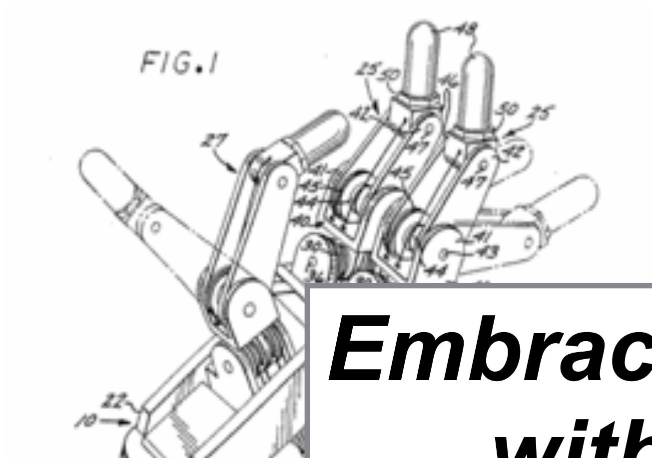
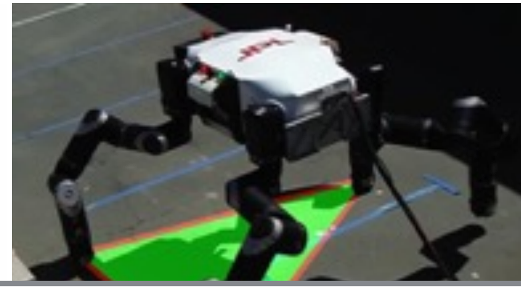
Biomimetics & Dexterous Manipulation Laboratory

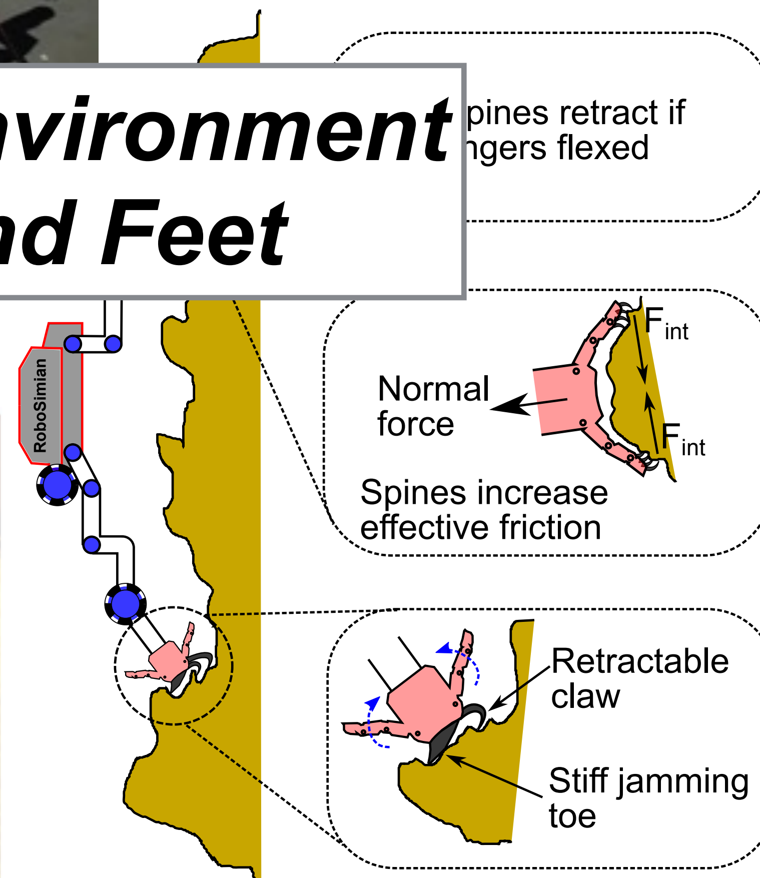
Mark R. Cutkosky
Stanford University
2-3 April 2015

Embracing the Environment with Hands and Feet

Locomotion versus Manipulation

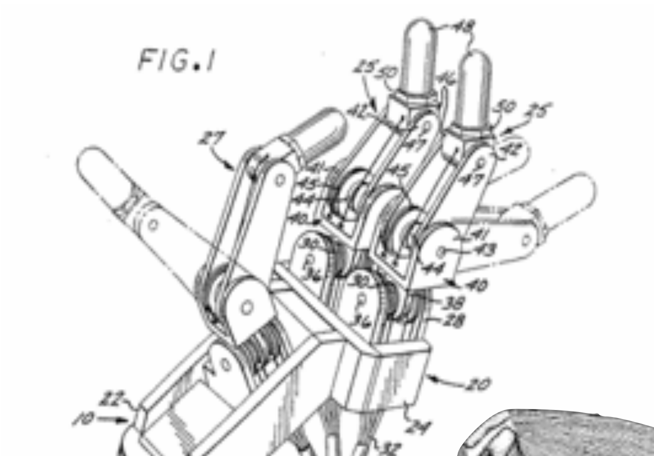


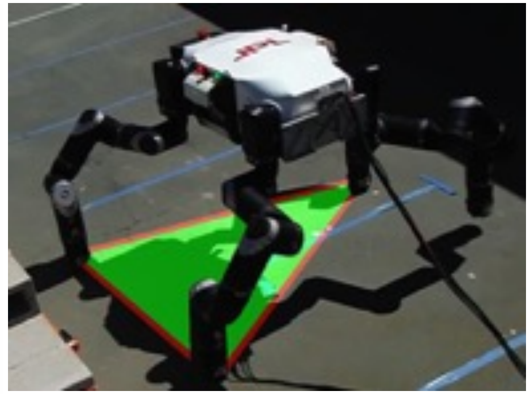




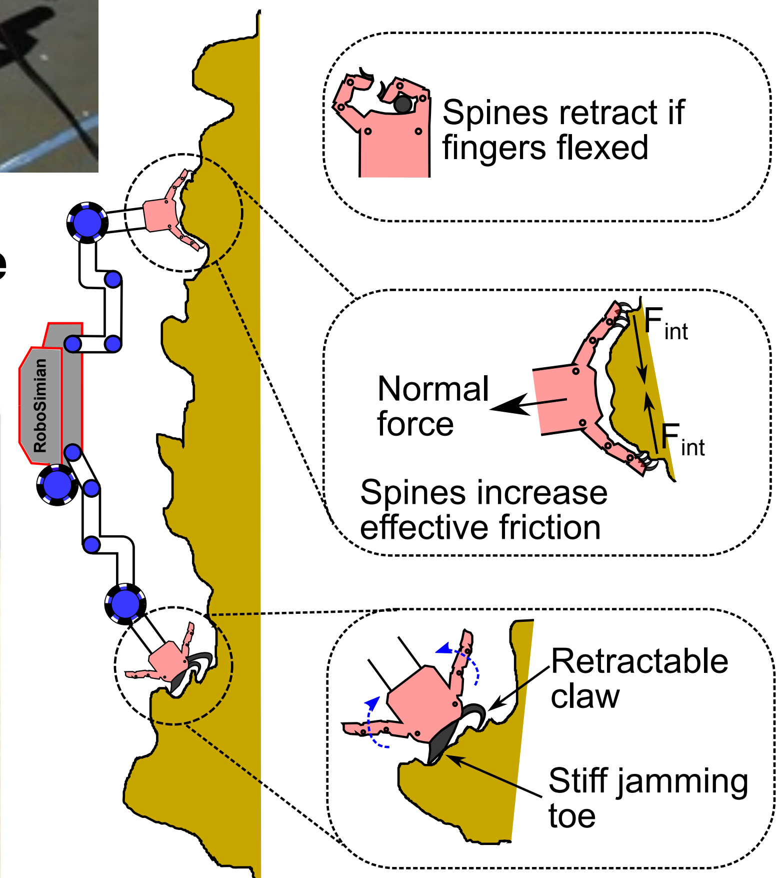
Passive Properties versus Active Control

Workshop Session Themes





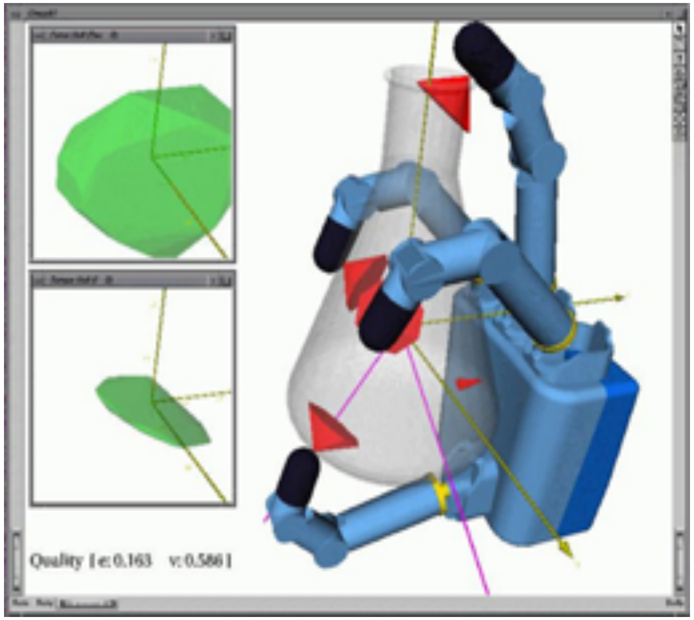
1. Locomotion versus Manipulation

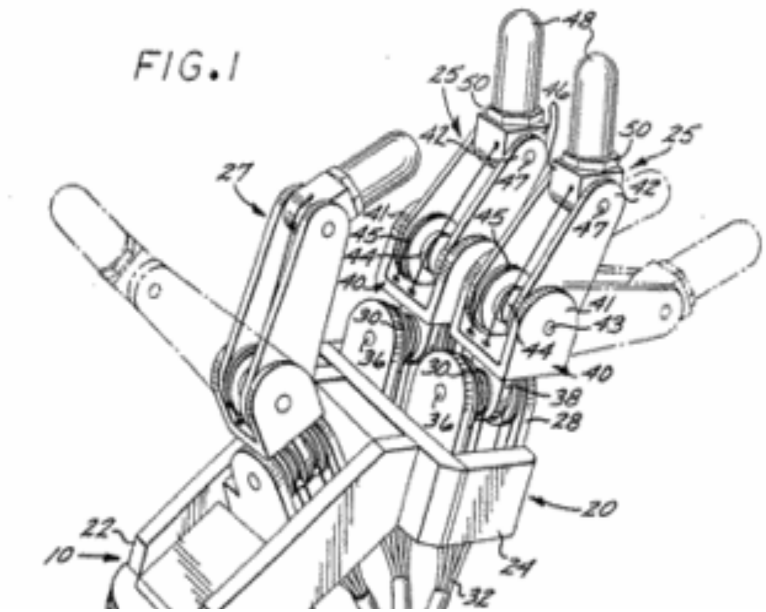


2. Embrace the Environment

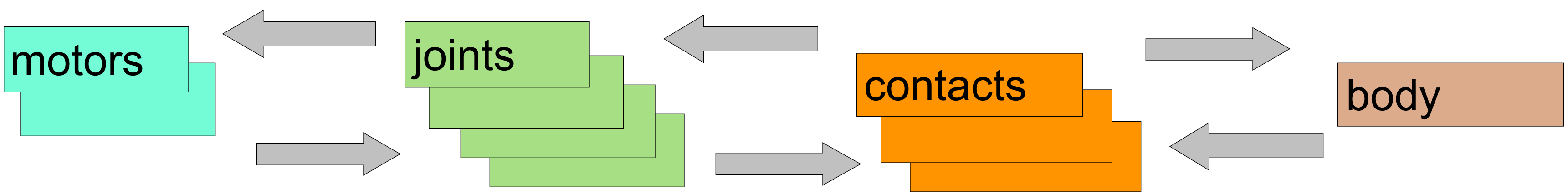
3. Passive Properties versus Active Control

