# Research opportunities for morphological computation

ICMC 2011
The 2nd Int. Conference on Morphological Computation
Venice, 12 - 14 September 2011

Rolf Pfeifer, Artificial Intelligence Laboratory
Department of informatics, University of Zurich, Switzerland
NCCR National Competence Center Robotics, Switzerland

University of Zurich

robotics Swiss National Centre of Competence in Research

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ICMC 2011 2nd International Conference on Morphological Computation
12-14 Sep., 2011 at Palace Franchetti, Venice, Italy

**General**

- Home
- Call for Abstracts
- Program
- Invited Speakers
- Steering committee
- Ecce workshop
- Registration
- Submission
- Contact

**Local**

- Travel
- Accommodation
- Conference Venue

**Last Conference**

- Proc. of ICMC2007
- Old Homepage

# Welcome

**More information about poster is available in program.**

**Registration is open.**

**Early registration is valid until 12th August 2011.**

**~~Hotel registration is valid until 15th July 2011.~~**

**Ecce workshop is open, please register if you are interested.**

Regular submission is now closed. However, to encourage broad discussion, we still provide an opportunity to present your research on a poster session. If you are interested in this opportunity, please refer to the information in the submission webpage.

We would like to invite you to attend the **2nd International Conference on Morphological Computation ICMC2011**.

**Date:** 12-14 Sep. 2011
**Place:** Palace Franchetti, Venice, Italy

The conference will be broadly interdisciplinary, including discussions in the area of robotics, frameworks for computation (reservoir computing, neural

# Thanks to ...

Hajime Asama
Rudolf Bannasch
Josh Bongard
Simon Bovet
Rodney Brooks
Weidong Chen
Steve Collins
Holk Cruse
Paolo Dario
Ezequiel di Paolo
Raja Dravid
Rodney Douglas
Peter Eggenberger
Andreas Engel
Martin Fischer
Dario Floreano
Toshio Fukuda
Robert Full
Gabriel Gomez
Fumio Hara
Inman Harvey
Alejandro Hernandez
Owen Holland
Koh Hosoda
Fumiya Iida
Auke Ijspeert
Takashi Ikegami
Masayuki Inaba
Akio Ishiguro
Oussama Kathib
Alois Knoll
Maarja Kruusma
Yasuo Kuniyoshi
Cecilia Laschi
Lukas Lichtensteiger
Max Lungarella
Ren Luo
Barbara Mazzolai
Shuhei Miyashita
Norman Packard
Mike Rinderknecht
Roy Ritzmann
Andy Ruina
Giulio Sandini
Olaf Sporns
Luc Steels
Russ Tedrake
Esthen Thelen
Barry Trimmer
Sethu Vijakyakumar
Oskar von Stryk
Ruediger Wehner
Martijn Wisse
Hiroshi Yokoi
Wenwei Yu
Marc Ziegler

# … for their ideas

Hajime Asama
Rudolf Bannasch
Josh Bongard
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# Contents

- morphological computation
- examples and case studies - research opportunities
- summary
- recommendation to speakers

# Buzzwords

amorphous computing

self-assembling robots/materials

cellular computing

biochemical circuits

passive dynamics

synthetic biology

molecular recognition systems

biomolecular devices

membrane computing

self-stabilization

autopoeisis

trading space

tensegrity

genetic regulatory networks

blob computing

DNA/molecular computing

patterning

neuromorphic computing/ engineering

self-organization

self-repair

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# Goals of conference

intuitions of “morphological computation”

identification of research fields

research opportunities

research program - road map

implications for cognitive science, artificial life, general theory of intelligence

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# Morphological computation

- functionality provided by physically embodied interactions
- Turing: probably OK with using the term "computation" (see his work on reaction-diffusion systems - to do "computation")
- when should dynamics/morphology be considered as "computing"?

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# Morphological computation

**Inman Harvey, Sussex University:**

**"I agree with everything you say, except that it should be called**

**morphological NON-computation."**

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# Morphological computation (Norman Packard)

- need I/O
- need programmability
- need teleological embedding (functionality, purpose, goal)

(from ICMC 2007 summary of discussion)

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# Spectrum of morphological computation

- fully embodied **(e.g. self-assembling vesicles / molecules, passive dynamic walker, "Stumpy", "Puppy")**
- embodied computation, digital result **- need for read-out process (e.g. DNA computing, molecular computing; reservoir computing)**
- digital computation, embodied result **(e.g. evolutionary optimization of chemical systems; PACE "life support system")**

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Fully embodied: here the desired functionality is the behavior of the system itself, irrespective of whether we consider the body as computing or not. However, the "computation" of the body can be exploited (e.g. to produce certain information about the environment, for example, the steepness of the terrain in "Puppy").

There has to be a readout process that can be viewed as the translation of the physical state of the system back to its digital interpretation in terms of the original – digital – problem. The standard computational problems – unusual (physical) computational process.

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# Examples and case studies of morphological computation

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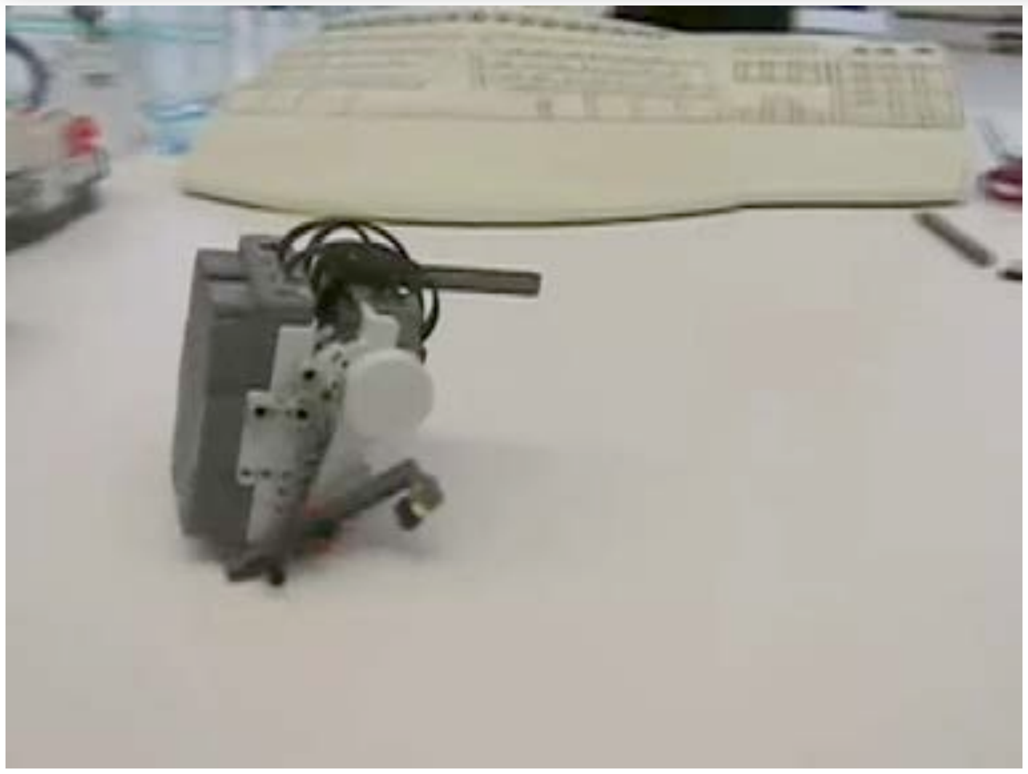
# The spirit of embodiment

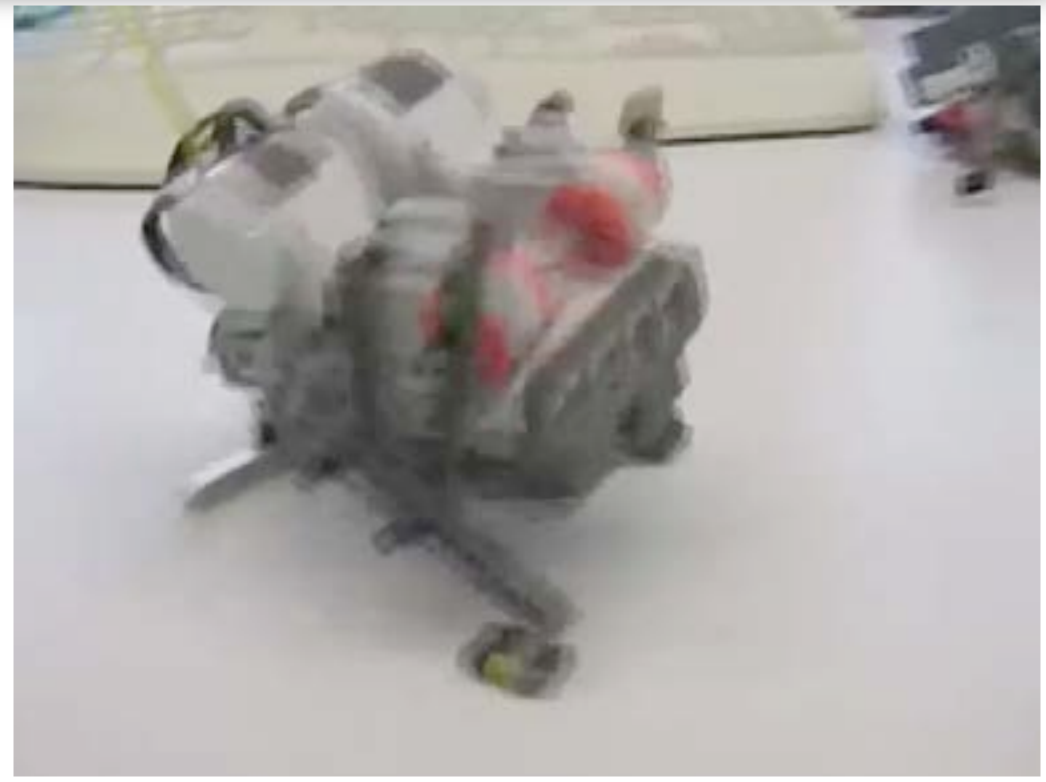




Three Lego Mindstorms “creatures”, all with the same control, i.e. constantly turning wheels

# The spirit of embodiment







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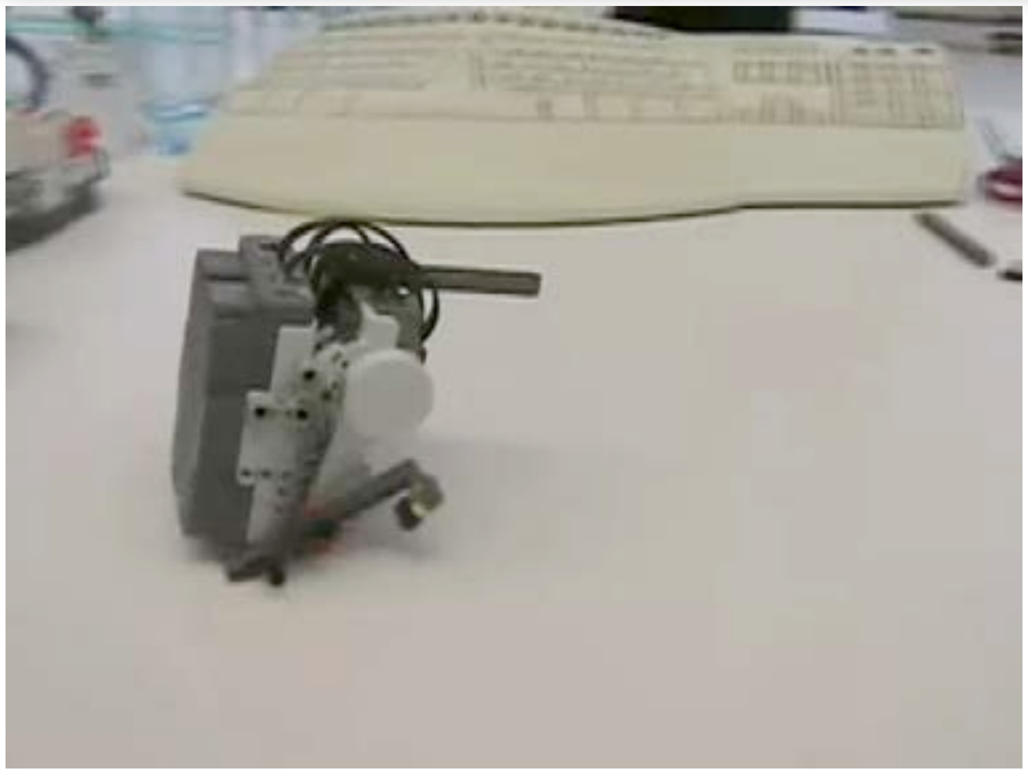

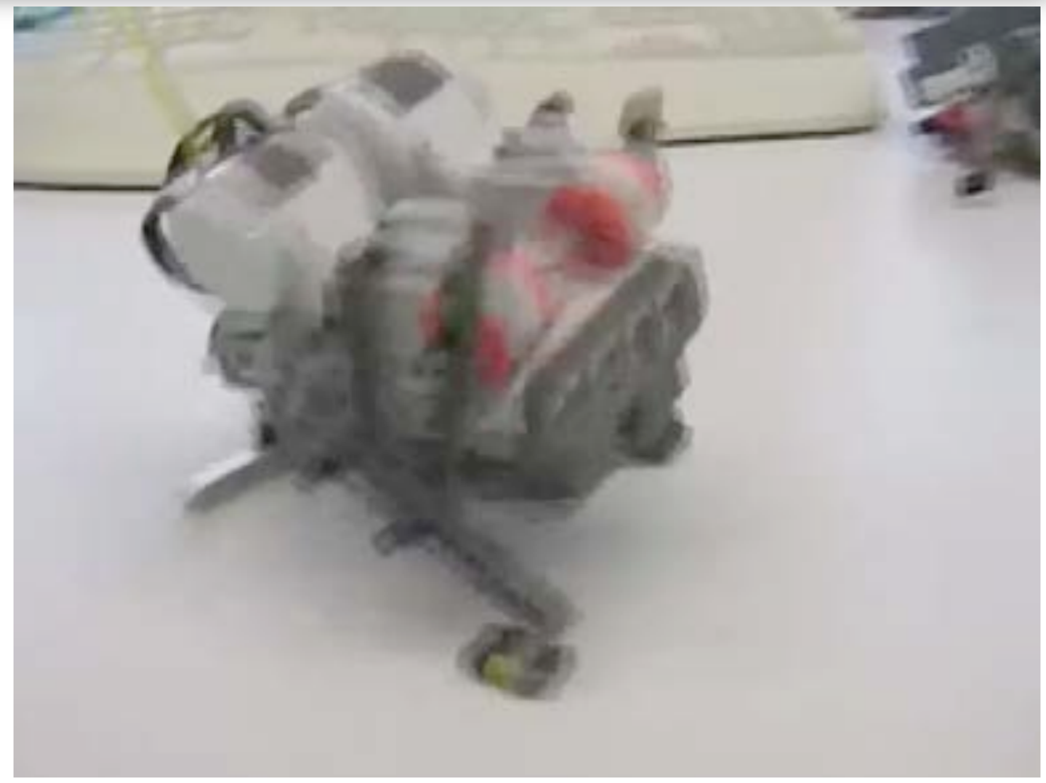





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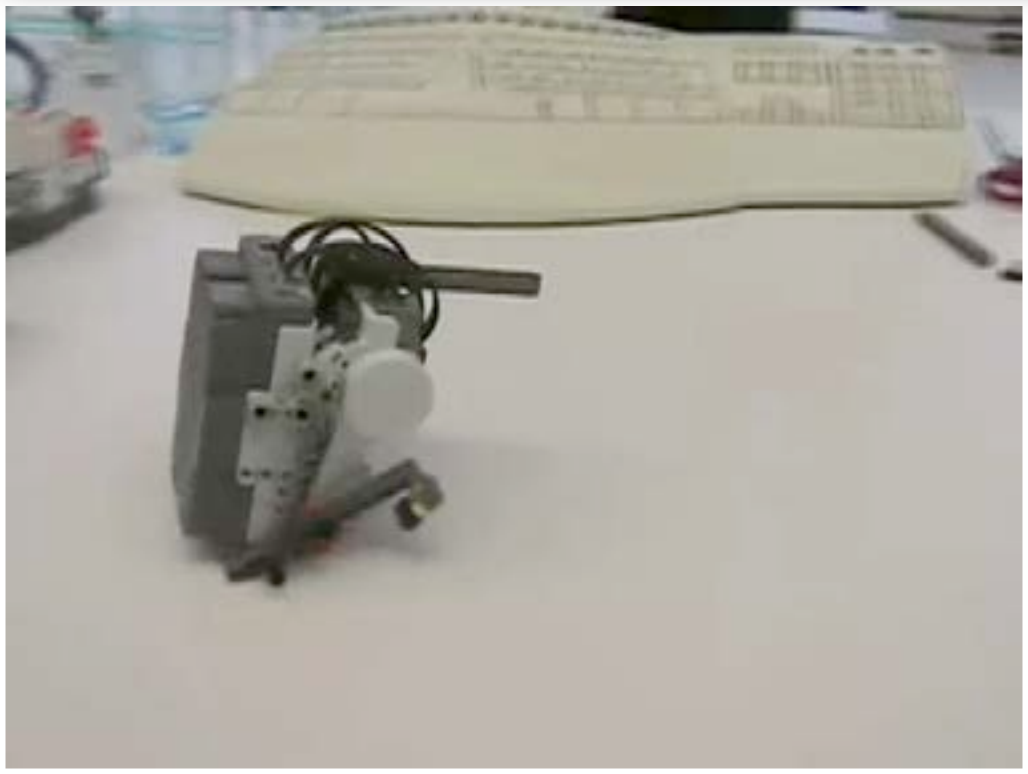

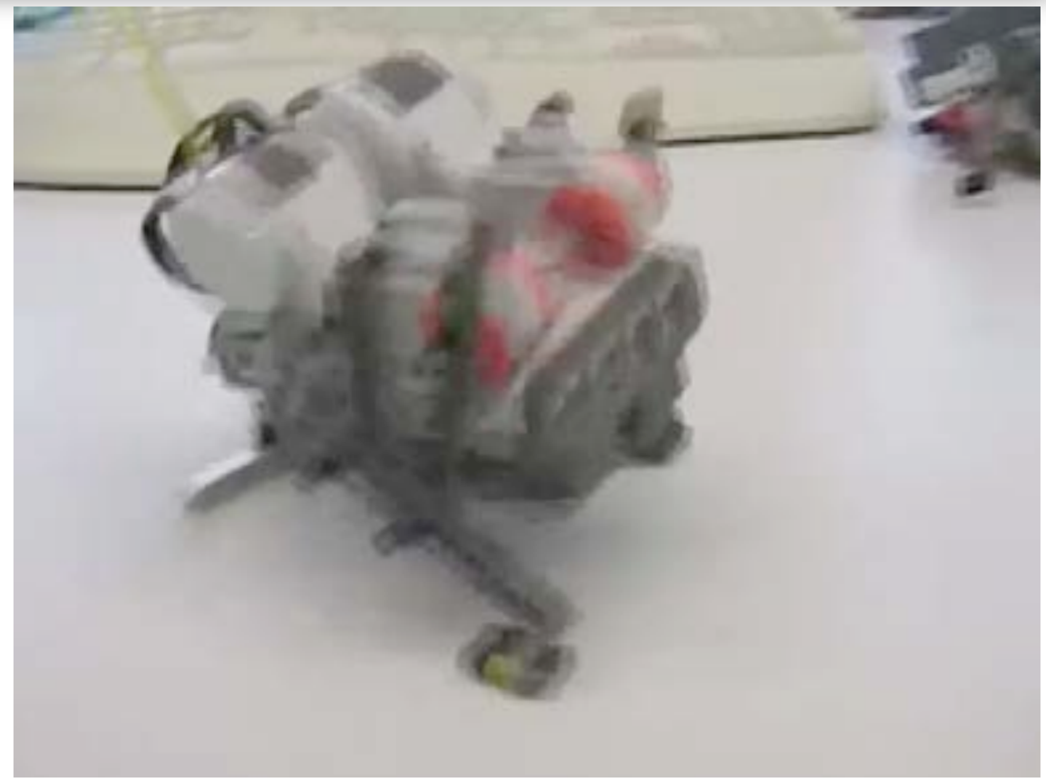





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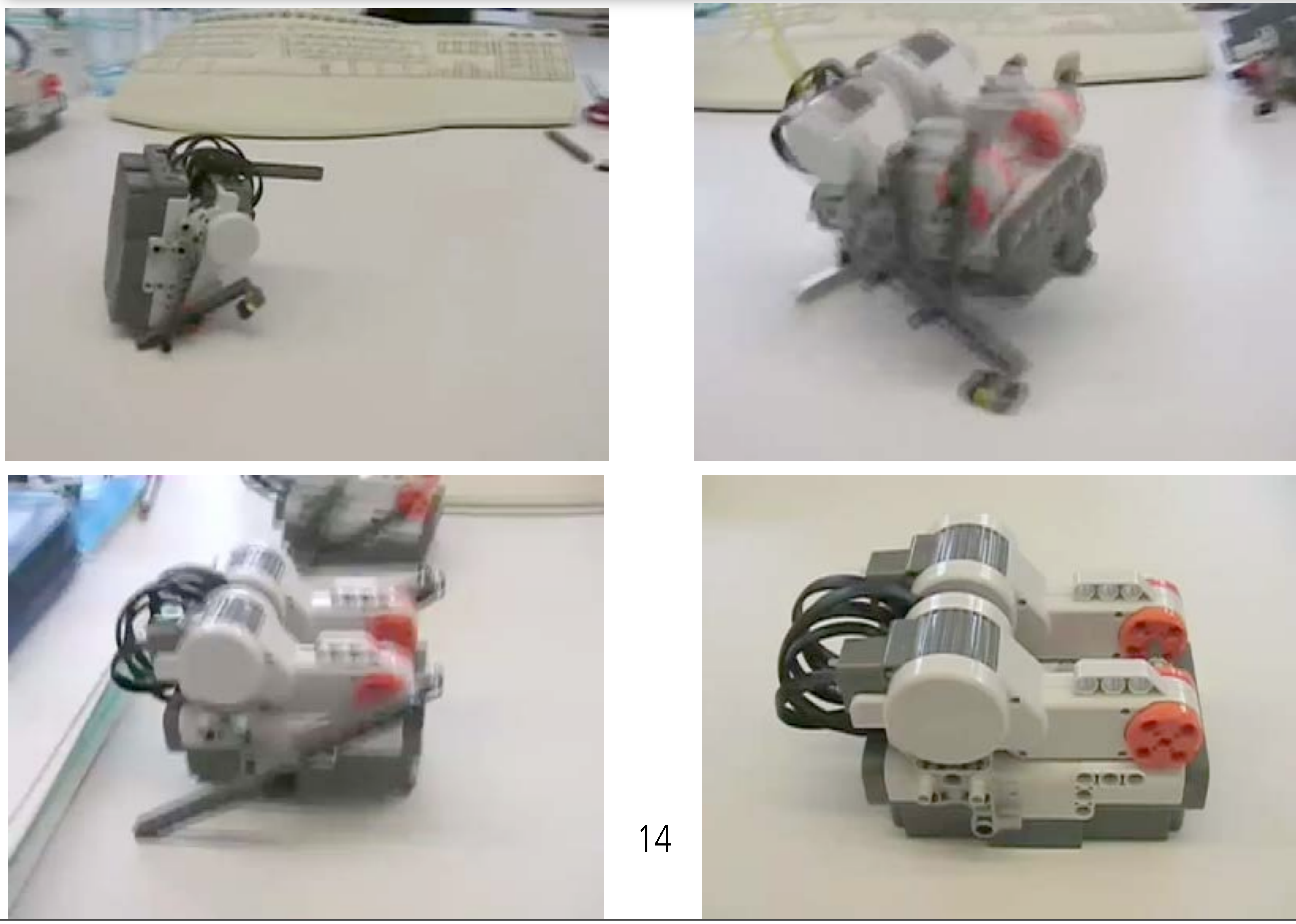





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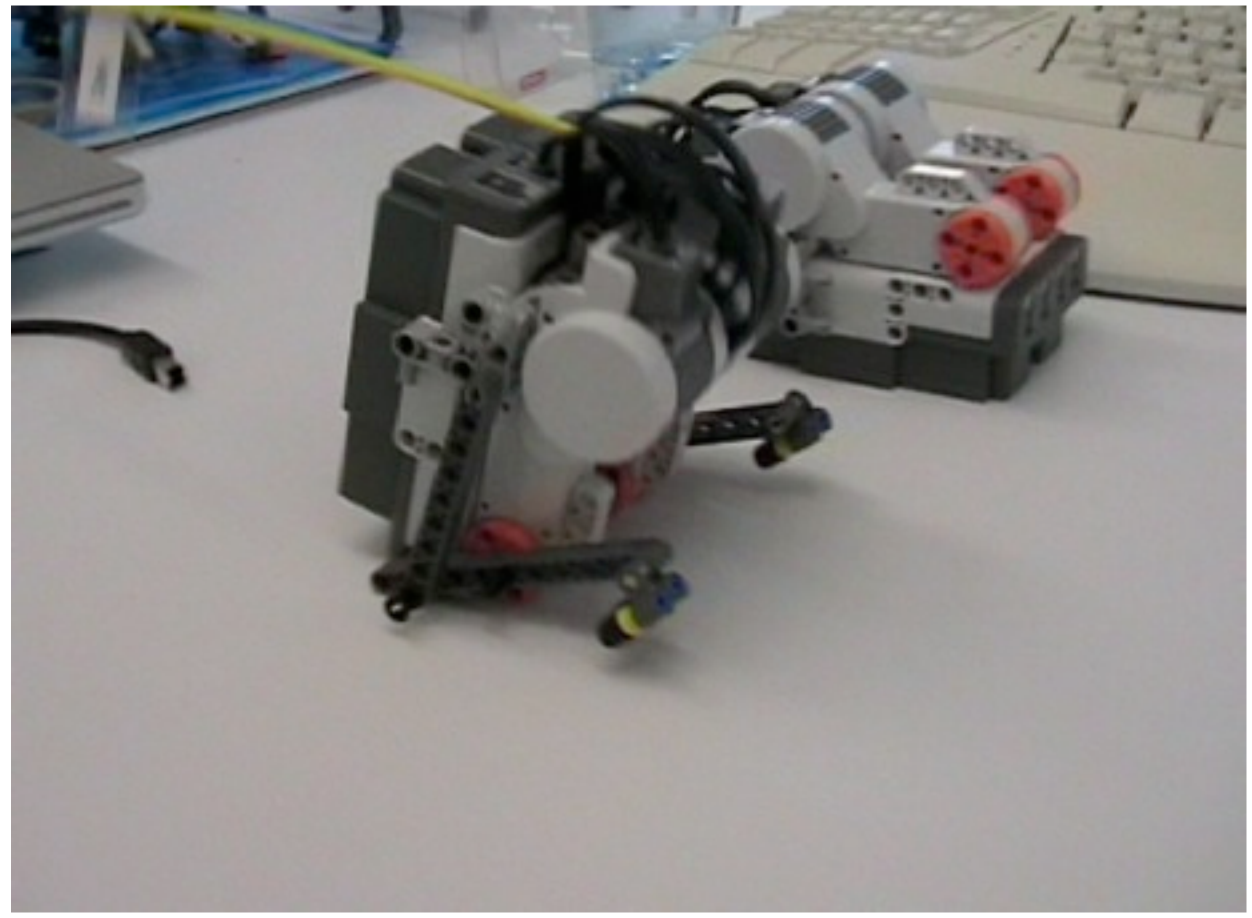
# “Crazy Bird” — Morphology, Control



loosely hanging feet
rubber/plastic





random component: loosely hanging feet
turning around it’s own axis: difference in friction between rubber and plastic

# By comparison: The "Passive Dynamic Walker"

Design and construction:
**Ruina, Wisse, Collins: Cornell University**
**Ithaca, New York**

**The "brainless" robot": walking without control**

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Application to human walking: forward swing of leg - largely passive. During forward swing phase: low stiffness, during impact: high stiffness.
knee joint not directly controlled: self-organizes into proper trajectory

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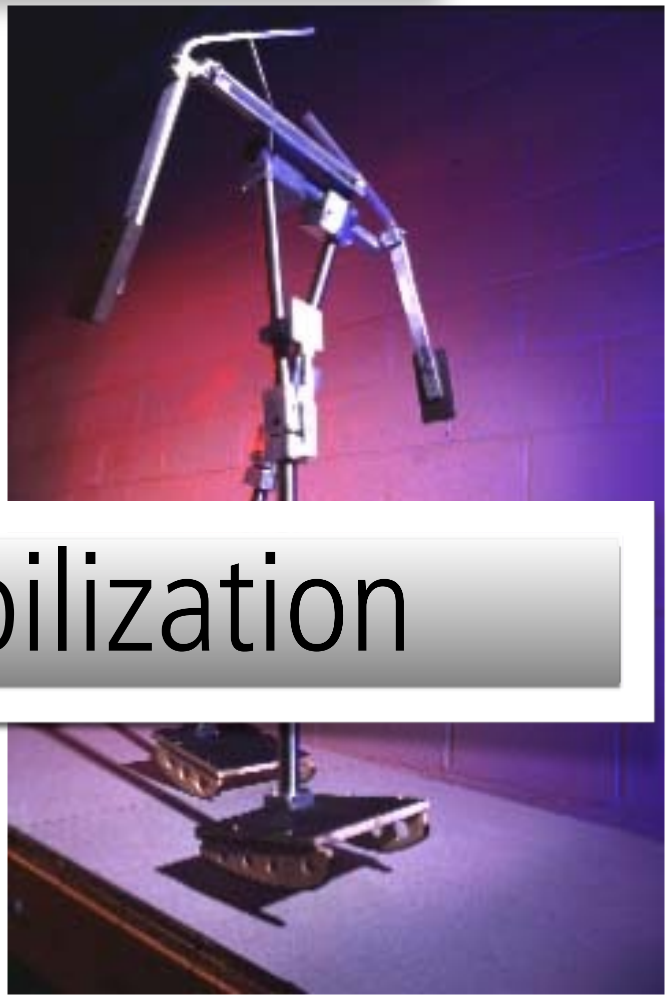

self-stabilization

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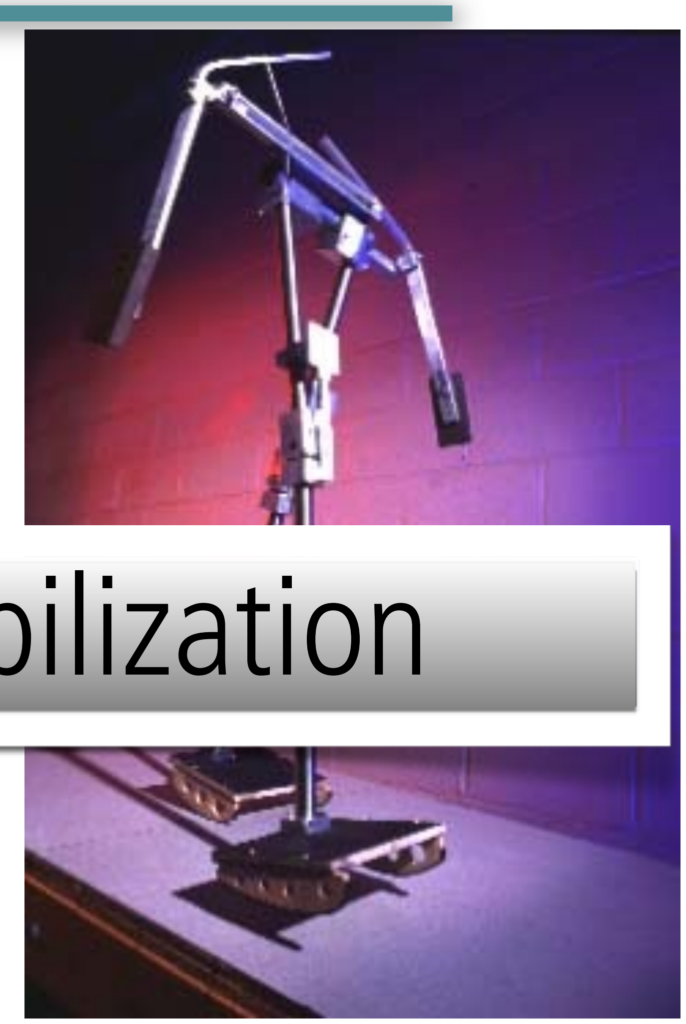

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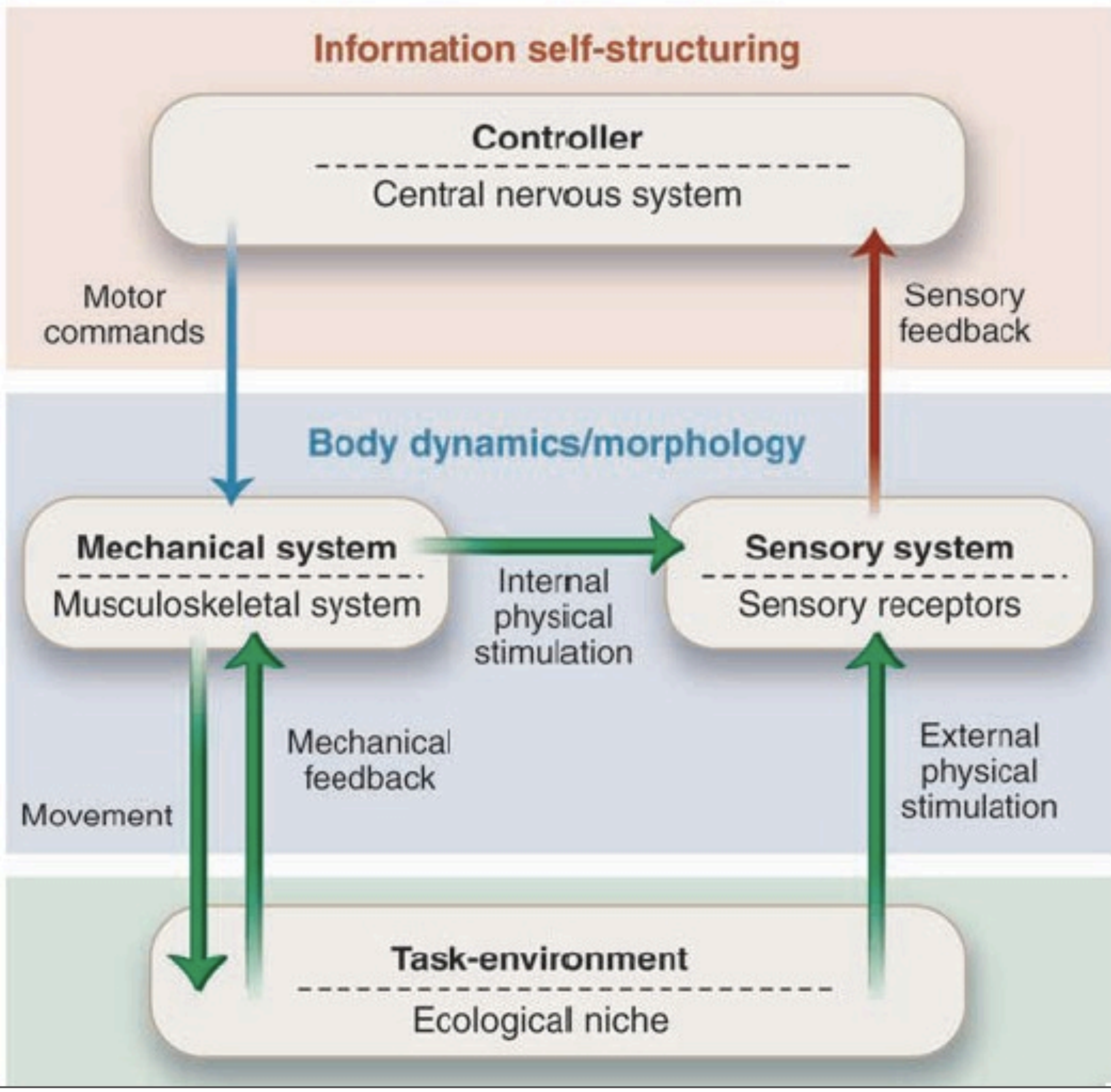
# Overall scheme: Self-stabilization in the Passive Dynamic Walker




Pfeifer et al.,Science, 16 Nov. 2007

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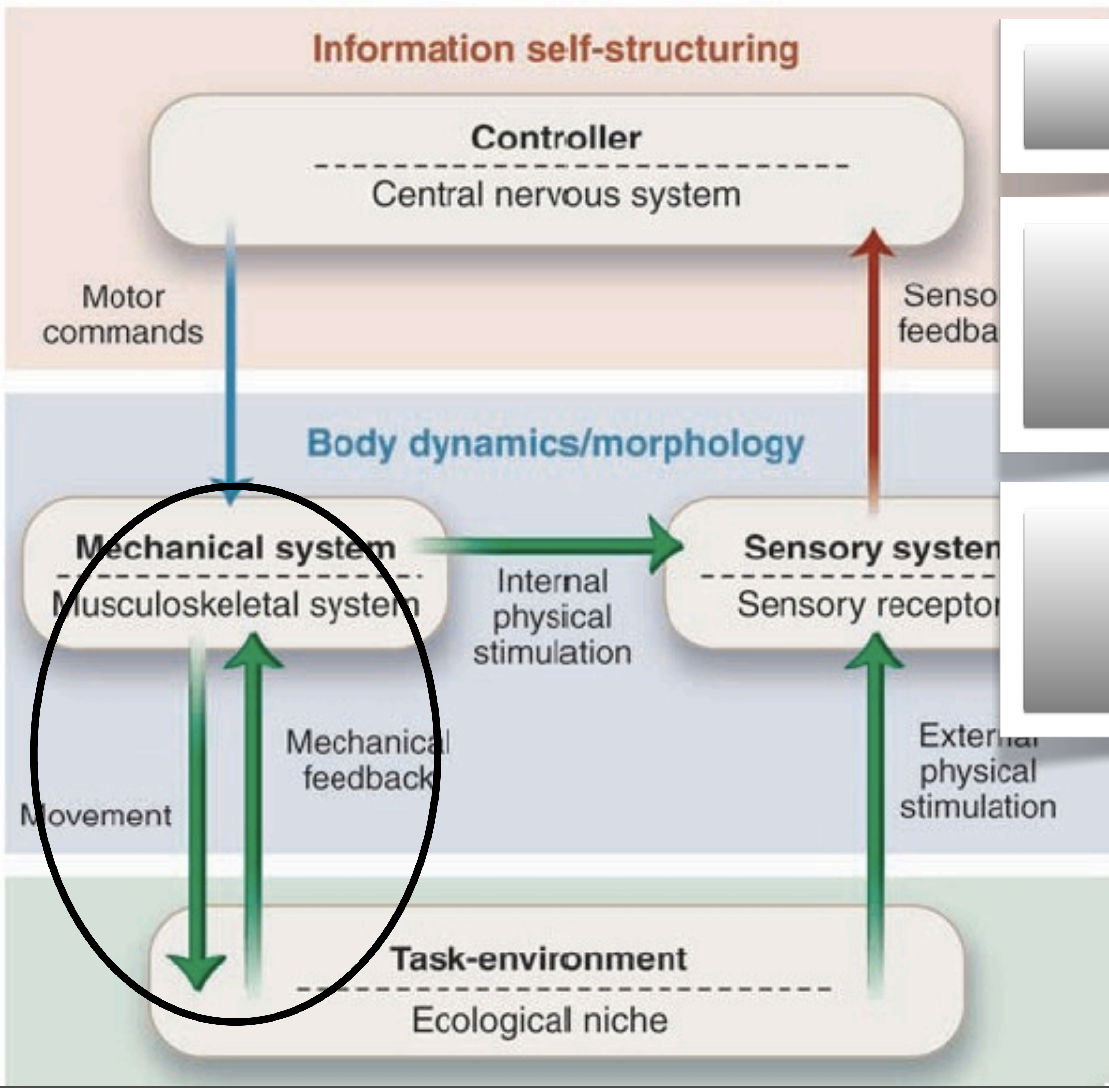


self-stabilization

morphological computation

intra-attractor dynamics

Pfeifer et al.,Science, 16 Nov. 2007

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The fact that the passive dynamic walker has no sensors for the mechanical feedback does not imply that it's not there!

