

人
工
智能

上
海
AI
Lectures
授
課

The
ShanghaiAI



The ShanghAI Lectures

An experiment in global teaching

Fabio Bonsignorio

The BioRobotics Institute, SSSA, Pisa and Heron Robots

欢迎您参与
“来自上海的人工智能系列讲座”

Table of contents

- Intelligence - things can be seen differently
- Embodied intelligence
- Design principles of intelligent systems
- Evolution - cognition from scratch
- Soft Robotics and Bioinspiration
- Cognition and Embodiment
- Ontogenetic development: from locomotion to cognition
- Special session on Community outreach and industry on Dec. 4th
- **Towards a theory of intelligence**
- How the body shapes the way we think - summary, conclusions, outlook



Today's program (CET)

08:30 sites begin connecting (chat, screensharing, videoconference)

08:55 all sites are ready

09:00 START - Fabio : Hello

09:05 Peter Corke:"The Quest for Robotic Vision"

09:50 Coffee Break



Today's program (CET)

10:00 Fabio: “Towards a Theory of Intelligence”

10:40 Coffee break

10:45 Johanna Bryson: “Semantics, Consciousness, Ethics...The Reality of AI Kicks Philosophy Out of the Arm Chair”

11:30 Wrap up (Fabio)



Lecture 9

Towards a theory of intelligence

11 December 2014



Successes and failures of the classical approach

successes	failures
applications (e.g. Google)	foundations of behavior
chess	natural forms of intelligence
manufacturing ("controlled" artificial worlds)	interaction with real world



Industrial robots vs. natural systems



robots



no direct transfer of methods

principles:

- low precision
- compliant
- reactive
- coping with uncertainty

humans



The “symbol grounding” problem

**real world:
doesn't come
with labels ...**

**How to put the
labels??**

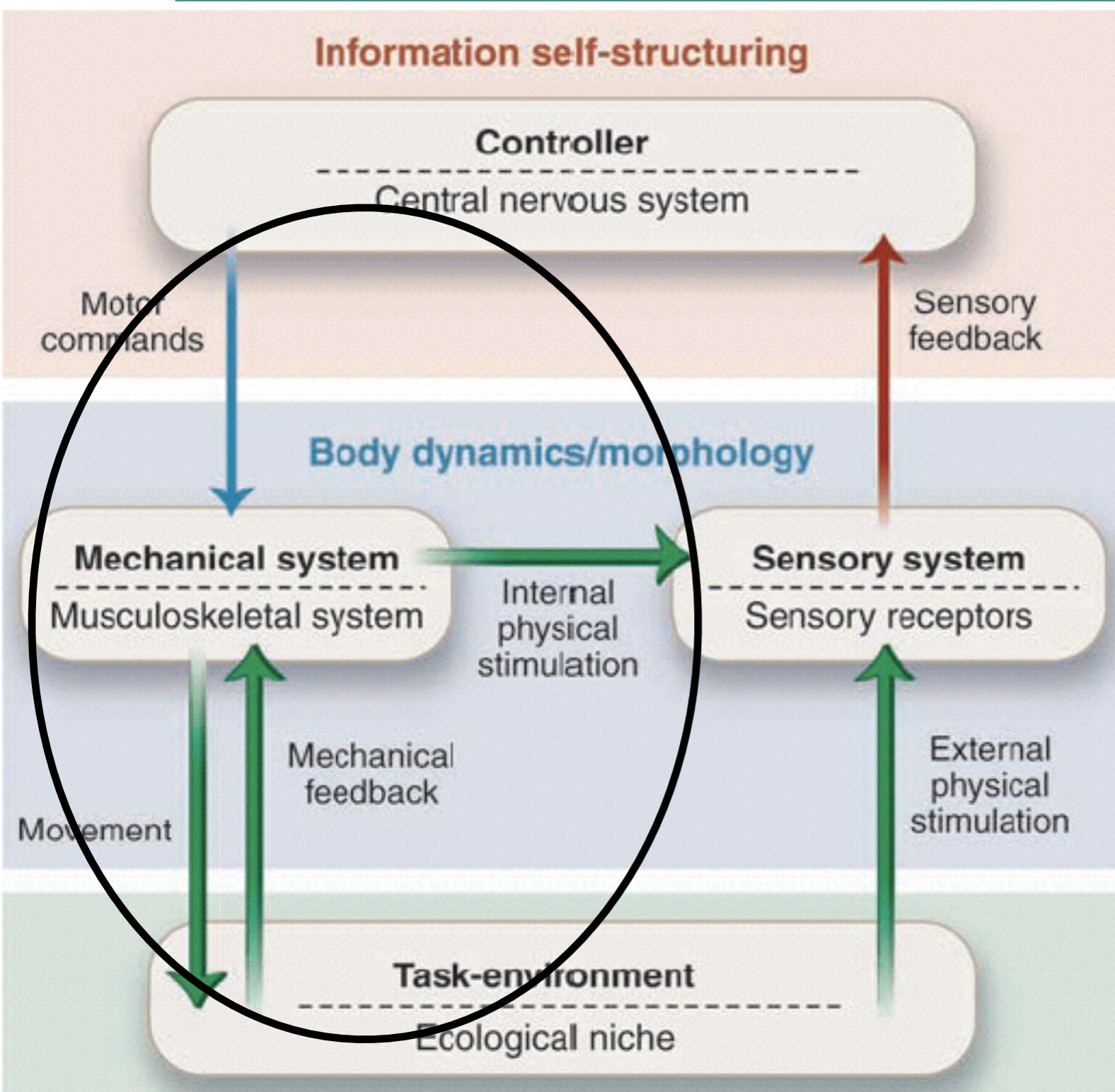
Gary Larson



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



Self-stabilization in Cornell Ranger (and Puppy!)



Pfeifer et al., Science, 2007

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

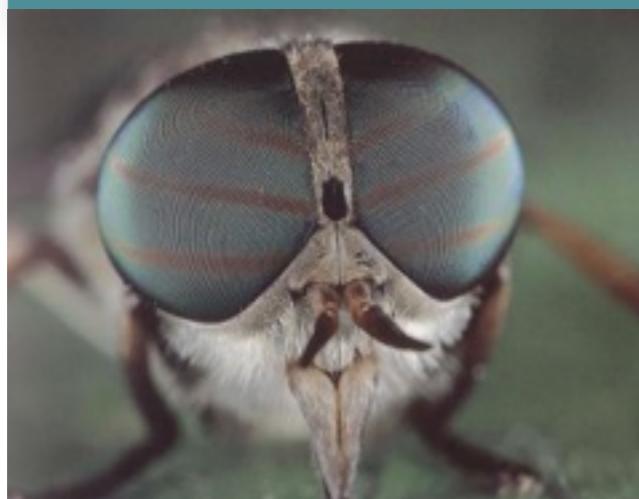
Principle 6: Redundancy

Principle 7: Ecological balance

Principle 8: Value



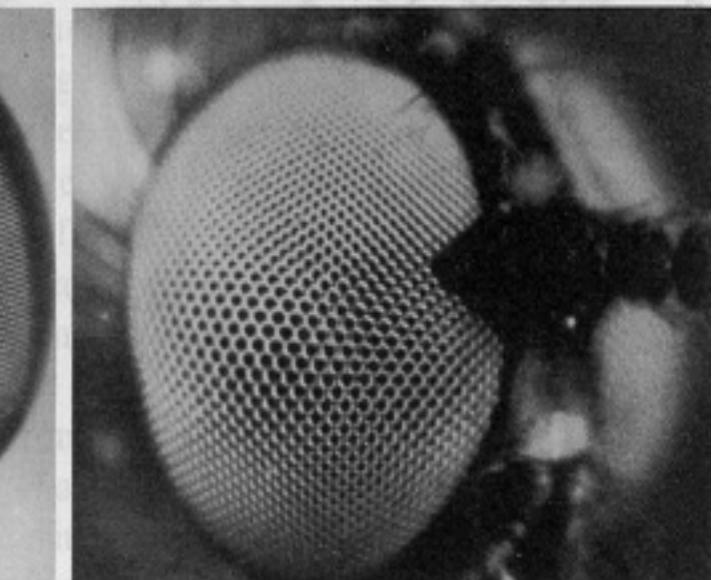
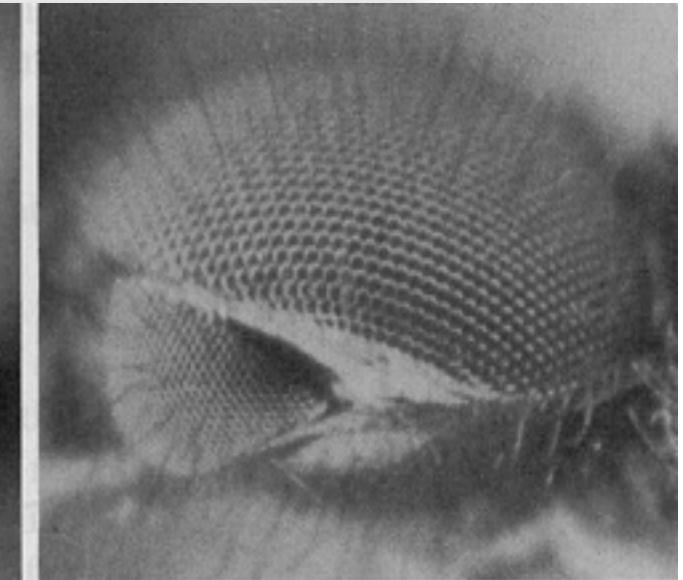
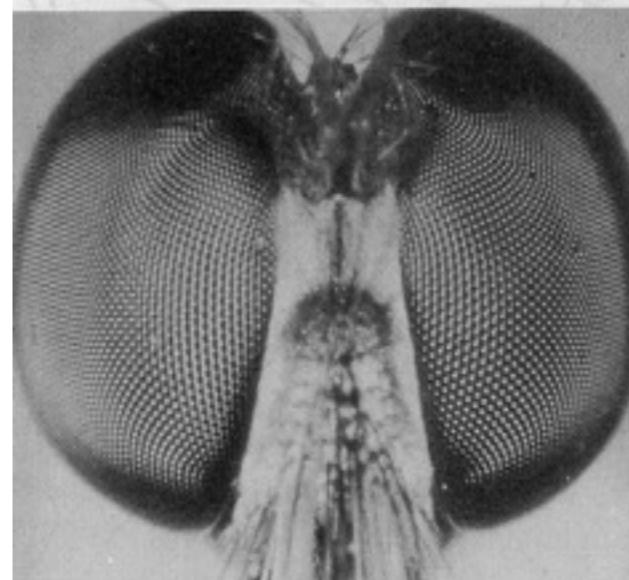
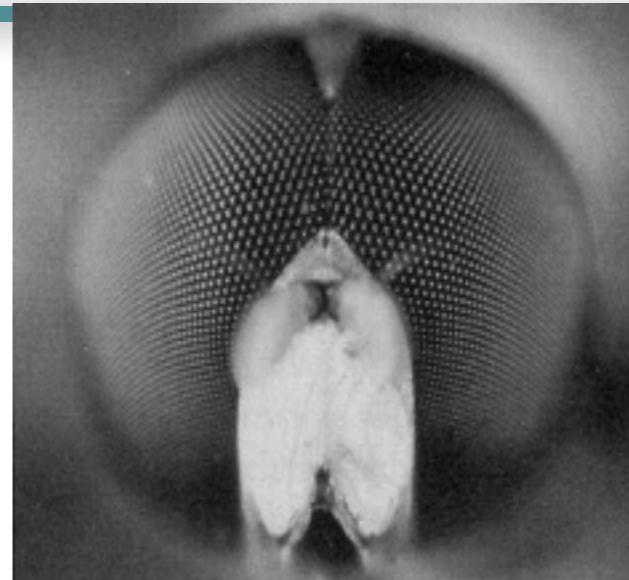
Different morphologies of insect eyes



