Lecture 5. Mc, self-organization of behaviors and adaptive morphologies

Fabio Bonsignorio
The BioRobotics Institute, SSSA, Pisa, Italy and Heron Robots

Older and newer attempts

Juanelo Torriano alias Gianello della Torre, (XVI century) a craftsman from Cremona, built for Emperor Charles V a mechanical young lady who was able to walk and play music by picking the strings of a real lute.

Hiroshi Ishiguro, early XXI century

Director of the Intelligent Robotics Laboratory, part of the Department of Adaptive Machine Systems at Osaka University, Japan

The need for an embodied perspective

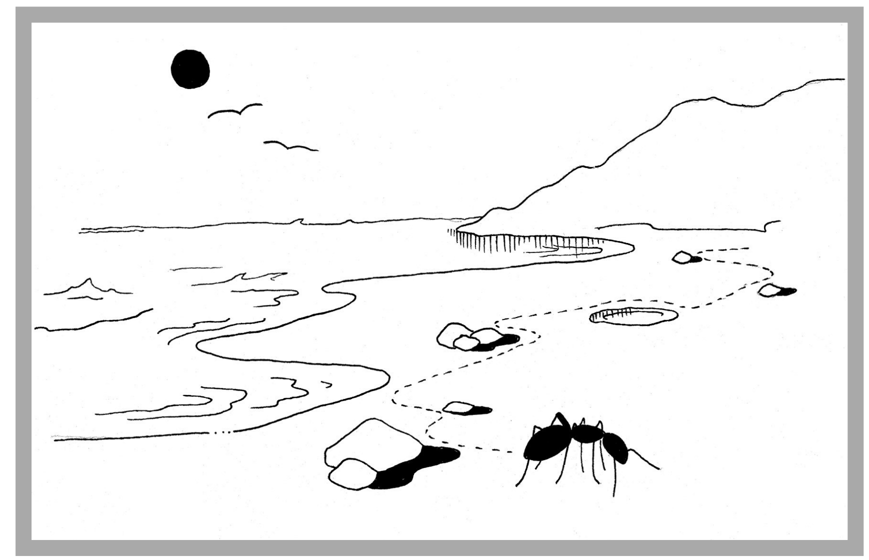
- "failures" of classical AI
- fundamental problems of classical approach
- Wolpert's quote: Why do plants not have a brain? (but check Barbara Mazzolai's lecture at the ShanghAI Lectures 2014)
- Interaction with environment: always mediated by body

Two views of intelligence

classical:
cognition as computation

embodiment:
cognition emergent from sensory-motor and interaction processes

“Frame-of-reference” Simon’s ant on the beach

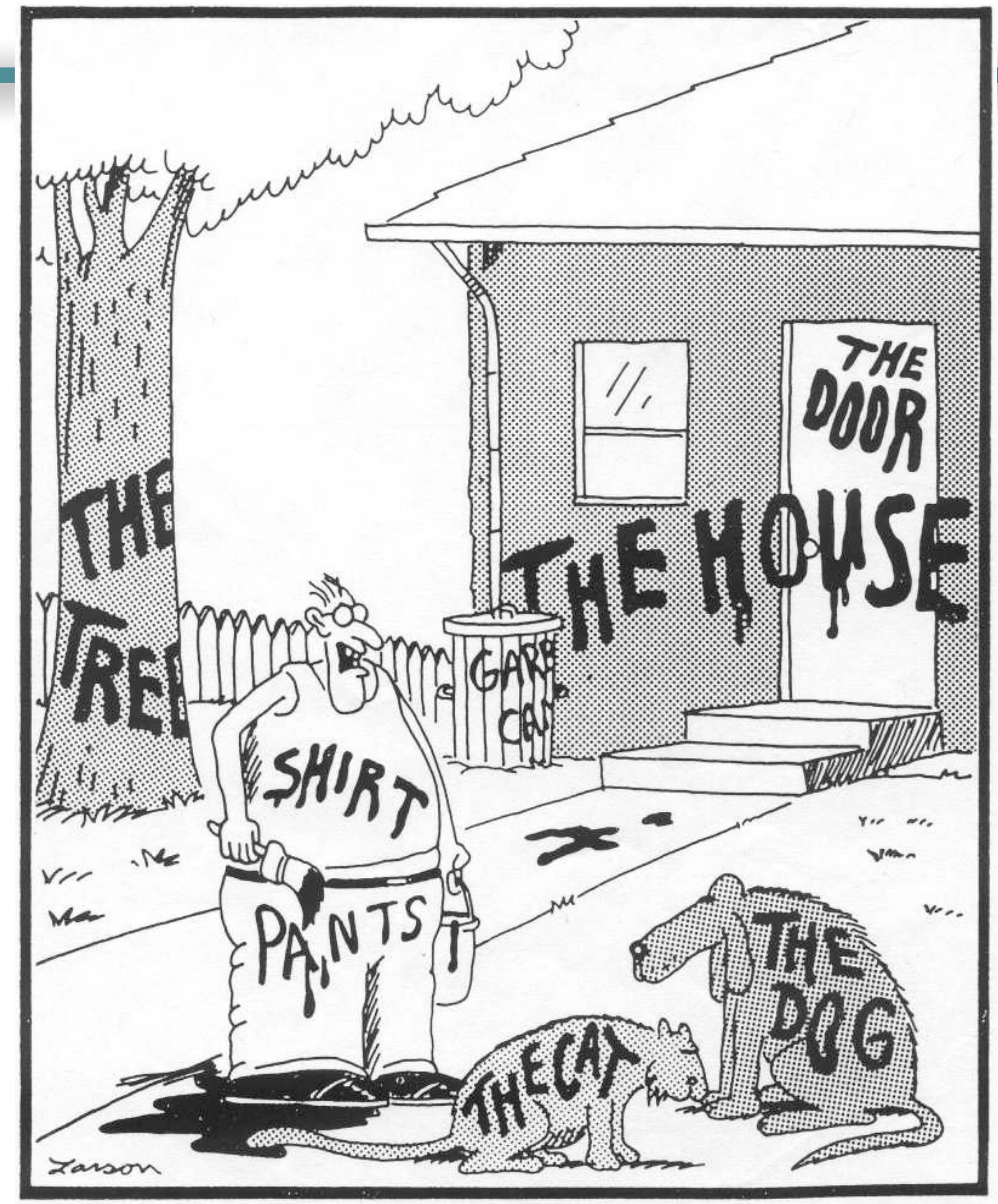


- **simple behavioral rules**
- **complexity in interaction, not — necessarily — in brain**

- thought experiment:
  increase body by factor of 1000

The “symbol grounding” problem

real world:
doesn’t come
with labels …



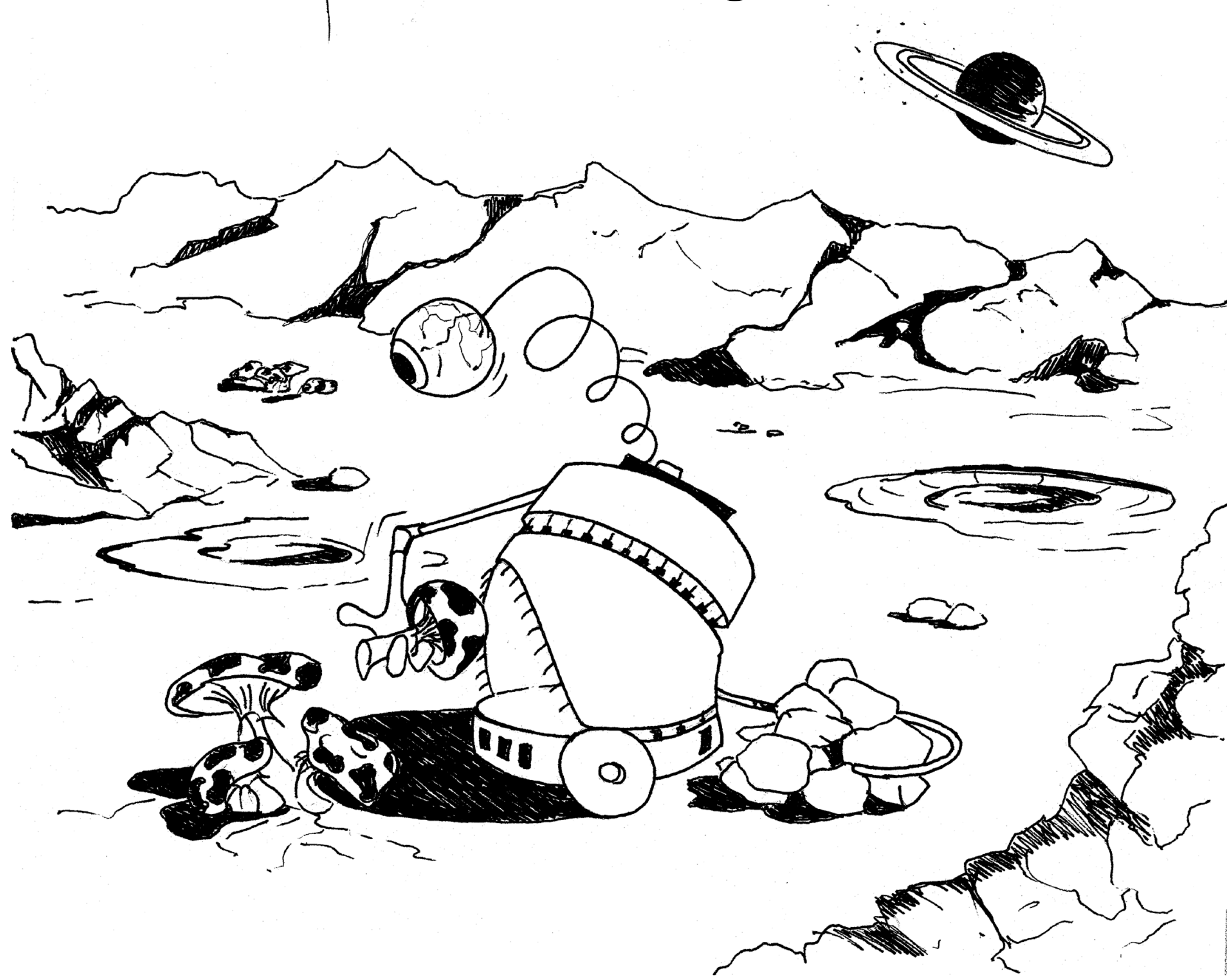
“Now! ... *That* should clear up a few things around here!”

How to put the labels??

Gary Larson

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

Complex dynamical systems

non-linear system -
in contrast to a linear one
—> Any idea?

Complex dynamical systems

concepts: focus box 4.1, p. 93, “How the body …”

- dynamical systems, complex systems, non-linear dynamics, chaos theory
- phase space
- non-linear system — limited predictability, sensitivity to initial conditions
- trajectory

Today’s topics

- short recap
- characteristics of complete agents
- **illustration of design principles**
- parallel, loosely coupled processes: the “subsumption architecture”
- case studies: “Puppy”, biped walking
- “cheap design” and redundancy

Design principles for intelligent systems

Principle 1: Three-constituents principle

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

Three-constituents principle

define and design

- **"ecological niche"**
- **desired behaviors and tasks**
- **design of agent itself**

design stances

scaffolding

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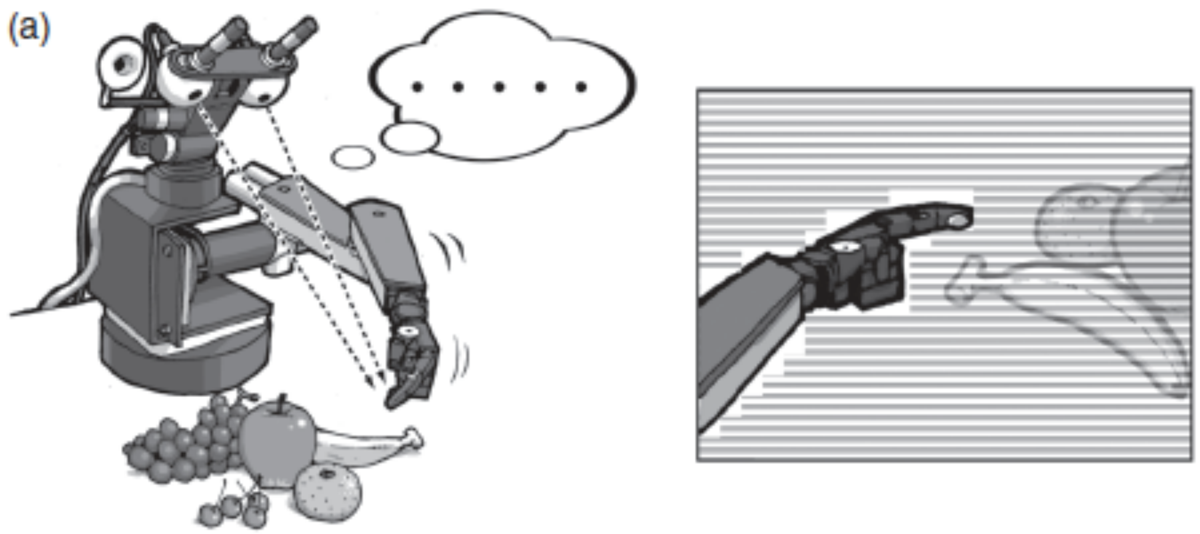
Complete-agent principle