# "Puppy" on treadmill

Design and construction:
**Fumiya Iida, AI Lab, UZH and ETH-Z**

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# “Puppy” on treadmill: Slow motion

self-stabilization
“intra-attractor dynamics”

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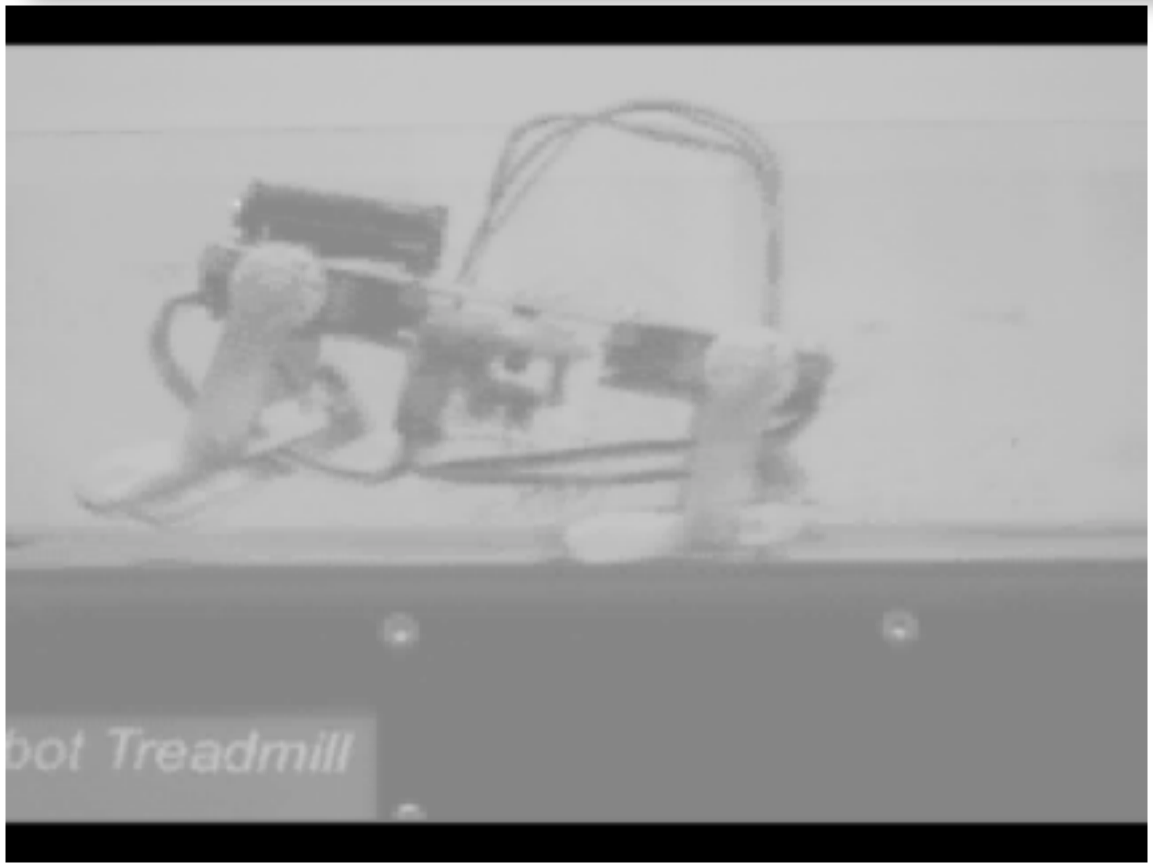
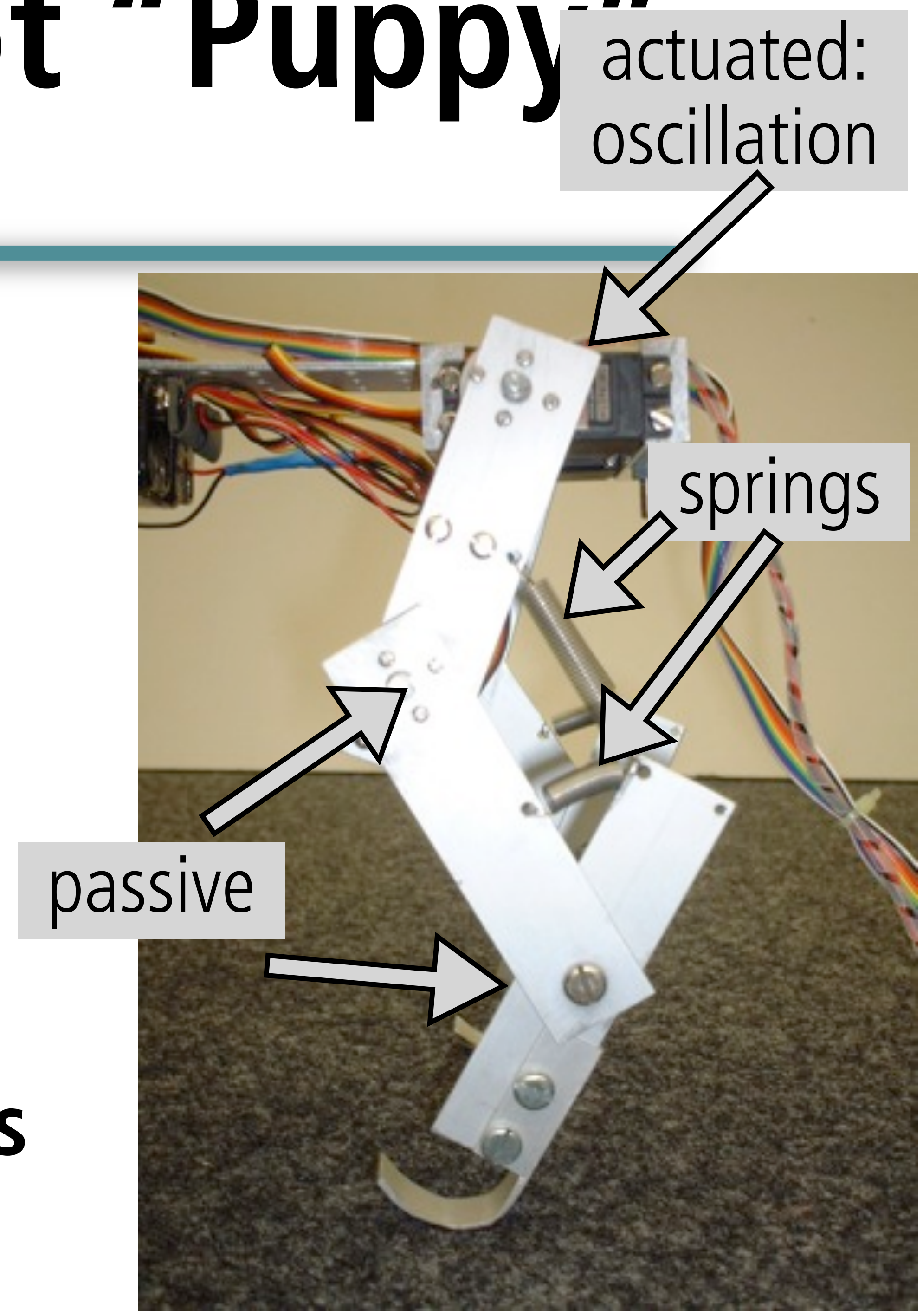
# “Puppy” on treadmill: Slow motion




self-stabilization
“intra-attractor dynamics”

# The quadruped robot "Puppy"

- simple control (oscillations of "hip" joints)
- passive joints connected by springs
- frictional characteristics on feet
- exploitation of passive dynamics

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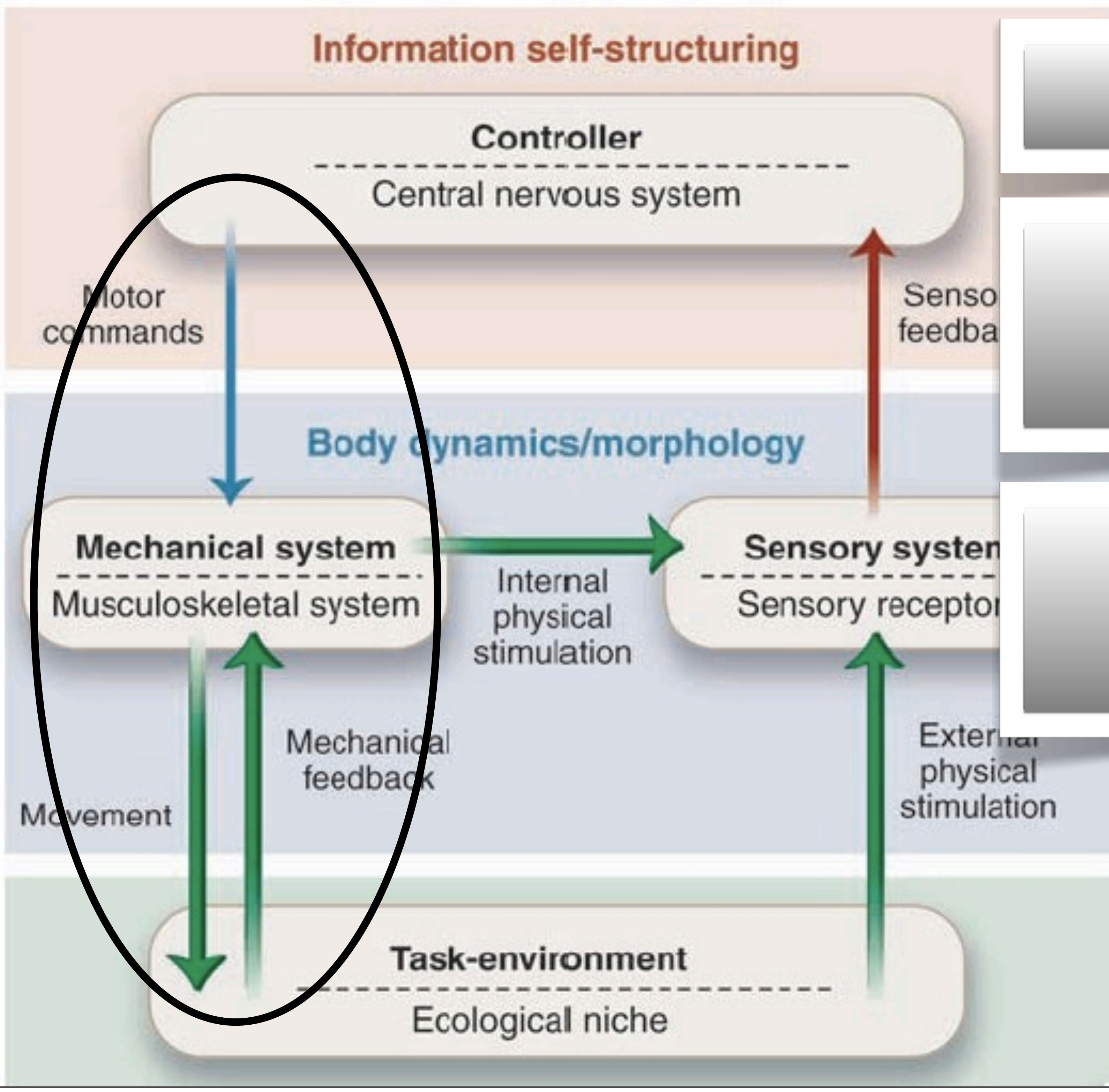


self-stabilization

morphological computation

intra-attractor dynamics

Pfeifer et al., Science, 16 Nov. 2007

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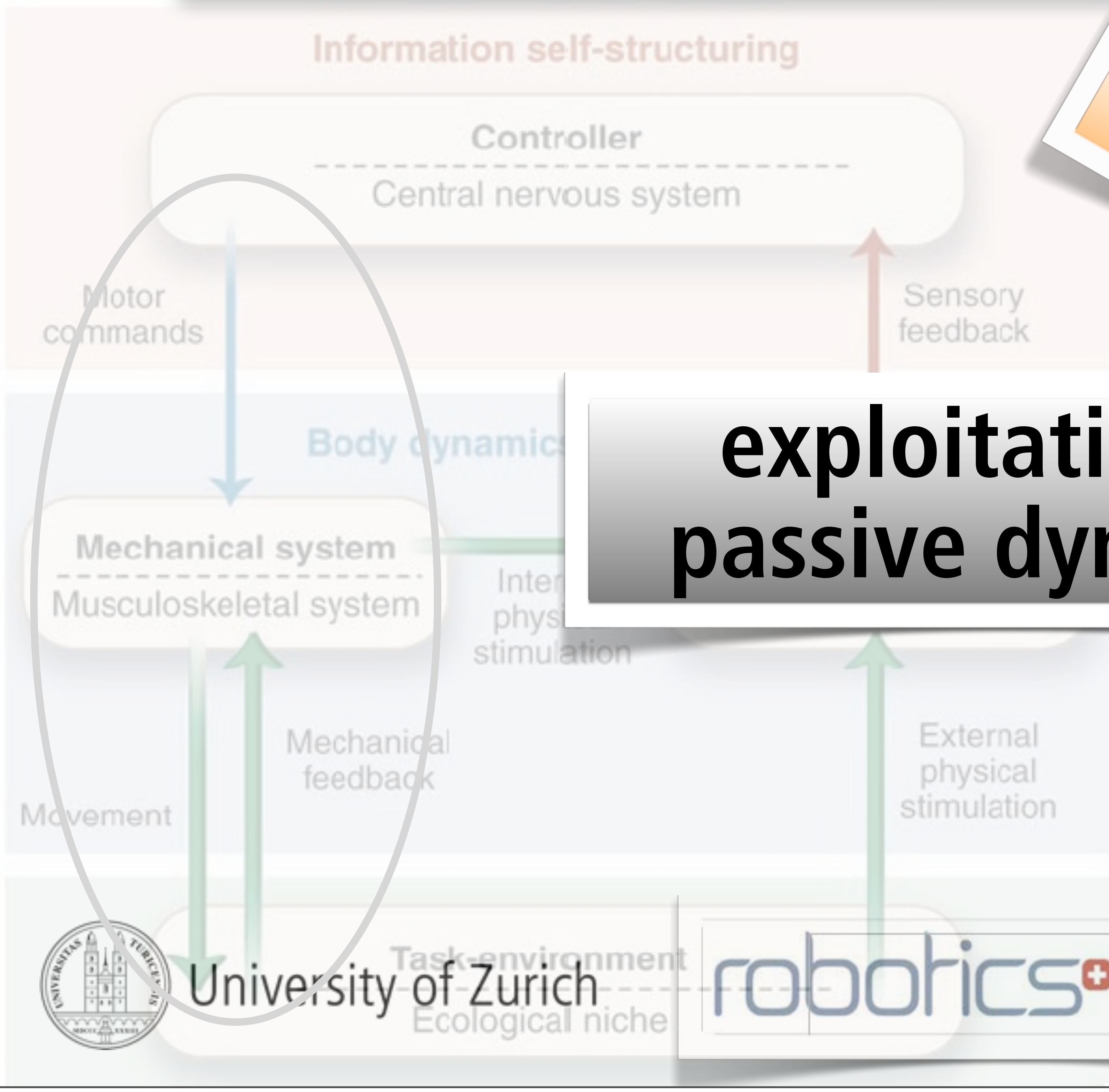


**exploitation of passive dynamics**

research opportunity

Pfeifer et al.,Science, 16 Nov. 2007

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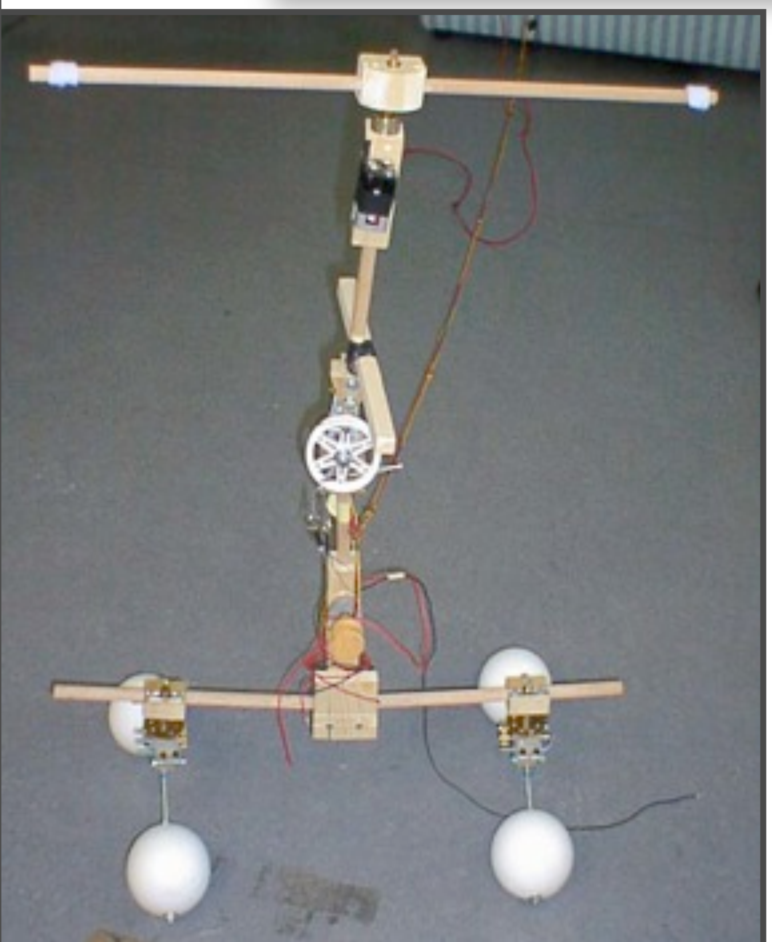
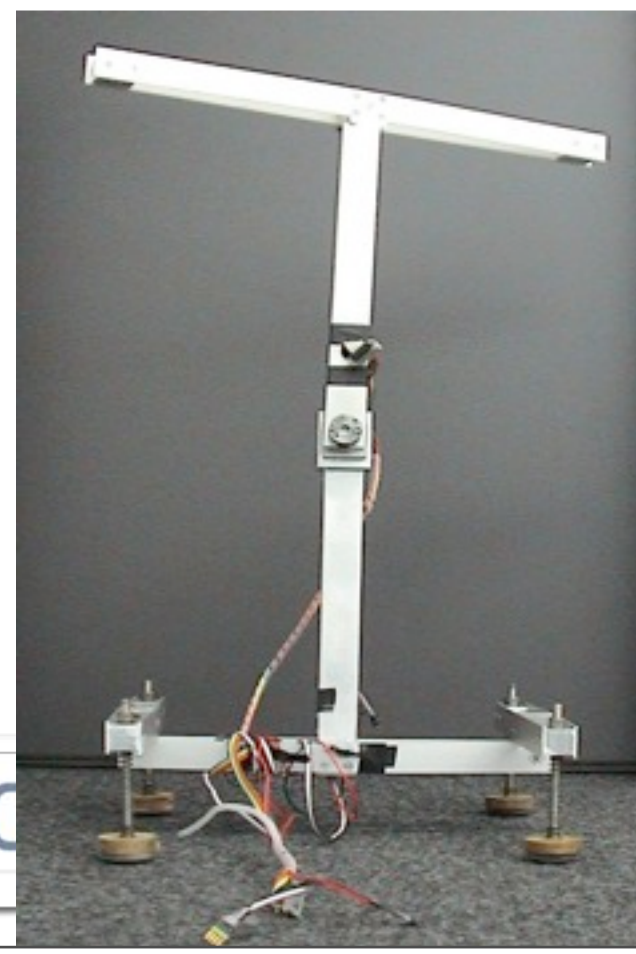
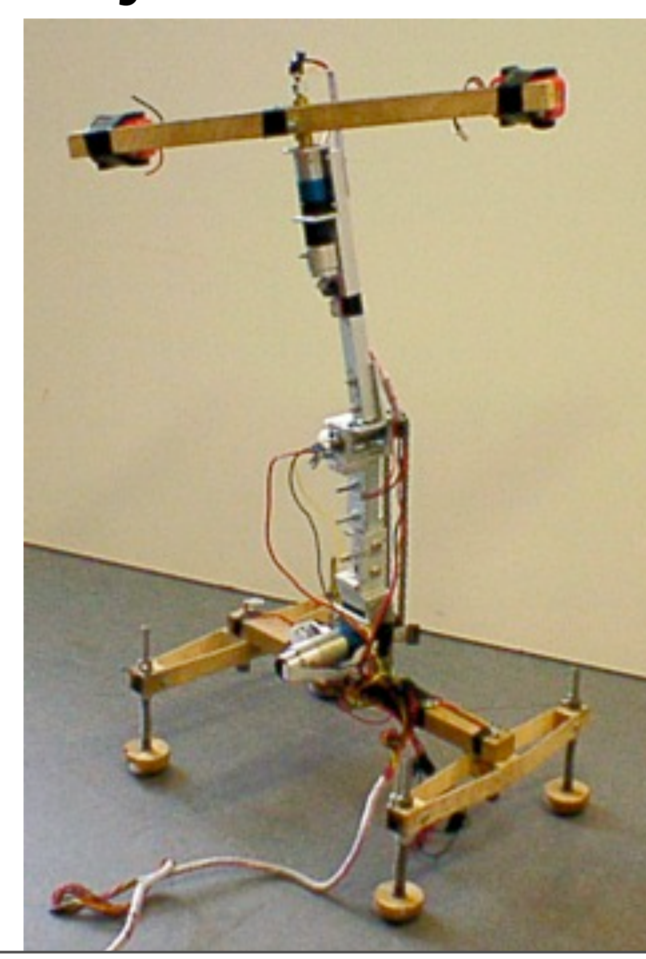
# “Stumpy”: task distribution



almost brainless: 2 actuated joints
springy materials
surface properties of feet

Design and construction: **Raja Dravid, Chandana Paul, Fumiya Iida**





self-stabilization

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robotic

# The dancing robot "Stumpy"

**Collaboration with Louis-Philippe Demers, Nanyang Technological University, Singapore**

Movie:
**Dynamic Devices and AILab, Zurich**

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# Task distribution

**Task distribution between brain (control), body (morphology, materials), and environment**

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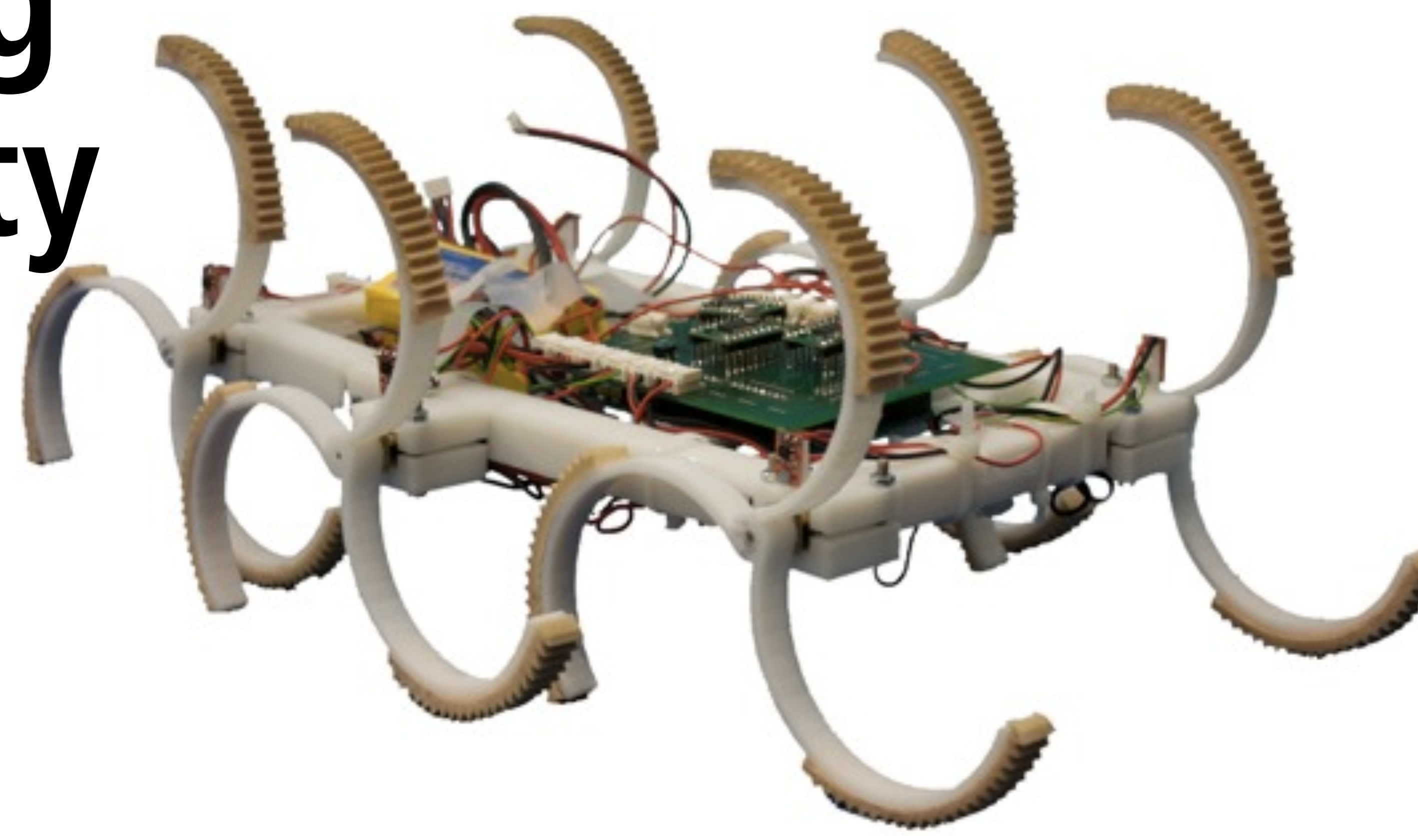
**no clear separation between control and hardware (“soft robotics”)**

morphological computation

# Outsourcing functionality



**Mini-rHex**
Design and construction:
**Robin Guldener, Lijin Aryananda**

**soft, flexible, elastic materials**

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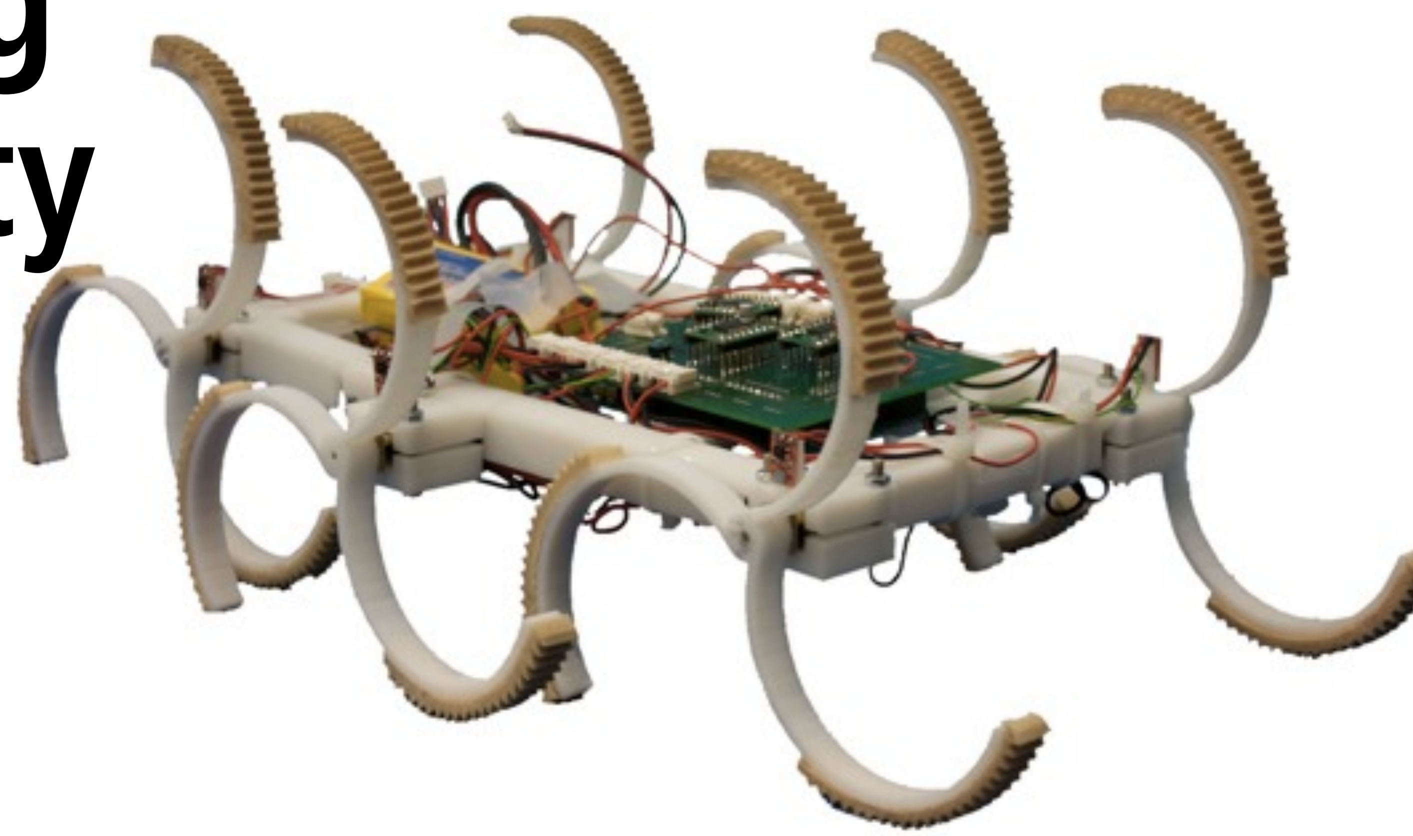

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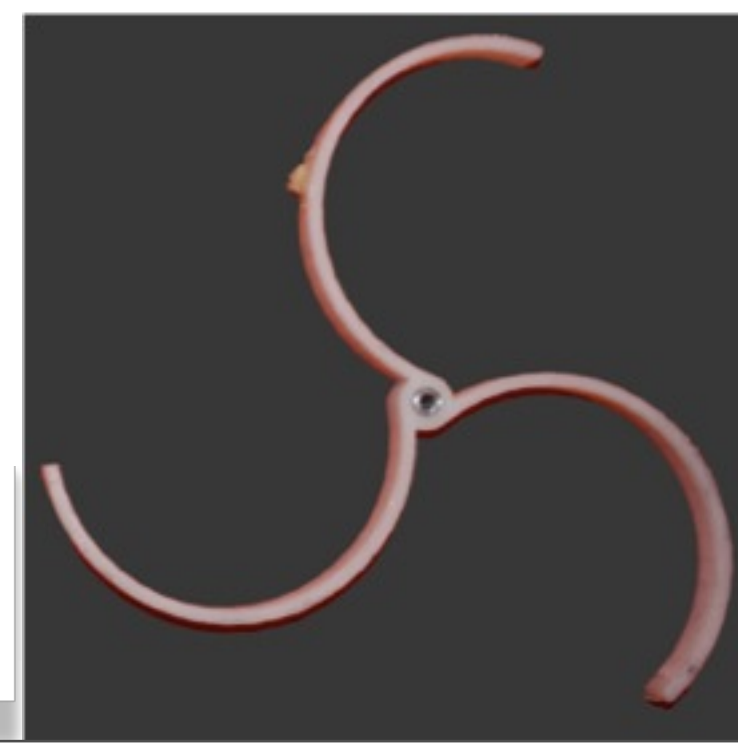

# The "robot frog" driven by pneumatic actuators (UTokyo)

Design and construction:
**Ryuma Niiyama and**
**Yasuo Kuniyoshi**
**University of Tokyo**

pneumatic actuators:
**compliant materials**

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The damped oscillatory movement after impact is not controlled but the result of the morphological and material characteristics (pneumatic actuators).