housefly



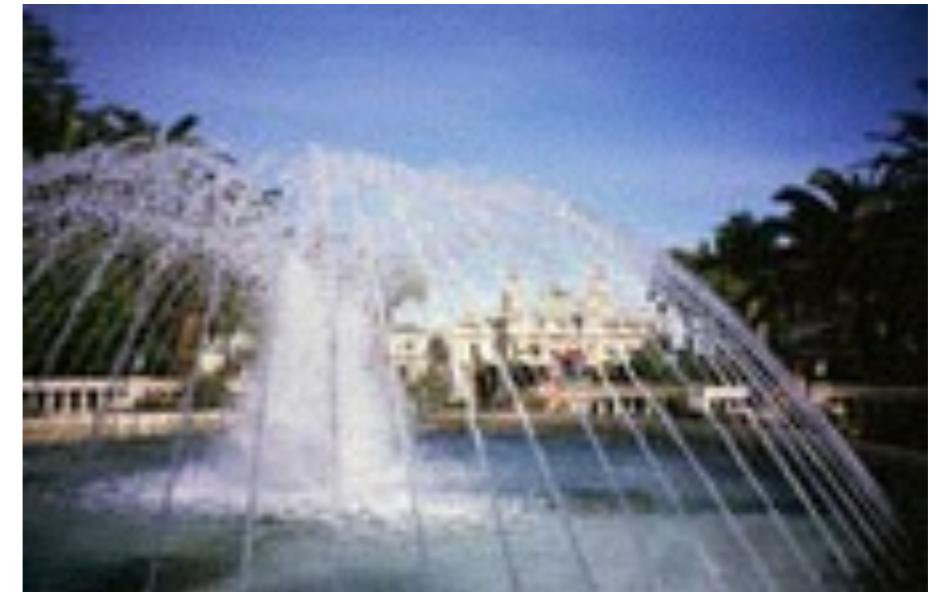
large variation of
shapes



honey bee

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?**

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



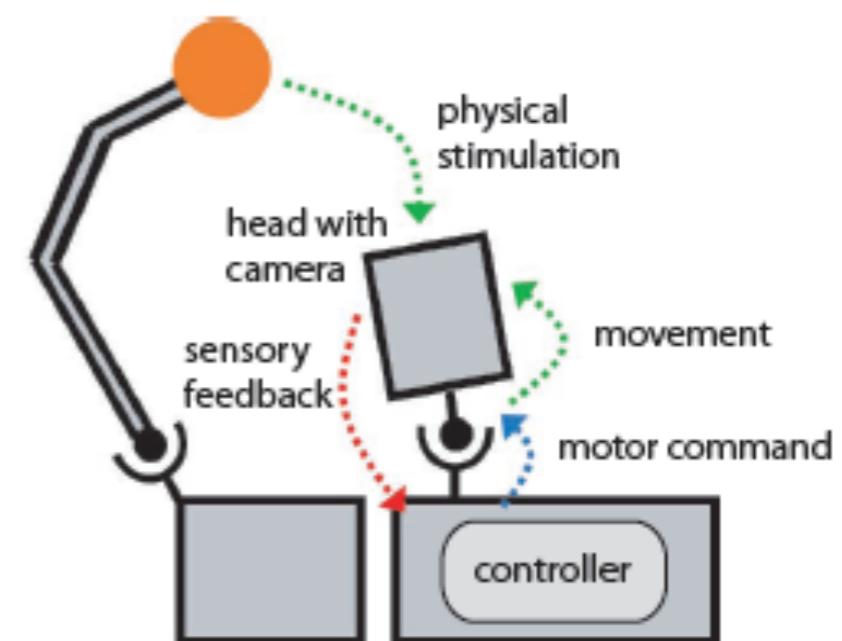
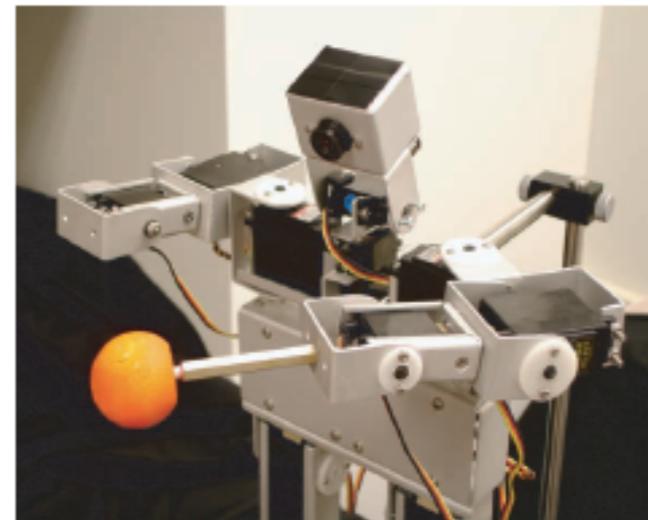
Information self-structuring

Experiments:

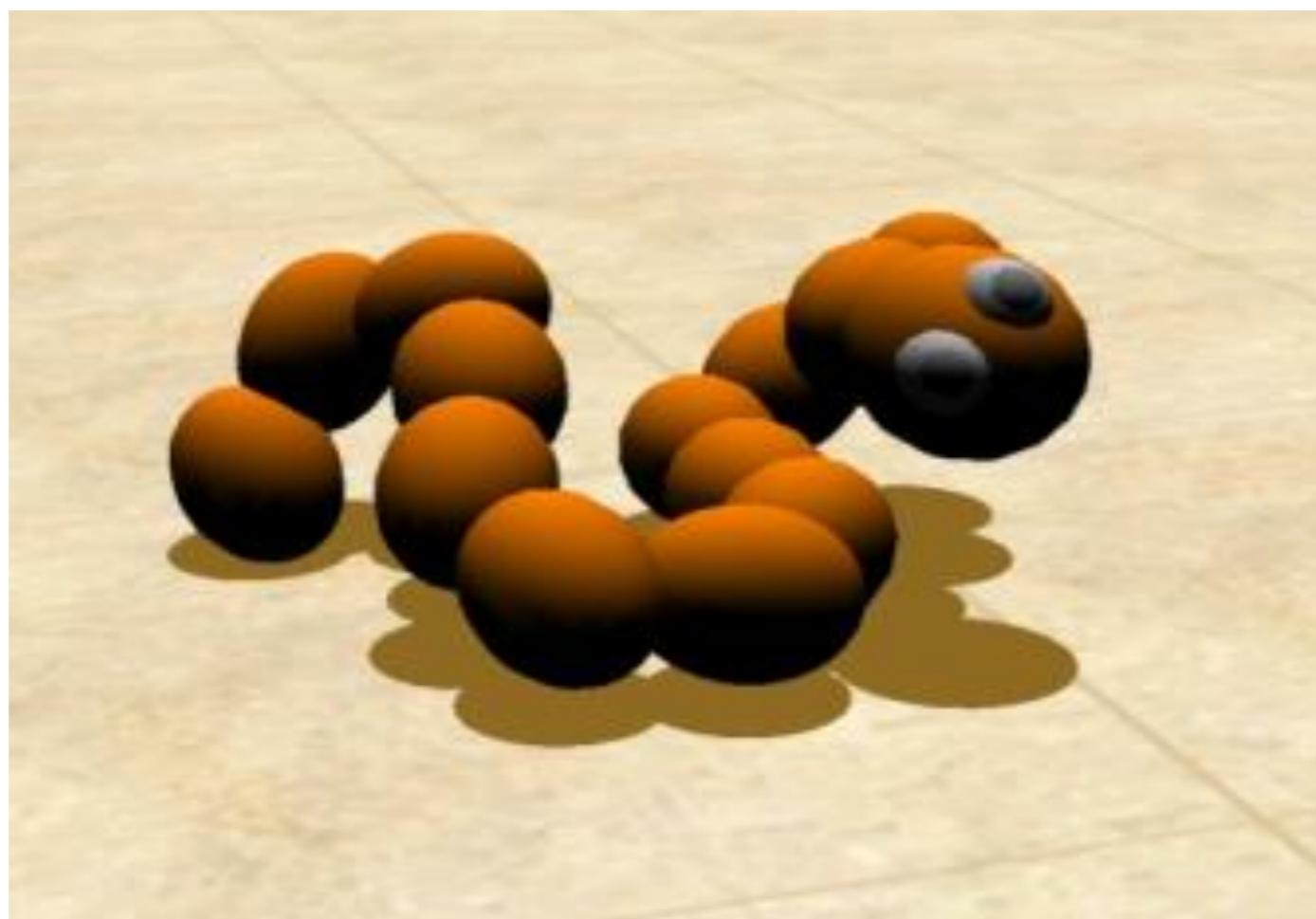
Lungarella and Sporns, 2006

Mapping information flow
in sensorimotor networks

PLoS Computational Biology

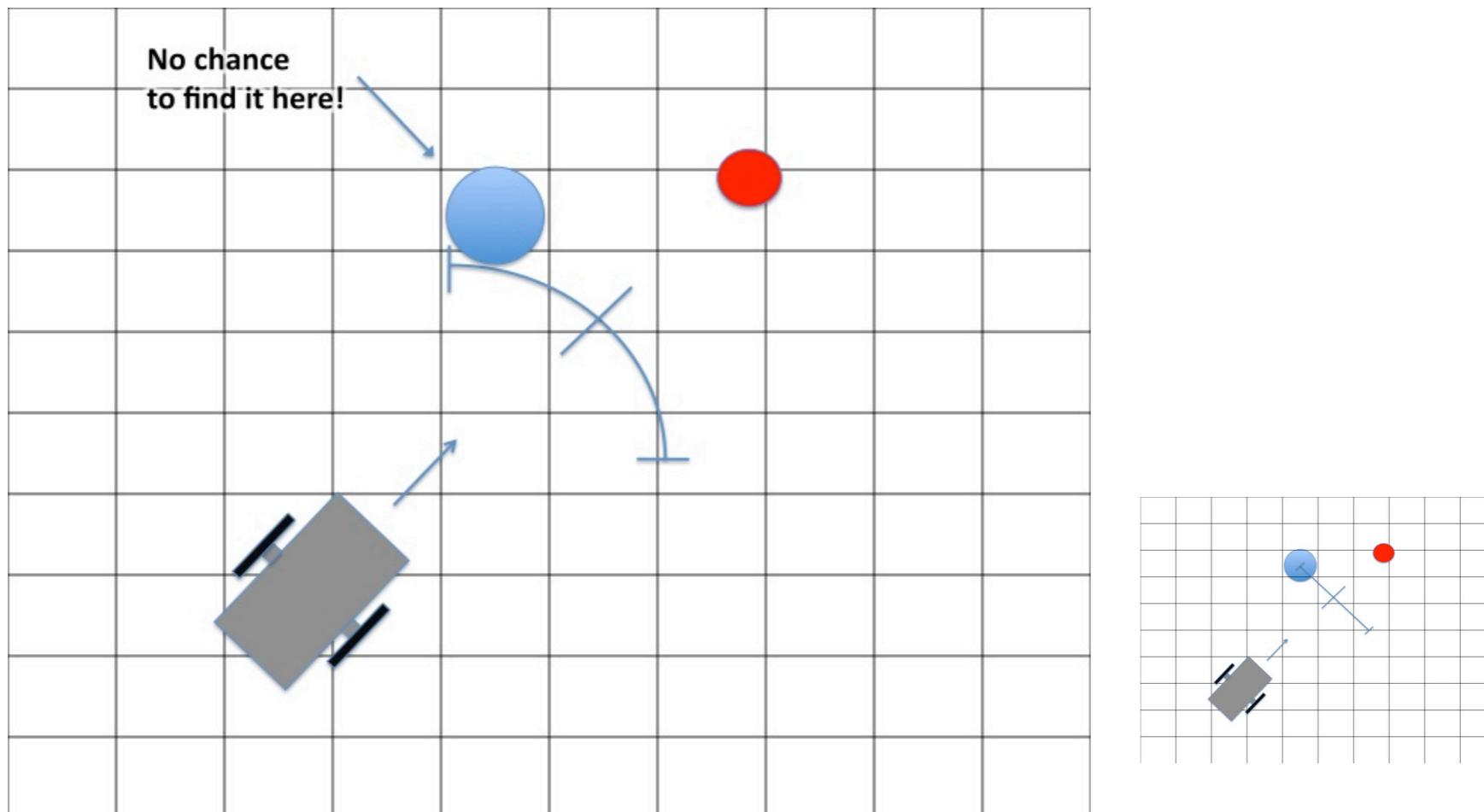


Snakebot



see: Tanev et. al, IEEE TRO, 2005

Maybe not GOF Euclidean space? :-)



