The ShanghAI Lectures

人工智能

上海授课

The ShanghAI Lectures

An experiment in global teaching

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University of Zurich

Fabio Bonsignorio
University Carlos III of Madrid and Heron Robots

Today from the University Carlos III of Madrid
Spain

欢迎您参与

“来自上海的人工智能系列讲座”

Lecture 9

Towards a theory of intelligence

12 December 2013

Successes and failures of the classical approach

successes

applications (e.g. Google)

chess

manufacturing

("controlled"artificial worlds)

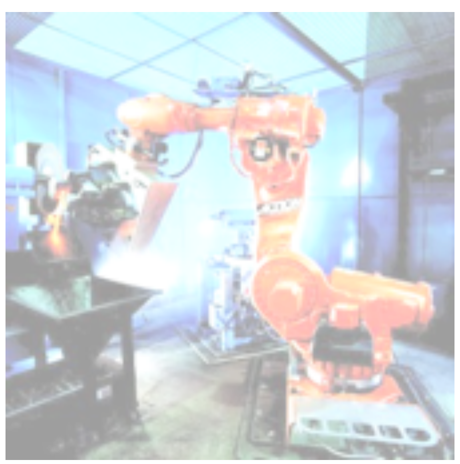
failures

foundations of behavior

natural forms of intelligence

interaction with real world

Industrial robots vs. natural systems



robots

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

humans

→ **no direct transfer of methods**

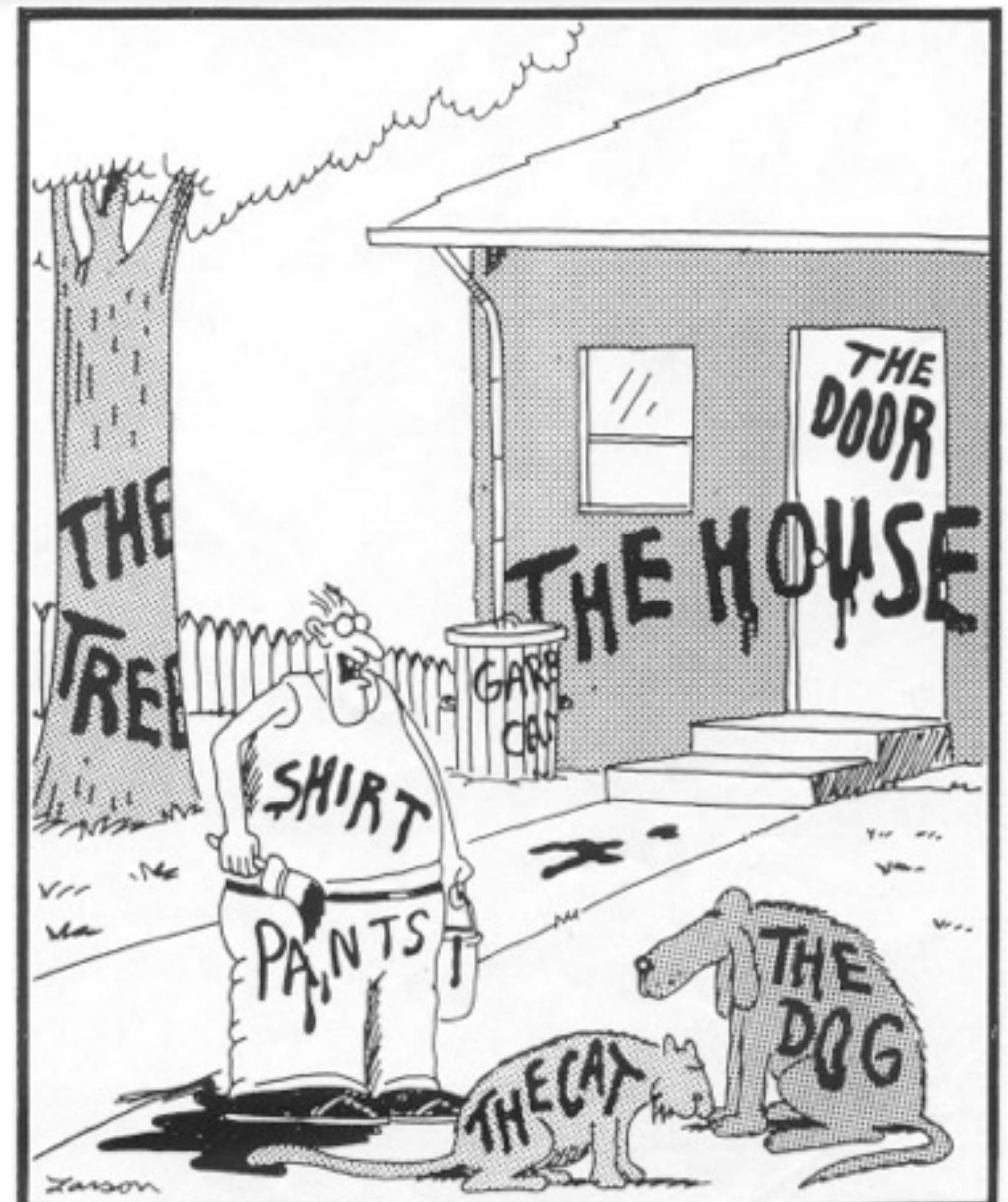
The “symbol grounding” problem

real world:
doesn’t come
with labels …

How to put the

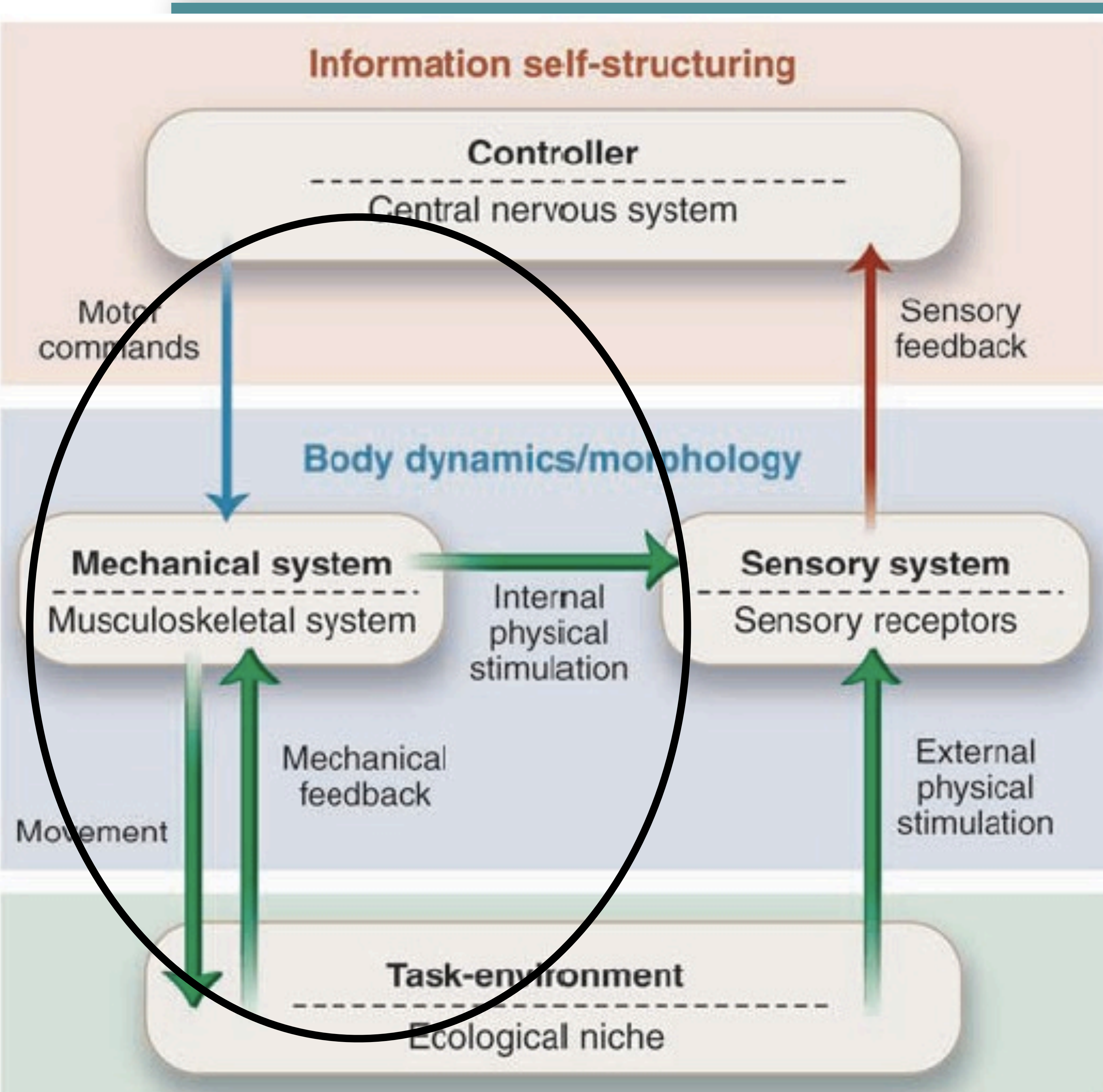
labels??