- always think about complete agent behaving in real world
- isolated solutions: often artifacts — e.g., computer vision (contrast with active vision)
- biology/bio-inspired systems: every action has potentially effect on entire system

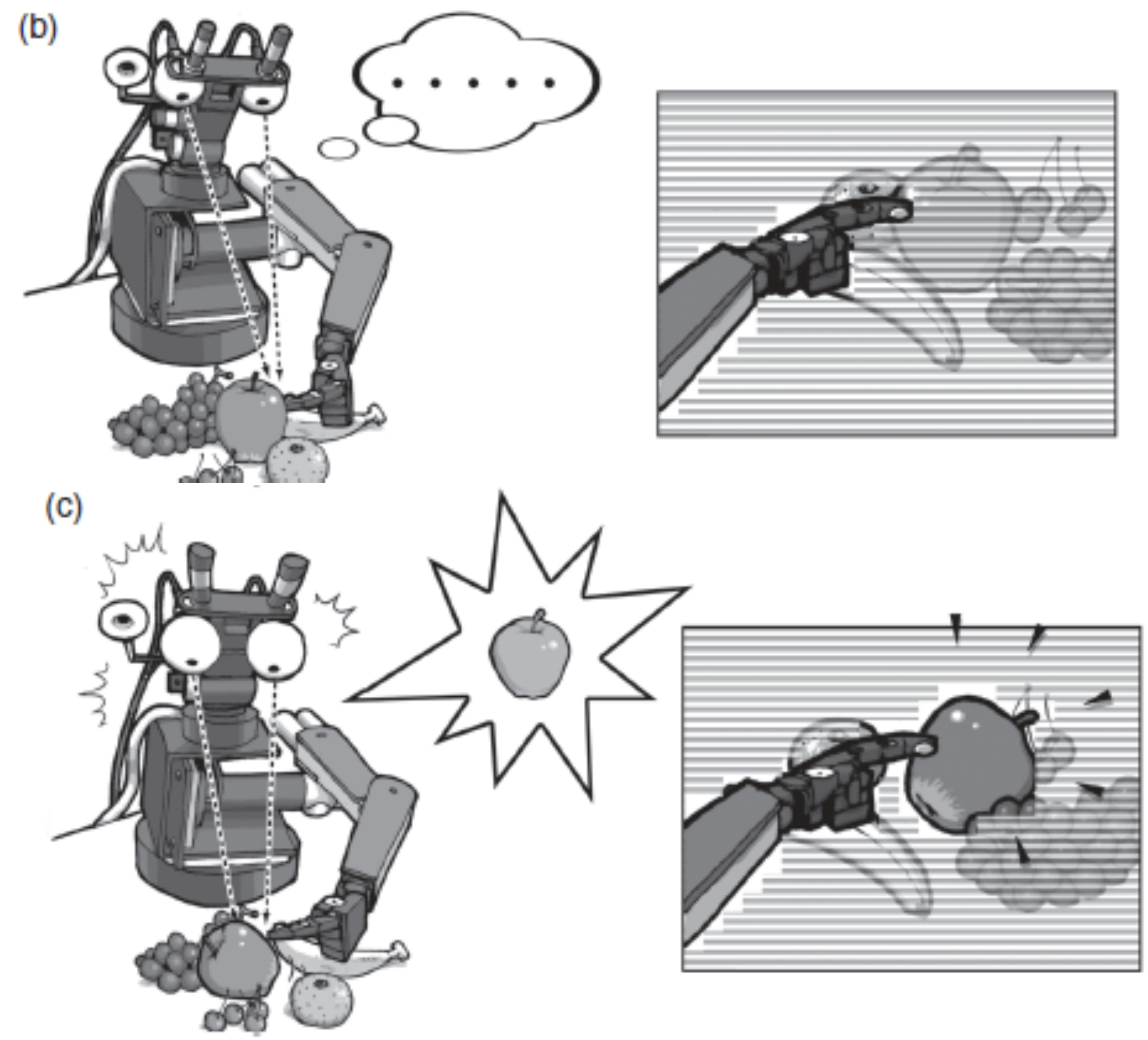
→ can be exploited!

Recognizing an object in a cluttered environment



manipulation of environment can facilitate perception

Experiments: **Giorgio Metta and Paul Fitzpatrick**



Illustrations by Shun Iwasawa

Today’s topics

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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**

The subsumption architecture

classical, cognitivistic

sensors → perception - modeling - planning - acting → actuators

sense-model-plan-act

sense-think-act

"behavior-based", subsumption

sensors

→ explore →

→ collect object →

→ avoid obstacle →

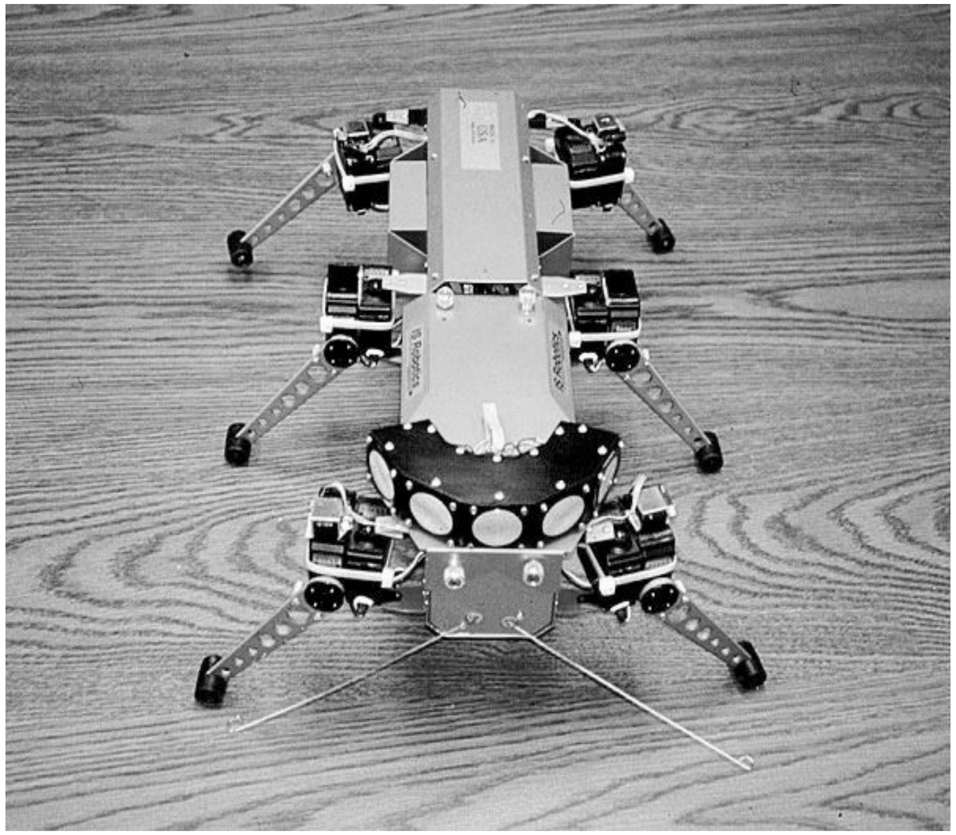
→ move foreward →

actuators

Mimicking insect walking

- **subsumption architecture well-suited**

six-legged robot “Ghenghis”