see: Bonsignorio, Artificial Life, 2013

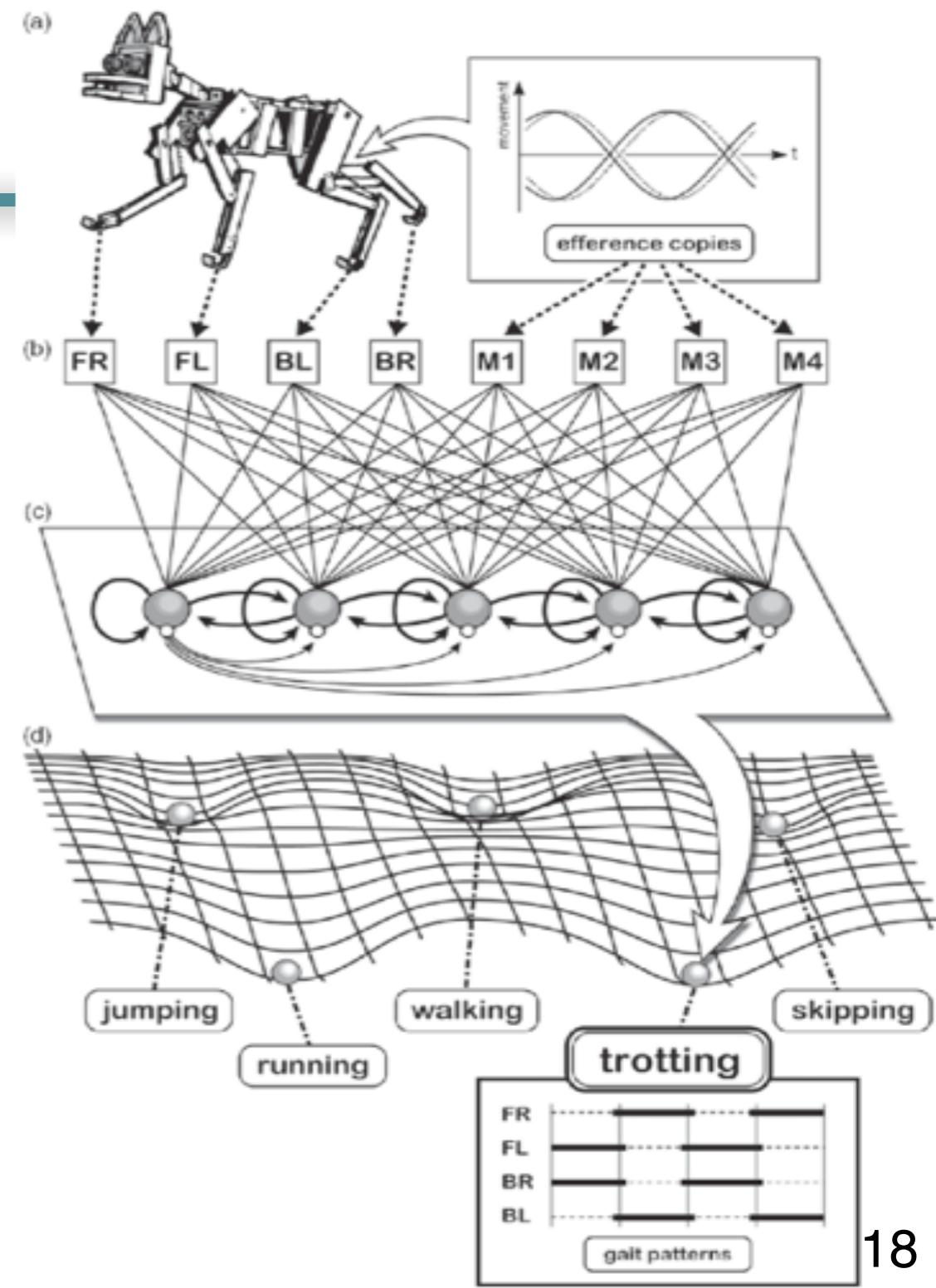
Building grounded symbols (labeling!)

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



Towards a theory of intelligence

- **on swarm behavior in real birds: video**
- **orchestration control**
- **sensory-motor coordination – information self-structuring**
- **linking to ontogenetic development**
- **high-level cognition: the Lakoff-Nunez hypothesis**
- **building embodied cognition: artificial neural networks**
- **principles for development**

Today's topics

- on swarm behavior in real birds: video

Video “real birds swarm”

- linking to ontogenetic development
- high-level cognition: the Lakoff-Nunez hypothesis
- building embodied cognition: artifical neural

Is our body a kind of ‘swarm’?

- remember the inner life of a cell

Video: “The inner life of a cell”

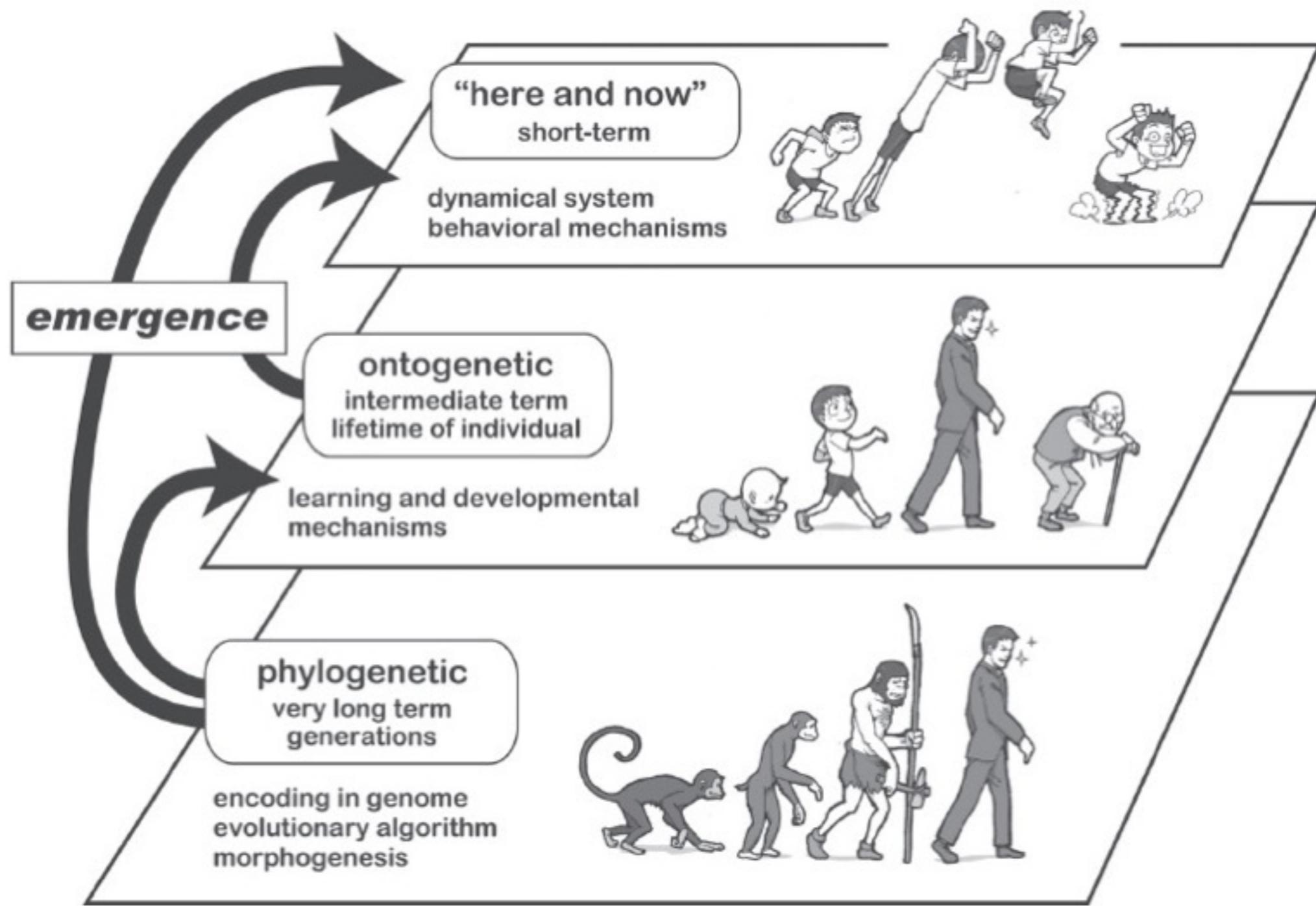
Motivation for developmental approach

- Time perspectives
- Turing's idea
- Learning essential characteristics of embodied system
- Scaling complexity through development (e.g., Bernstein's problem)

Motivation for developmental approach

- **Time perspectives**
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Time perspectives



Motivation for developmental approach

- Time perspectives
- Turing's idea
- Learning essential characteristics of embodied system
- Scaling complexity through development (e.g. Bernstein's problem)

Turing's idea

Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain. Presumably the child brain is something like a notebook as one buys it from the stationer's. Rather little mechanism, and lots of blank sheets. ... Our hope is that there is so little mechanism in the child brain that something like it can be easily programmed. The amount of work in the education we can assume, as a first approximation, to be much the same as the human child.

Turing, 1950/1963, p. 31

Motivation for developmental approach

- Time perspectives
- Turing's idea
- Learning essential characteristics of embodied system
- Scaling complexity through development (e.g., Bernstein's problem)

Motivation for developmental approach

difference between learning

- Time perspectives
and development?
- Turing's idea →
- Learning essential characteristics of embodied system
- Scaling complexity through development
(e.g., Bernstein's problem)

The “story”: physical dynamics and information

- cross-modal association, learning, concept formation
- extraction of mutual information
- prediction: embodied anticipatory behaviors
- categorization (fundamental for cognition)



Learning and development in embodied systems

Through sensory-motor coordinated interaction: induction of sensory patterns containing information structure.

F-O-R:

**Sensory-motor coupling: control scheme;
Induction of information structure: effect
(principle of “information self-structuring”)**

Learning and development in embodied systems

Through sensory-motor coordinated interaction: induction of sensory patterns containing information structure.

F-O-R:

Sensory-motor coupling: control scheme;
Induction of information structure: effect
(principle)



foundation of learning and development

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High-level cognition: the Lakoff-Núñez Hypothesis

Even highly abstract concepts such as “transitivity”, “numbers”, or “limits” are grounded in our embodiment. Mathematical concepts are constructed in a way that — metaphorically — reflects our embodiment.

George Lakoff und Rafael Núñez (2000).

Where mathematics comes from: how the embodied mind brings mathematics into being.

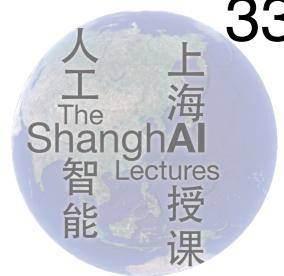
New York: Basic Books.

Robots for studying development: Why humanoids?

Reasons?

