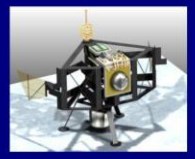
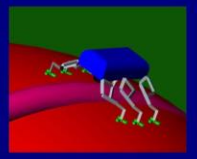


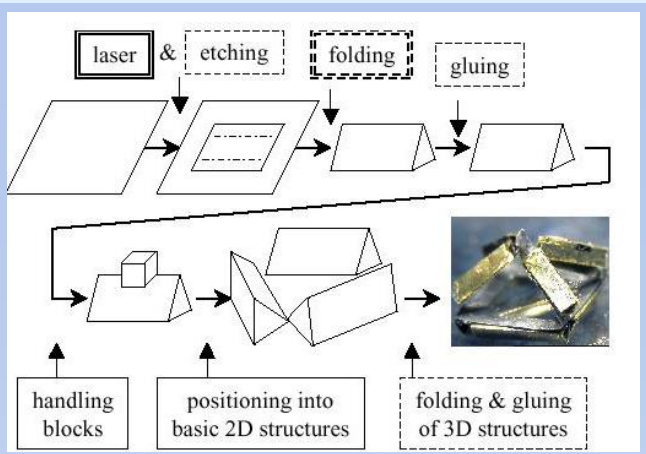



Minimal Actuation in Legged Locomotion

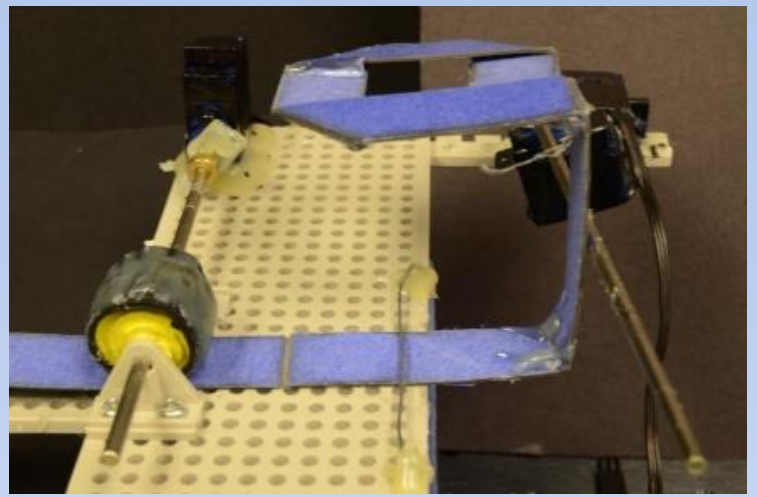
Prof. Ron Fearing
Dept. of EECS
Univ. of California, Berkeley
http://bml.eecs.Berkeley.edu