1. Manipulation vs Locomotion





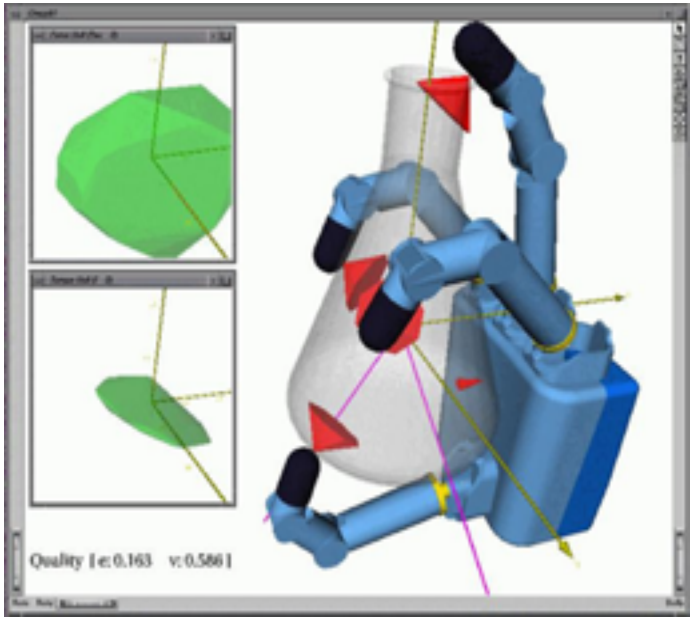
forces, moments

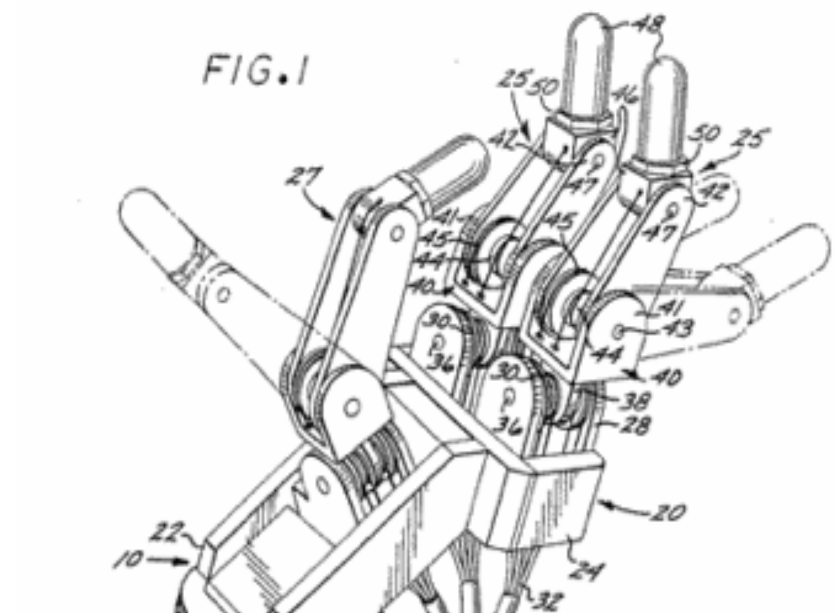


velocities

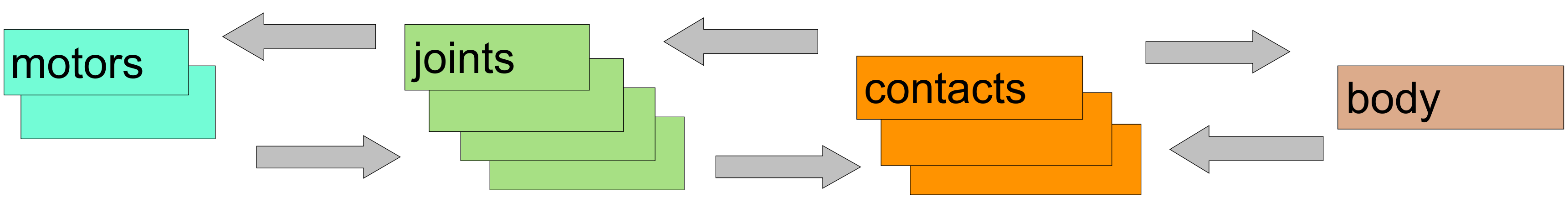
$$H\,R\,J_0\,T(U^*\dot{\mathbf{q}}_m) = \dot{\mathbf{x}}_c = R_b J_b \dot{\mathbf{x}}_b.$$

Manipulation



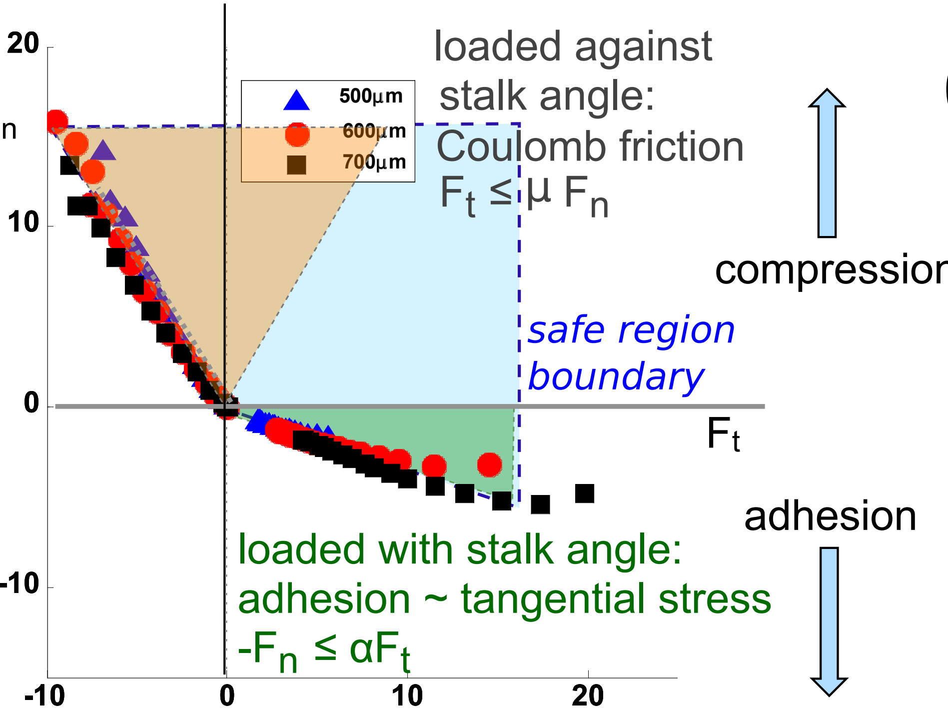


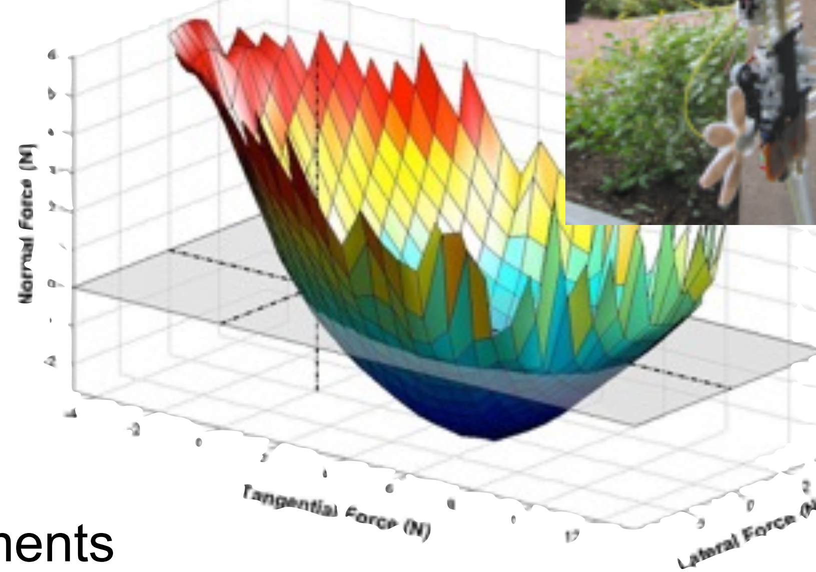
forces, moments



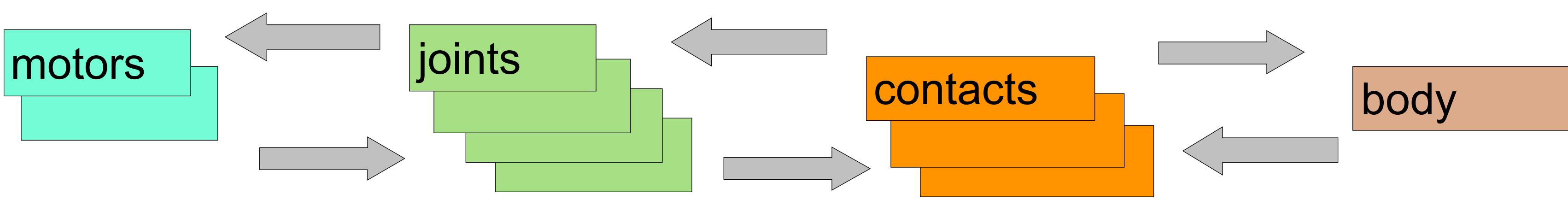
Key idea: control internal grasp forces
(in the null space of the equilibrium equations)
to control friction forces
and achieve grasping objectives

Climbing





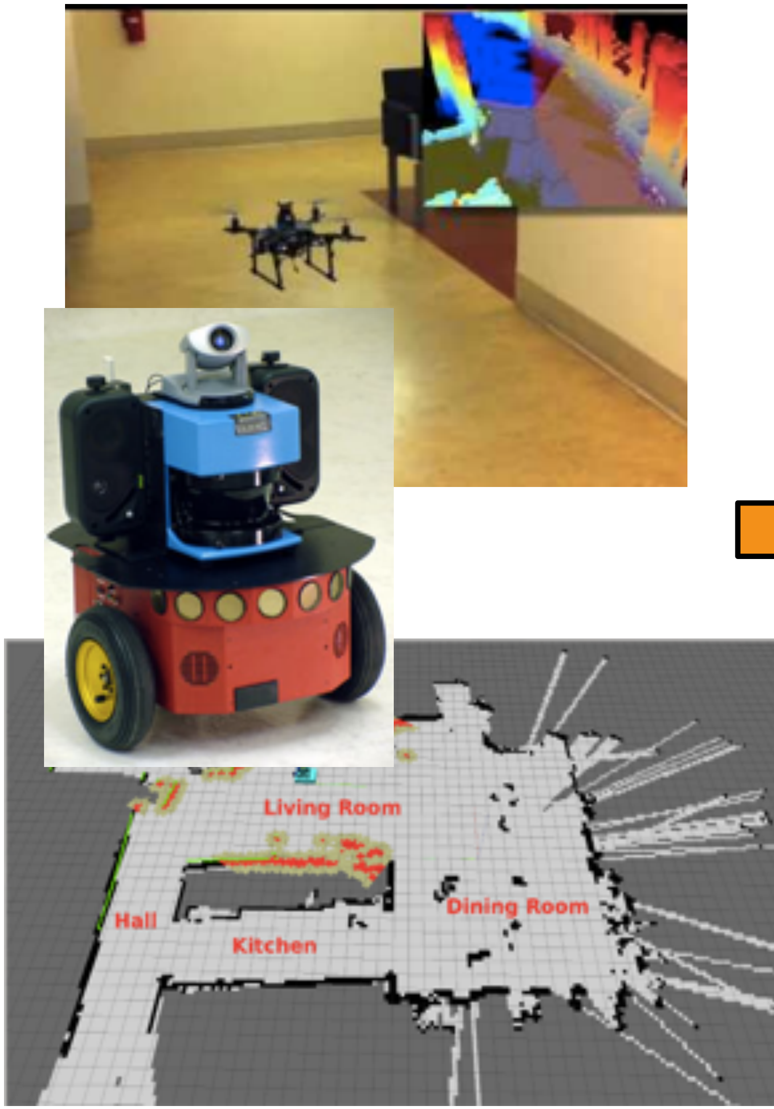
forces, moments



Key idea: control internal forces
(in the null space of the equilibrium equations)
to control friction and adhesion forces
and achieve climbing objectives

