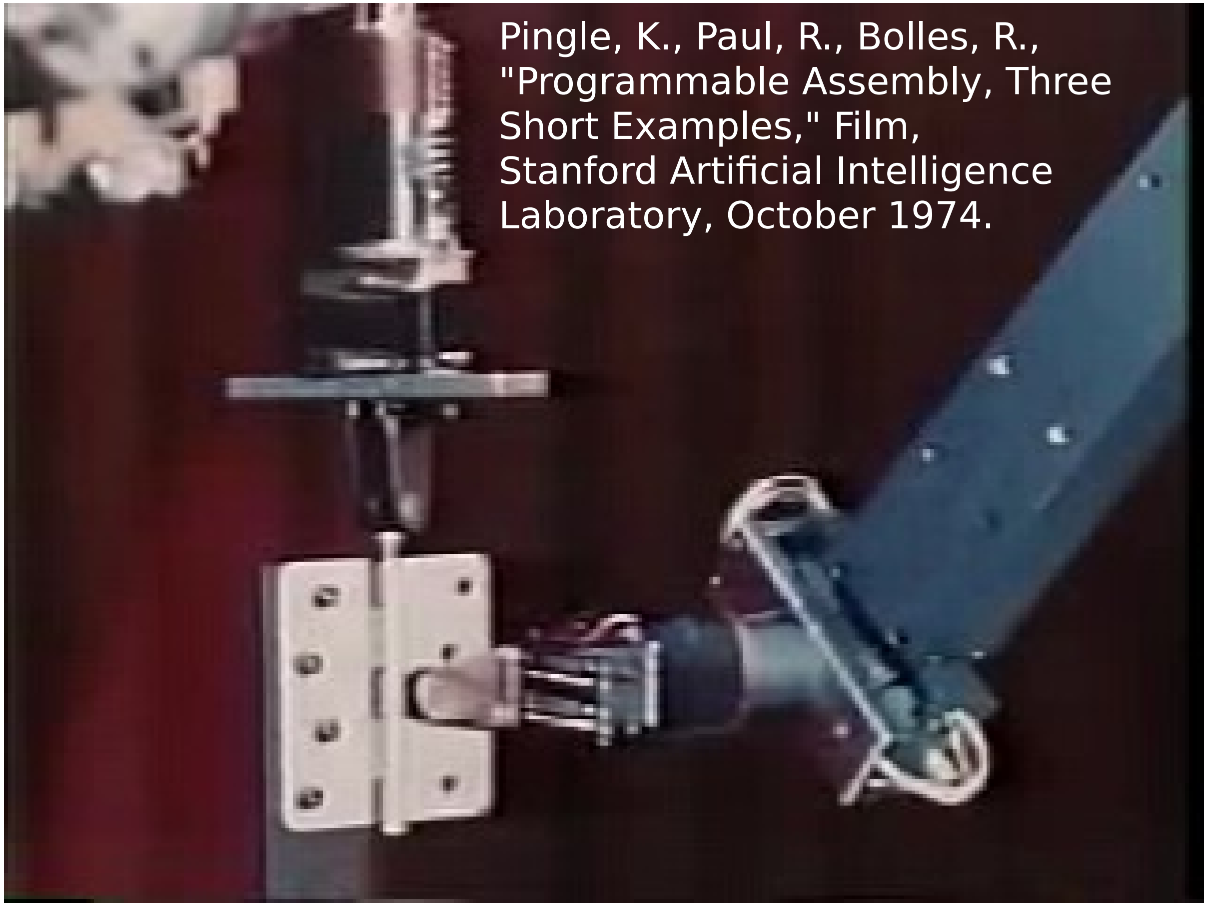
Constraints Are Your Friend

- 2 DOF Arm over a conveyor belt (2JOC)



Constraints Are Your Friend

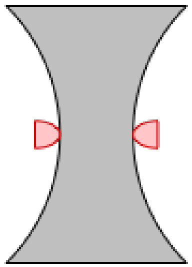
- Example: Hinge Assembly

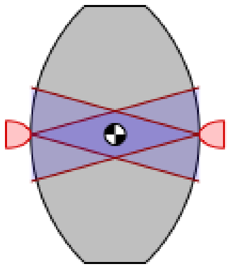


Grasping

- What does it mean to “hold” something?
  - *Form closure*: object is “secure” — can’t move without moving a contact point
  - *Force closure*: can apply any desired force
- Not necessarily the same thing — depends on your friction model (next lecture)