ARL

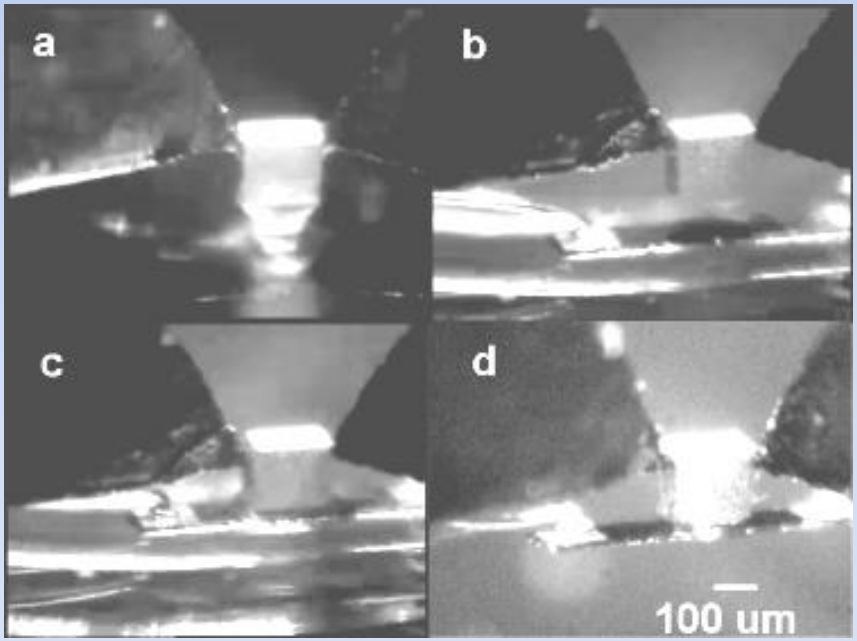
Minimality in Design/Fabrication



Sahai IROS 2003

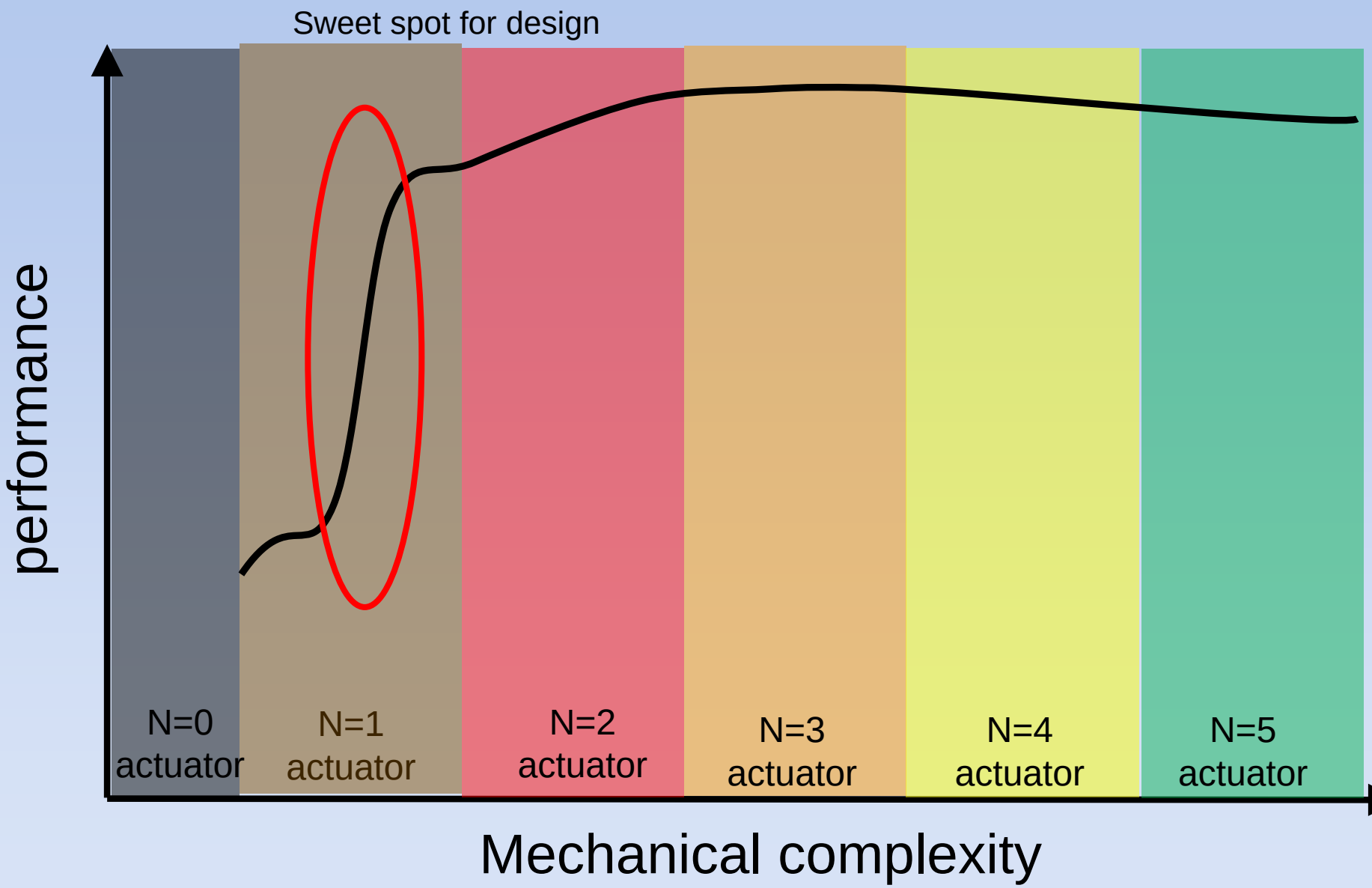


``Robozome”
Robotic Folding of 2D and 3D Structures from a Ribbon,
Liyu Wang, Mark Plecnik, Ronald Fearing IEEE Int. Conf. Robotics and Automation, Stockholm, May 2016.



Strain gauge attachment using handling block
Thompson&Fearing, IROS 2001

Complexity and Minimality for Legged Locomotion



Complexity

- **Number of motors**
- **Structure: joints, stiffness, feet**
- **Control**
- **Sensing**

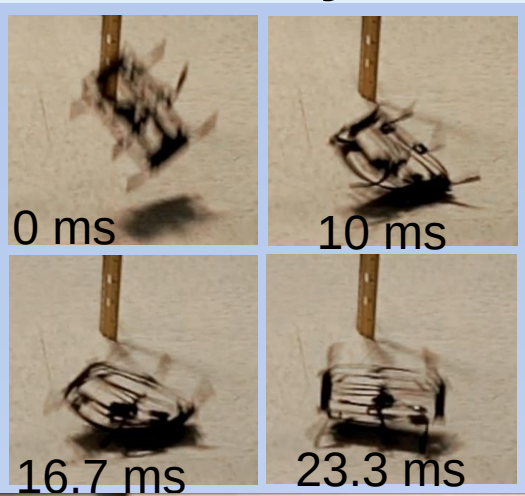
➔For high speed running:

1 motor + tuned structure,

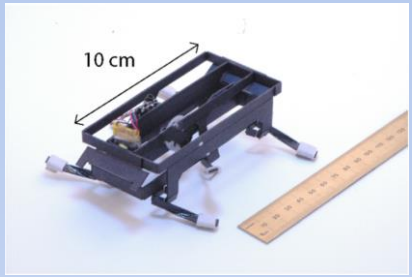
no control or sensing

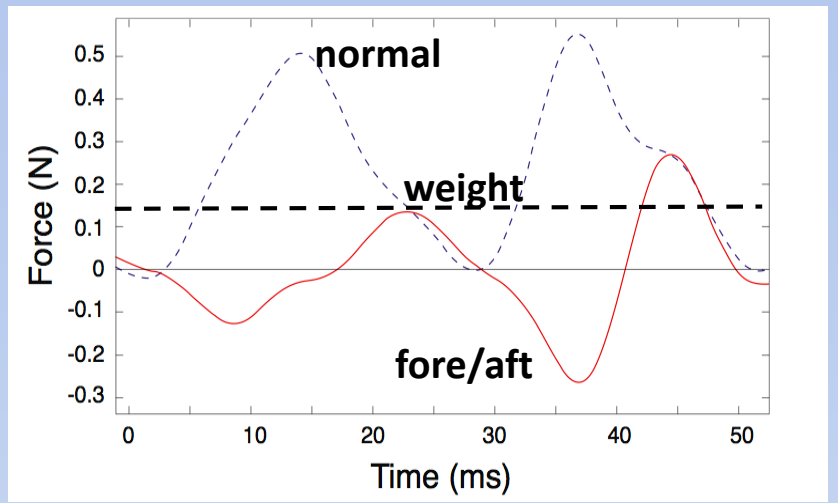
Claim: tuned structure reduces control and sensing

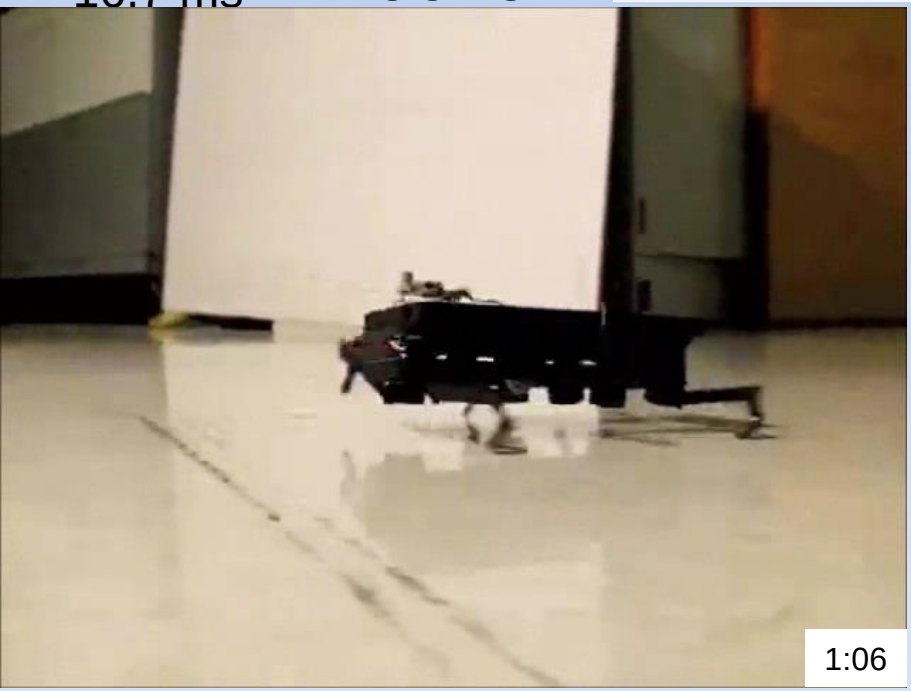
DASH- Dynamic Autonomous Sprawled Hexapod