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# Task distribution

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**no clear separation between control and hardware ("soft robotics")**

re-thinking of "control"
("orchestration")
in terms of morphological
computation

Un

lab

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# Trading space morphology — control

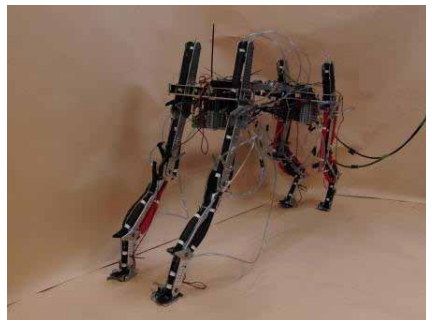
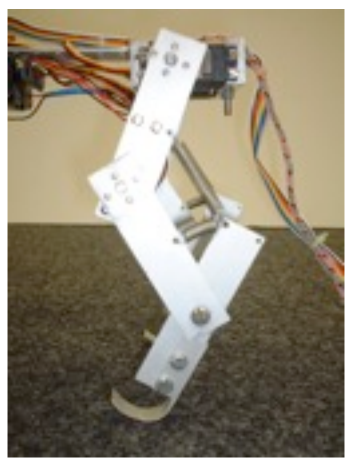
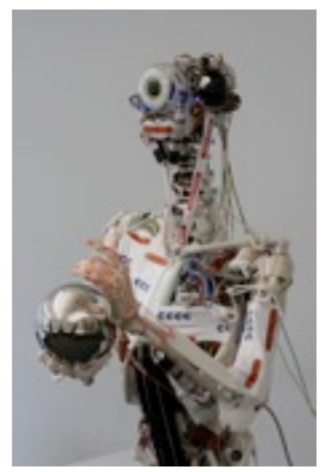


Fig. 1. Proposed pneumatic quadruped robot, "Pneudog".





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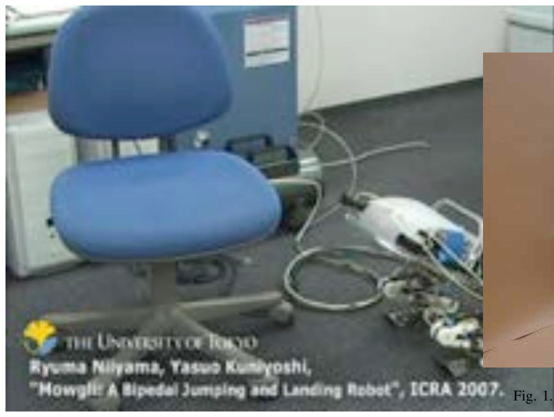
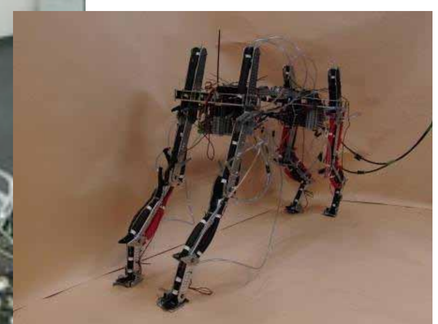
# Trading space morphology — control



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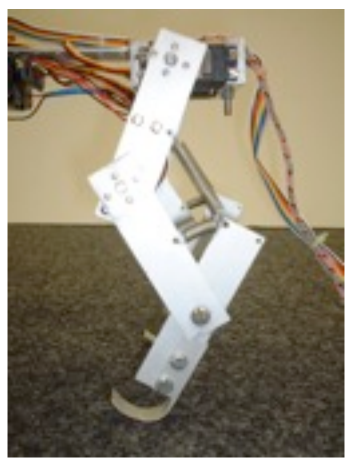

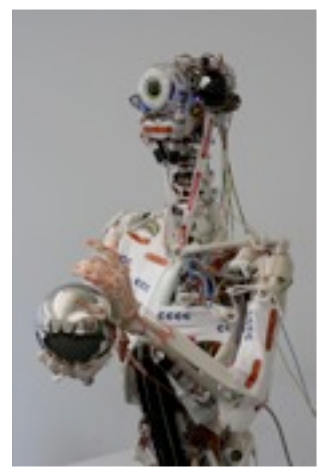

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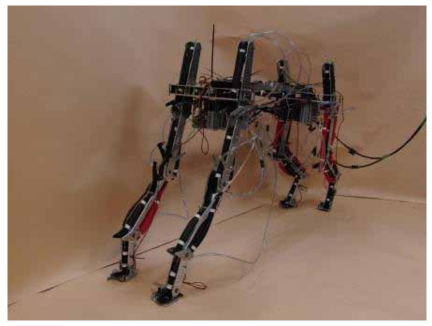
# Trading space morphology — trol

research opportunity



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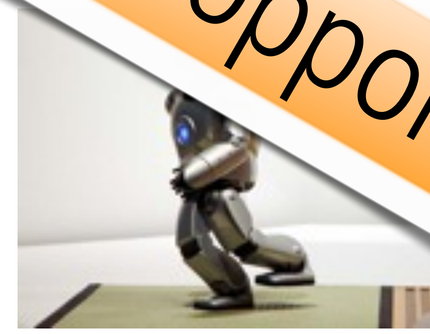

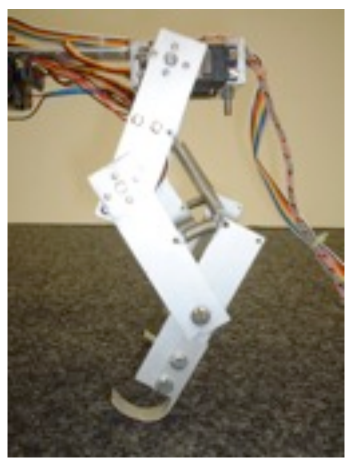

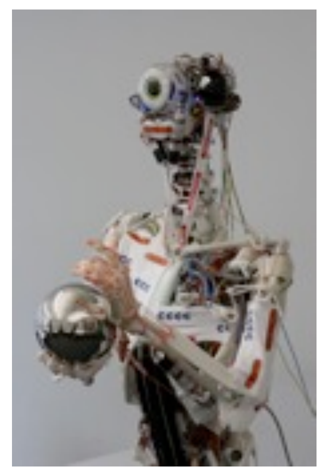

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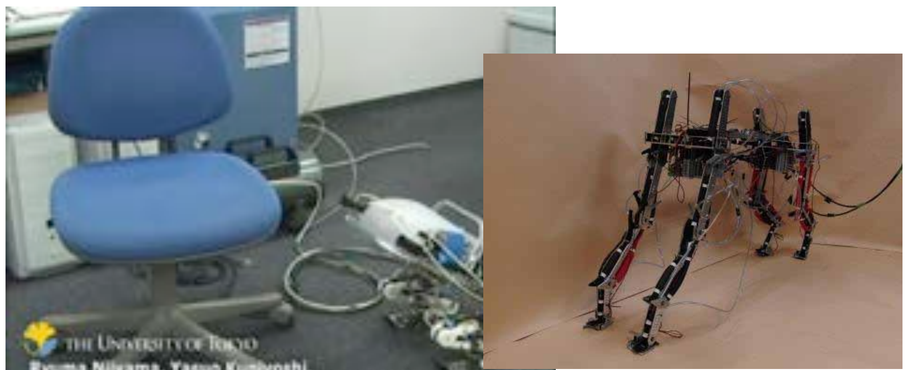

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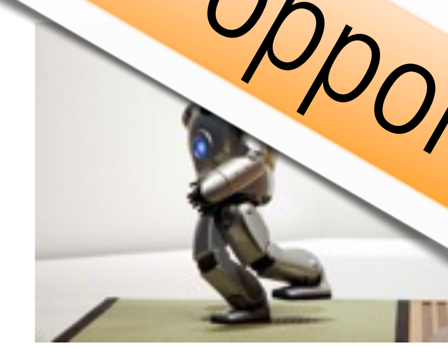



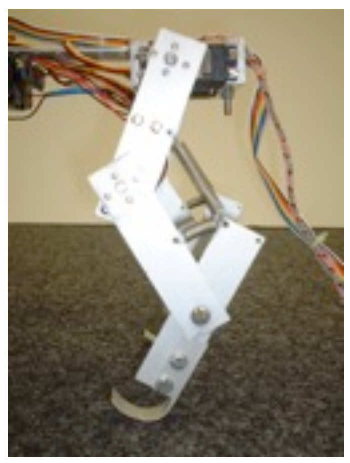
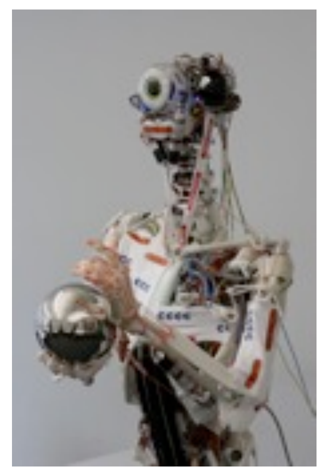

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# Optic flow and morphological computation

- **amazing navigational skills**
- **fast obstacle avoidance**
- **learning**

photos courtesy
Rüdiger Wehner

photo
P.O. Gustavson

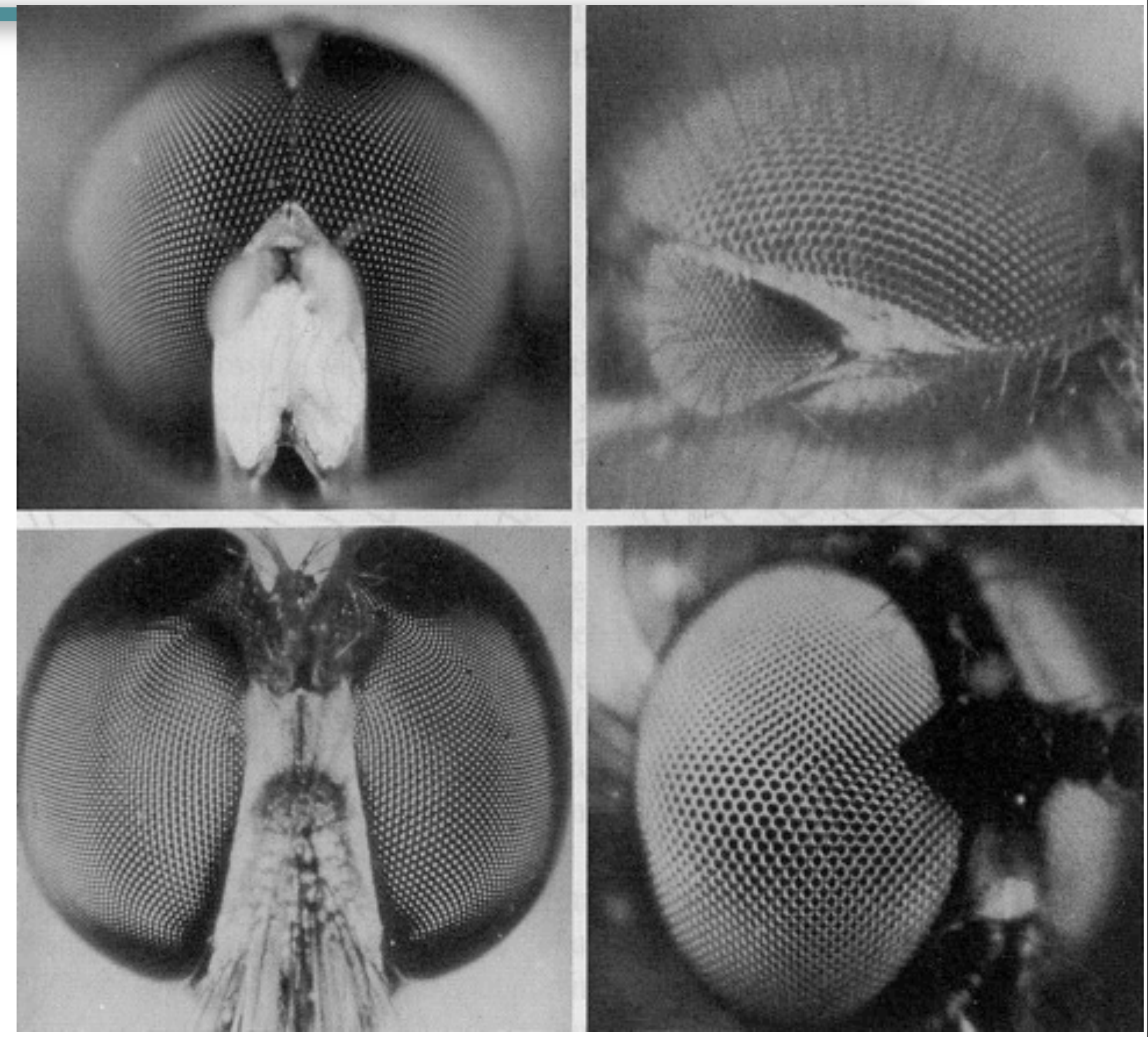



Ecological niche of Cataglyphis; salt pan near Maharès in Southern Tunisia.

# Different morphologies of insect eyes

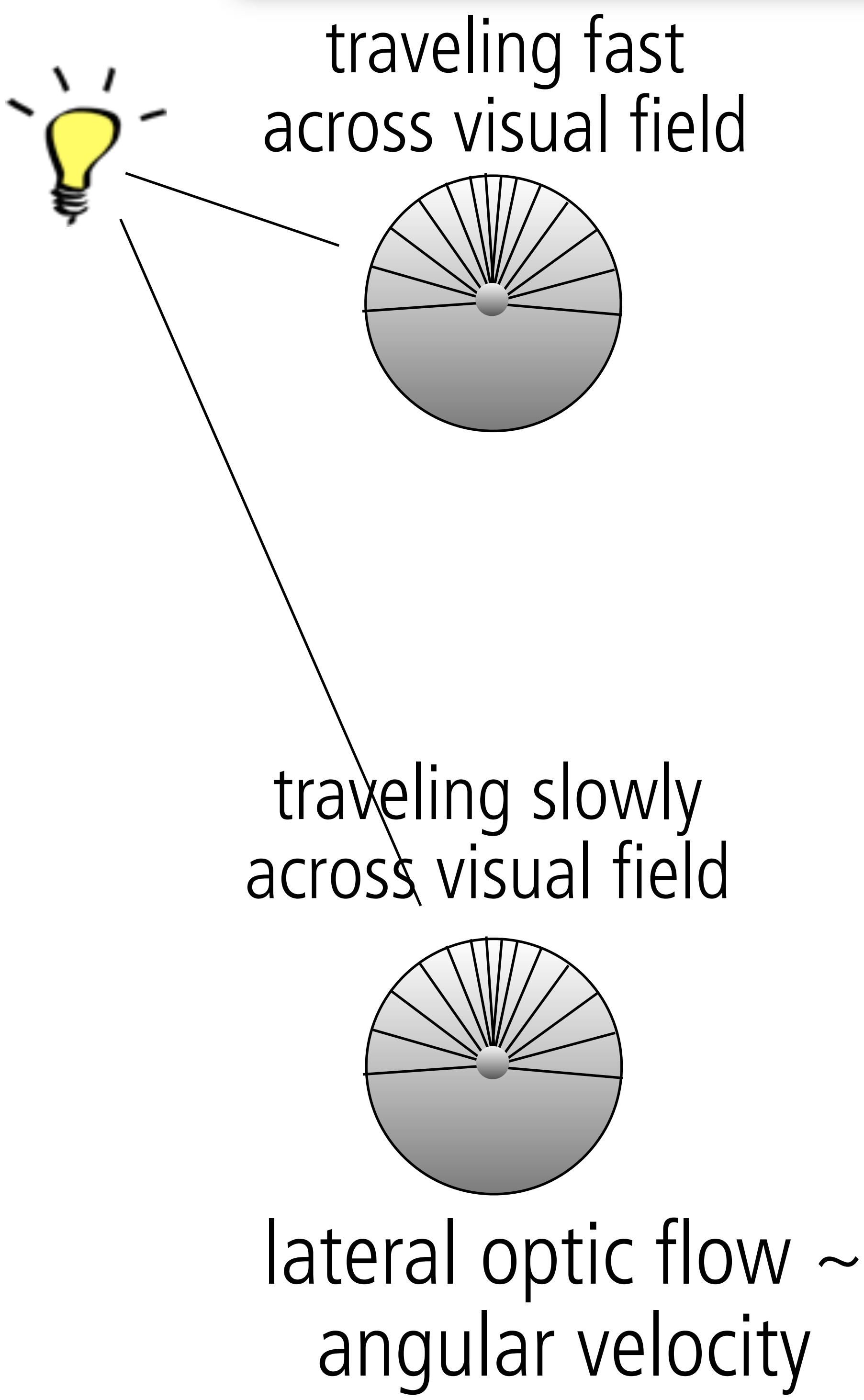
housefly

large variation of shapes



honey bee

# Motion parallax and sensor morphology

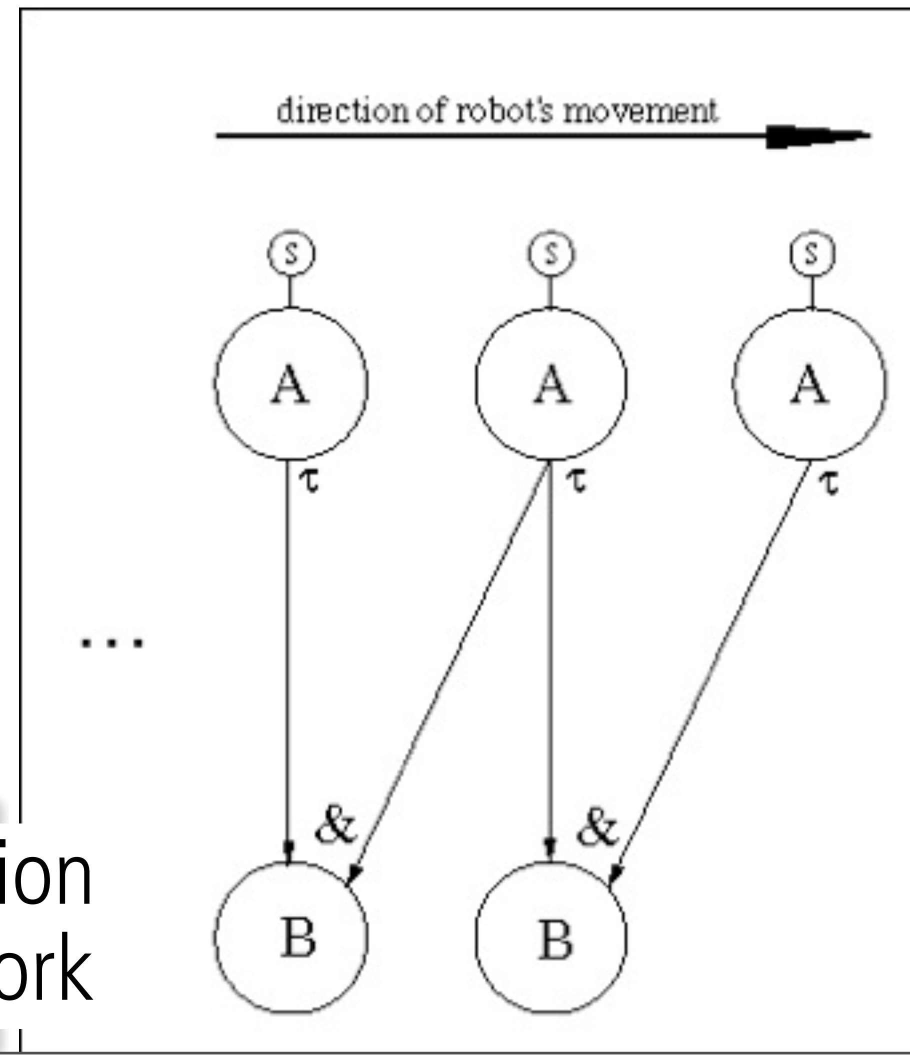



**non-homogeneous arrangement of facets: higher density in front**

**"pre-processing" through physical arrangement of facets: compensation of motion parallax**

**morphological computation**

very simple motion detector network





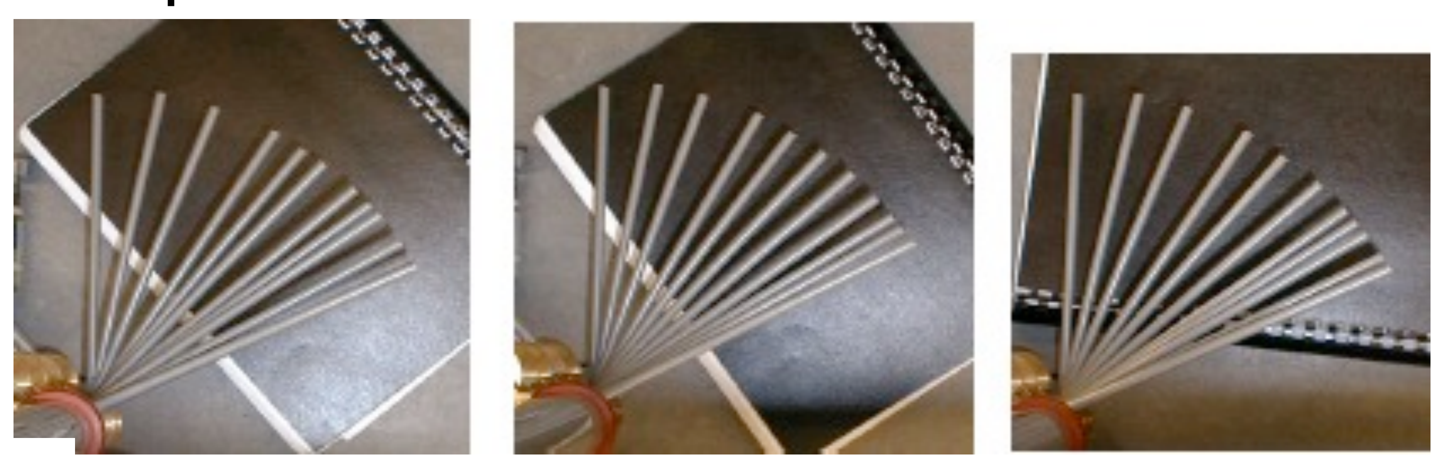

Non-homogenious arrangement of facts --> compensates motion parallaxe.

# Adaptive behavior through morphology change

## "Eyebot"

Design and construction:
Lukas Lichtensteiger and Peter Eggenberger, AI Lab, UZH

output from three different runs



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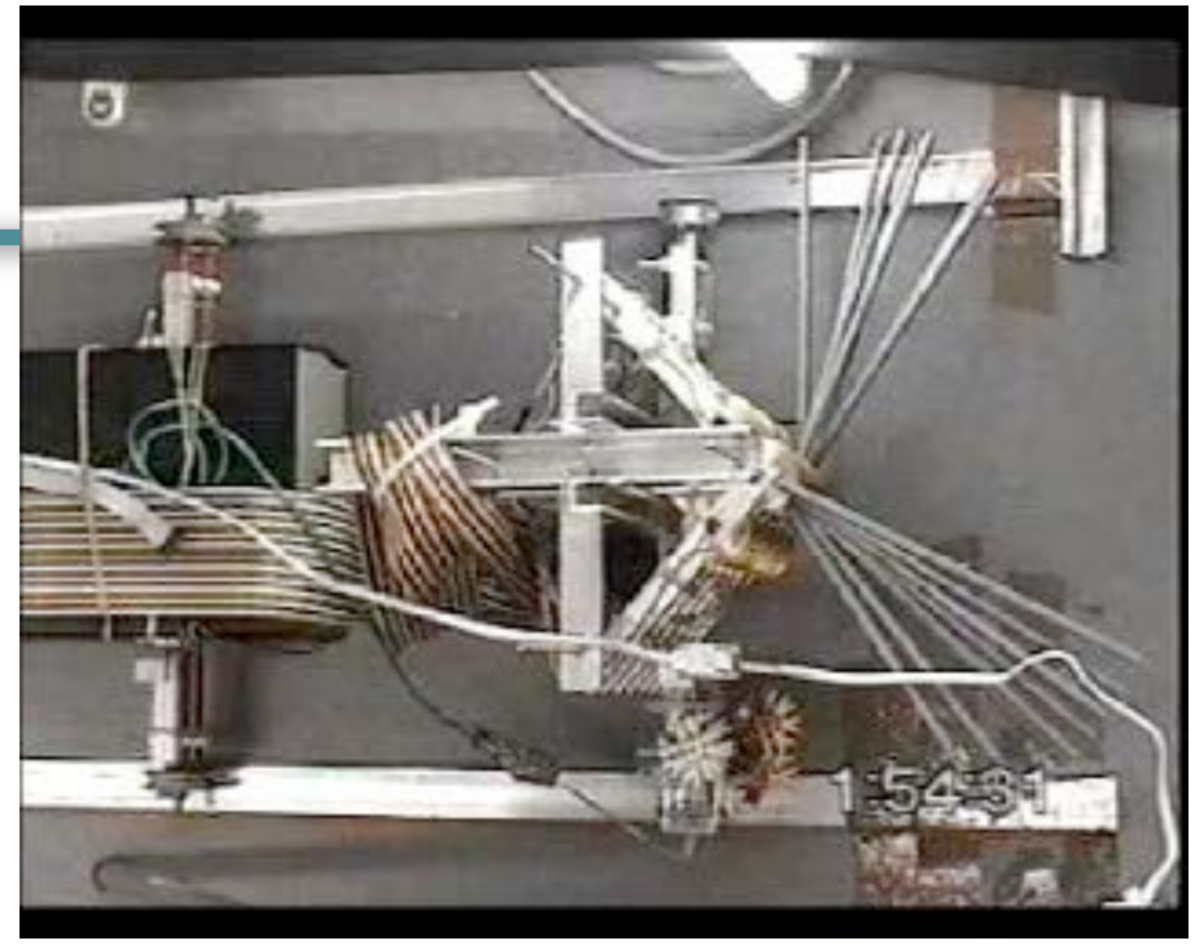
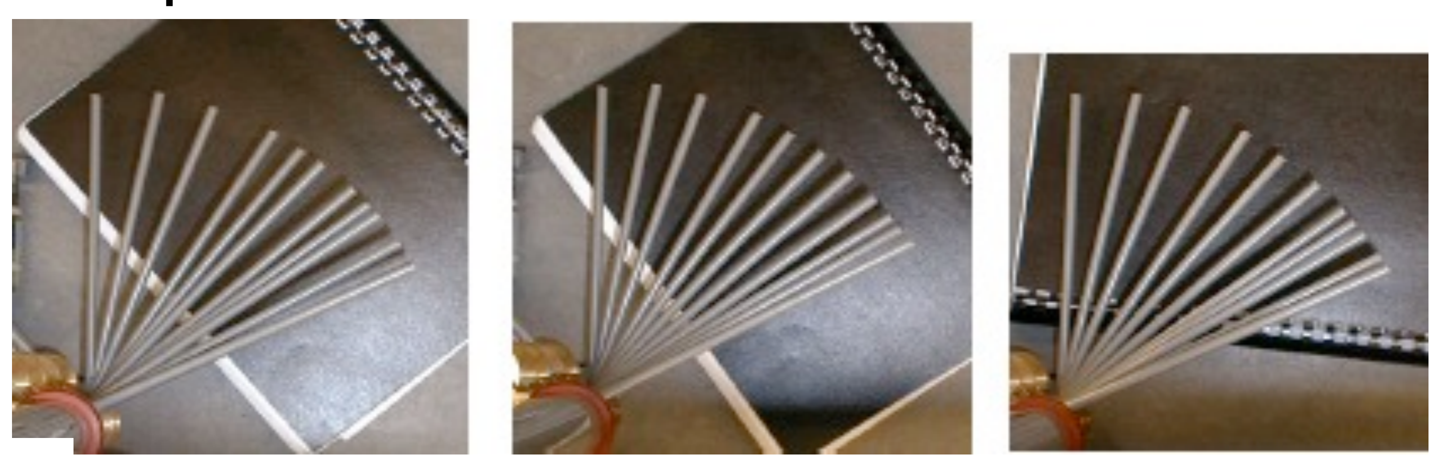
The "facets" which are tubes with a light-sensitive cell at the end, can be moved individually. The task of the robot was to maintain a fixed lateral distance to a light source. An evolutionary algorithm (see lecture 6) was run that modified the angular positions of the "facets". The "brain" of the robot, i.e. the controller in the form of a neural network was not changed; the robot had to solve the problem by changing its morphology. If the robot managed to solve the task, nothing was changed, if not, the angular positions of the "facets" were changed ("mutation"). Because of motion parallax, this is a hard problem. The output from three different runs shows that the resulting arrangements are all non-homogeneous, with densities higher in the front.

# Adaptive behavior through morphology change




## "Eyebot"

output from three different runs



Design and construction:
Lukas Lichtensteiger and Peter Eggenberger,
AI Lab, UZH

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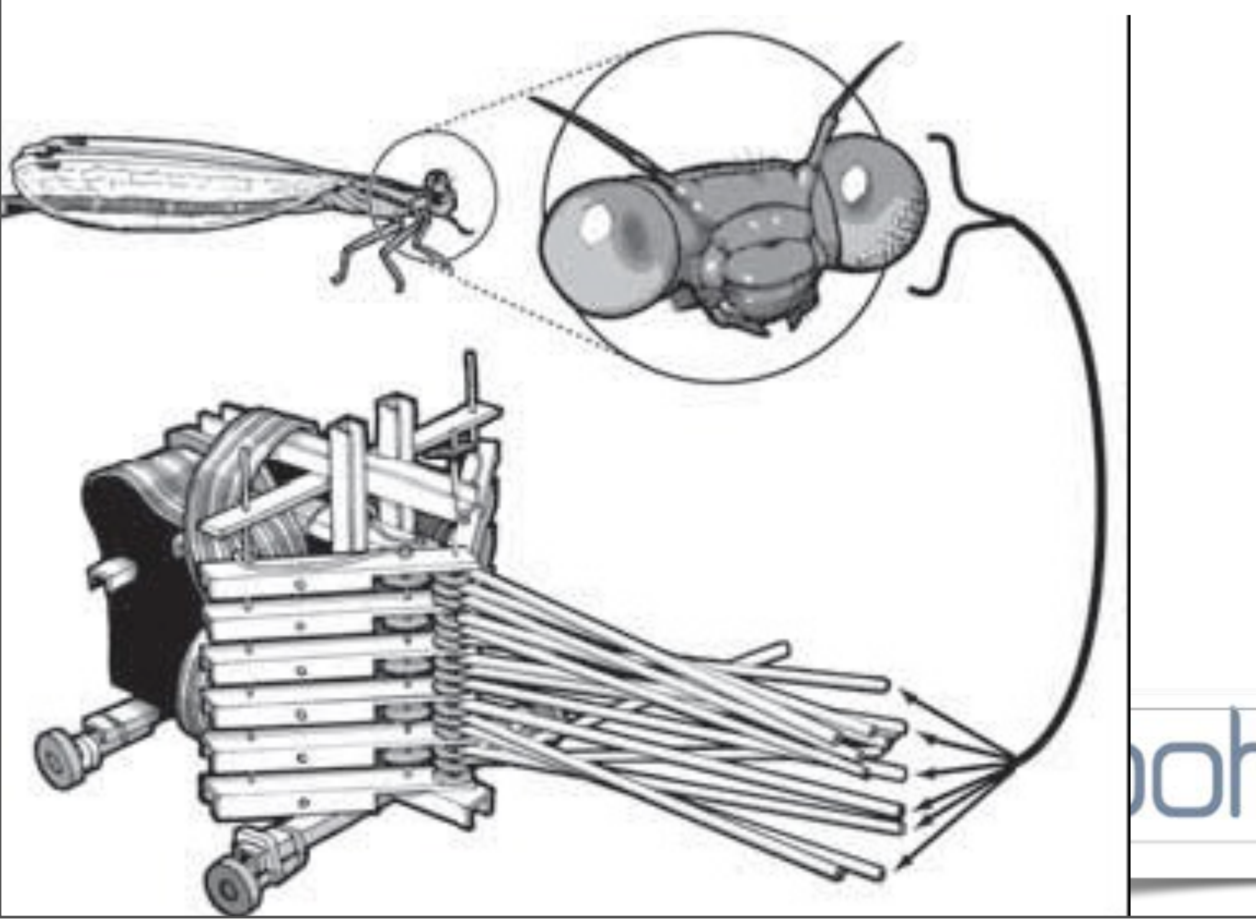
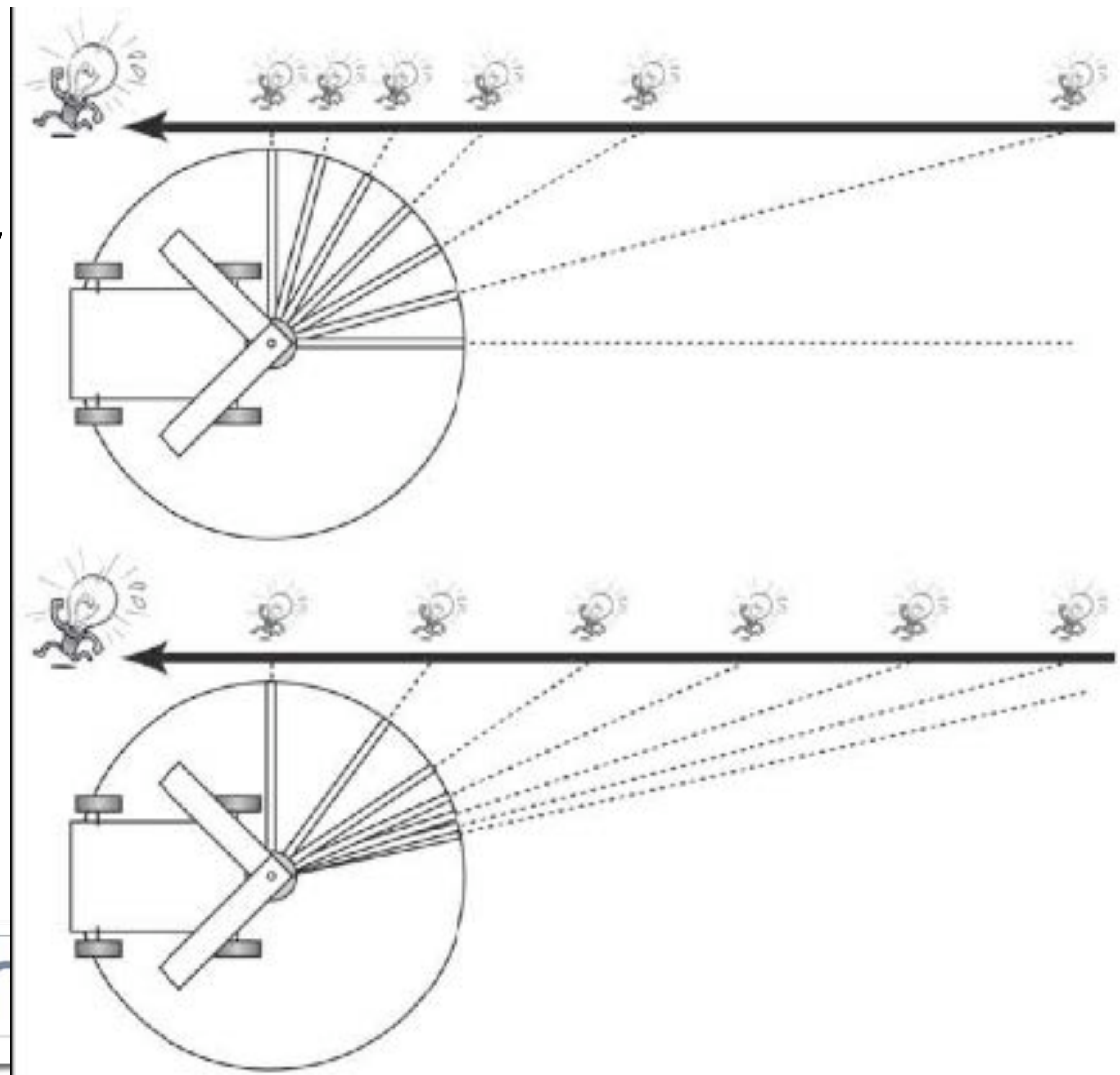
# The “Eyebot” and motion parallax

read details in:
“How the body…” p. 131

Cartoons by
Shun Iwasawa





# Motion parallax and sensor morphology: summary

- must know embedding of "brain" (neural circuit) in physical organism
- morphology (physical arrangement of facets): part of "computation" (pre-processing)
- fast, "free"