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

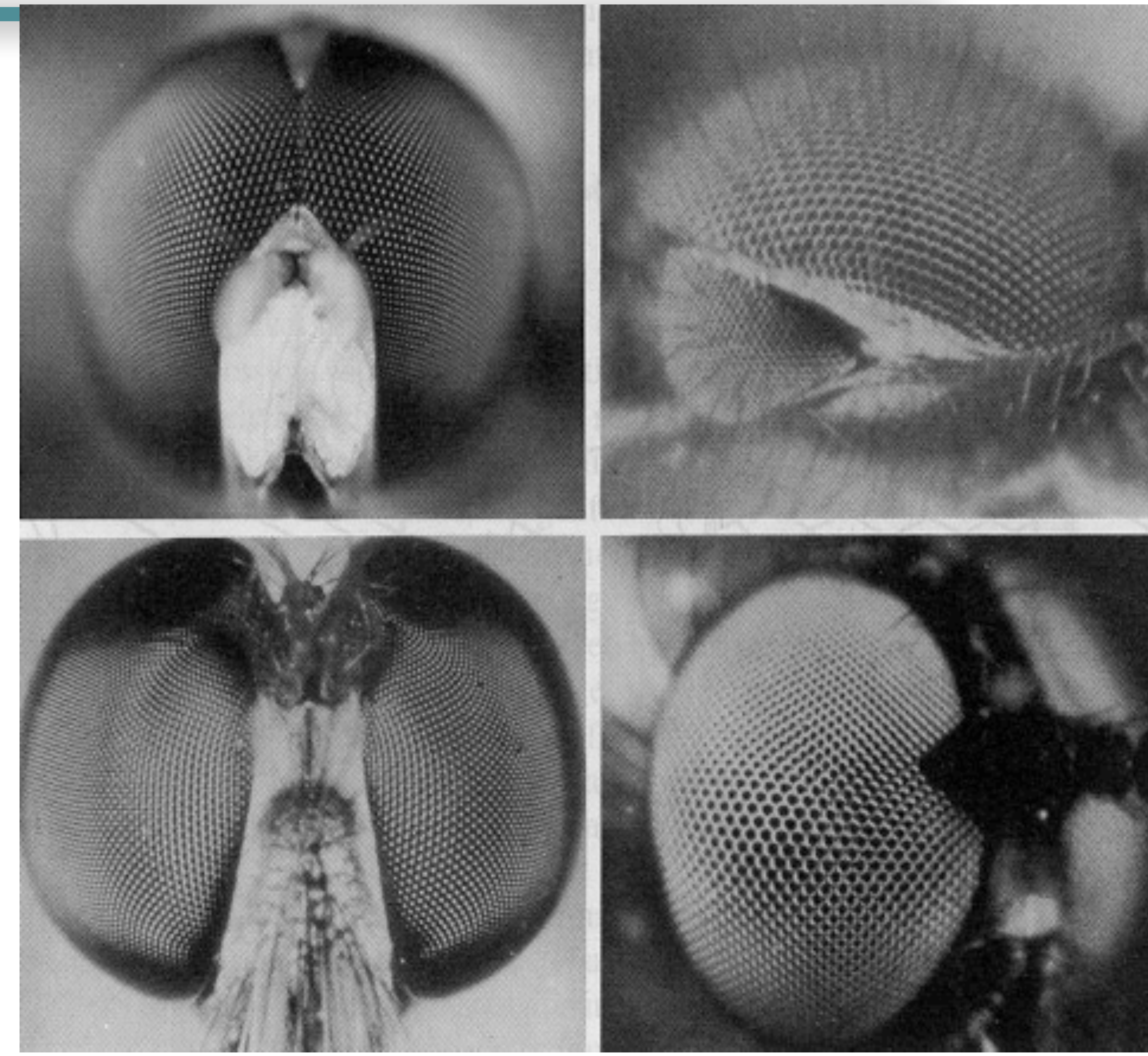
Principle 7: Ecological balance

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?

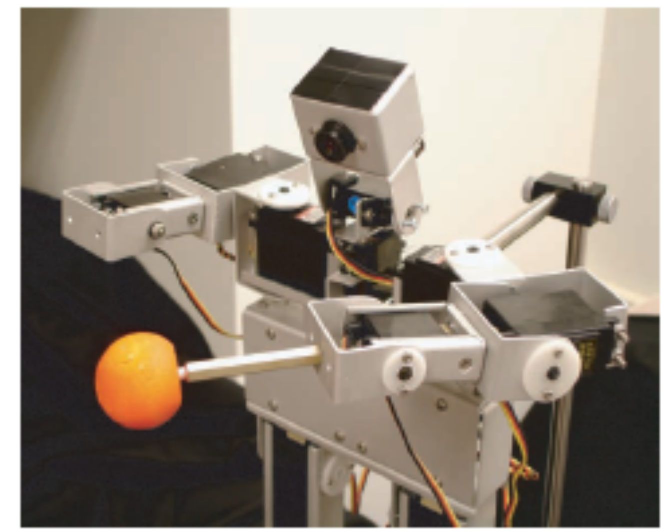
Where does 'symbols' come from?: physical dynamics and information processing

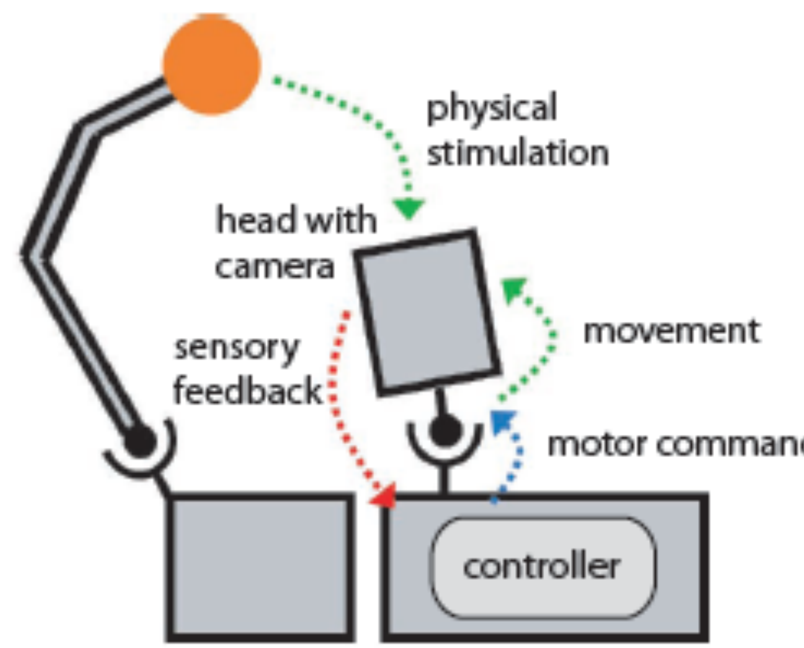
- morphology and materials
- orchestration control
- exploration
- preferred trajectories from biomechanical constraints
- induction of patterns of sensory stimulation in different sensory channels
- sensory-motor coordination —> induction of information structure
-

Information self-structuring

Experiments:

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





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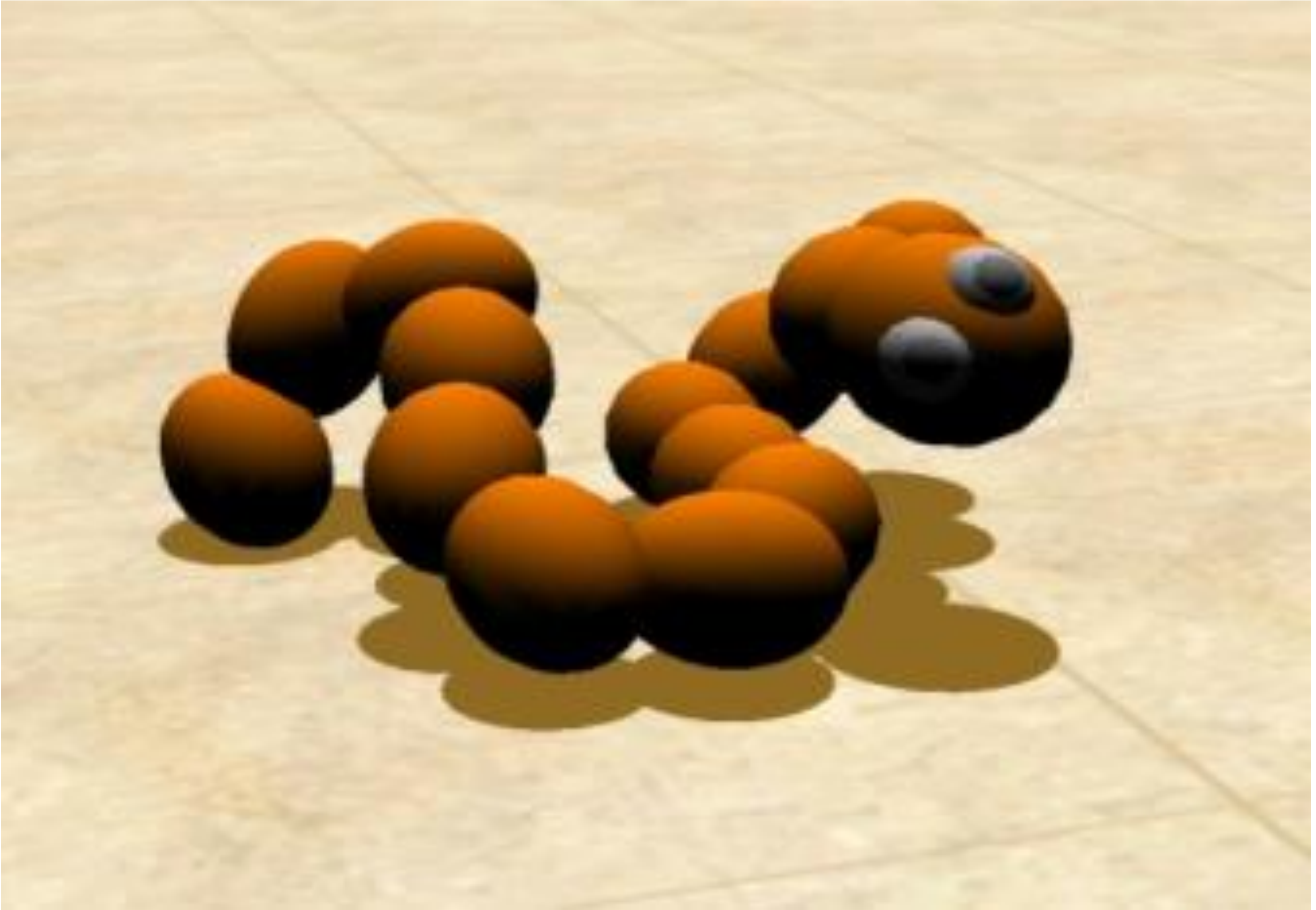
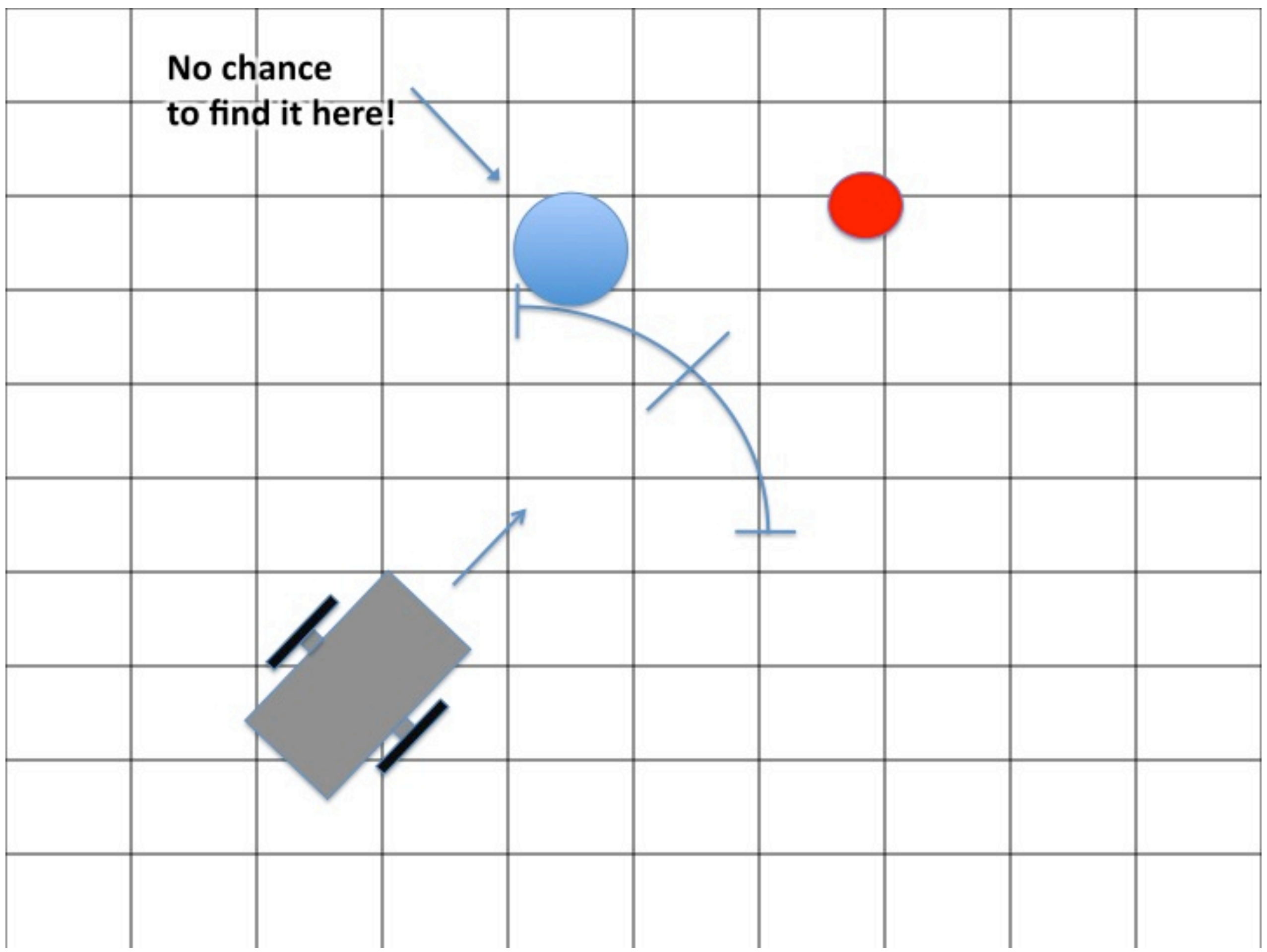
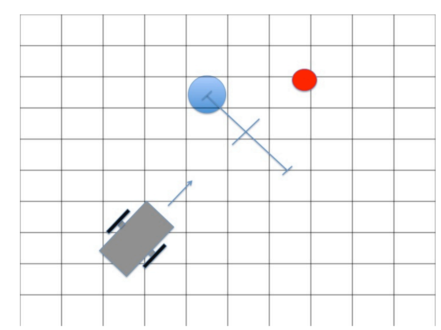
Snakebot



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

Maybe not GOF Euclidean space? :-)





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

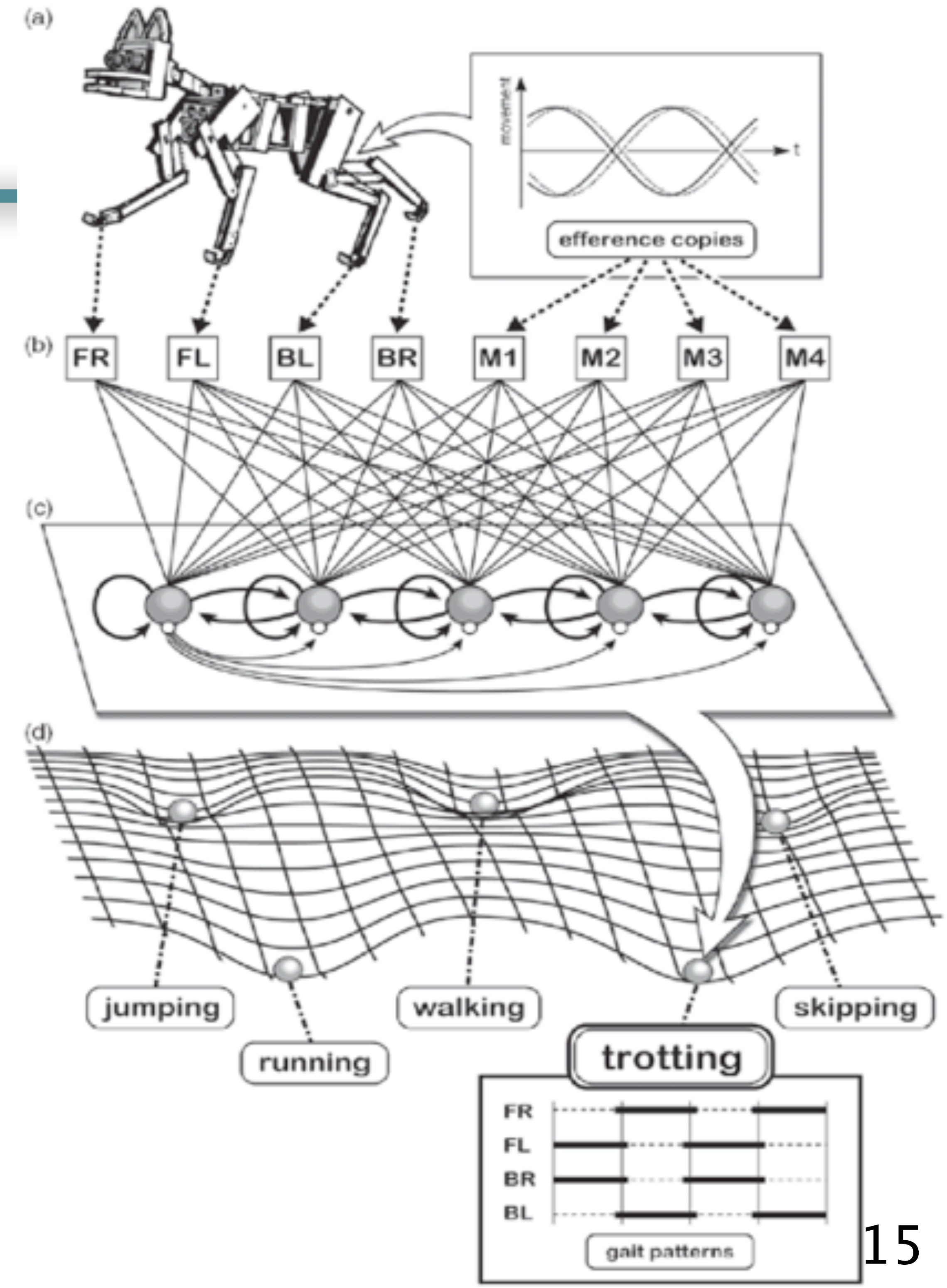
Building grounded symbols (labeling!)

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

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

Is our body a kind of ‘swarm’?

- remenber 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)