Ground impact at ~6.5 m/s



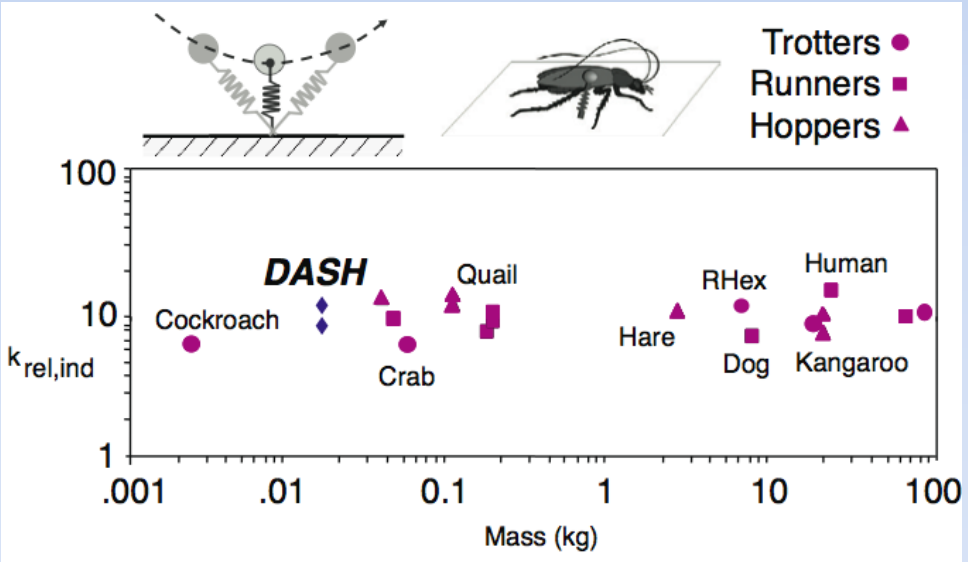




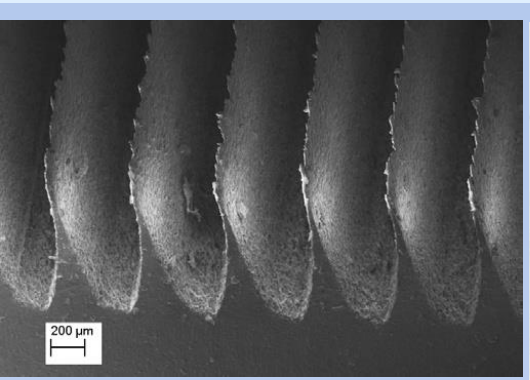
first 10 cm scale folded robot: 2009

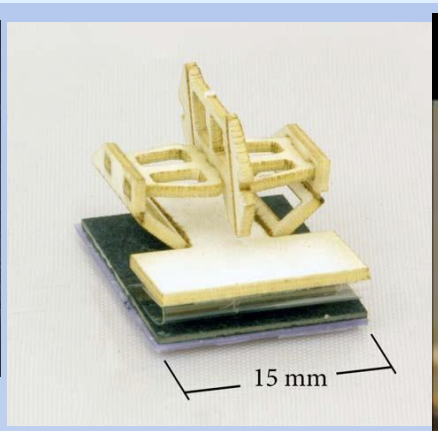
Birkmeyer, Peterson, Fearing, IROS 2009

One drive + 1 steering motor



CLASH robot climbing with PDMS directional adhesive



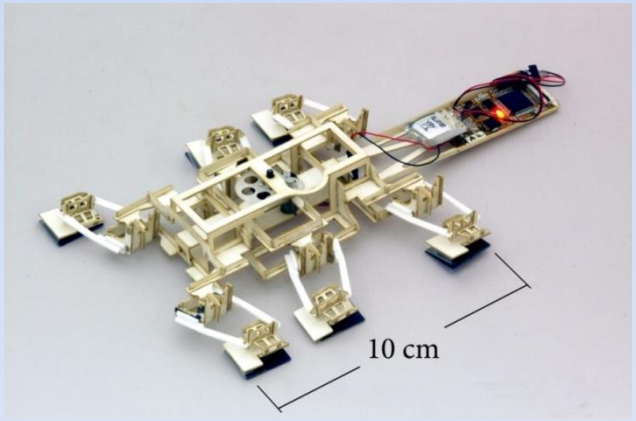


e.g. Parness et al.
JRSI 2009

video:
http://robotics.eecs.berkeley.edu/~ronf/Ambulation/Movies/65deg-climb.wmv

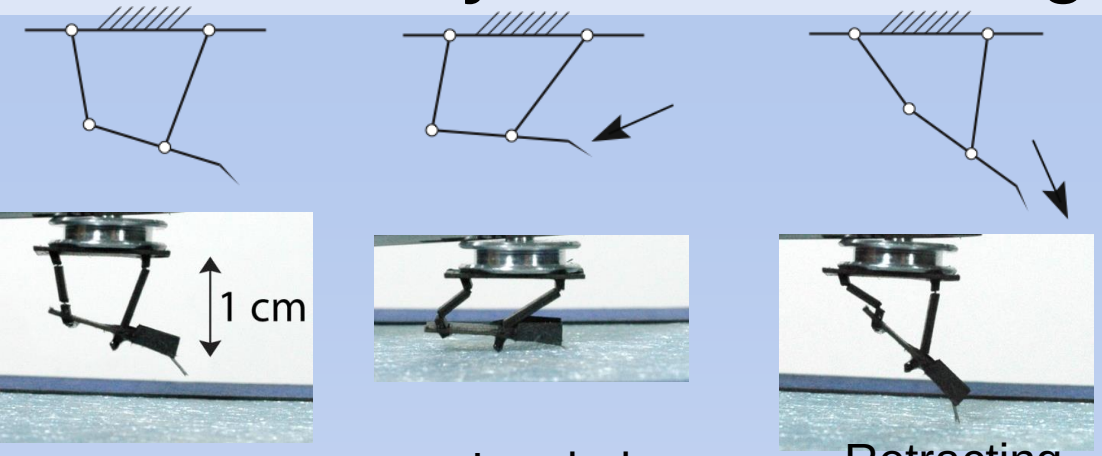