Embrace the Environment

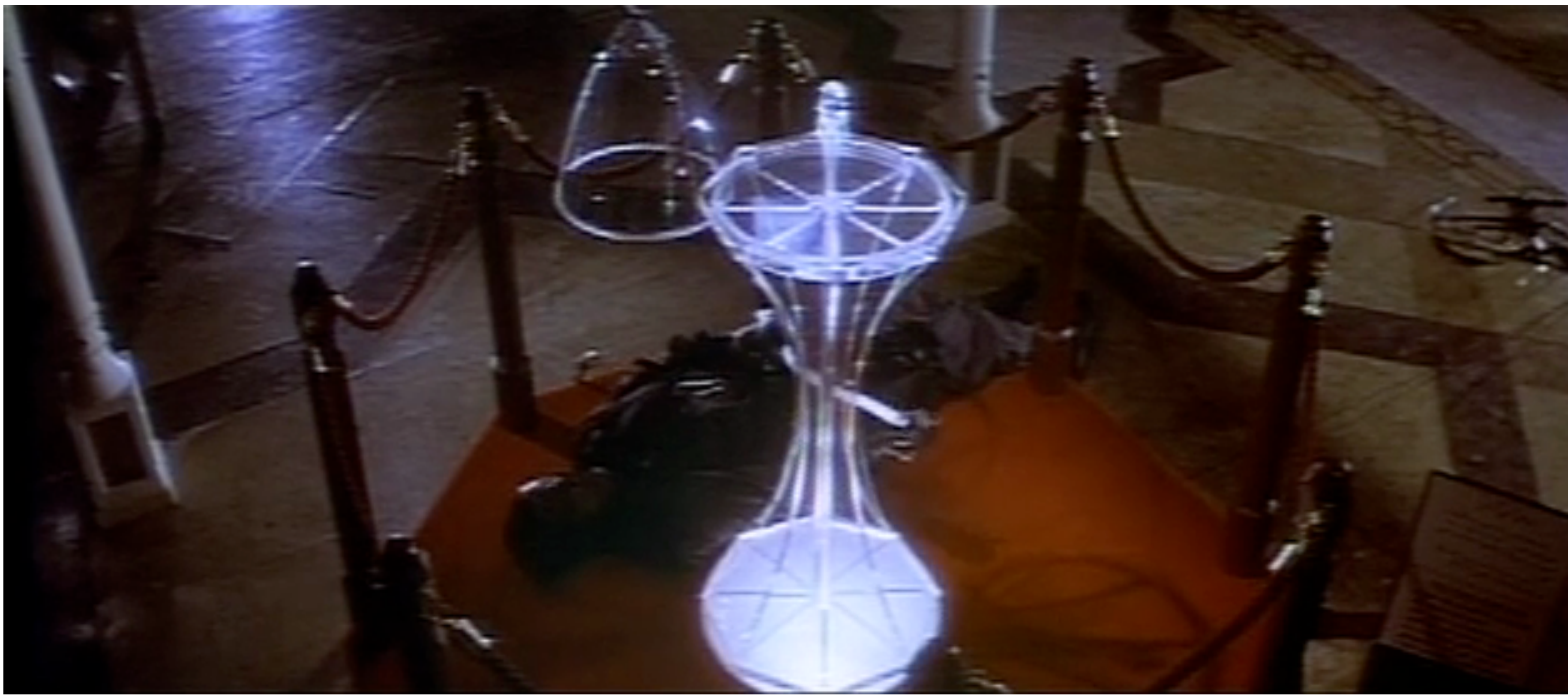
From "Hands off" to "Hands on" — robots interact energetically with the environment.



Embracing and exploiting the environment — *not*

Traditional manipulation and motion planning:

- Carefully plan trajectories in space.
- Highly restrict contacts.
- Minimize uncertainty.

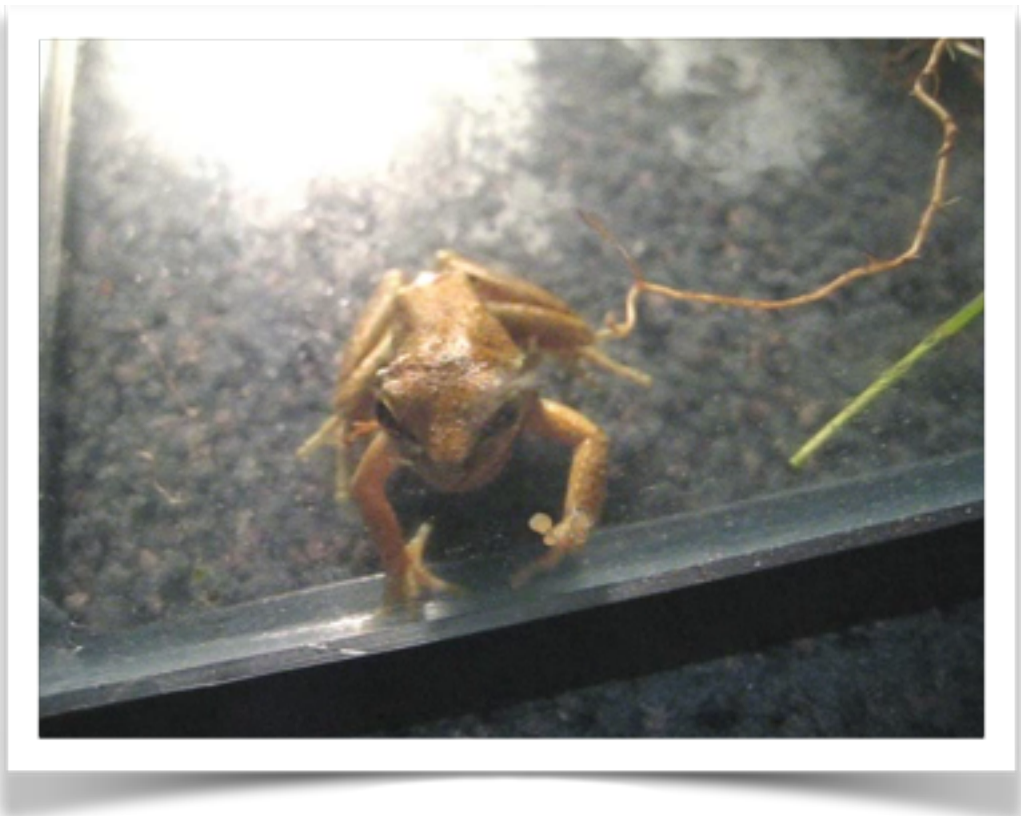


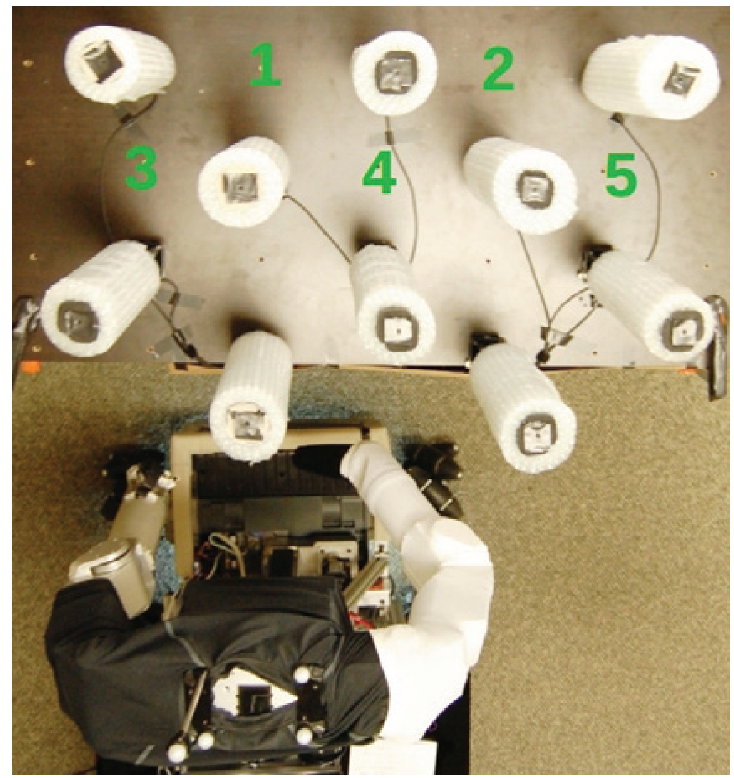
The Pink Panther, stealing a rare diamond from inside a Museum

Embracing and exploiting the environment

Biological manipulation and motion planning:

- Any contact is good contact
- Use highly robust strategies and appendages
- If it fails, try again!





Jain et al., “Reaching in clutter with whole-arm tactile sensing,” IJRR (2013)

Lessons from biology for bio-inspired design:

R.J. Full

1. Reduce Complexity - Collapse Dimensions

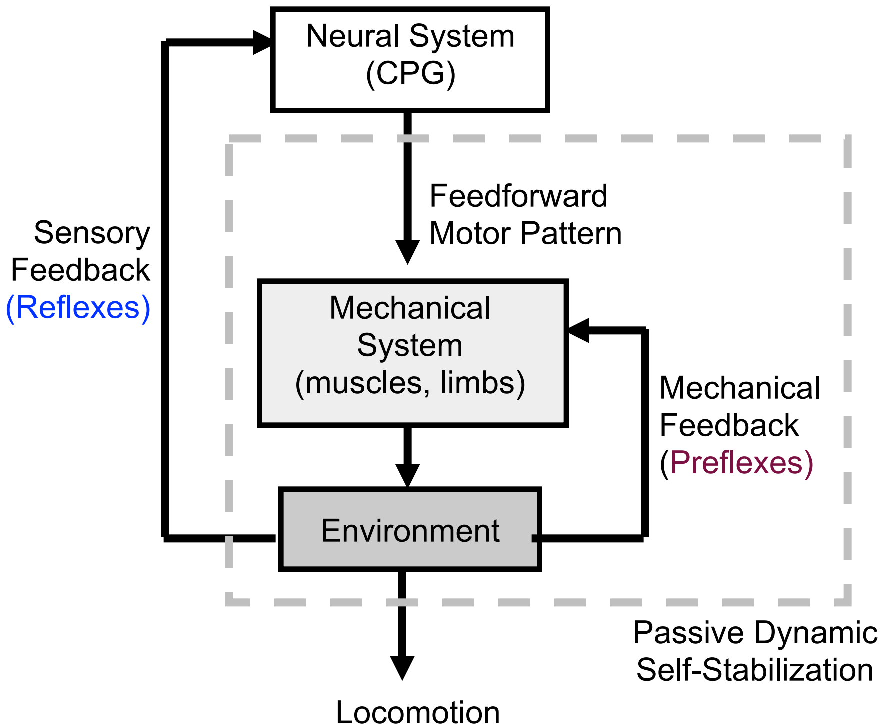
2. Manage Energy

3. Use Multifunctional Materials - Tuned, Integrated & Robust

4. Exploit Interaction with Environment

Biological Inspiration

- Control heirarchy
  - Passive component
  - Active component



Mechanical System		Neural System
Feedforward	*Preflex*	*Reflex*
Motor program acting through moment arms	Intrinsic musculo-skeletal properties	Neural feedback loops
Predictive	Rapid acting	Slow acting
Passive Dynamic Self-stabilization		Active Stabilization

Full and Koditschek, 1999

Embracing and exploiting the environment

As robots venture into the world they too need strategies that embrace the environment with:

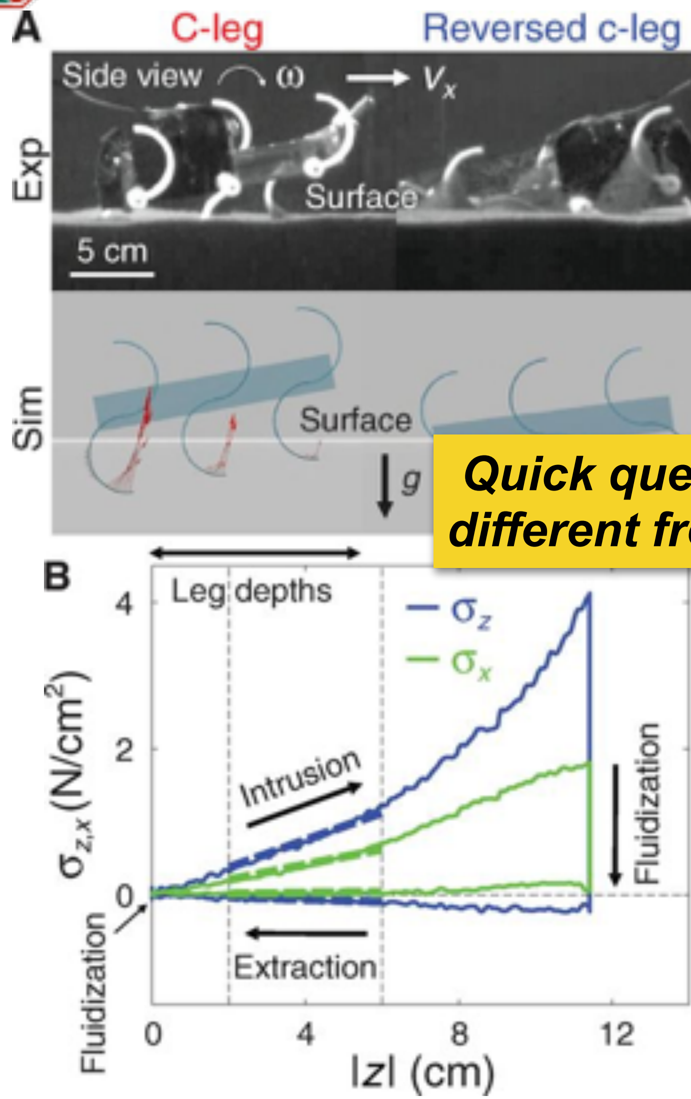
- ***models*** of the physical interaction,
- compliant, robust ***mechanisms***
- ability to ***sense*** and respond to changing conditions

Easy ← Terrain difficulty → Hard

Flat ground	Pipes & Trees	Unstructured obstacles
		
Basic gaits	Specialized gaits	Non-gait motions

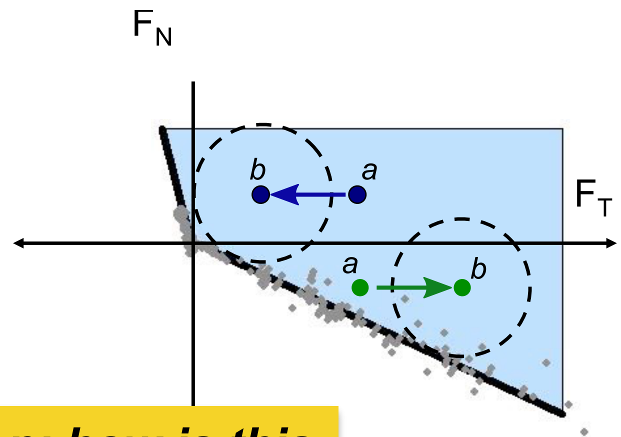
Hatton et al, ICRA 2013

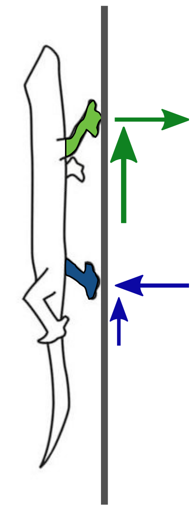
Modeling physical interactions

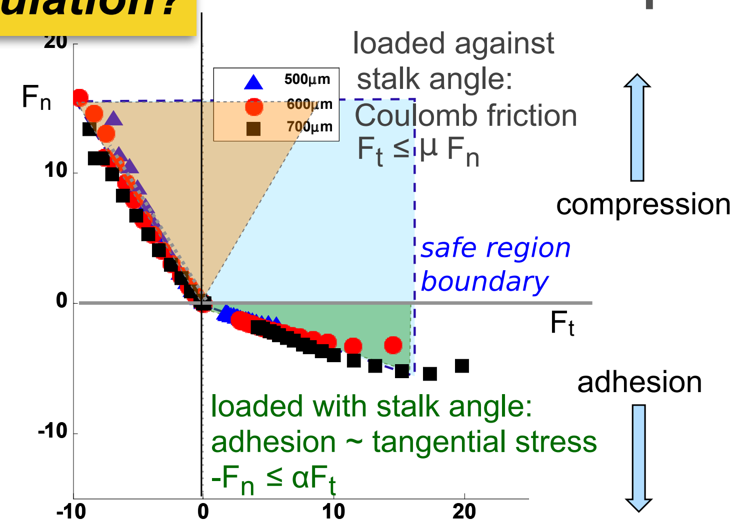


Fluidization effects for running in granular media [Li,Zhang,Goldman2013]

Quick question: how is this different from manipulation?

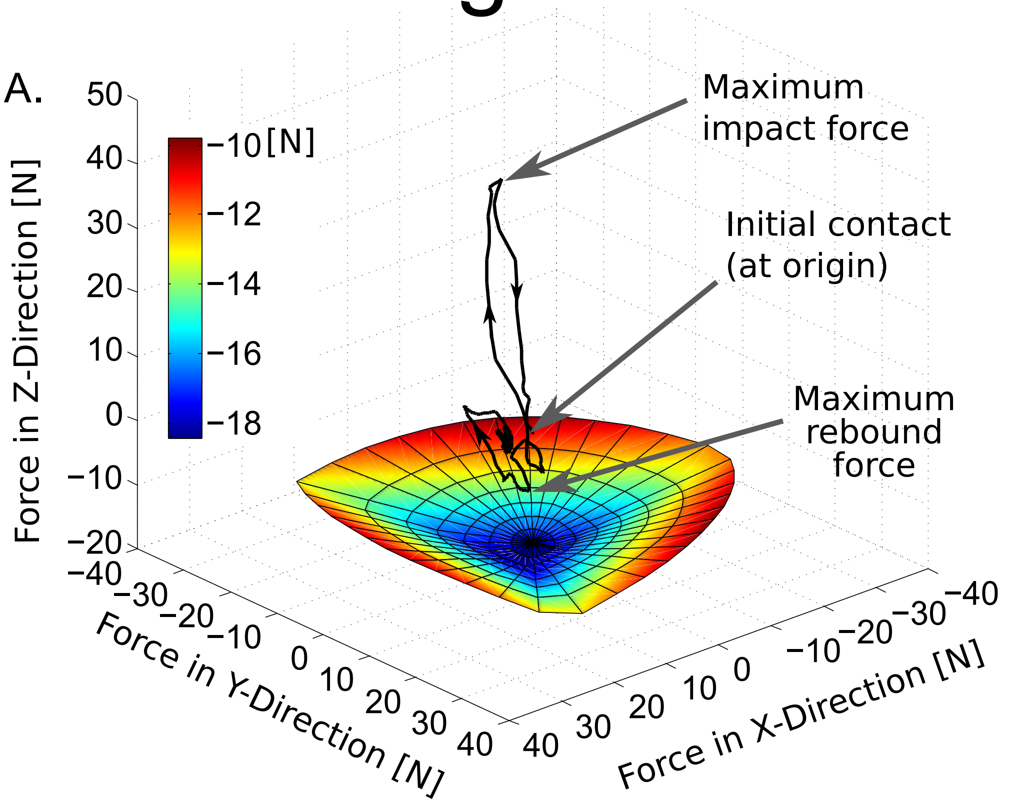






Friction and adhesion for climbing or grasping

Modeling the dynamics of making, breaking contact

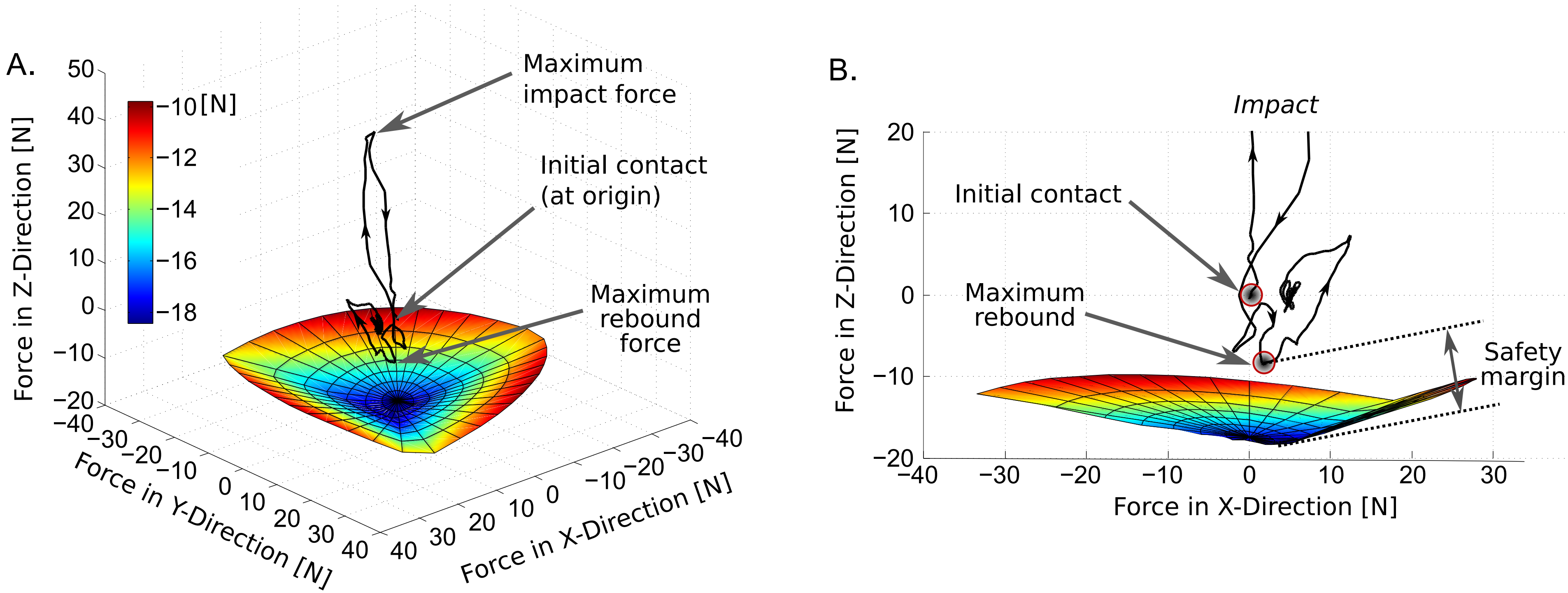


Jiang, H., et al, "Modeling the Dynamics of Perching with Opposed-Grip Mechanisms," ICRA 2014

The interesting stuff happens when contact conditions are changing rapidly

http://youtu.be/wD-9oAuB9do

Modeling the dynamics of making, breaking contact



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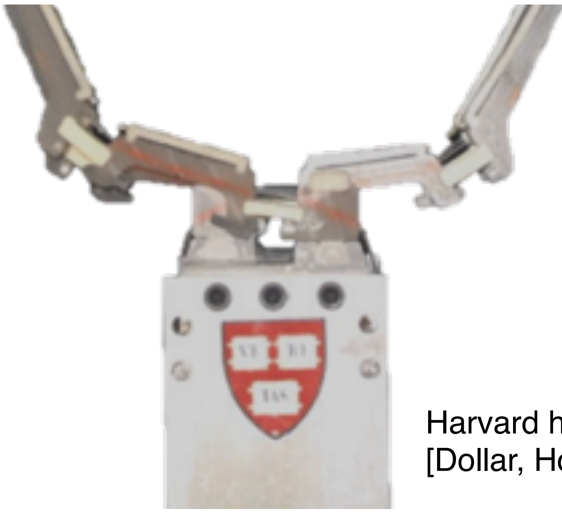
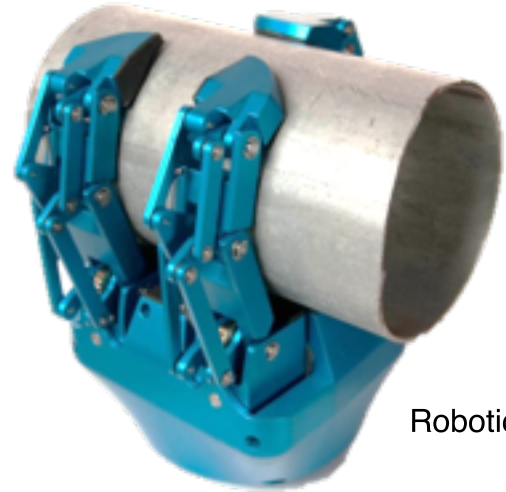
The interesting stuff happens when contact conditions are changing rapidly