→ **morphological computation**

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It can also be shown that there is a dependence of learning speed on morphology (because the environment is sampled differently)

# Motion parallax and sensor morphology: summary

- must know ... eural circuit) in physical ...
- morphology ... f facets): part of "comput...
- fast, "free"

**field of space-variant vision neuro-morphic engineering**

→ **morphological computation**

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It can also be shown that there is a dependence of learning speed on morphology (because the environment is sampled differently)

# Motion parallax and sensor morphology: s...ary

research opportunity

- must know ... in physical ...
- morphology ... f facets): part of "comput...
- fast, "free"

field of
space-variant vision
neuro-morphic
engineering

→ morphological computation

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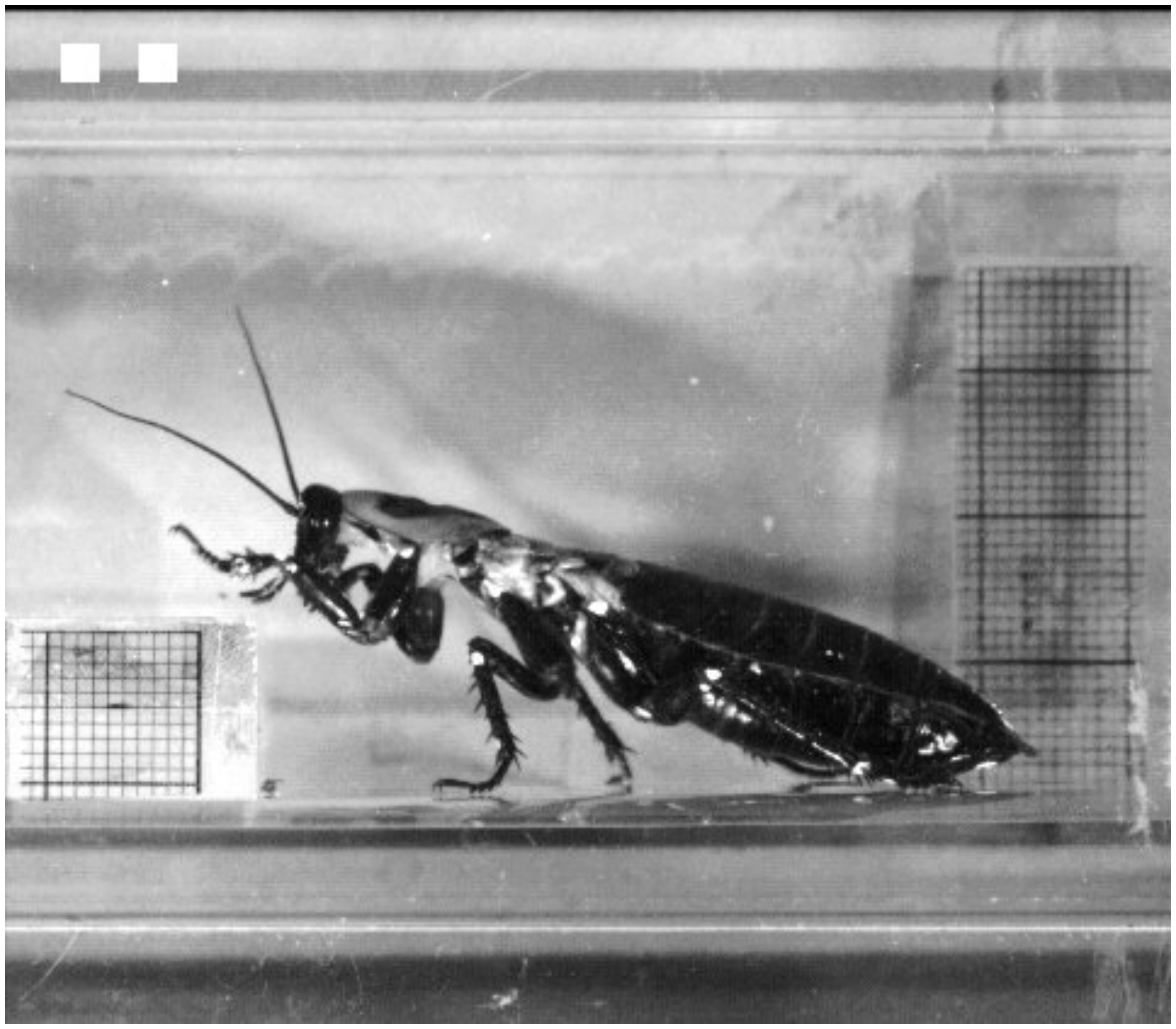
It can also be shown that there is a dependence of learning speed on morphology (because the environment is sampled differently)

# Uses of optic flow

- obstacle avoidance
- visual odometry (measuring distance)
- centering
- saliency detection
- landing

# Exploiting morphology: managing complex bodies



pictures and ideas:
**courtesy Roy Ritzmann Case Western Reserve University**

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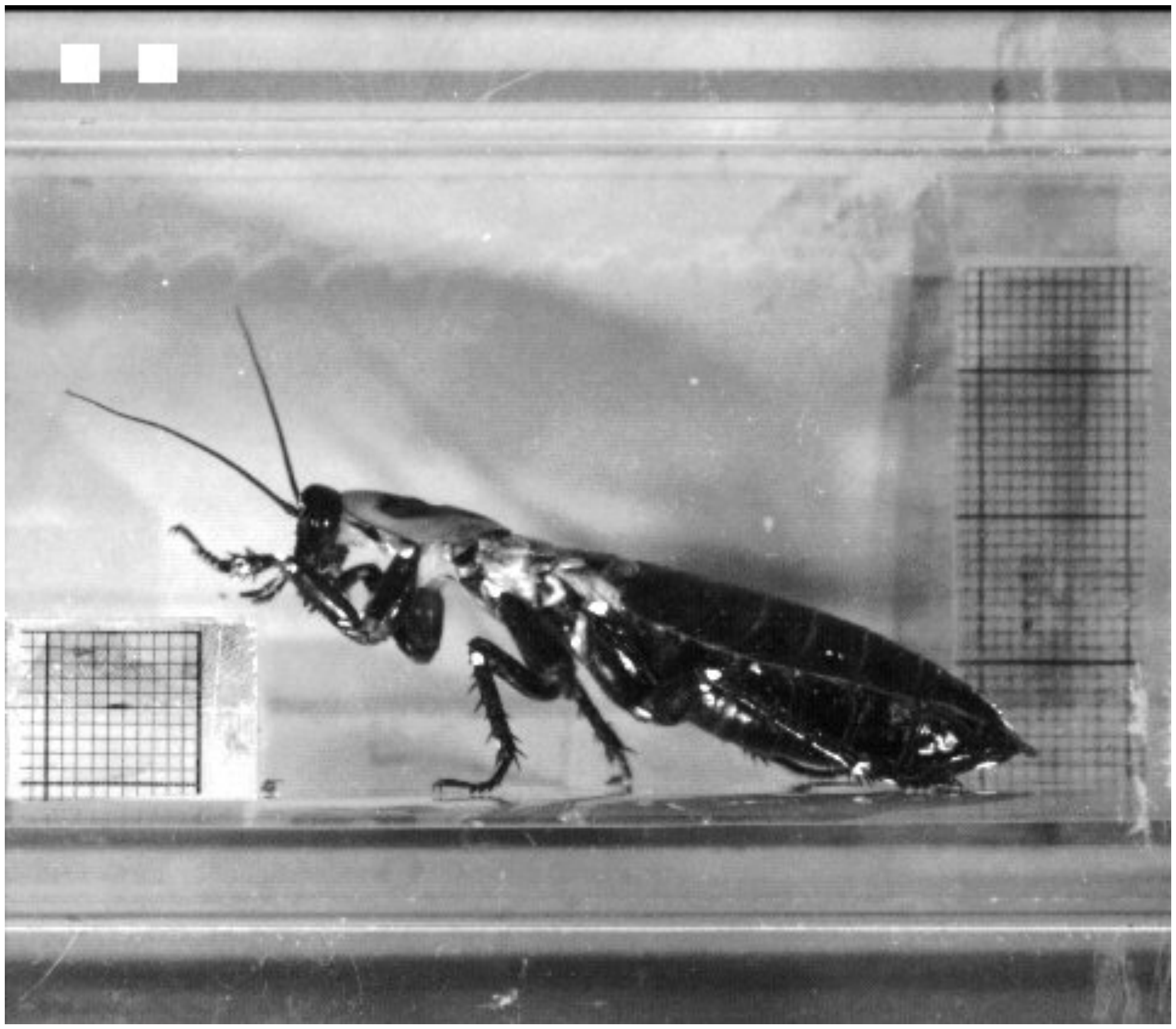
# Exploiting morphology: managing complex bodies



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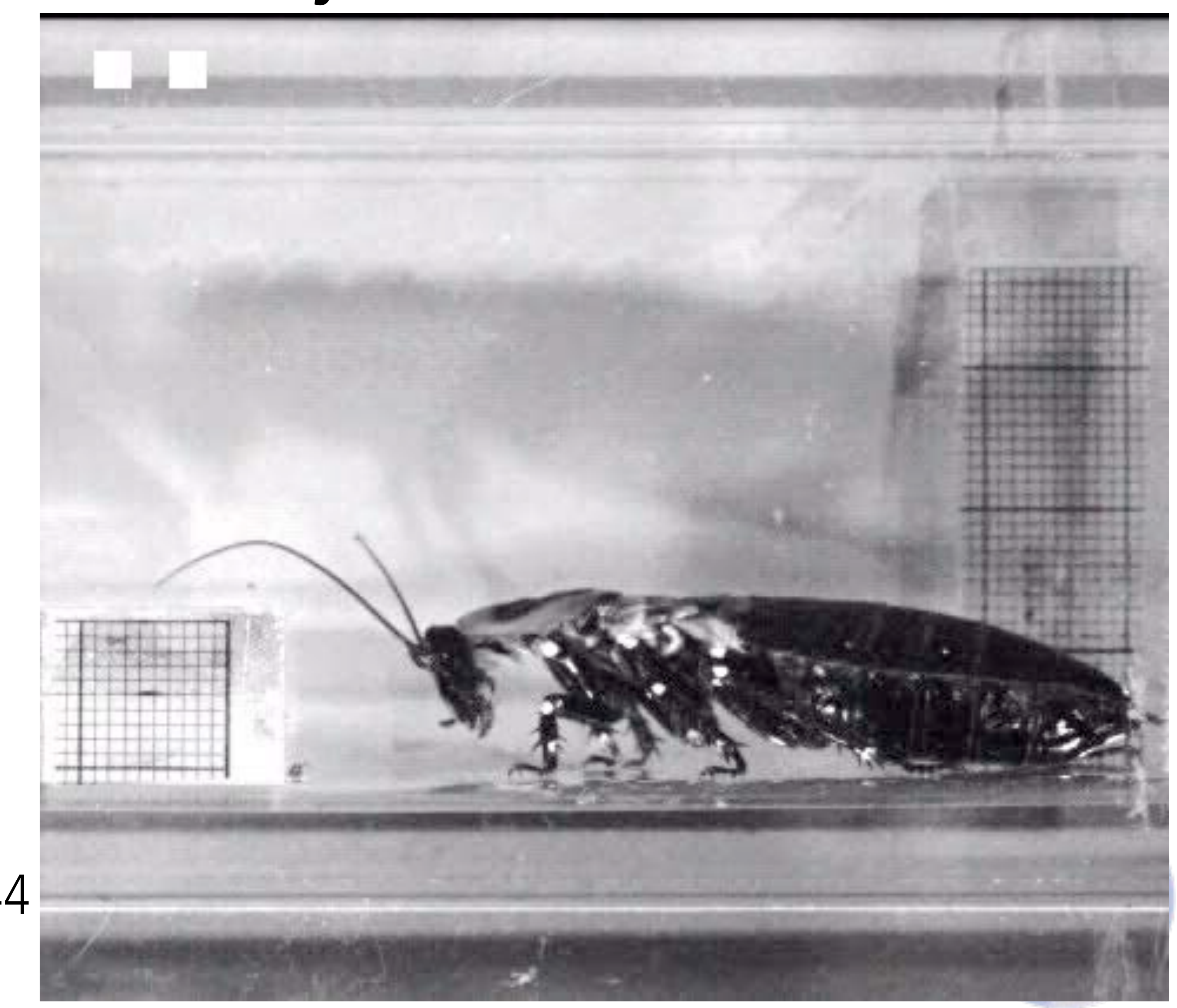

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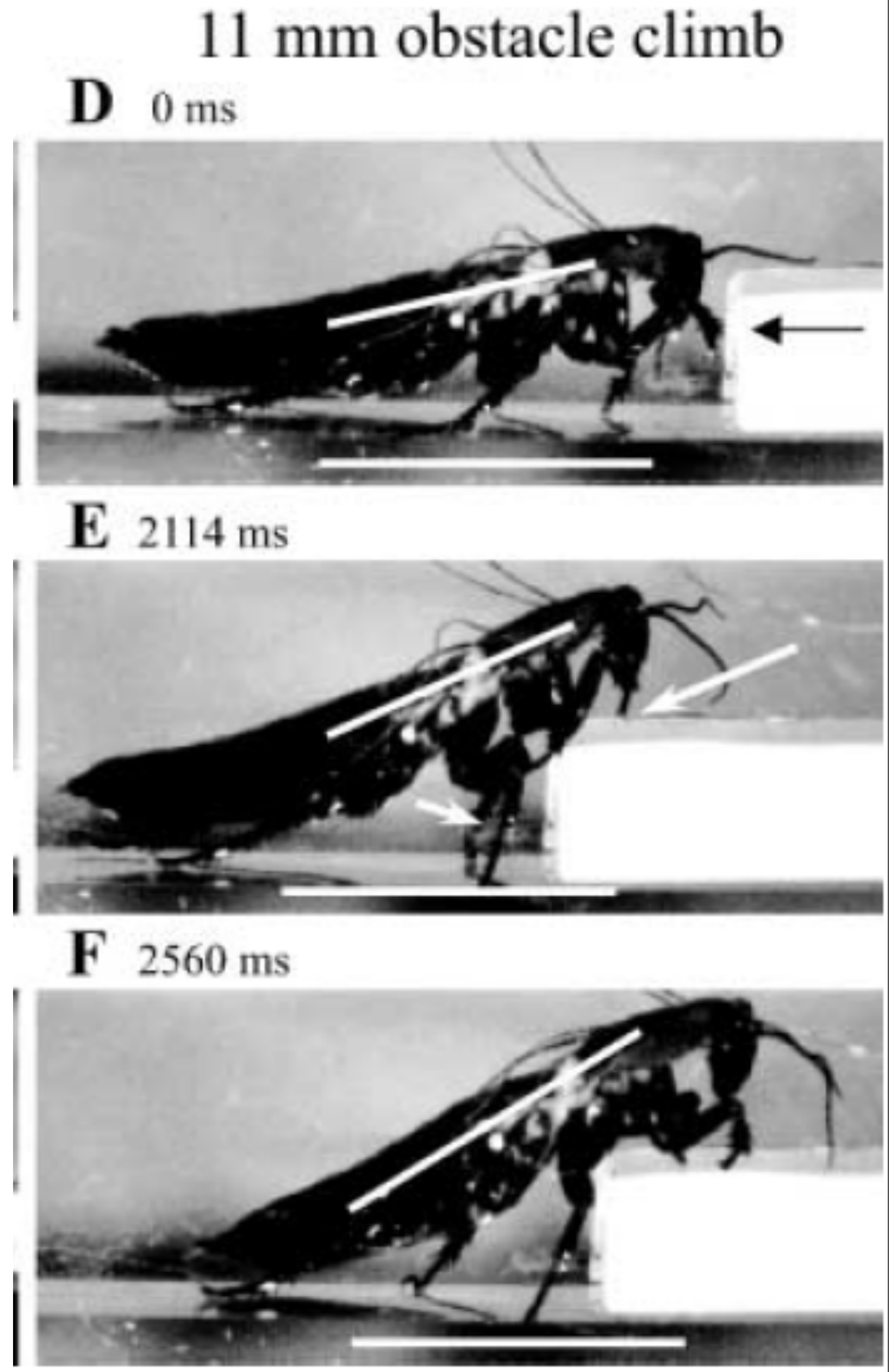
# "Outsourcing" functionality: exploiting morphology

- **brain: 1 Million neurons (rough estimate)**
- **descending neurons: 200 (!)**
- brain:
  **- cooperation with local circuits**
  **- morphological changes (shoulder joint)**




- **Watson, Ritzmann, Zill & Pollack, 2002, J Comp Physiol A**

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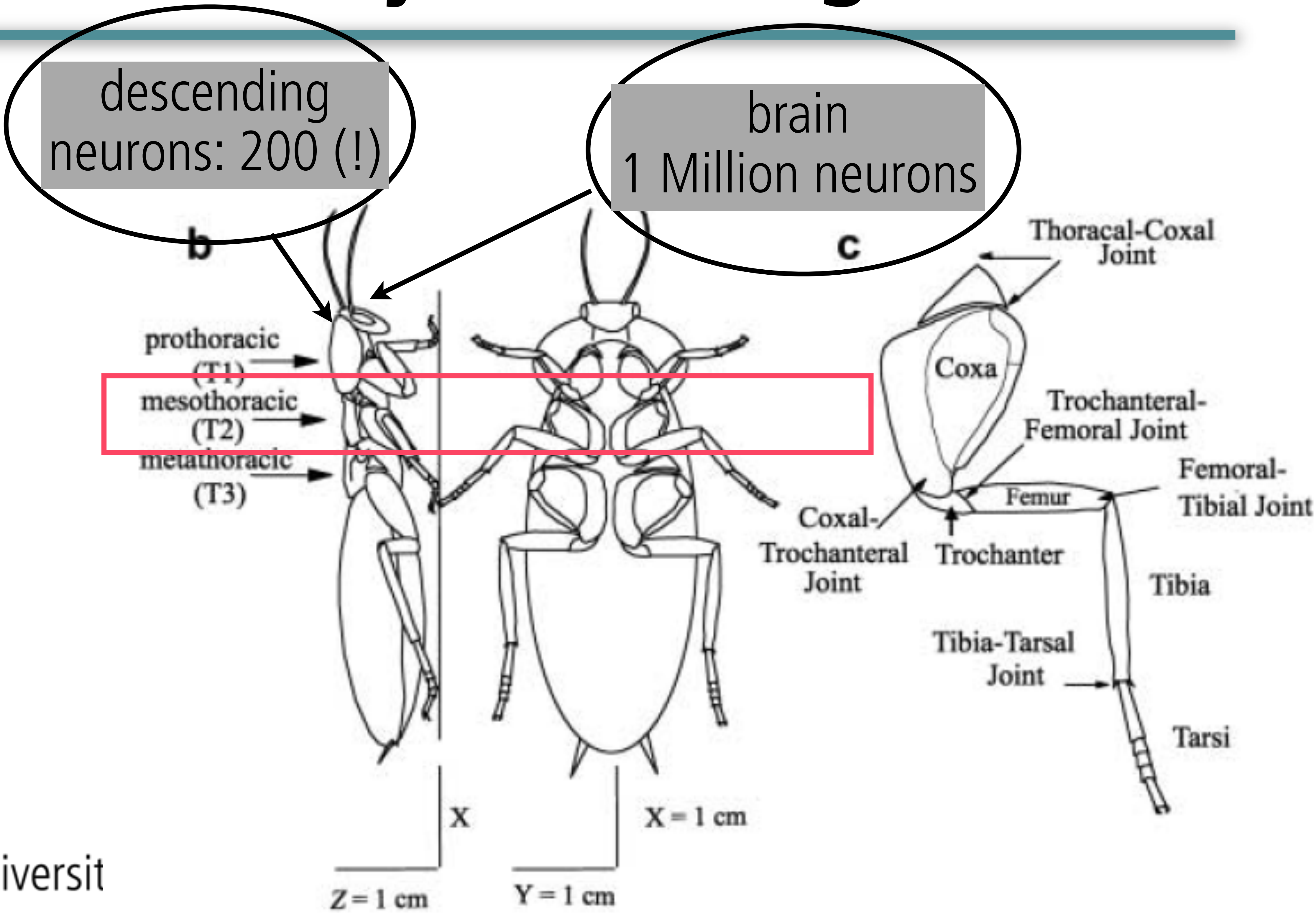
The following considerations are highly speculative but they make, hopefully, a good story about morphological computation.

# Effects of morphology change shoulder joint configuration

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rather than recalculating the joint trajectories: changing the mechanical configuration of the mesothoracic shoulder joint (morphological - global - parameter)

# Climbing over obstacles

- CPG on flat ground
- get hight estimate from antenna
- change configuration of shoulder joint
- CPG continue to function as before (don’t “know” about climbing)
- brain-body cooperation

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because the mechanical configuration of the shoulder joint is changed, even though the local CPGs continue doing the same thing, the effect on behavior will be different

# Climbing over obstacles

- CPG on flat ground
- get hight estimate from an
- 
- re (don
- brain-body cooperation

morphological computation:
**exploiting morphology/**
**materials for control**

research opportunity

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# On the power of materials

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# Specifically: Orchestration of grasping

stably grasping hard object

other manipulation tasks

morphological computation:
**exploiting morphology/ materials for control**

Design and construction: **Koh Hosoda**
**Osaka, University, Japan**

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# Specifically: Orchestration of grasping

research opportunity

**stably grasping ... ect**

**other manipulation tasks**

morphological computation:
**exploiting morphology/ materials for control**

Design and construction: **Koh Hosoda**
**Osaka, University, Japan**

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# The power of materials: The robot fish “Wanda”

design and construction:
**Marc Ziegler, AI Lab, UZH**

**materials**

**changeable stiffness**

**maneuverability in 3D space**

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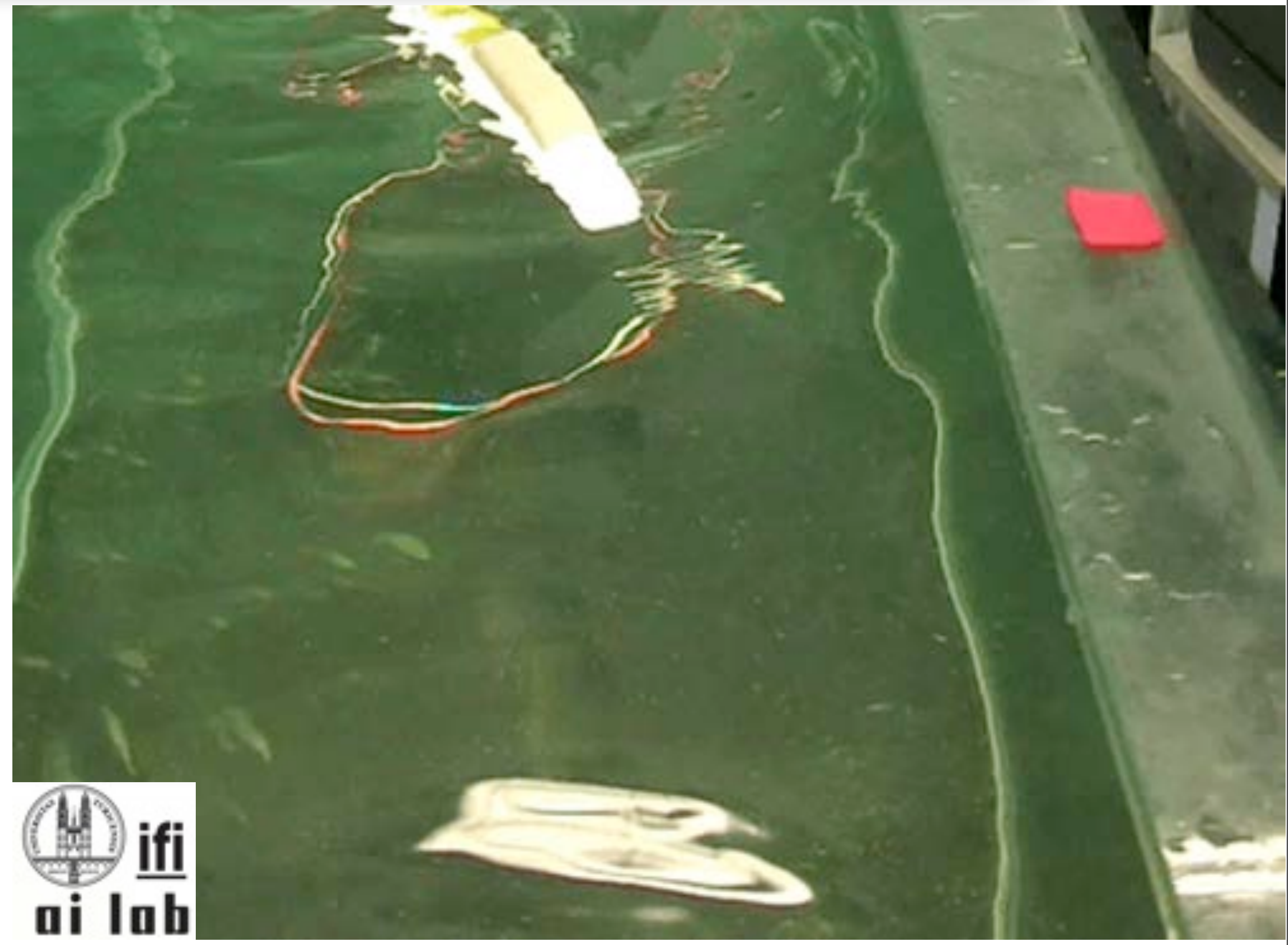


**materials**

**changeable stiffness**

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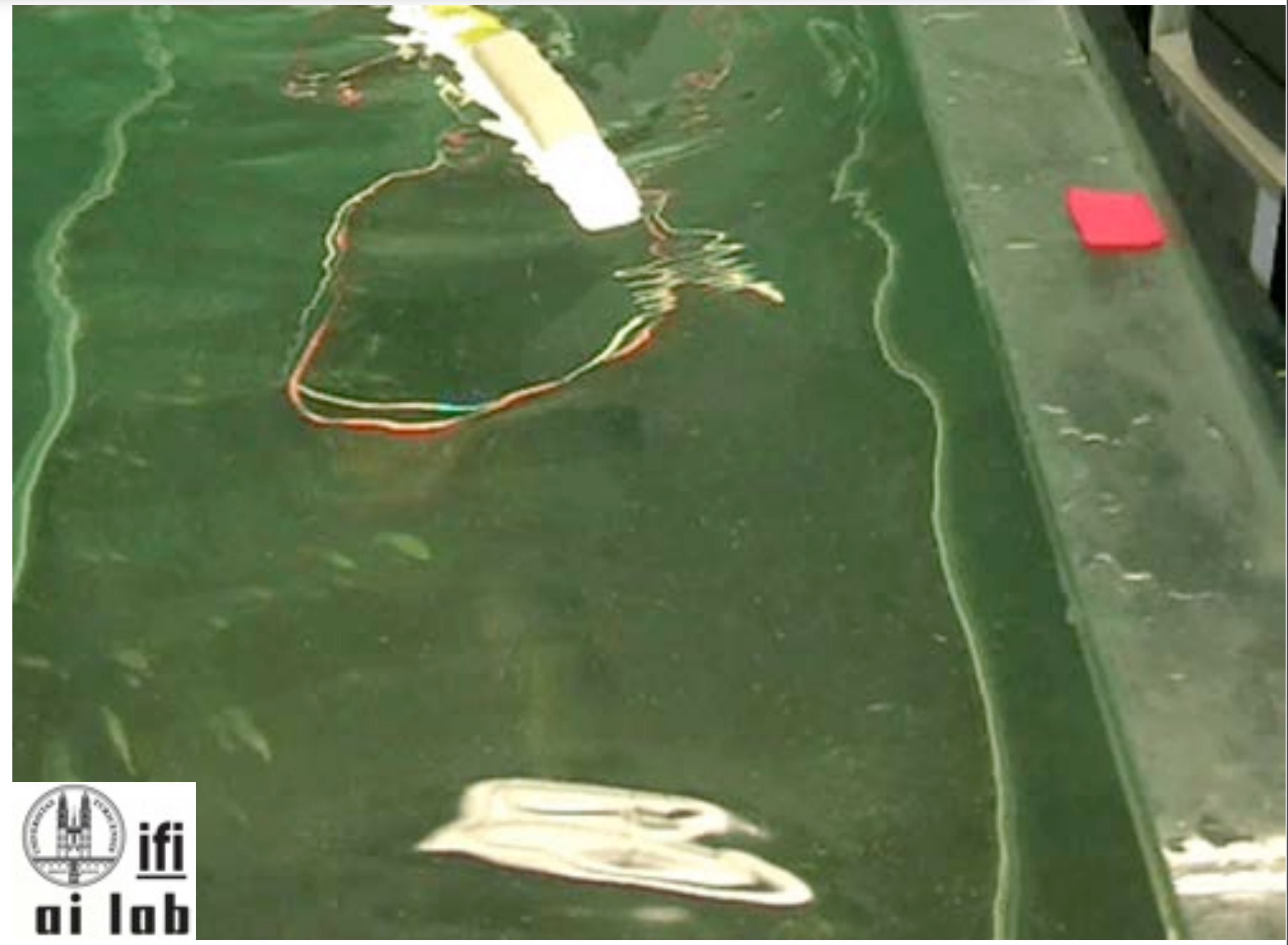
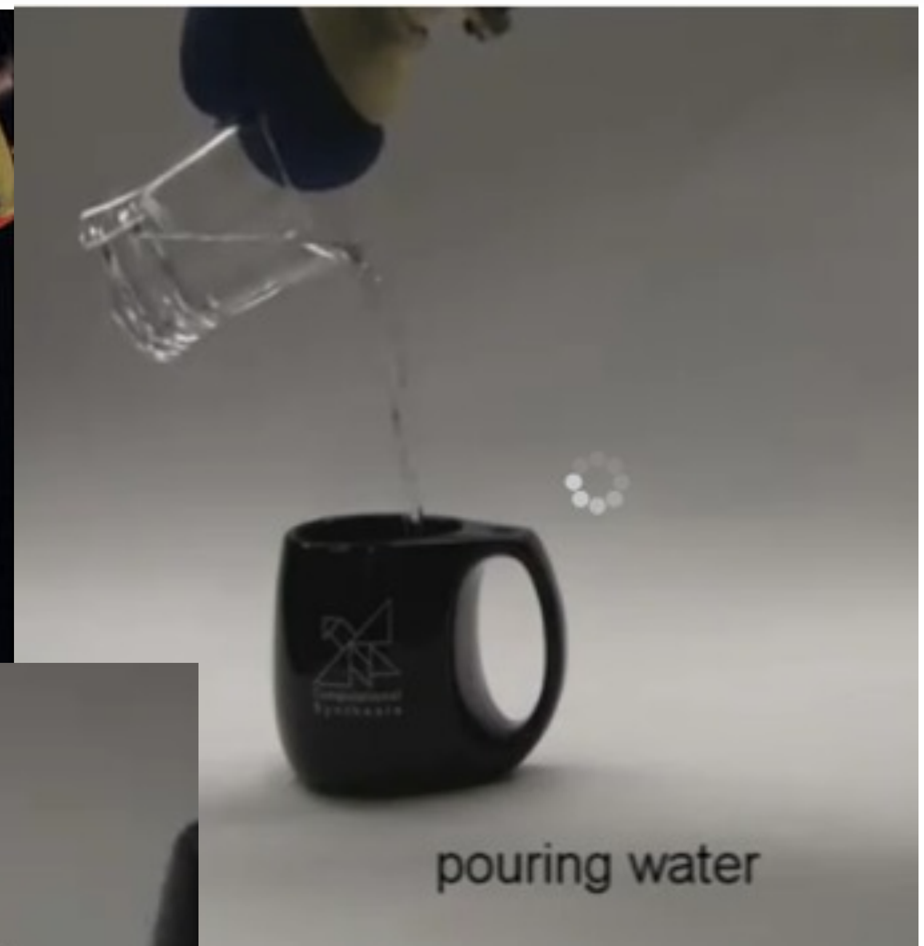
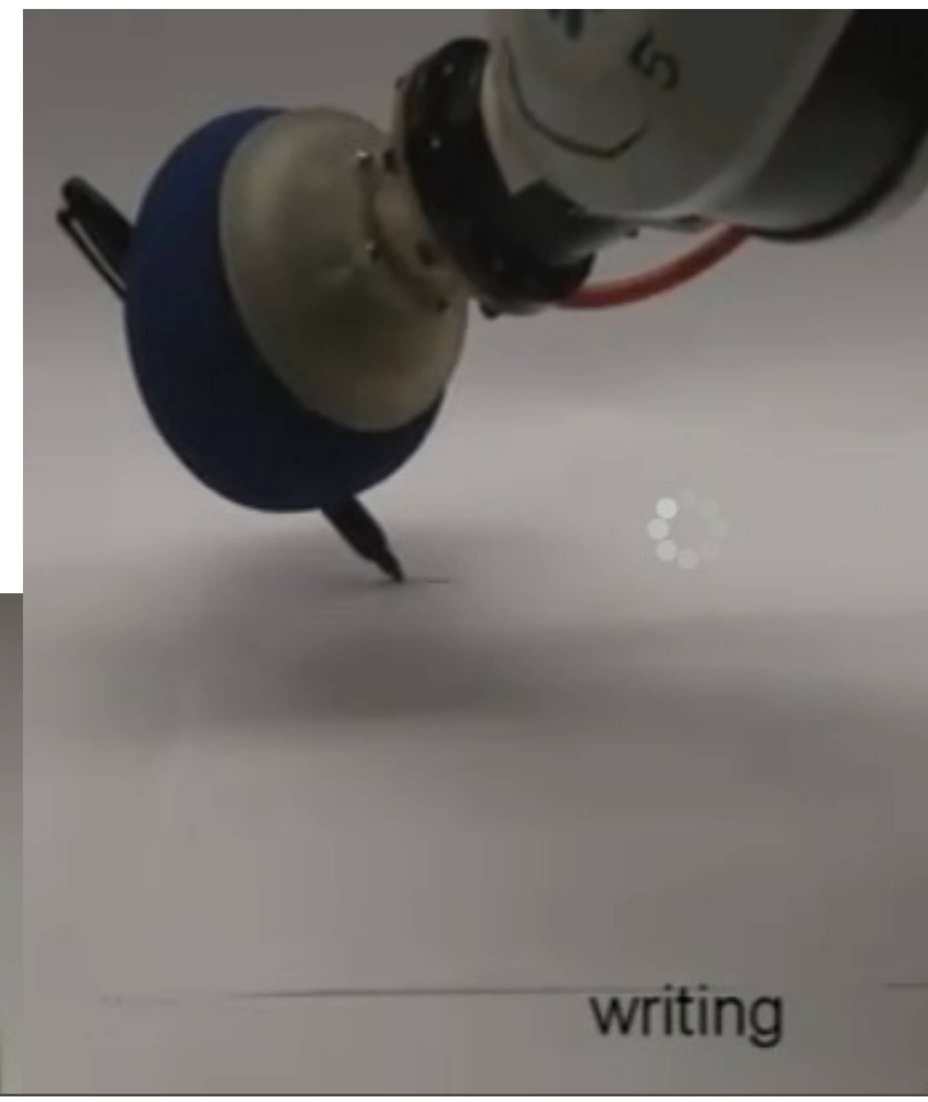
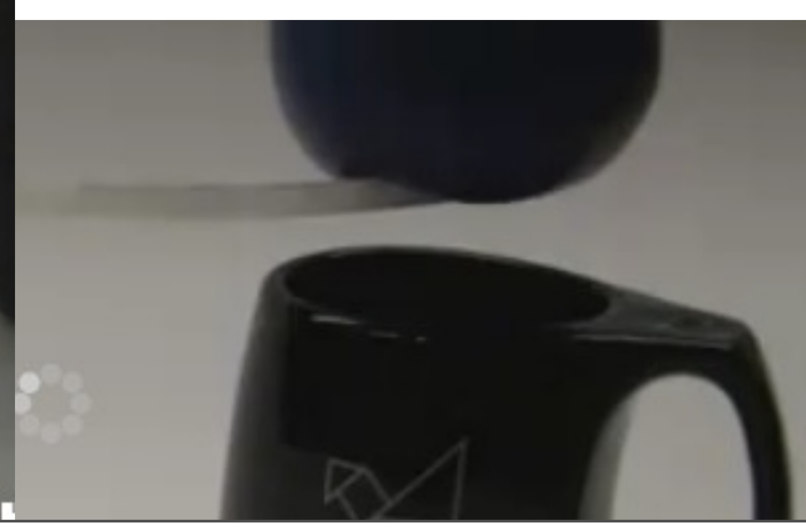


# Jaeger/Lipson "coffee balloon gripper"



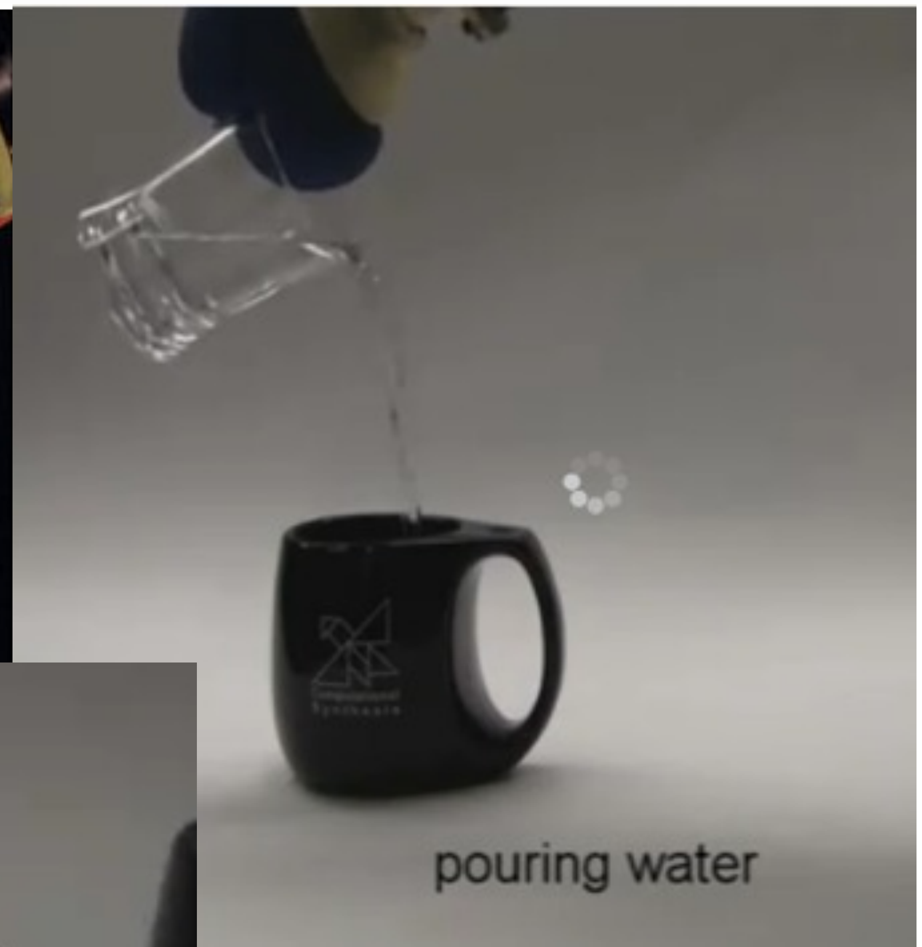




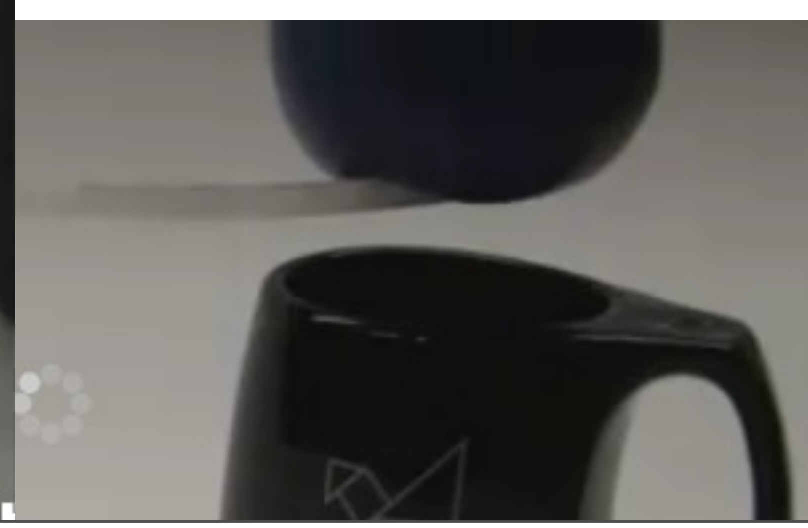


If you buy ground coffee in a supermarket, because of the vacuum, it will be hard like a rock. If you open it, it will get very soft.
The global control parameter is the hardness of the sack - this can be manipulated through a vacuum pump: soft when balloon adapts to shape of object, hard when it has to pick it up (apply vacuum pump to increase stiffness of material).