One drive motor+foot

70 degree slope



Birkmeyer , Gillies, and Fearing, *IROS 2012*

Dynamic Climbing with Claws

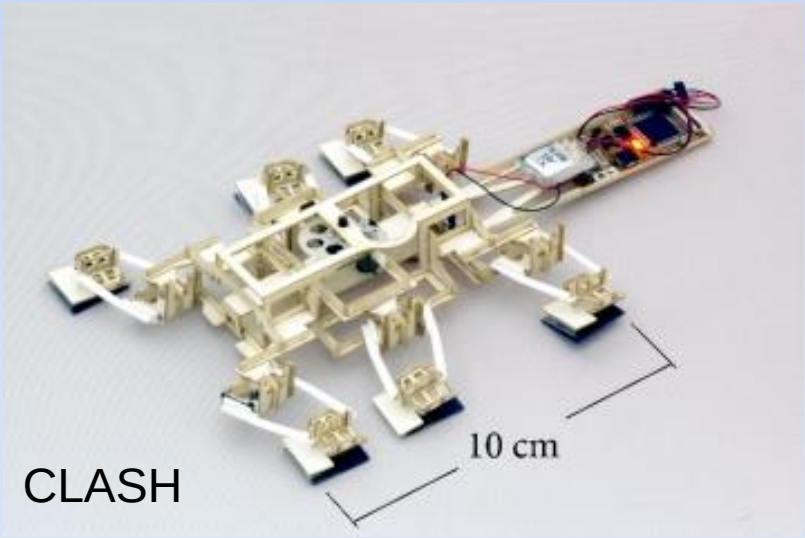


Unloaded Loaded Retracting

One drive motor+foot

loose-quilt.asf

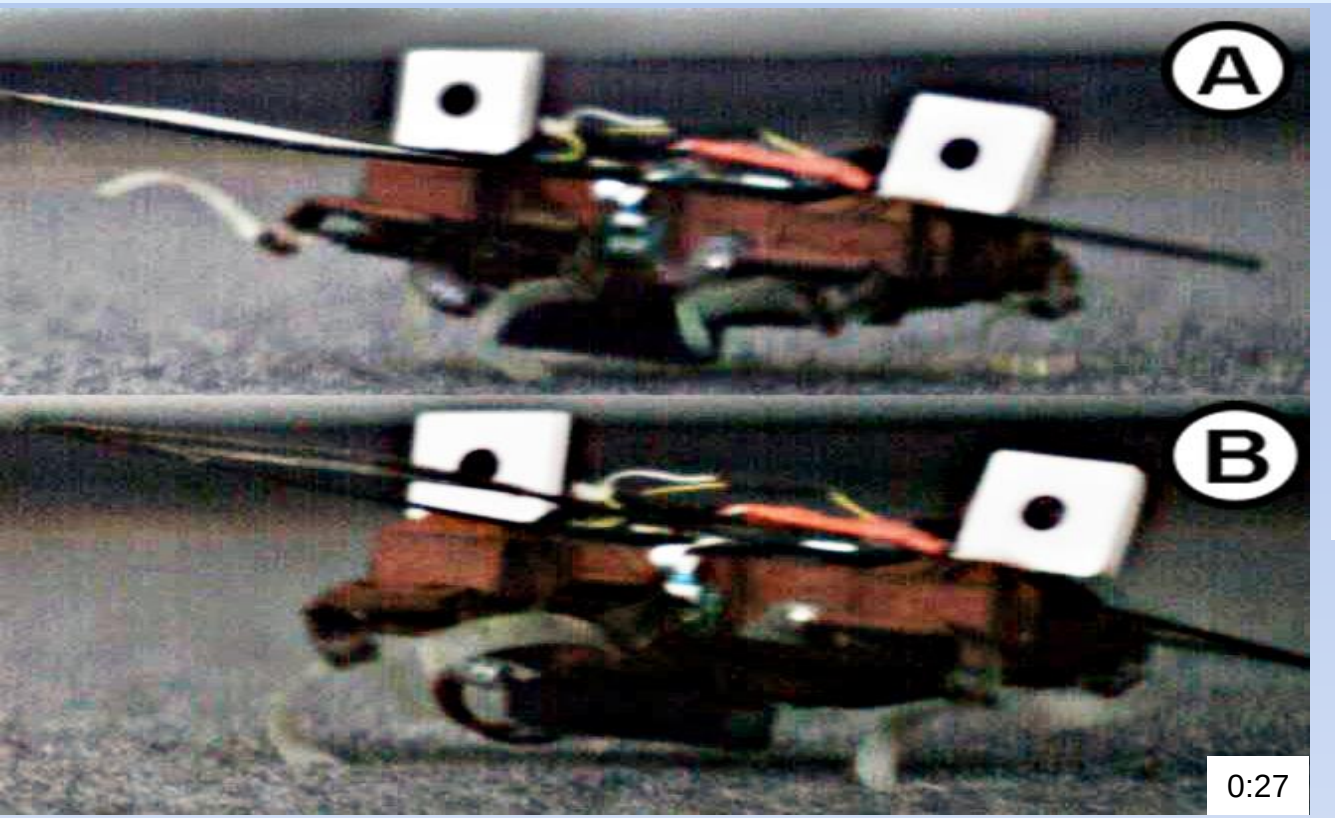
Claws



CLASH

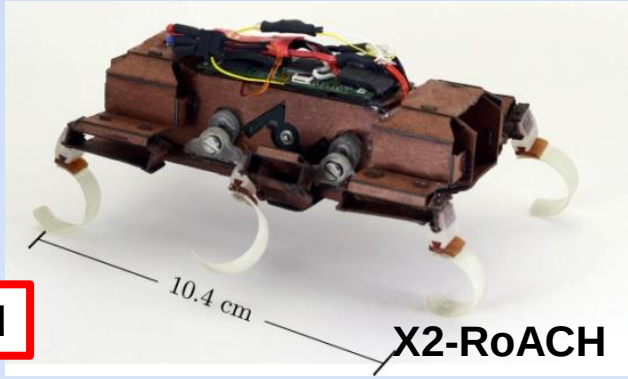
Birkmeyer et al IROS 2011

Running Beyond the Bioinspired Regime

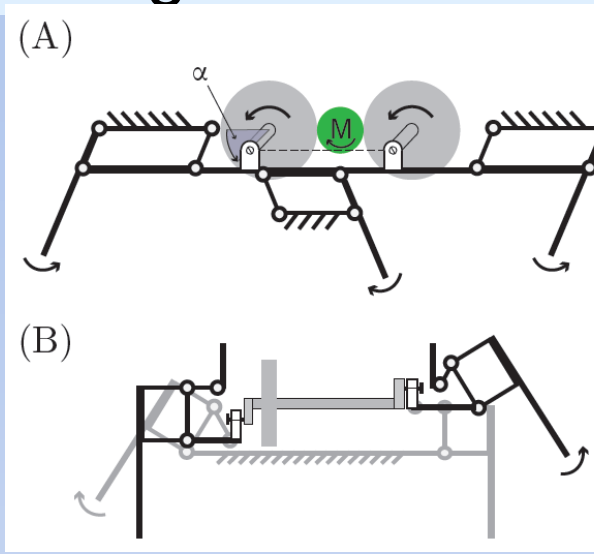


video: robotics.eecs.berkeley.edu/~ronf/Ambulation/Movies/RunBeyondBioInspired.mp4

