人工智能

The ShanghAI Lectures

上海授课

The ShanghAI Lectures

An experiment in global teaching

Fabio Bonsignorio
The BioRobotics Institute, SSSA and Heron Robots

Today from the BioRobotics Institute, Pontedera (PI)

欢迎您参与
“来自上海的人工智能系列讲座”

Lecture 6

Morphological Computation, Self-Organization of Behaviors and Adaptive Morphologies

1 December 2016

skype: PhD.Biorobotics

(only for lecture sites connected by streaming)

ISTITUTO DI BIOROBOTICA

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The need for an embodied perspective

- “failures” of classical AI
- fundamental problems of classical approach
- Wolpert’s quote: Why do plants not have a brain? (but check Barbara Mazzolai’s lecture at the ShanghAI Lectures 2014)
- Interaction with environment: always mediated by body

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Successes and failures of the classical approach

successes

applications (e.g. Google)

chess

manufacturing

(“controlled”artificial worlds)

failures

foundations of behavior

natural forms of intelligence

interaction with real world

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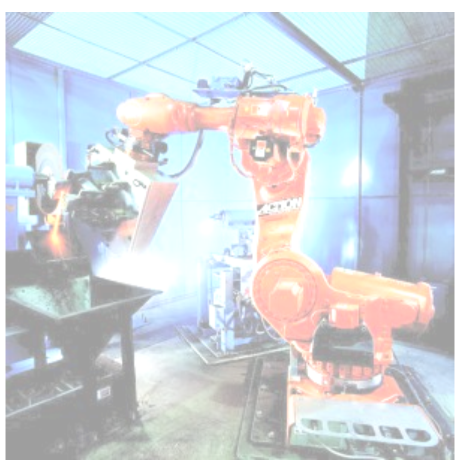
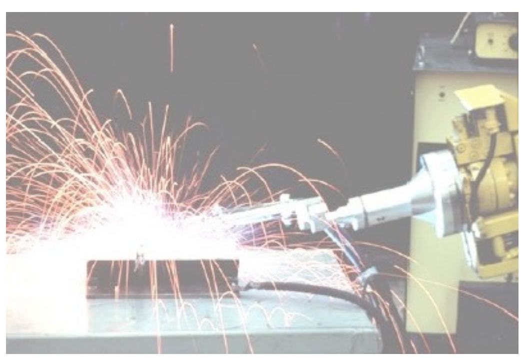
Industrial robots vs. natural systems

principles:
- **low precision**
- **compliant**
- **reactive**
- **coping with uncertainty**

humans





robots

→ **no direct transfer of methods**

Complete agents

Masano Toda's
Fungus Eaters

Properties of embodied agents

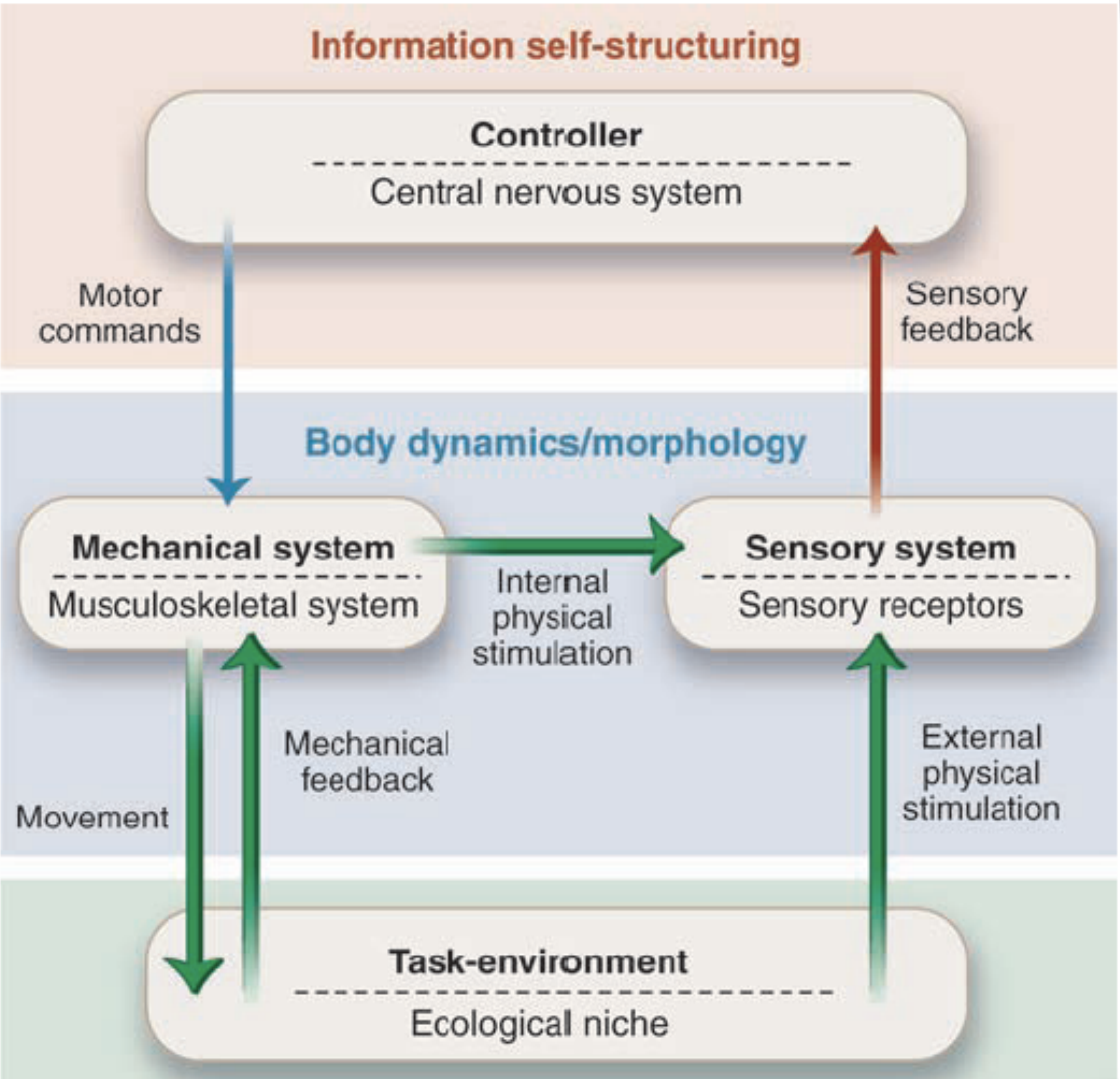
- subject to the laws of physics
- generation of sensory stimulation through interaction with real world
- affect environment through behavior
- complex dynamical systems
- perform morphological computation

Parallel, loosely coupled processes

intelligent behavior:

- **emergent from system-environment interaction**
- **based on large number of parallel, loosely coupled processes**
- **asynchronous**
- **coupled through agent's sensory-motor system and environment**

Implications of embodiment



"Puppy"

Pfeifer et al.,Science, 16 Nov. 2007

How to quantify?

- **Some hints Today!**

Approaches to evolutionary robotics

- given robot → evolve control (neural network)
- embodied approach → co-evolution of morphology and control

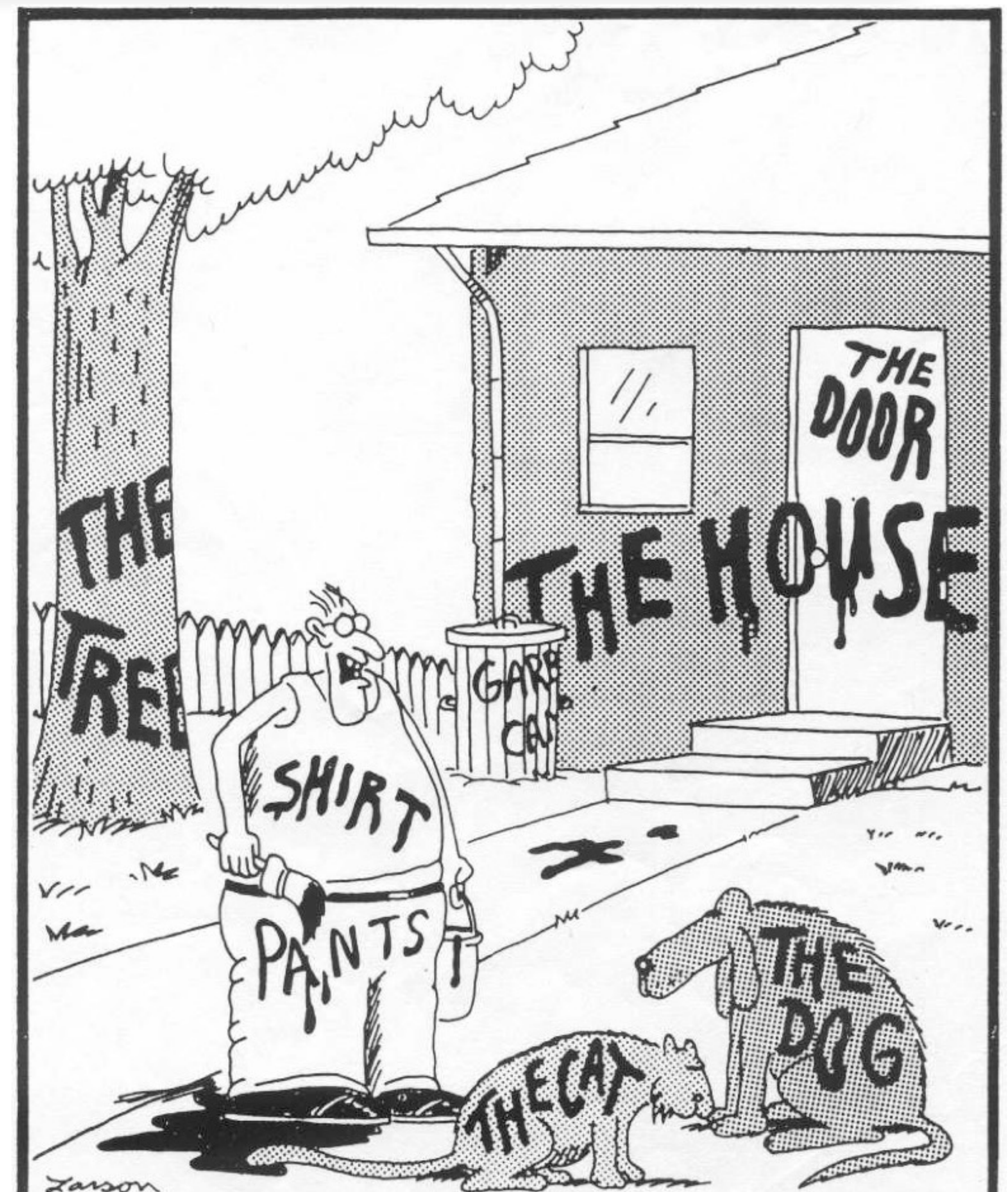
The “symbol grounding” problem

real world:
doesn’t come
with labels ...

How to put the

labels??

Gary Larson



“Now! ... *That* should clear up a few things around here!”