No friction: Form closure, but no force closure

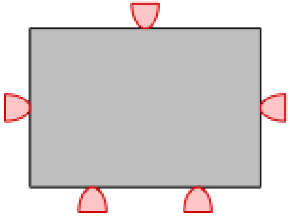




With friction: Force closure, but no form closure

Grasping

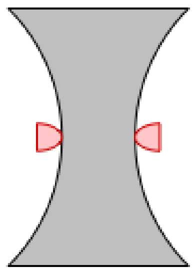
- Form closure is defined in increasing *orders*: position, velocity, acceleration, etc.
- Force closure does not have orders (you have it or you don't)
- Frictionless force closure equates to *first-order* (positional) form closure



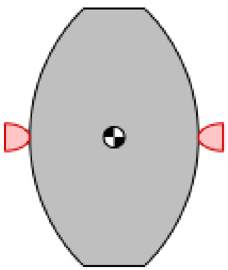
Example grasp with both force closure and first-order form closure, regardless of frictional model

Grasping

- Original examples do not have force closure
- Left figure can be moved infinitesimally up or down, although cannot be in motion vertically (so it has second-order form closure)



With no friction, neither example has force closure nor <u>first-order</u> form closure



Closure Is Not Essential

Grasping

- What does it mean to “hold” something?
  - *Form closure*: object is “secure” — can’t move without moving a contact point
  - *Force closure*: can apply any desired force
  - *Equilibrium*: can resist environmental forces (gravity)
  - *Stablity*: how much variance from the environment can be tolerated and still maintain equilibrium

Taxonomy of Contacts

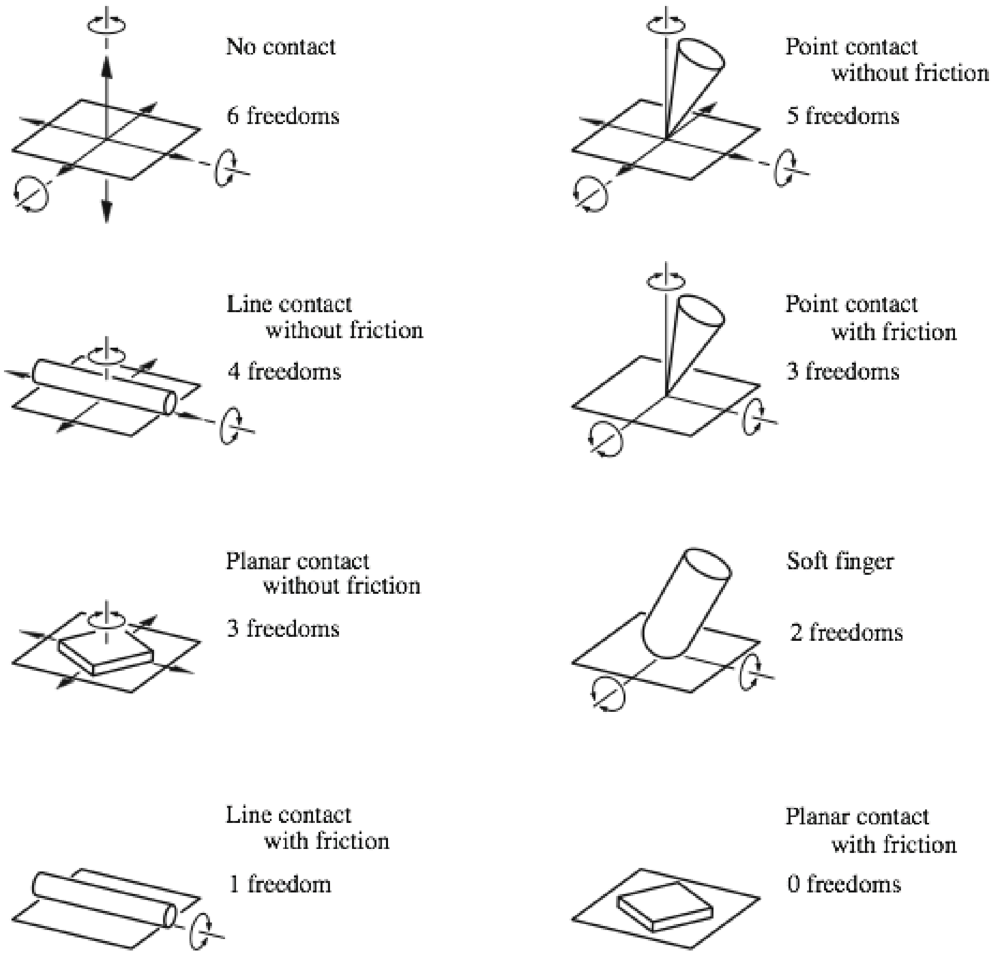
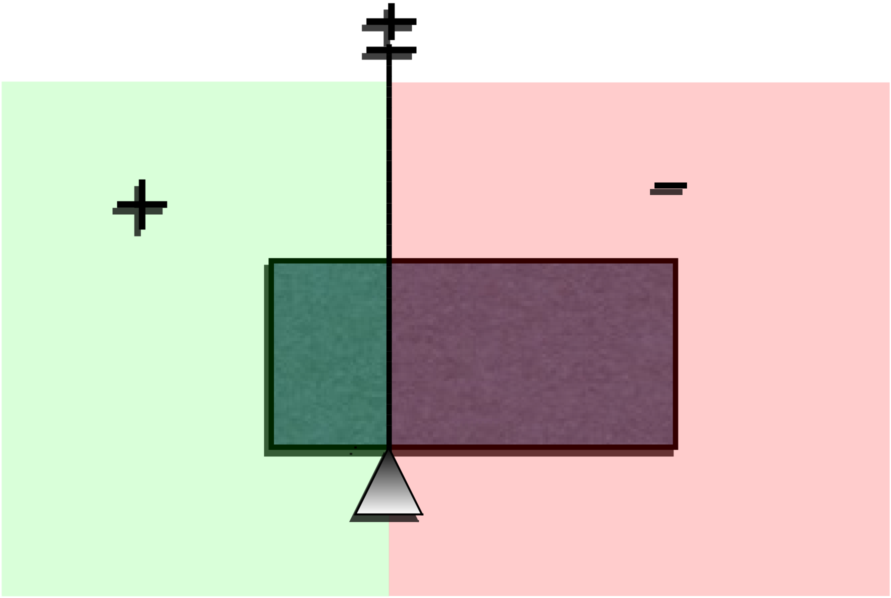