# Jaeger/Lipson "coffee balloon gripper"







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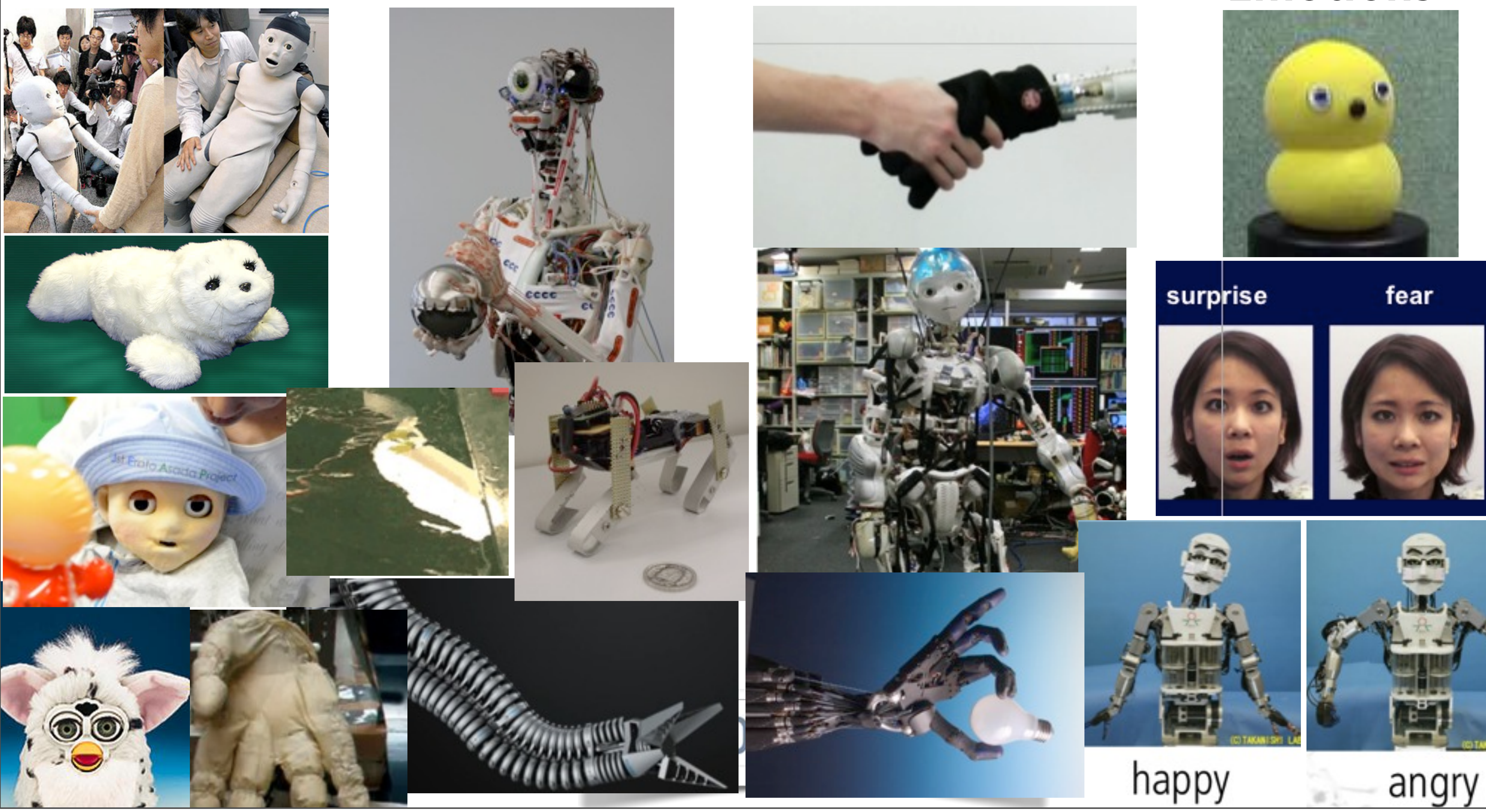
# "Soft Robotics"

## Soft to touch

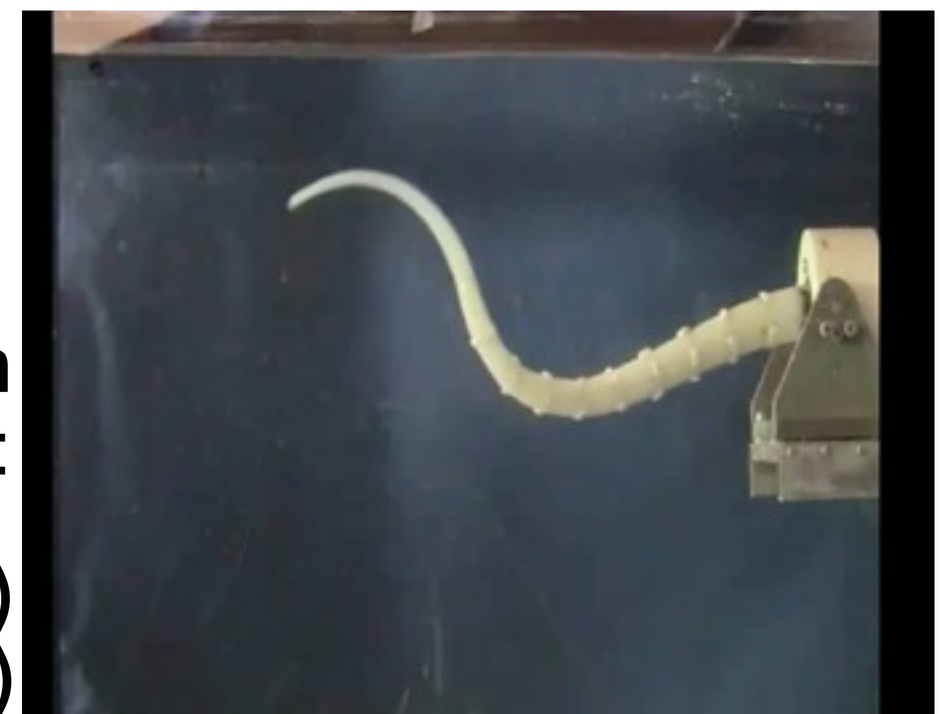
## Soft movement

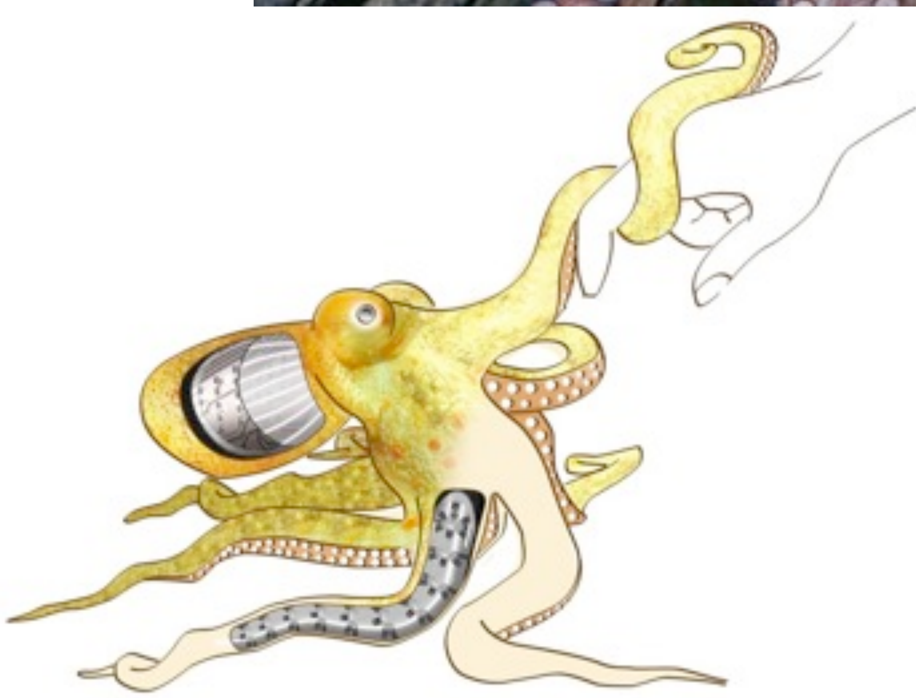
## Soft interaction

## Emotions



# Exploiting materials: Octopus (EU Project)





**Octopus Arm**
Design and construction:

**atteo Cianchetti (SSSA)**
**Cecilia Laschi (SSSA)**
**Tao Li (UZH)**
**een Kuppuswami (UZH)**

nal
ompetence

# Octopus Armbewegungen

**Octopus Arm**
Design and construction:

**Matteo Cianchetti (SSSA)**
**Cecilia Laschi (SSSA)**

control:

**Kohei Nakajima (AI Lab)**
**Tao Li (AI Lab)**

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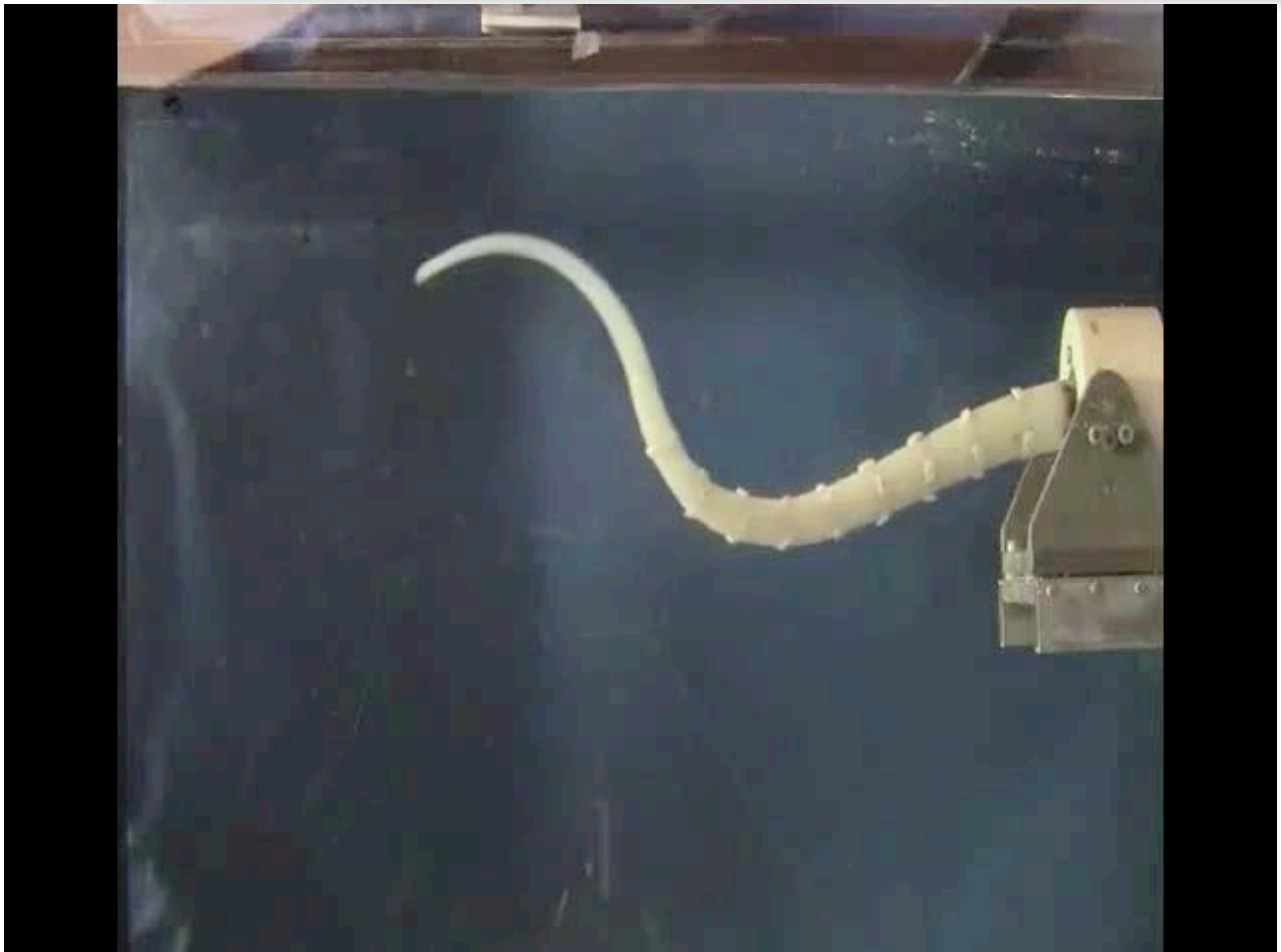
movements of a first prototype arm

# Octopus Armbewegungen



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movements of a first prototype arm

# Grasping a bottle

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control:

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movements of a first prototype arm

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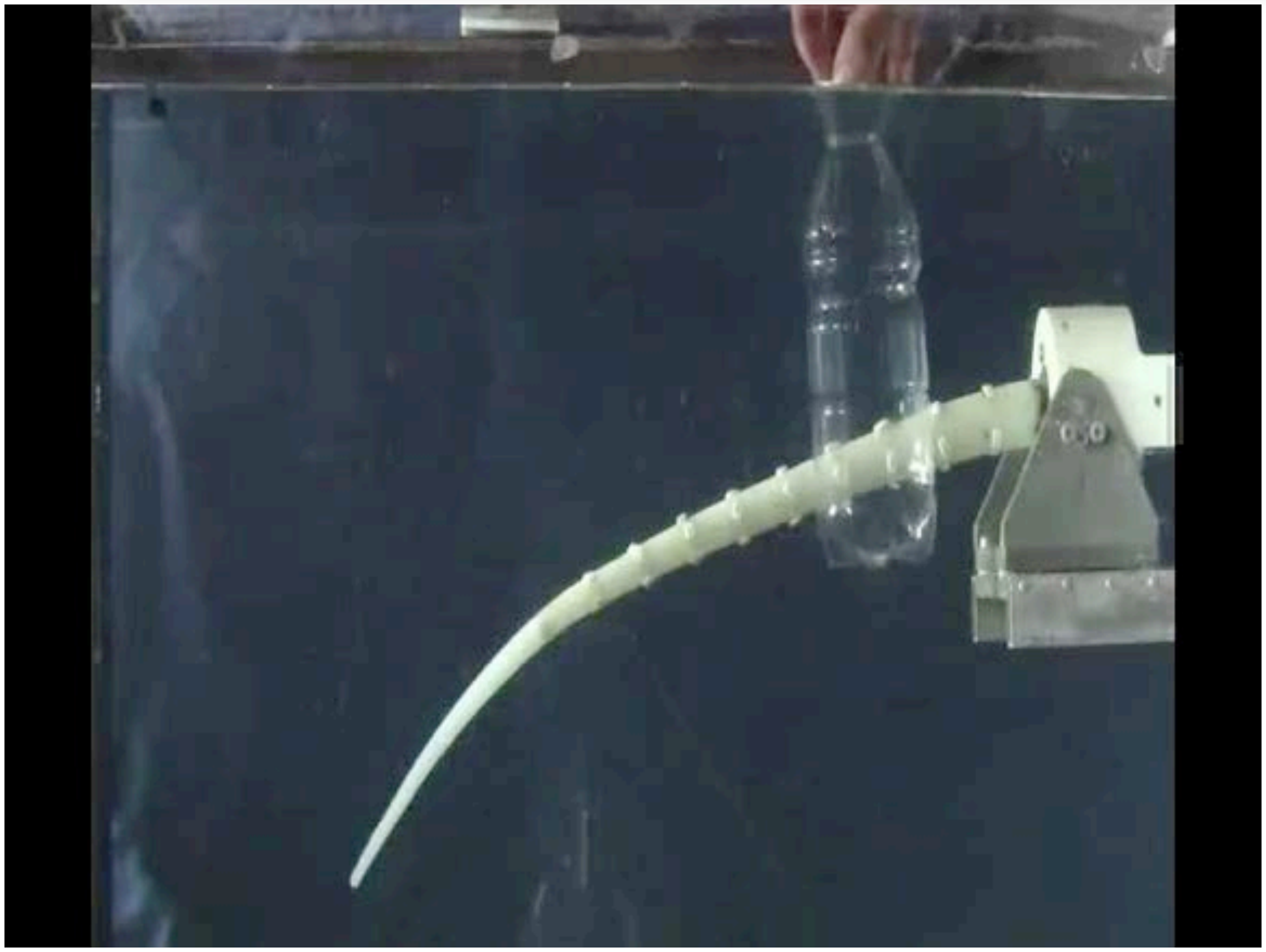

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movements of a first prototype arm

# Grasp... a bottle

research opportunity

**Octo...**
Design an...

**Matteo Cianche...**
**...schi (SSSA)**

**systems with infinitely many DOFs (continuous)**

**...kajima (AI Lab)**
**... Lab)**

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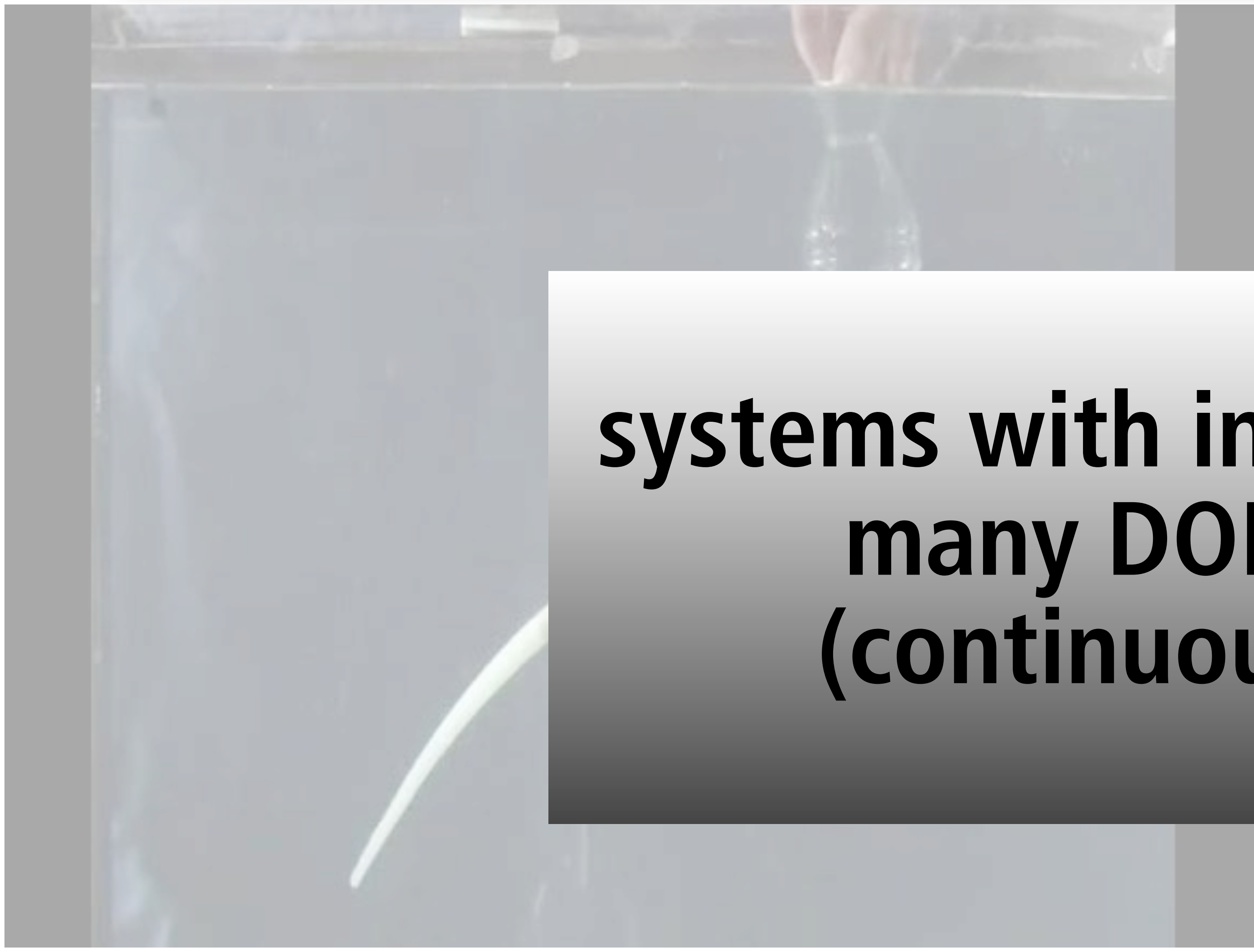
movements of a first prototype arm

# Grasp a bottle

research opportunity



**Octo**
Design and

**Matteo Cianchet**
**schi (SSSA)**

**kajima (AI Lab)**
**Lab)**

**systems with infinitely many DOFs (continuous)**

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movements of a first prototype arm

# Modular robots: emergence of structure and functionality

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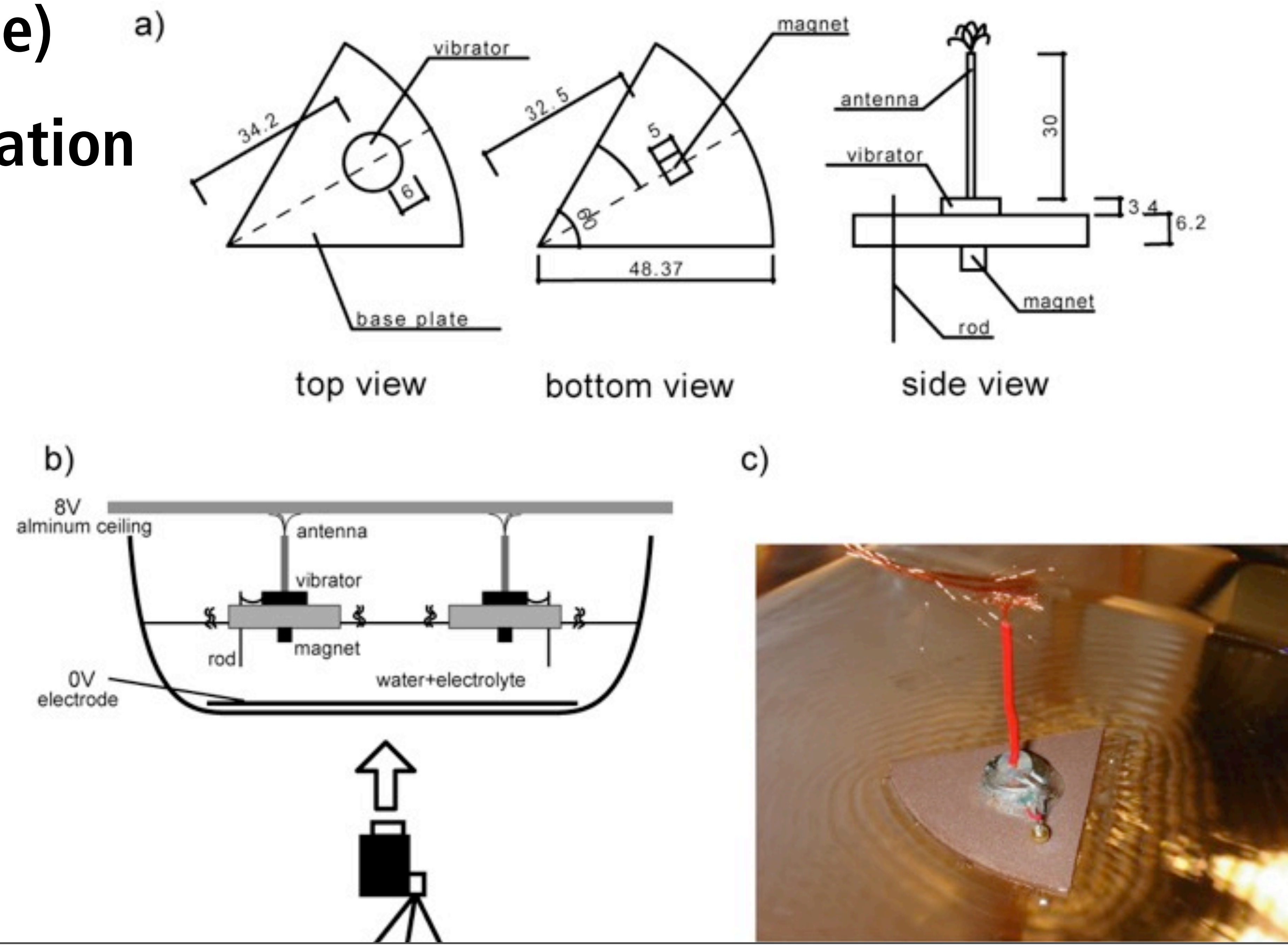
# Self-assembly
# Shuhei Miyashita’s “Tribolons”

- **light, swimming on water (electrolyte)**
- **magnet and vibration motor**
- **“pantograph”**

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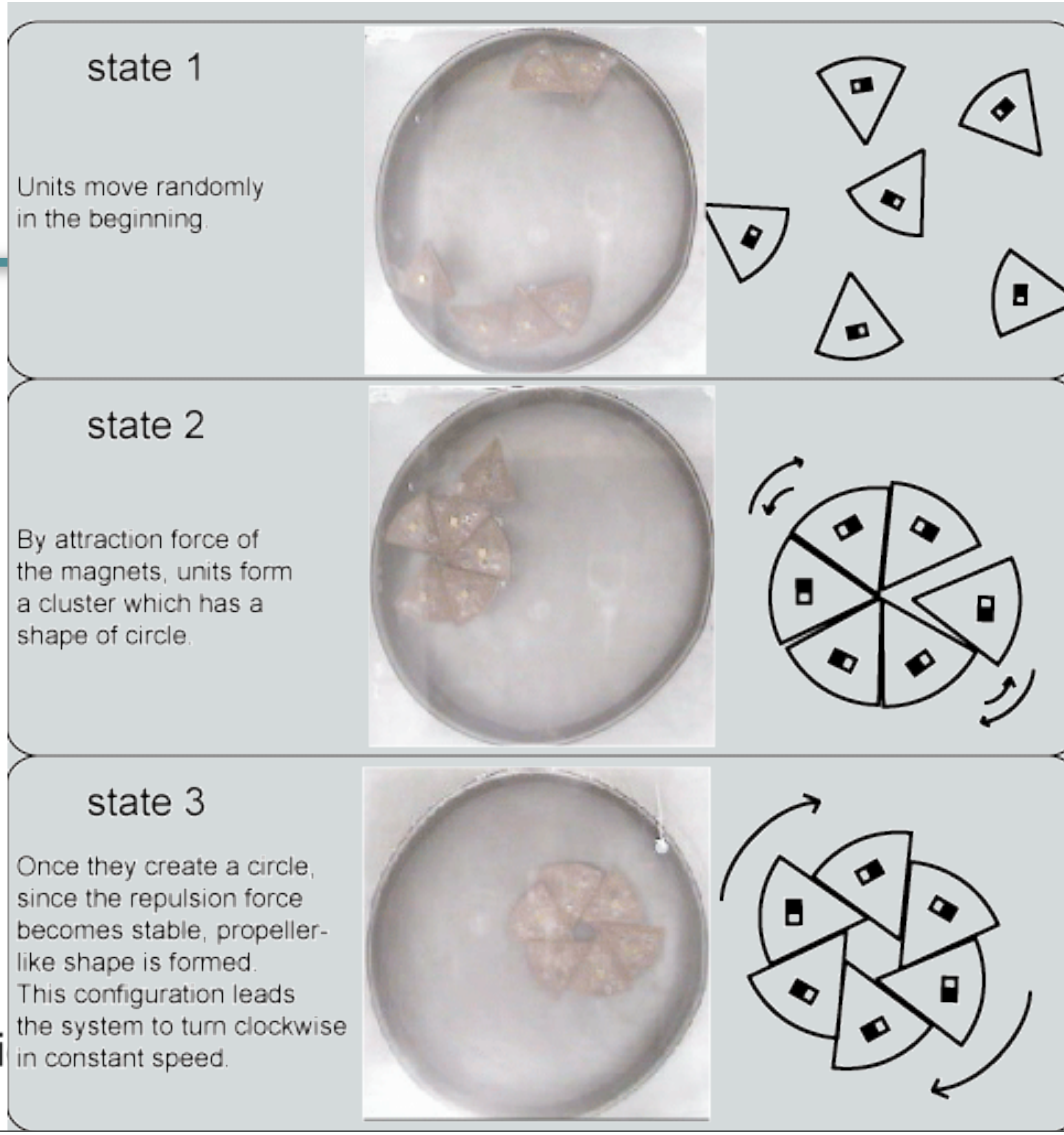
# "Pizza" self-assembly




University of Zuri

# "Pizza" self-assembly

Design and construction:
Shuhei Miyashita, AI Lab, UZH and CMU

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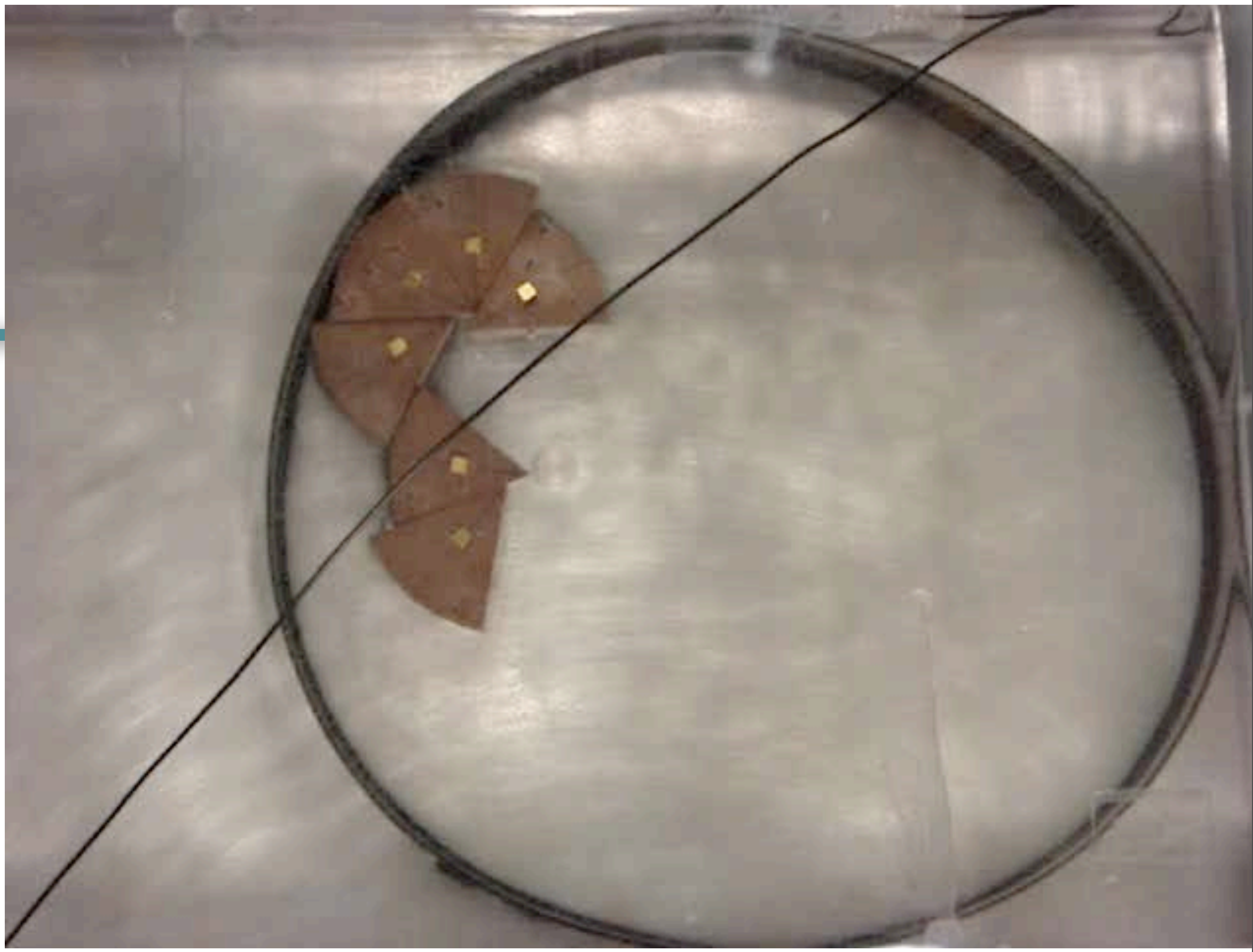
In this example, there is emergent functionality. Even though the individual tiles don't rotate, the structure as a whole will. As can be clearly seen from the videos, the global structure is the result of a dynamic equilibrium, i.e. the structure is continuously moving.