—>

33

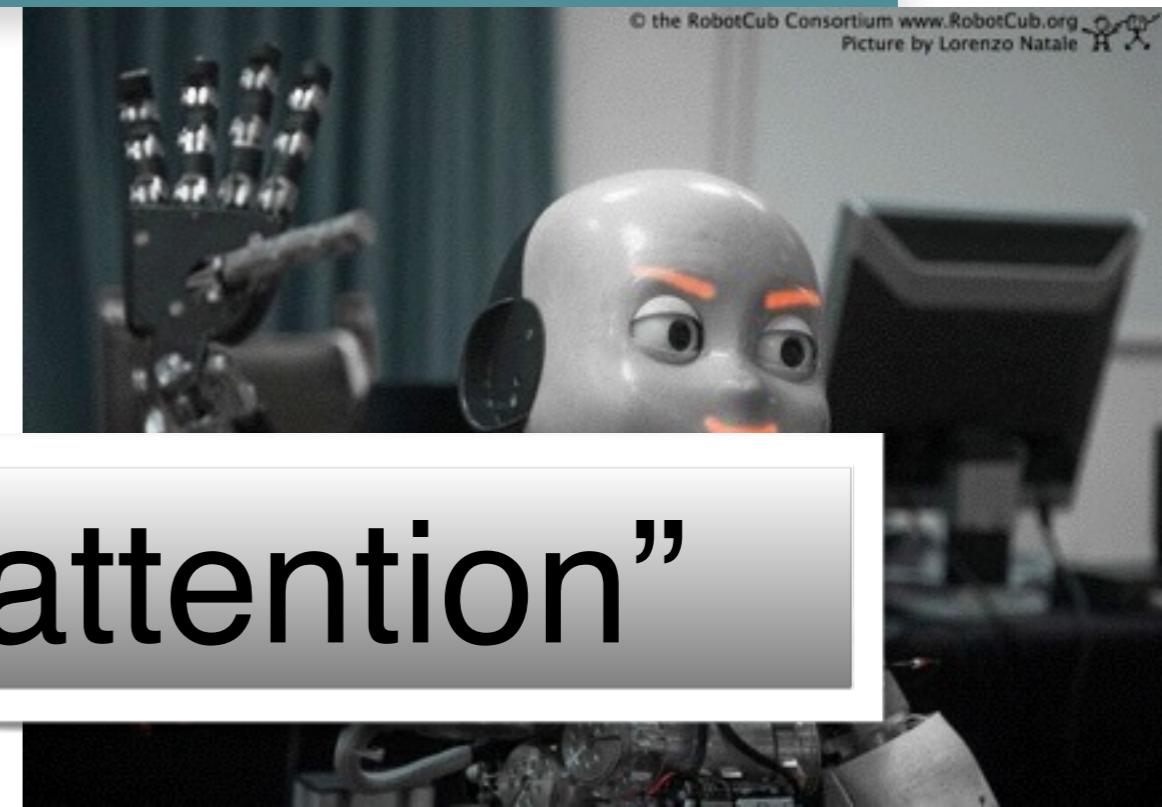
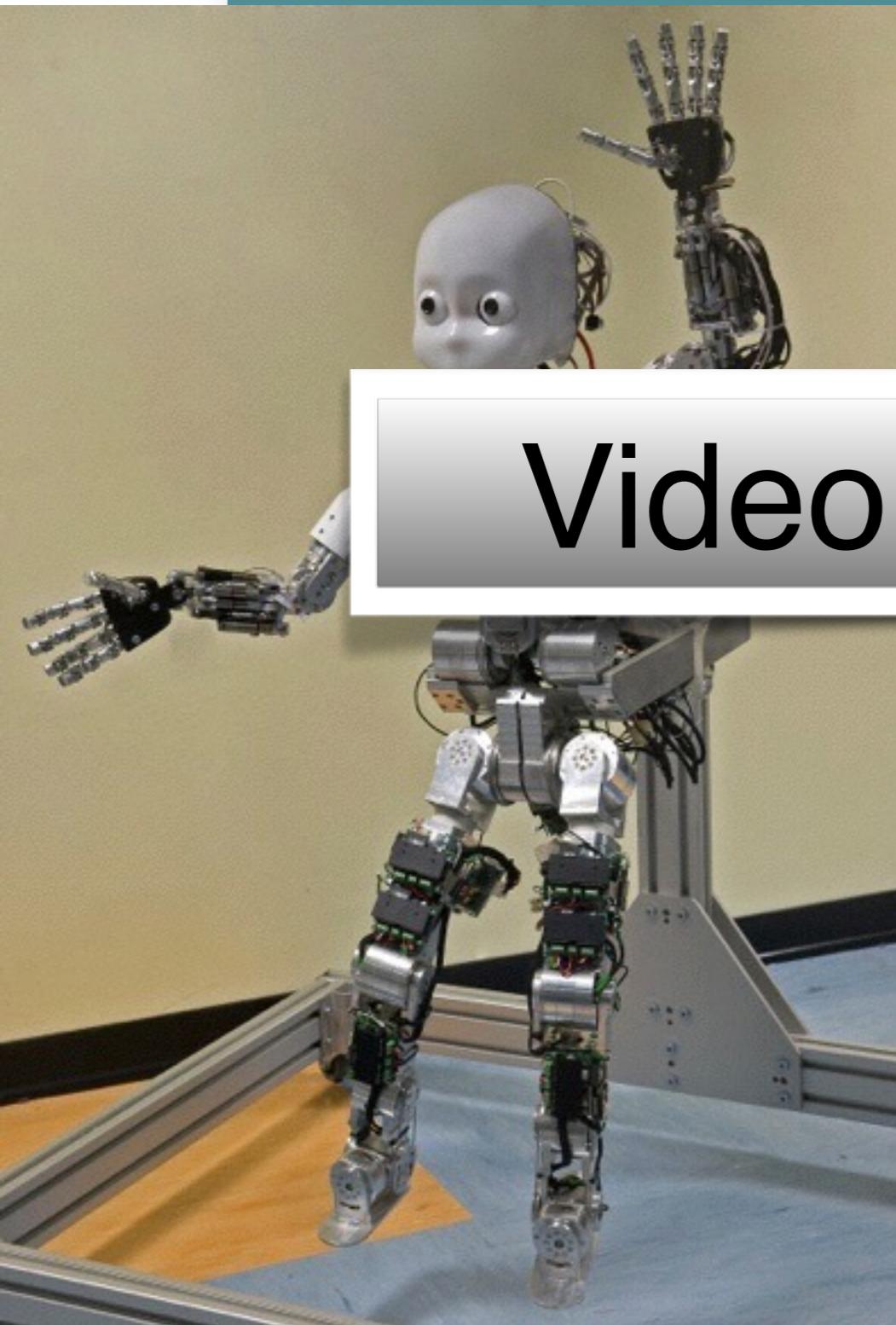


Robots for studying development: Why humanoids?

- **huge engineering challenge**
- **synthetic methodology: what are the real challenges?**
- **no modification of environment required**

beware: **anthropomorphization ...**

Robots for studying development: iCub

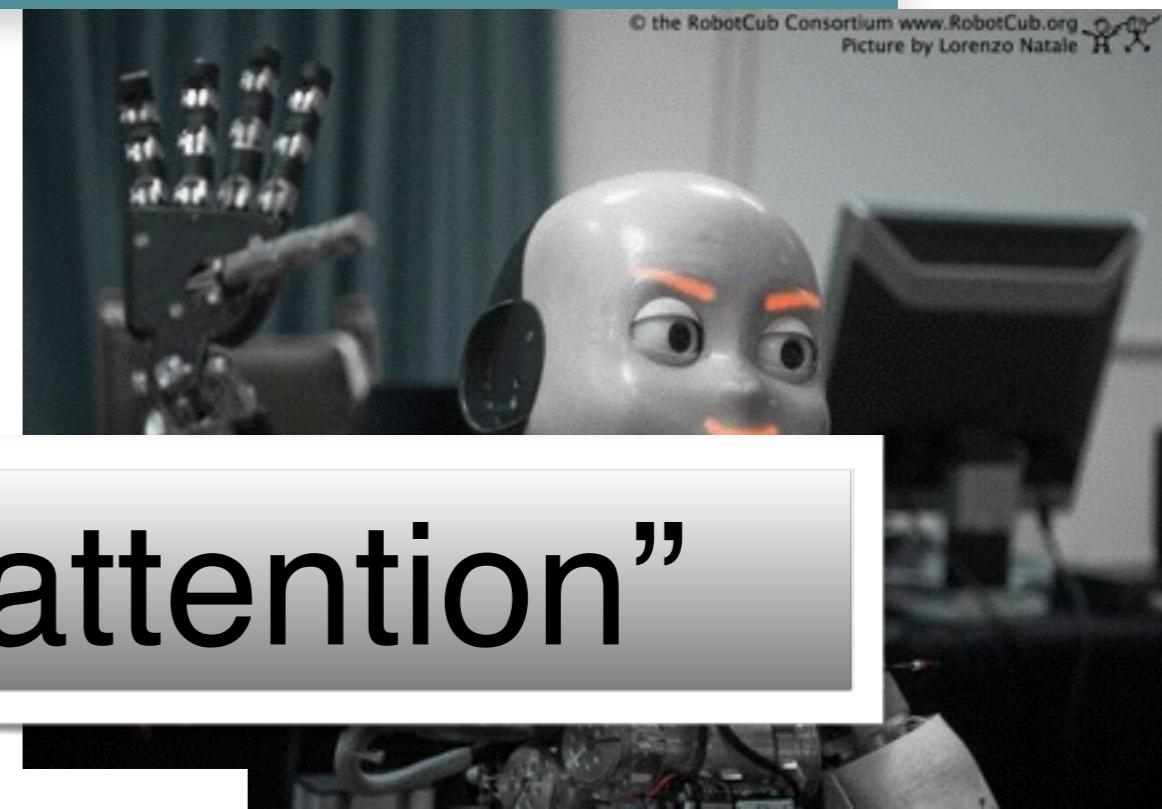
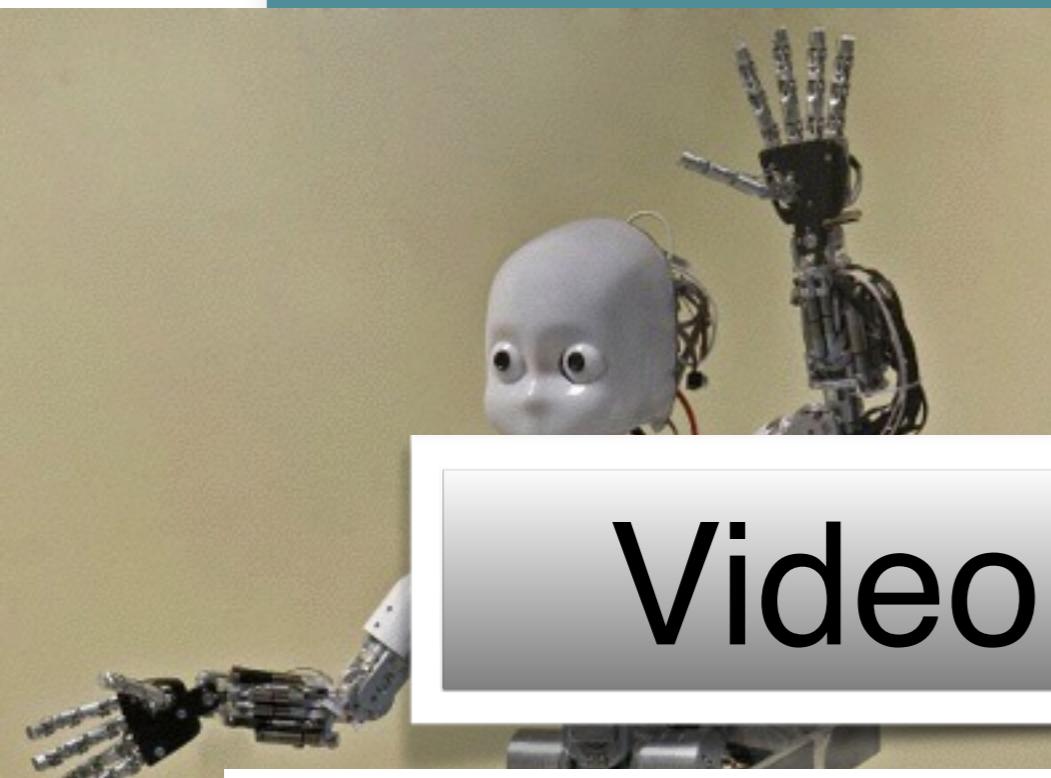


Video “iCub attention”

The iCub project by
Giorgio Metta and Giulio
Sandini

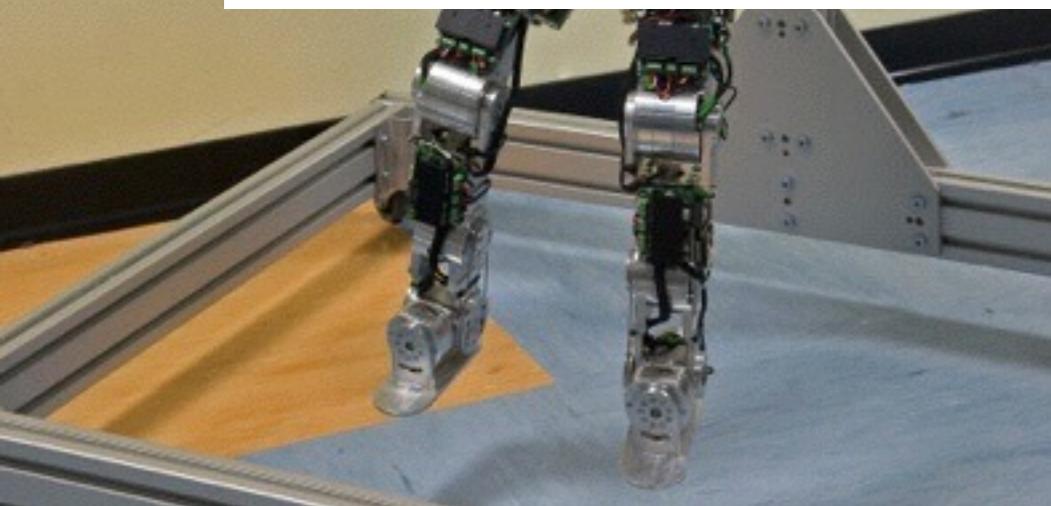


Robots for studying development: iCub



Video “iCub attention”

Reactions, comments on
video?



object by
Giorgio Metta and Giulio
Sandini



A research platform for sensori-motor development



Adding sensors: generation of sensory stimulation through

- knowledge about environment:
pressure, haptic, acceleration, vision, ...
- knowledge about own body:
angle, torque, force, vestibular, ...



