# The ShanghAI Lectures

人工智能

上海授课

# Today's schedule

08.00 - 08.05 Introduction

09.00 - 09.05 CET, 16.00h China, 17.00 Japan, 18.00 Australia (Tasmania)

08.05 - 09.00 From locomotion/movement to cognition

16.50 Break

17.00 - 17.30 Prof. Barbara Webb, University of Edinburgh, UK, "AI - Artificial Insects"

17.30 - 18.00 Dr. Tamas Haidegger, Budapest: "Humans-robots-humans: who is operating who?"

# The ShanghAI Lectures
# by the University of Zurich
# An experiment in global teaching

Today from the University of Salford (Manchester), UK

8 December 2011

**欢迎您参与**

**“来自上海的人工智能系列讲座”**

# Lecture 6

## Ontogenetic development: From locomotion to cognition

8 December 2011



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# Today's topics

- short recap and motivation
- sensory-motor coordination — information self-structuring
- linking to ontogenetic development
- high-level cognition: the Lakoff-Nunez hypothesis
- building embodied cognition: artifical neural networks
- principles for development

# 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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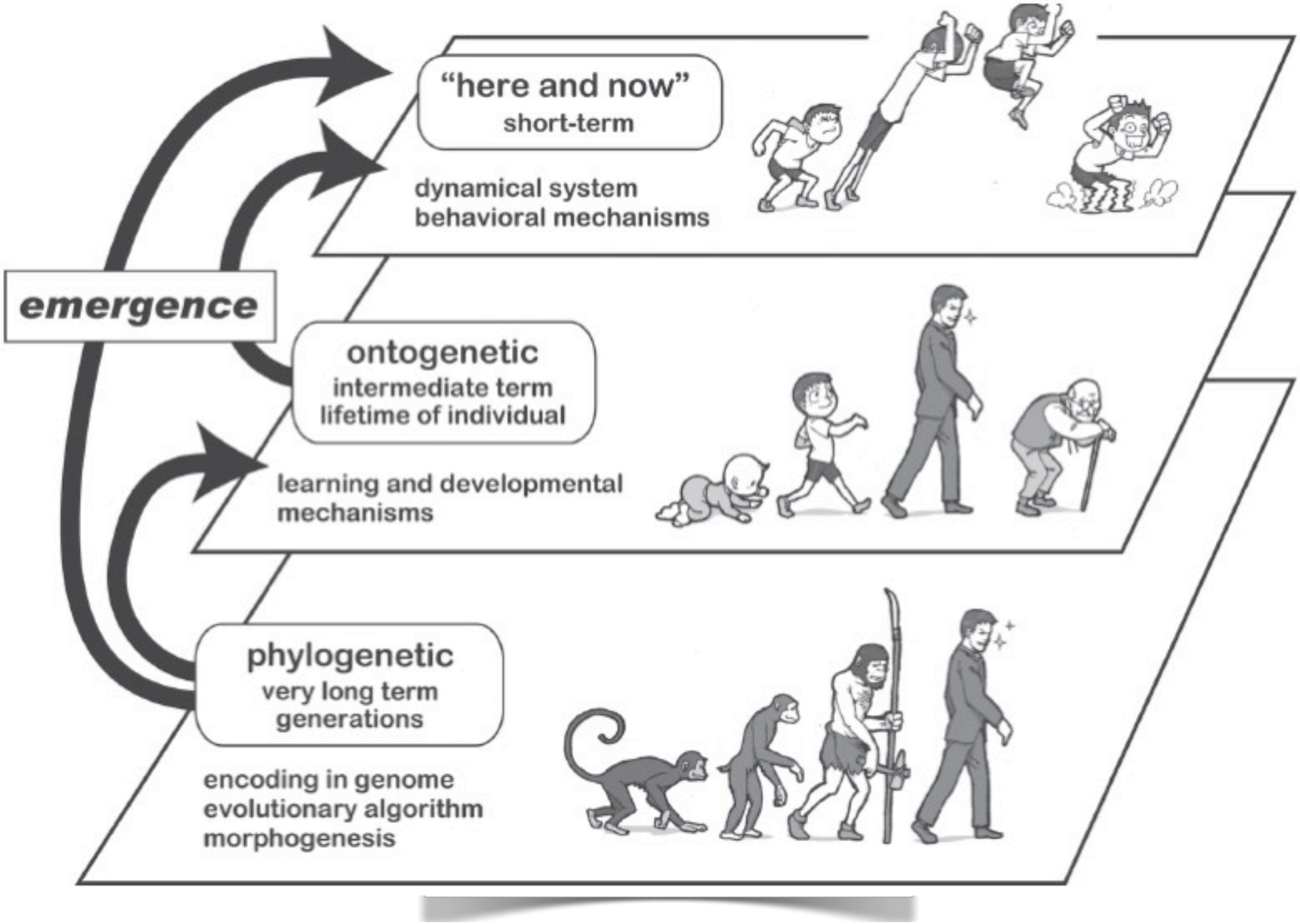
# Time perspectives



# Motivation for developmental approach

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





Alain Turing, in his article "Computing machinery and intelligence," Mind, October 1950, 59, 433-460, also suggested, instead of designing a robot with all its abilities directly, to build a simple one, but one that es equipped with learning abilities. Through its interaction with the environment (including other agents), it will then, over time, successively learn the required skills, a process that might be substantially simpler."