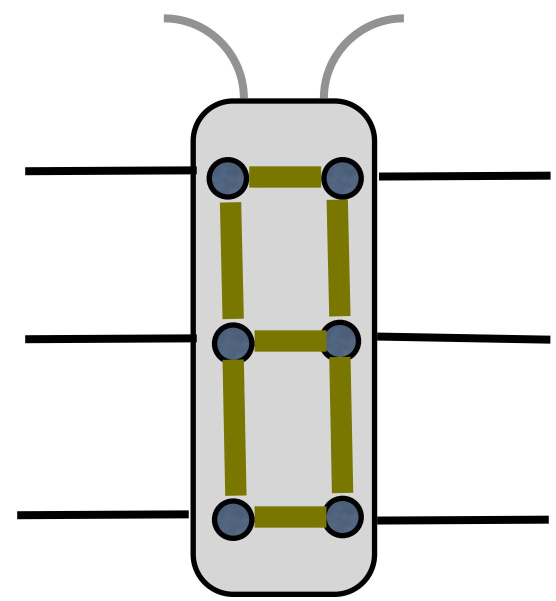


Insect walking

Holk Cruse, German biologist

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

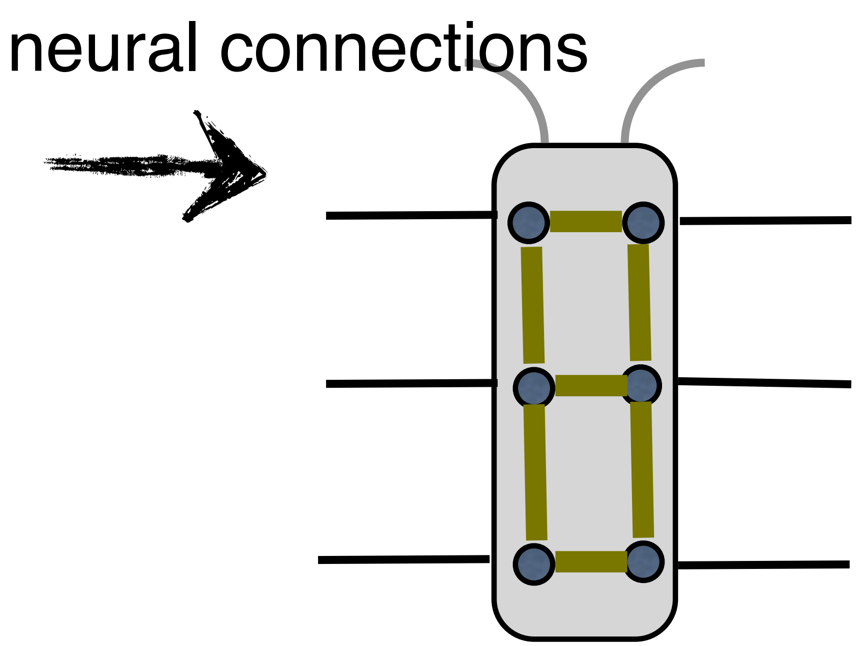
neural connections



Insect walking

Holk Cruse, German biologist

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



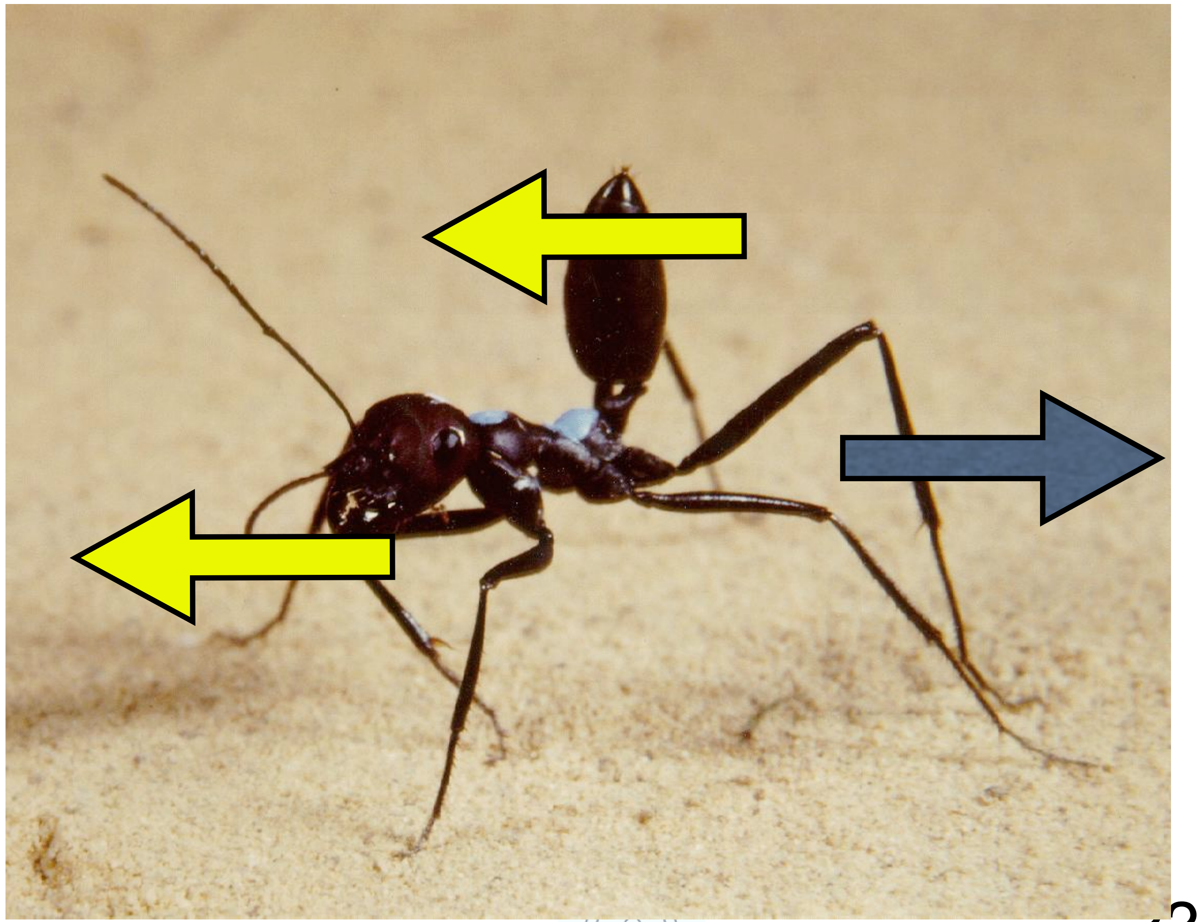
Communication through interaction with

- **exploitation of interaction with environment**

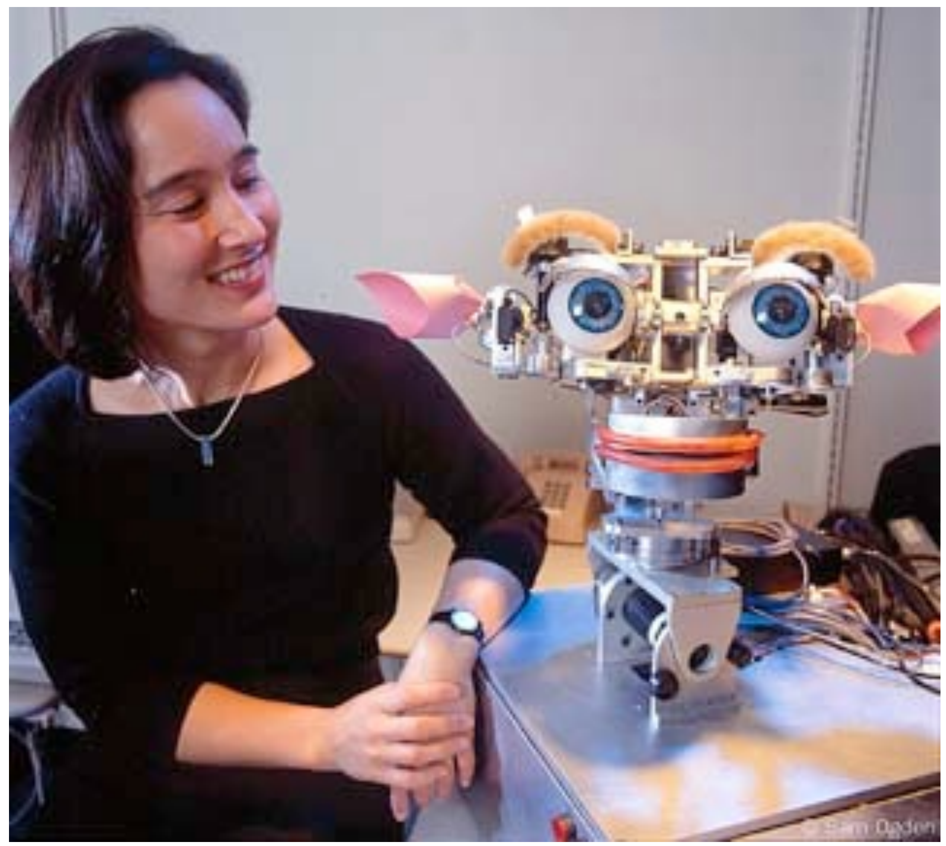
  → **simpler neural circuits**

angle sensors in joints

“parallel, loosely coupled processes”



Kismet: The social interaction robot



Cynthia Breazeal, MIT Media Lab
(prev. MIT AI Lab)

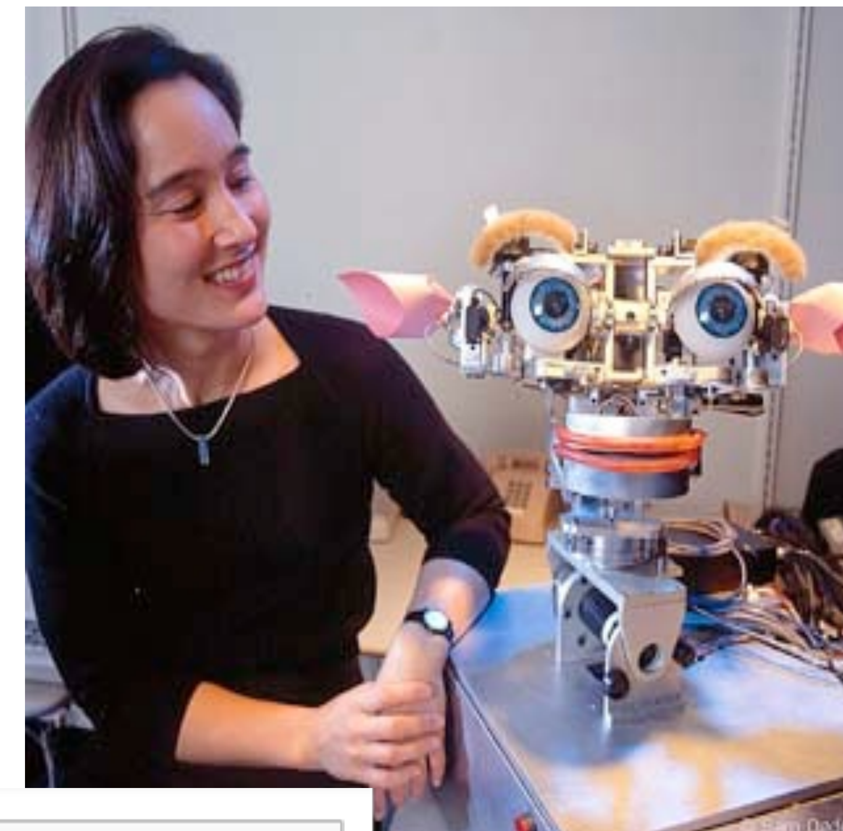
Kismet: The social interaction robot

Video "Kismet"

Cynthia Breazeal, MIT Media Lab
(prev. MIT AI Lab)

Kismet: The social interaction robot

Reflexes:
- **turn towards loud noise**
- **turn towards moving objects**
- **follow slowly moving objects**
- **habituation**



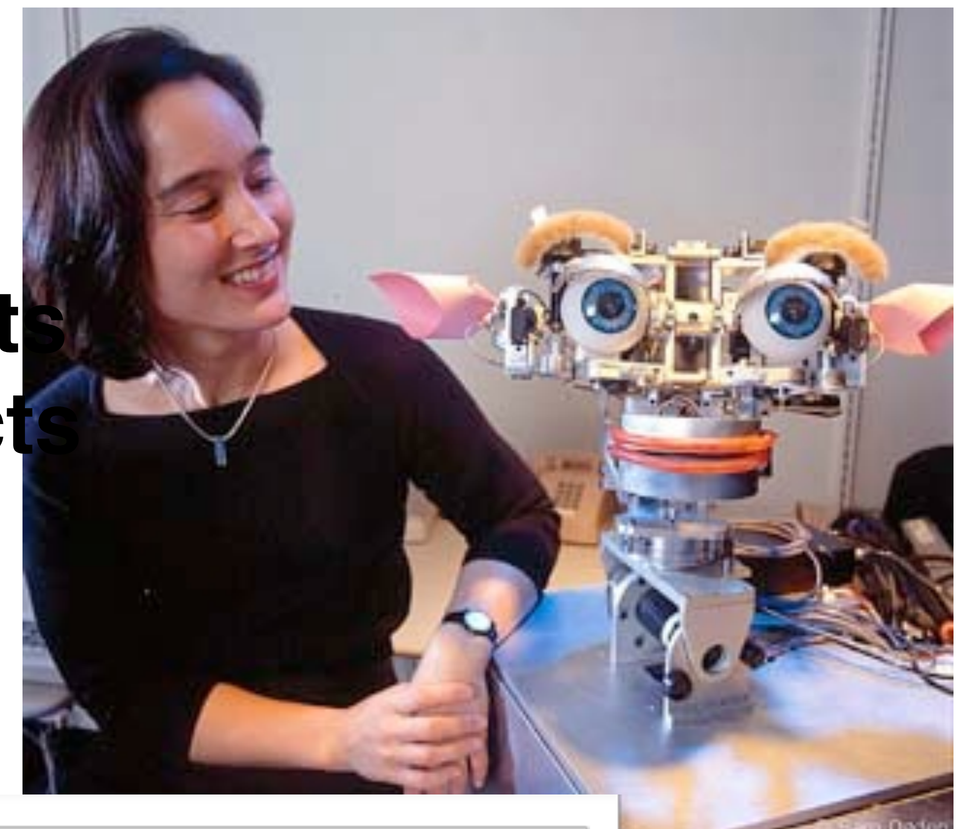
principle of “parallel, loosely coupled processes”

zeal, MIT

lab (prev. MIT AI Lab)

Kismet: The social interaction robot

Reflexes:
- turn towards loud noise
- turn towards moving objects
- follow slowly moving objects
- habituation



zeal, MIT

lab (prev. MIT AI Lab)

social competence: a collection of reflexes ?!?!???

Scaling issue: the "Brooks-Kirsh" debate

insect level —> human level?

David Kirsh (1991): "Today the earwig, tomorrow man?"

Rodney Brooks (1997): "From earwigs to humans."

Scaling issue: the "Brooks-Kirsh" debate

insect level —> human level?

David K… tomorrow man?"

Rodney … to humans…

volunteer for brief presentation on the "Brooks-Kirsh" debate - or generally, scalability of subsumption (on a later date)

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- short recap
- characteristics of complete agents
- illustration of design principles
- parallel, loosely coupled processes: the subsumption architecture"
- **case studies: "Puppy", biped walking**
- "cheap design" and redundancy

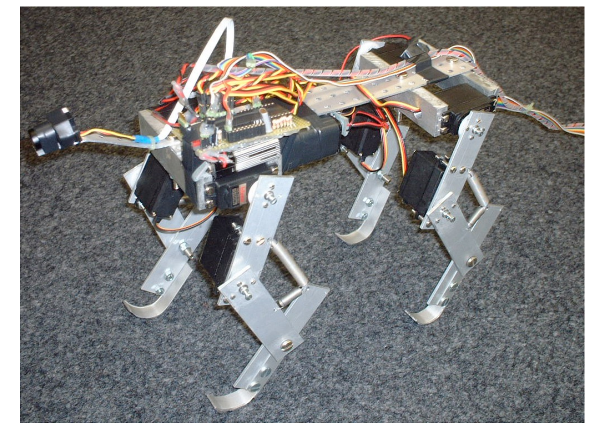
Case study: “Puppy” as a complex dynamical

- **running: hard problem**
- **time scales: neural system — damped oscillation of knee-joint**
- **“outsourcing/offloading” of functionality to morphological/material properties**