Haldane and Fearing, ICRA2015



One drive motor (2 sides pinned

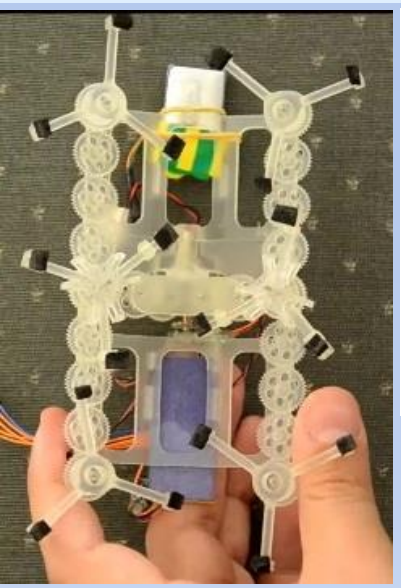


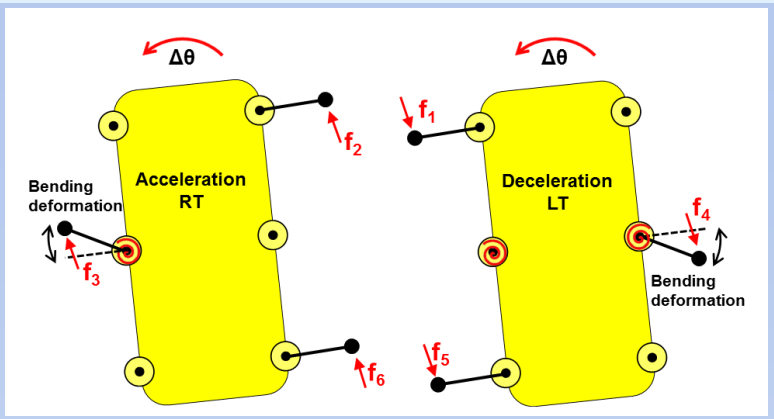
single motor,
minimally actuated

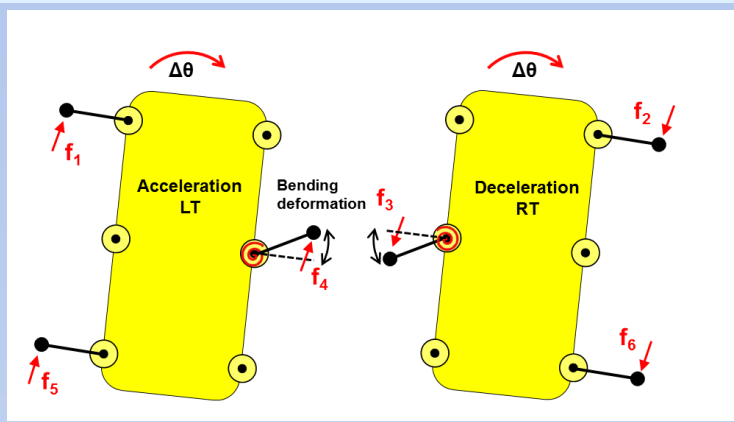
VelociRoACH ~30 W/kg
X2-RoACH ~120 W/kg

47 body lengths/second

1 STAR- steering robot with one actuator





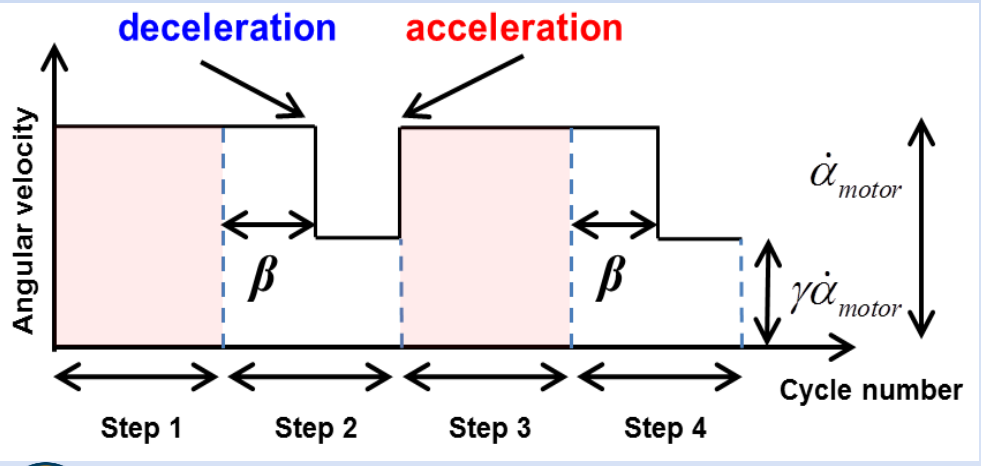


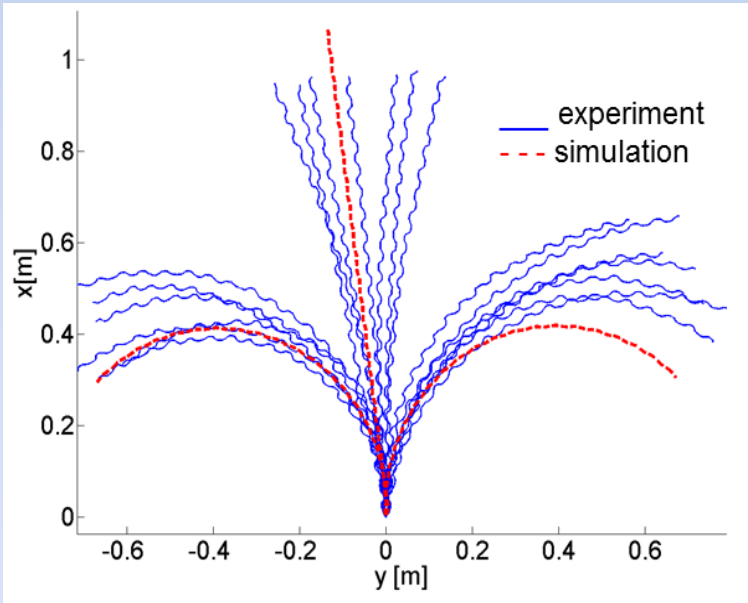
Turn Left

Turn Right

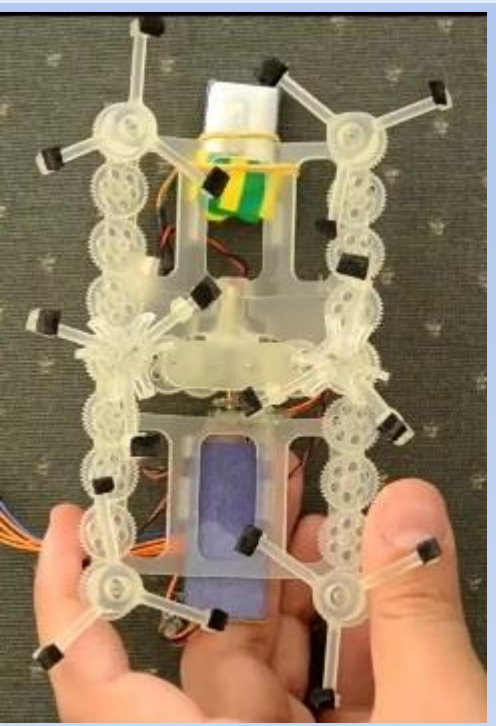
D. Zarrouk and R.S. Fearing, *IEEE Transactions on Robotics*, Feb. 2015.