Bernstein's problem refers to the issue of how it is possible that humans learn to control such an enormously complex body, with so many degrees of freedom.

# 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)**





Note: difference between learning and development
- development: includes learning and maturation of organism. Note that the organism goes through enormous morphological changes as it grows from a single cell into an adult organism; the systems control mechanisms have to cope with that, a fantastic challenge.
- learning: typically only brain/cognitive system considered (no morphological changes taken into account)

# Physical dynamics and information processing

# Grasping an object

- **many ways**
- **winding spring (effort)**
- **release**
- **exploitation by brain (“cheap design”, exploitation of material properties, “free”)**





When releasing, arm will turn back into natural position (largely) without control from the brain; it’s as if the brain were outsourcing this functionality to the morphology and material characteristics of the arm/shoulder system (with its muscles and tendons). The brain is not so much *controlling* the movement but *orchestrating* it.

# Grasping an object

- **induction of sensory stimulation**
- **dependence on**
  - **morphology: high density of touch, temperature and 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”



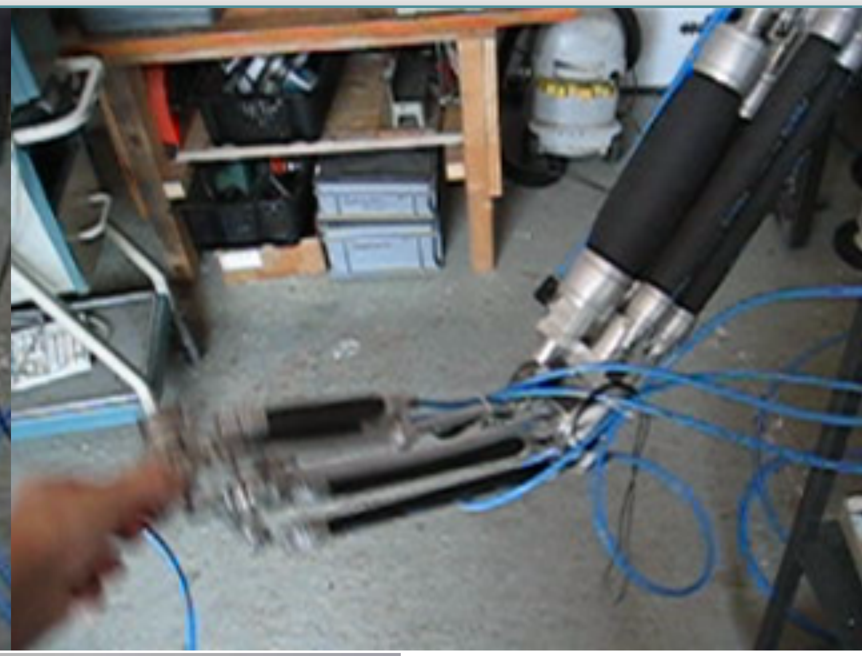


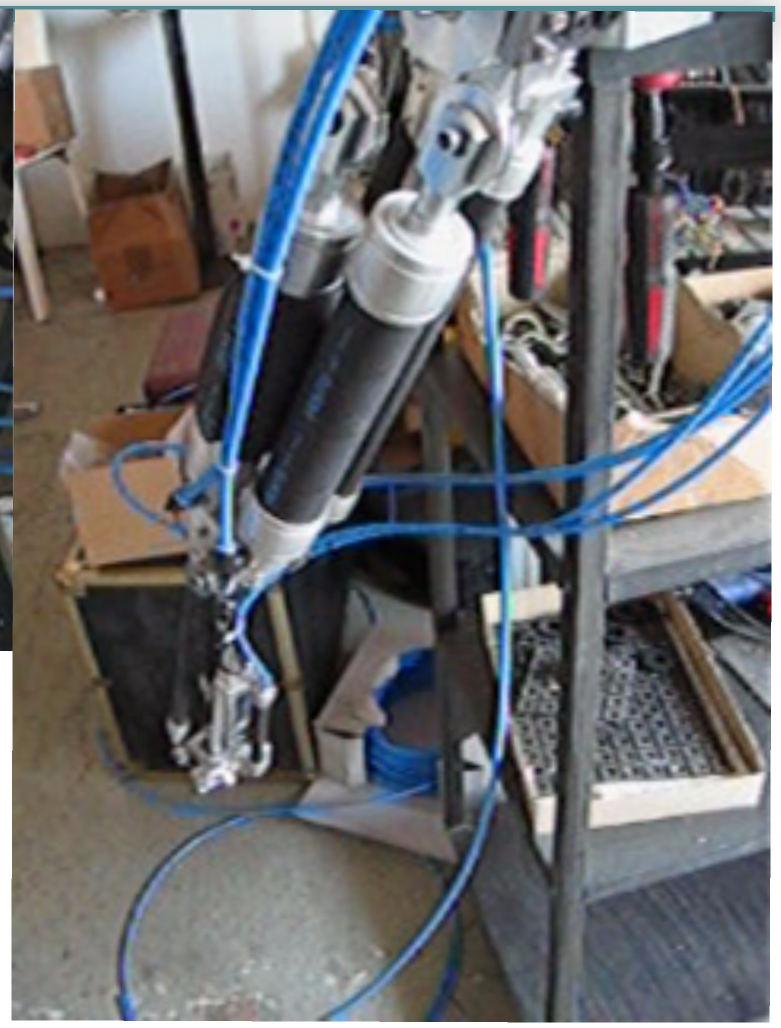
There seems to be an evolutionary predisposition for this kind of movement that makes it on the one hand easy to control, on the other it is very energy-efficient. It is useful for exploring the environment in constrained ways such that the probability of something interesting happening is high (compared other, less natural movements).