Figure 4.8 - Mason, Mechanics Of Robotic Manipulation

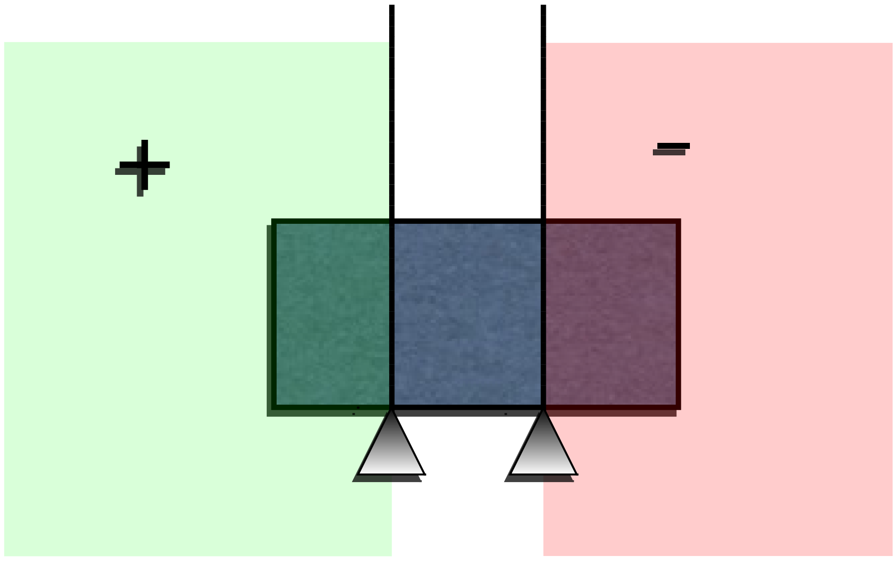
Grasp Analysis: Reuleaux's Method

- For each constraint, divide the plane into areas which can hold positive or negative centers of rotation (IC's - instantaneous centers)