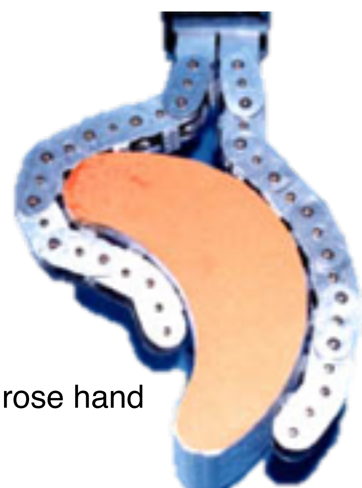
“Preflexes”: robust, compliant, under-actuated mechanisms



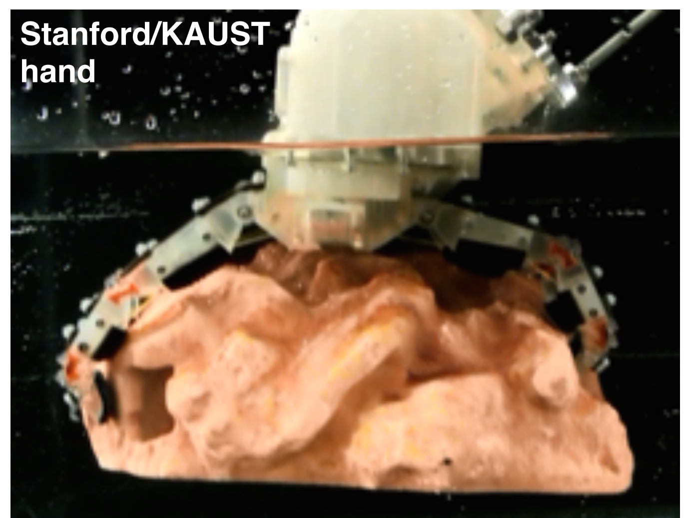
Harvard hand
[Dollar, Howe]



Robotiq hand



Hirose hand



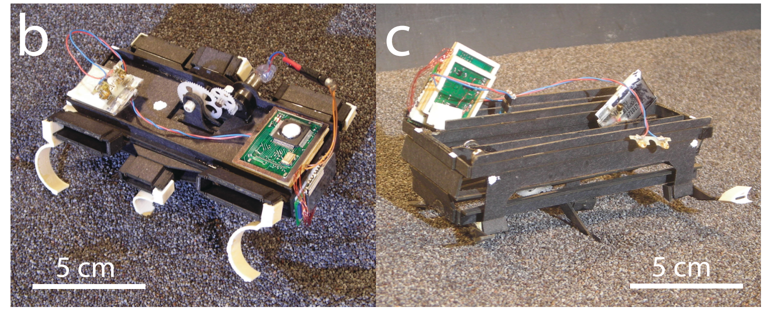
Stanford/KAUST hand

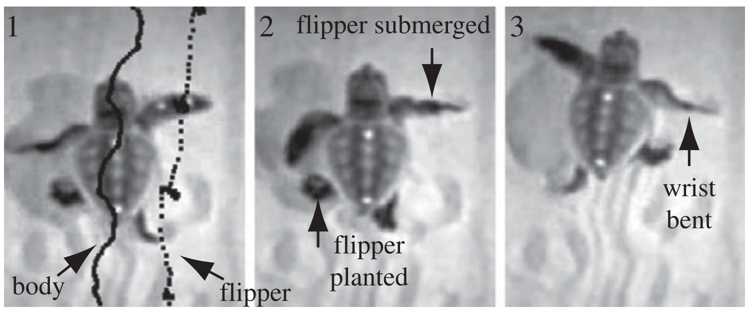
Use end-Effectors that embrace the environment

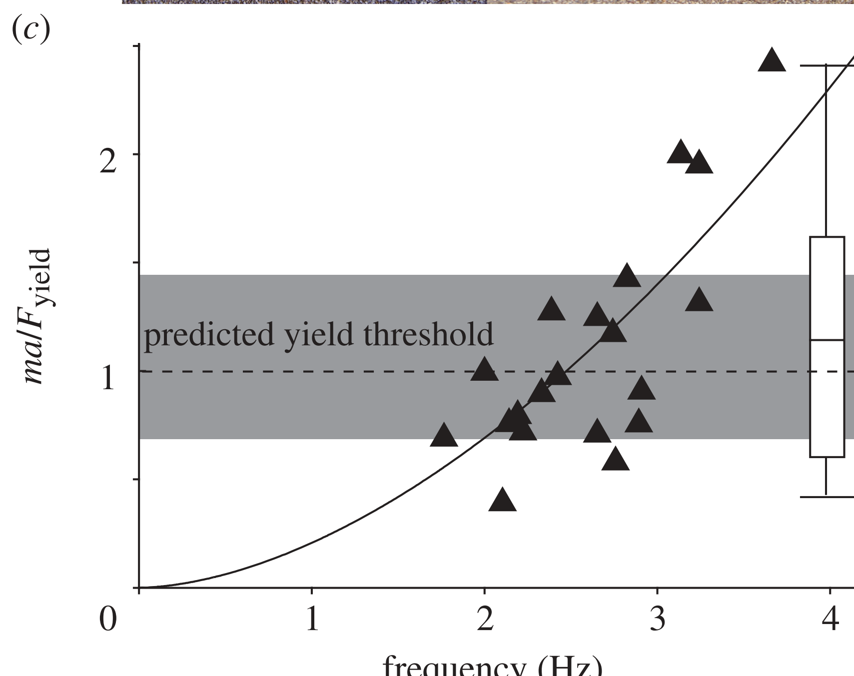
Embrace and *exploit* the environment

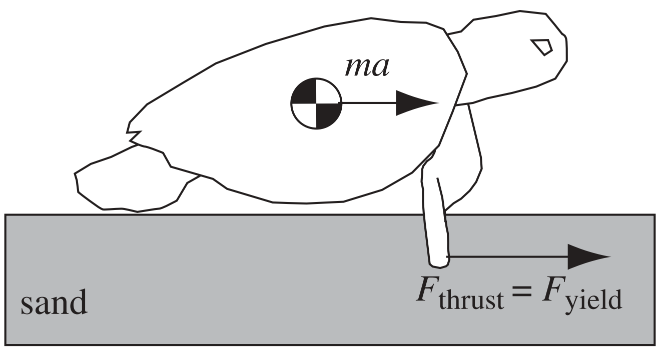
Modify the physics of the interaction with the environment

Dash and Roach in granular media
Li et al. SPIE 2010





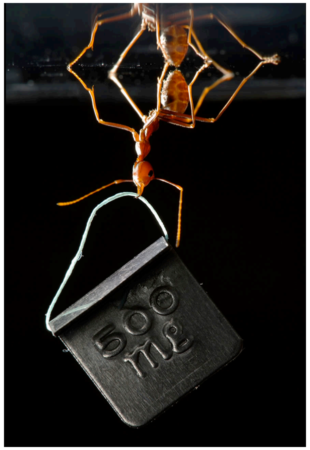




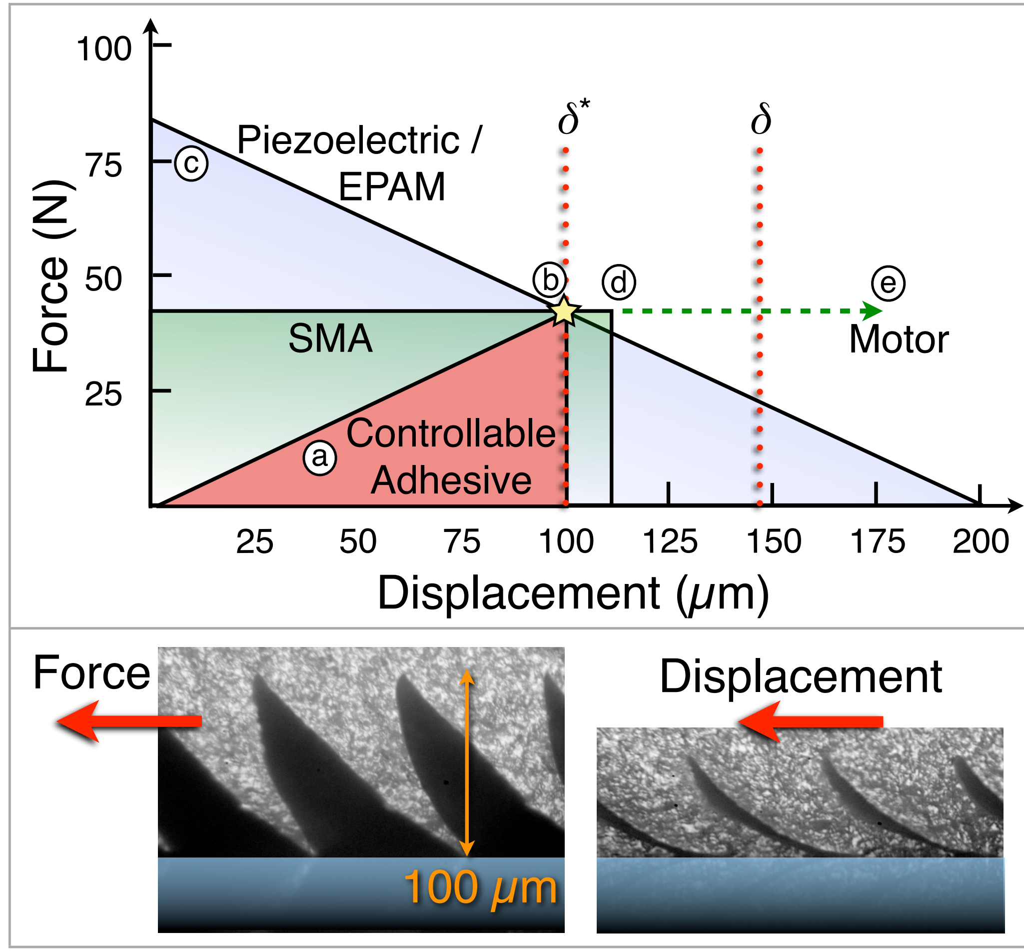
Utilization of granular solidification during terrestrial locomotion of hatchling sea turtles
Mazouchova, Gravish, Savu, Goldman, Biology Letters (2010)

Embrace and exploit the environment

Modify the physics of the interaction with the environment



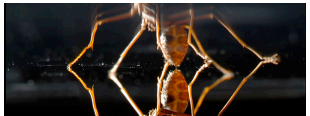
If you are small, and friction is inadequate, exploit adhesion!