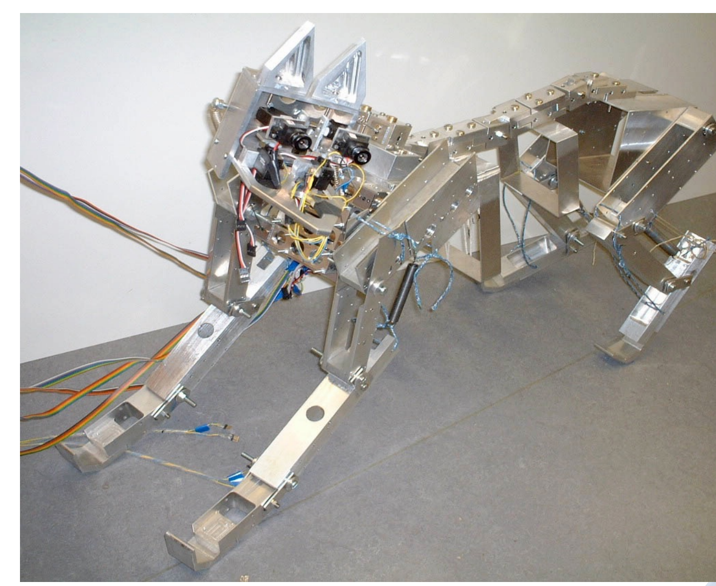
→ morphological computation

Recall: “Puppy’s” simple control

rapid locomotion in biological systems



recall: emergence of behavior

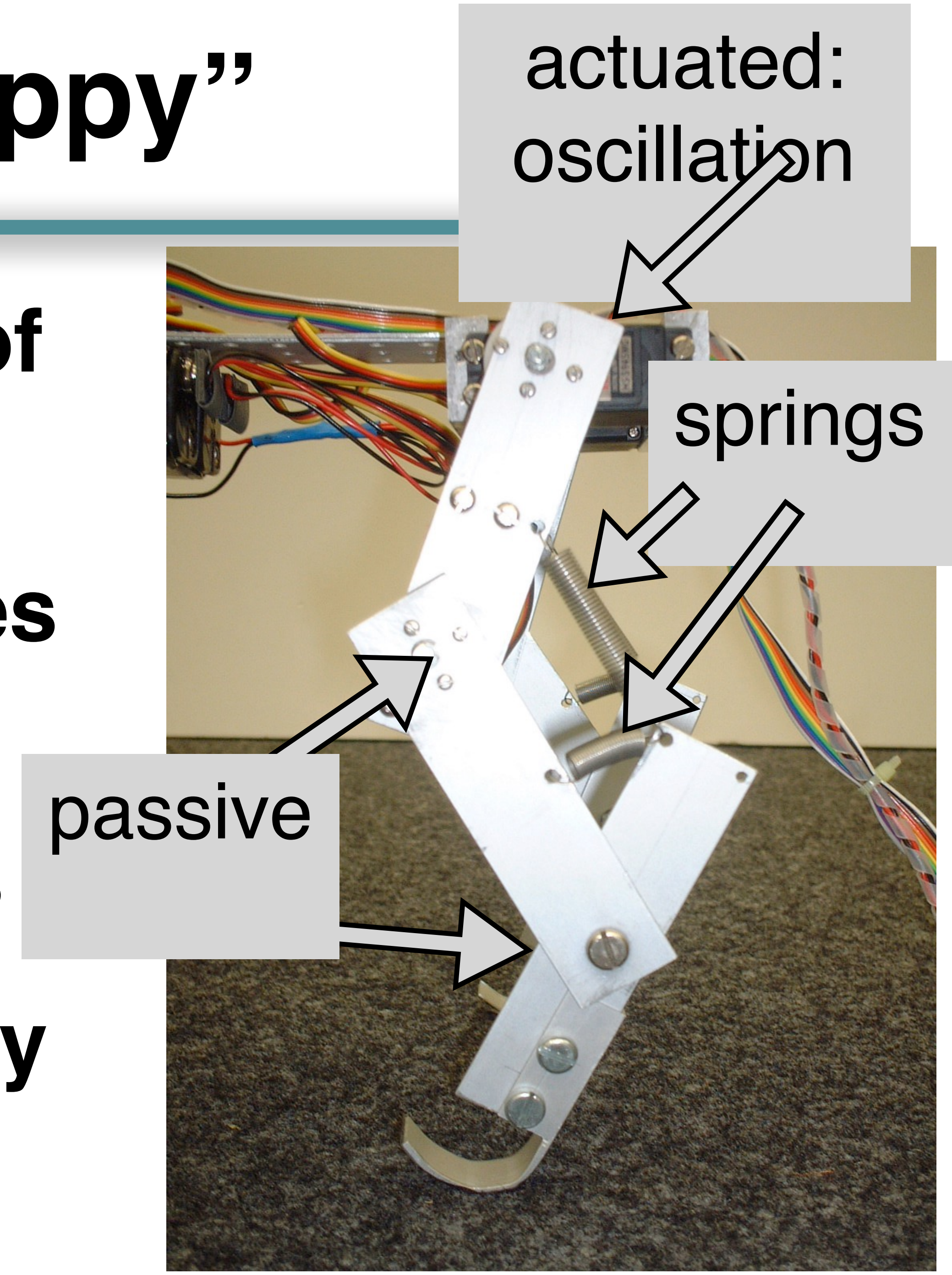


Design and construction:
Fumiya Iida, AI Lab, UZH and ETH-Z

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



Self-stabilization: “Puppy” on a treadmill

Video “Puppy” on treadmill

Self-stabilization: “Puppy” on a treadmill

Video “Puppy” on treadmill slow motion

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

self-stabilization

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Self-stabilization: “Puppy” on a treadmill

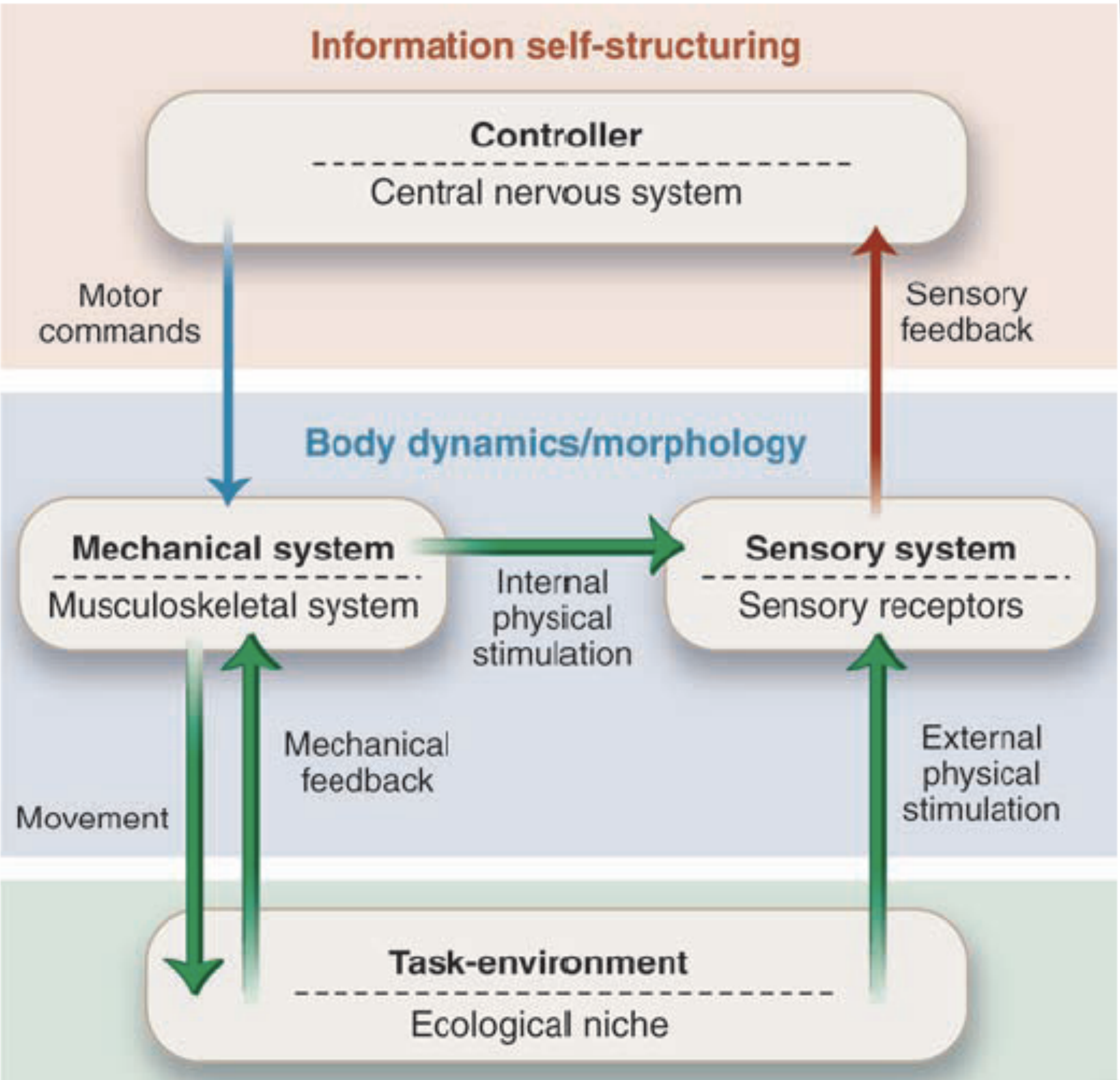
Video “Puppy” on treadmill slow motion

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

principle of “cheap design”

self-stabilization

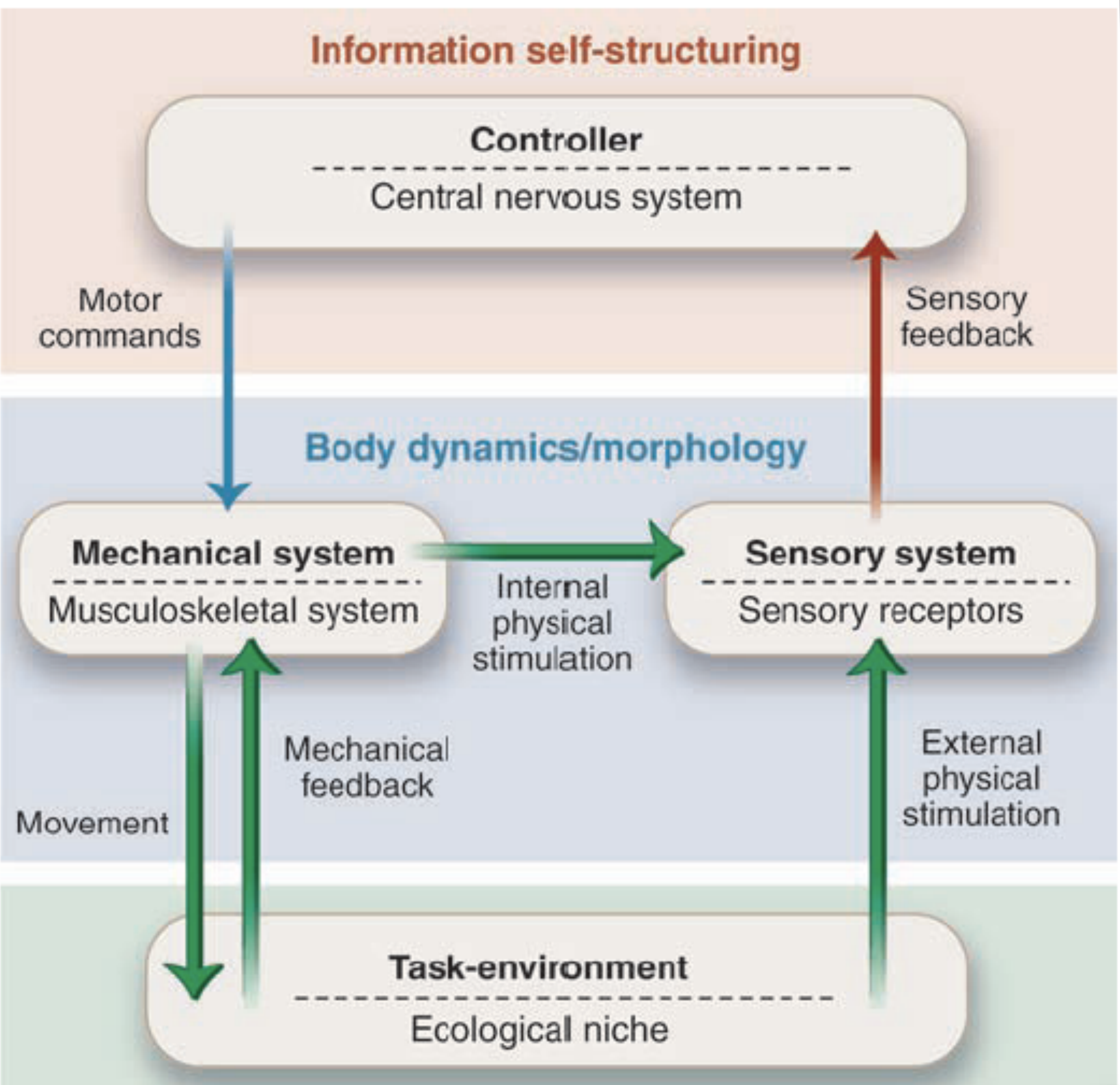
Implications of embodiment



"Puppy"

Pfeifer et al.,Science, 16 Nov. 2007

Implications of embodiment



"Puppy"

which part of diagram is relevant?