A step back:
"Puppy" on a treadmill

Video "Puppy" on treadmill slow motion

- **no sensors**
- **no control**

→ self-stabilization

Self-stabilization: “Puppy” on a treadmill

Video “Puppy” on treadmill slow motion

- **no sensors**
- **no control**

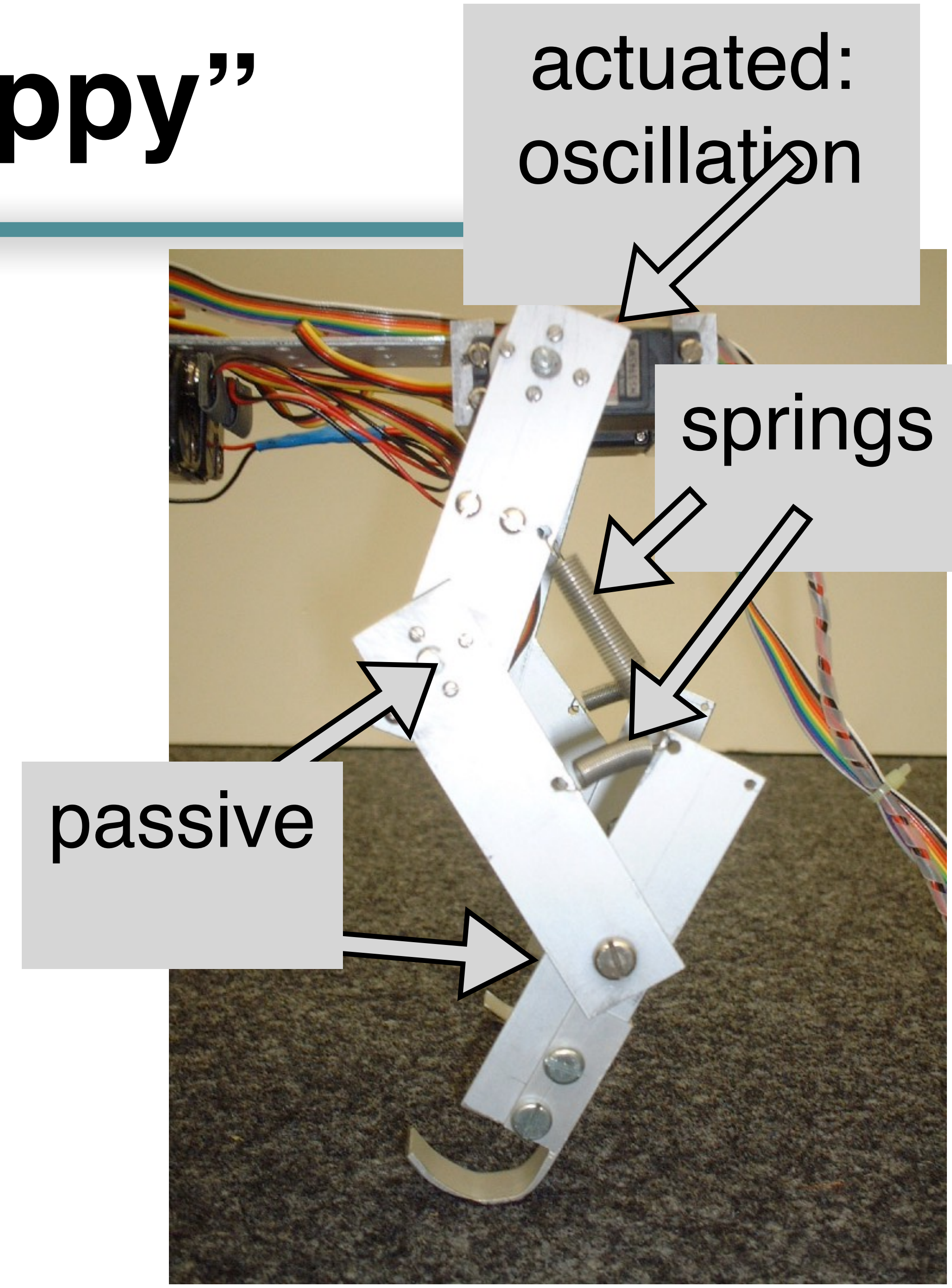
→ self-stabilization

principle of “cheap design”

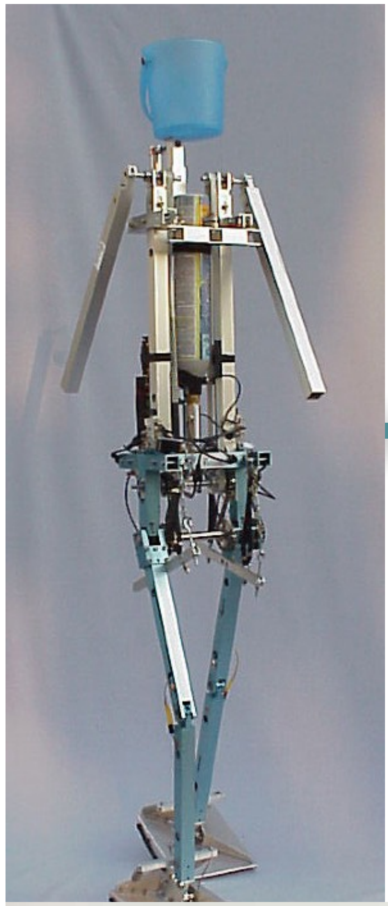
Emergence of behavior: the quadruped "Puppy"

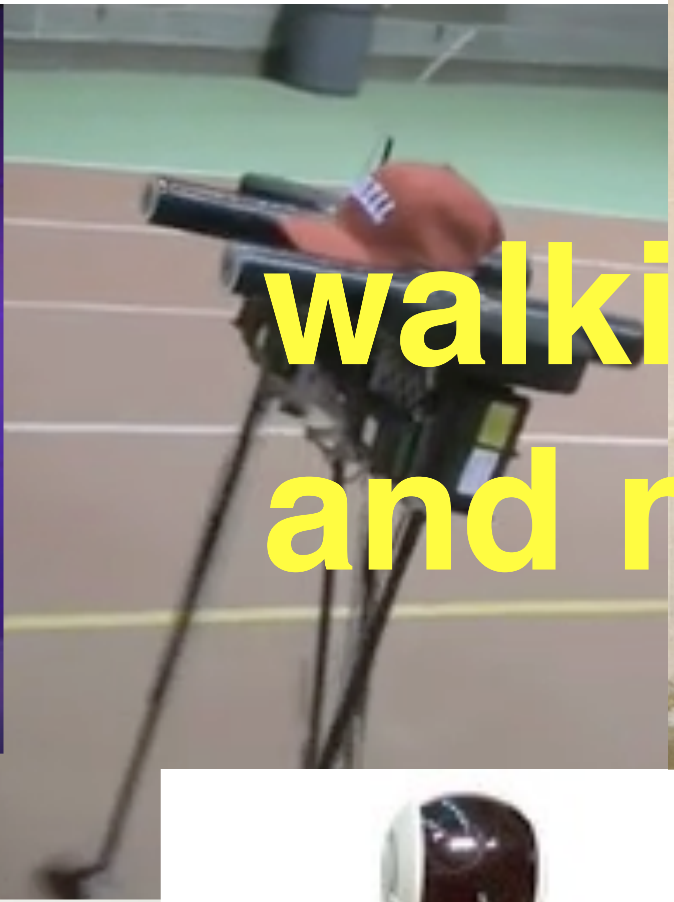
- simple control (oscillations of "hip" joints)
- spring-like material properties ("under-actuated" system)
- self-stabilization, no sensors
- "outsourcing" of functionality

→ morphological computation

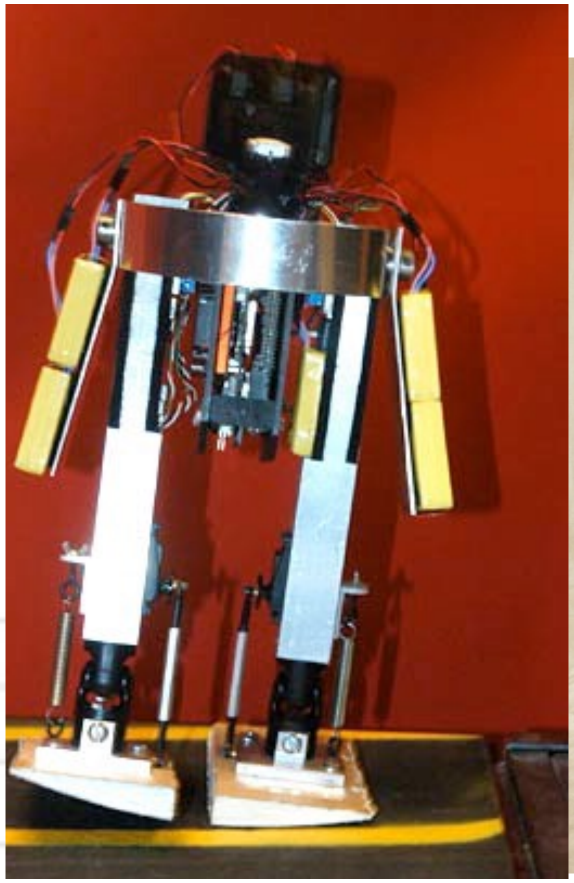
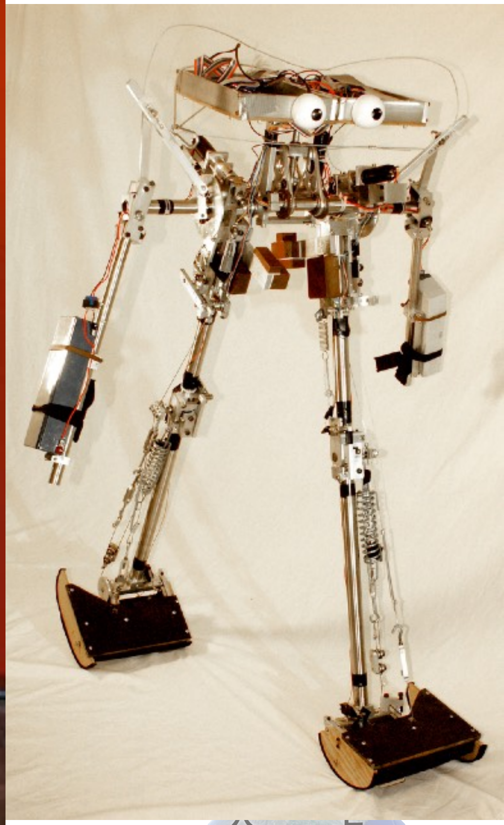


walking: GOF :-) and new designs







Extreme case: The "Passive Dynamic

The "brainless" robot": walking without control

Video "Passive Dynamic Walker"

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

The Cornell Ranger

design and construction:
Andy Ruina
Corr

Video ”Cornell Ranger”

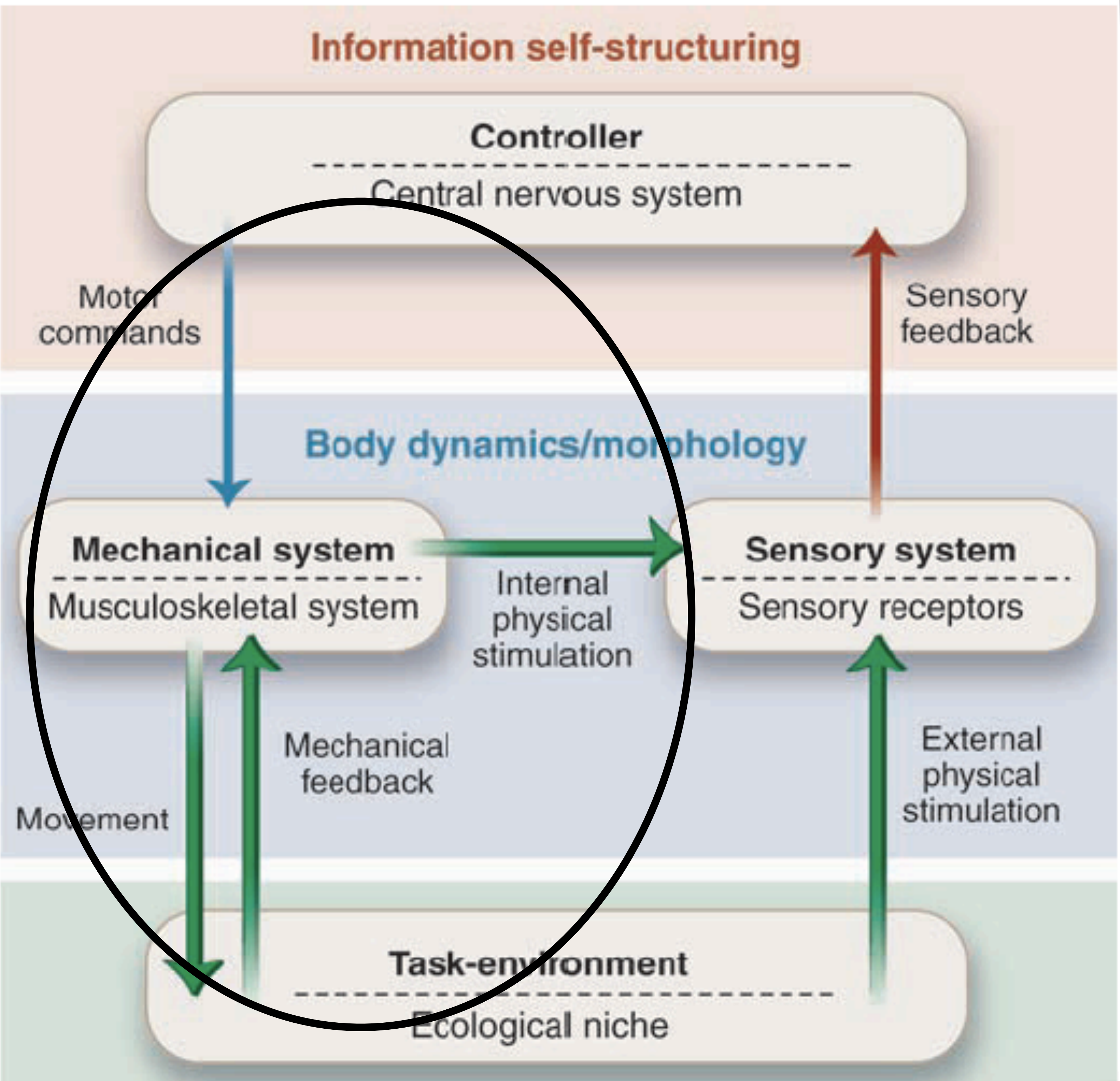
exploitation of passive dynamics

The Cornell Ranger

conception et construction:
Andy Ruina
Cornell University

65km with one battery charge!