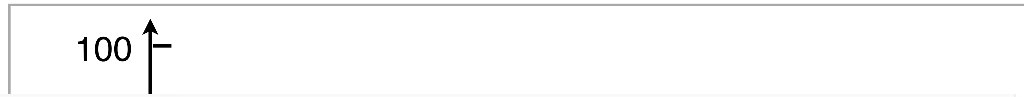
(a) Required work to load adhesive, (b) corresponding force. (c) Piezo and EPAM actuators match poorly, (d,e) SMA and motor match better

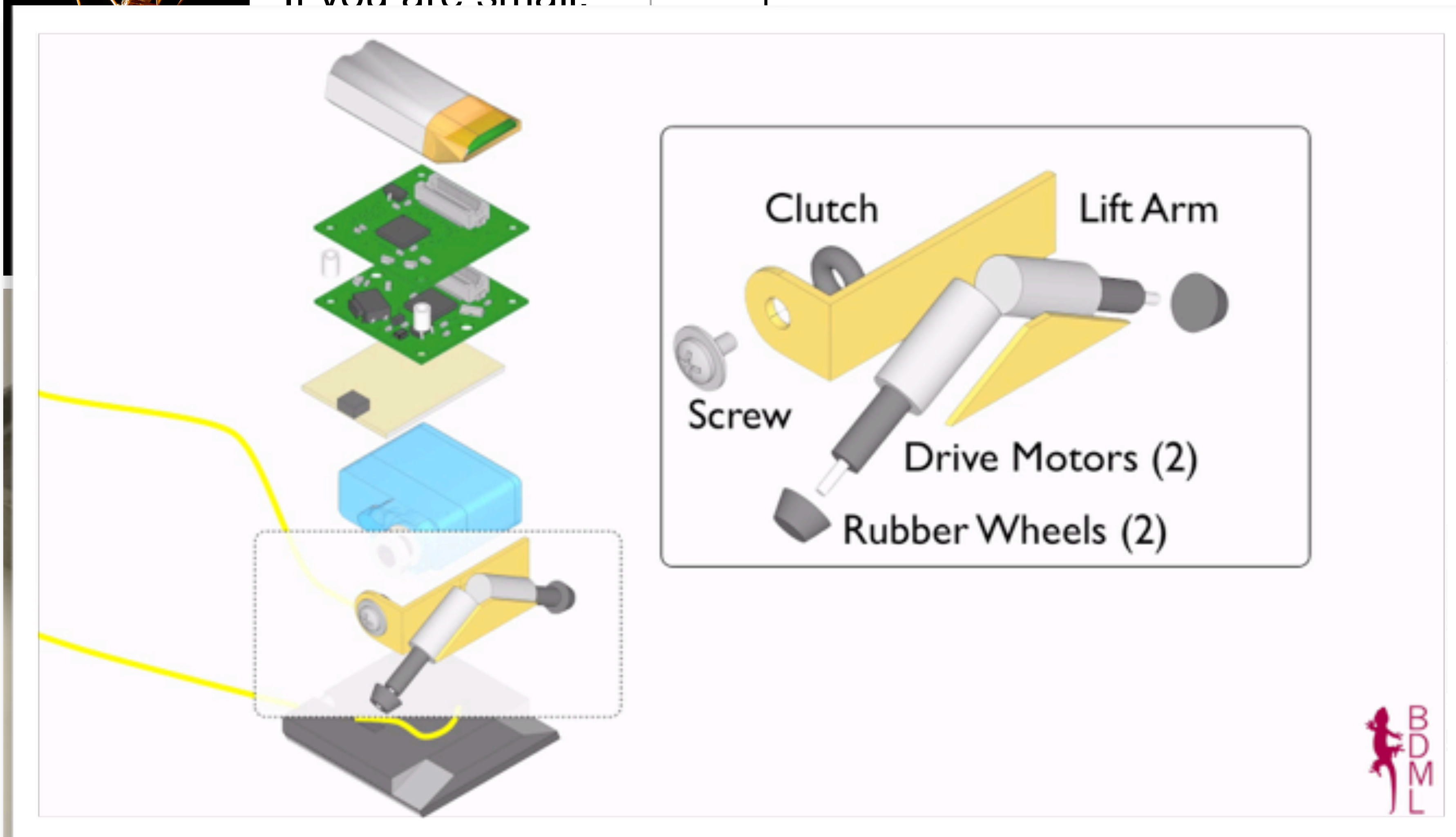
Embrace and exploit the environment

Modify the physics of the interaction with the environment



If you are small,

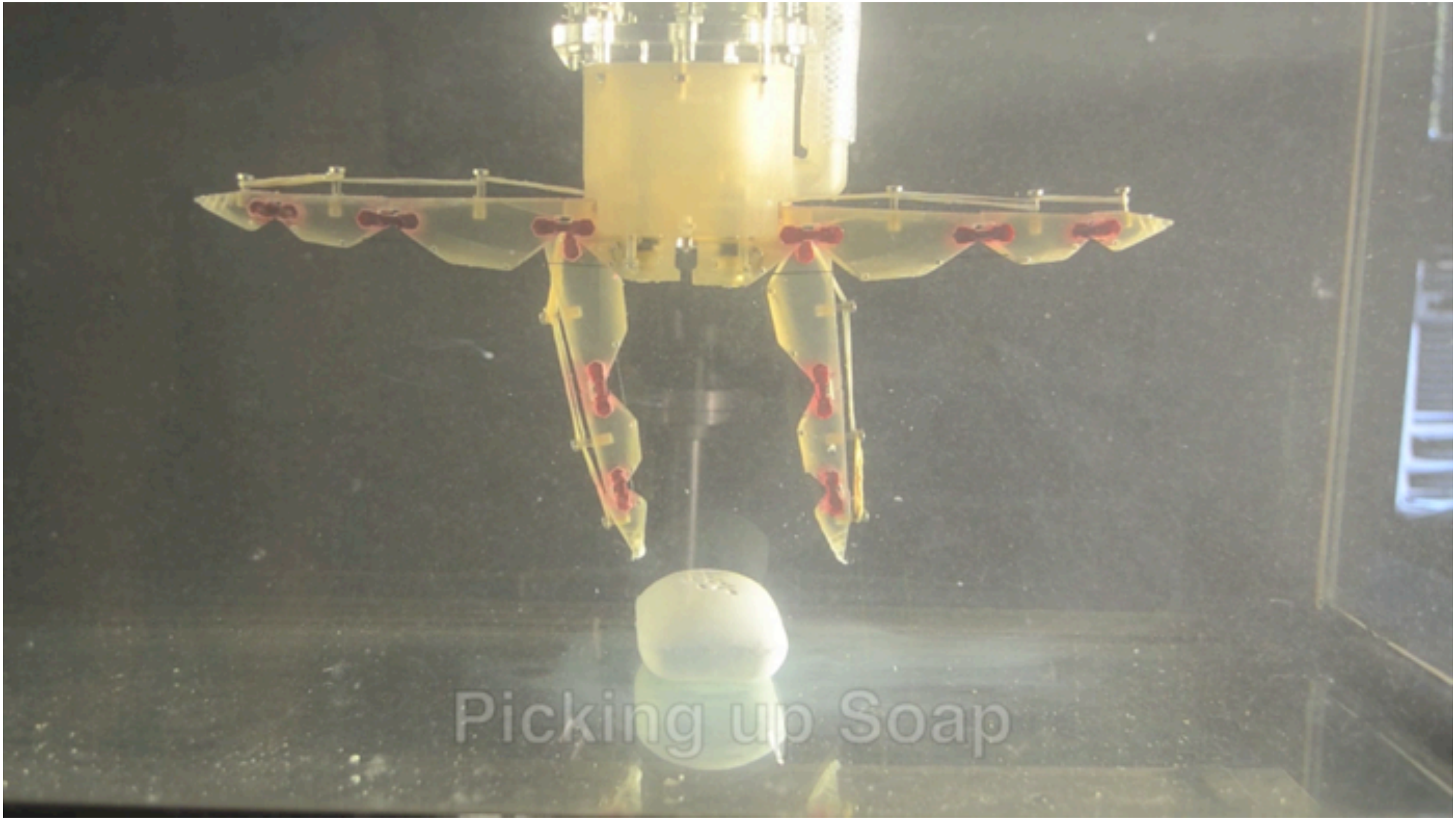




Video: http://youtu.be/IvXGjSPOR0w

Embrace and exploit the environment

Modify the physics of the interaction with the environment

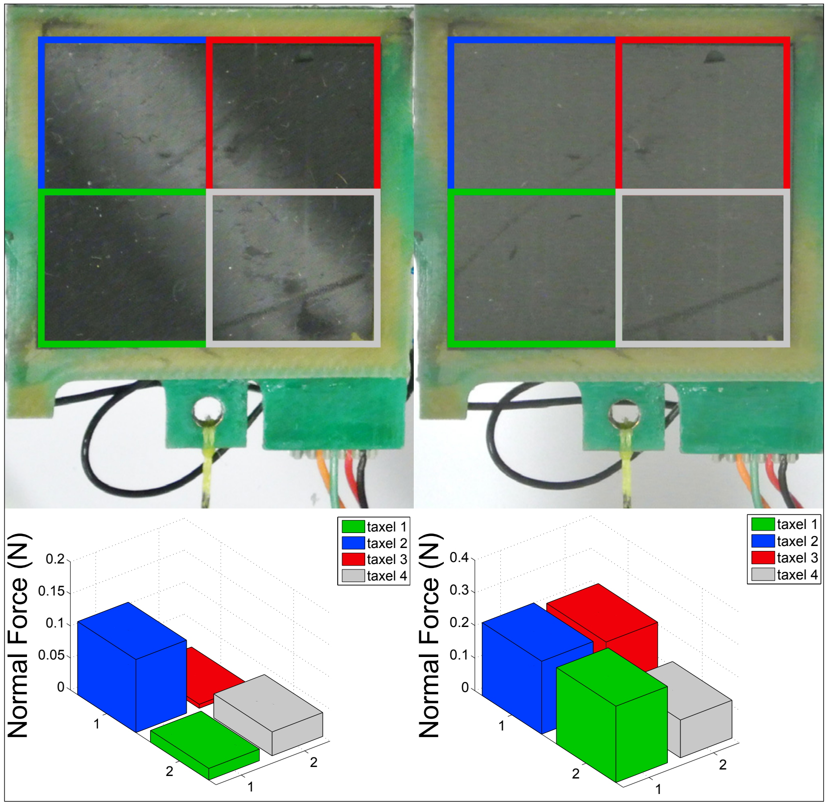


Video: https://youtu.be/X_iyLWsrPGg

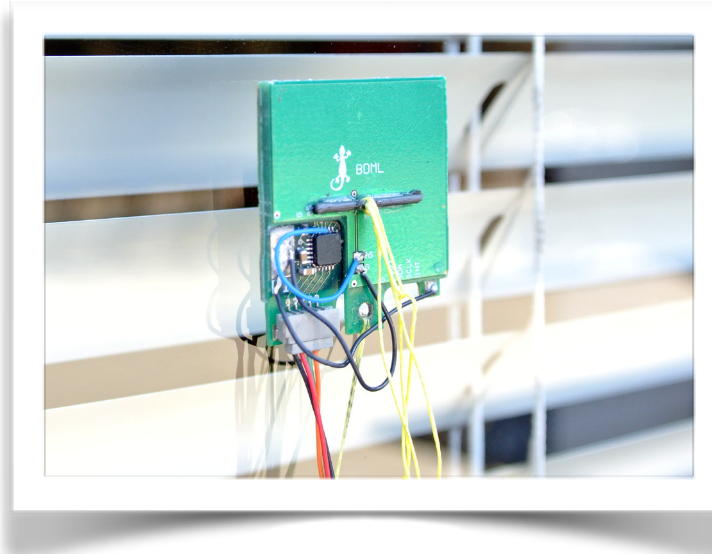
Sensing: detect and react to changes in interactions with the environment