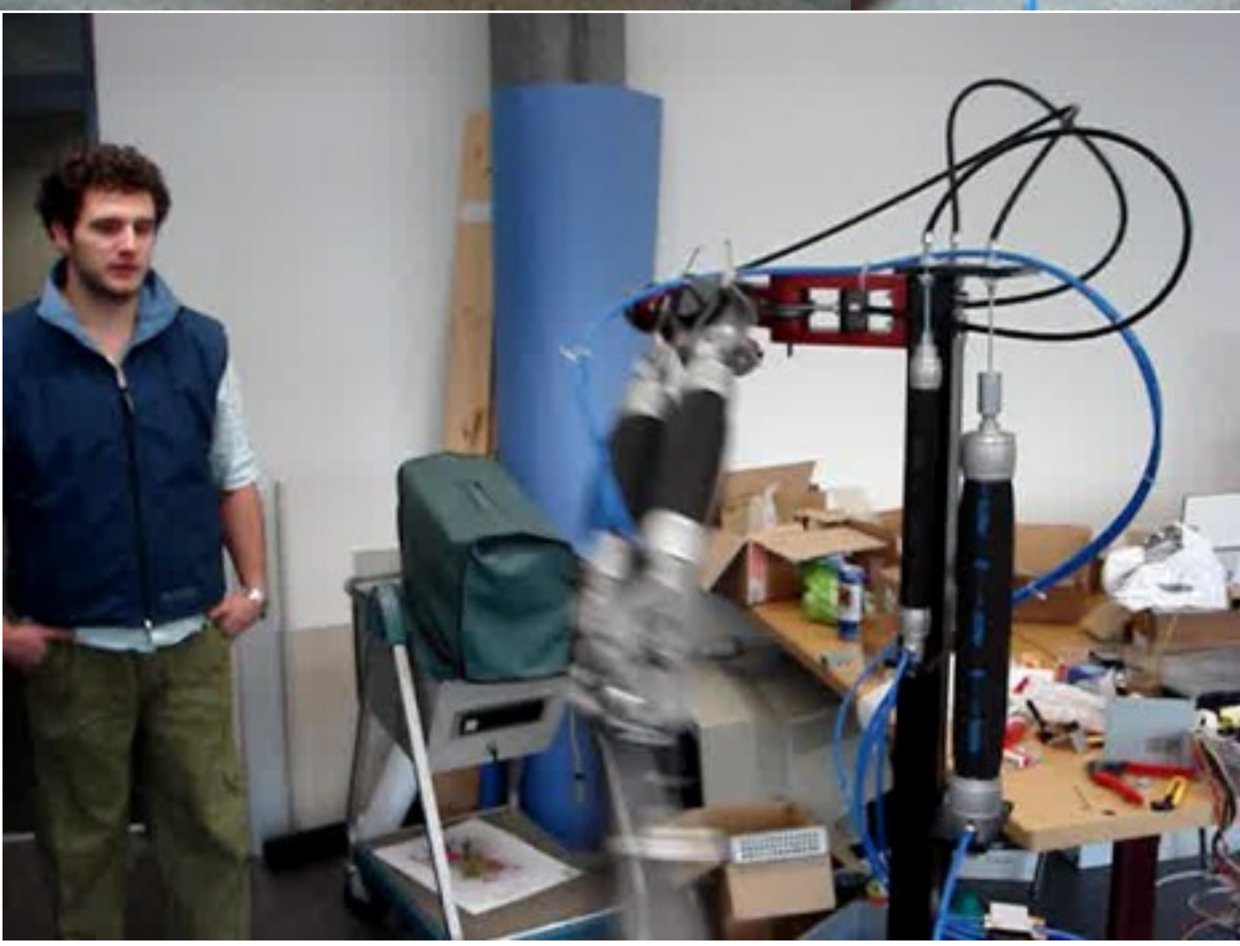
# Compliance

- What does the term “compliance” designate?
- Why is variable compliance interesting?
- Pneumatic actuators?