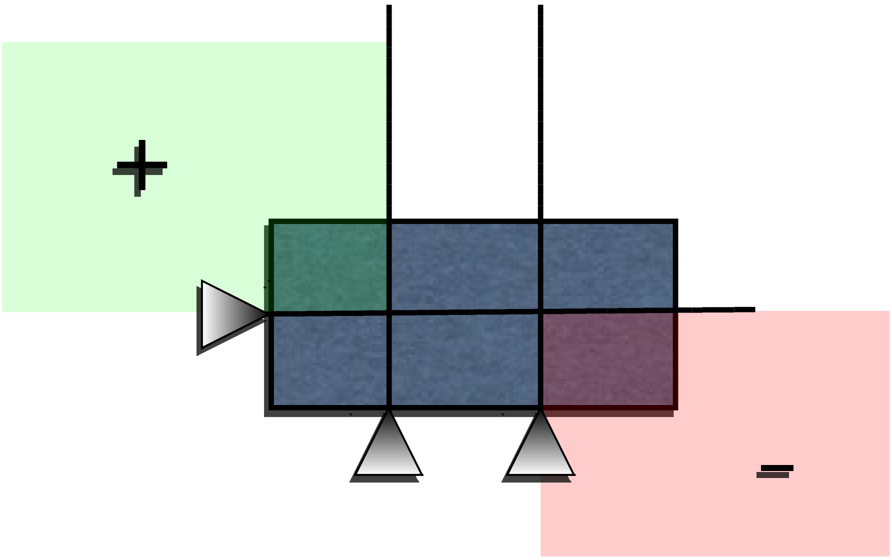
Grasp Analysis: Reuleaux’s Method

- Intersect common regions



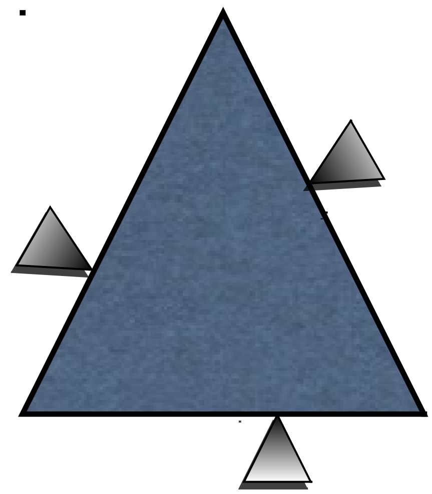
Grasp Analysis: Reuleaux's Method

- Intersect common regions



Grasp Analysis: Reuleaux's Method

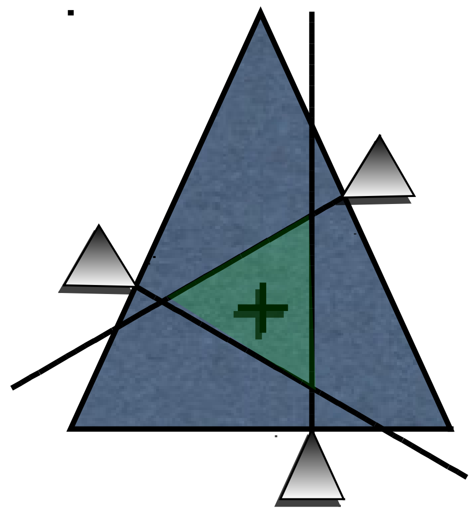
- Another example:



- Is this completely constrained?

Grasp Analysis: Reuleaux's Method

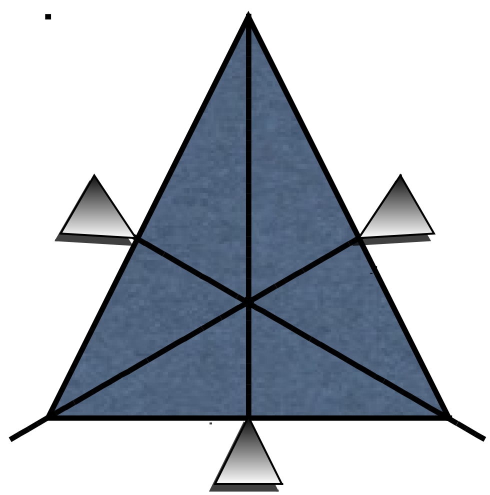
- Another example:



- Can spin counter-clockwise around area in the middle — but not clockwise!

Grasp Analysis: Reuleaux’s Method

- How about now?