Self-stabilization in Cornell Ranger (and Puppy!)

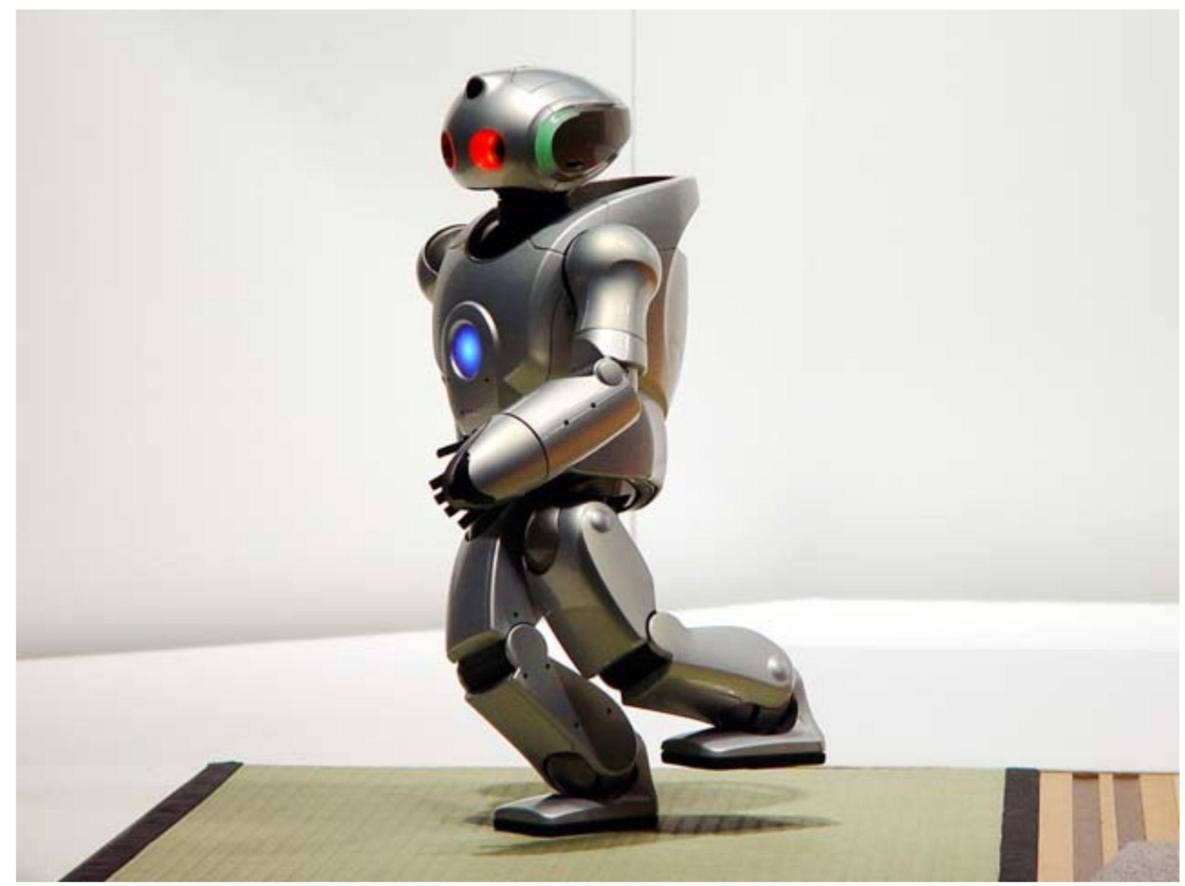


Pfeifer et al.,Science, 2007

Contrast: Full control

Honda Asimo

Sony Qrio



Redundancy principle

Redundancy/examples? —>

further examples? —>

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Design principles for intelligent systems

Principle 1: Three-constituents principle (ecological niche, desired behaviors/tasks, agent's organization)

Principle 2: Complete-agent principle

Principle 3: Parallel, loosely coupled processes

Principle 4: Sensory-motor coordination/ information self-structuring

Principle 5: Cheap design

Principle 6: Redundancy

Principle 7: Ecological balance

Principle 8: Value

Principle of “cheap design”

The principle of “cheap design” states that if agents are built to exploit the properties of their ecological niche and the characteristics of the interaction with the environment, their design and construction will be much easier, or “cheaper”.

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The value principle

The value principle states that intelligent agents are equipped with a '**value system**' which constitutes a basic set of assumptions about what is good for the agent.

Principle of “ecological balance”

balance in complexity

given task environment: match in complexity of sensory, motor, and neural system

balance / task distribution

brain (control), morphology, materials, and interaction with environment

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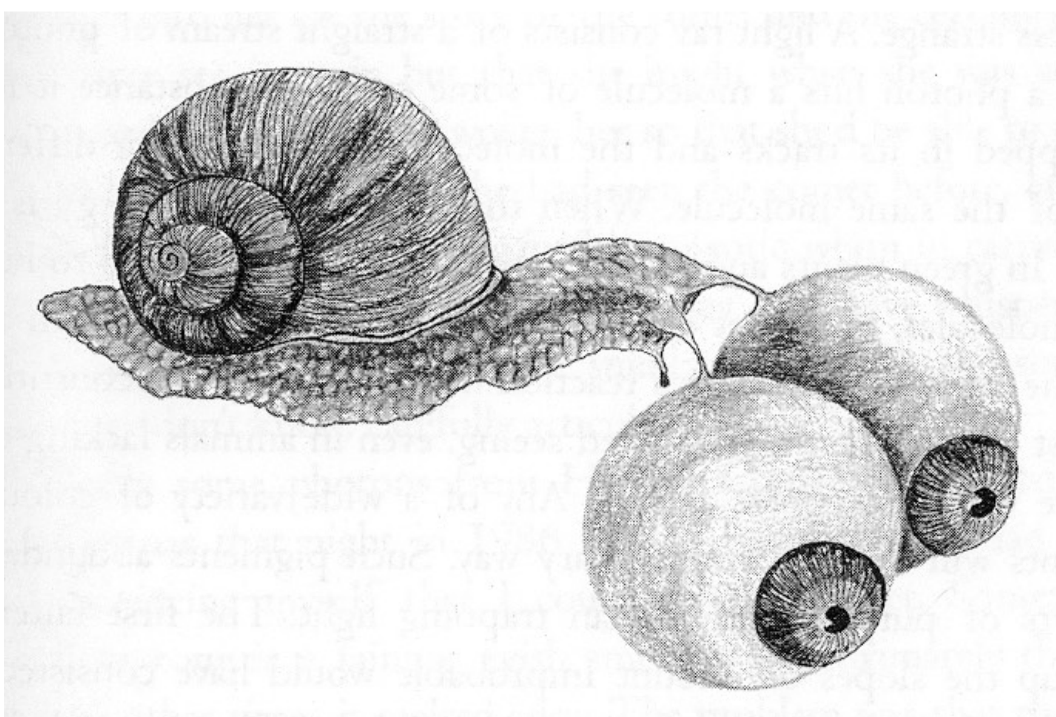
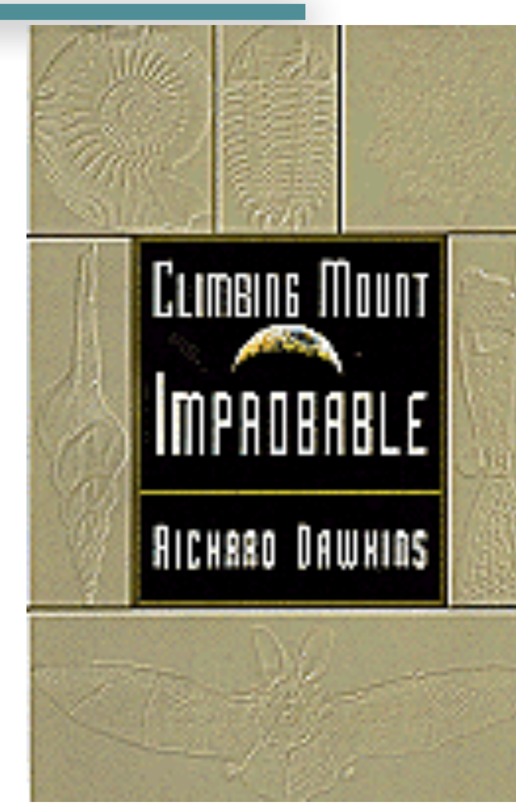
Richard Dawkins's snail with giant eyes

ecologically _unbalanced_ system





Author of:
"The selfish gene" and
"The blind watchmaker"

Task distribution

between brain, morphology, materials, and environment

extreme case: Passive Dynamic Walker

Puppy, Stumpy

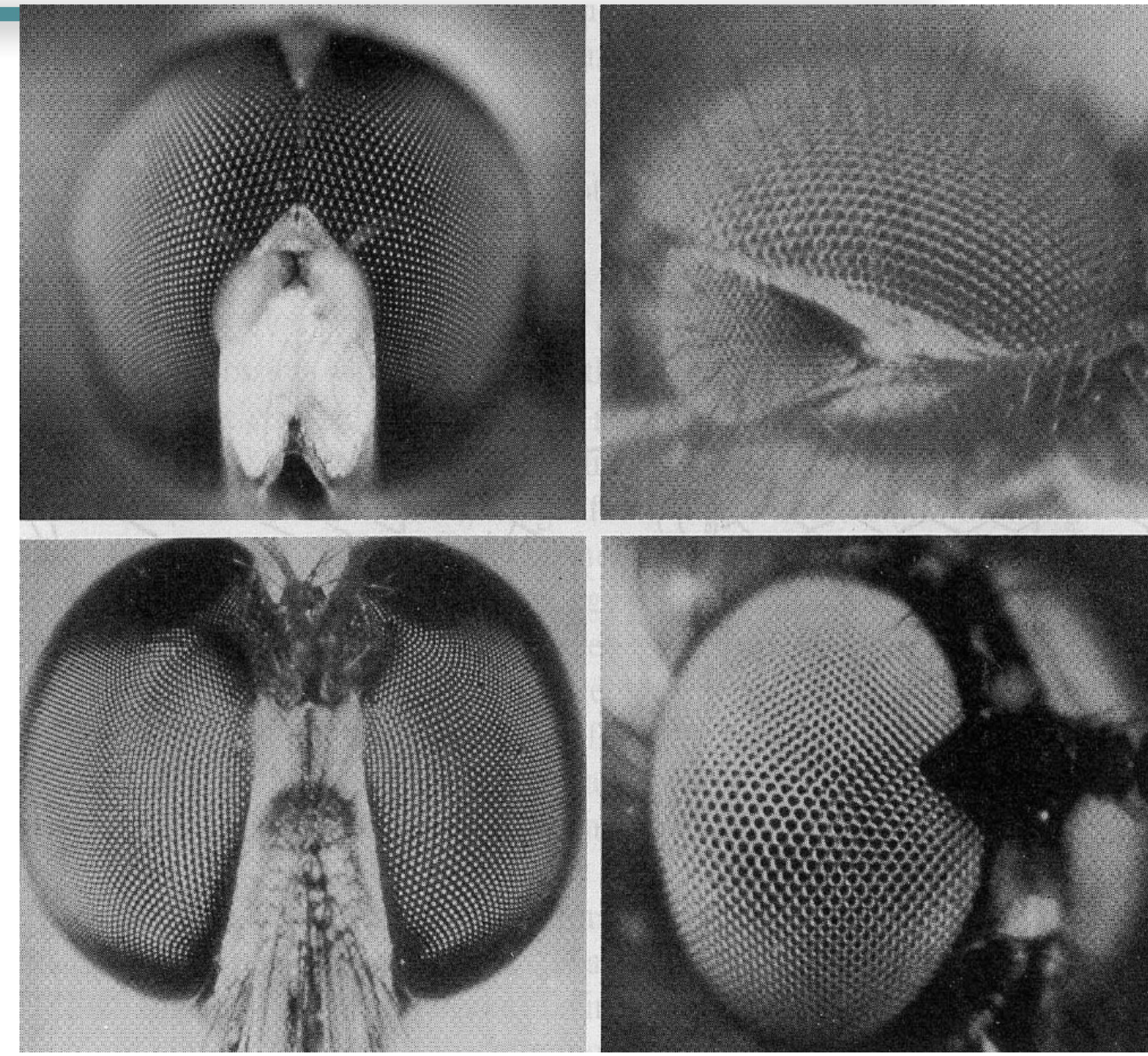
Animals, humans: dynamic change of muscle stiffness