# Anthropomorphic arm with pneumatic actuators





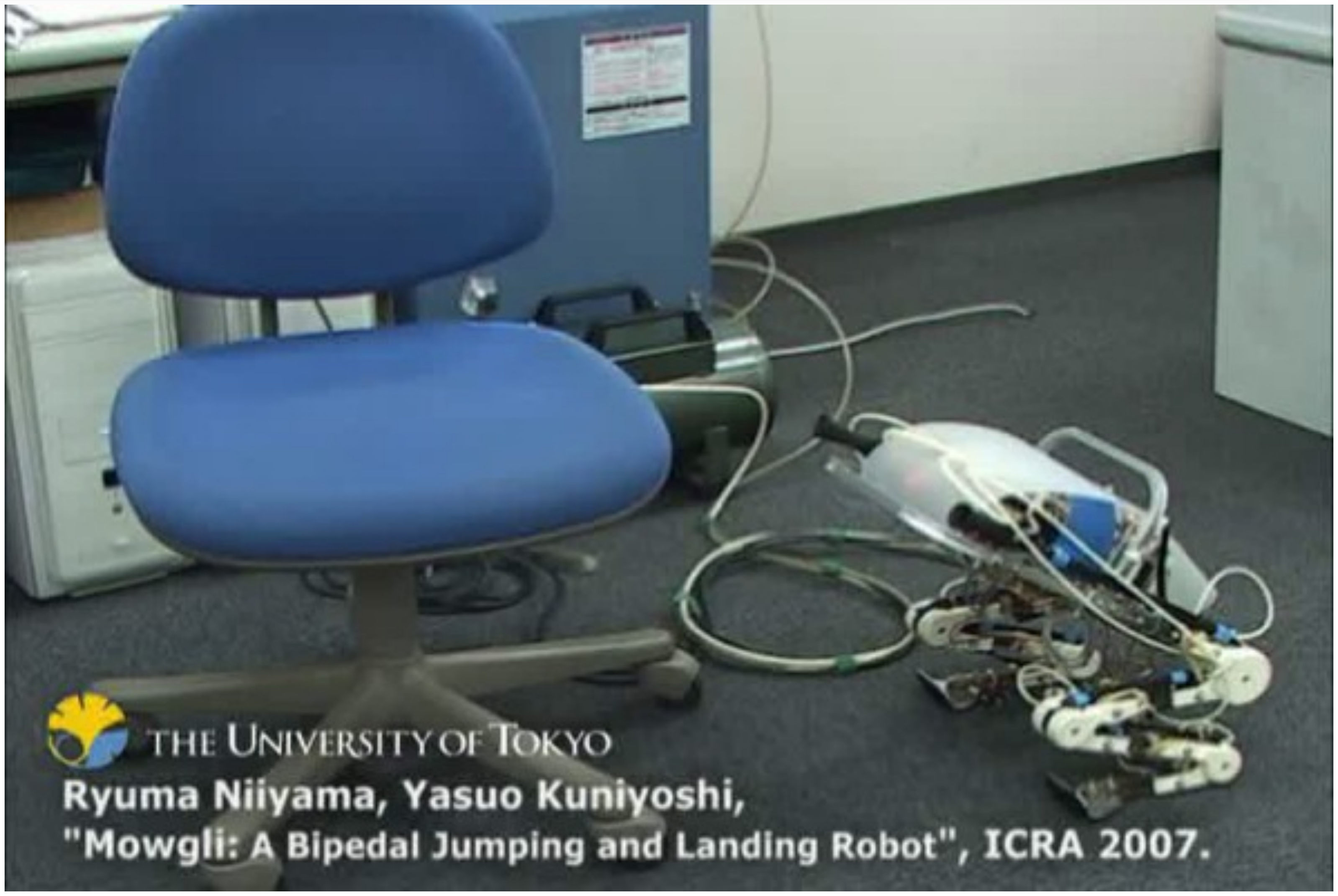


Design and construction:
**Raja Dravid, Max Lungarella, Juan Pablo Carbajal, AI Lab, Zurich**



Pneumatic actuators (also called “air muscles”) are rubber tubes with a braided fabric around them so that when air pressure is applied, they contract, and because of the rubbery material, the have a certain elasticity like natural muscles. Also, when contracting, their stiffness increases, which provides an easy way to dynamically change their material properties. In these examples, the actuation is only performed by the muscles on the body, not on the arm - the arm is entirely passive (nevertheless, the elbow joint does the right thing).