Physical dynamics and information structure

Induction of patterns of sensory stimulation through physical interaction with environment



raw material for information processing of brain (control)

induction of correlations (information structure)



Physical dynamics and information structure

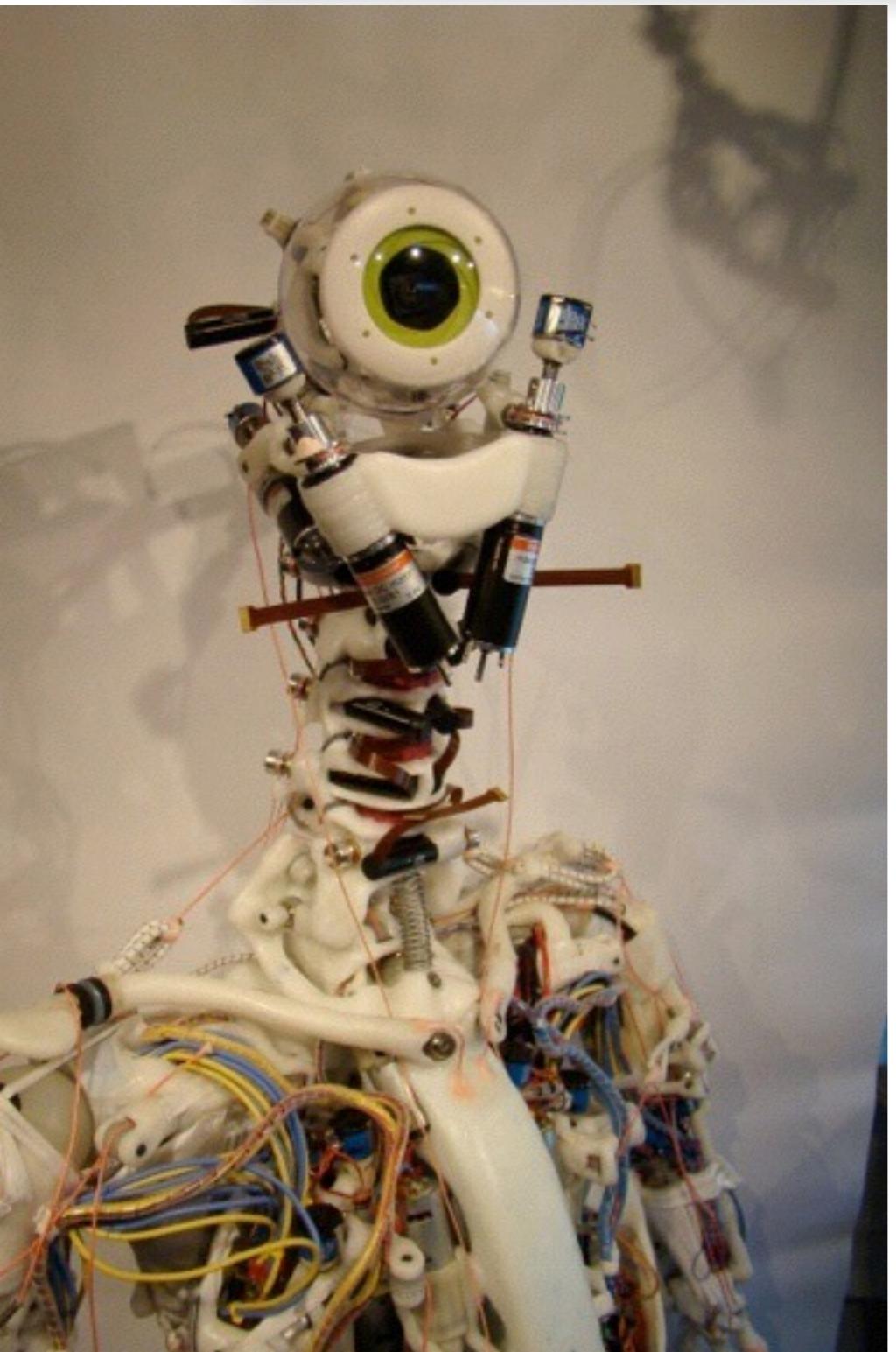
Induction of patterns of sensory stimulation through physical interaction
why is it important to have correlations in the different sensory channels? (e.g. visual and haptic)

raw material for information processing of brain (control)

induction of correlations (information structure)



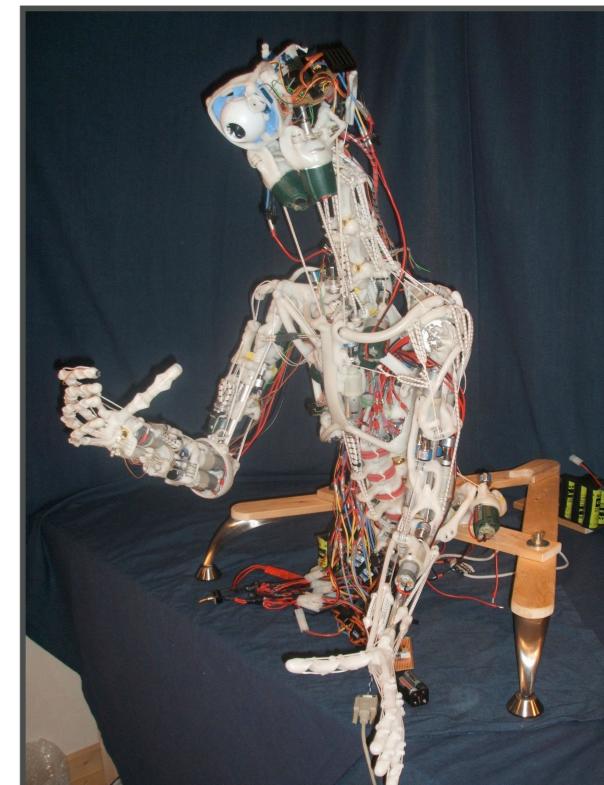
The super-compliant, “soft”, robot ECCE for development



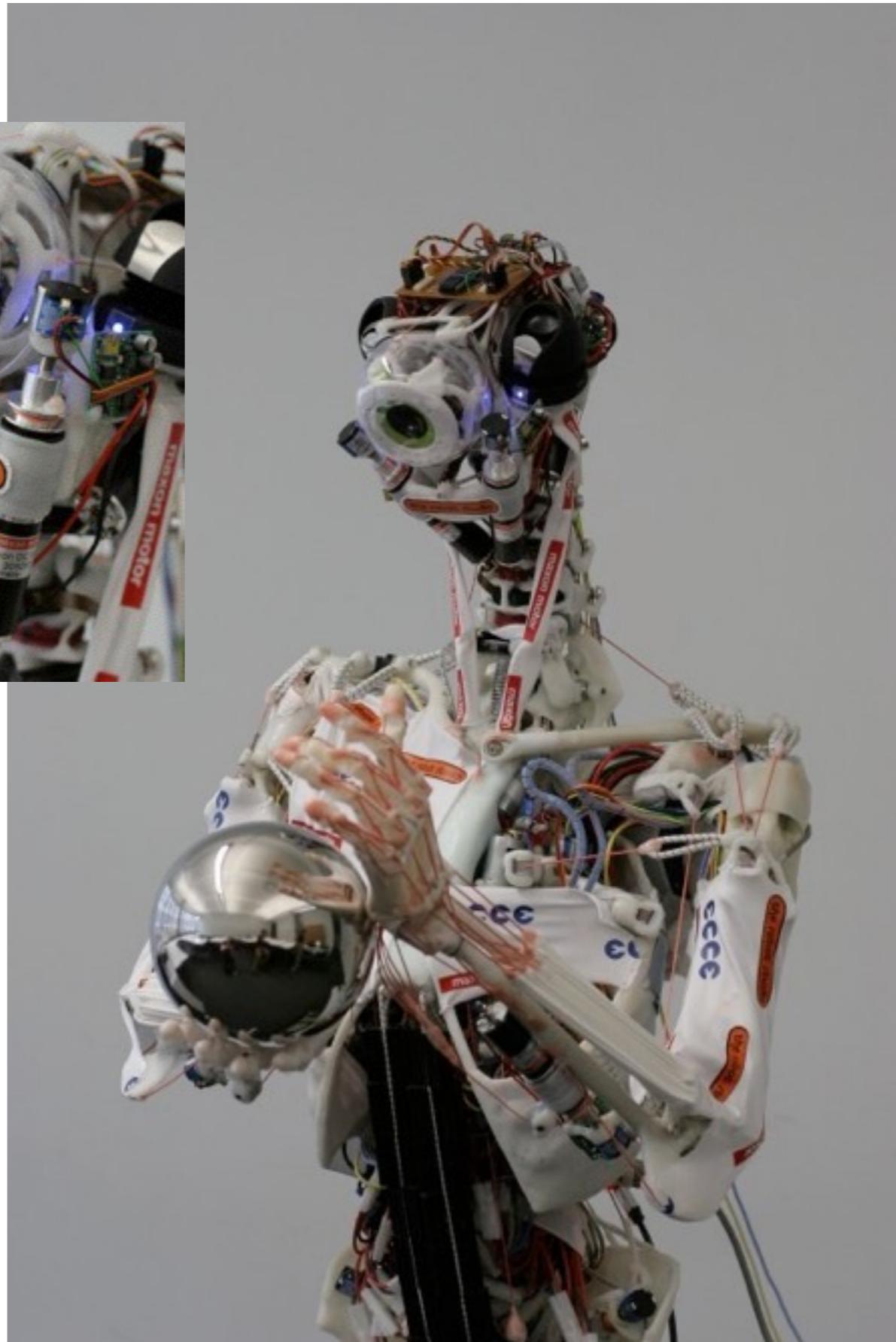
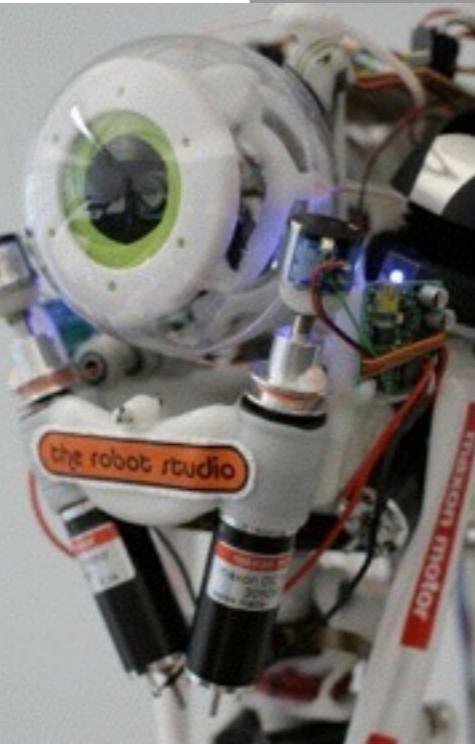
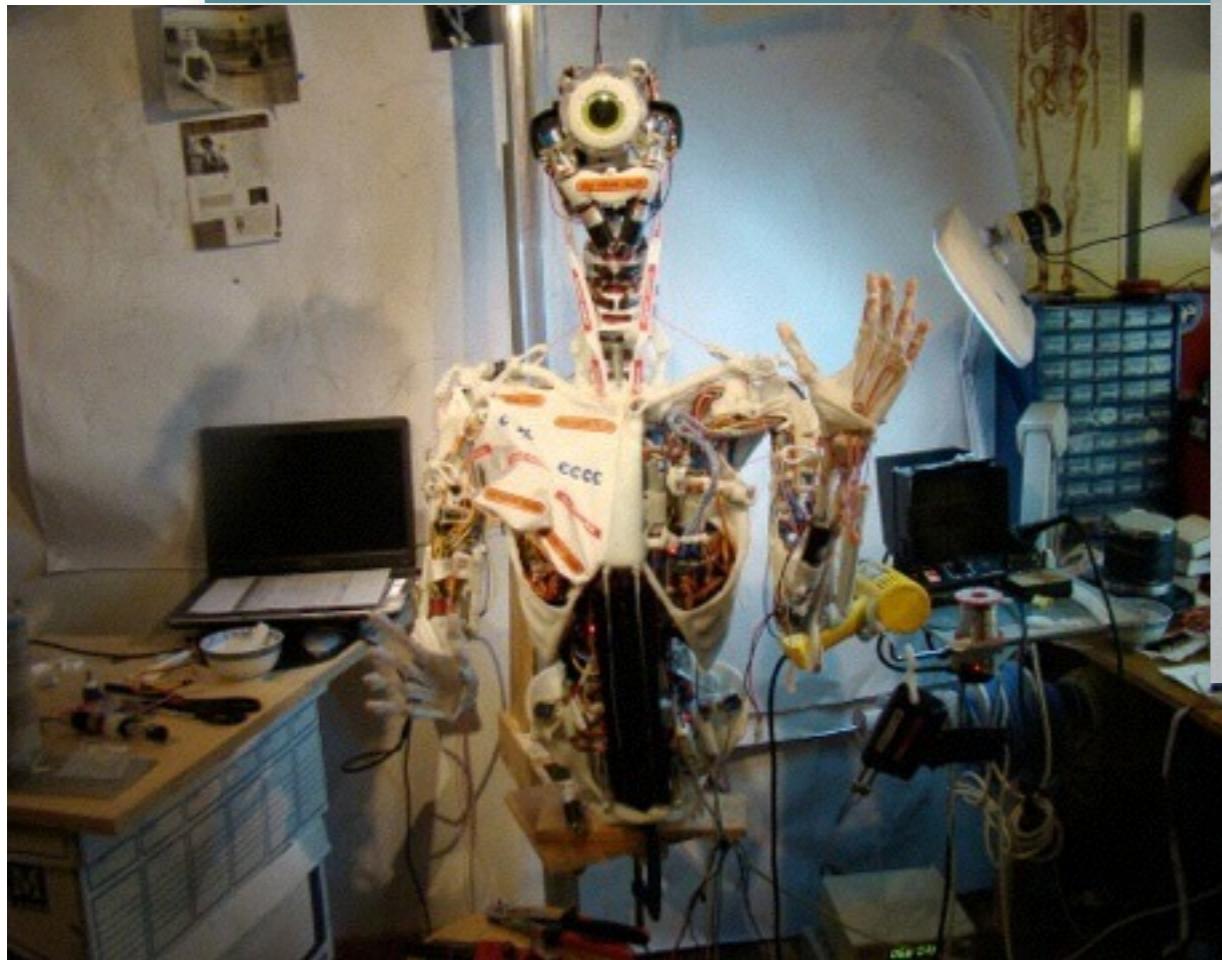
Design and construction:
Rob Knight – robotstudio, Geneva
Richard Newcombe – Imperial College
Owen Holland – Essex/Sussex