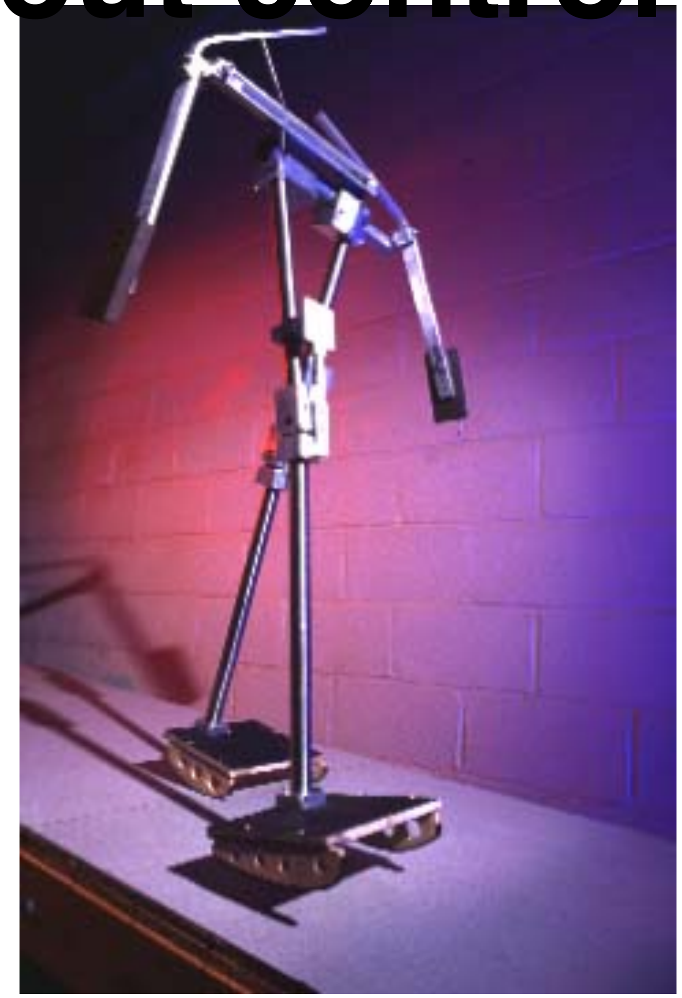
—>

Pfeifer et al.,Science, 16 Nov. 2007

Extreme case: The "Passive Dynamic

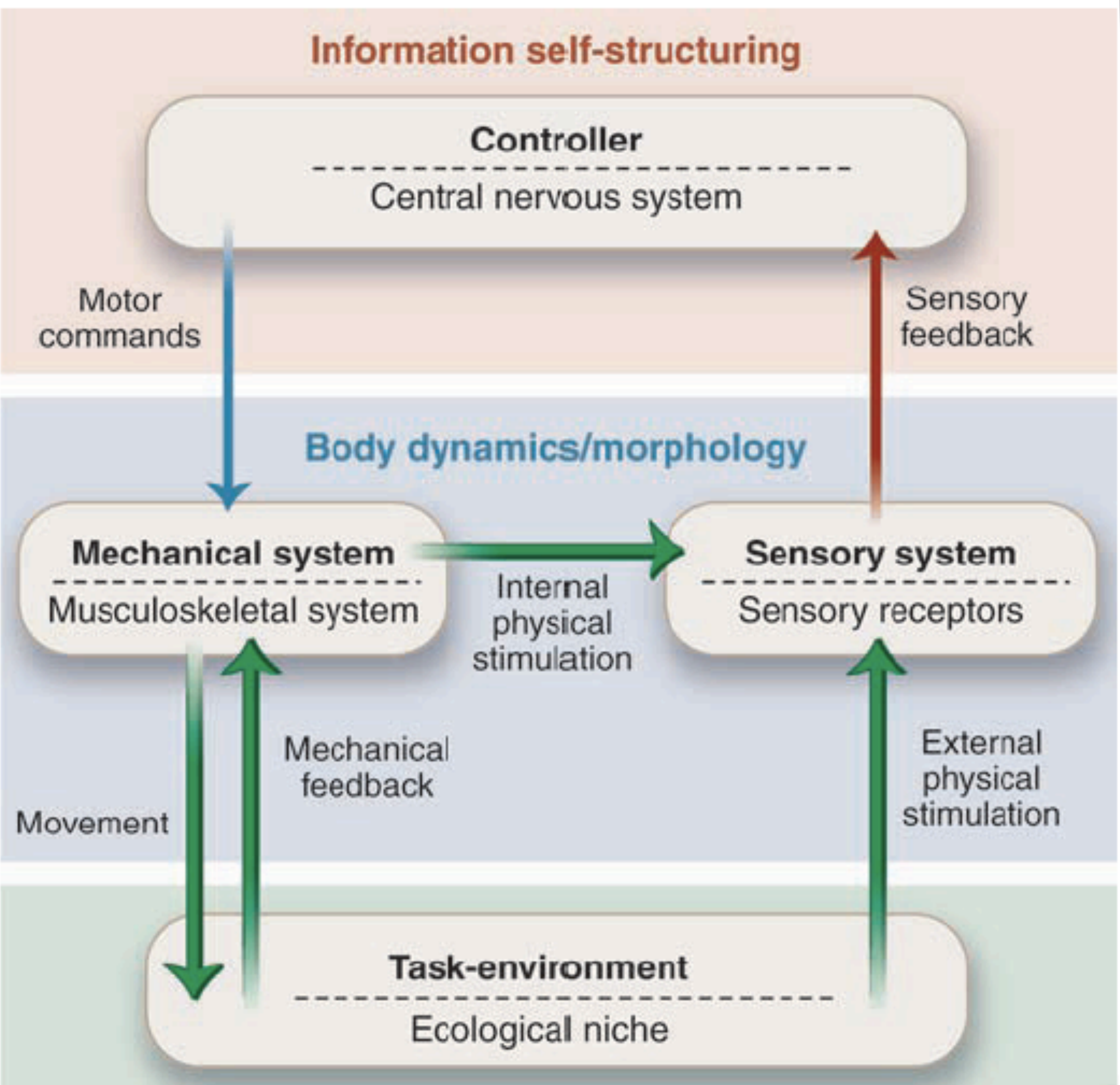
The "brainless" robot": walking without control

Video "Passive Dynamic Walker"



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

Implications of embodiment



Passive Dynamic Wal

which part of diagram relevant? —> Shanghai

Pfeifer et al.,Science, 16 Nov. 2007

Short question

memory for walking?

The Cornell Ranger

design and construction:
Andy Ruina
Corr

Video ”Cornell Ranger”

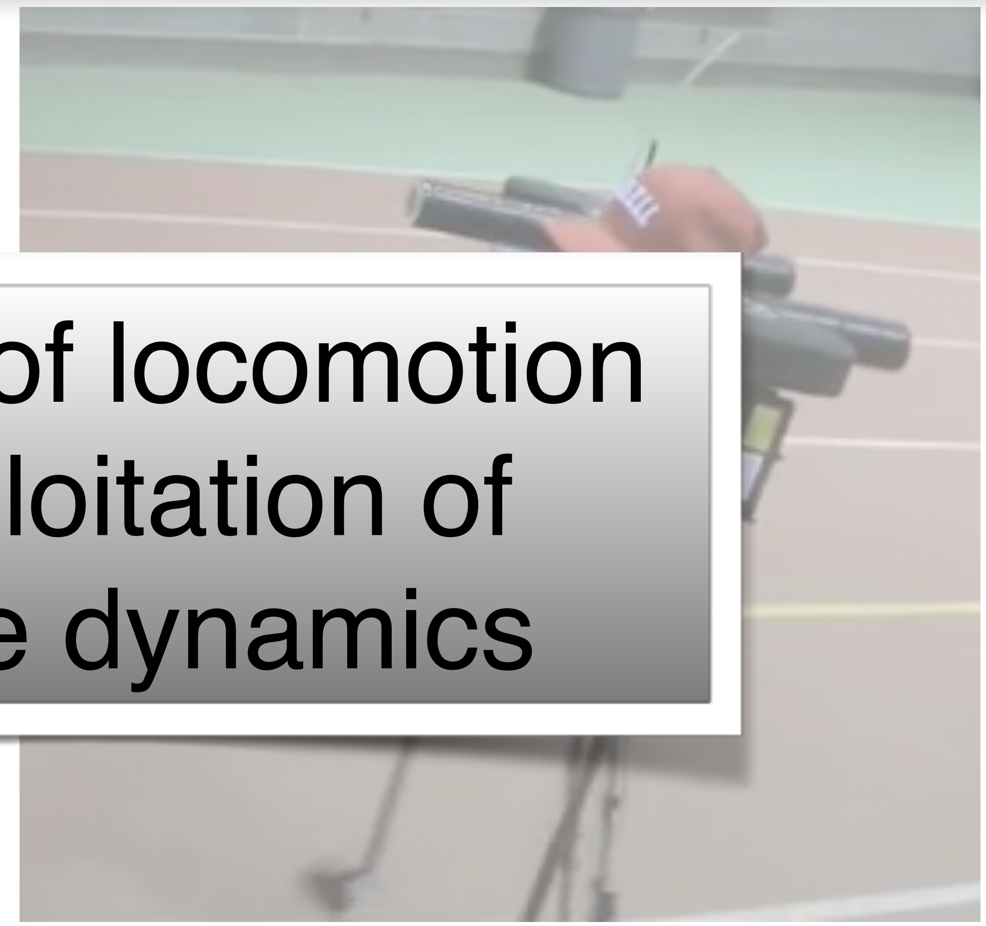
exploitation of passive dynamics

The Cornell Ranger

conception et construction:
Andy Ruina
Cornell University

65km with one battery charge!

The Cornell Ranger

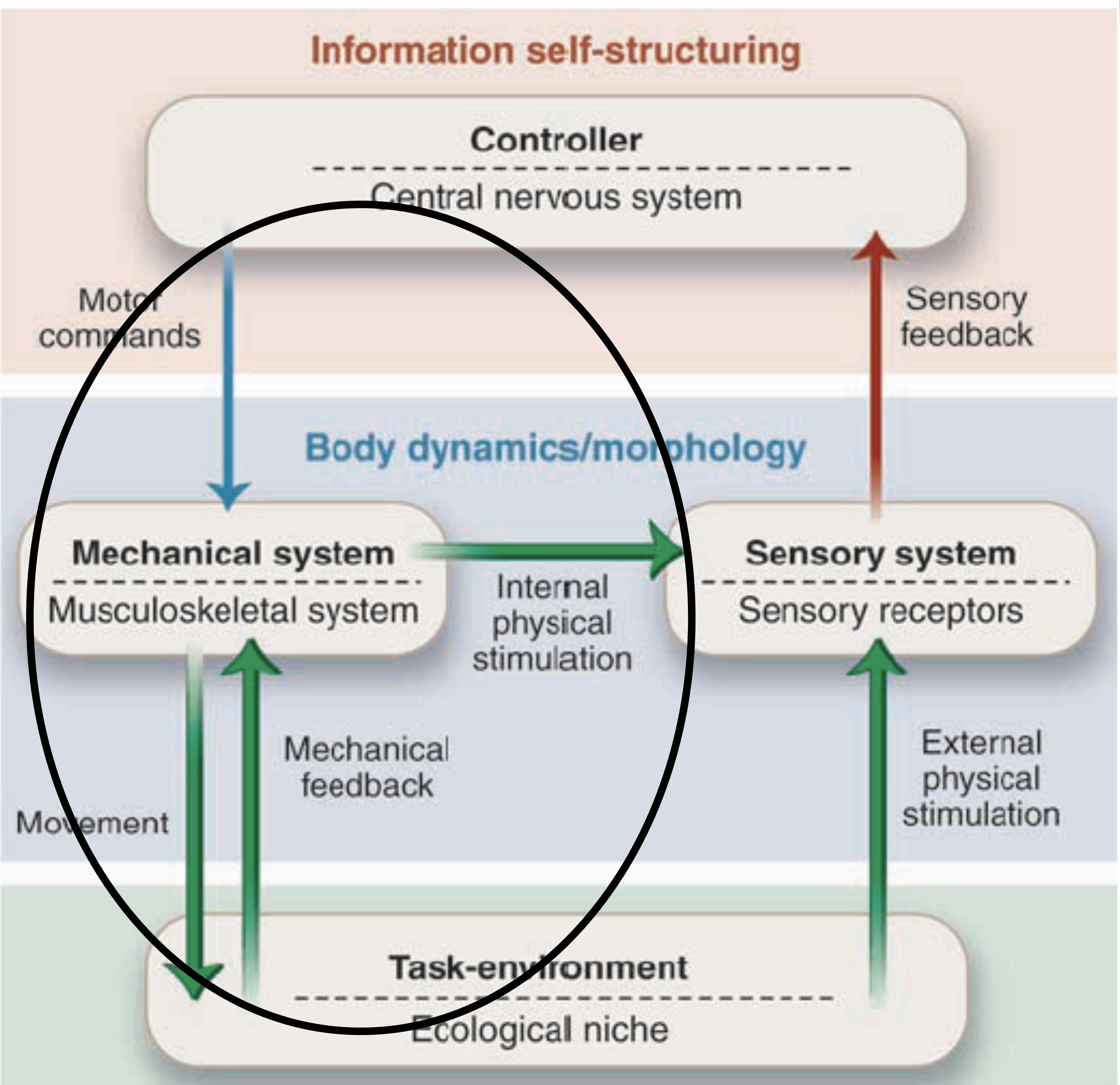


“control” of locomotion
by exploitation of
passive dynamics

conception
Andy Ruina
Cornell University

65km with one battery charge!