# Robot Frog "Mowgli" driven by pneumatic actuators




**Design and construction:**
**Ryuma Niiyama, Yasuo Koniyoshi, The University of Tokyo** 18

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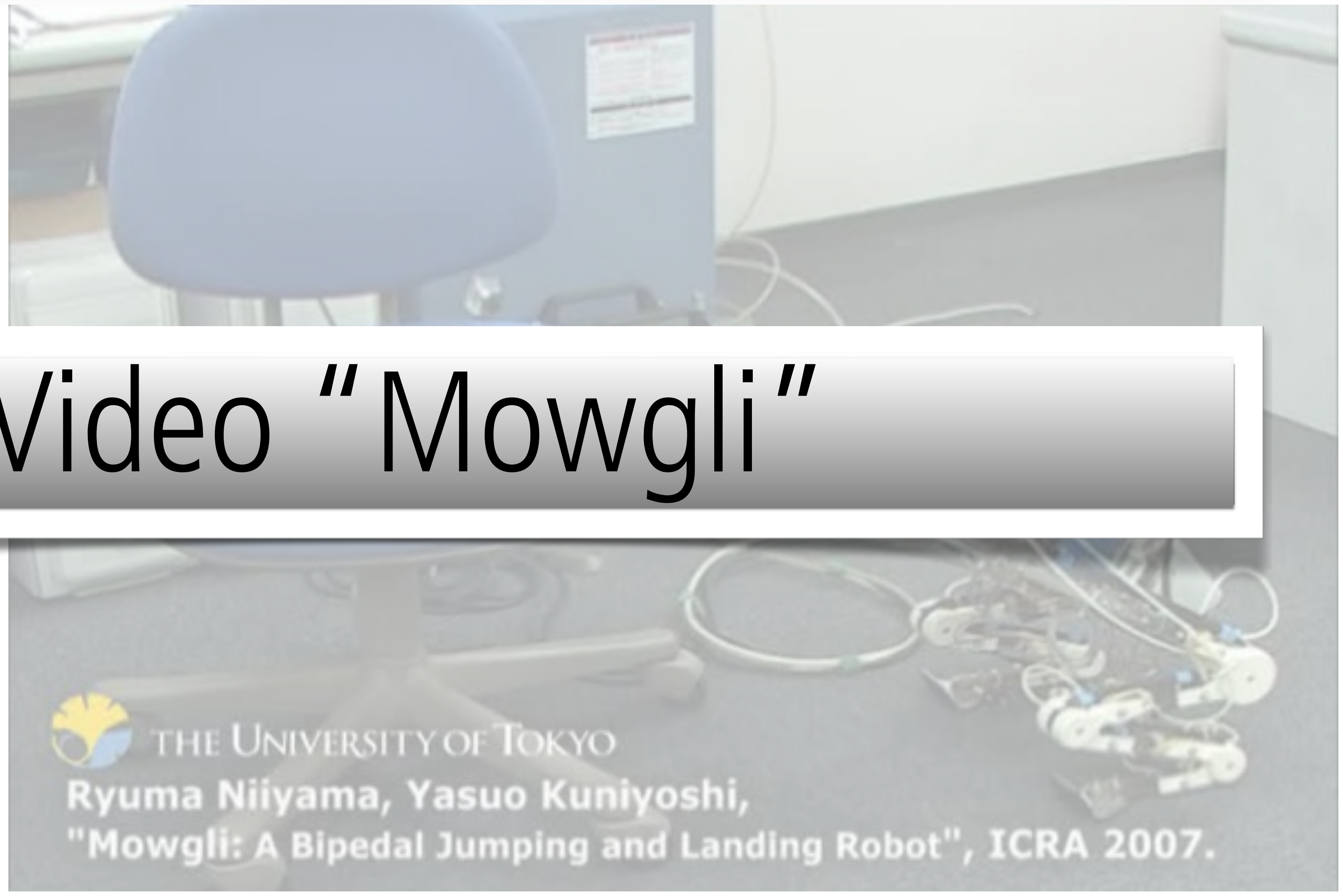
Coping with impact is taken over by the material properties of the pneumatic actuators and the morphology of the leg/body system.

# Robot Frog "Mowgli" driven by pneumatic actuators




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

# The "story": physical dynamics and information processing

- morphology and materials
- exploration
- preferred trajectories from biomechanical constraints
- induction of patterns of sensory stimulation
- sensory-motor coordination → induction of information structure
- good "raw material" for brain





The loosely swinging arm in the front/side of the body is easy to control and energy efficient. There seems to be an evolutionary predisposition because this kind of movement has turned out to provide adaptive value. If the hand happens to encounter an object, it is very natural to grasp it, which then, almost automatically brings it into the center of the visual field, where it can then be manipulated. Moreover, this leads to induction of rich sensory stimulation in the hand an on the fingertips, but also proprioceptively (forces, torques in the arm) and visually. Because of the information structure - the correlations - thus induced, cross-modal associations can easily be formed. These cross-modal associations in turn can be exploited to learn expectations.

# The “story”: physical dynamics and information processing

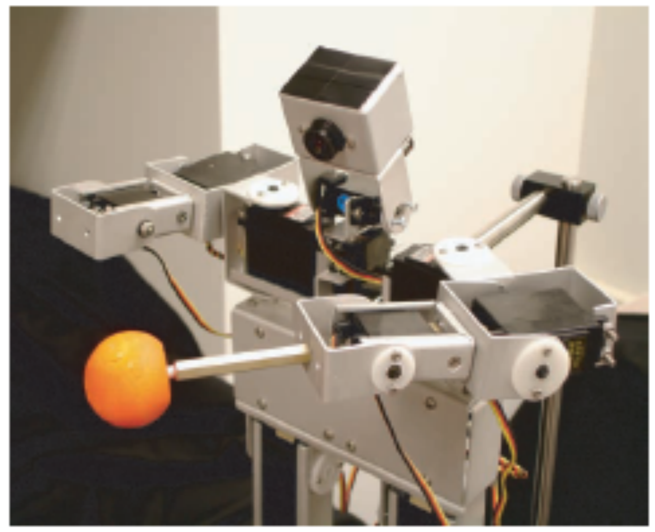
- cross-modal association, learning, concept formation
- extraction of mutual information → prediction
- categorization (fundamental for cognition)