# "Pizza" self-assembly



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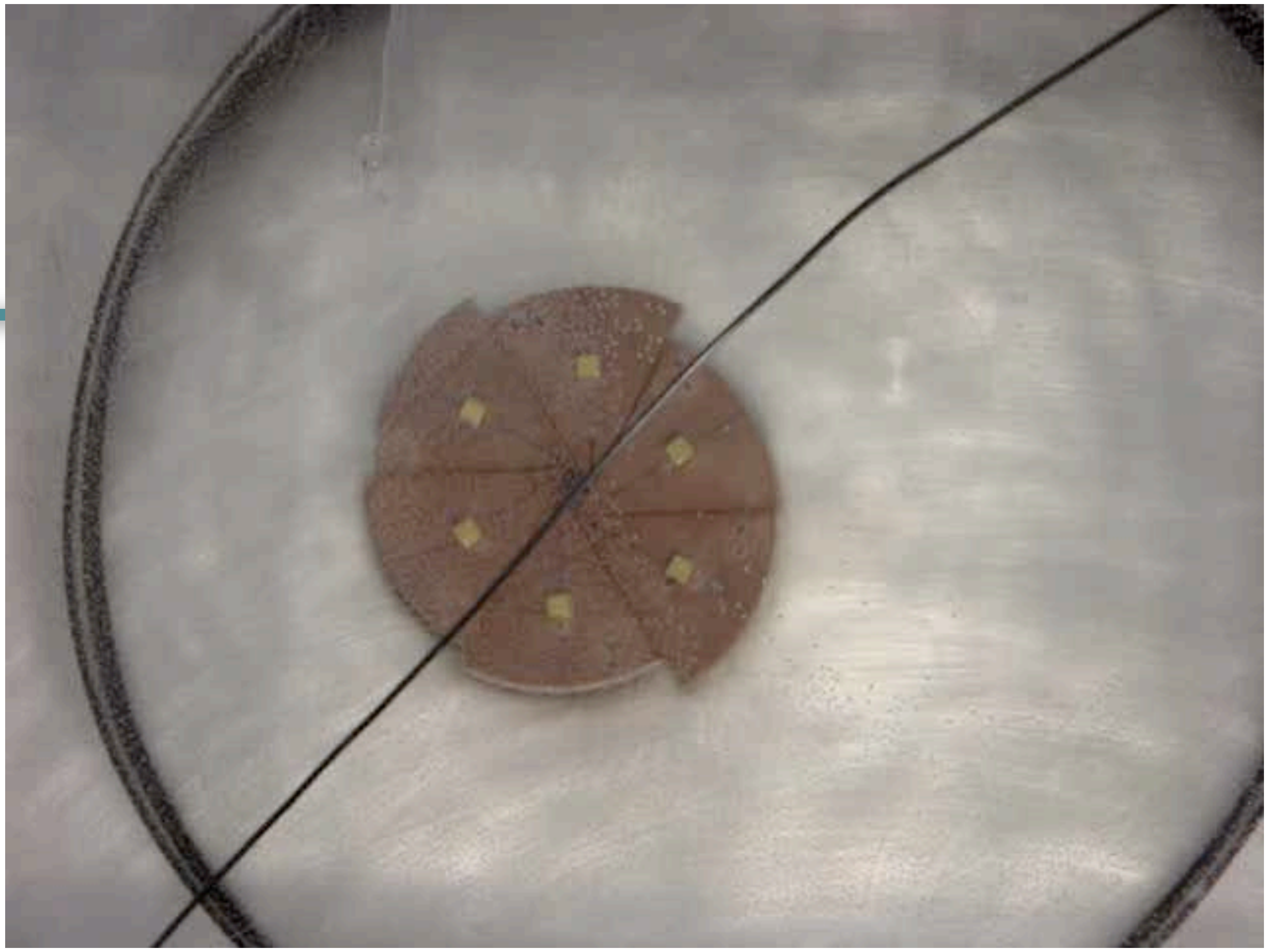

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# "Pizza" self-assembly

research opportunity

**self-assembly/reconfiguration**
**at different scales**
**mechanisms and principles**

Design and construction:
Shuhei Miyashita, AI Lab, UZH and CMU

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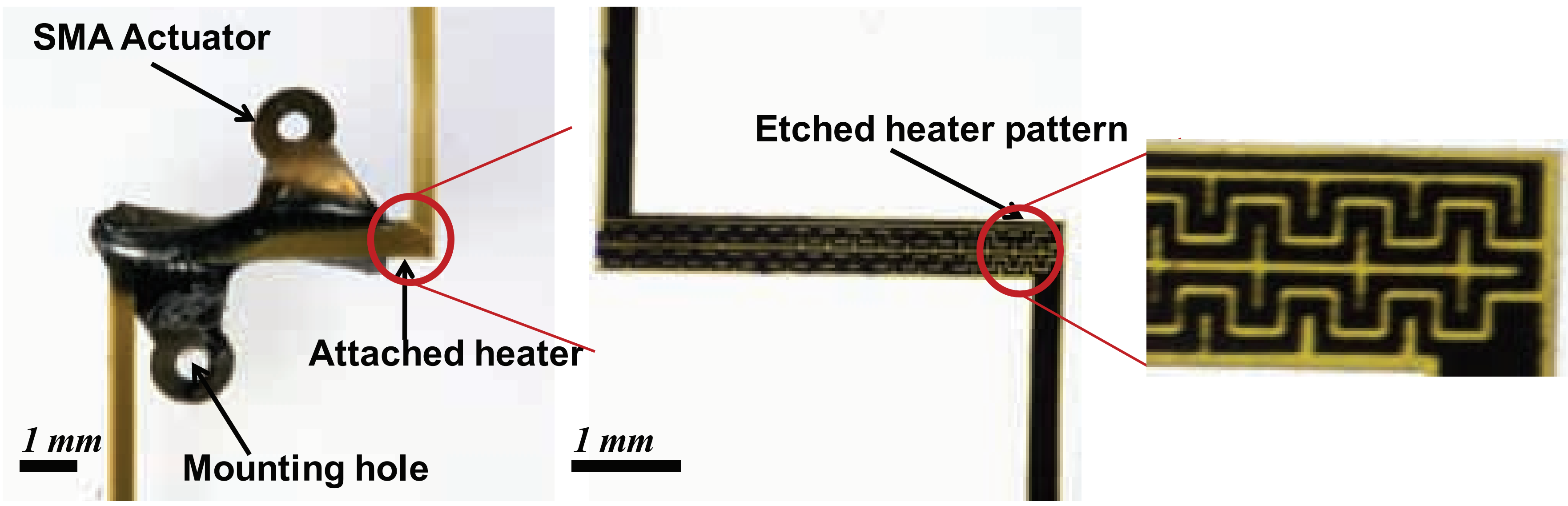
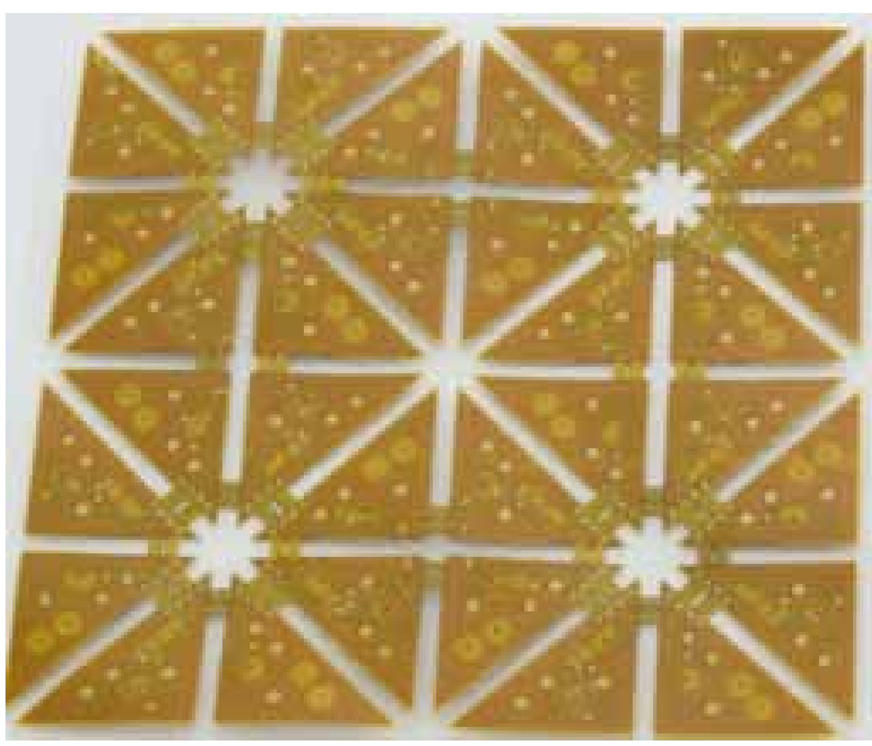
In this example, there is emergent functionality. Even though the individual tiles don't rotate, the structure as a whole will. As can be clearly seen from the videos, the global structure is the result of a dynamic equilibrium, i.e. the structure is continuously moving.

# Self-morphing modular robots (Paik et al.)



66

# Connection mechanisms for soft modular robots (Germann et al.)

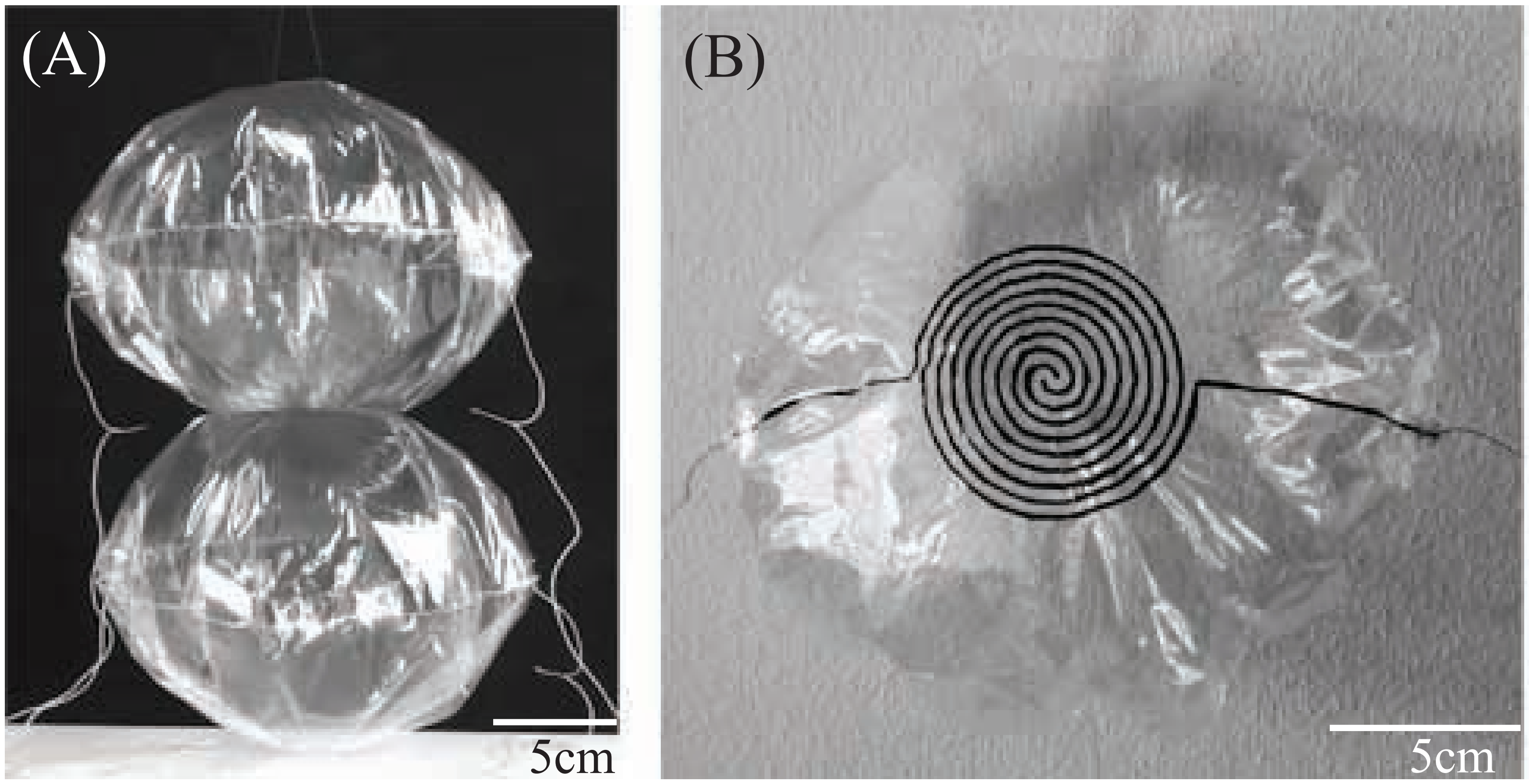
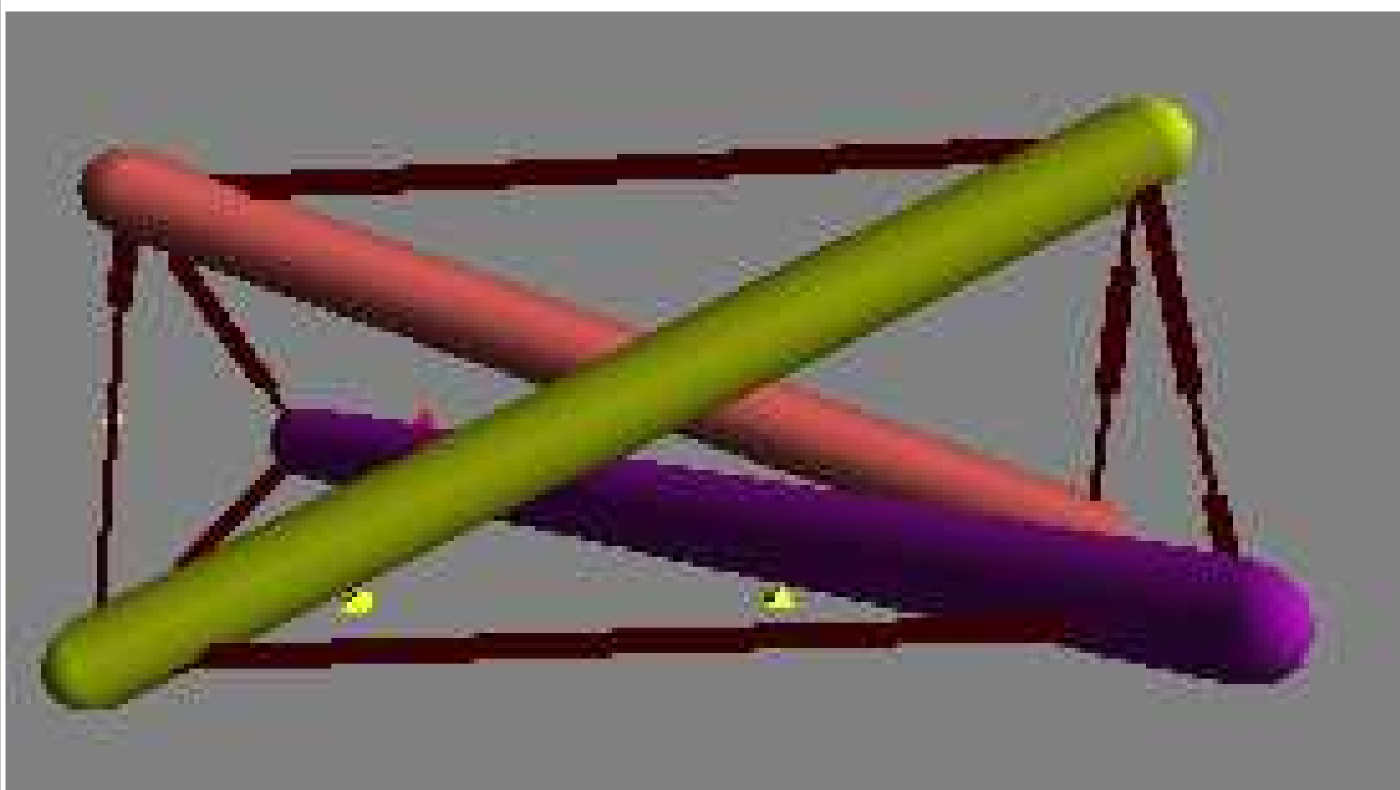



Figure 2. Fabricated prototype: (A) two modules connected together, (B) the module has a diameter of 18cm and weighs 1.5g, the pad has a radius of 3.9cm and the electrode and gap width are 2mm.

# Hod Lipsons modular "tensegrity" robot

information transmission through tensions in strings



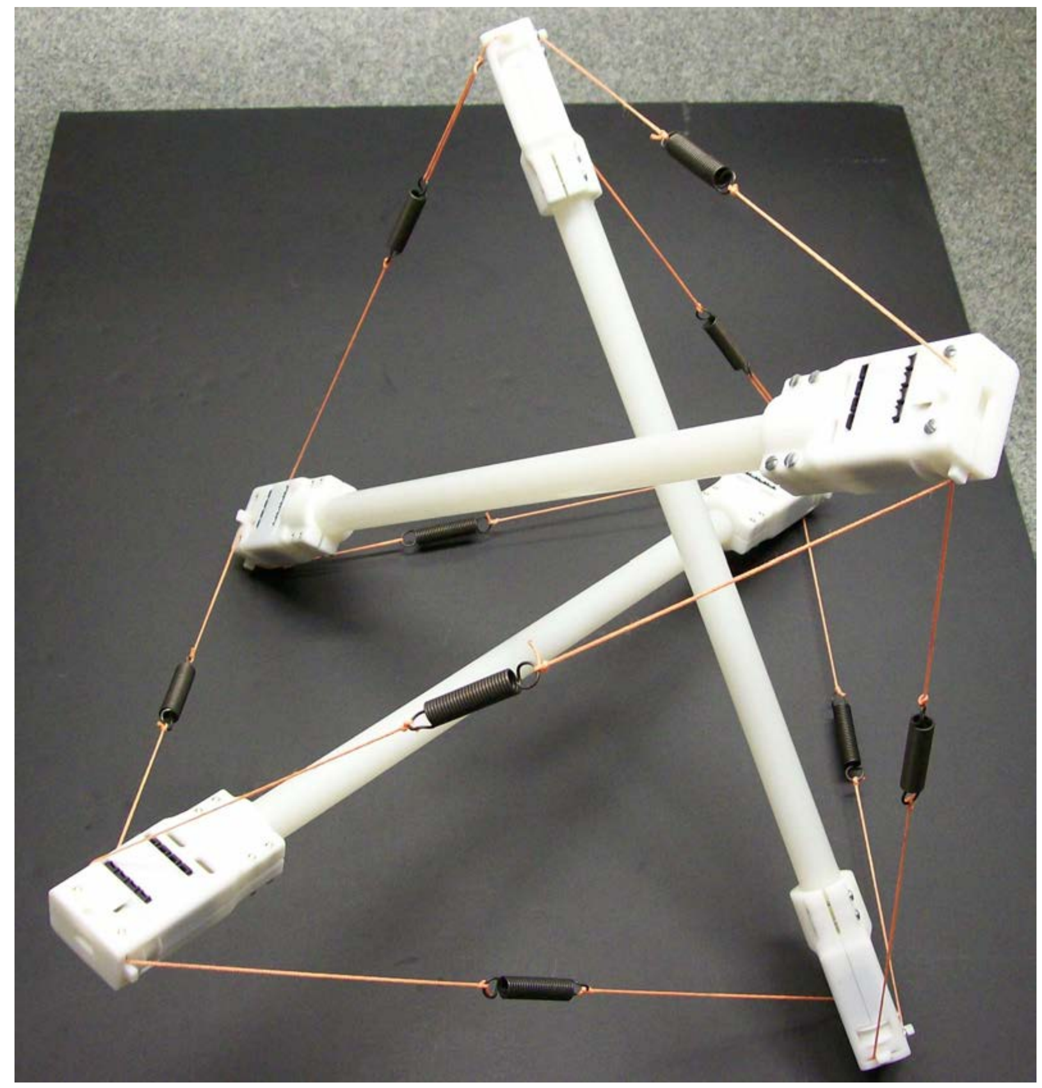


Figure 6: The fully assembled modular tensegrity robot

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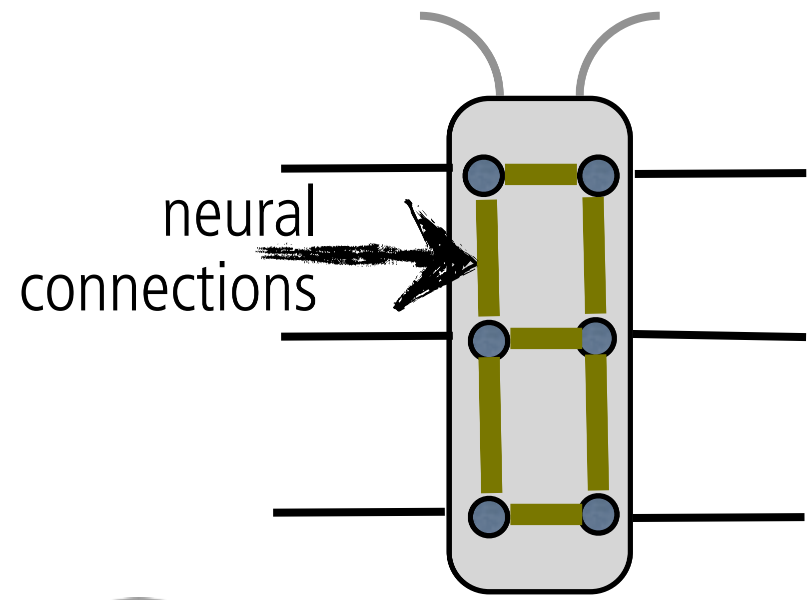
# Insect walking: Information transmission through interaction

Holk Cruse, German biologist

- **no central control for leg-coordination**
- **only communication between neighboring legs**

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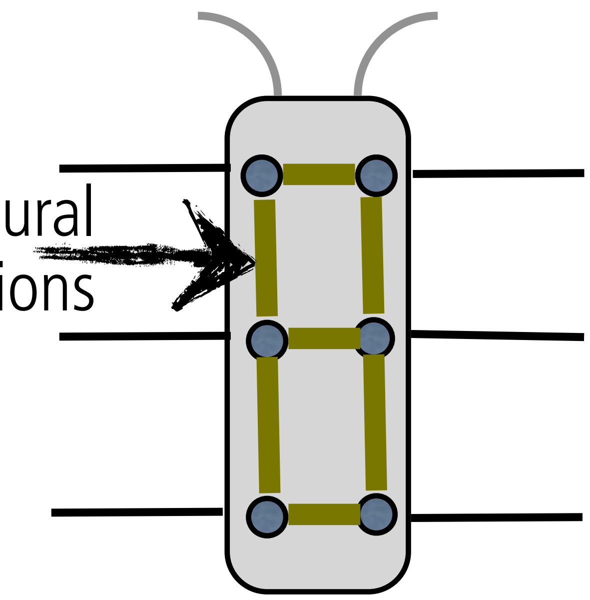
# Insect walking




Holk Cruse, German biologist

- **no central control for leg-coordination**
- **only communication between neighboring legs**
- **global communication:**

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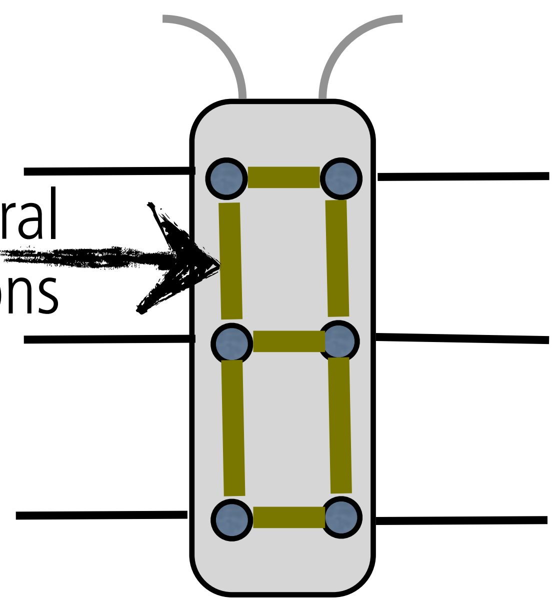
# Insect walking




Holk Cruse, German biologist

- **no central control for leg-coordination**
- **only communication between neighboring legs**
- **global communication: through interaction with environment**

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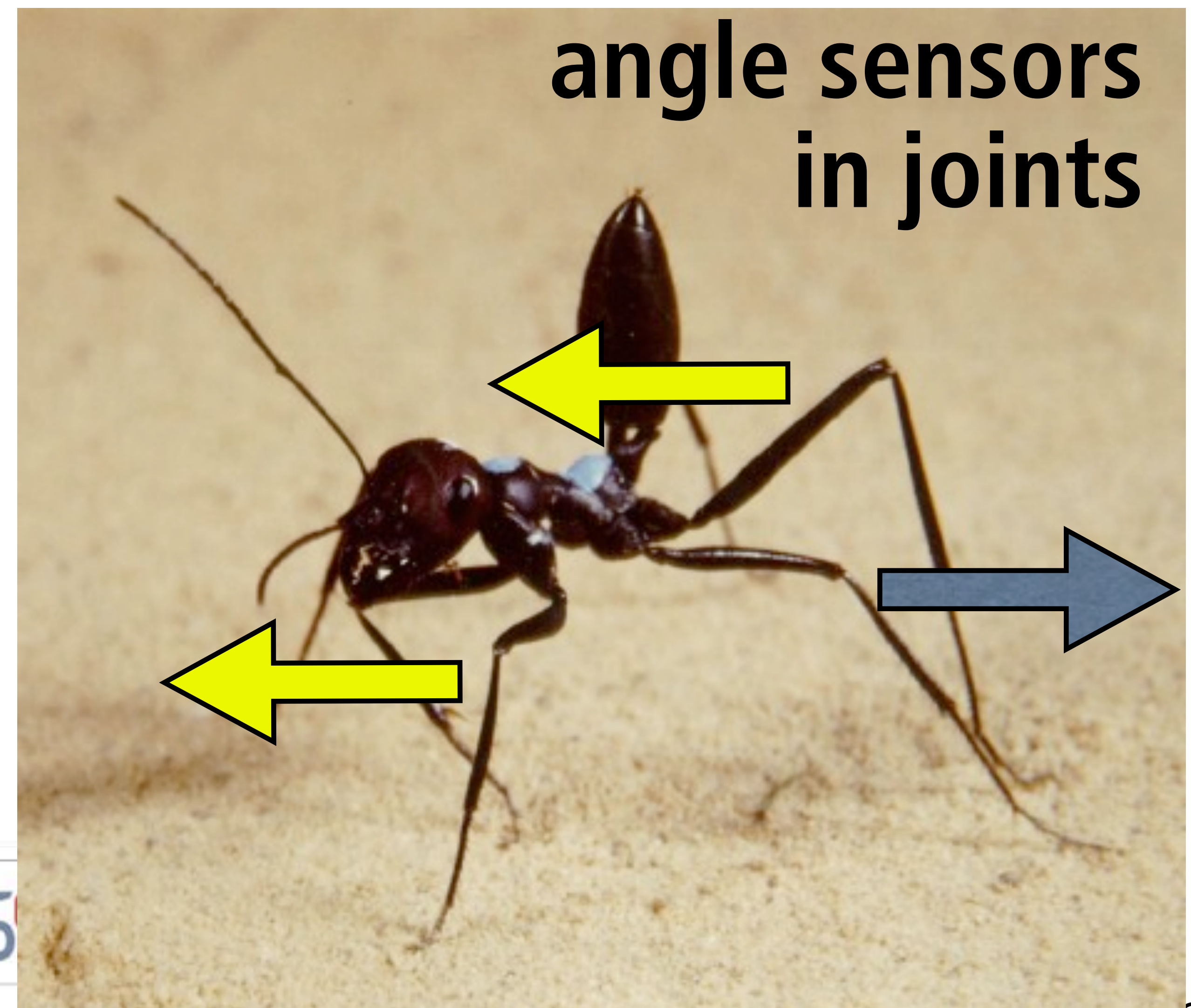
# Communication through interaction with environment

- exploitation of interaction with environment

→ simpler neural circuits

**morphological computation**



# Spectrum of morphological computation

- fully embodied **(e.g. self-assembling vesicles / molecules, passive dynamic walker, "Stumpy", "Puppy")**
- embodied computation, digital result **- need for read-out process (e.g. DNA computing, molecular computing; reservoir computing)**
- digital computation, embodied result **(e.g. evolutionary optimization of chemical systems; PACE "life support system")**

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Fully embodied: here the desired functionality is the behavior of the system itself, irrespective of whether we consider the body as computing or not. However, the "computation" of the body can be exploited (e.g. to produce certain information about the environment, for example, the steepness of the terrain in "Puppy").

There has to be a readout process that can be viewed as the translation of the physical state of the system back to its digital interpretation in terms of the original – digital – problem. The standard computational problems – unusual (physical) computational process.

# Embodied computation - digital result

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# Reservoir computing

- Echo-state networks
- Liquid-state machines
- Spring-mass models
- Physical substrates

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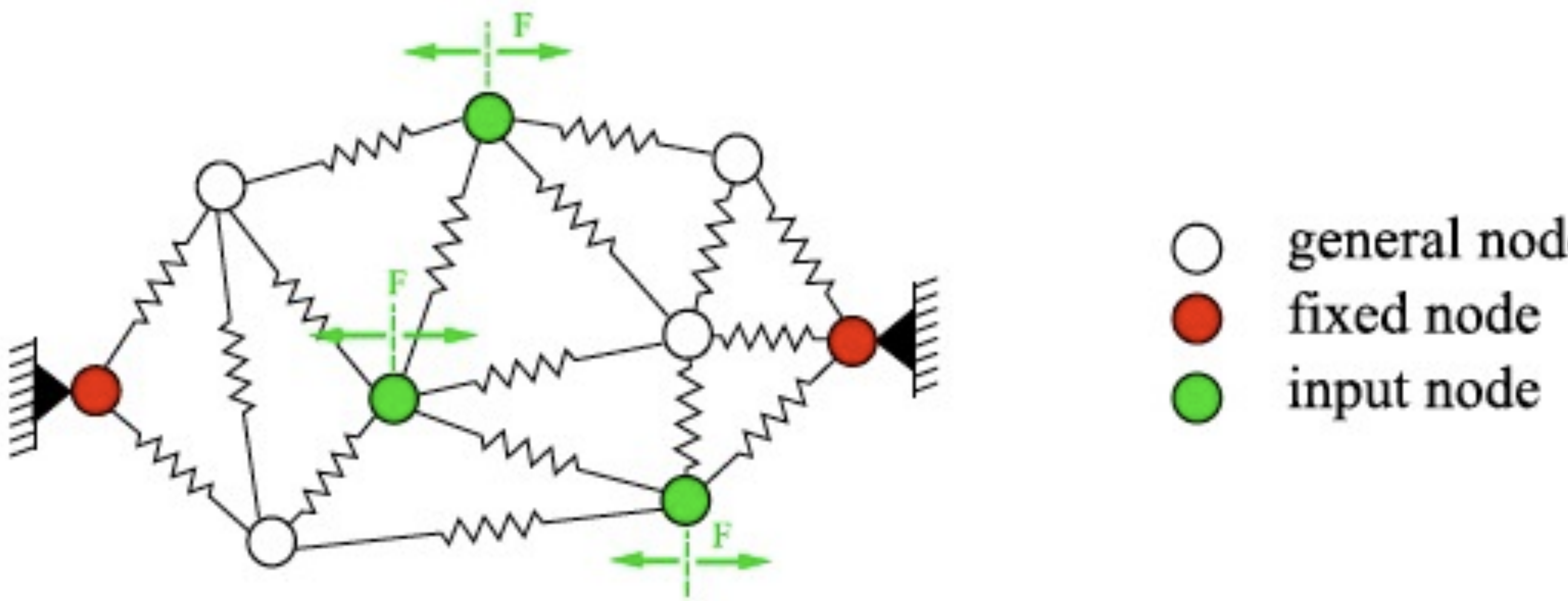
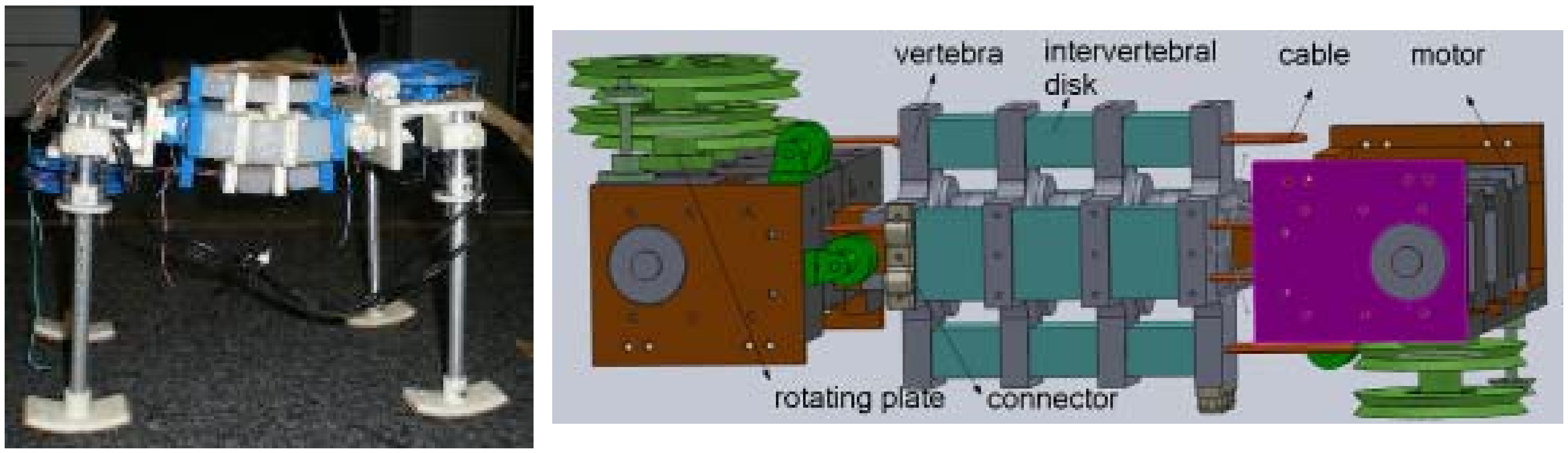
# Mass-spring models



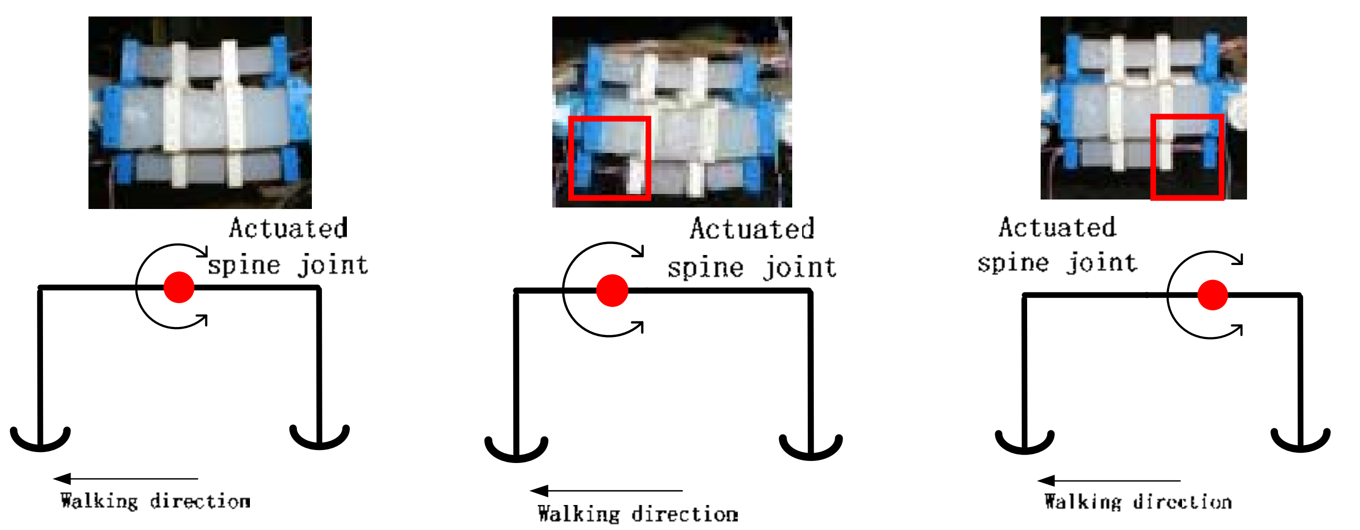

**Hauser, Ijspeert, Fuechslin, Pfeifer, Maas, "The role of feedback in MC"**

# Effect of robot morphology on locomotion (spine) (Zhao/Sumioka)



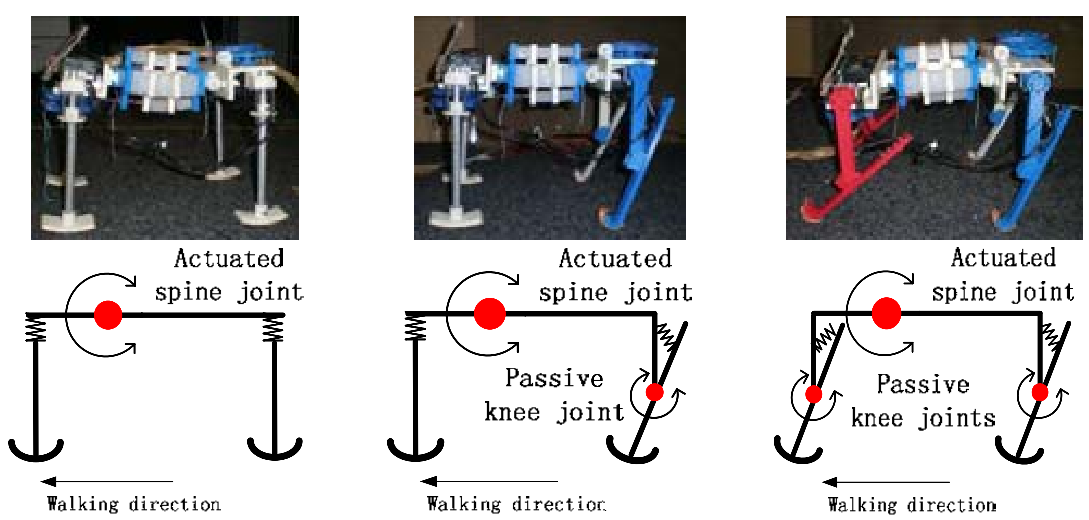

(a) (b)

Fig. 1: The robot structure (a) and its spinal structure (b).