Self-stabilization in Cornell Ranger

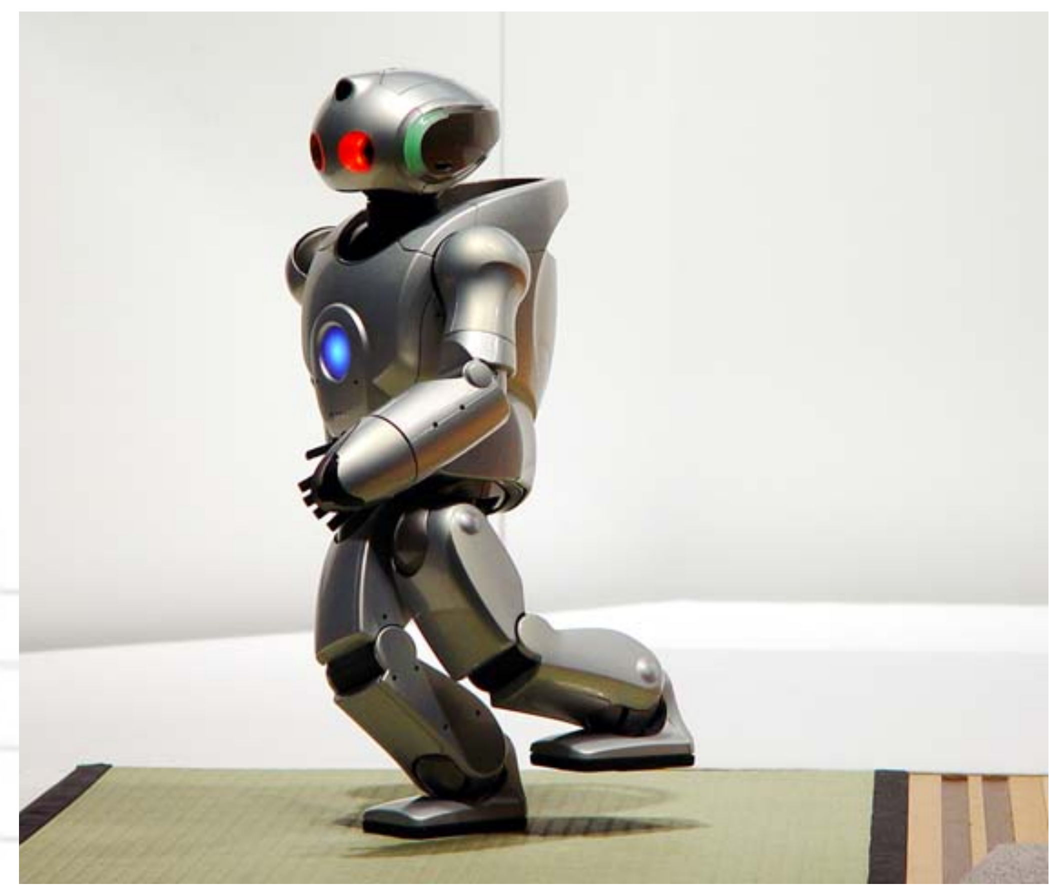


Pfeifer et al.,Science, 2007

Contrast: Full control

Honda Asimo

Sony Qrio



Principle of “ecological balance”

balance in complexity

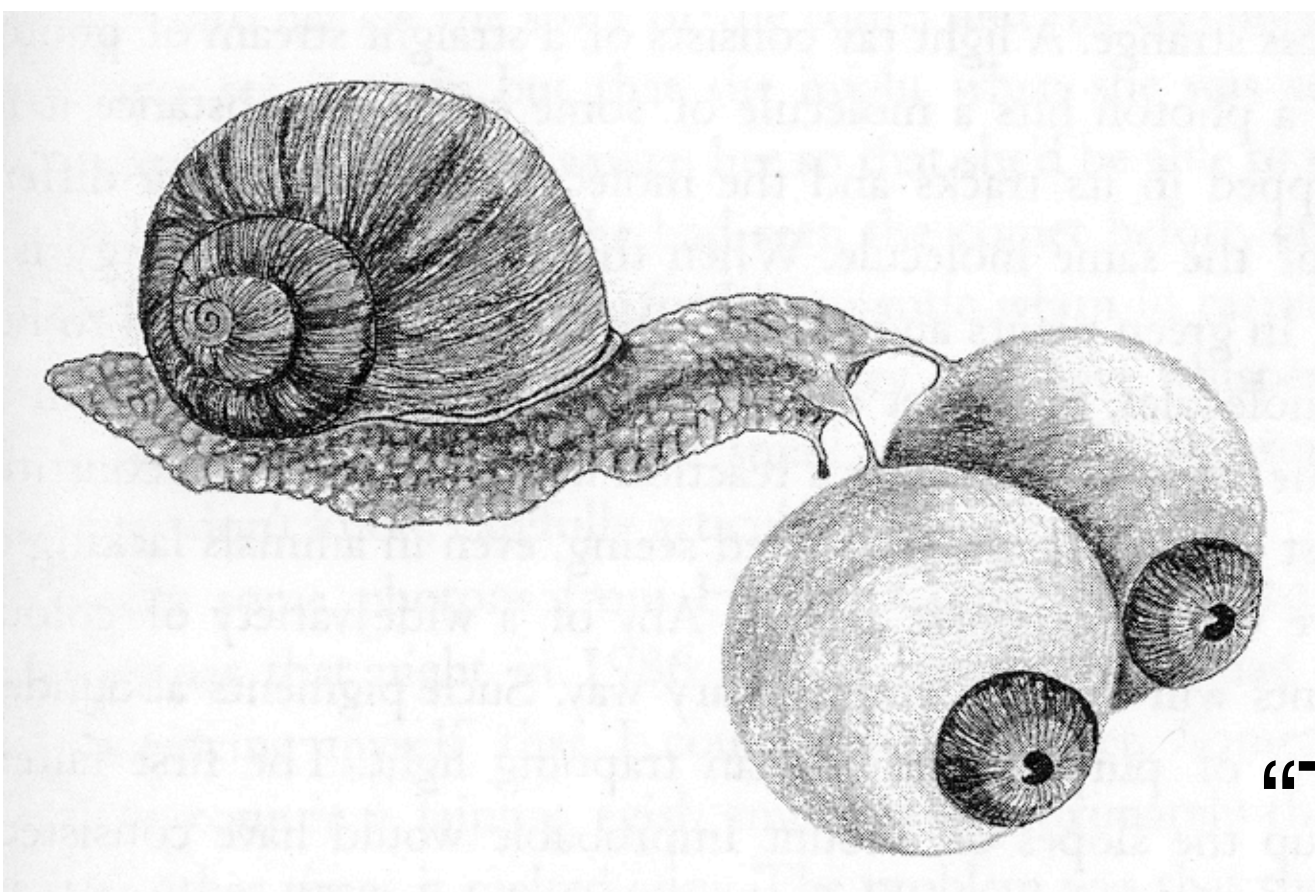
given task environment: match in complexity of sensory, motor, and neural system

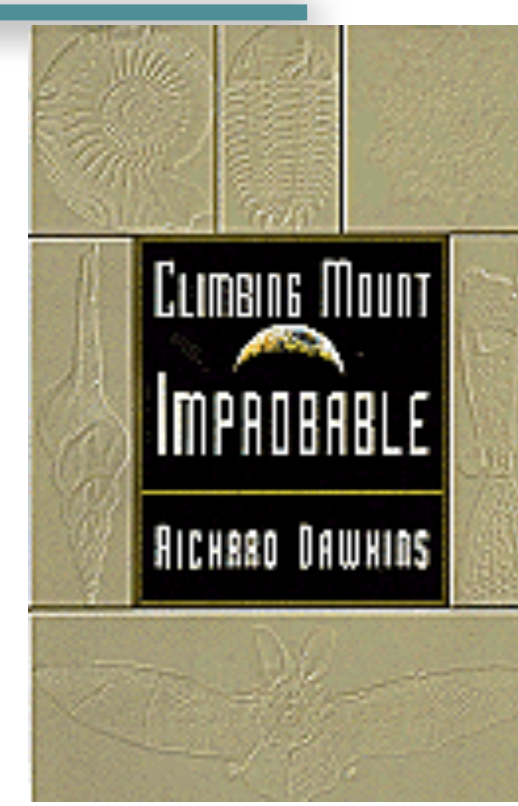
balance / task distribution

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

Richard Dawkins's snail with giant eyes

ecologically unbalanced system



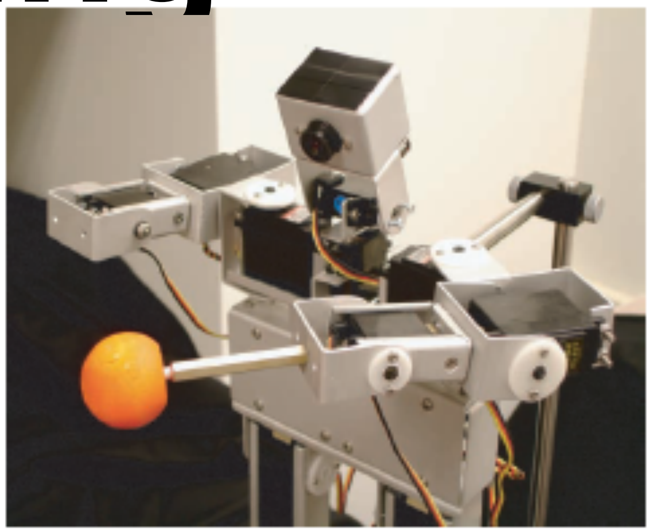


Author of:
"The selfish gene" and
"The blind watchmaker"

Probabilistic Model Of Control

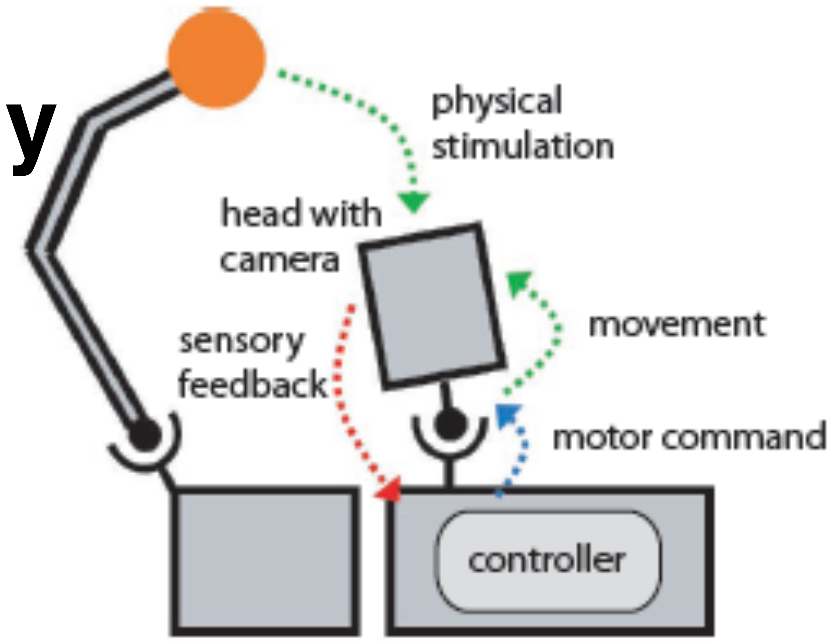
- Although it may seem strange only in recent times the classical results from Shannon theory, have been applied to the modeling of control systems.
- As the complexity of control tasks namely in robotics applications lead to an increase in the complexity of control programs, it becomes interesting to verify if, from a theoretical standpoint, there are limits to the information that a control program must manage in order to be able to control a given system.

Information self-structuring



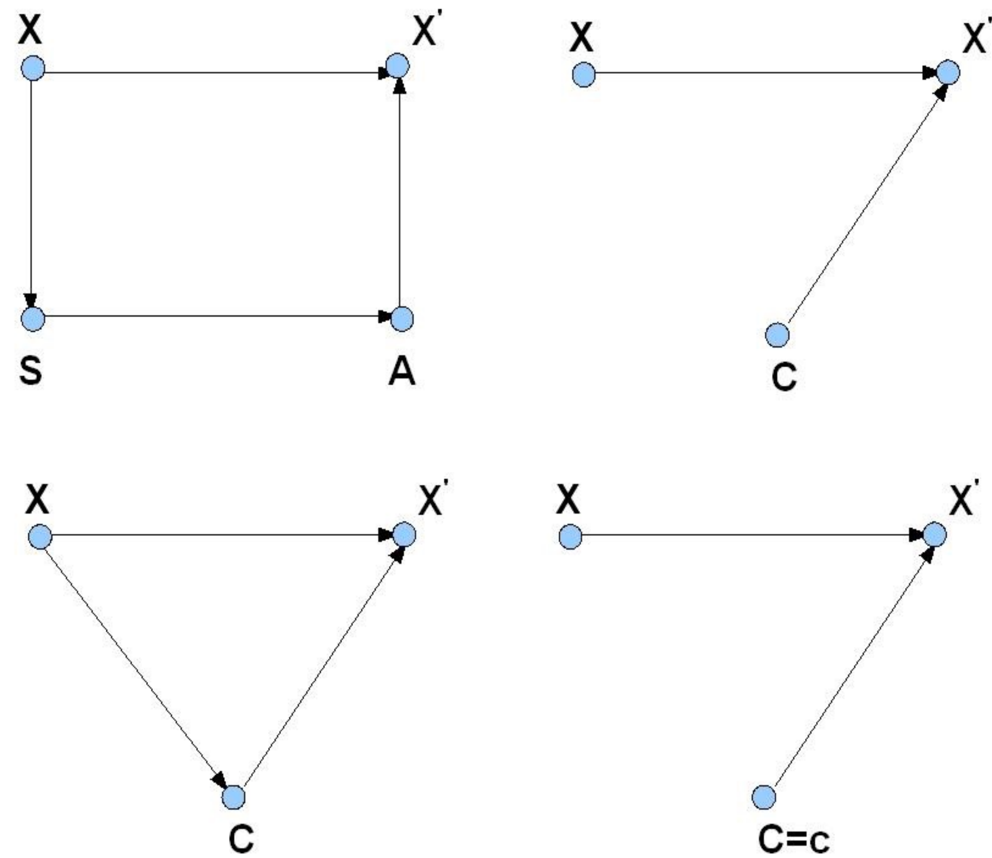
Experiments:

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



Probabilistic Model Of Control

Touchette, Lloyd (2004)



Directed acyclic graphs representing a control process. (Upper left) Full control system with a sensor and an actuator. (Lower left) Shrinked Closed Loop diagram merging sensor and actuator, (Upper right) Reduced open loop diagram. (Lower right) Single actuation channel enacted by the controller's state C=c.