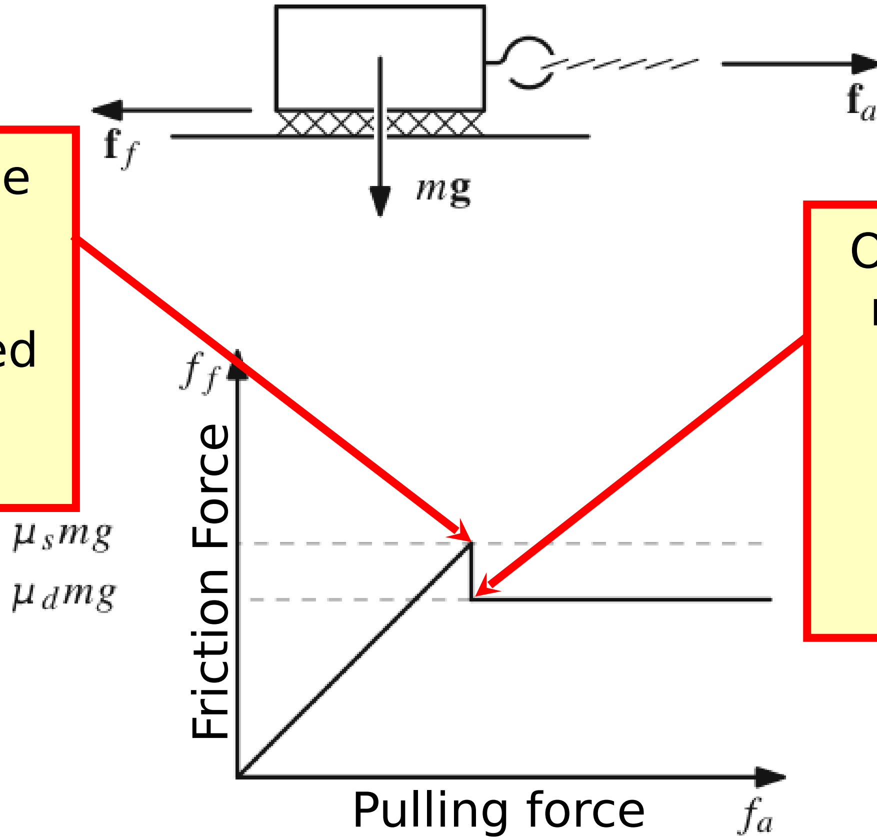


- Common intersections may indicate, but *do not guarantee*, that rotation is possible

Grasp Analysis: Reuleaux's Method

- Reuleaux's Method is good for humans, not so good for machines
- Doesn't extend to three dimensions
- Analytical solution would require a lecture unto itself
  - 16-741: Mechanics of Manipulation
  - Learn about screws, twists, wrenches, and moments

Friction: Coulomb's Law



Static friction force balances pulling force, up to maximum specified by static friction coefficient

Once object begins moving, frictional force drops to constant value, called sliding friction or kinetic friction

Figure 6.1 - Mason, Mechanics Of Robotic Manipulation

Friction: Coulomb's Law

- For common tasks, independent of velocity and surface area
  - With extreme pressures, coefficient rises
  - With extreme velocities, coefficient drops
- Coefficients of friction are different for every pair of surfaces — table lookup
  - also differ for every change in temperature, humidity, dust/dirt, vibration, celestial alignment, etc. — not terribly accurate

Friction within Joints

- Static friction is a headache for fine motor control
  - motor has to ramp up power to overcome static friction within gears, but as soon as it succeeds in doing so, it’s now providing too much power and will “jump” to life.
  - this is the fundamental reason you see the Aibo’s joints twitch from time to time
  - the higher the gear ratio, the bigger the problem

Computing with Forces

- Forces are defined by a line through space, and a magnitude
  - usually represented by a vector and a point
  - but the point is not unique — any point along the vector is equally valid (“line of action”)

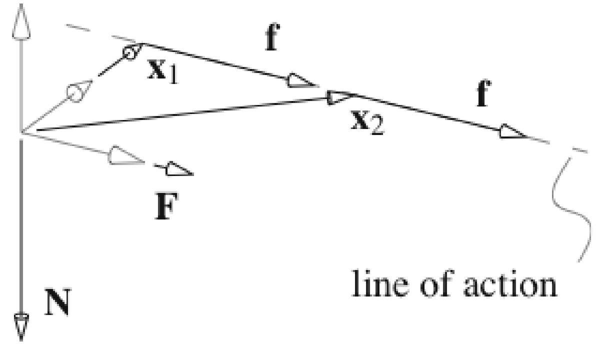
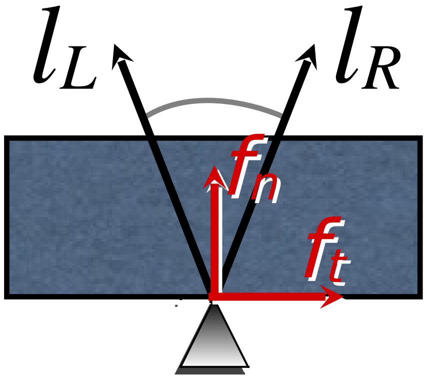