Loosely swinging arm (later today)

Different morphologies of insect eyes

housefly

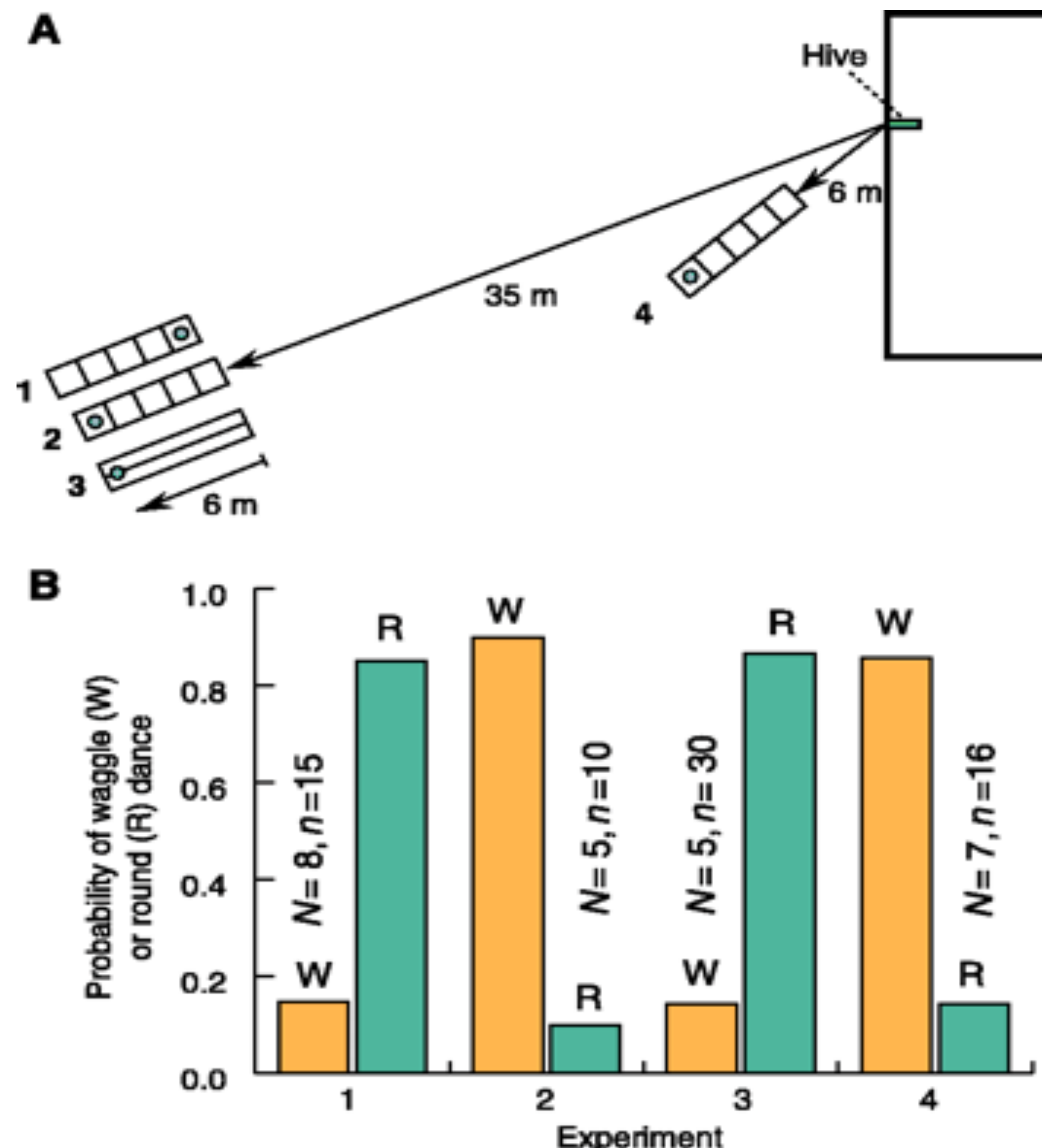
large variation of shapes



honey bee

Optic flow-based odometry in bees

Srinivasan's fascinating experiments (2000)



(A) Layout for experiments using tunnels. Each tunnel represents a separate experiment (1, 2, 3, or 4). The dot in the tunnel shows the position of the feeder in each case. (B) Probability of waggle (W) round (R) dance for experiments 1 to 4. N and n represent the numbers of bees and dances analyzed, respectively in each experiment. Science, 287, p. 852, 2000.

Design principles for intelligent systems

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The principle of sensory-motor coordination

induction of structured sensory stimulation through sensory-motor coordinated action

principle of information self-structuring: effect

Grasping an object

- many ways
- winding spring (effort)
- release
- exploitation by brain
  - "cheap design", exploitation of material properties, "free"
  - "ecological balance": outsourcing of functionality to morph. and material

Grasping an object

- induction of sensory stimulation
- dependence on
  - morphology: high density of touch, temperature, vibration sensors in hand
  - actuation: sensory-motor coordination

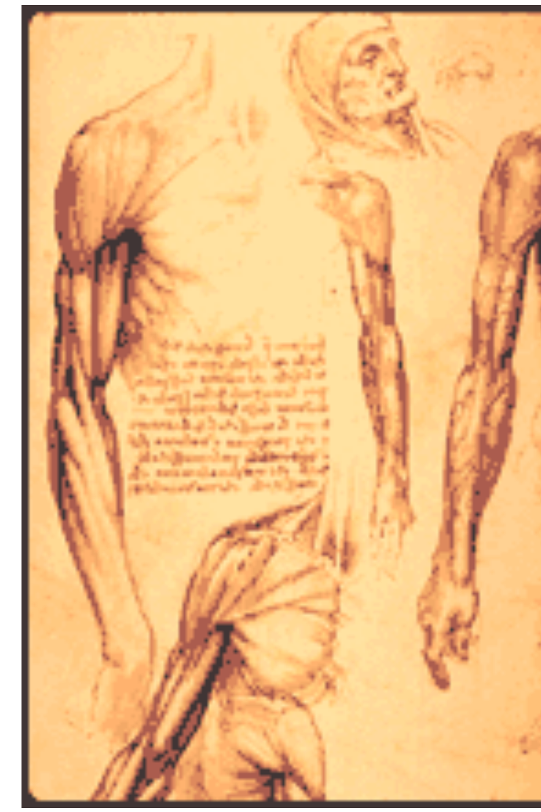
→

  - induction of correlations

“raw material” for information processing of brain

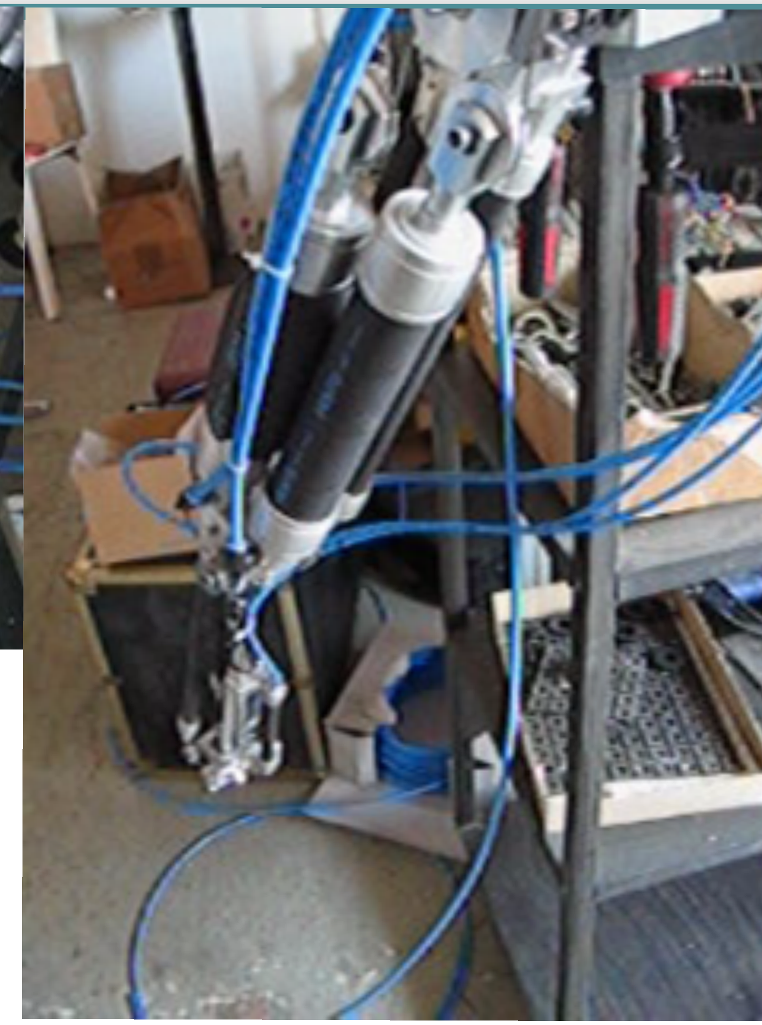
Loosely swinging arm

- **complex trajectory of hand**
- **simple control (“cheap design”, “ecological balance”)**
- **exploitation of morphology/ materials (biomechanical contraints)**



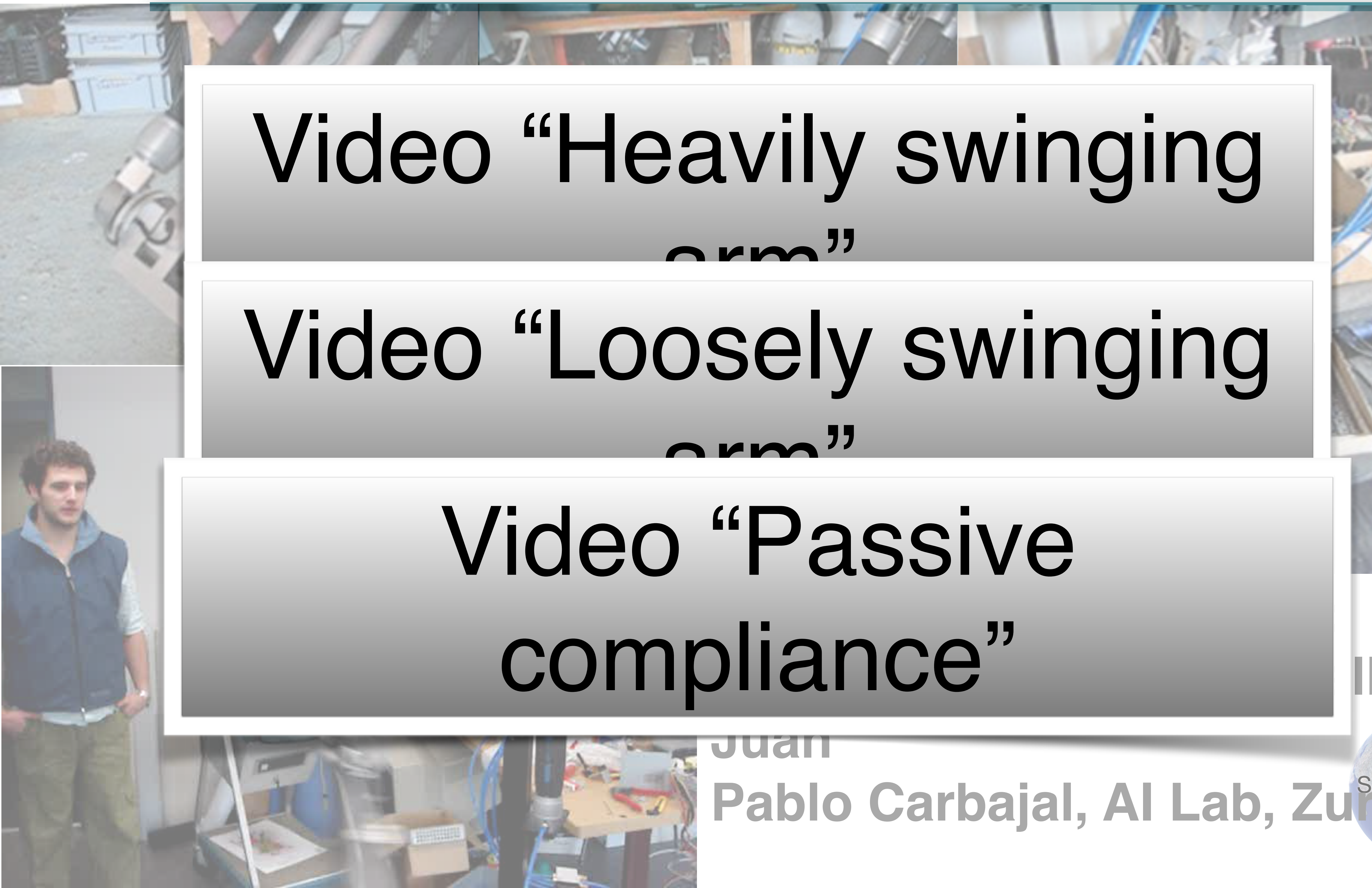
→ control “decentralized” “free”