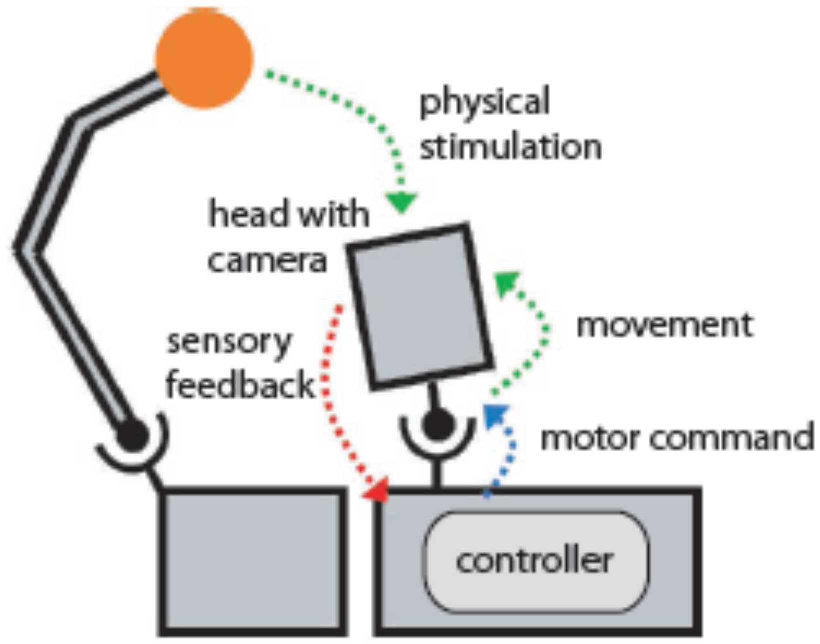
# Quantification of information structure

# Information self-structuring

Experiments:

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



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Two conditions: random, i.e. movement of ball and robot head (camera) independent from each other,  and sensory-motor coordinated, i.e. robot head follows the orange ball.

# 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**

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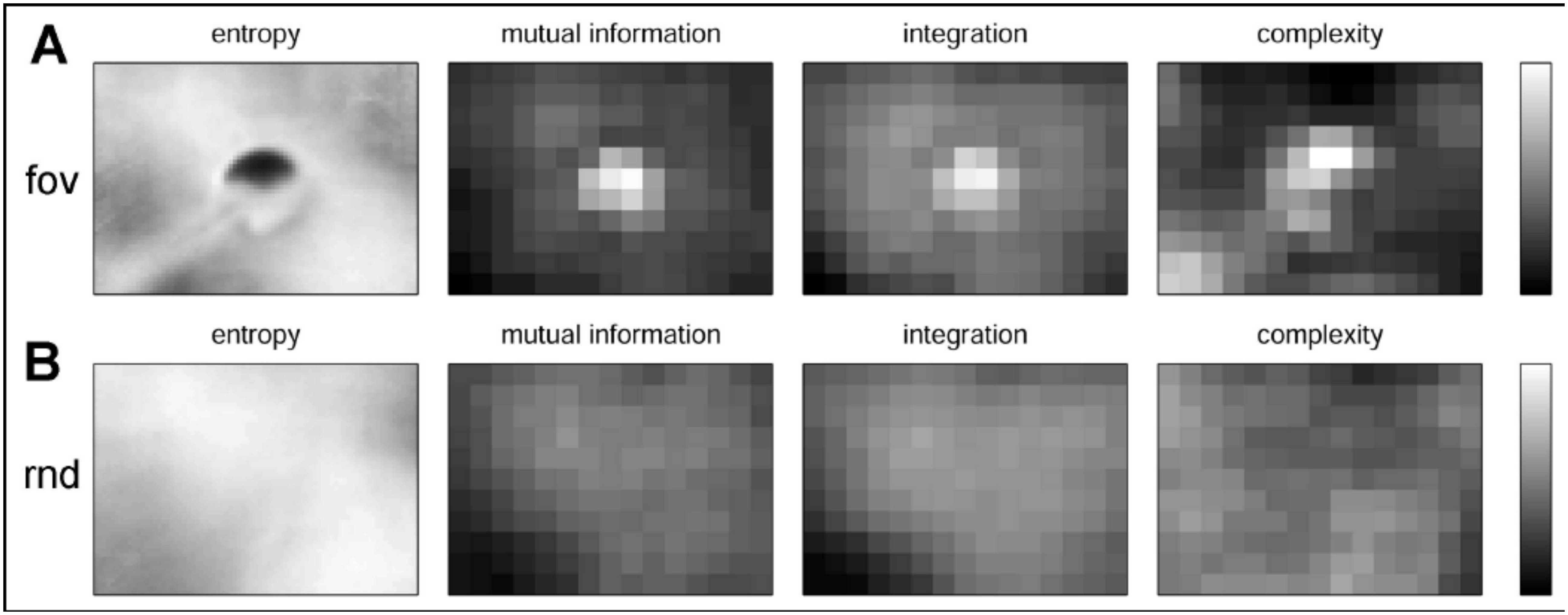
Taken from measures of brain complexity by Tononi, Sporns, and Edelman, 1994, 1996.
Intuitively: mutual information – give example of vision and touch. Both provide good spatial information, so there is an information overlap. Recall the redundancy principle: different modalities based on different physical processes make the system more adaptive.
@students: you don’t need to memorize the formulas ;-)