Sometimes under-actuation, compliance and mechanical robustness do not suffice…

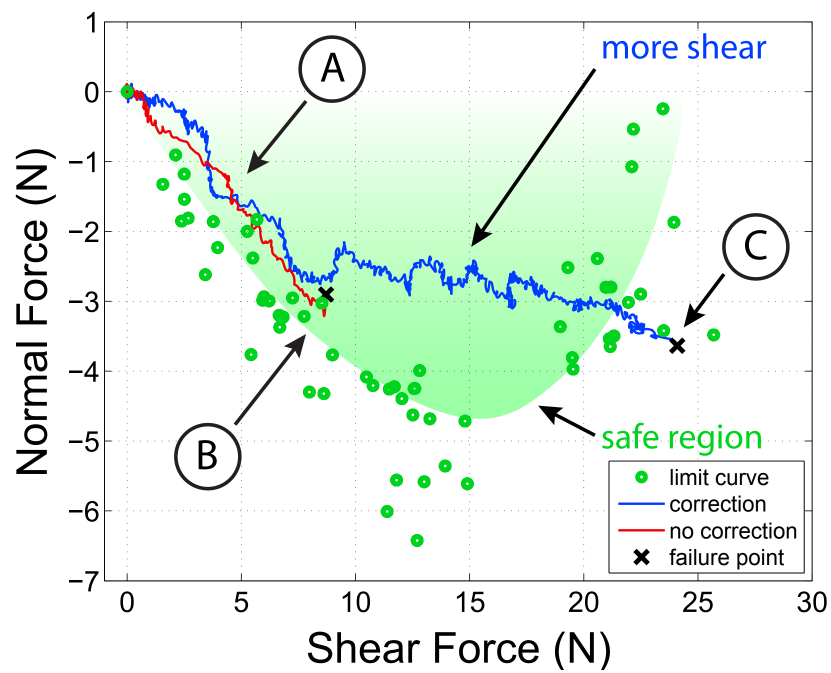
Sensing the wall



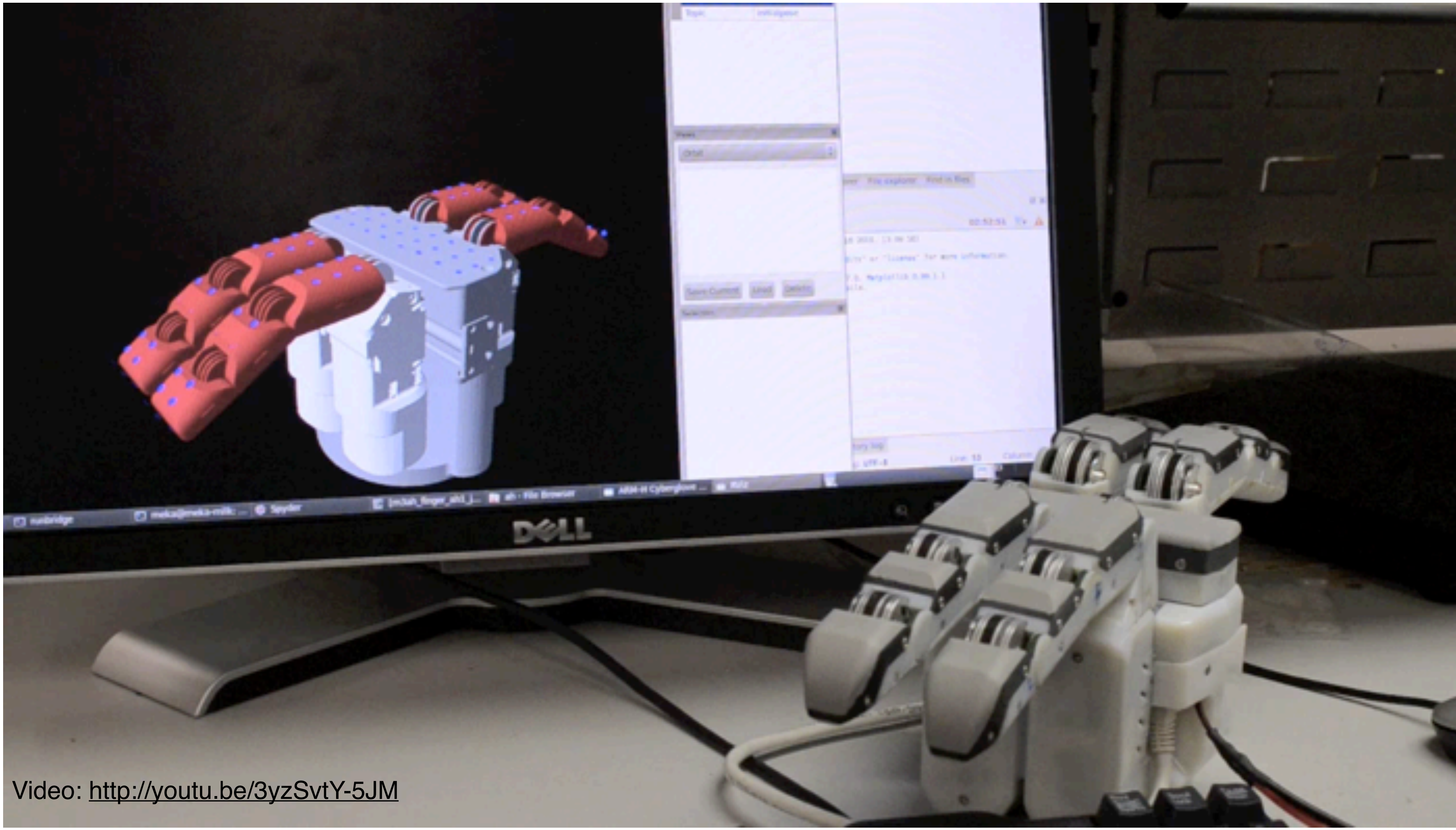
Above: Adhesion sensor detects non-uniform loading.
Right: Comparing normal and shear forces with adhesion limit surface allows loading adjustment



When climbing or perching on a window: *do we have a good grip?*

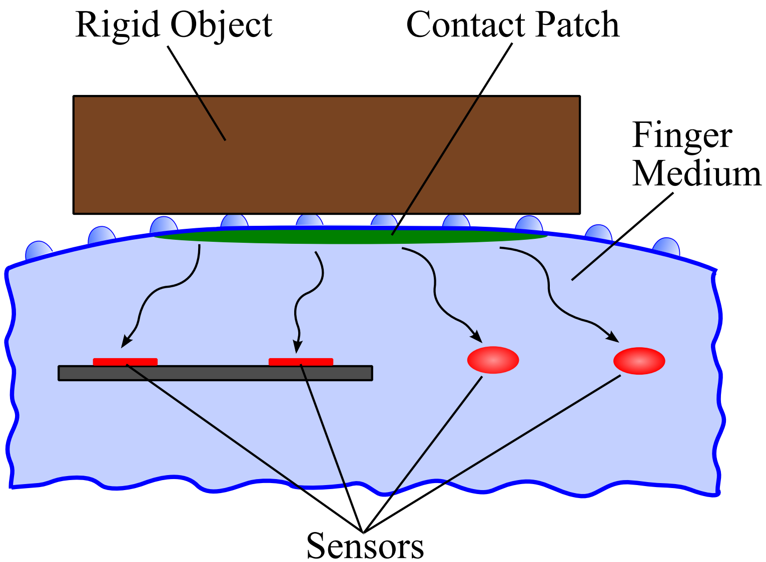


Multi-axis capacitive tactile sensing

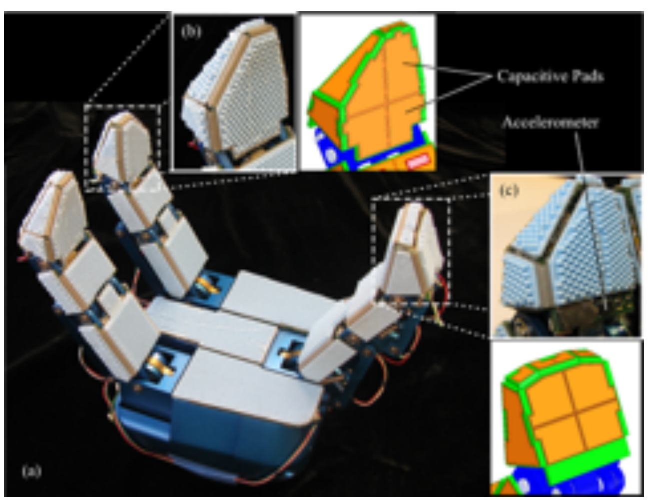


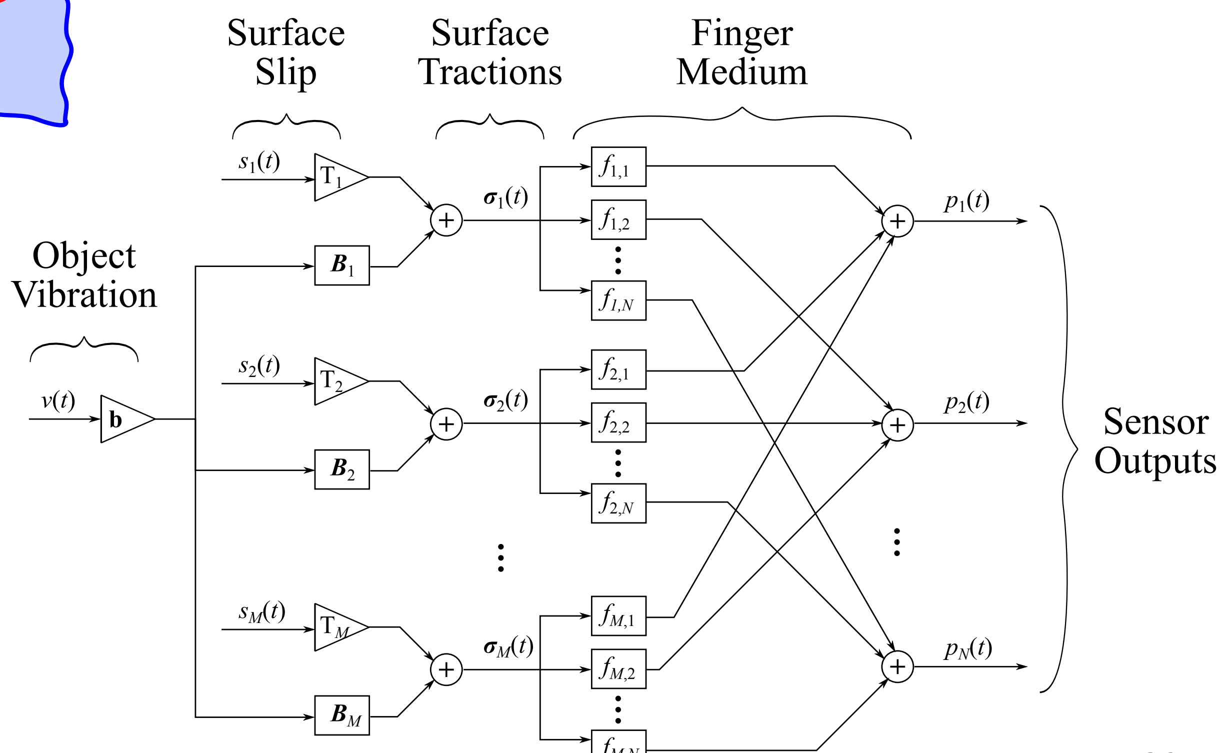
D. M. Aukes, M. R. Cutkosky, S. Kim, J. Ulmen, P. Garcia, H. Stuart, and A. Edsinger, “Design and Testing of a Selectively Compliant Underactuated Hand,” International Journal of Robotics Research, v. 33, pp. 721-725.

Dynamic Tactile Signal processing



- *New tactile array sensors are fast enough for dynamic tactile sensing and interpretation (e.g. using coherence)*
- Sensing is improving, but still impoverished compared to animals





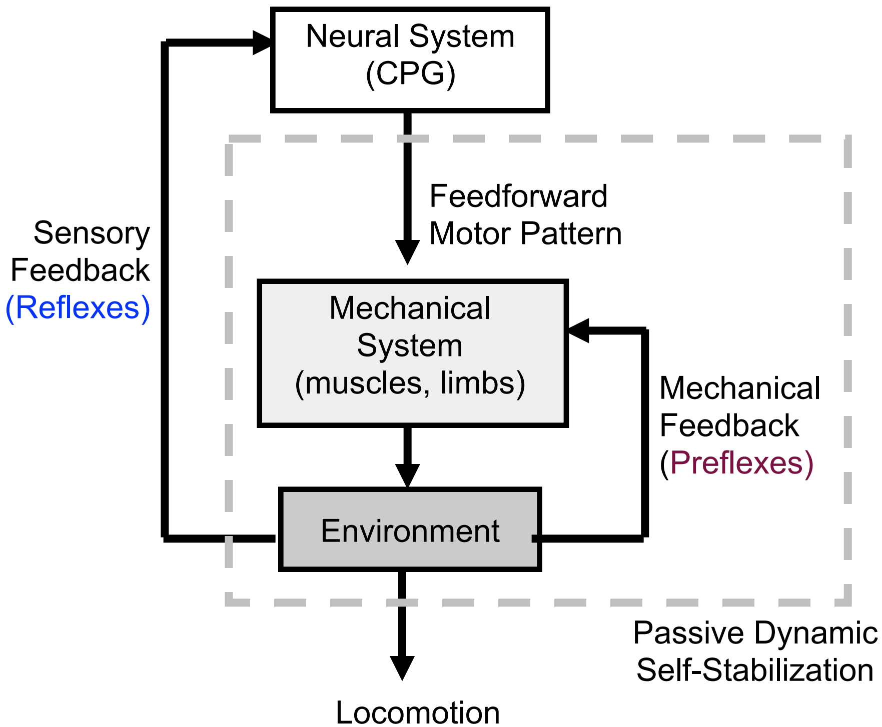
Heyneman & Cutkosky "Slip Classification for Dynamic Tactile Array Sensors," IJRR (2015)

Sensing increases robustness

Perching success/failure detection: 91% accuracy at 40 ms, 94% at 80 ms — with onboard sensing.