Anthropomorphic arm with pneumatic actuators



Design and construction:
Raja Dravid, Max Lungarella, Juan Pablo Carbajal, AI Lab, Zurich

Anthropomorphic arm with pneumatic actuators



Video “Heavily swinging arm”

Video “Loosely swinging arm”

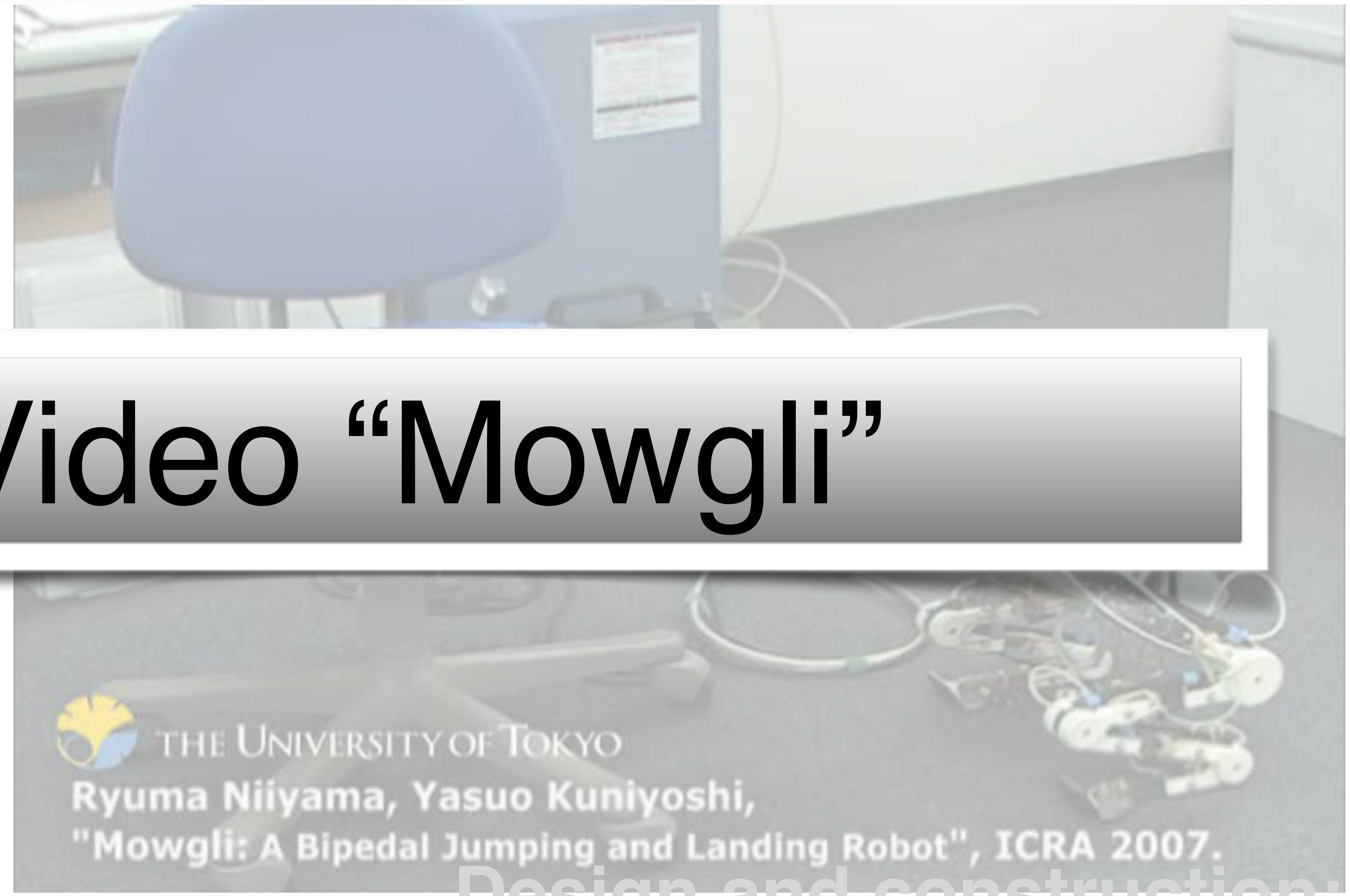
Video “Passive compliance”

lla,
Juan
Pablo Carbajal, AI Lab, Zu

Robot Frog "Mowgli" driven by pneumatic

Design and construction:
Ryuma Niiyama, Yasuo Kuniyoshi, The University of Tokyo

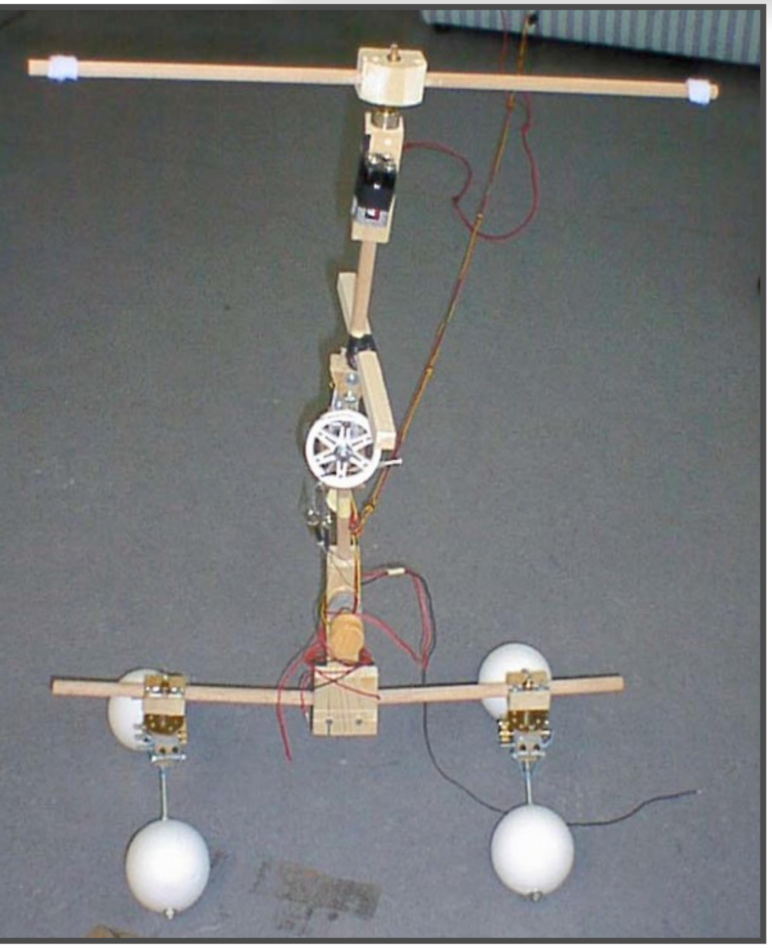
Robot Frog "Mowgli" driven by pneumatic



Video "Mowgli"

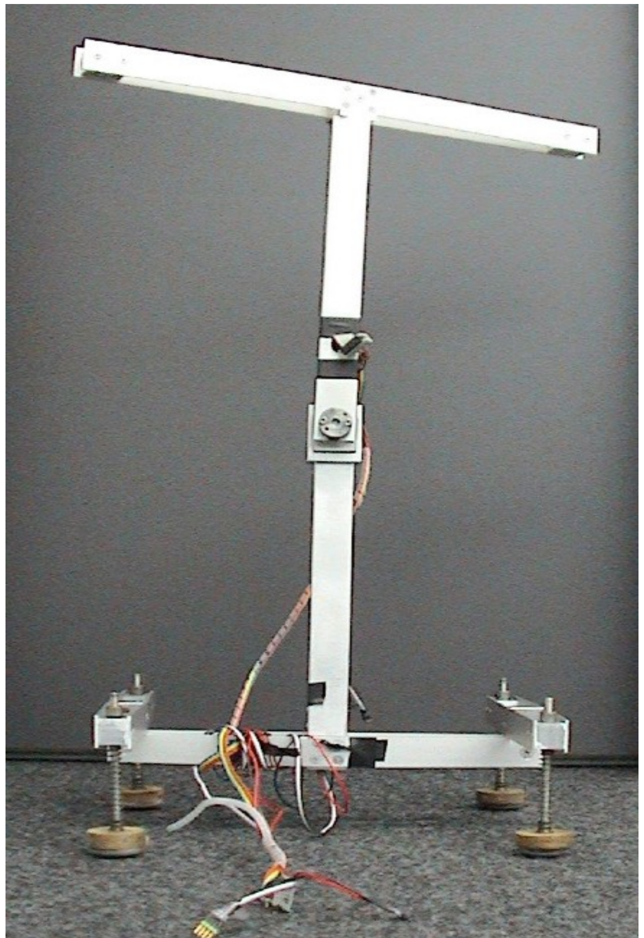
Design and construction:
Ryuma Niiyama, Yasuo Koniyoshi, The University of Tokyo

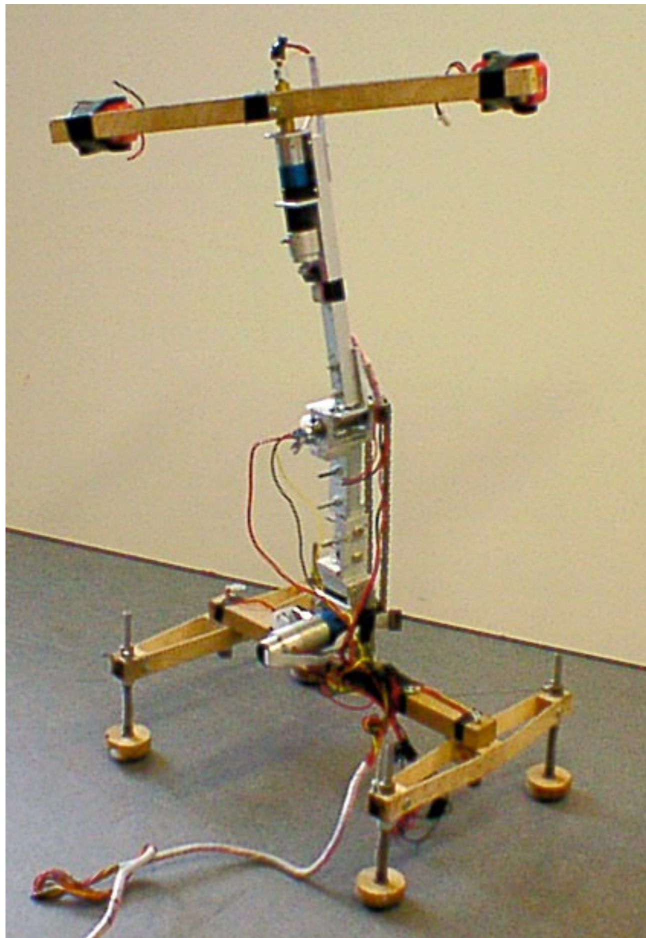
"Stumpy": task distribution



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

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





self-stabilization

Cognition: Memory: Are ‘symbols’ always needed?

which part of
diagram relevant?
—>

memory for walking?