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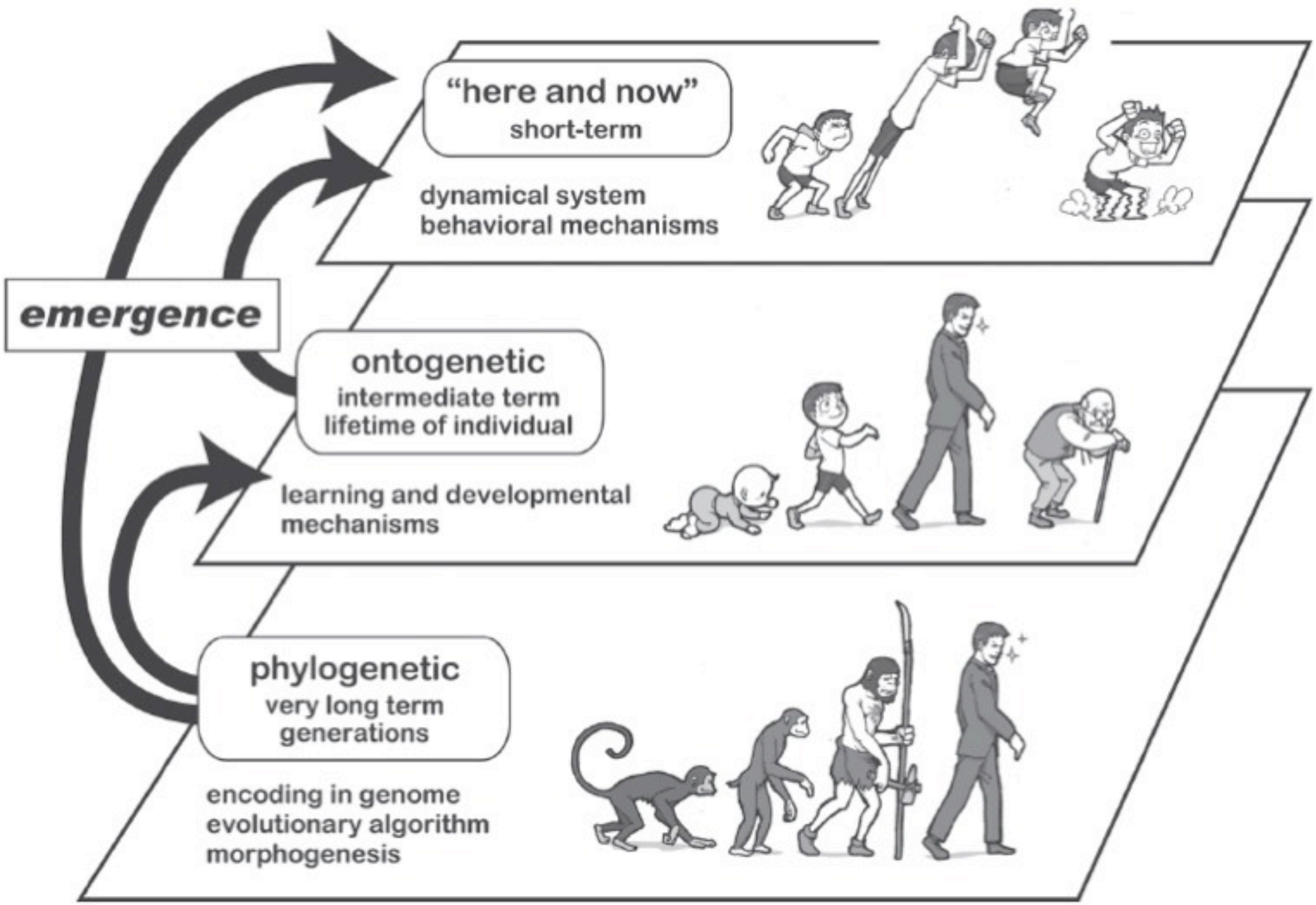
Time perspectives



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 and development?

—>

- Time perspectives
- 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 ... e: effect
(principle ...
structurin...

foundation of learning and development

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?

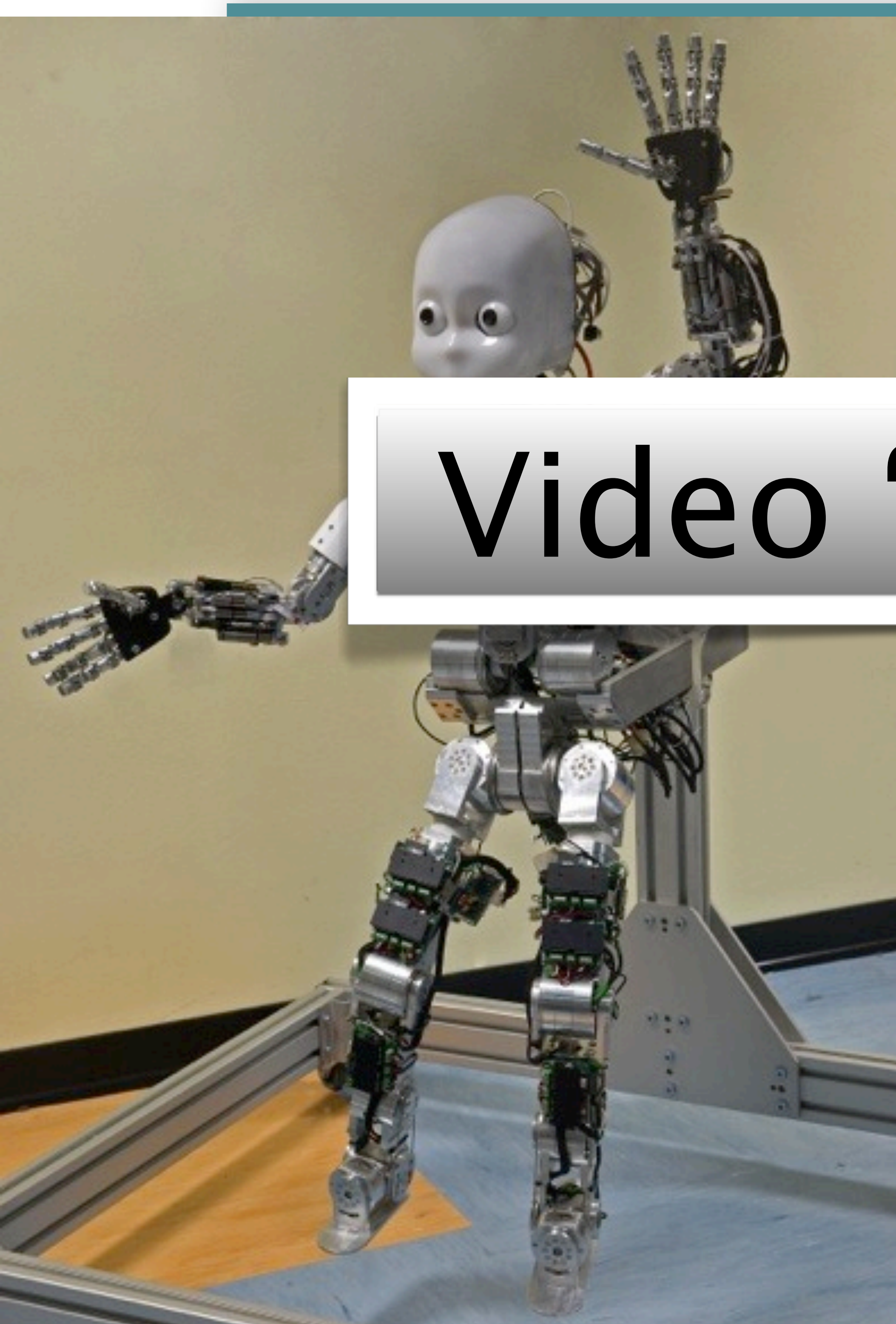
—>

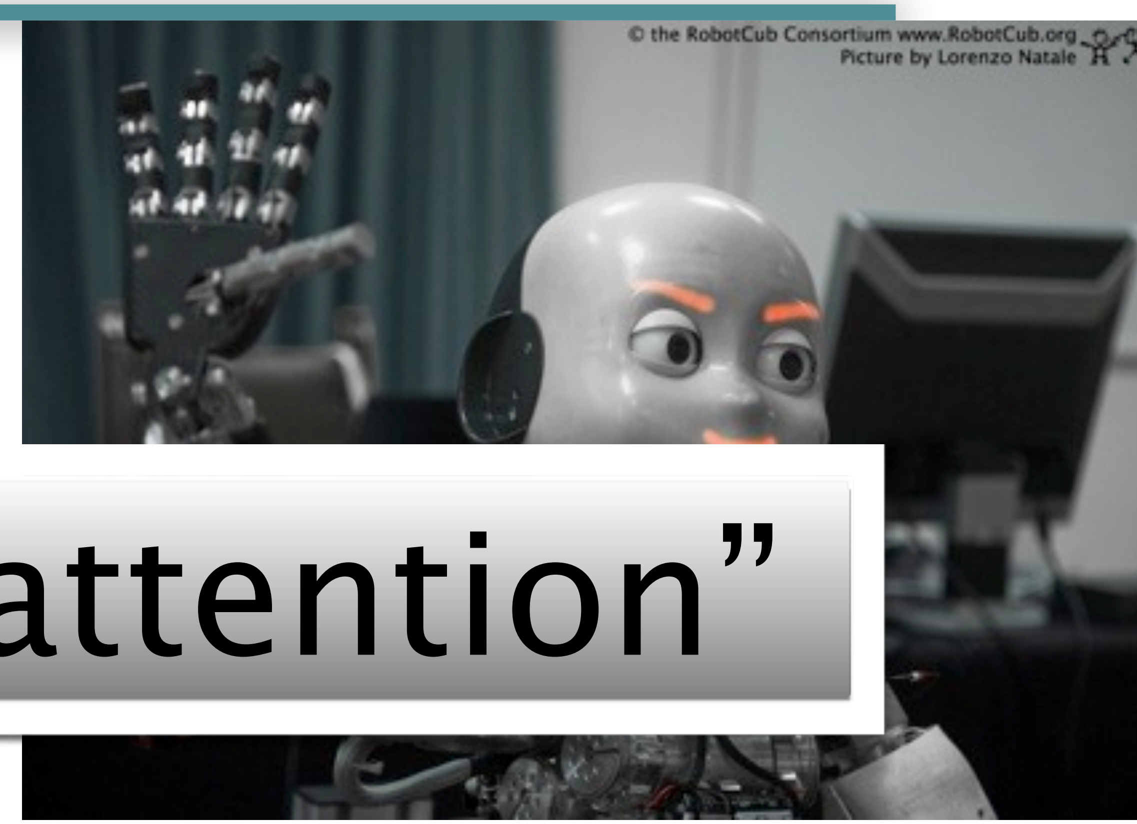
Robots for studying development: Why humanoids?