Figure 5.1 - Mason,
Mechanics Of Robotic Manipulation

$2\tan^{-1}\mu$

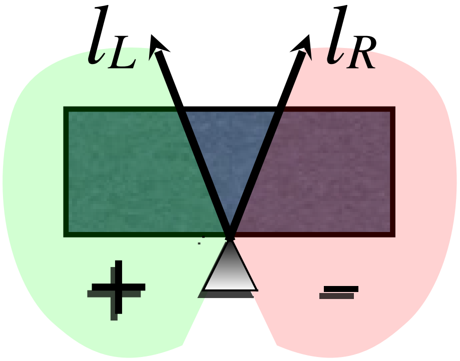
Friction with Objects

- Now we can define a friction cone:

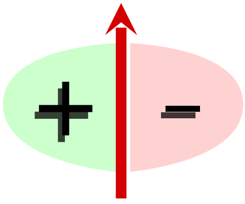


- Edges of the cone define maximum angle allowed for forces without slippage
- If you break applied force into normal force f_n and tangental force f_t, friction cone is defined as $|f_t| \leq \mu|f_n|$, with interior angle 2 $\tan^{-1}\mu$

Friction with Objects

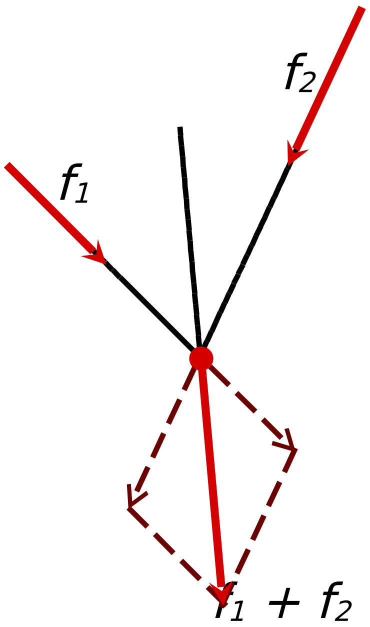


- Remember Reuleaux's Method?
  - Works with friction cones as well
- Now we're analyzing forces, not displacements, *a different interpretation!* (be careful about trying to mix them…)
- Only forces which agree with the all of the contacts' constraints can be applied by the contact(s):