Water fountain
Where is the memory for shape?

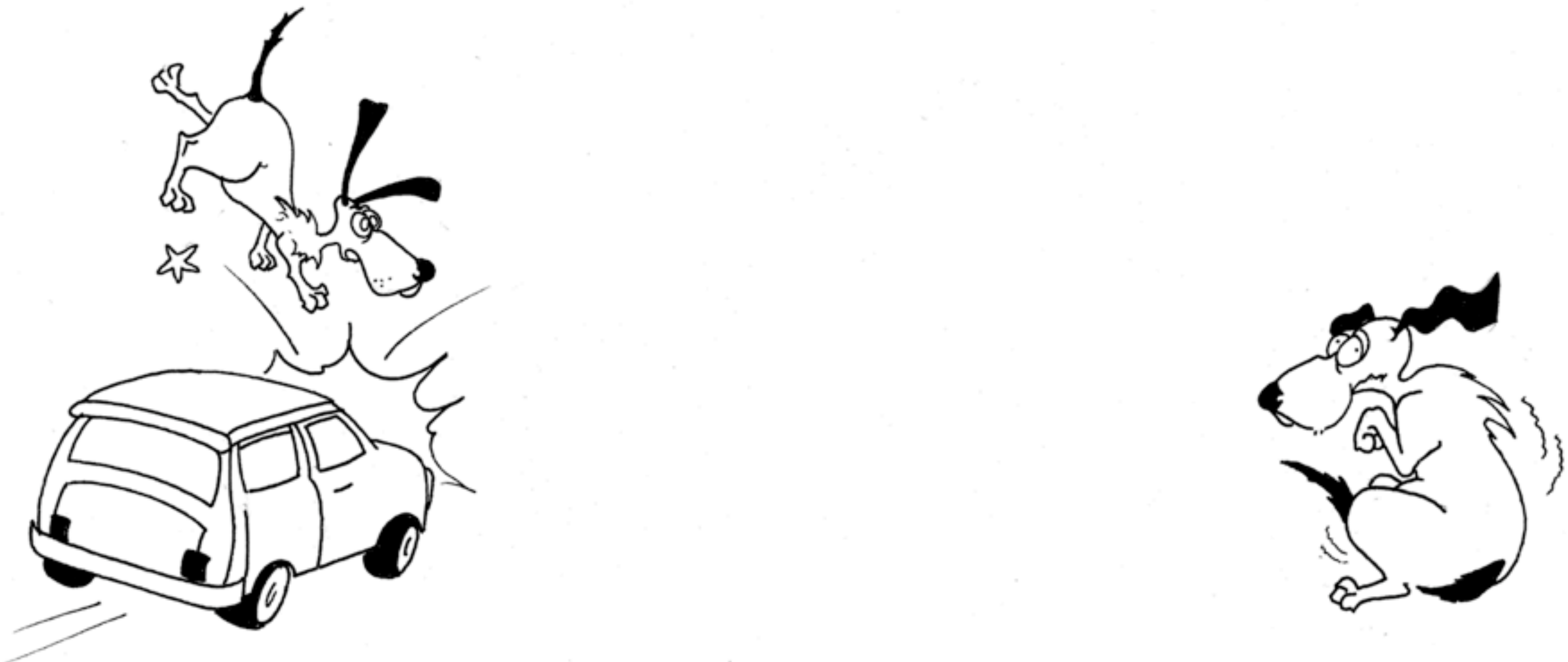
clear structure visible

underlying mechanism?

Where is the “structure” stored? - what can we learn for human memory?

Ashby's concept of "memory as a theoretical construct"

W. Ross Ashby (1956). An introduction to cybernetics.



a. b.

Where does ‘symbols’ come from?: physical dynamics and information processing

- **morphology and materials**
- **orchestration control**
- **exploration**
- **preferred trajectories from biomechanical constraints**
- **induction of patterns of sensory stimulation in different sensory channels**
- **sensory-motor coordination —> induction of information structure**

The “story”: physical dynamics and information

- good “raw material” for brain
- cross-modal association, learning, concept formation
- extraction of mutual information —> prediction
  (expectations: crucial for motor control)
- categorization (fundamental for cognition)

Sensory-motor coordination (“active perception”)

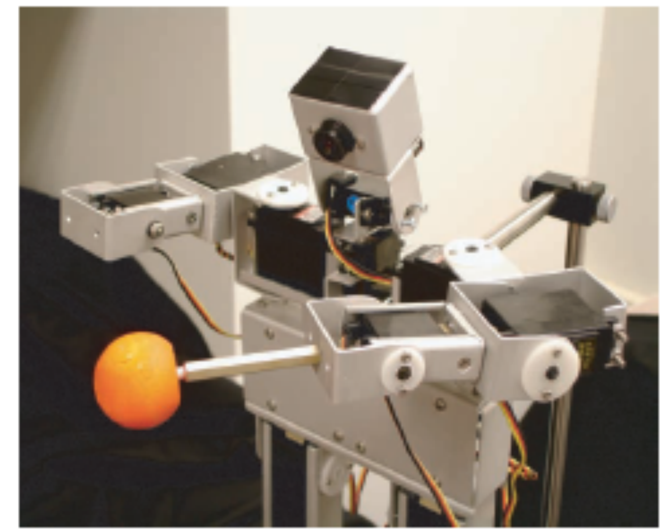
“We begin not with a sensory stimulus, but with a sensory-motor coordination […] In a certain sense it is the movement which is primary, and the sensation which is secondary, the movement of the body, head, and eye muscles determining the quality of what is experienced. In other words, the real beginning is with the act of seeing; it is looking, and not a sensation of light.” (“The reflex arc concept in psychology,” John Dewey, 1896)

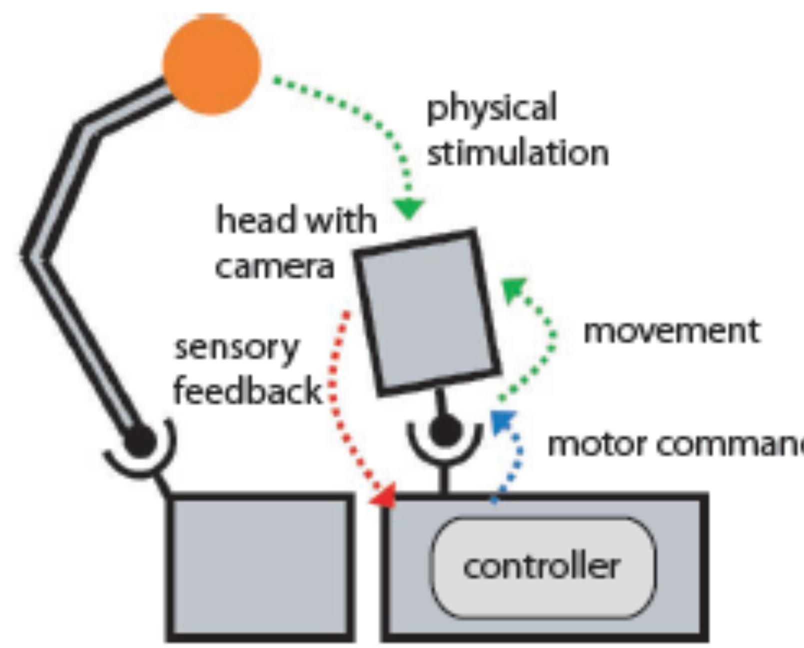
“Since all the stimulations which the organism receives have in turn been possible only by its preceding movements which have culminated in exposing the receptor organ to external influences, one could also say that behavior is the first cause of all the stimulations.” (“The structure of Behavior,” Maurice Merleau-Ponty, 1963)

Information self-structuring

Experiments:

Lungarella and Sporns, **2006**
Mapping information flow in sensorimotor networks
PLoS Computational Biology





Quantitative measures

entropy: disorder, information

$$H(X) = -\sum_i p(x_i) \log p(x_i)$$

mutual information: statistical dependency

$$MI(X,Y) = H(X) + H(Y) - H(XY) = -\sum_i \sum_j p(x_i, y_j) \log \frac{p(x_i)p(y_j)}{p(x_i, y_j)}$$

integration: global statistical dependence

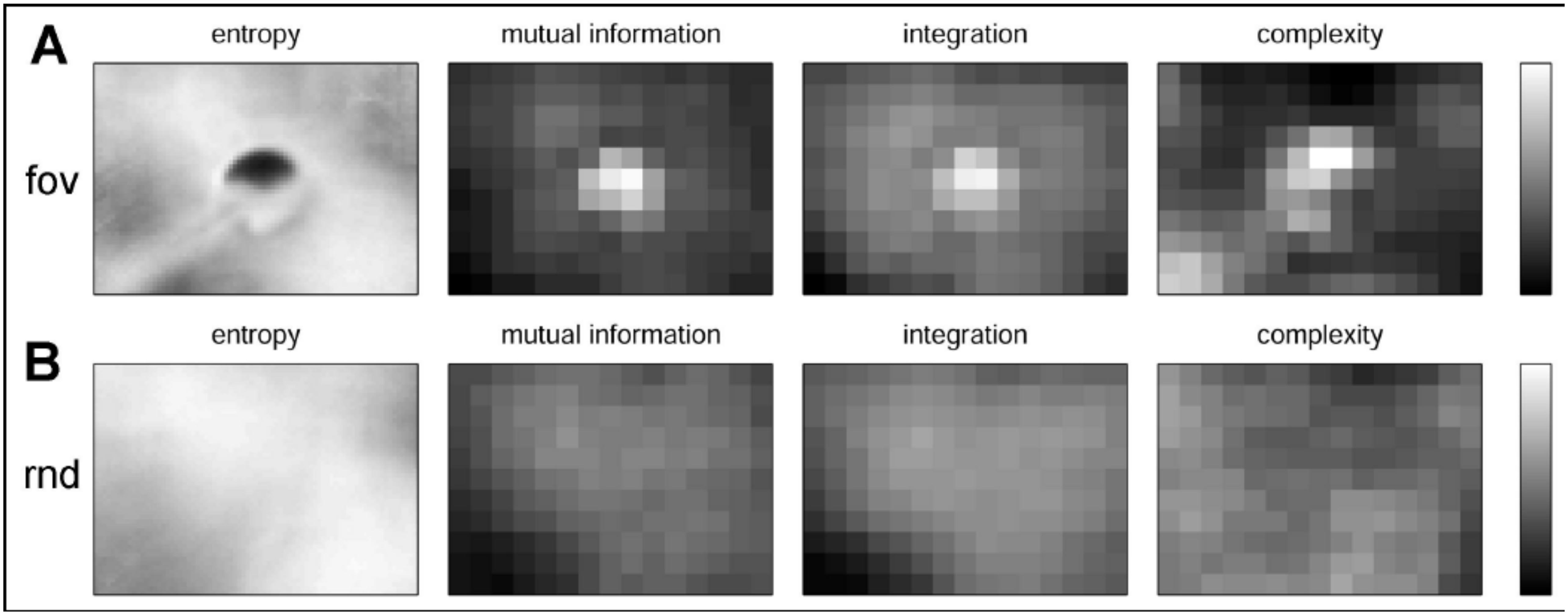
$$I(\boldsymbol{X}) = \sum_i H(x_i) - H(\boldsymbol{X})$$

complexity: co-existence of local and global structure

$$C(\boldsymbol{X}) = H(\boldsymbol{X}) - \sum_i H(x_i | \boldsymbol{X} - x_i).$$

from: **Tononi, Sporns, and Edelman, PNAS, 1994, 1996**

Results: foveation vs. random



entropy

mutual information

integration (over patch)

complexity (over patch)