Models of ‘Morphological Computation’

$$K(X) \overset{+}{\leq} \log \frac{W_{closed}}{W_{open}^{closed}} \qquad \text{(I)}$$

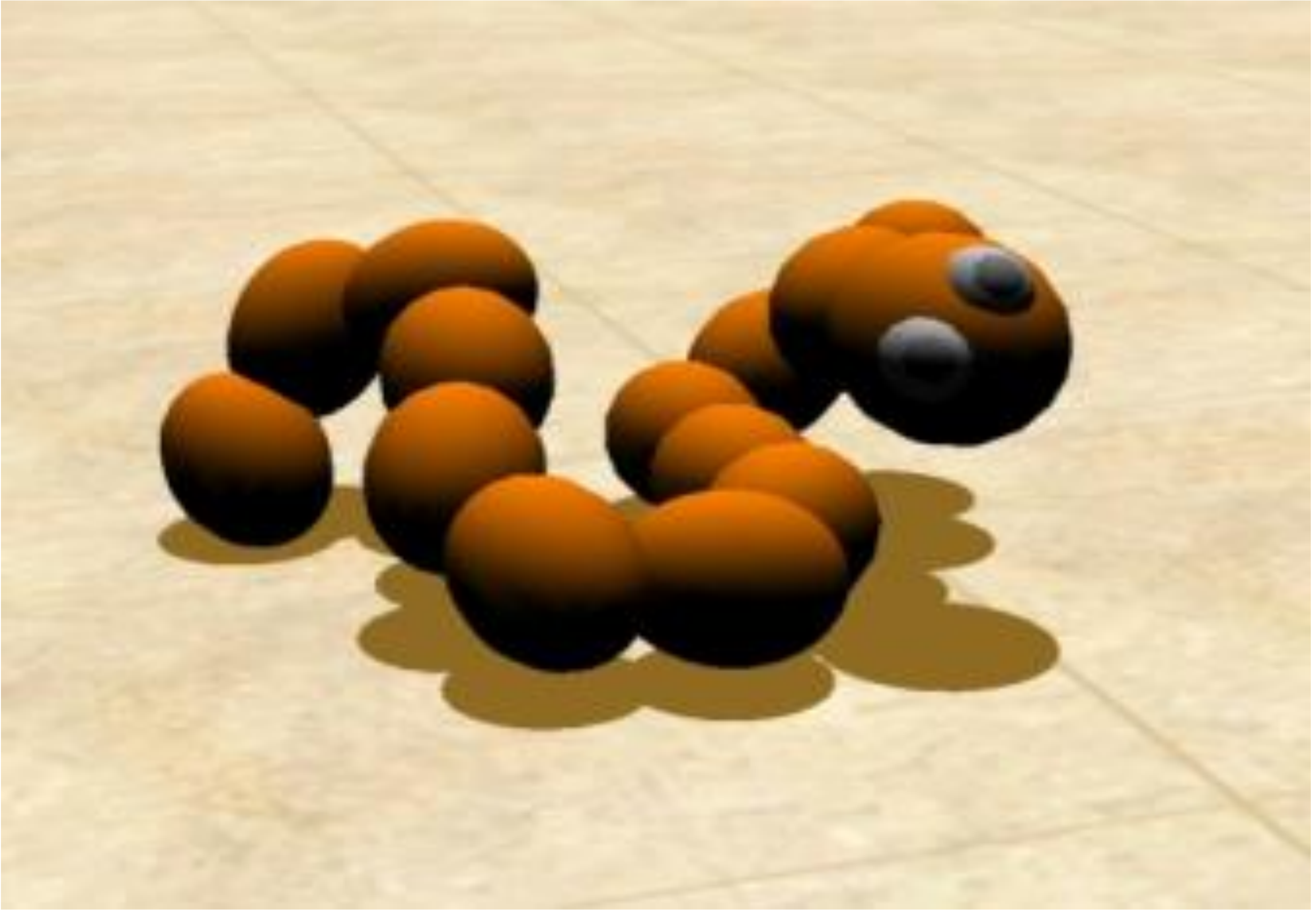
Relation (I) links the complexity ('the length') of the control program of a physical element to the state available in closed loop and the non controlled condition.
This show the benefits of designing stuctures whose 'basin of attractions' are close to the desired behaviors in the phase space.

Models of ‘Morphological Computation’

$$\Delta HN + \sum_{i}^{n} \Delta H_{i} - \Delta I \leq I\left(X;C\right) \quad \text{(II)}$$

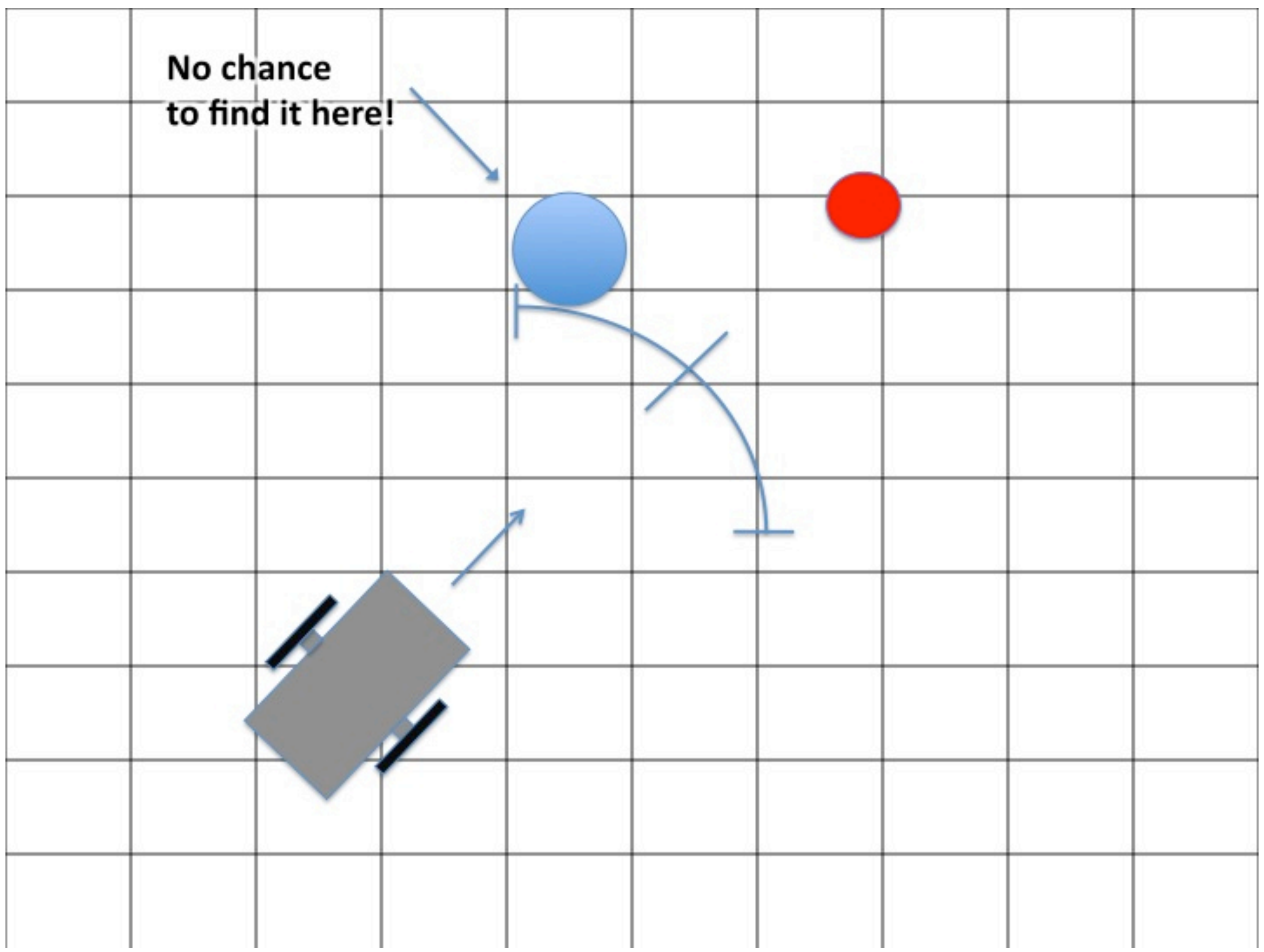
Relations (II) links the mutual information between the controlled variable and the controller to the information stored in the elements, the mutual information between them and the information stored in the network and accounts for the redundancies through the multi information term *ΔI*.

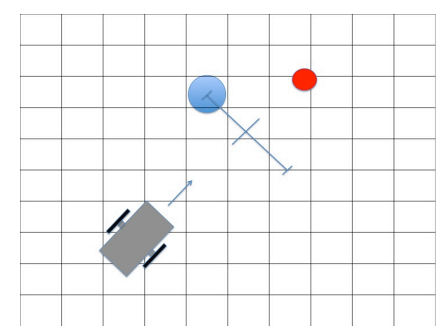
Snakebot



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

Maybe not GOF Euclidean space? :-)





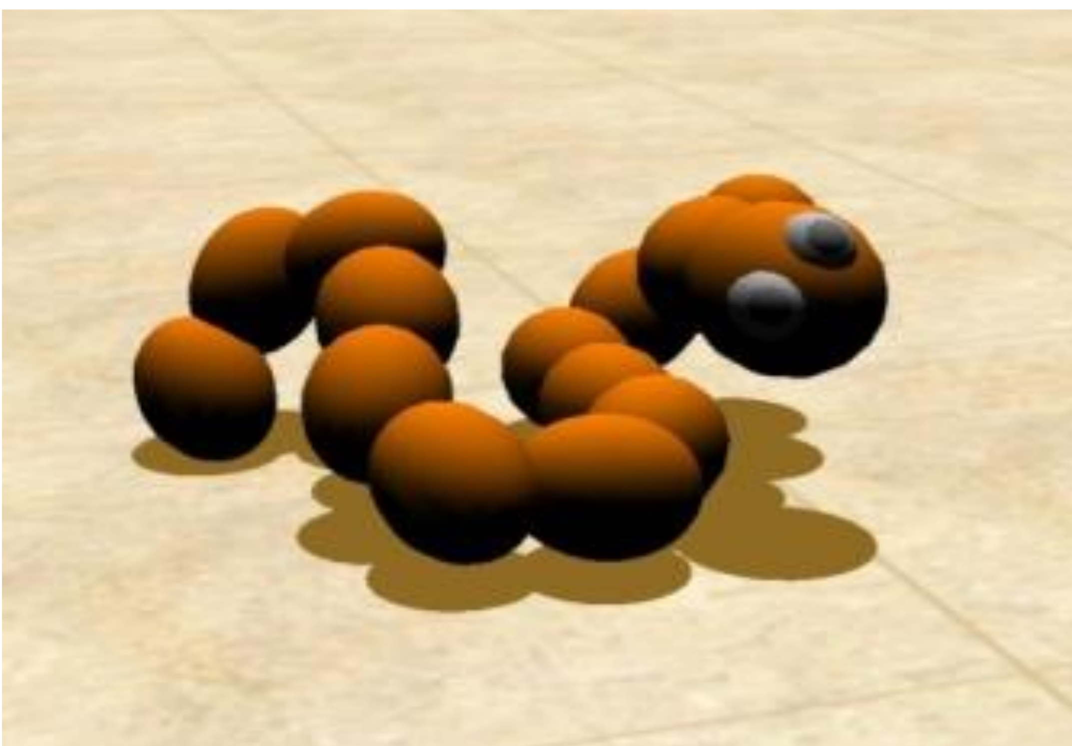
see: **Bonsignorio, Artificial Life, 2013**