- **huge engineering challenge**
- **synthetic methology: 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

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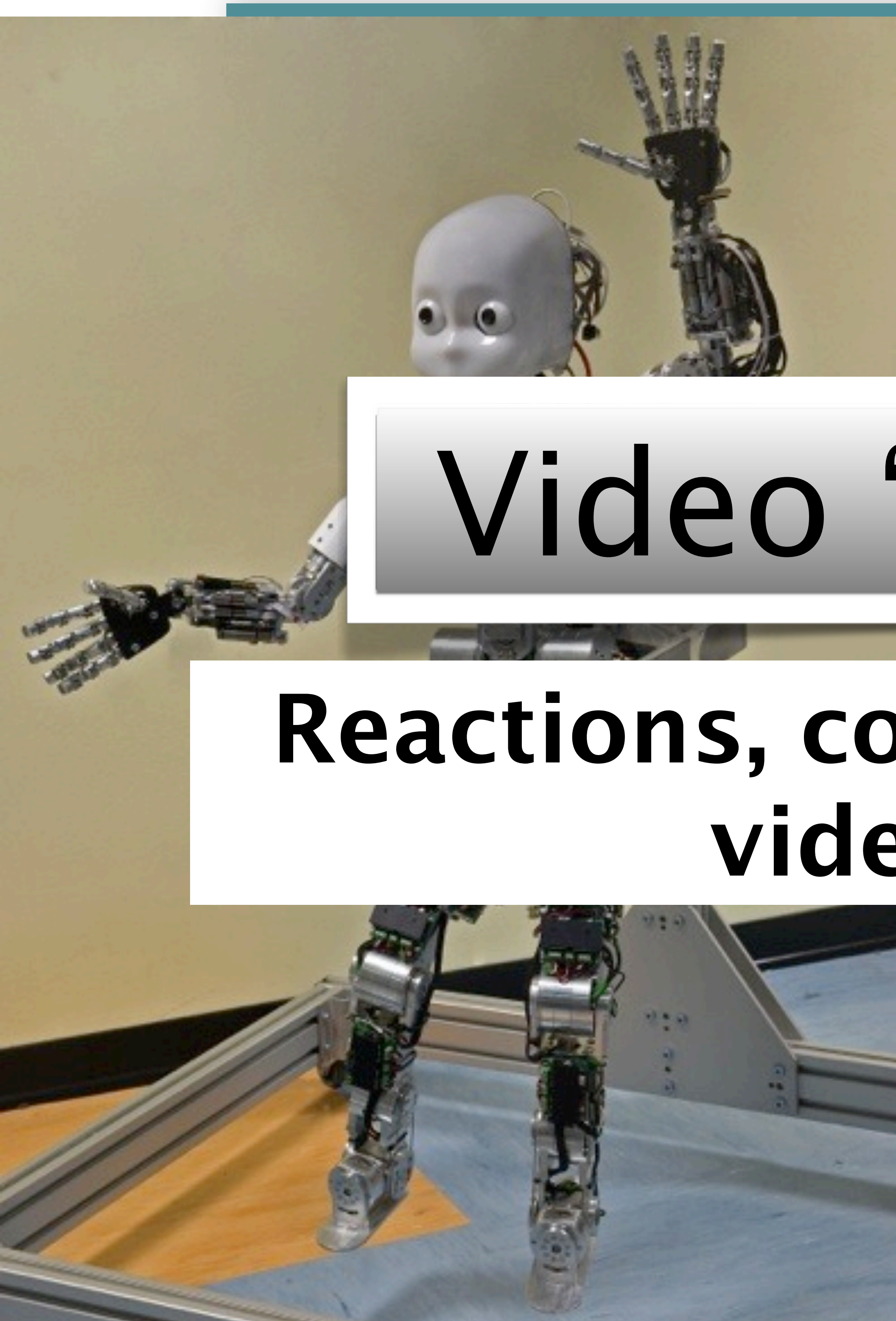
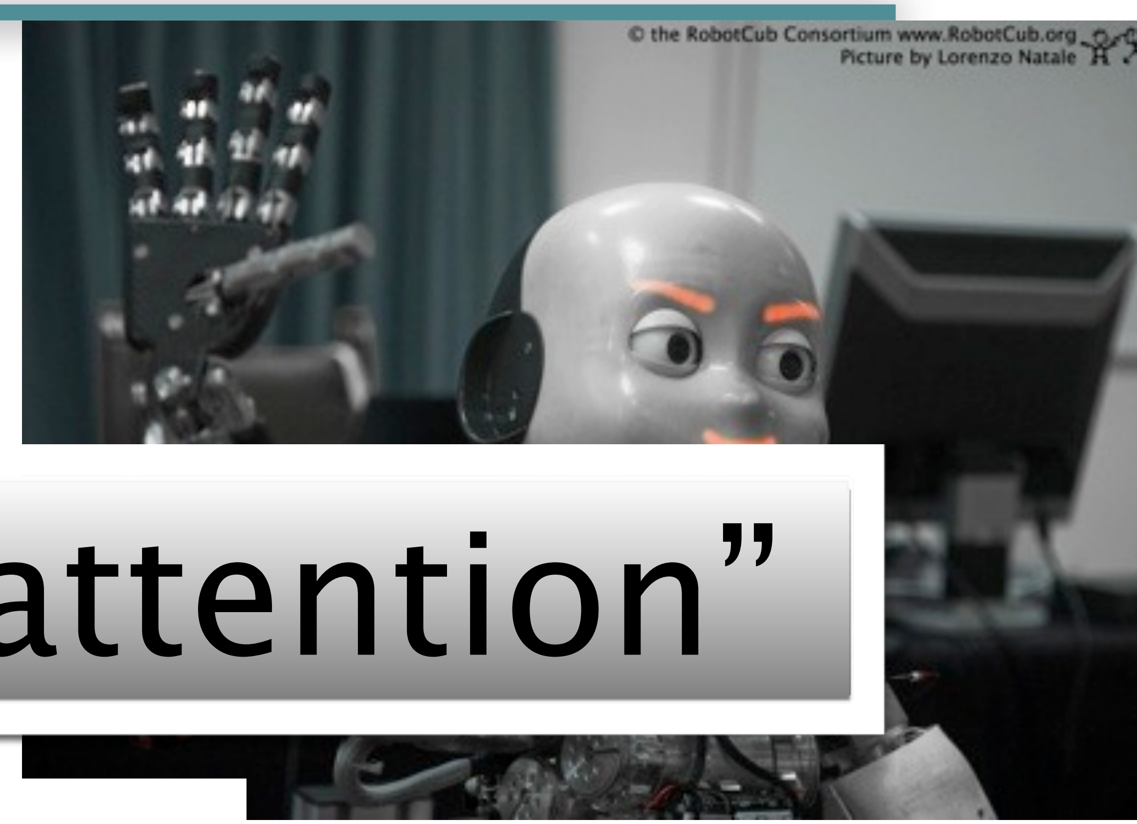
Robots for studying development: iCub





Video "iCub attention"

Reactions, comments on video?

roject by
Giorgio Metta and Giulio Sandini

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A research platform for sensori-motor development

Adding sensors: generation of sensory stimulation

- 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)

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Physical dynamics and information structure

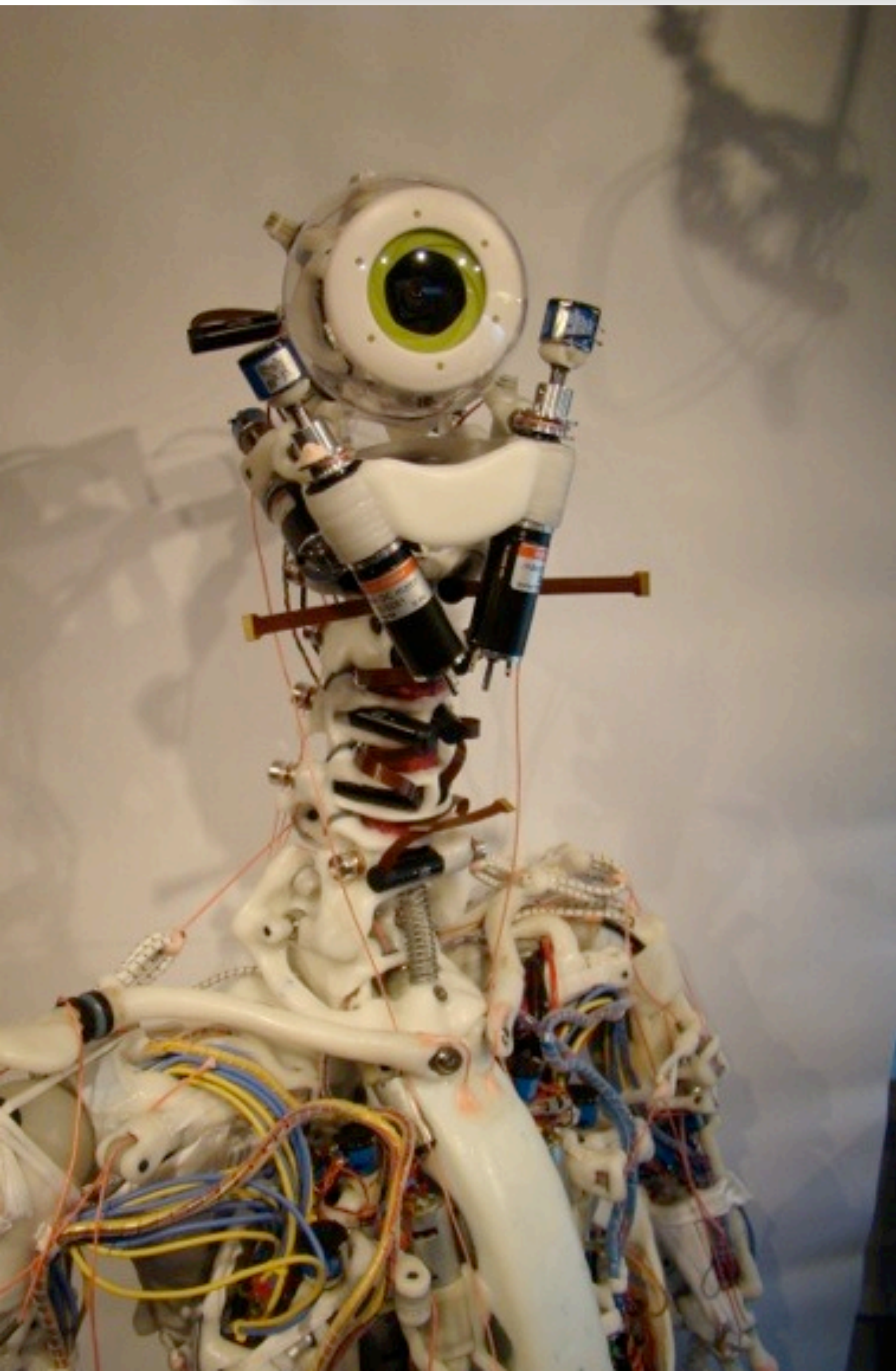
Induction of patterns of sensory stimulation through physical interaction with environment

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)