(a) SM1 (b) SM2 (c) SM3

Fig. 2: Robot equipped with spine whose virtual joint is in the middle (a), front (b) and the rear (c) part of the body. The red square highlights the area where the silicon block is taken out.




(a) LM1 (b) LM2 (c) LM3

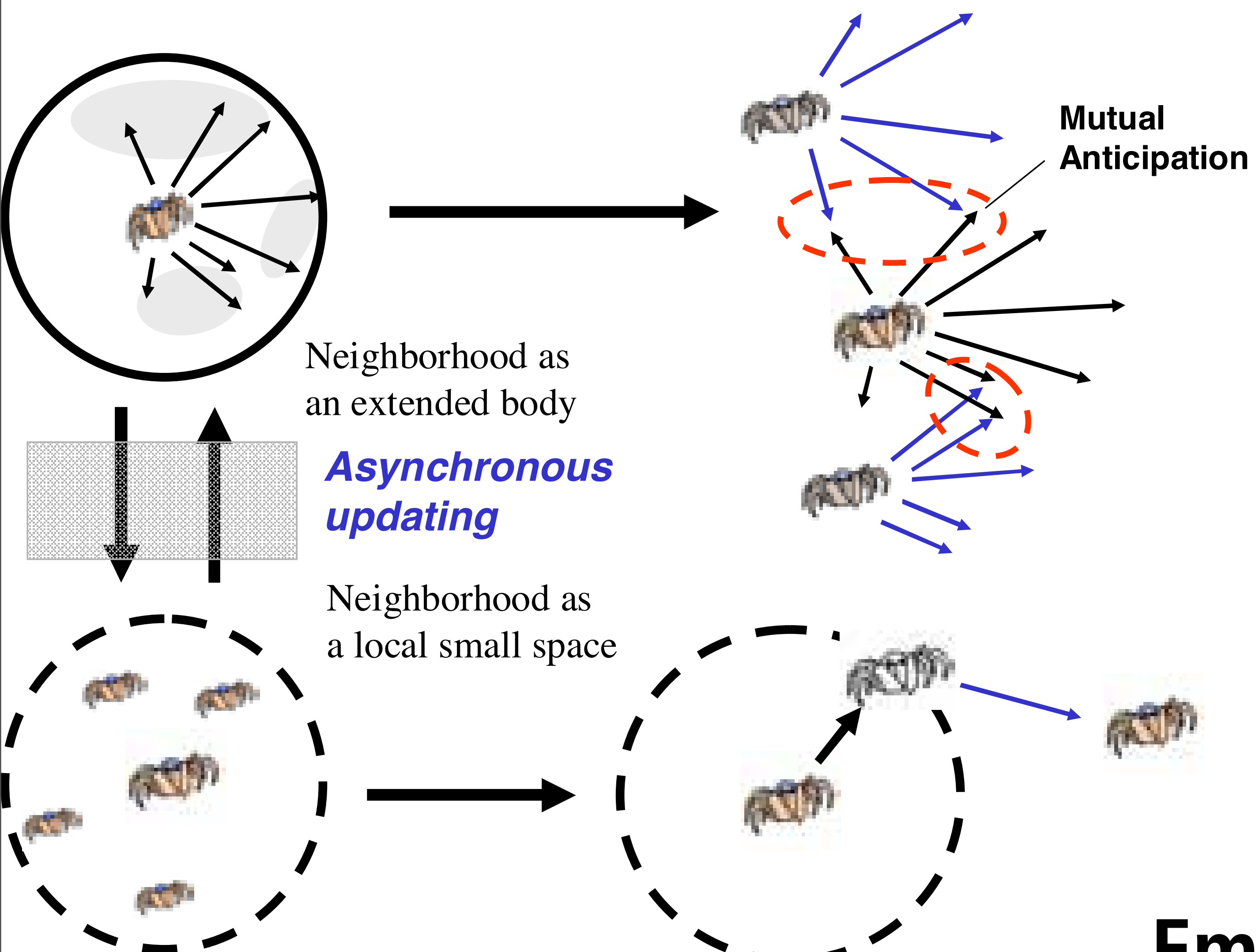
Fig.3: Leg configuration: LM1 with all stick-shaped legs (a); LM2 with stick-shaped fore legs and rear legs with springy passive joint (b); LM3 with all springy-passive-joint legs.



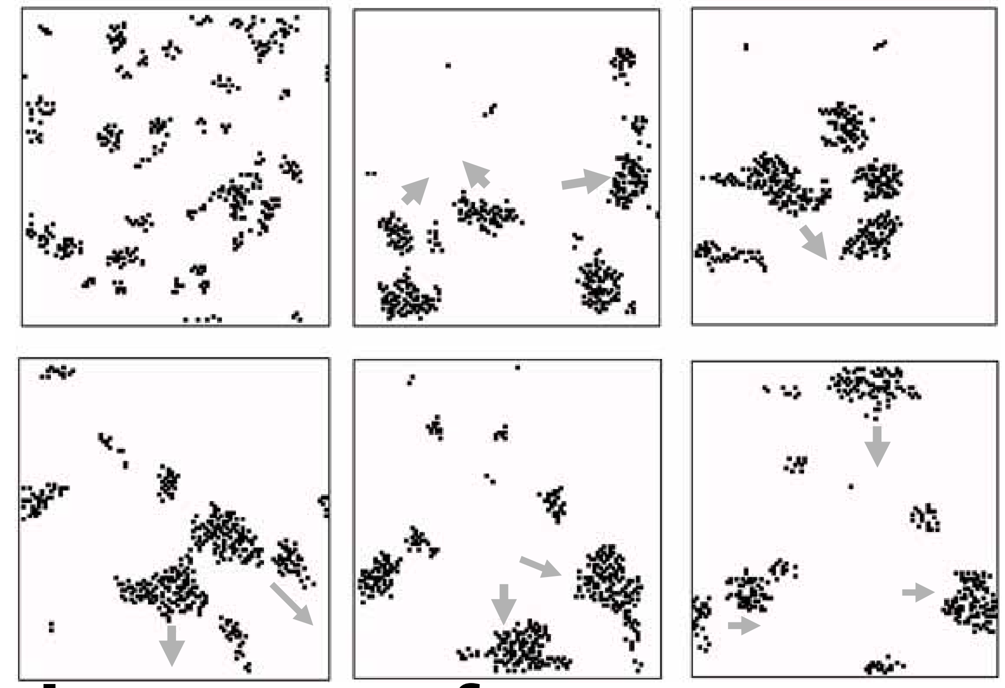
The spine, on the one hand, provides important functionality, and on the other it is the reservoir for morphological computation. Flexible spine used as “reservoir” for “computation”, but at the same time providing the desired functionality.

# Additional examples

# Emergent body of swarm (Gunji, Adamatzky et al.)

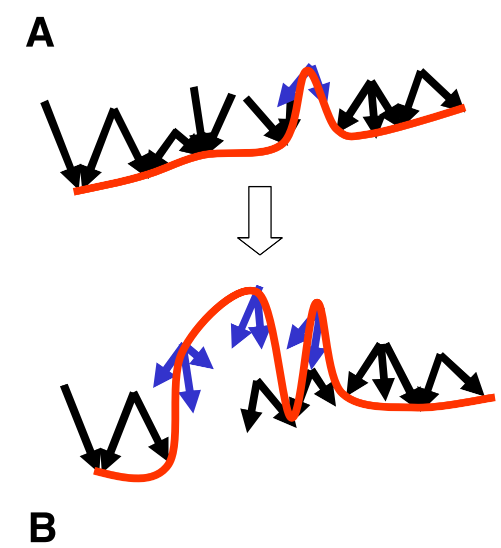



**Dual neighborhood system**



**Development of swarm model over time**

**Emergent boundaries from mutual anticipation**

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# Bacteria-inspired 1-DOF under-water robot
## (Nurzaman, et al.)

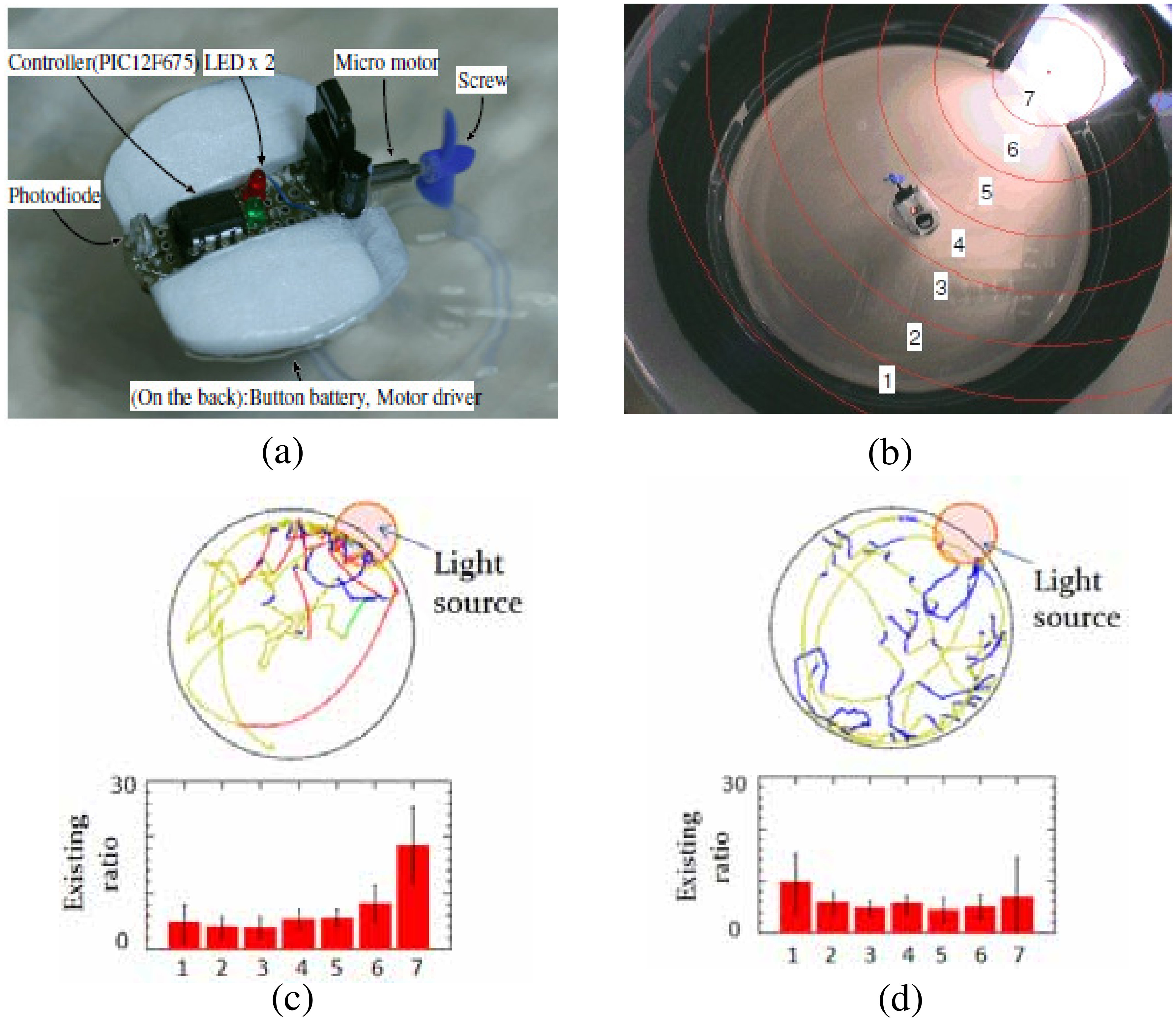



Figure 2. Real robot experiment: (a) the built robot (b) the experiment setting (c) the proposed strategy result (d) the random walk result

# How morph-ology supports eye contact

# (Wilkinson et al.)

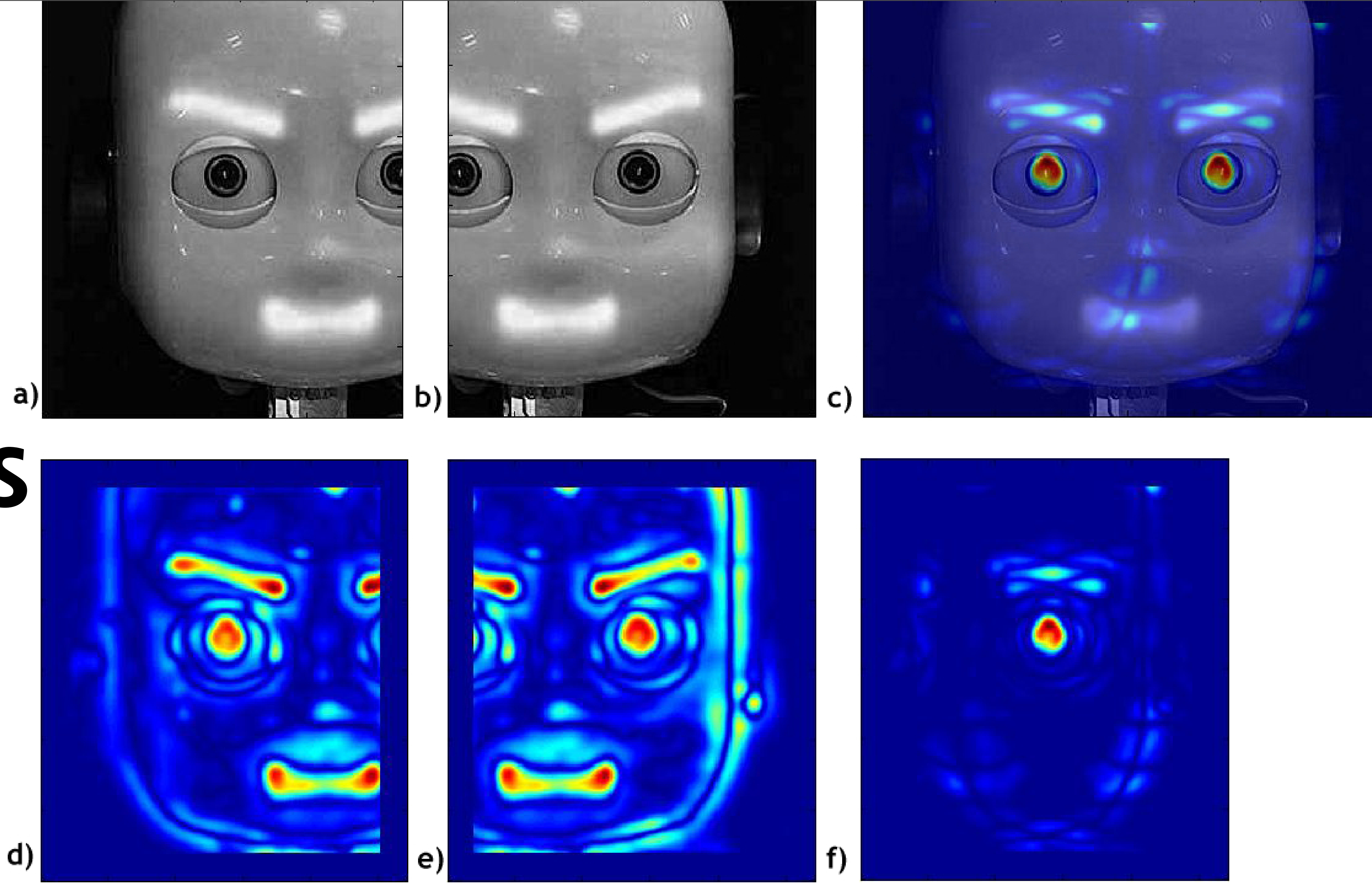



Fig. 2. *A demonstration of how sensor distribution can focus attention on eyes. (a) and (b) are the left and right pseudo-stereo pair derived image of the iCub robot. (d) and (e) show the summed output of multi-scale centre-surround filtering. (f) depicts the pointwise product of (d) shows (f) projected on to the original monocular image wrt left and right eye positions.*

# Ambiguous figure precpetion base on slime mold (Tani et al.)

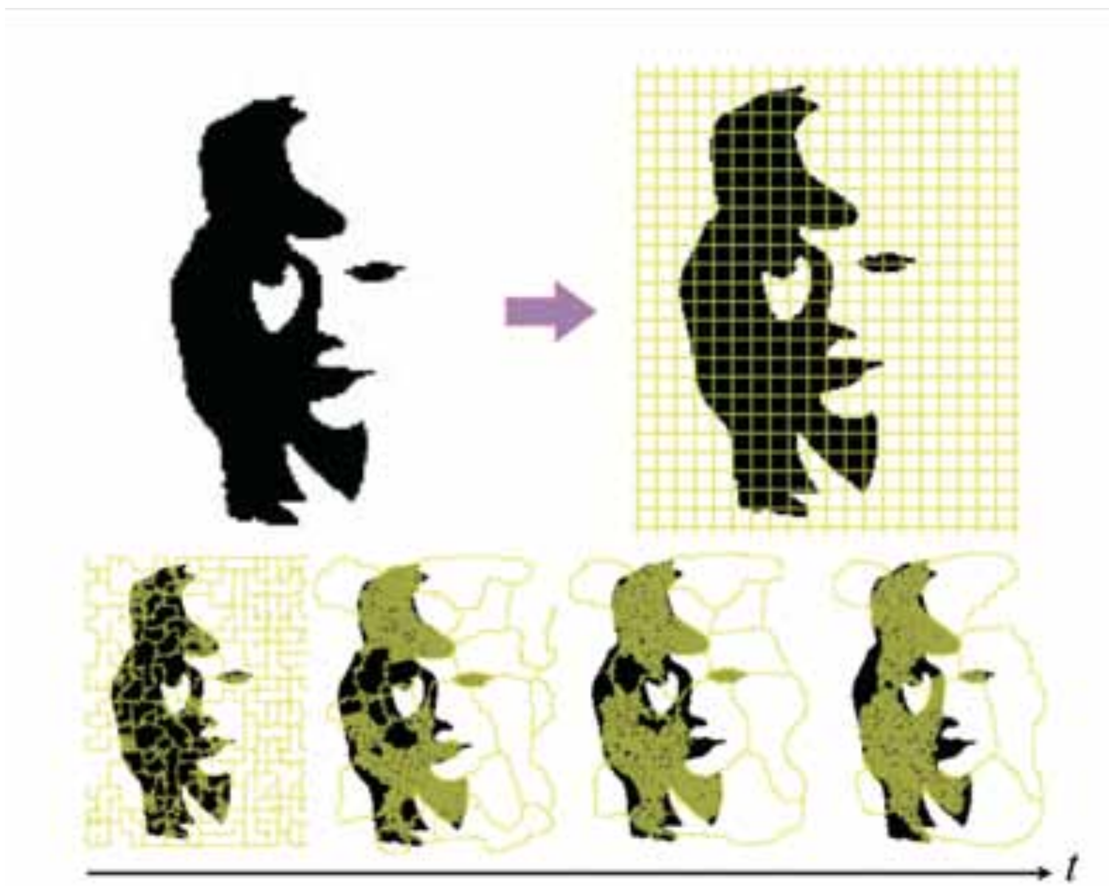



Figure 2. CELL defined on an ambiguous figure and time evolution

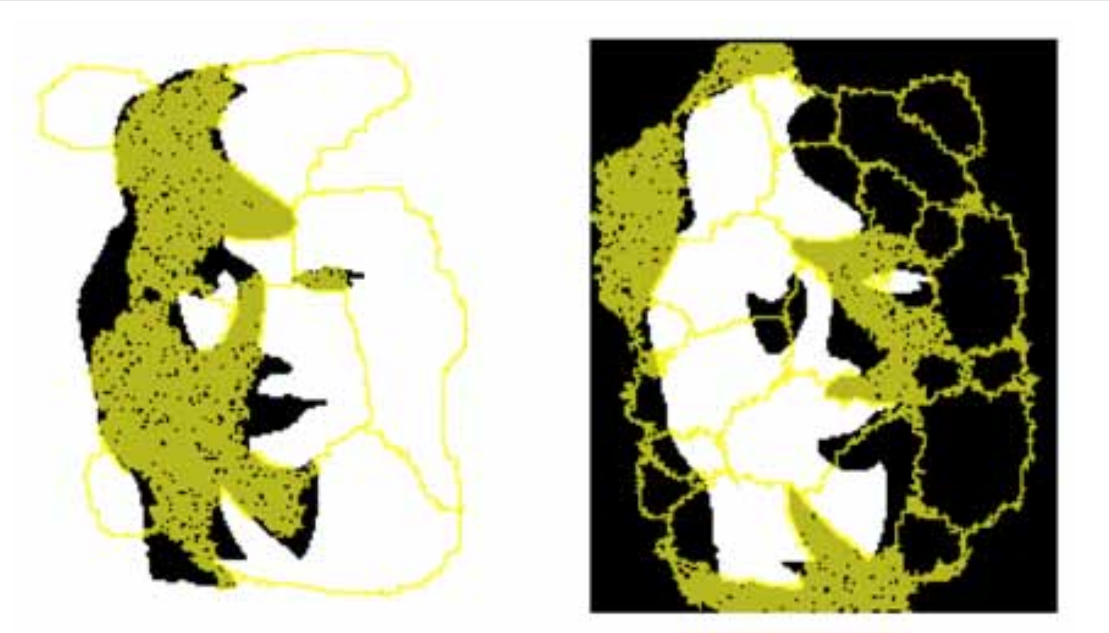
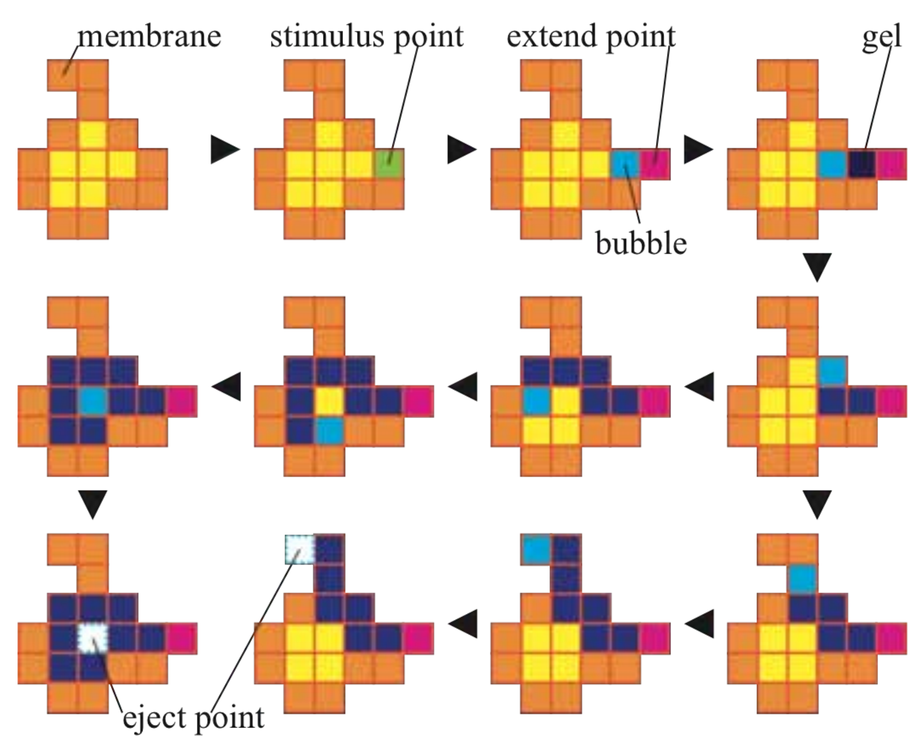


Figure 3. Network formation of CELL for each contrast

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# Exploiting friction (Dermitzakis et al.)

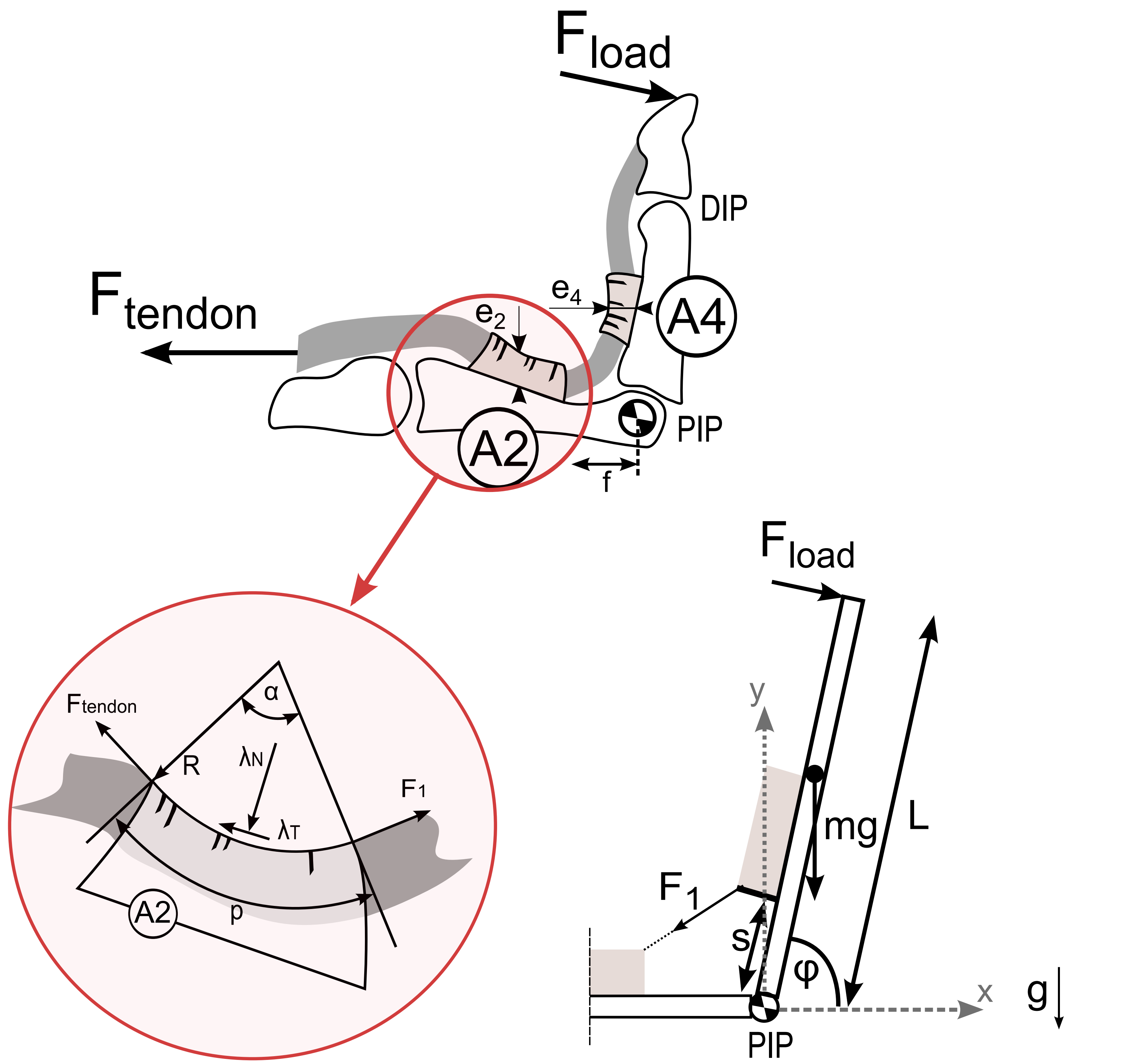



Fig. 1. Human finger and its abstraction for use in our model. The distal interphalangeal joint (DIP) is fixed, while the proximal interphalangeal joint (PIP) is not. The model consists of a two link, one-joint frictional tendon-driven system. The metacarpal bone and joint are not modeled. The capstan friction model is used to account for friction in a non-elastic tendon-sheath system (red area).

# Using shape to simplify computation in force display (Ludersdorfer et al.)

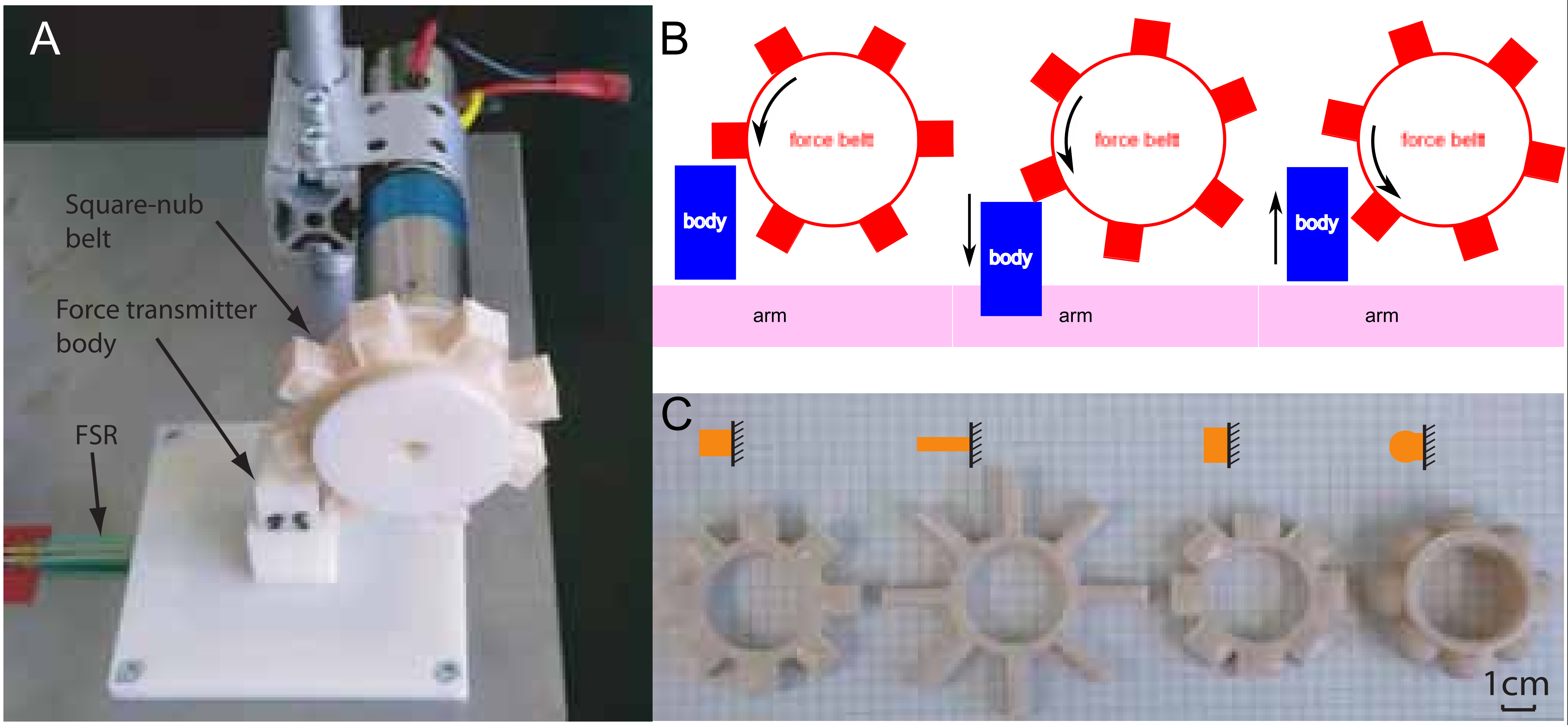



Fig. 1. Experimental setup. A. The haptic device consists of a belt featuring nubs of various shapes rotated by a DC motor. B. Schematic representation

# The robot OSCILLEX: excitatory and oscillatory control (Ishiguro et al.)

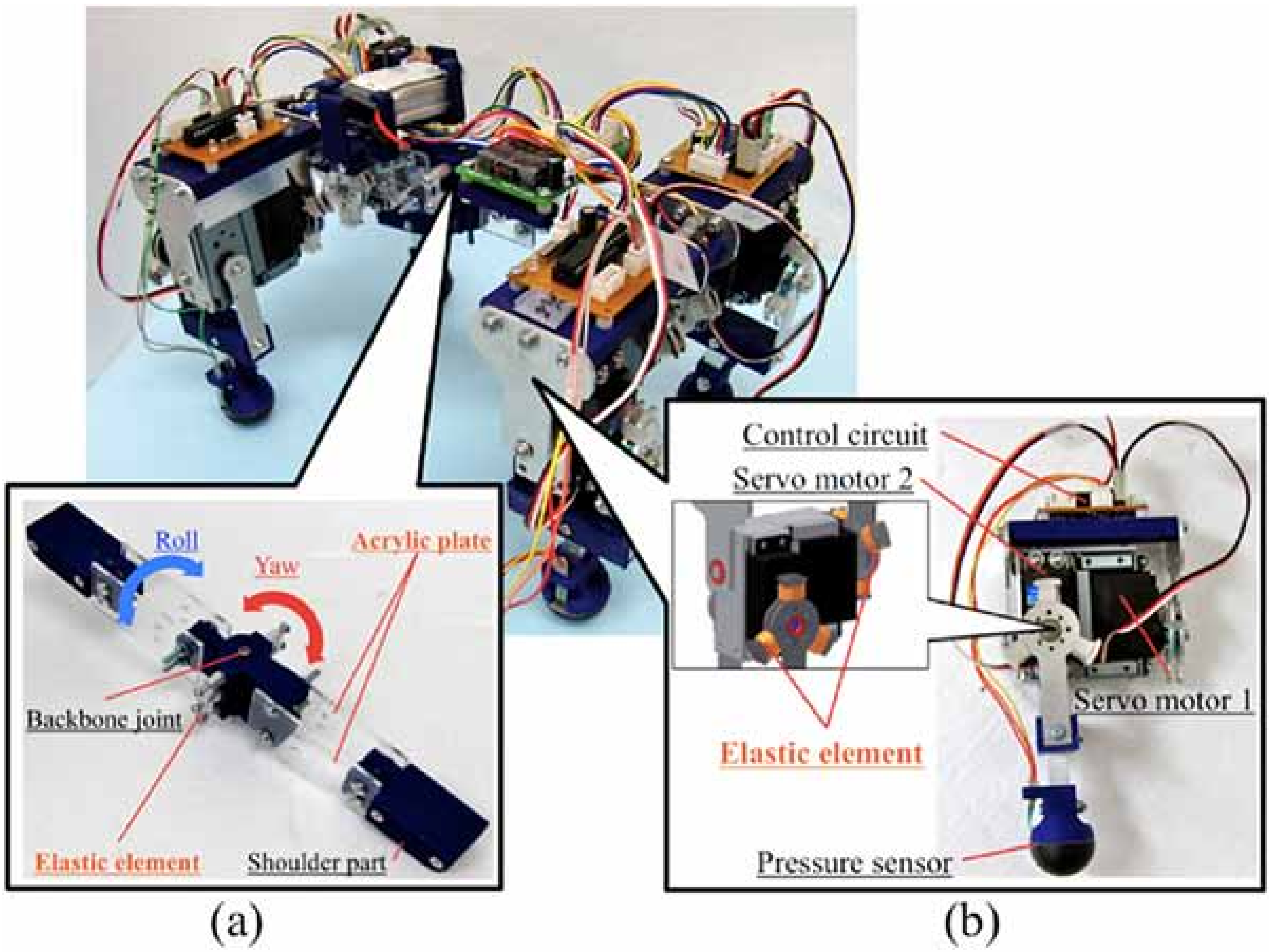



Fig. 1. Real quadruped robot OSCILLEX.