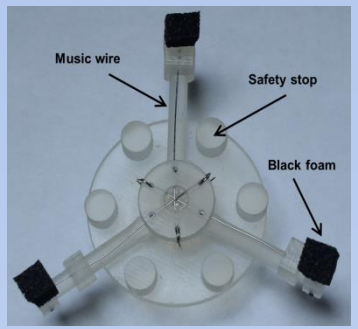
D. Zarrouk and R.S. Fearing, IROS 2012



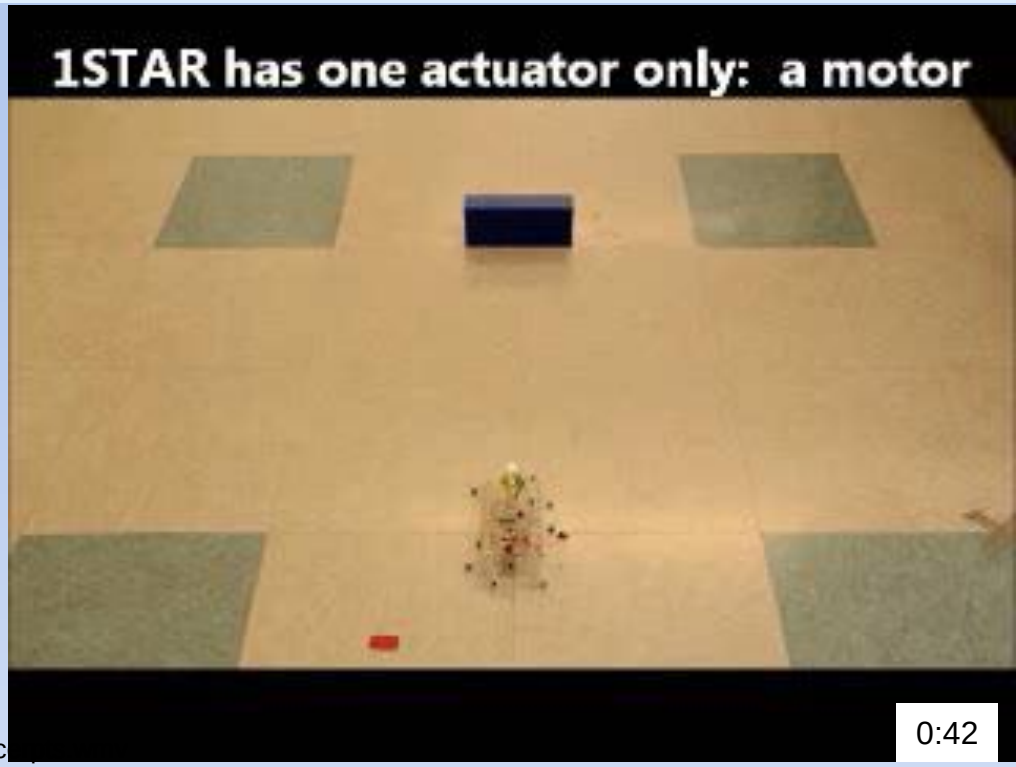


1 STAR- steering robot with one actuator



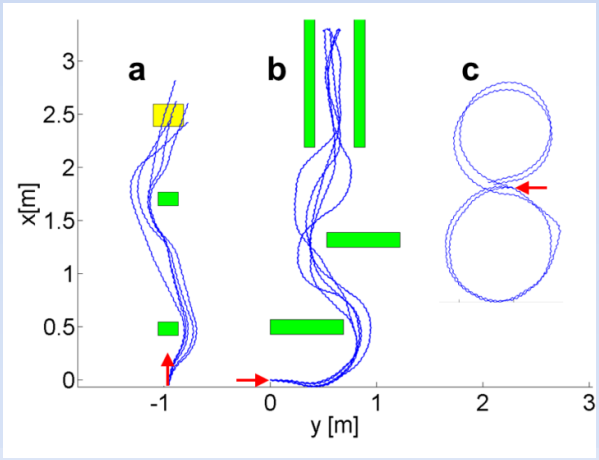


Compliant Leg



1star-exc

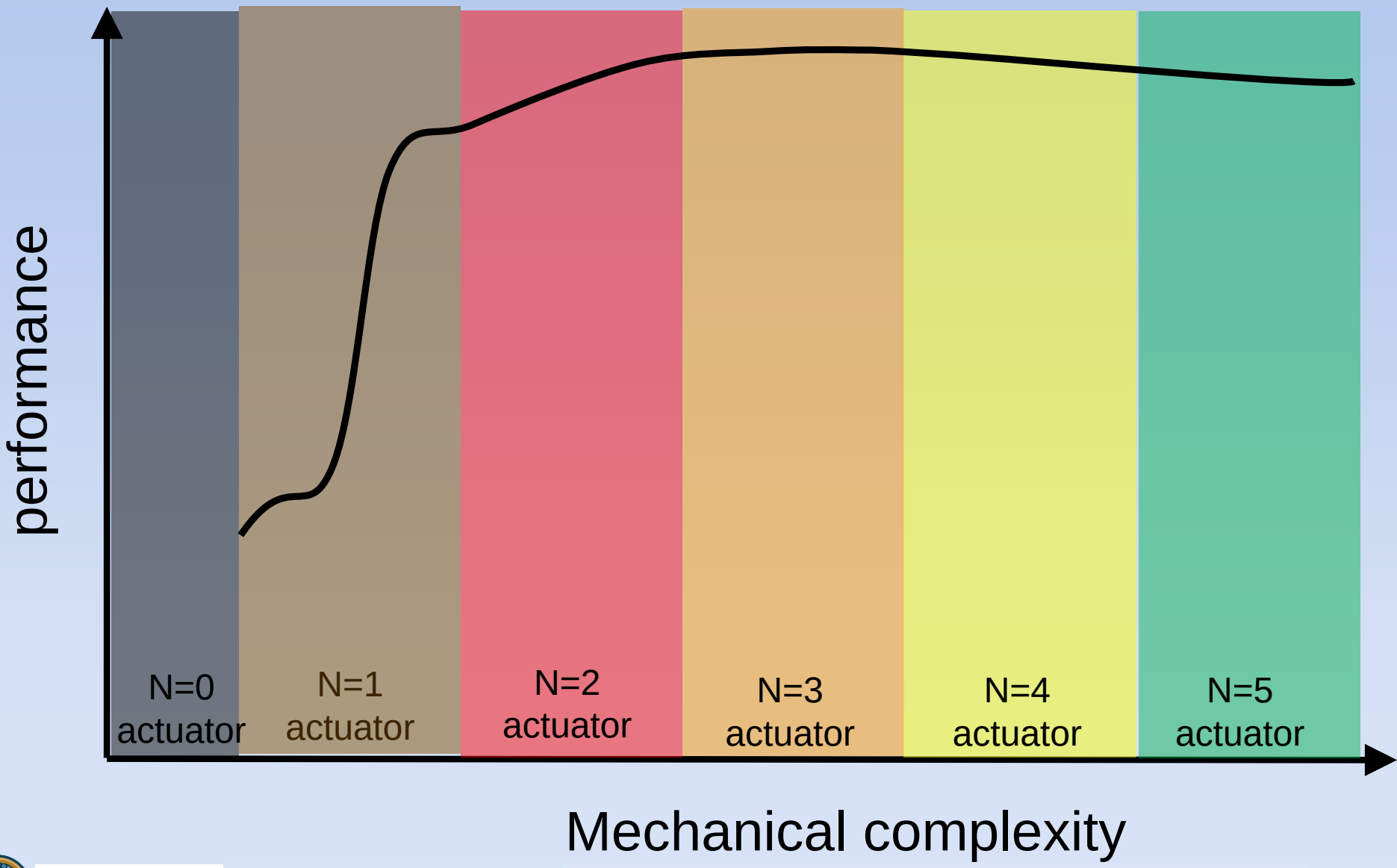
video: http://robotics.eecs.berkeley.edu/~ronf/Ambulation/Movies/1Star-ICRA14.mp4



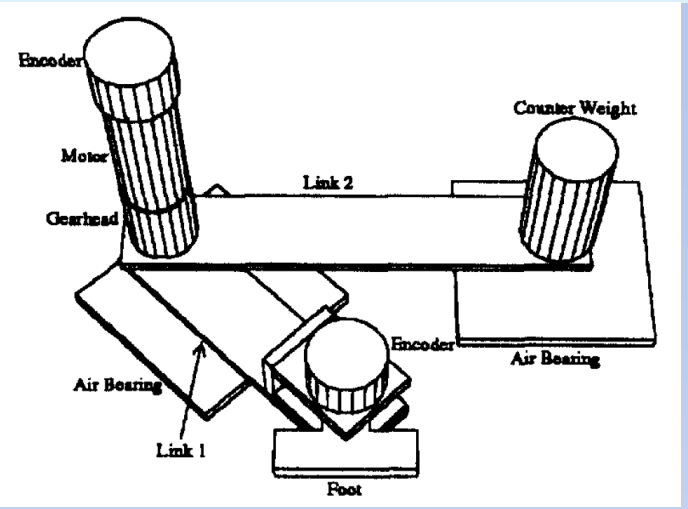
D. Zarrouk and R.S. Fearing, Controlled In-Plane Locomotion of a Hexapod Using a Single Actuator, *IEEE Trans. on Robotics*, 2015.