Biological Inspiration

- Control heirarchy
  - Passive component
  - Active component



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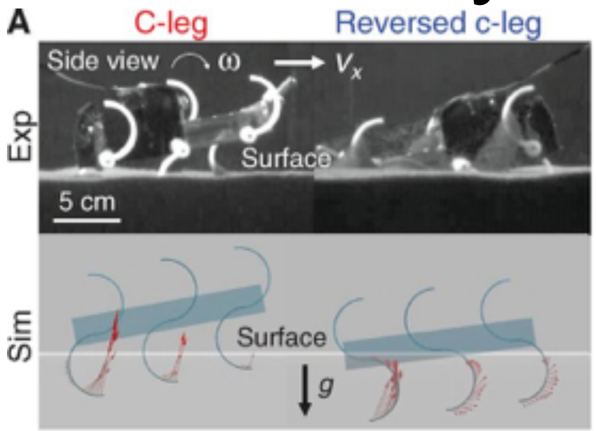
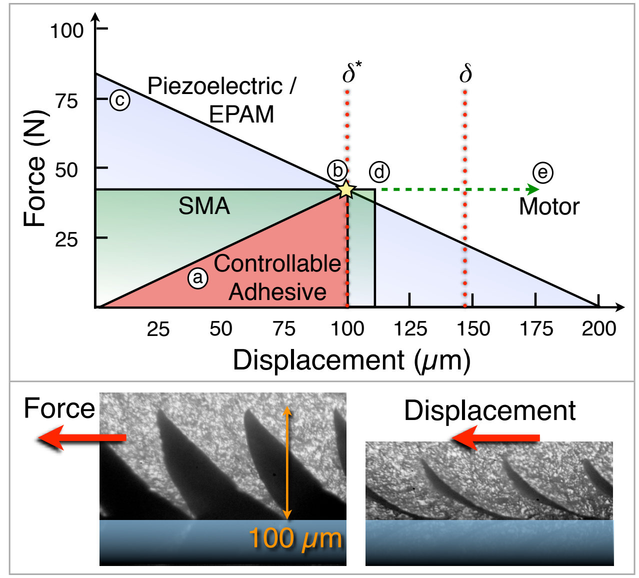
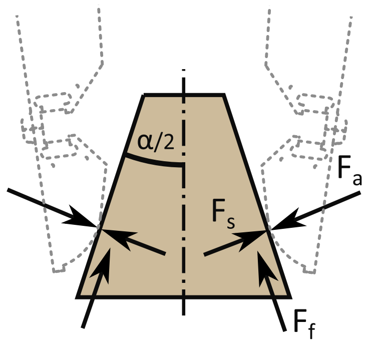
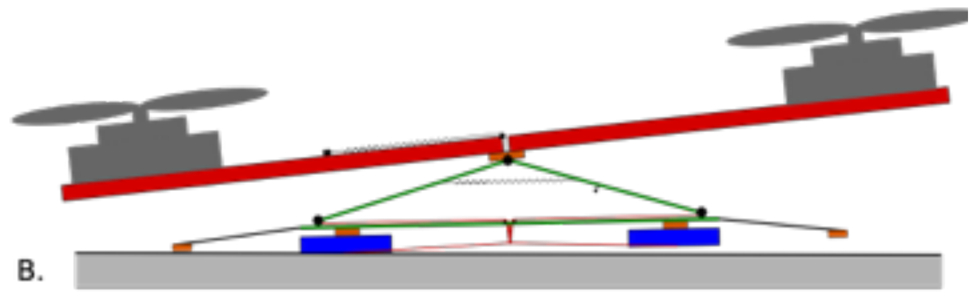
Full and Koditschek, 1999

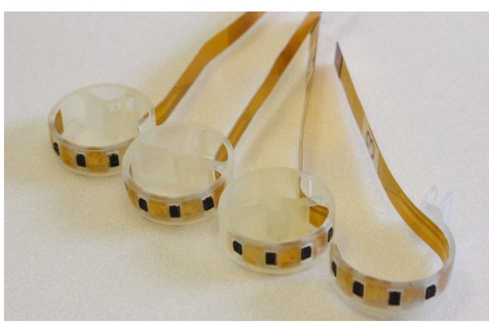
In summary

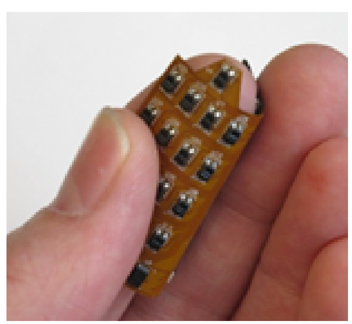

A
C-leg
Reversed c-leg
Side view ω
V_x
Exp
Surface
5 cm
Sim
Surface
g

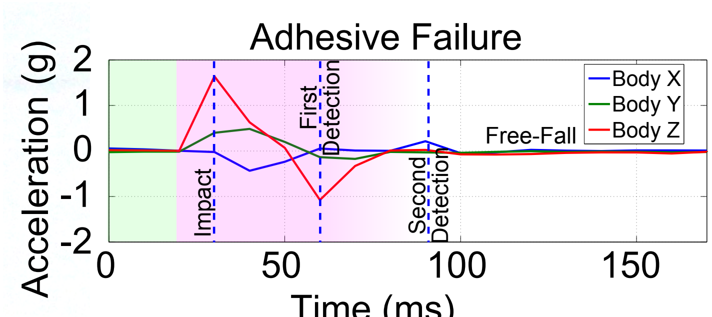

Force (N)
100
75
50
25
Piezoelectric / EPAM
SMA
Controllable Adhesive
Motor
δ*
δ
ⓐ ⓑ ⓒ ⓓ ⓔ
25 50 75 100 125 150 175 200
Displacement (μm)
Force
Displacement
100 μm

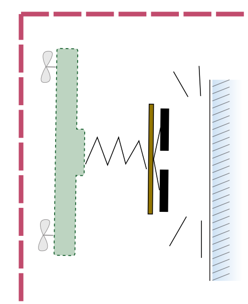

α/2
F_a
F_s
F_f


B.

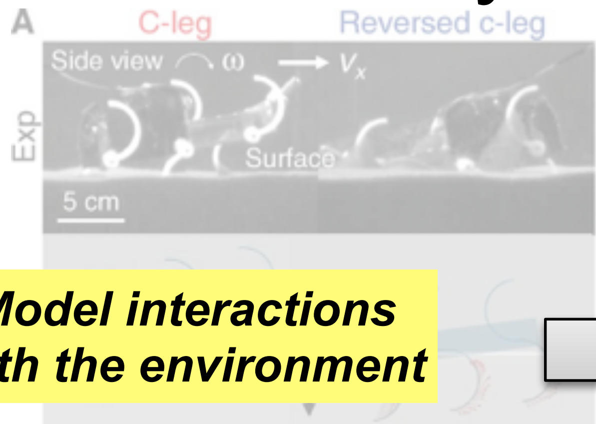


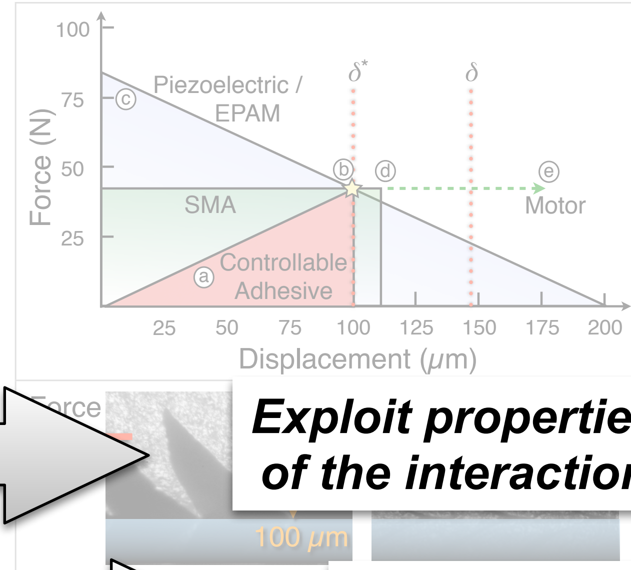



Adhesive Failure
Acceleration (g)
2
1
0
-1
-2
0
50
100
150
Time (ms)
Impact
First Detection
Second Detection
Free-Fall
Body X
Body Y
Body Z



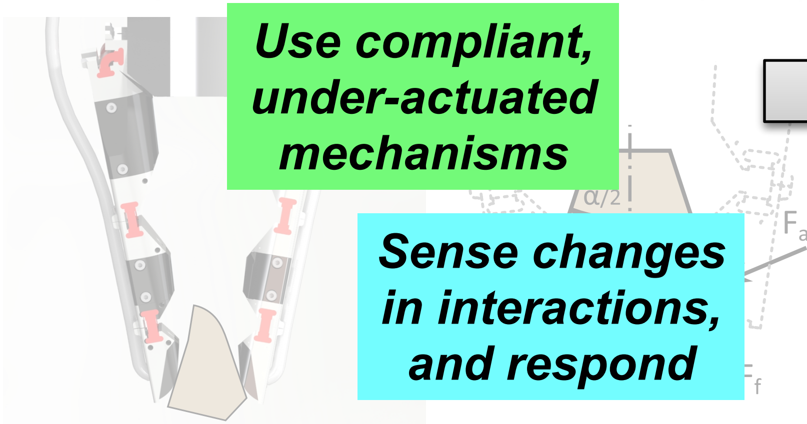
In summary



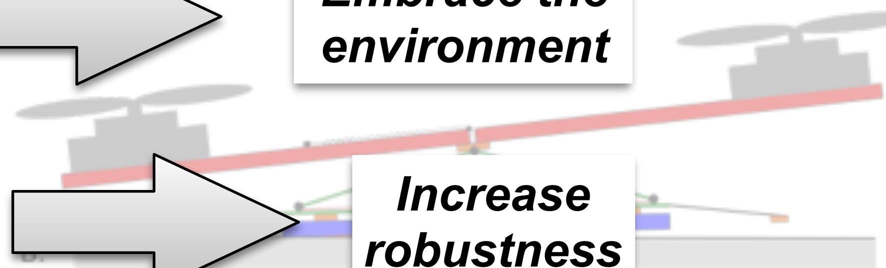


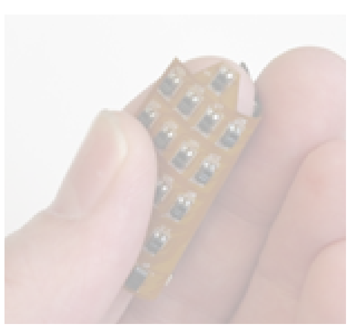
Model interactions with the environment → ***Exploit properties of the interaction***

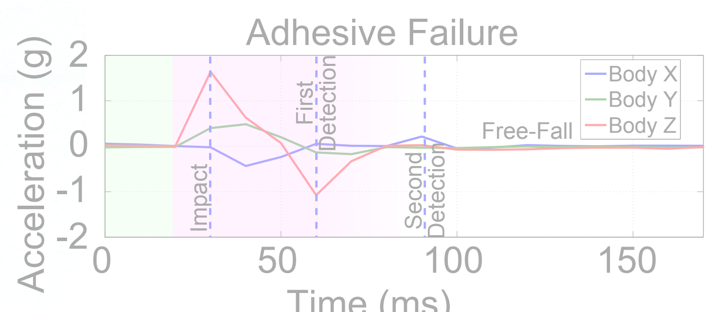
Use compliant, under-actuated mechanisms → ***Embrace the environment***

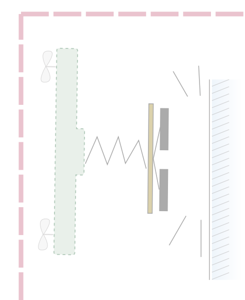


Sense changes in interactions, and respond → ***Increase robustness***









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