ECCE – Embodied Cognition in a Compliantly Engineered Robot

**Anthropomorphic
design**



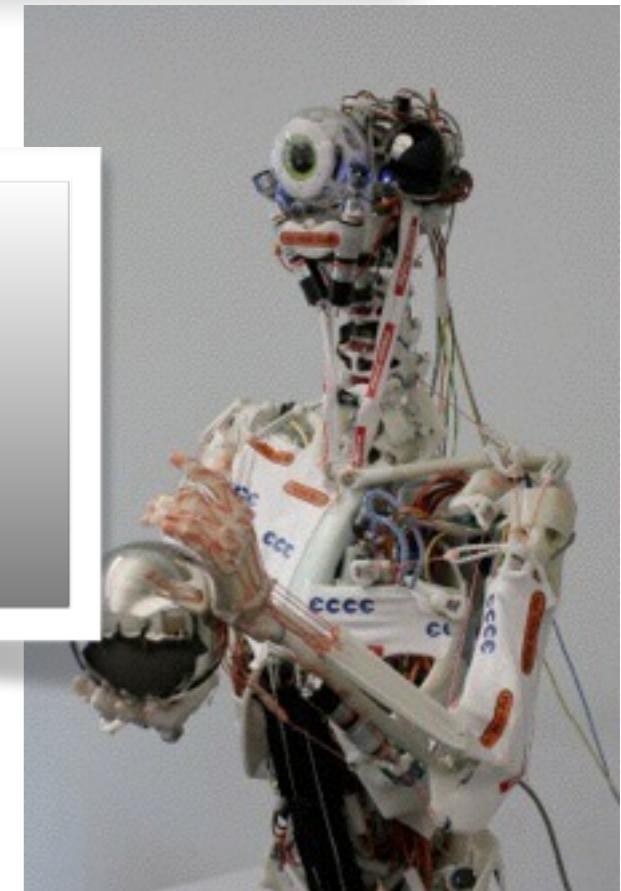
The super-compliant “soft” robot ECCE



fully tendon-
driven

The super-compliant, “soft”, robot ECCE

Video
“ECCE_Promovideo”



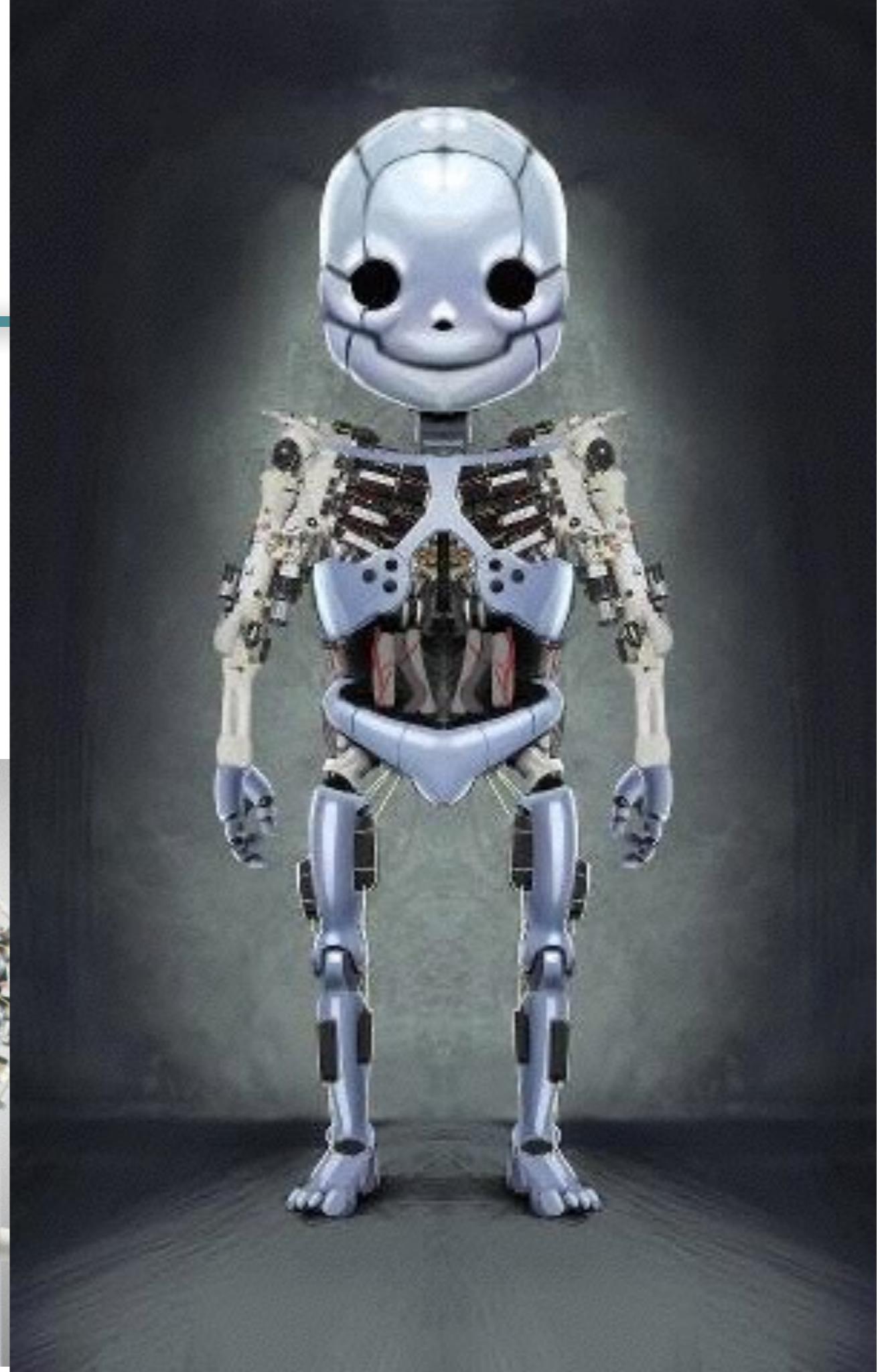
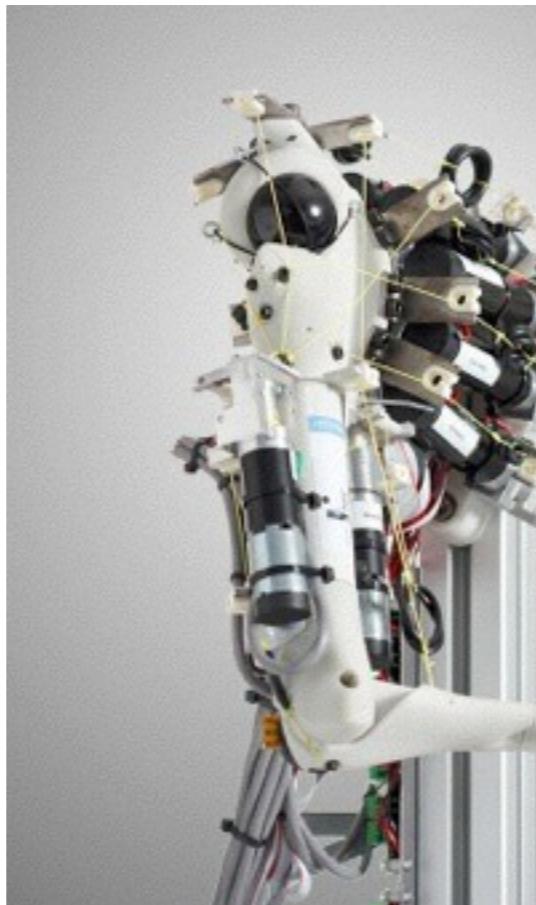
must have learning

Anthropomorphic
design

Neue Plattform: Roboy

(in - schneller - Entwicklung:
Ziel Februar 2013)

- **sehnengesteuert**
- **anthropomorph**
- **Grösse: 1.20/1.30m**
- **Q&A facility**
- **manufacturable**
- **crowd funded**





facebook 1 1 2

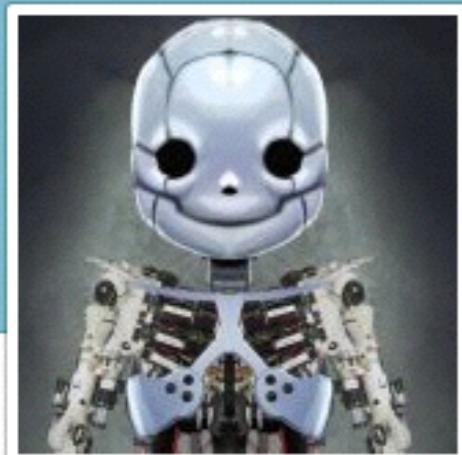
Search for people, places and things



Rolf Pfeifer

Find Friends

Home

Tendon Driven
Humanoid RobotDeveloped till to the
Robots on Tour, March
8/9 2013, ZurichFinanced by
Crowdfunding

- Robot at Laboratory of Artificial Intelligence
- Studied at University of Zurich
- Lives in Zürich, Switzerland
- In an open relationship

About

Post Photo

Write something...