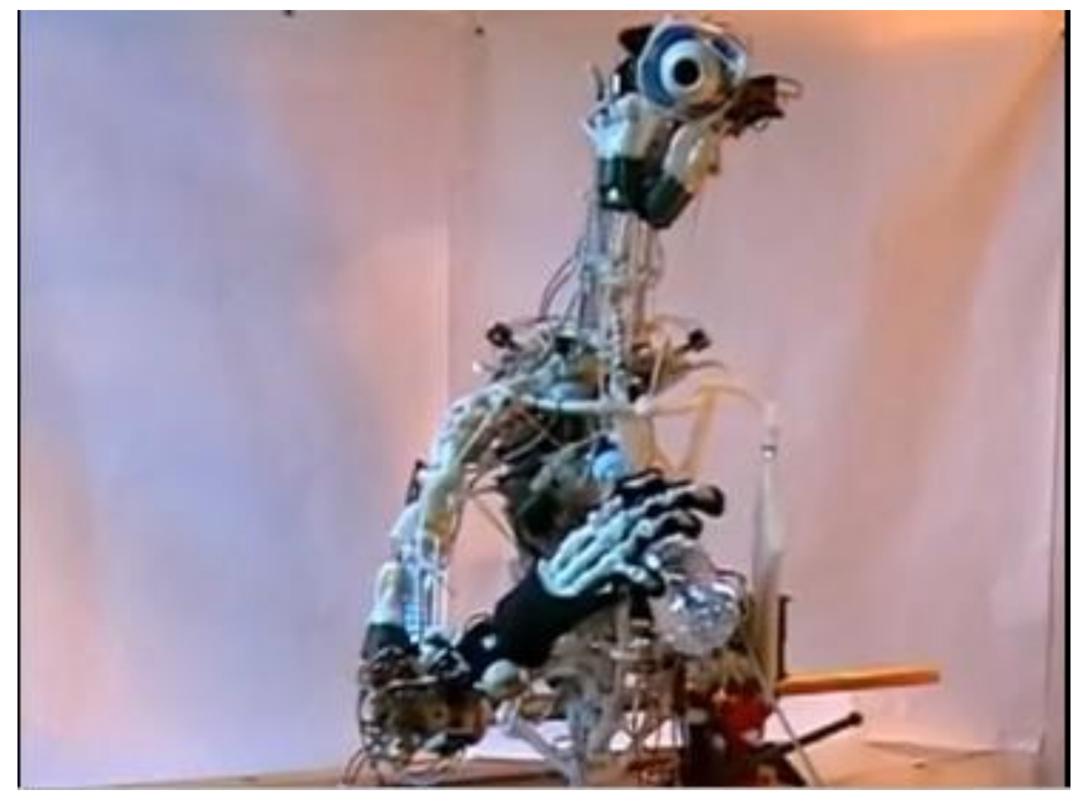
Synthetical methodology

In order to understand (and design)
the behaviors of this kind of systems…

Synthetical methodology

We may build, and mathematically model, simpler ones…





and design discriminating experiments…

Embodied Intelligence or Morphological Computation: the modern view of Artificial Intelligence

Classical approach

The focus is on the brain and central processing

Modern approach

The focus is on interaction with the environment. Cognition is emergent from system-environment interaction

PARADIGM CLASHES

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Rolf Pfeifer and Josh C. Bongard, *How the body shapes the way we think: a new view of intelligence*, The MIT Press, Cambridge, MA, 2007

Soft Robotics: a working definition

Variable impedance actuators and stiffness control

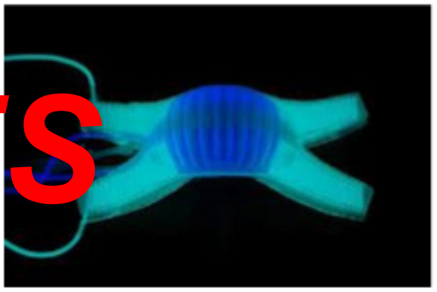
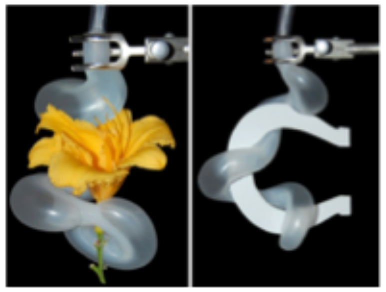
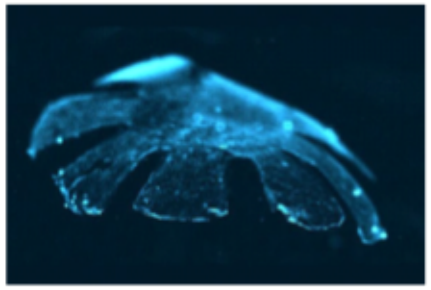
* Actuators with variable impedance
* Compliance/impedance control
* Highly flexible (hyper-redundant or continuum) robots

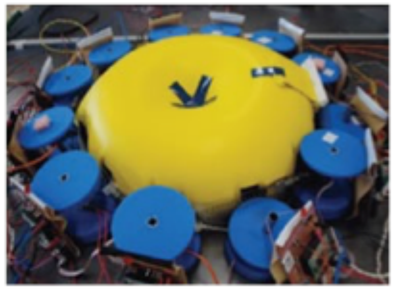
PARADIGM CLASHES

IEEE Robotics and Automation Magazine, Special Issue on Soft Robotics, 2008
A. Albu-Schaffer et al. (Ed.s)

Use of soft materials in robotics

* Robots made of soft materials that undergo high deformations in interaction
* Soft actuators and soft components
* Control partially embedded in the robot morphology and mechanical properties



Kim S., Laschi C., and Trimmer B. (2013) Soft robotics: a bioinspired evolution in robotics, *Trends in Biotechnology*, April 2013.
Laschi C. and Cianchetti M. (2014) "Soft Robotics: new perspectives for robot bodyware and control" *Frontiers in Bioengineering and Biotechnology*, 2(3)

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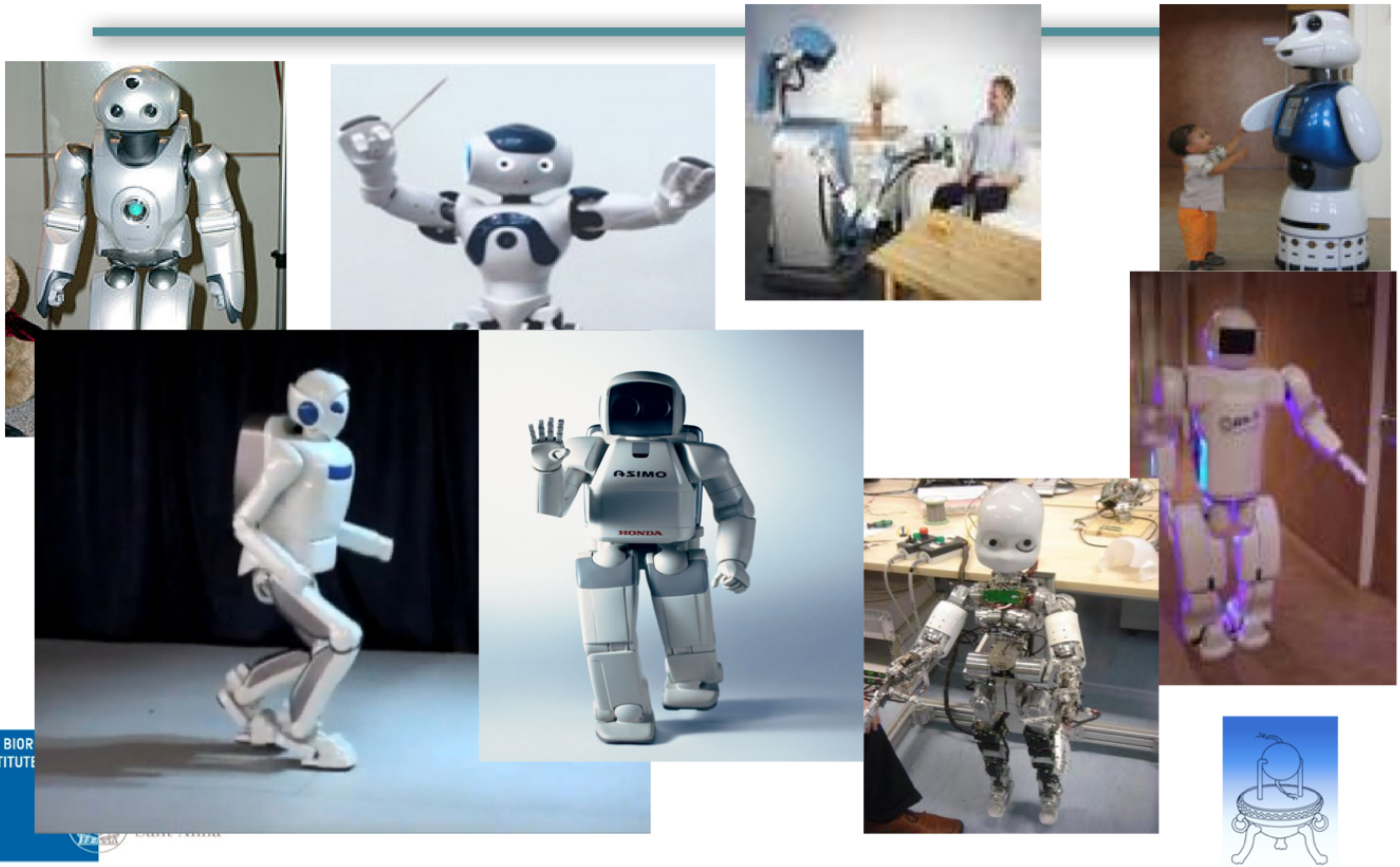
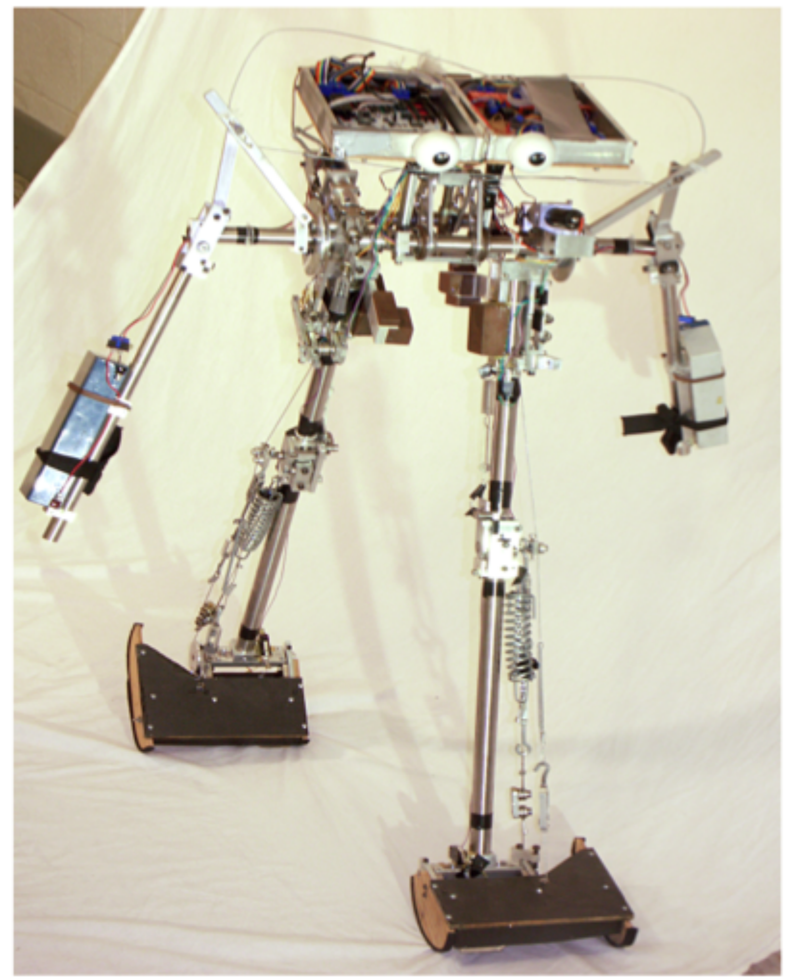
Today's humanoids



Conceptually different humanoid designs (mainly research)



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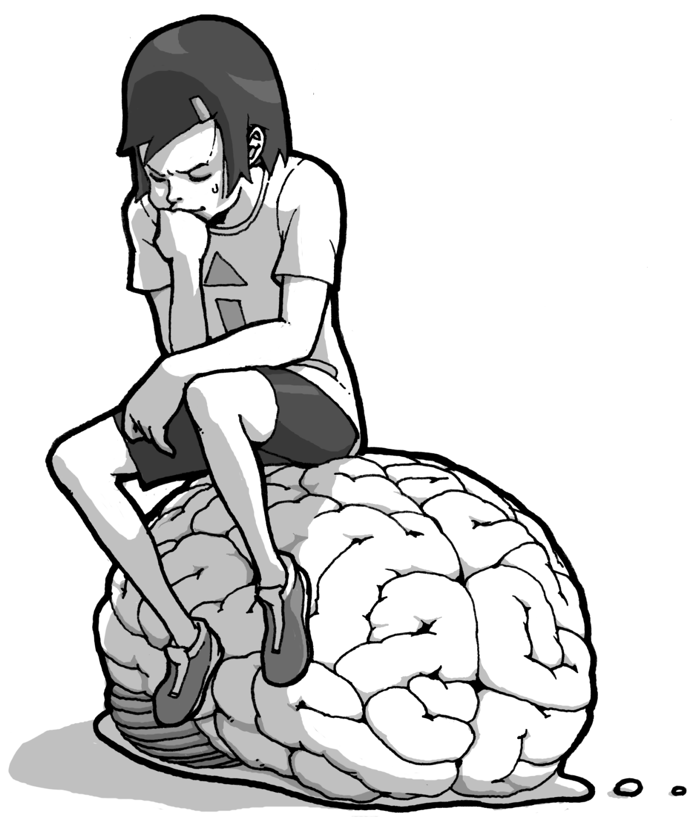
How to build a ‘new paradigm’ robot like the Cornell Ranger able to wave the hands like NAO? (and manipulate…)

a) Cornell ranger

b) Nao walking down a ramp

Thank you for your attention!



www.shanghailectures.org