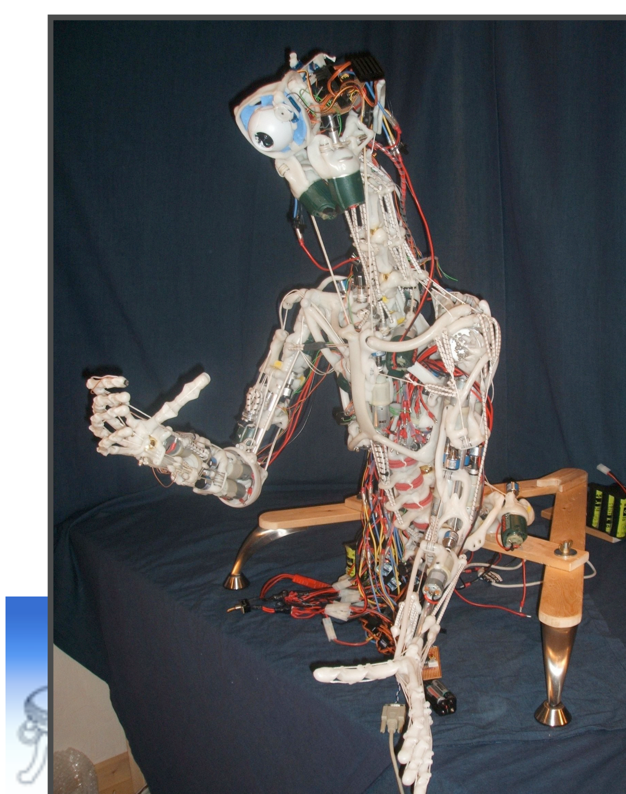
The super-compliant, “soft”, robot ECCE for development



Design and construction:
Rob Knight — robotstudio, Geneva
Richard Newcombe — Imperial College

ECCE — Embodied Cognition in a Compliantly Engineered Robot

Anthropomorphic design



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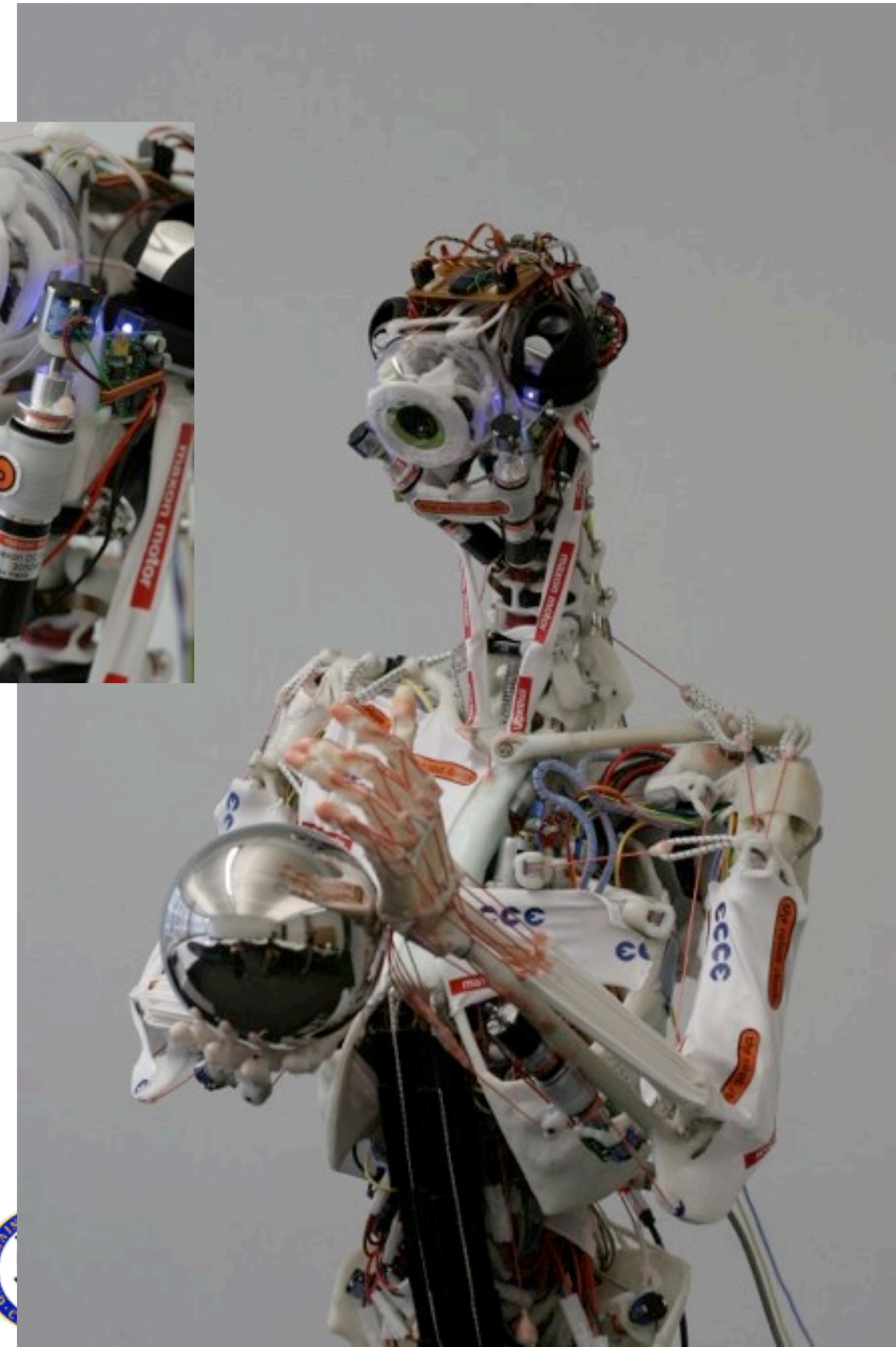
The super-compliant “soft” robot ECCE



fully tendon-driven

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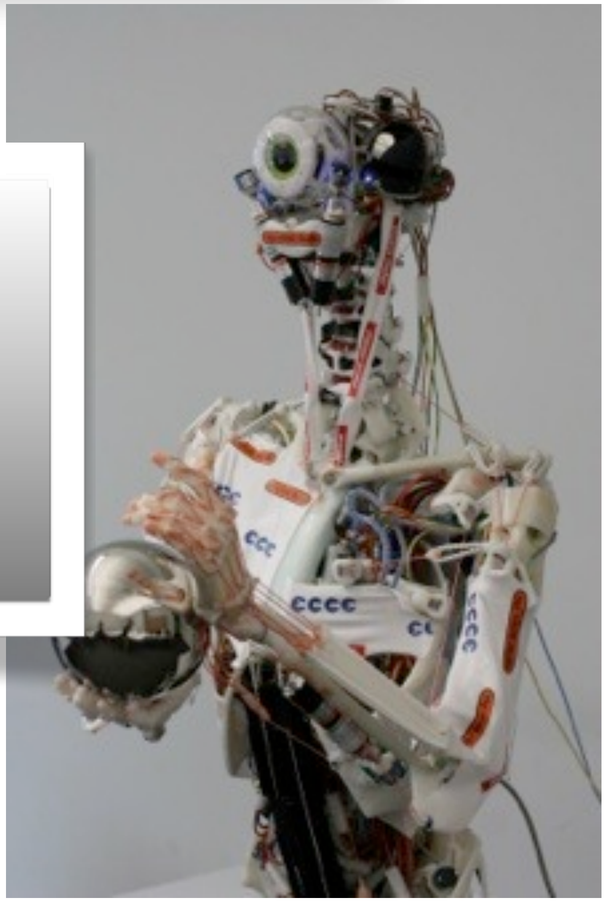
The super-compliant, "soft", robot ECCE

Video "ECCE_Promovideo"



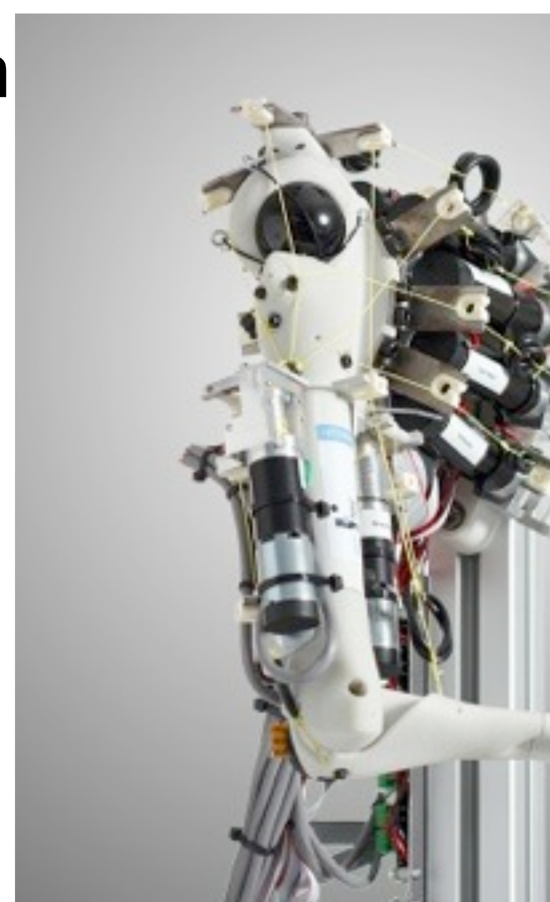
Anthropomorphic design

→ must have learning

Neue Plattform: Roboy

(in - schneller - Entwicklung: Ziel Februar 2013)

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



Visit:

become friends with “Roboy” on facebook!

Bernstein's problem

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

→ complexity barrier

research opportunity

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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)

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Bernstein's problem

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

research opportunity

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How to quantify?

research opportunity

- The main concept is tha
  information processing 'computing' is a general characteristics of any material system, while 'intelligence' and 'meaning' should be syncronisation processes within networks of autonomous agents.