# The robot “Pneudog”: achieving bouncing gait (Shimizu et al.)

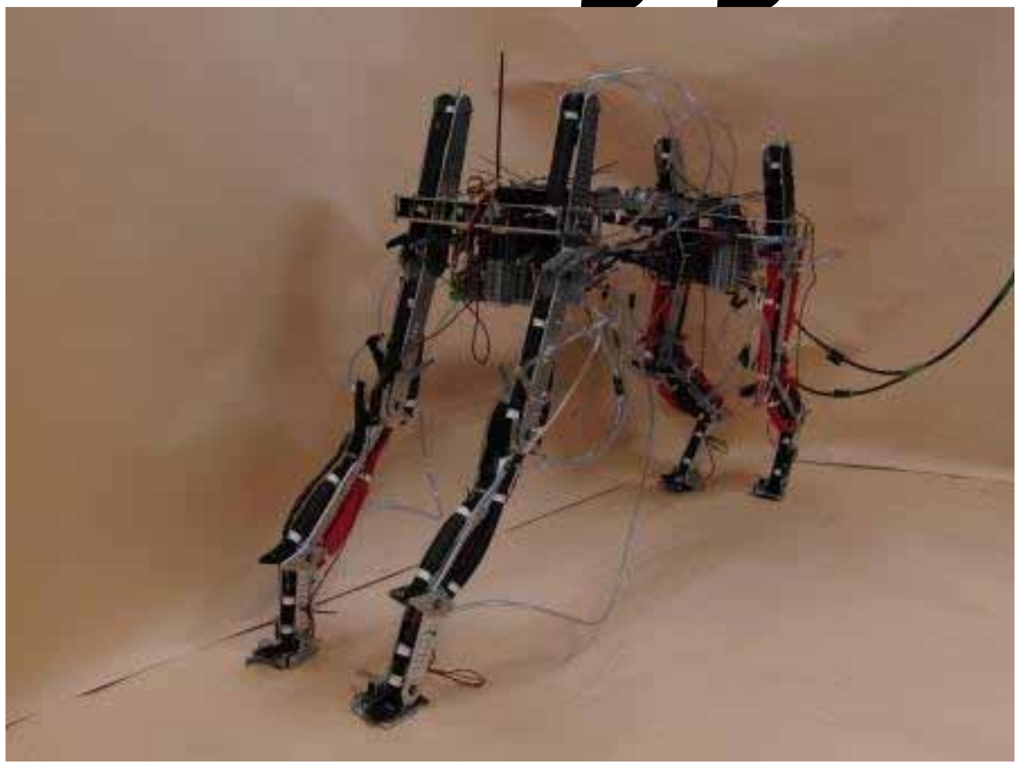


Fig. 1. Proposed pneumatic quadruped robot, “Pneudog”.

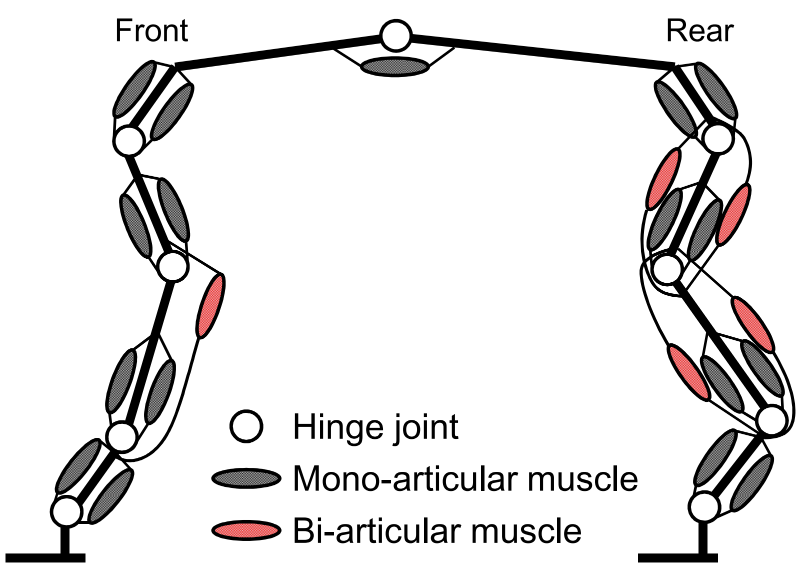
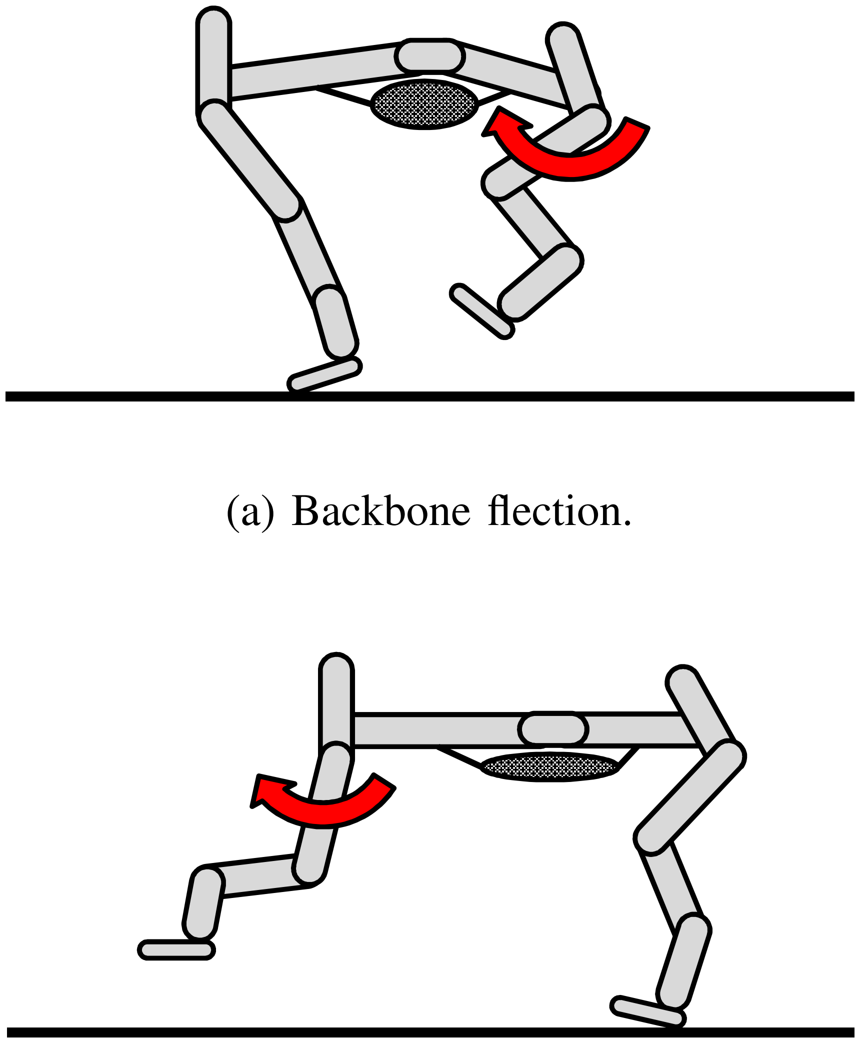



Fig. 2. Arrangement of McKibben type pneumatic artifical muscles implemented.



(a) Backbone flection.

(b) Backbone extension.

Fig. 4. Active movement of the backbone.

# Super multi-legged PDW robot "Jenkka-III" (Sugimoto/Osuka)

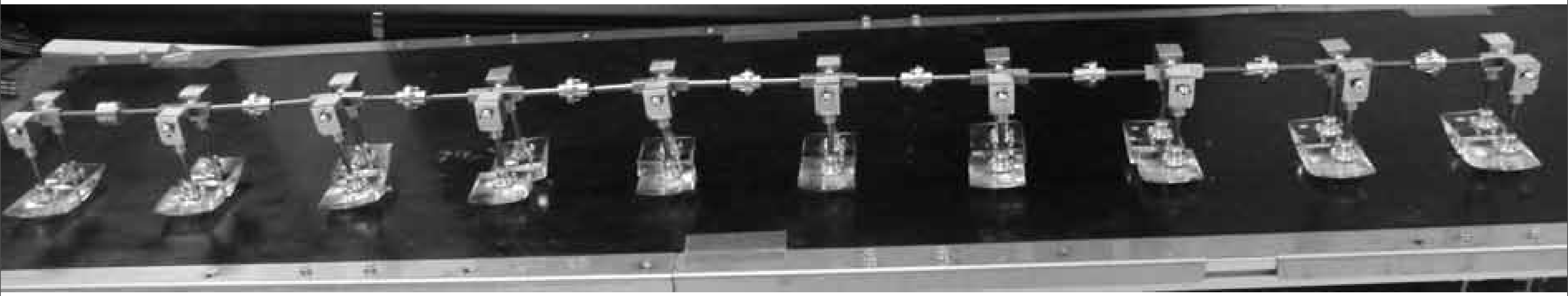
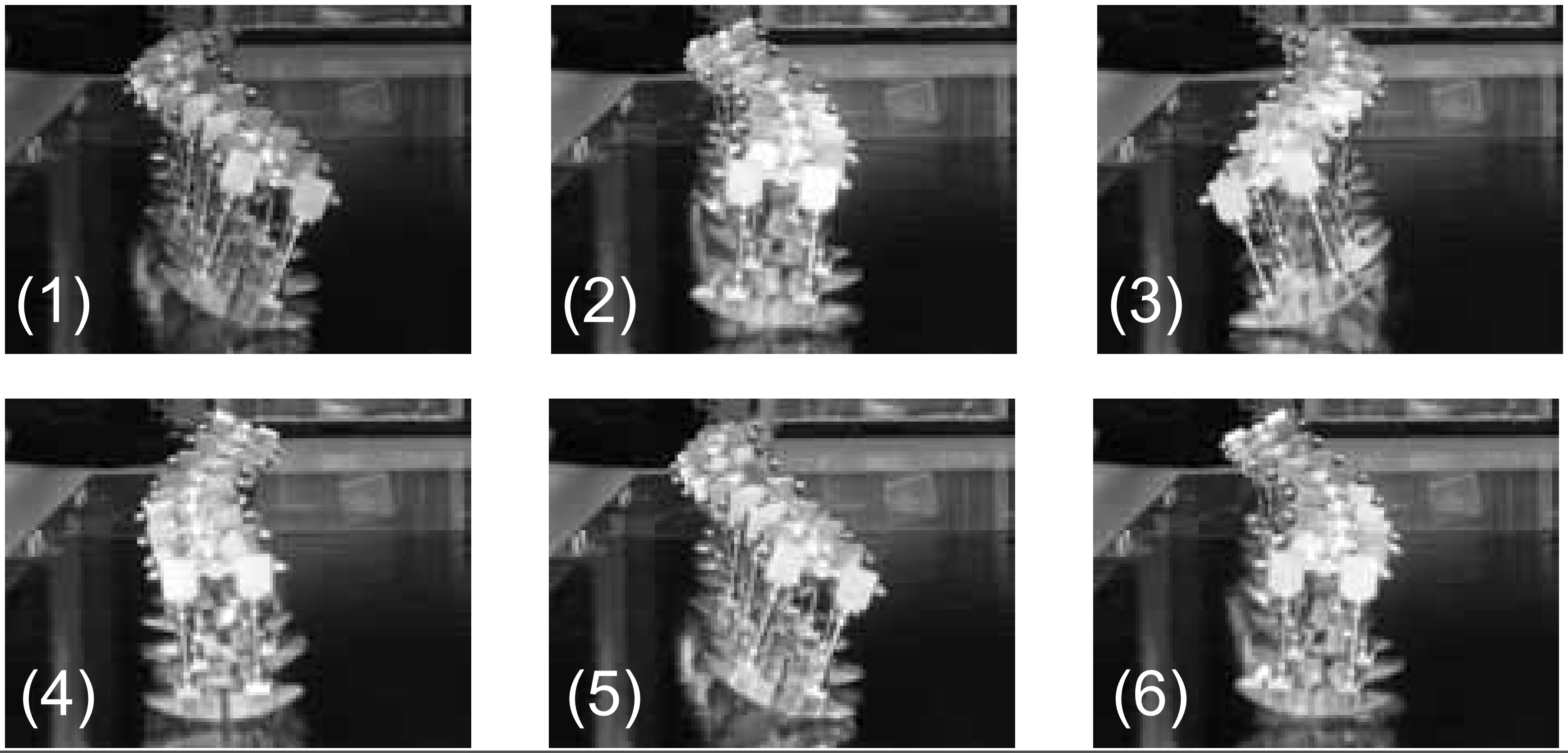


Fig. 1. Side-view of Jenkka-III



# Contents

- morphological computation
- examples and case studies - research opportunities
- **summary**
- **recommendation to speakers**

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# Research opportunities

- Theoretical/conceptual
- Methodological
- Technological
- Societal

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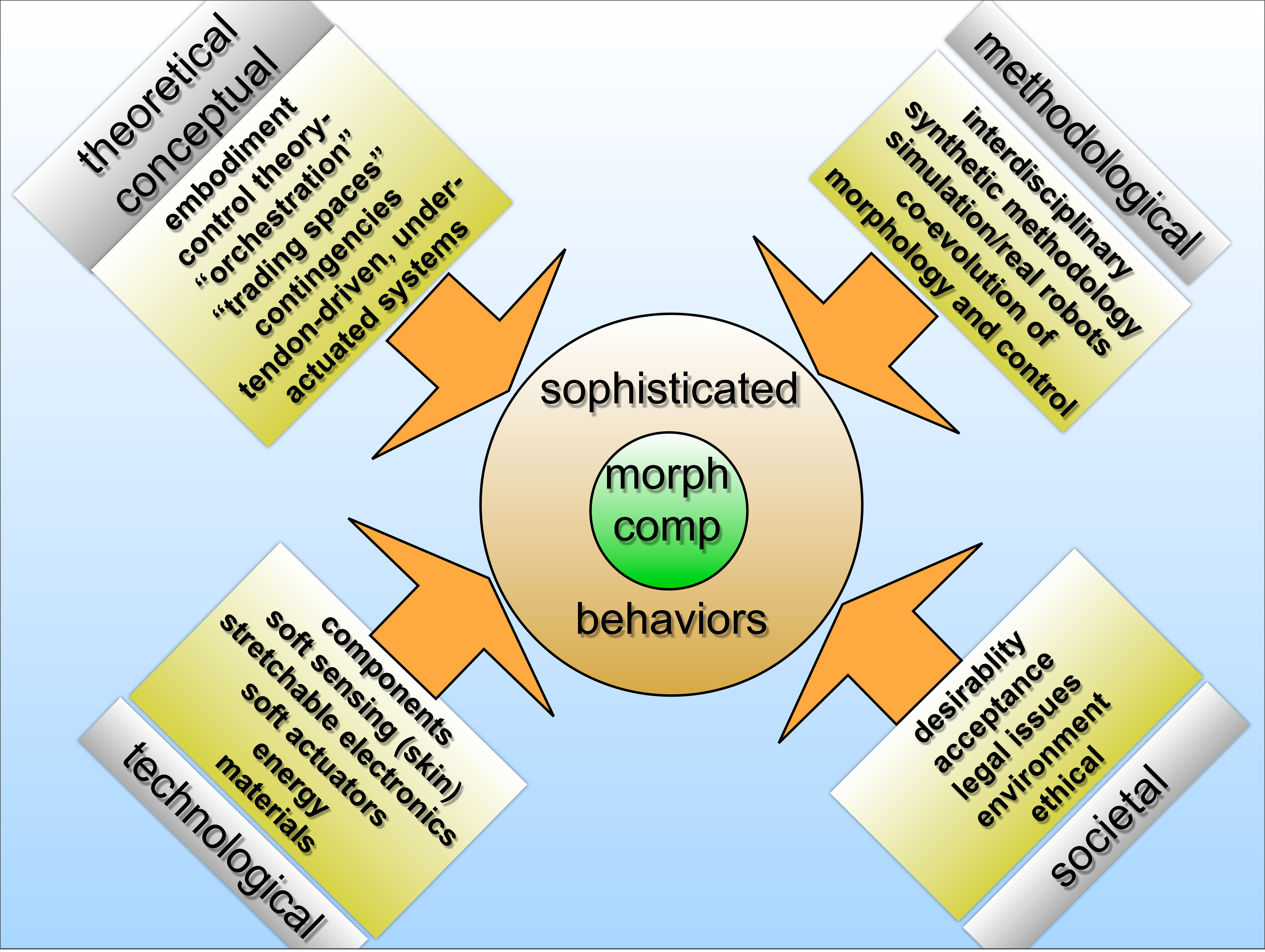
theoretical
conceptual
embodiment
control theory-
"orchestration"
"trading spaces"
contingencies
tendon-driven, under-
actuated systems
methodological
interdisciplinary
synthetic methodology
simulation/real robots
co-evolution of
morphology and control
sophisticated
morph
comp
behaviors
technological
components
soft sensing (skin)
stretchable electronics
soft actuators
energy
materials
societal
desirablity
acceptance
legal issues
environment
ethical

# Research opportunities

- characterization of morphological computation (theoretical, examples and case studies)
- “How much” morphological computation (quantification of morphology; sensory-motor contingencies)?
- comparison to classical computation
- causalities in sensory-motor networks

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# Research opportunities

- mechanisms of ontogenetic development (GRNs, encoding in genome)
- inventory of different forms of morphological computation
- programmability (at different scales; different application areas)
- macro/micro: common principles?

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# Research opportunities

- canonical problems: e.g. the "piano movers problem"
- dynamical systems, attractor states, basins, proto-symbols
- elaboration of "trading space" (what can be traded against what?)
- etc.

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# Buzzwords

amorphous computing

sel… …ssembling ro… …terials

cellular computing

biochemical circuits

passive dynamics

molecular …cognition …ms

biomolecular devices

membrane computing

…poeisis

sta…

trading space

…netic regulatory networks

blob computing

DNA/molecular computing

self-organization

self-repair

co… engin…

...

**isolated ideas? overarching set of principles?**

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# Recommendations for speakers

- Relate your contribution to morphological computation
- How does it compare to traditional notions of computation?
- Try to identify essential research issues/ opportunities
- Address lectures to interdisciplinary audience (avoid technical jargon)

| September 12 (1st Day) | September 13 (2nd Day)<br>Joint sessions of ICMC and ECCEROBOT Workshop | September 14 (3rd Day) |
|---|---|---|
| 8:30 Registration | | |
| Session 1 (Chair: Hidenobu Sumioka)<br><br>9:00-9:45 Invited speaker (Rolf Pfeifer)<br>9:45-10:30 Invited speaker (Fumiya Iida)<br>10:30-10:55 **Koh Hosoda and Shunsuke Sekimoto.** Object recognition based on dynamic touch by anthropomorphic muscular-skeleton upper limb<br><br>10:55-11:25 Coffee Break | Session 5 (Chair: Helmut Hauser)<br><br>9:00-9:45 Invited speaker (Wolfgang Maass)<br>9:45-10:30 Invited speaker (Massar Serge )<br>10:30-10:55 **Ken Caluwaerts and Benjamin Schrauwen.** The body as a reservoir: locomotion and sensing with linear feedback<br><br>10:55-11:25 Coffee Break | Session 7 (Chair: Norman Packard)<br><br>9:00-9:45 Invited speaker (Jim Crutchfield)<br>9:45-10:30 Invited speaker (Takashi Ikegami)<br>10:30-10:55 **Takuya Umedachi, Ryo Idei, and Akio Ishiguro.** A fluid-filled soft robot that exhibits spontaneous switching among versatile spatio-temporal oscillatory patterns inspired by true slime mold<br><br>10:55-11:25 Coffee Break |
| Session 2 (Chair: Akio Ishiguro)<br><br>11:25-12:10 Invited speaker (Metin Sitti)<br>12:10-12:35 **Jamie Paik, Byoungkwon An, Daniela Rus and Rob Wood.** Robotic origamis: self-morphing modular robots<br>12:35-13:00 **Gregor Hoerzer, Robert Legenstein and Wolfgang Maass.** Eliminating the teacher in reservoir computing<br><br>13:00-14:00 Lunch Break | Session 6 (Chair: Takashi Ikegami)<br><br>11:25-12:10 Invited speaker (Rachel Armstrong)<br>12:10-12:35 **Tao Li, Kohei Nakajima and Matteo Cianchetti.** Finding structure in deadtime<br>12:35-13:00 **Elmar Rückert and Gerhard Neumann.** A study of morphological computation by using probabilistic inference for motor planning<br><br>13:00-14:00 Lunch Break | Session 8 (Chair: Rolf Pfeifer)<br><br>11:25-12:10 Invited speaker (Norman Packard)<br><br>12:10-13:00 Panel discussion<br><br>13:00-14:00 Lunch Break |
| Session 3 (Chair: Rudolf M. Füchslin)<br><br>14:00-14:45 Invited speaker (Serge Kernbach )<br>14:45-15:10 **Yukio Gunji, Hisashi Murakami, Takayuki Niizato and Andrew Adamatzky.** Self-similar boundary in an embodied swarm<br>15:10-15:35 **Takayuki Niizato and Yukio Gunji.** Using criticality in flocking model<br><br>15:35-16:05 Coffee Break | Poster session (Chair: Kohei Nakajima)<br>14:00-14:45 Introduction of Posters<br>14:45-16:30 Poster session (Odd)<br><br>(Coffee Break)<br><br>16:45-18:30 Poster session (Even)<br><br>ECCEROBOT workshop at ECLT 14:00-18:30 | |
| Session 4 (Chair: Shogo Hamada)<br><br>16:05-16:50 Invited speaker (Gusz Eiben)<br>16:50-17:15 **Fabio Bonsignorio.** Quantifying the evolutionary self structuring of embodied cognitive networks<br>17:15- 17:40 **Rudolf M. Füchslin, Helmut Hauser, Rolf H. Luchsinger, Benedikt Reller, and Stephan Scheidegger.** Morphological computation: applications on different scales exploiting classical and statistical mechanics<br><br>17:40-18:30 Reception | 20:00-22:00 Social event (dinner) | |

# ECCERobot workshop

- Super-compliant, tendon-driven robots
- with hands-on practice
- work with Rob Knight, the constructor of the hardware of ECCE
- Tuesday, 14.00 - 19.00h
- Venue: ECLT (European Center for Living Technology)

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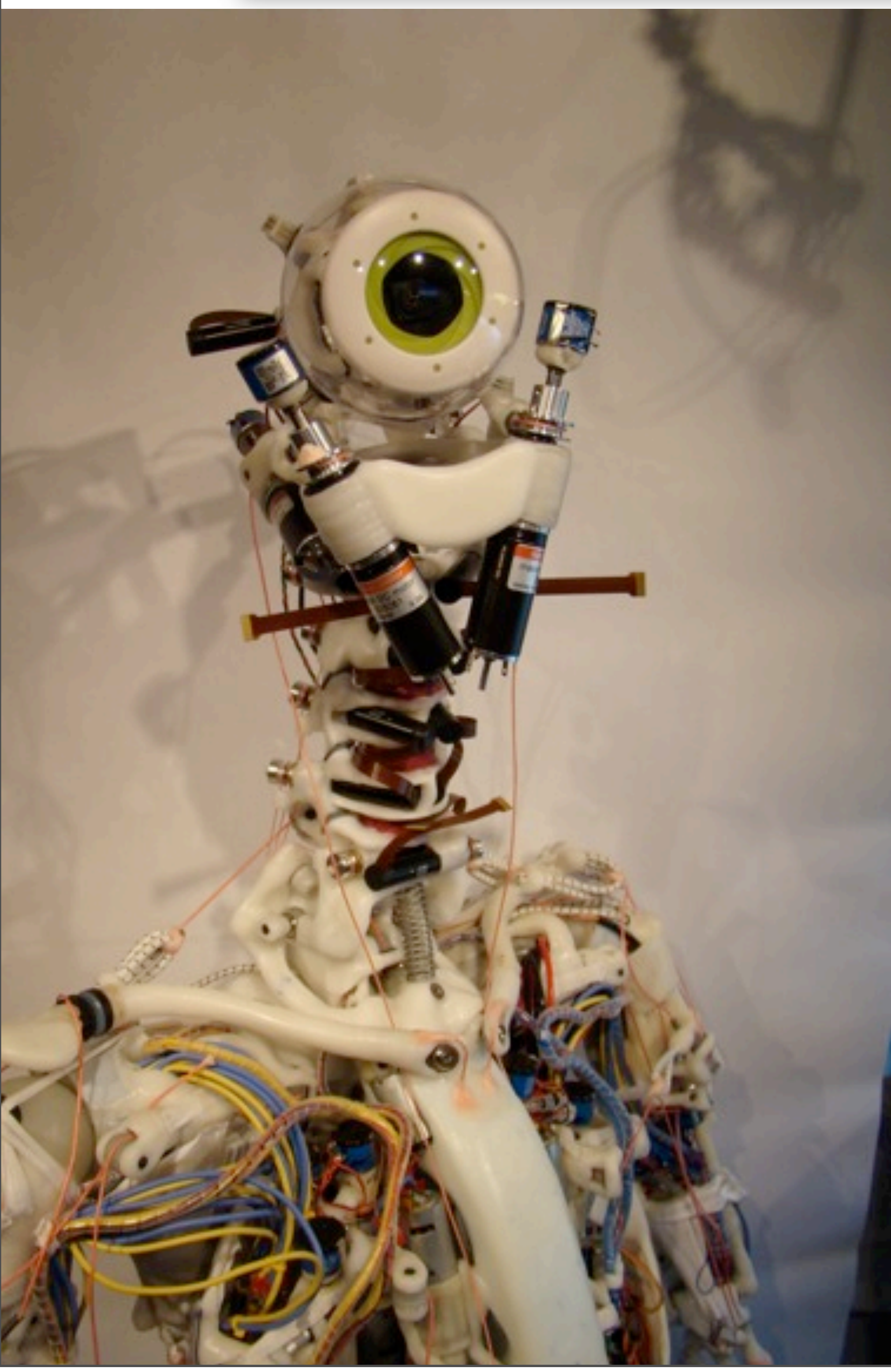
# The super-compliant, “soft”, robot ECCE



**Design and construction:**
**Rob Knight — robotstudio, Geneva**
**Richard Newcombe — Imperial College**
**Owen Holland — Essex/Sussex University**
**Hugo Marques, Cristiano Alessandro, Max Lungarella — UZH, experiments**

ECCE — Embodied Cognition in a Compliantly Engineered Robot

Anthropomorphic design

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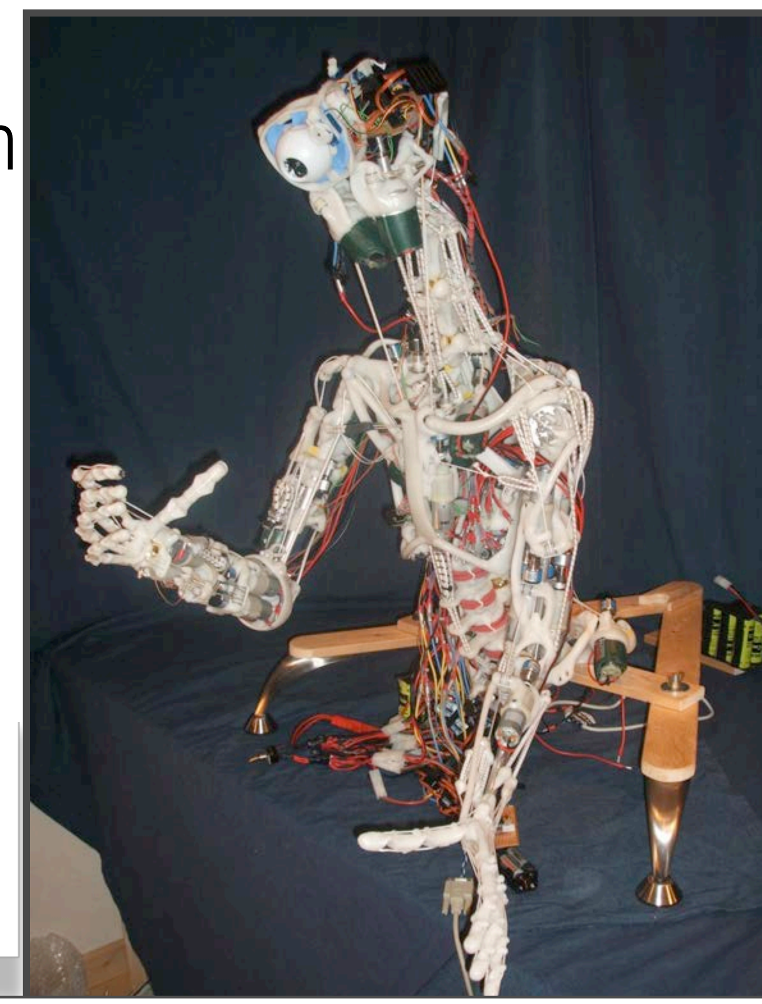
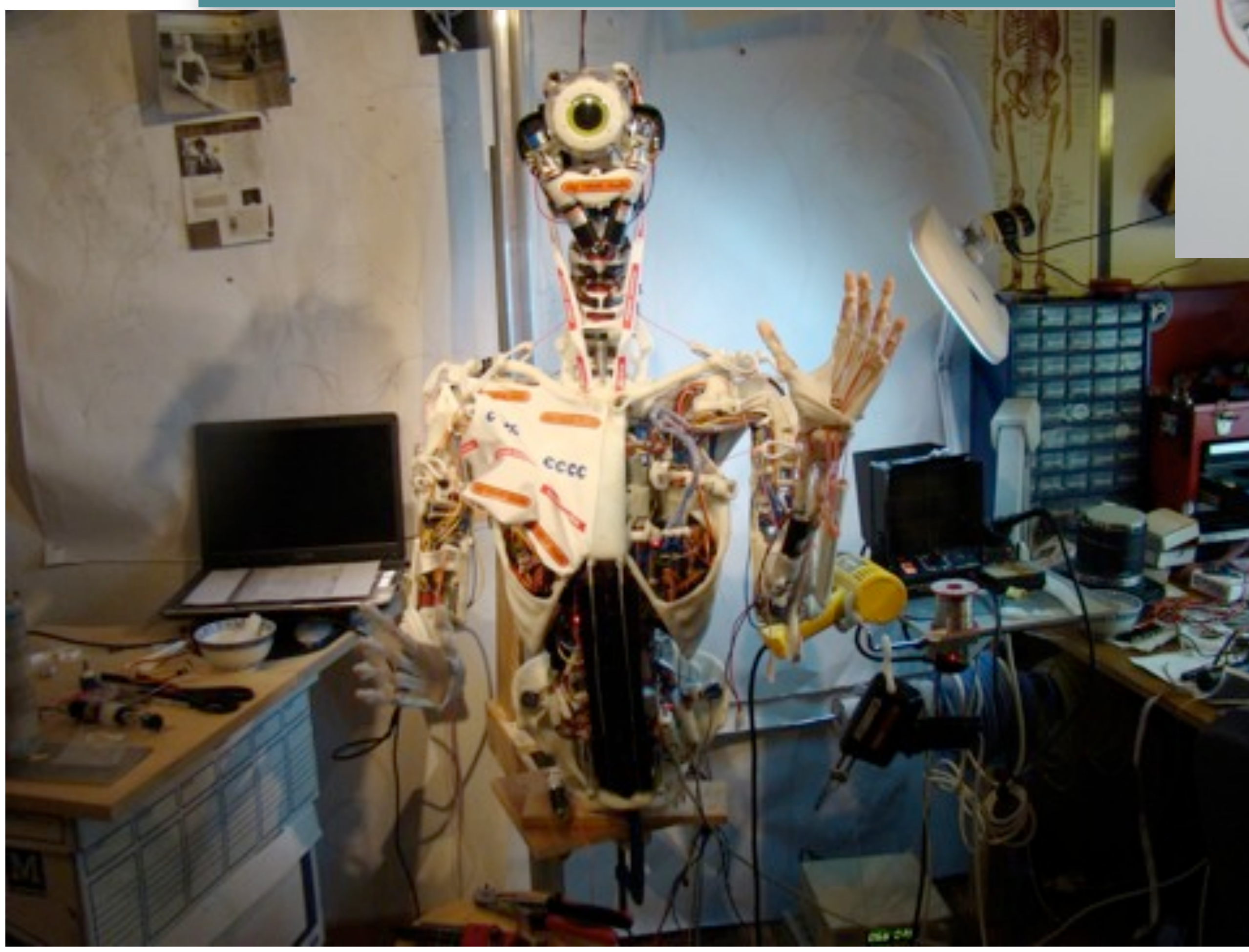




ECCE is a fully tendon-driven robot with tendons that incorporate a soft element.

# The super-compliant "soft" robot ECCE





fully tendon-driven

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# Acknowledgement

- Host institute: ECLT
- Steering committee
- Local arrangements
- Senior advisory board
- Program committee
- Reviewers
- Technical assistants
- Sponsors
- Participants

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details: proceedings

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# Sponsors, organizers

Università Ca'Foscari Venezia

eclt European Centre for Living Technology

ECCE ROBOT

AMARSi Adaptive Modular Architectures for Rich Motor Skills

EUCOGII

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# Thank you for your attention!

**Enjoy the conference!**

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