ROBOY 2013

A UNIQUE HUMANOID ROBOT

LEARN MORE

www.roboy.org



we need this

500 000.-

275 125.-

supported

become friends with
“Roboy” on facebook!

Recent

Roboy is now friends with Marc Lenzi and 19
other people.

Sponsored

Klassenfotos
von...1953, 1954, 1955,
1956, 1957, 1958,
1959, 1960, 1961,
1962, 1963, 1964,
1965, 1966, 1967.Probiotiques &
L'Allergie
trialreach.comÉtude rémunéré:
Effets des
probiotiques sur
l'allergie aux
poussières de
maison. 1200 CHF

Now

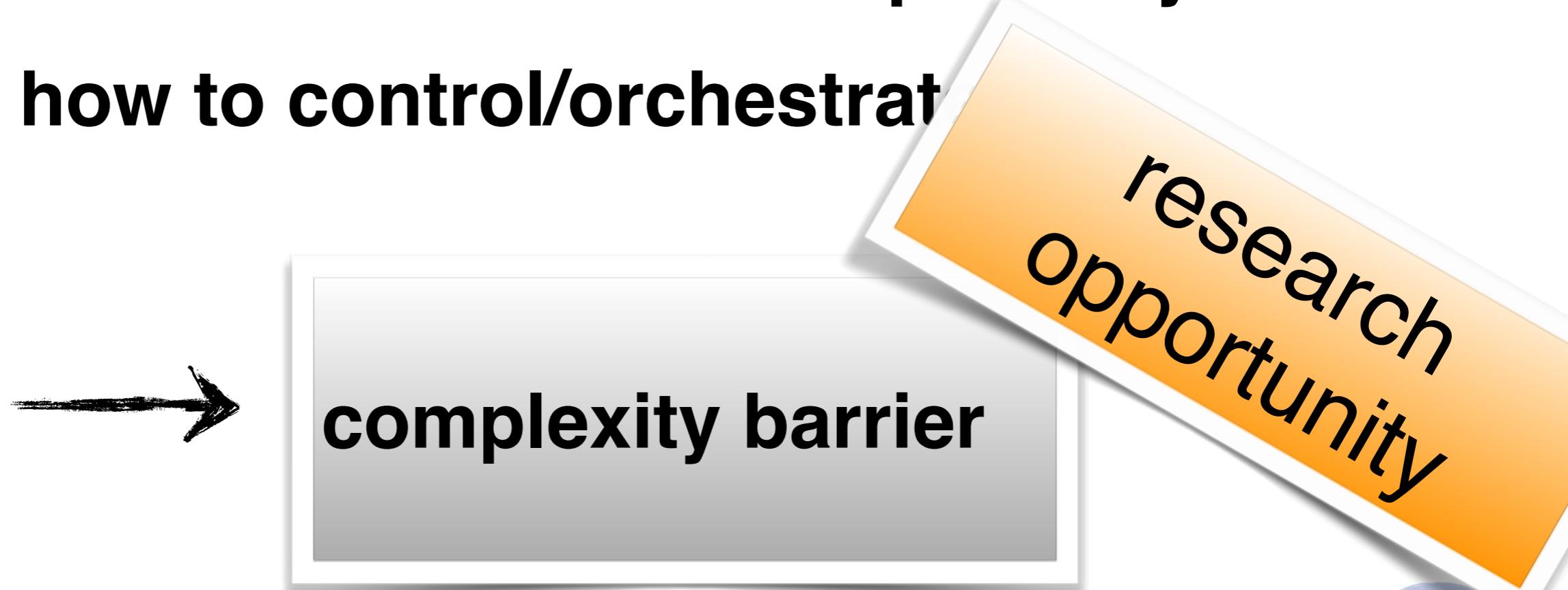
October

2012

Born

Bernstein's problem

- highly complex system; large number of redundant DOFs in compliant system
- how to control/orchestrat



(Nikolai Bernstein, Russian physiologist,

Approaches

- learning/development (robot learning its own dynamics through “motor babbling”)
- freezing/freeing DOFs (natural systems)
- exploiting “morphological computation” (“outsourcing functionality”)
- exploiting biomechanical constraints
- global dynamics (parameters – cockroach)



Bernstein's problem

- **acquisition of own body schema (non-linear characteristics of body)**
- **expected patterns of sensory stimulation**



How to quantify?

- The main concept is that the processing 'computing' is a general characteristic of any material system, while 'intelligence' and 'meaning' should be synchronisation processes within networks of autonomous agents.
- In particular we should be able to

research
opportunity



How to quantify?

- How the dynamics of an (embodied) agent is related to its information/computing capabilities (morphological computation)?
- How information/computing capabilities behave in a multi body soft agent system?
- How 'intelligence' and 'meaning' emerge from networks of embodied agents?

research
opportunity

F. Bonsignorio, in 50 Years of AI,
Lungarella et al. (eds), 2007



Implementation of learning in embodied systems

important approaches:

“Artificial Neural Networks”

“Deep Learning”

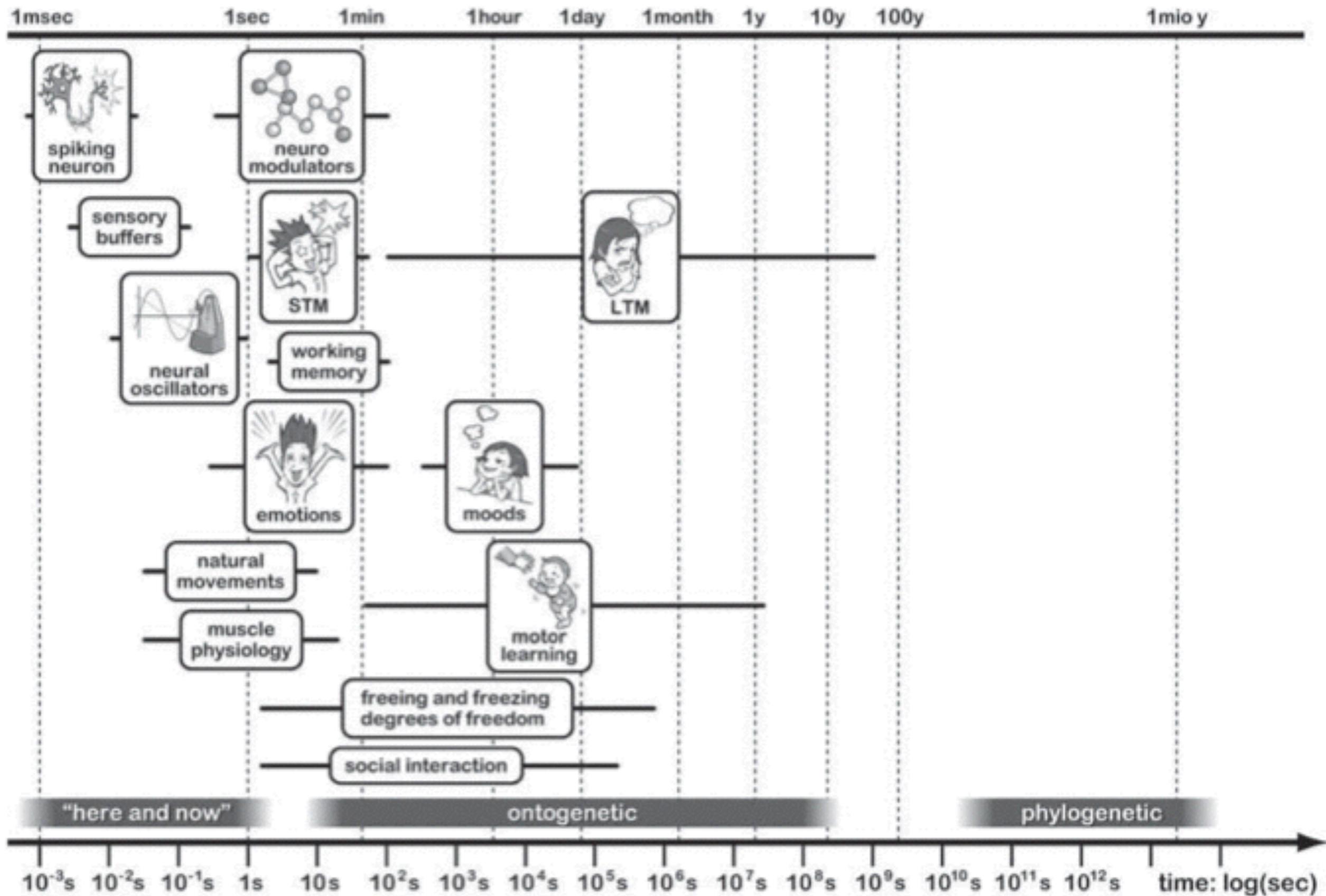
“Information Theory”(on curved spaces, too)

“Network physics”

Additional aspects of development

- **integration of many different time scales**
- **social interaction**
 - imitation, joint attention, scaffolding
 - natural language

Integration of time scales



Additional aspects of development

- integration of many different time scales
- social interaction
 - imitation, joint attention, scaffolding
 - natural language

Steps toward a theory of intelligence

- 1. Meta-considerations: “Mind Set”**
- 2. Properties of physically embodied agents**
- 3. Characteristics of real world**
- 4. Design principles**



Steps toward a theory of intelligence

- 1. Meta-considerations: “Mind Set”**
2. Properties of physically embodied agents
3. Characteristics of real world
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Steps toward a theory of intelligence

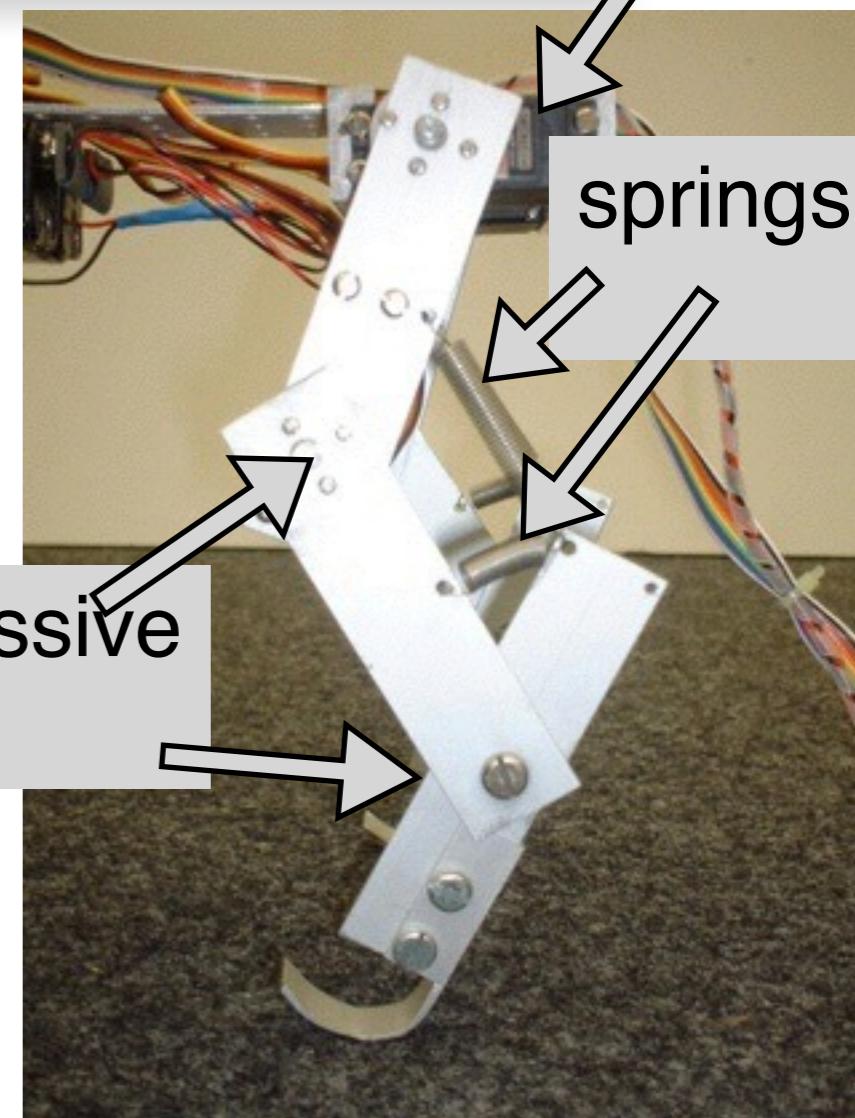
- **level of generality and form of theory**
- **diversity-compliance**
- **frame-of-reference**
- **synthetic methodology**
- **time perspectives**
- **emergence**



actuated:
oscillation

Emergence of stable gait patterns: the quadruped

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



Emergence of clustering



entire process: $\sim 20\text{min}$
frames: 2-3min

Design for emergence: a “bicycle” following the

emergent functionality (not self-assembly)