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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

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Implementation of learning in embodied systems

important approaches:

"Artificial Neural Networks"

"Deep Learning"

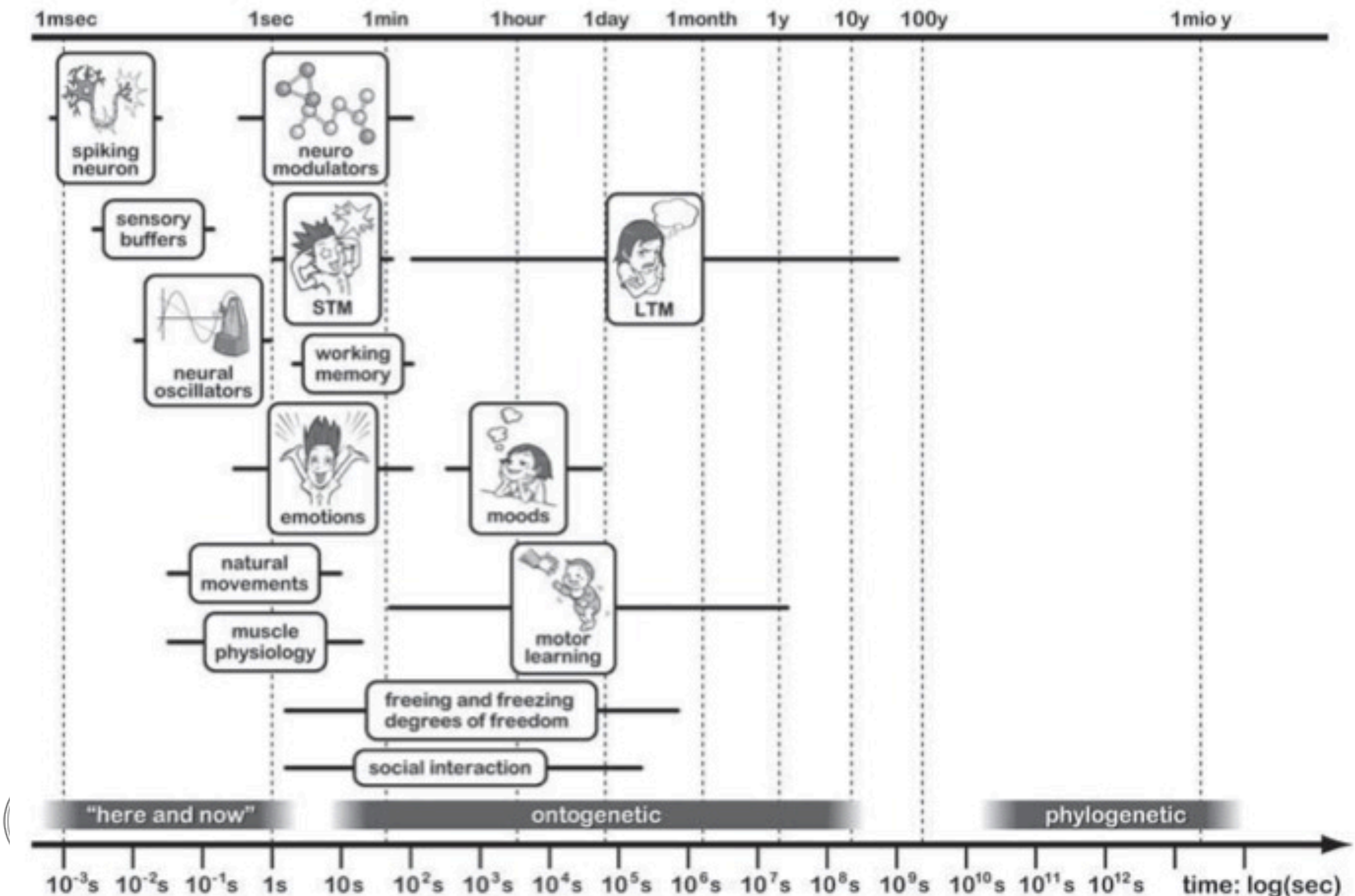
"Information Theory"(on curved spaces, too)

"Network physics"

Additional aspects of development

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

Integration of time



Additional aspects of development

- integration of many different time scales

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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

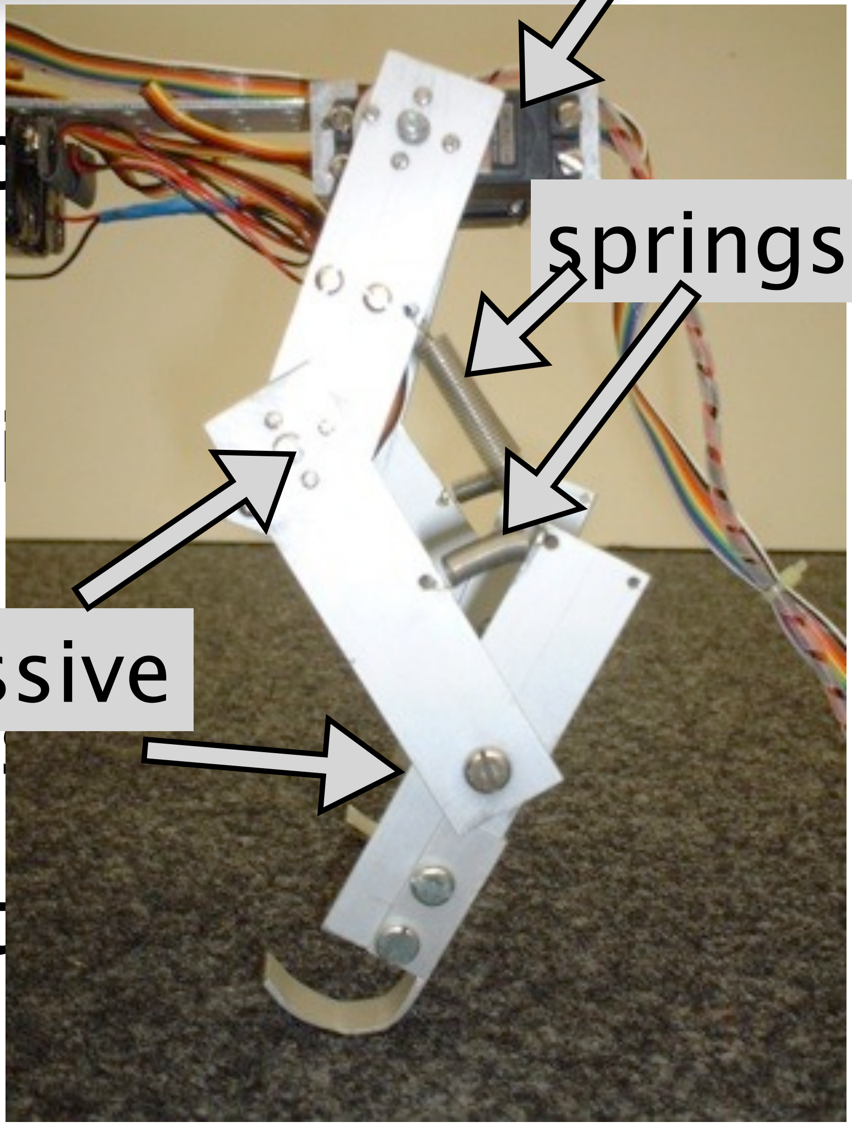
1. Meta-considerations: “Mind Set”
2. Properties of physically embodied agents
3. Characteristics of real world
4. Design principles

Steps toward a theory of intelligence

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

Emergence of stable gait patterns: the quadruped

- simple control (oscillations o "hip" joints)
- spring-like material properti ("under-actuated" system)
- self-stabilization, no sensor
- "outsourcing" of functionalit



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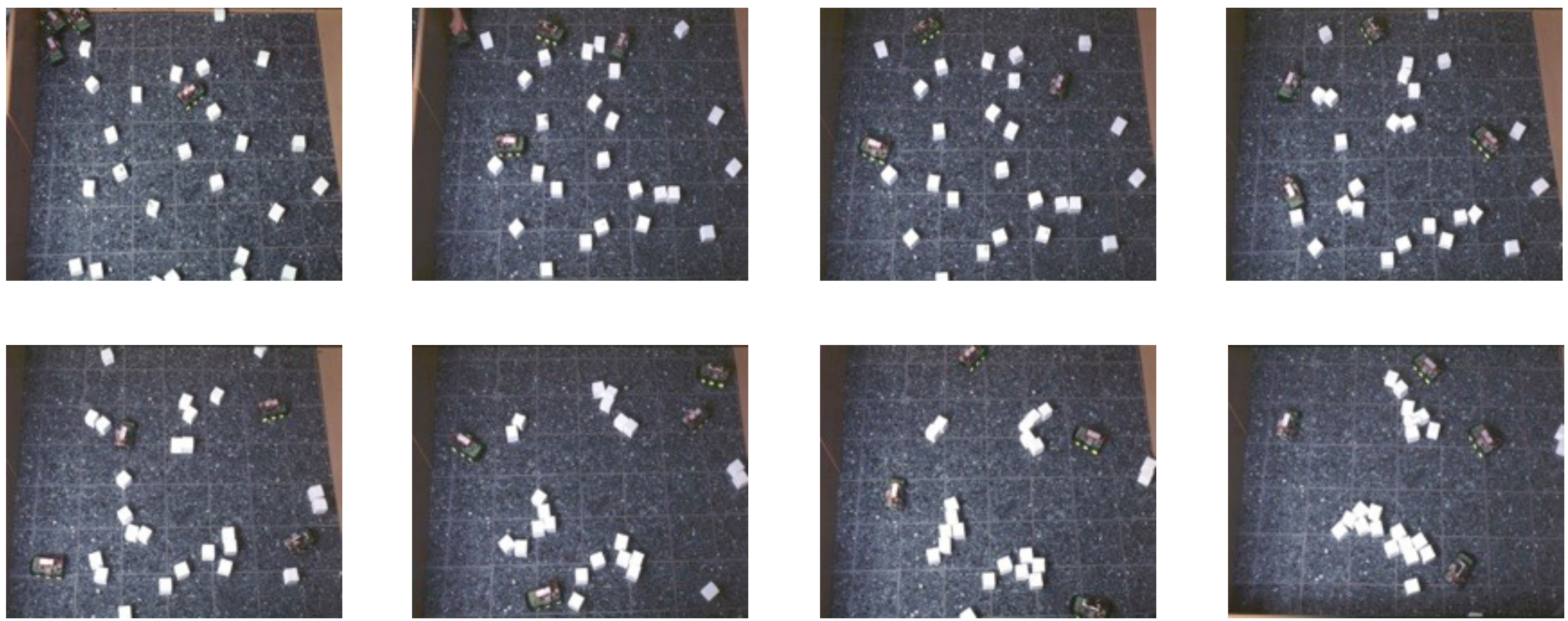
Emergence of clustering