Information Driven Self Organization

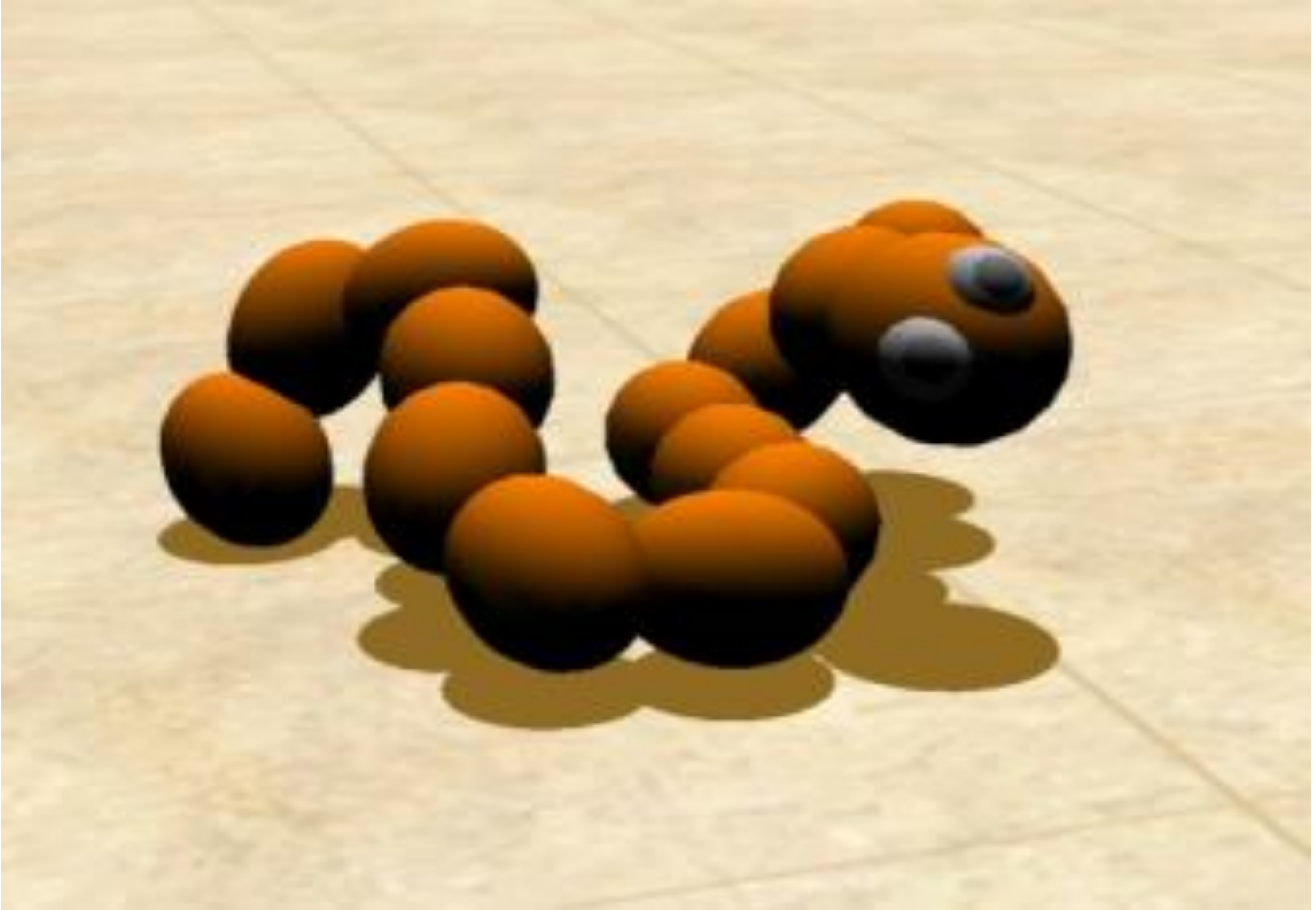
Why not using information metrics to implement an emergent control?

Several researchers have shown the importance of Information Driven Self Organization (IDSO).

In particular Prokopenko, Ralf Der and others have shown simple demonstrators, mainly in simulation, with snake-bots, humanoids and grasping systems.

These approaches seem very promising.

Snakebot



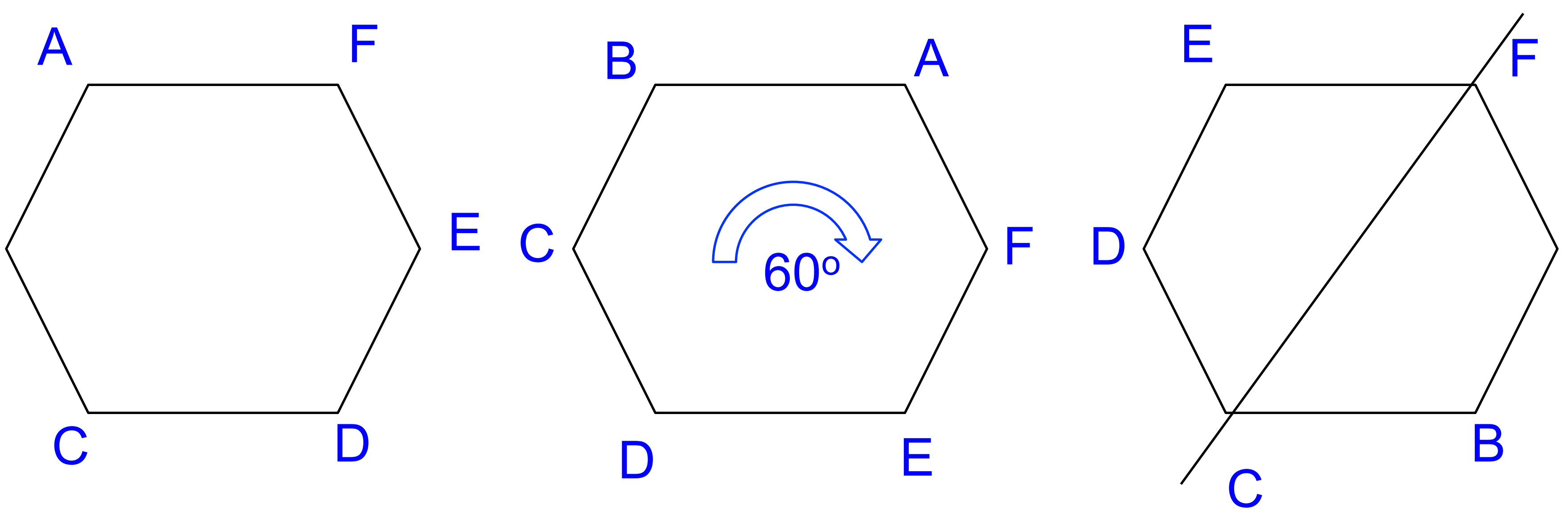
see: **Tanev et. al, IEEE TRO, 2005**

Maybe not GOF Euclidean space? :-)

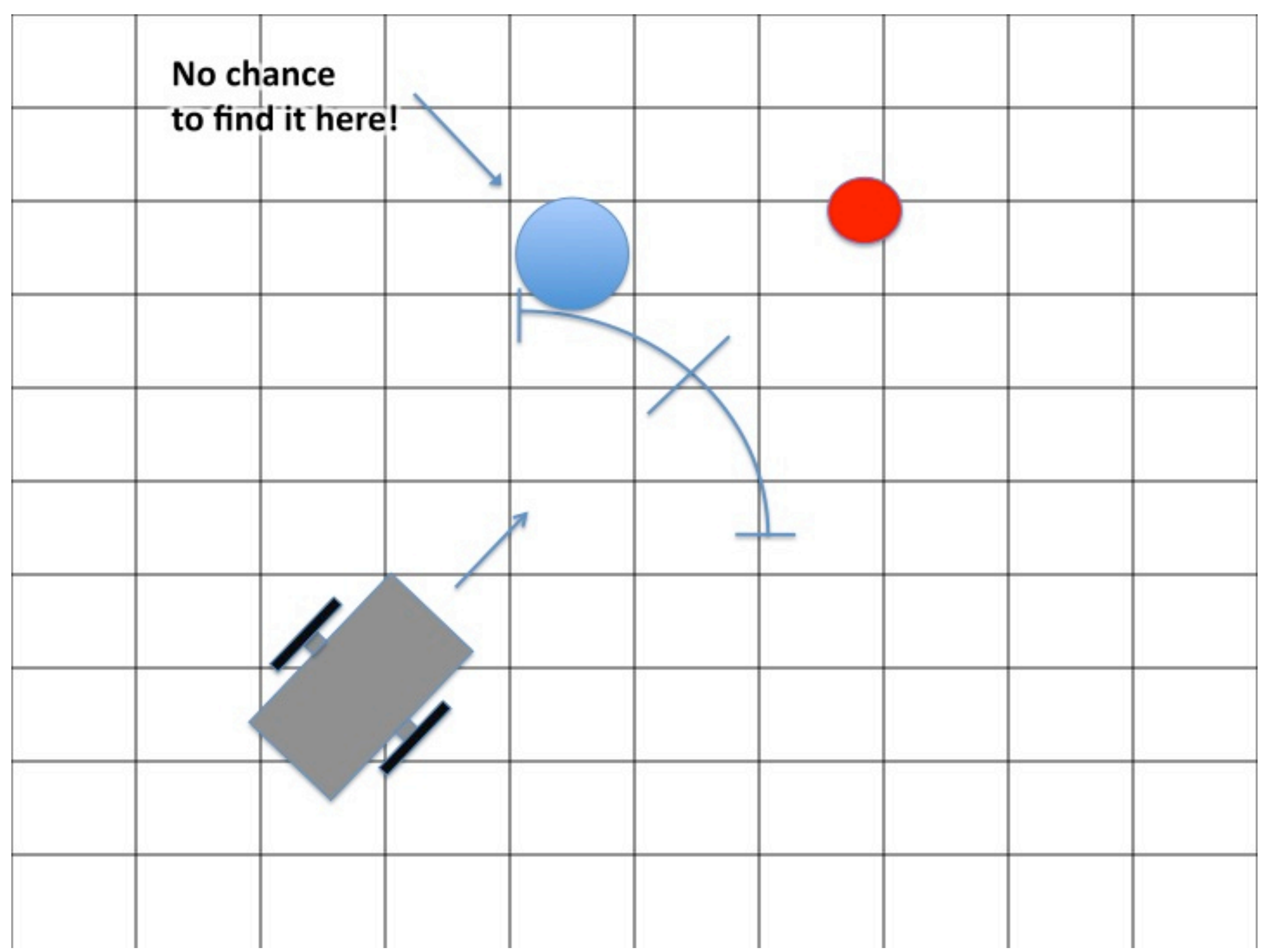
Unfortunately IDSO approaches are computationally heavy.

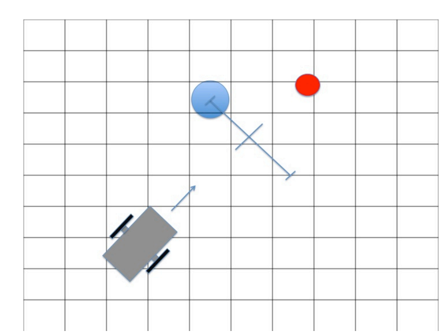
In [Chirikjian, 2010; Bonsignorio, 2010] it is argued that the recognition of the Lie group structure of the mobility space may help planning methods based on searching in the configurations space.

In Bonsignorio, Artificial Life,19(2), 2013 the possibilities of the IDSO on Lie groups are shown from a theoretical standpoint.