D. Zarrouk and R.S. Fearing, ``Compliance-Based Dynamic Steering for Hexapods,'' IROS 2012

Complexity and Minimality for Planar Jumping



1 motor 2 link Acrobot (1992)



Berkemeier and Fearing
IROS 1992, ICRA 1994, TRA 1998

Sliding and Hopping Gaits
for the
Underactuated Acrobot.
M. Berkemeier and R. Fearing
IEEE TRA 1998

Hopping gait

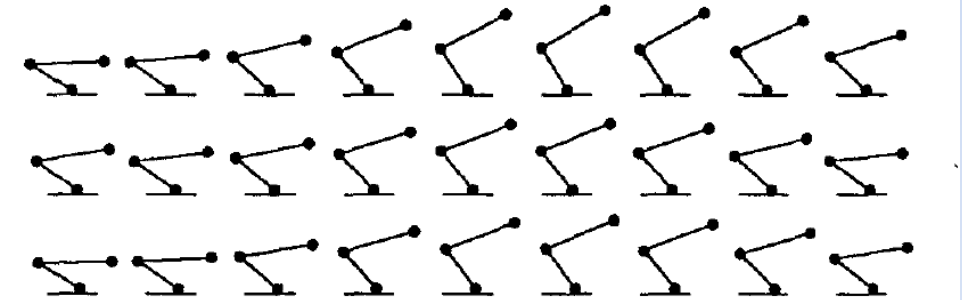


Figure 6: Frames for Sliding Gait

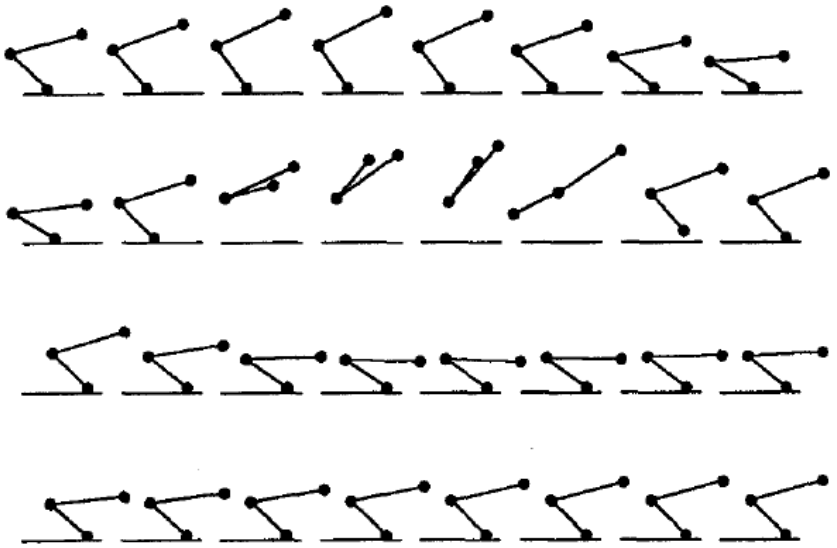
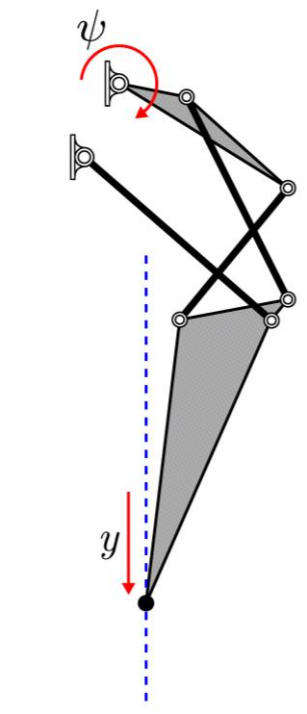
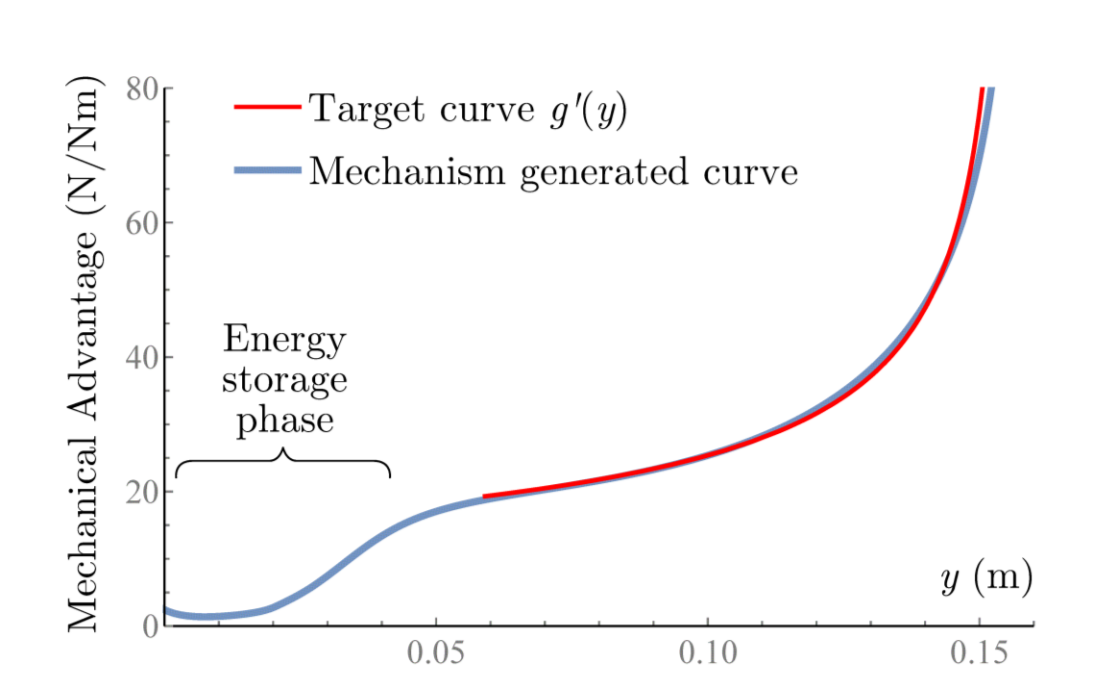


Figure 8: Frames for Hopping Gait

1 motor 8 bar linkage jumper (2016)