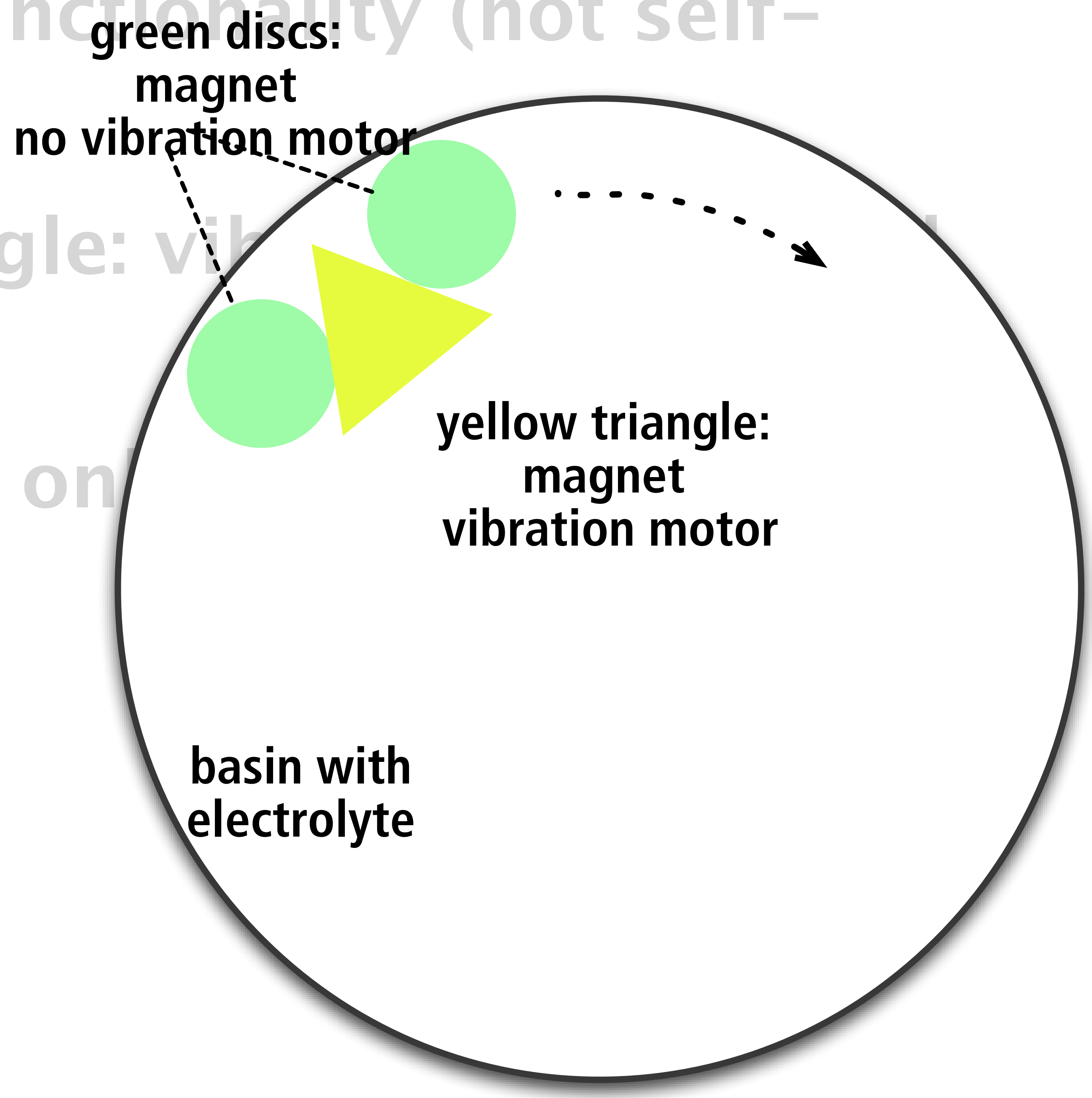
entire process: ∼20min
frames: 2-3min

Design for emergence: a “bicycle” following the

emergent functionality (not self-assembly)

yellow triangle: vib…
magnet

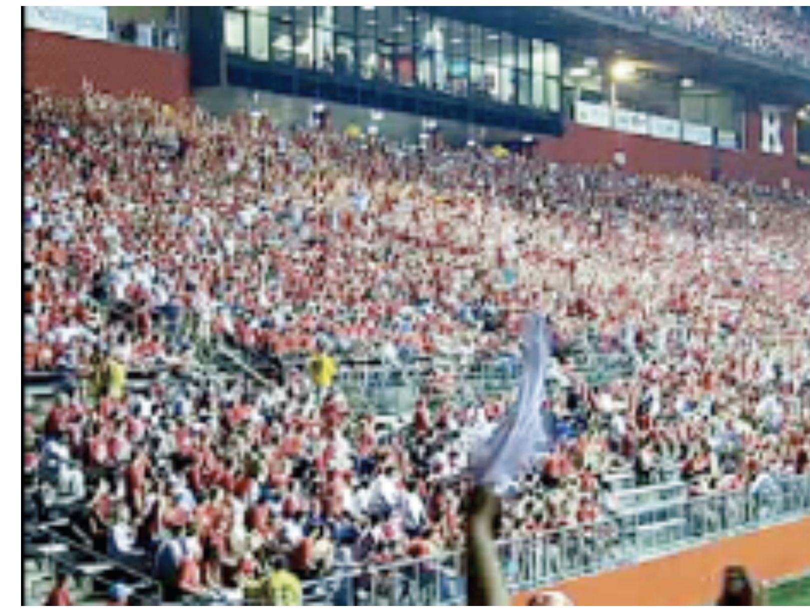
green discs: on…



Emergence of global patterns from local rules — self-organization

bee hive

termite mound



“wave”in stadium

open source development community

Emergence of scaling in cities

bee
hive

termite
mound

human
cities

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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

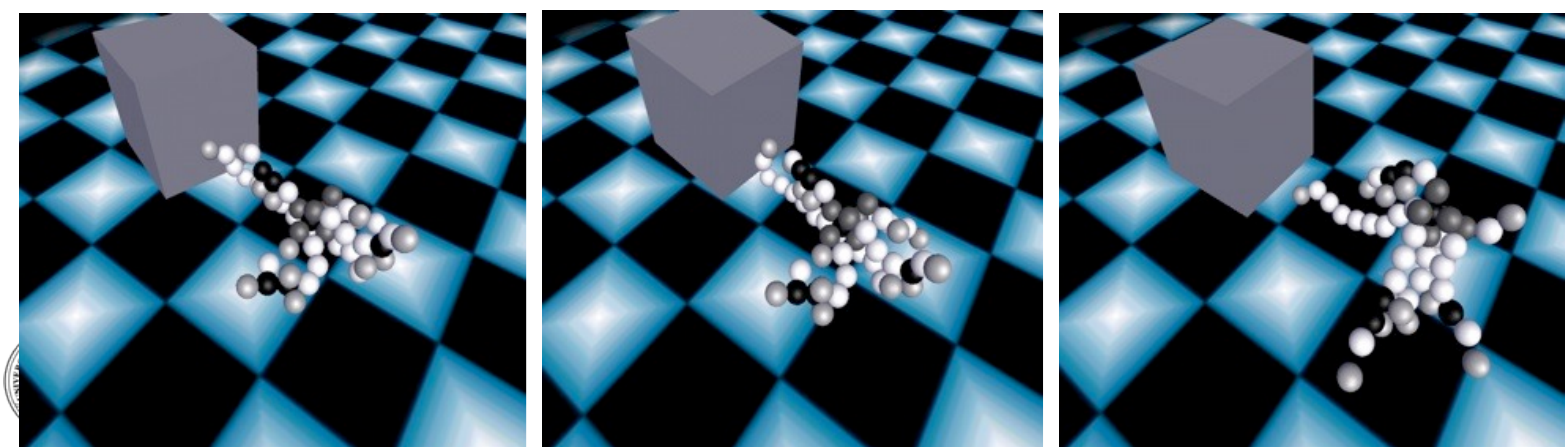
- Confirmation of these predictions was observed for thousands of cities worldwide,

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

Chengdu

Characteristics of real-world environments

- information acquistion takes time
- information always limited
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- rapid changes — time pressure
- non-linearity: intrinsic uncertainty

Herbert Simon's concept of "bounded rationality"

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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 activites
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 emplying several specialized types

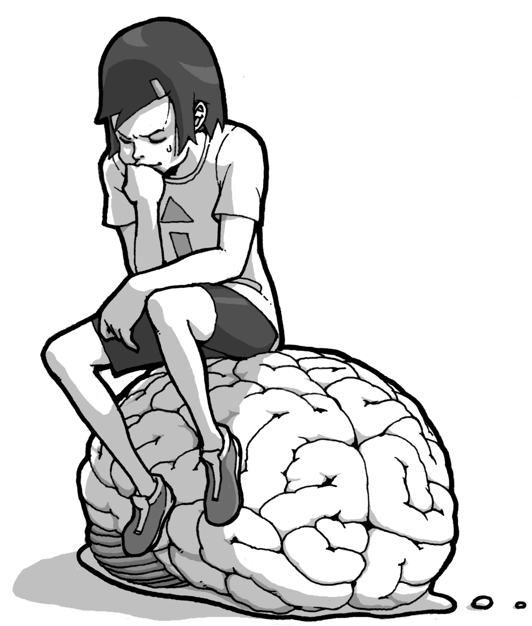
End of lecture 9

Thank you for your attention!

stay tuned for lecture 10

“How the body shape the way we think

The road ahead”



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