# Results: foveation vs. random




**entropy** **mutual information** **integration (over patch)** **complexity (over patch)**



top panels, sensory-motor coordinated condition: more information structure is induced (from calculations over patches of 5x5 pixels moved over the entire camera image).
bottom panels: less information structure

# Measuring "causality"

**Transfer entropy: derived from Kullback-Leibler Entropy**

$$T(Y \to X) = \sum_{x_{t+1}} \sum_{x_t} \sum_{y_t} p(x_{t+1}, x_t, y_t) \log \frac{p(x_{t+1} | x_t, y_t)}{p(x_{t+1} | x_t)}$$

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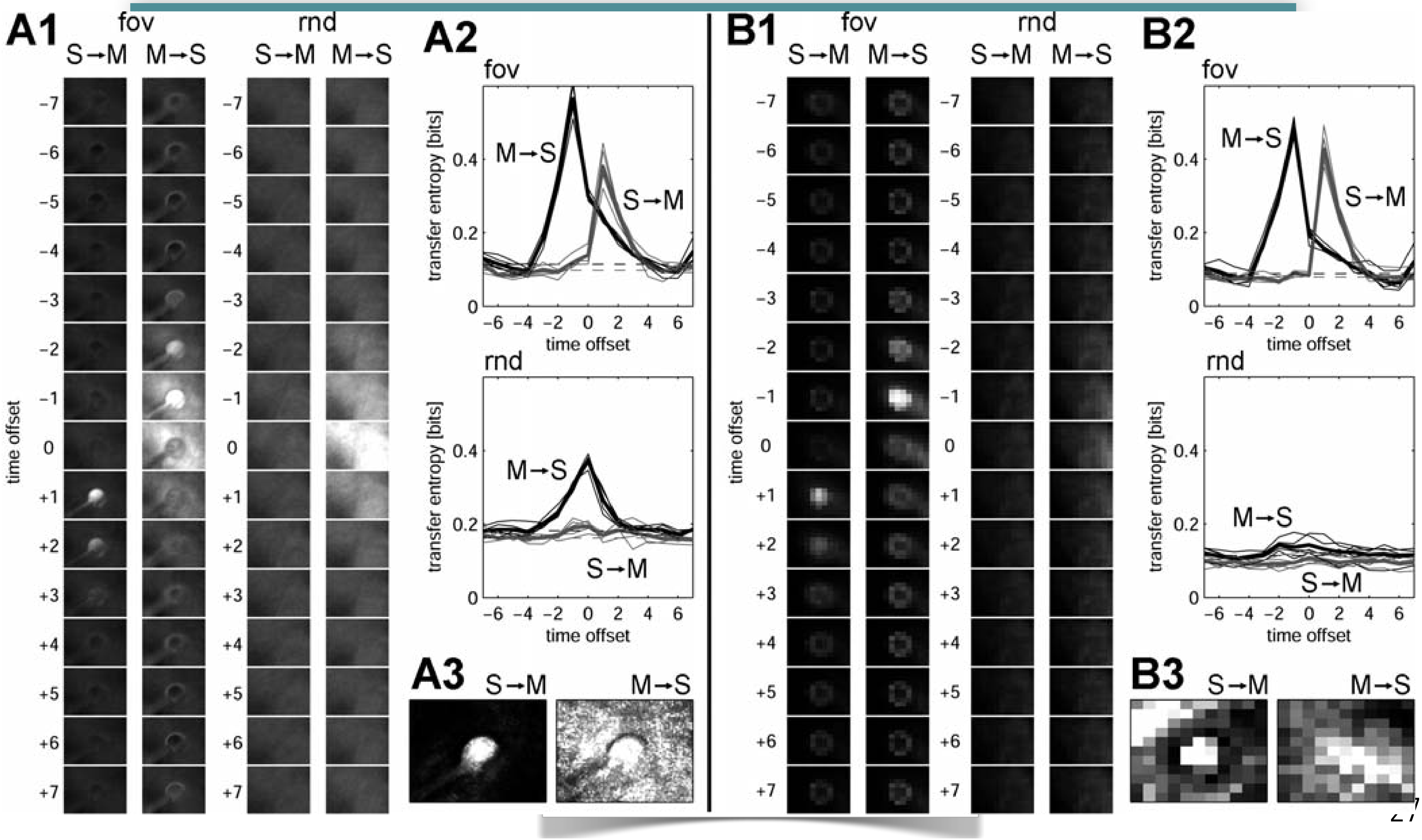
no need to remember the formula :-).

# Transfer entropy between sensory inputs and motor variables




Attempt to capture "causalities".
S: Sensor signals
M: Motor signals
fov: foveation condition (sensory-motor coordinated)
rnd: random condition (movements of camera and orange ball independent)

Granger causality: two time series. If one can be partially predicted from the other, then the two are "causally" conntected in the sense of Granger.