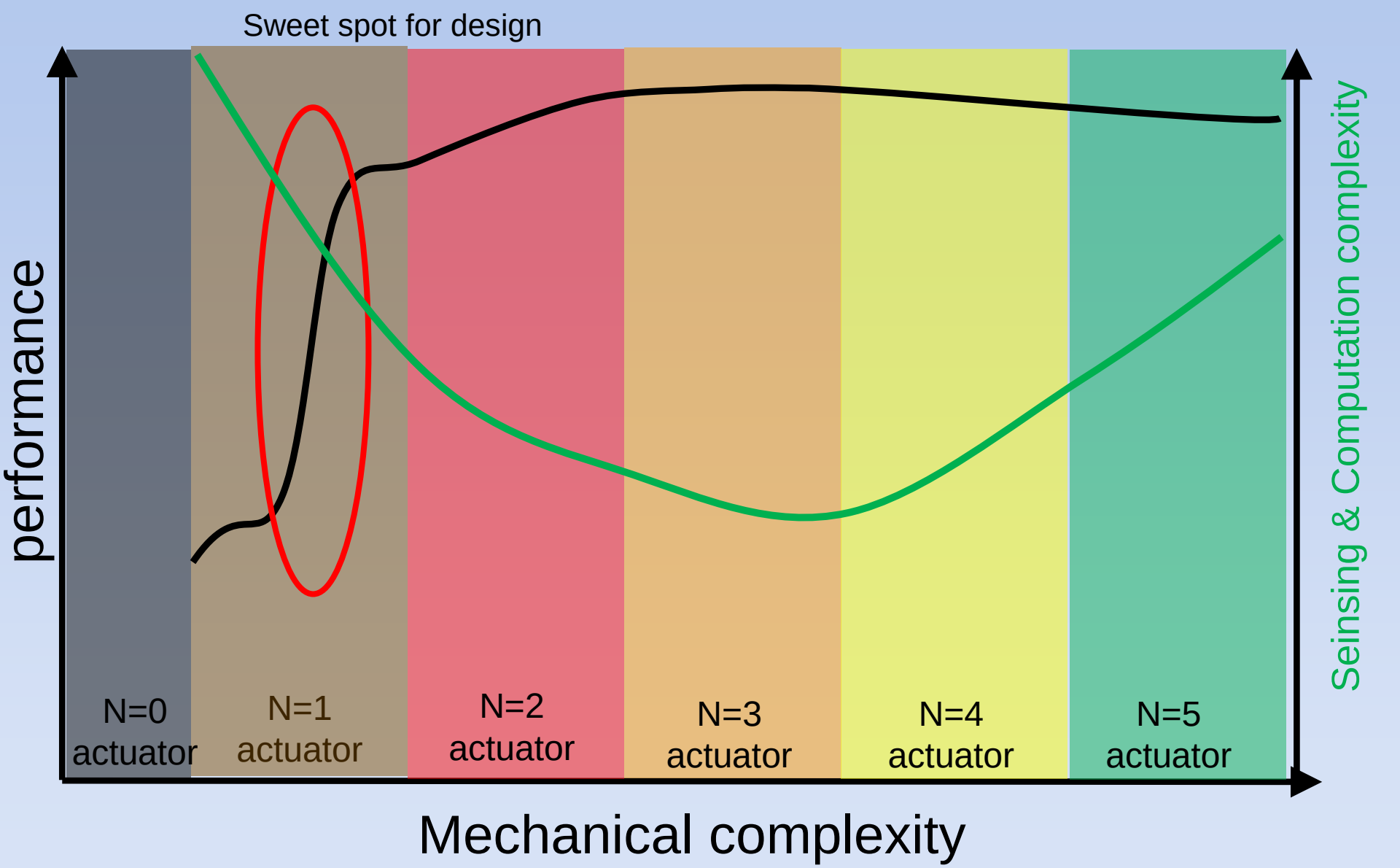


Built in to mechanism:

- Compliance
- Straight line motion
- Constant acceleration
- Energy storage
- Minimum angular velocity at takeoff

Haldane, Plecnik, Yim, Fearing, submitted

Complexity and Minimality for legged locomotion



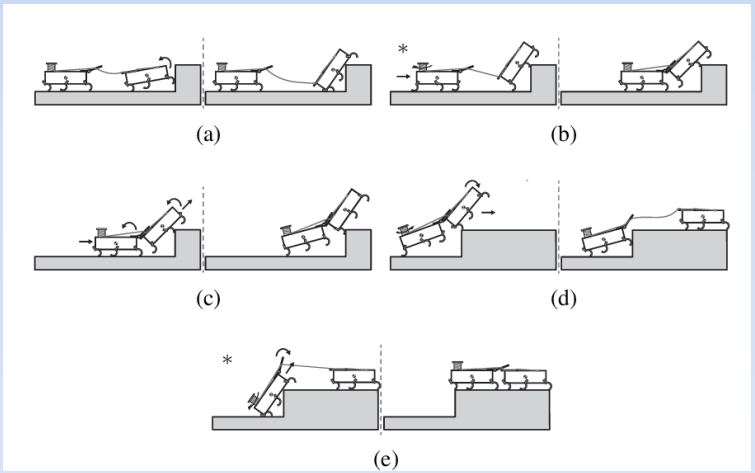
Step climbing by Dextrous Manipulation (joint operation)

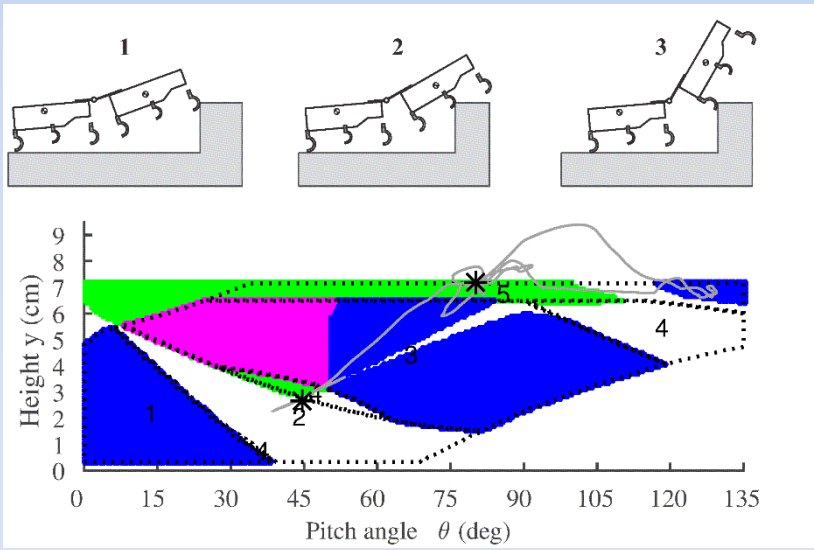
2 robots X 2 drive motors
+ 1 motor driven tether

Joint complexity?

0:29

C. Casarez ICRA 2016





Conclusions

Minimally-actuated dynamic ambulation

(possible tool for biological questions):

1. dynamics from structure and interactions, not nervous system (passive stabilization)
2. Contact mechanics + compliance may have bigger effect than control (for underactuated systems)
3. rich dynamic behavior can be exploited for yaw maneuverability
4. high power density from using single motor

What about combining minimal robots to get complex behavior at linear cost?