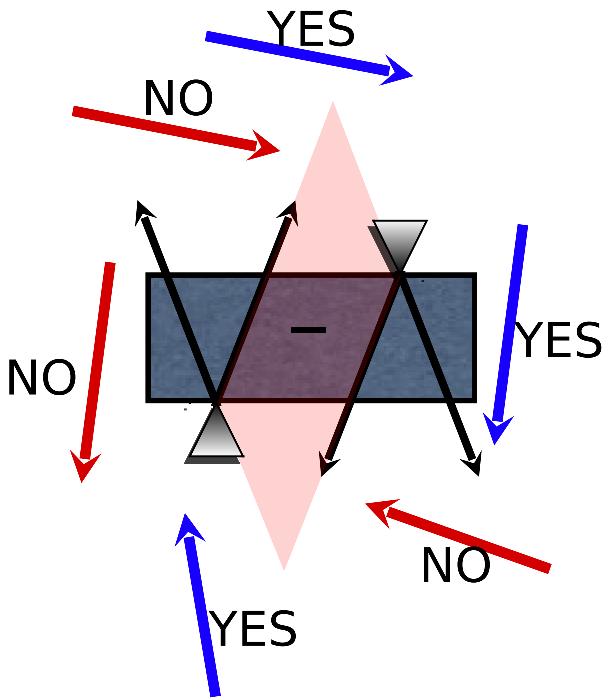


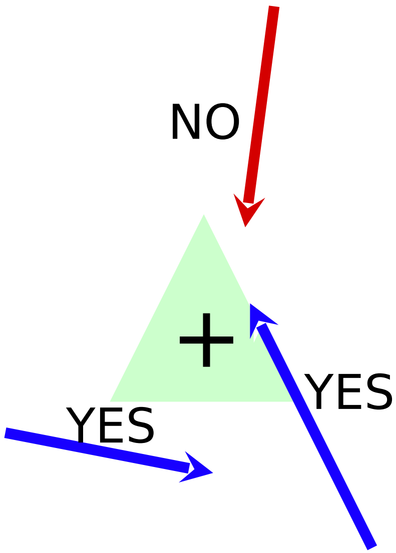
Combining Forces

- Adding multiple contacts allows you to apply any force in the linear span of their friction cones
- Remember that forces act along a line through space
  - slide forces along line of action to intersection
  - Resultant force is the vector sum of the two forces, acting through common intersection



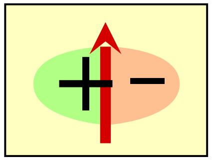
Friction with Objects: Examples





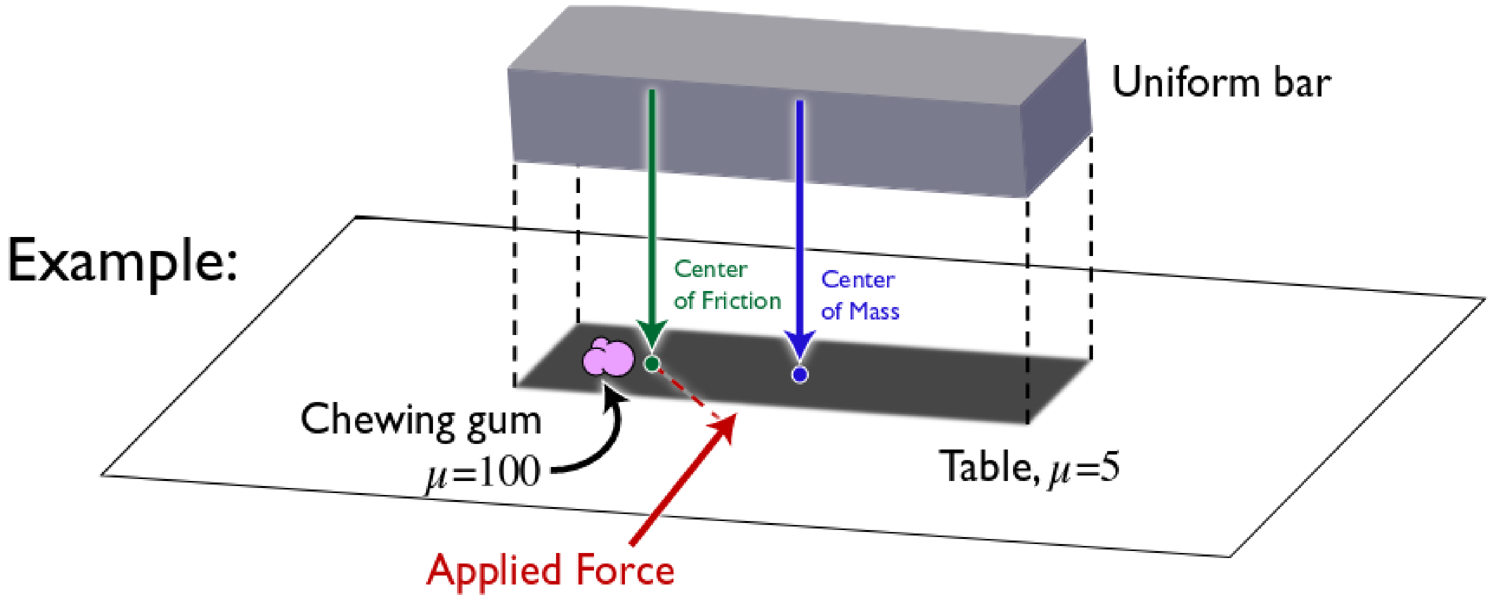
Don't actually care about the object itself once contacts have been analyzed

For reference:



Center of Friction

- Similar to center of mass, center of friction is the integrated pressure over the support region
- Allows you to treat the interaction as a single contact



Center of Friction

- Hard to model — with a rigid body, small variances completely throw off pressure distribution
- Ever play Jenga?

Applying Friction & Forces

- Use weight to flip brick
- Use wall to direct ball (extra arm)
- Get ball away from wall
- Use wall to align/direct brick
- Stand brick upright
- Insert objects without jamming or wedging