Maybe not GOF Euclidean space? :-)





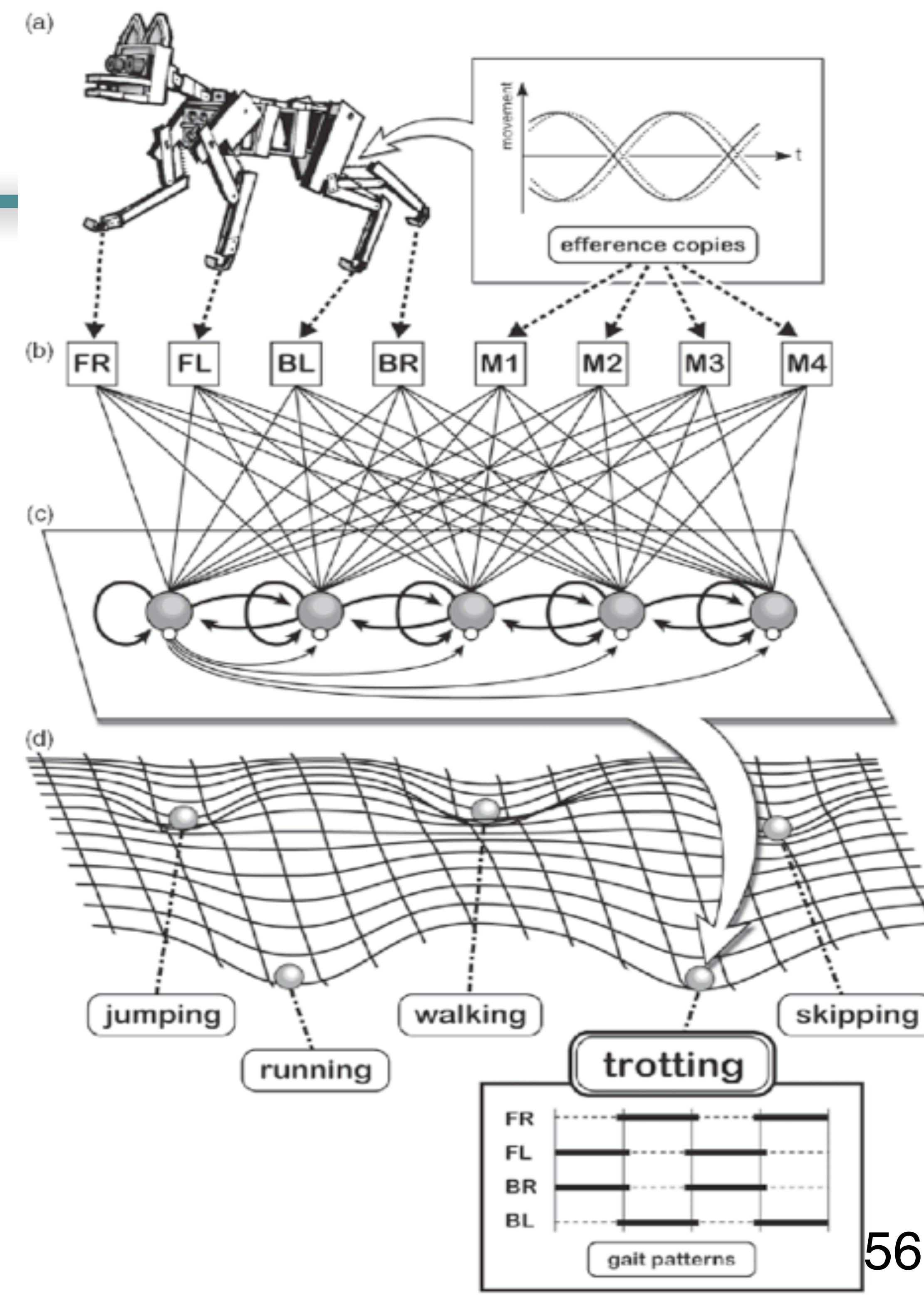
see: **Bonsignorio, Artificial Life, 2013**

Building grounded symbols (labeling!)

Human: **grasping object — patterns of sensory stimulation "match" morphology of agent**

Puppy: **patterns from pressure sensors or joint angle trajectories: match morphology of agent**

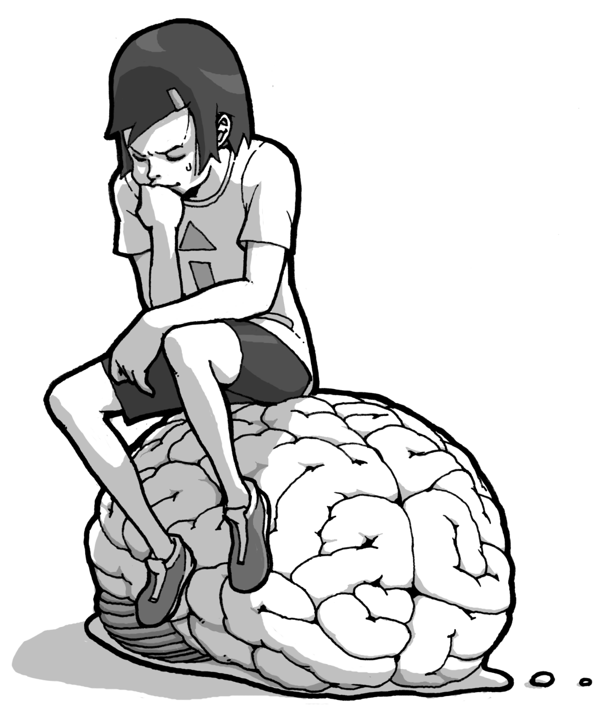
grounding for "high-level" cognition



End of lecture 6

Thank you for your attention!

stay tuned for the guest lecture



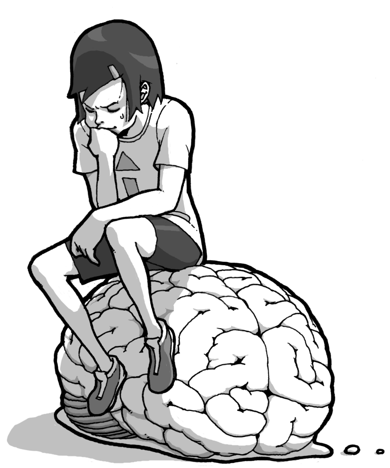
Assignments for next week

- **Next lecture on 8 December 2016: “Industry Day/…”.**
- **Continue to read “How the body …”**
- **Additional study materials (on web site)**

End of lecture 6

Thank you for your attention!

stay tuned for lecture 7 “Industry day/Ethics-Societal-Economy”



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Fabio Bonsignorio
Prof,the BioRobotics Institute, SSSA
CEO and Founder Heron Robots
Santander - UC3M Chair of Excellence 2010

Research interests

- **embodied intelligence, cognition/AI and robotics**
- **experimental methods in Robotics and AI**
- **Advanced approaches to Industry 4.0**
- **synthetic modeling of life and cognition**
- **novel technologically enabled approaches to higher education and lifelong learning**

The ShanghAI Lectures
2013-2016

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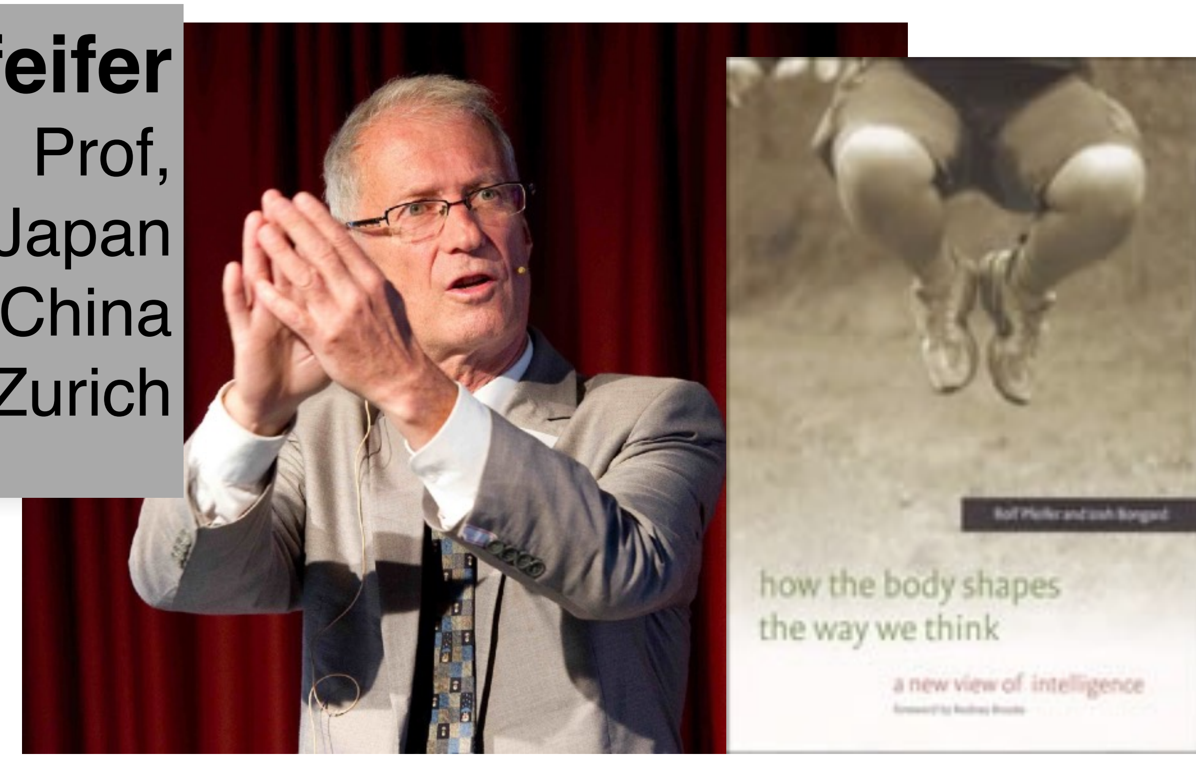
Dept. of Automation, Shanghai Jiao Tong University, China
Prof Em.,Former Director AI Lab, Univ. of Zurich

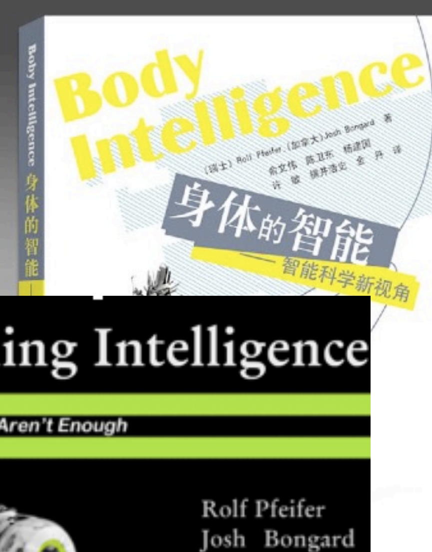


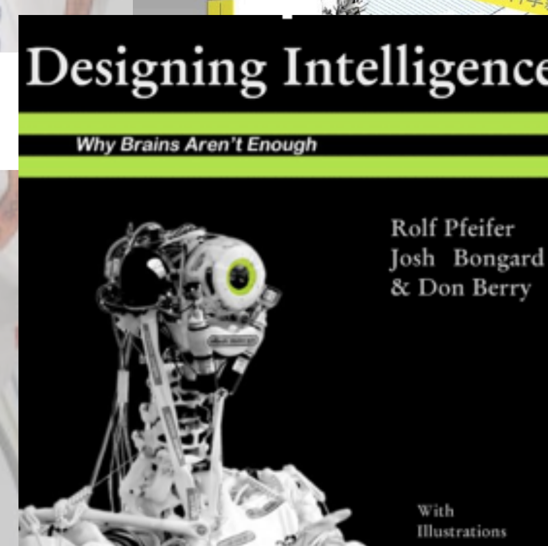
Research interests

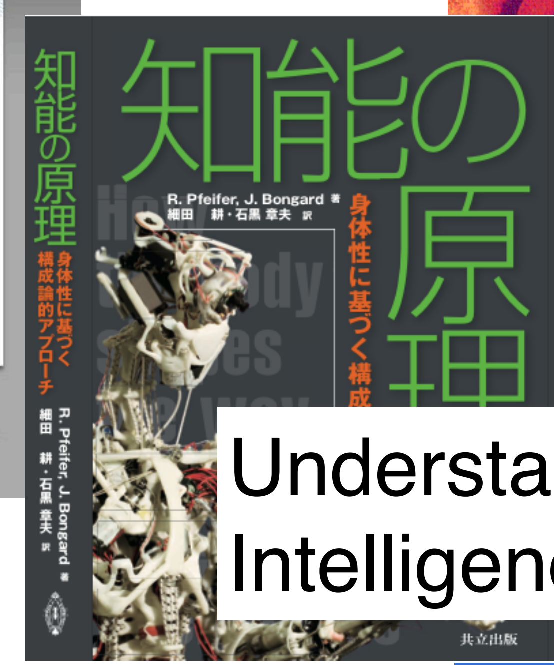
- **embodied intelligence**
- **bio-inspired robotics**
- **self-organization and emergence**
- **educational technologies**

How the body shapes the way we think

MIT Press







Understanding Intelligence

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