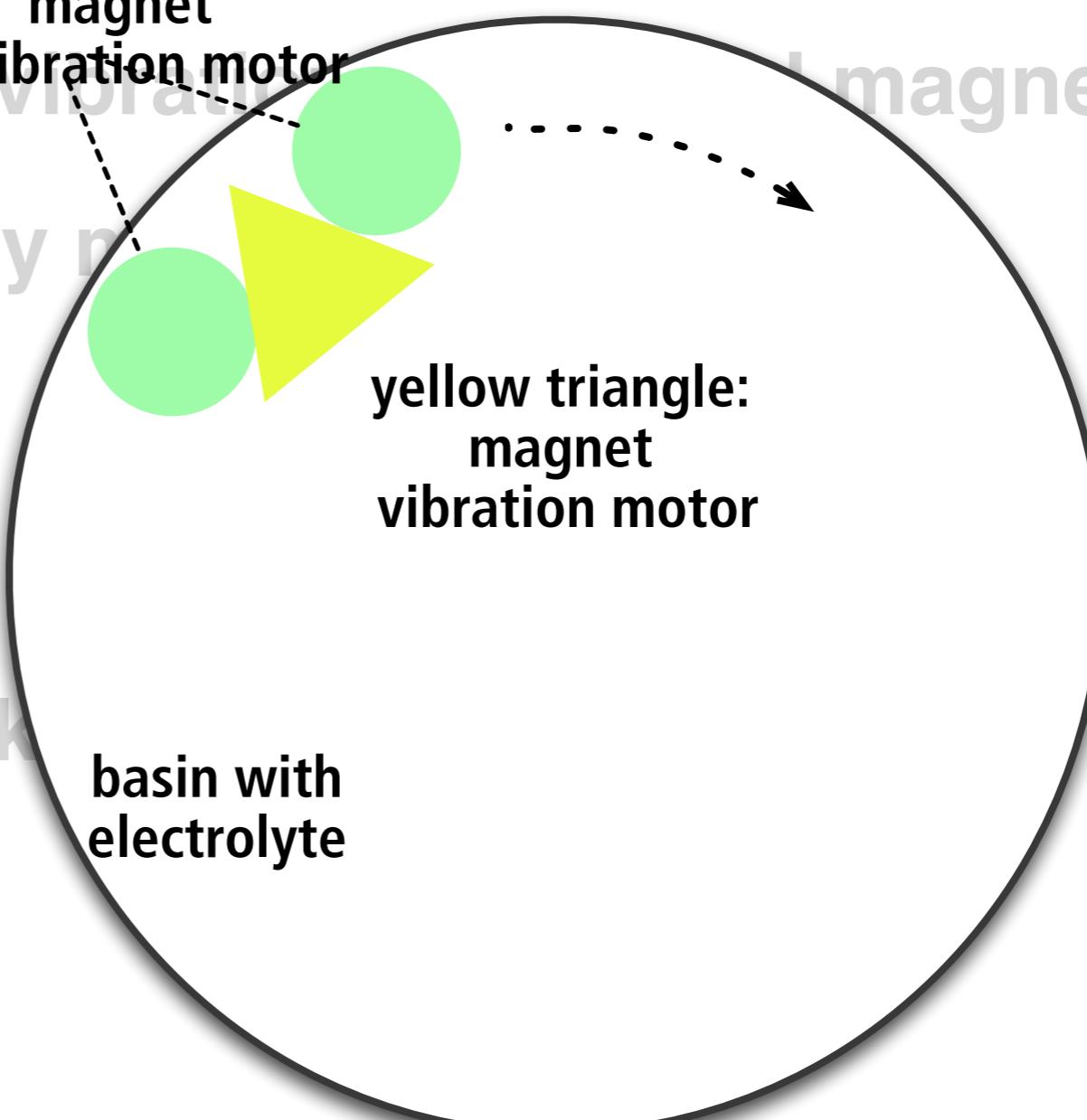
green discs:

magnet

no vibration motor

yellow triangle: vibration motor

green discs: only magnet



how does it work

Emergence of global patterns from local rules — self-organization



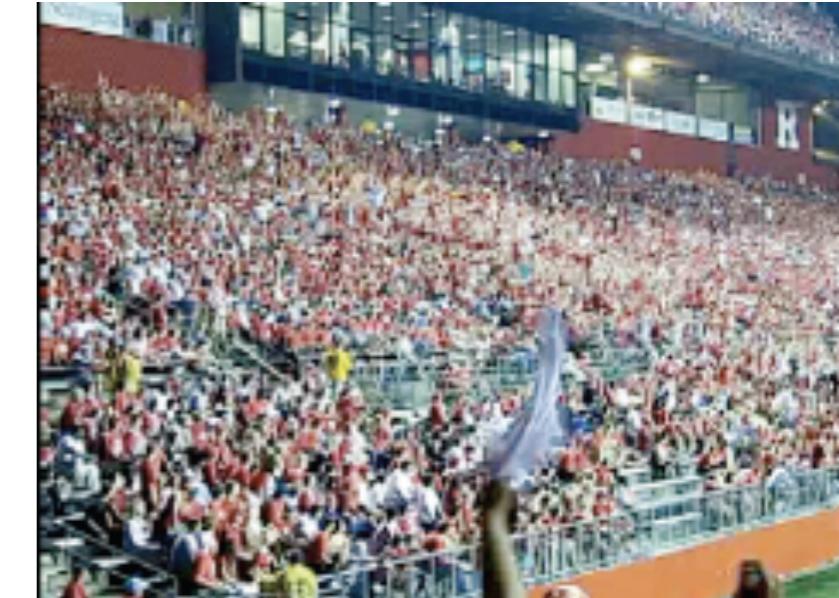
bee
hive



termite mound



open source development
community



“wave” in
stadium

Emergence of scaling in cities



bee
hive



termite
mound

human
cities



A network physics model of urban growth

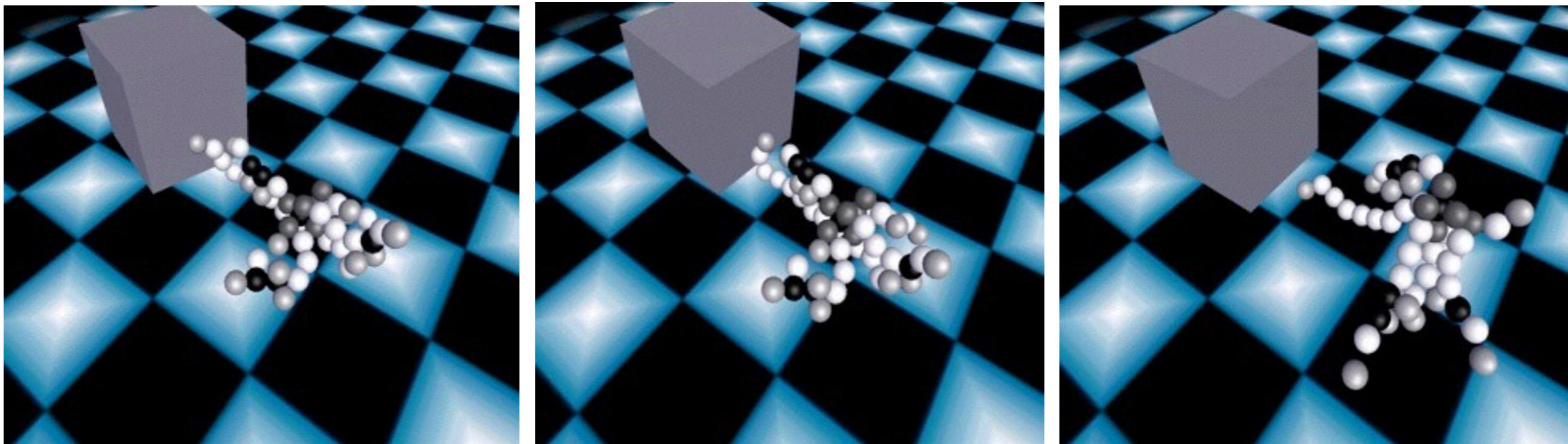
- A theoretical framework to predict the average social, spatial, and infrastructural properties of cities as a set of scaling relations that apply to all urban systems
- Confirmation of these predictions was observed for thousands of cities worldwide,
- Measures of urban efficiency independent of city size and possible useful means to evaluate urban planning strategies.

L M. A. Bettencourt, The Origins of Scaling in Cities,
Science 340(6139), 201



Emergence of behavior from time scales: locomotion and pushing

- development (morphogenesis) embedded into evolutionary process, based on GRNs
- testing of phenotypes in physically realistic simulation



Characteristics of real-world environments

- information acquisition takes time
- information always limited
- noise and malfunction
- no clearly defined states
- multiple tasks
- rapid changes – time pressure
- non-linearity: intrinsic uncertainty



Characteristics of real-world environments

- information acquisition takes time

**Herbert Simon's concept of
“bounded rationality”**

- information always limited
- noise and malfunction
- no clearly defined states
- multiple tasks
- rapid changes – time pressure
- non-linearity: intrinsic uncertainty



Agent design principles

Agent design principles	Description
Three constituents	ecological niche, behaviors/tasks, and agents
Complete agent	complete agent, not only isolated components
Parallel, loosely coupled processes	parallel, asynchronous, processes, largely coupled through interaction with environment
Sensory-motor coordination	behavior sensory-motor coordinated with respect to target; self-generated sensory stimulation
Cheap design	exploitation of niche and interaction; parsimony
Redundancy	partial overlap in functionality based on different physical processes
Ecological balance	Balance in complexity of sensory-motor and neural system; task-distribution: morphology, materials, control, environment
Value	driving forces, developmental mechanisms, self-organization

Design principles for development

Principles for development	Description
Integration of time scales	many time scales need to be integrated into one agent
Development as an incremental process	start simply, build successively on top of what has already been learned
Discover	agent must have ability to explore and evaluate, which implies that agent can discover through its own activities
Social interaction	sensory-motor coordination together with social interaction provides most powerful engine for development
Motivated complexity	why complexity increases during ontogenetic development (driving force)

Design principles for evolution

Principles for evolution	Description
Population	Population is the prerequisite for evolution to function
Cumulative selection and self-organization	Cumulative selection will produce interesting results only if evolutionary process exploits processes of self-organization
Brain-body co-evolution	“Brain” (neural control) and body must be evolved simultaneously
Scalable complexity	In order for complex organisms to emerge, the ontogenetic developmental processes must be encoded in the genome
Evolution as a fluid process	Agents should be modeled with a large number of cells: evolution should make only small modifications (at the genome)
Minimal designer bias	Design as little as possible and let evolution do as much work as possible

Design principles for collective intelligence

Principles for collective systems	Description
Level of abstraction	Proper level of abstraction must be chosen, and the implications (of abstraction) important
Design for emergence	Find local rules of interaction that lead to desired global behavioral patterns (holds also for individual agents)
From agent to group	Agent design principles often applicable to collective systems (e.g. parallel, loosely coupled processes)
Homogeneity-heterogeneity tradeoff	Find compromise between systems using only one type of module/robot and systems employing several specialized types

End of lecture 9

Thank you for your attention!

stay tuned for lecture 10

**“How the body shape the way we think:
Future Trends”**