# Essence

- **self-structuring of sensory data through — physical — interaction with world**
- **physical process, not computational**

**pre-requisite for learning**

→ predictions / expectations

**Inspiration:**
John Dewey, 1896 (!)
Merleau-Ponty, 1963
Bajcsy, 1963; Aloimonos, 1990; Ballard, 1991
Sporns, Edelman, and co-workers
Thelen and Smith (developmental studies)

# 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)

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Interestingly, Dewey's quote reads like an argument against the computer metaphor.

# 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")**

**foundation of learning and development**

# Learning and development in embodied systems

Through sensory-motor coordinated interaction
sensor patterns are induced that contain

**Note:**
**Induction of information structure through physical interaction with real world**

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

→ foundation of learning and development

# Learning and development in embodied systems

- principle of “ecological balance” (exploration)
- principle of “cheap design” (exploiting morphology and material for exploration)
- principle of “sensory-motor coordination” / “information self-structuring” (induction of information structure)

# Building grounded cognition

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

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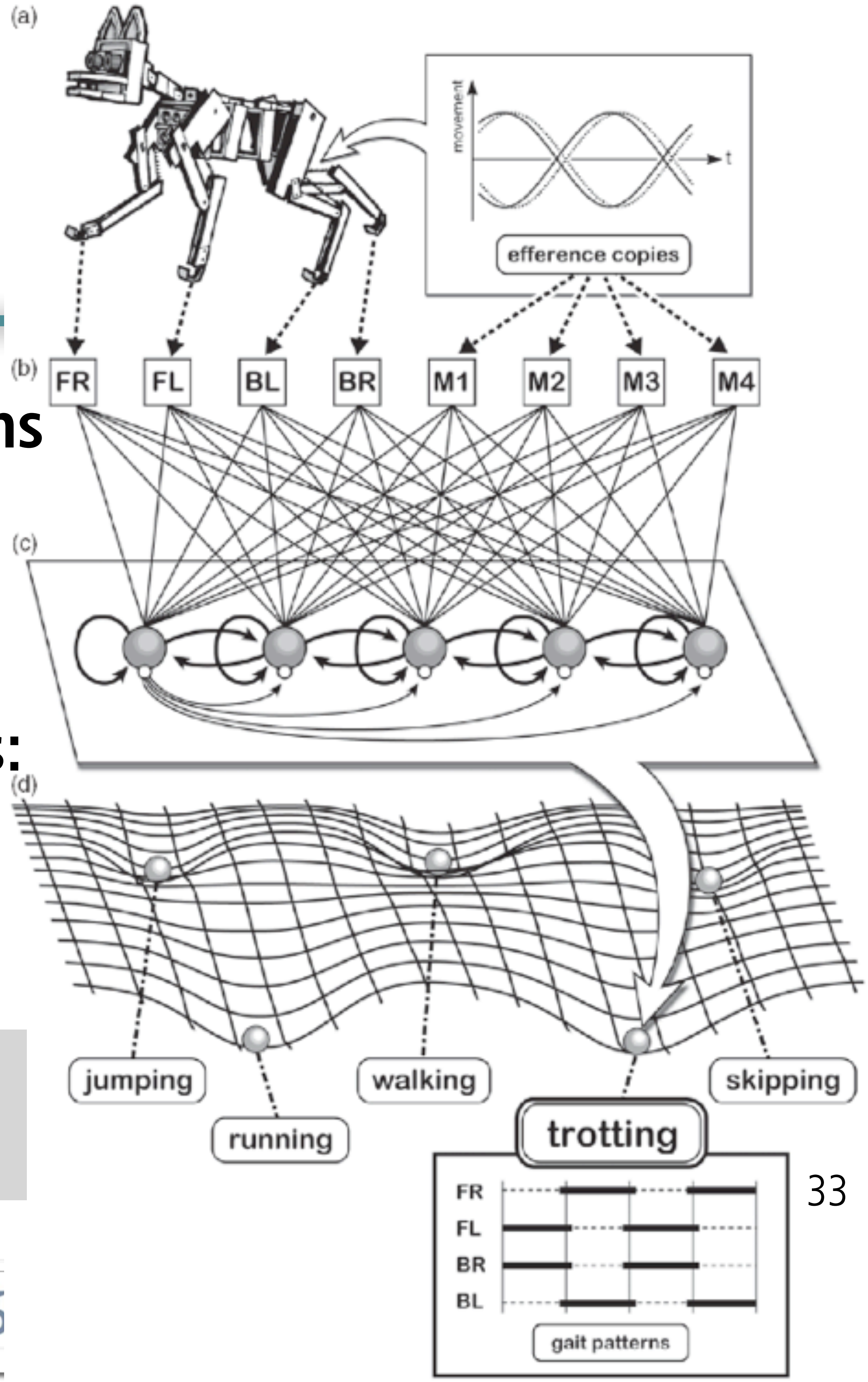


# High-level cognition: The Lakoff-Núñez Hypothesis

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.

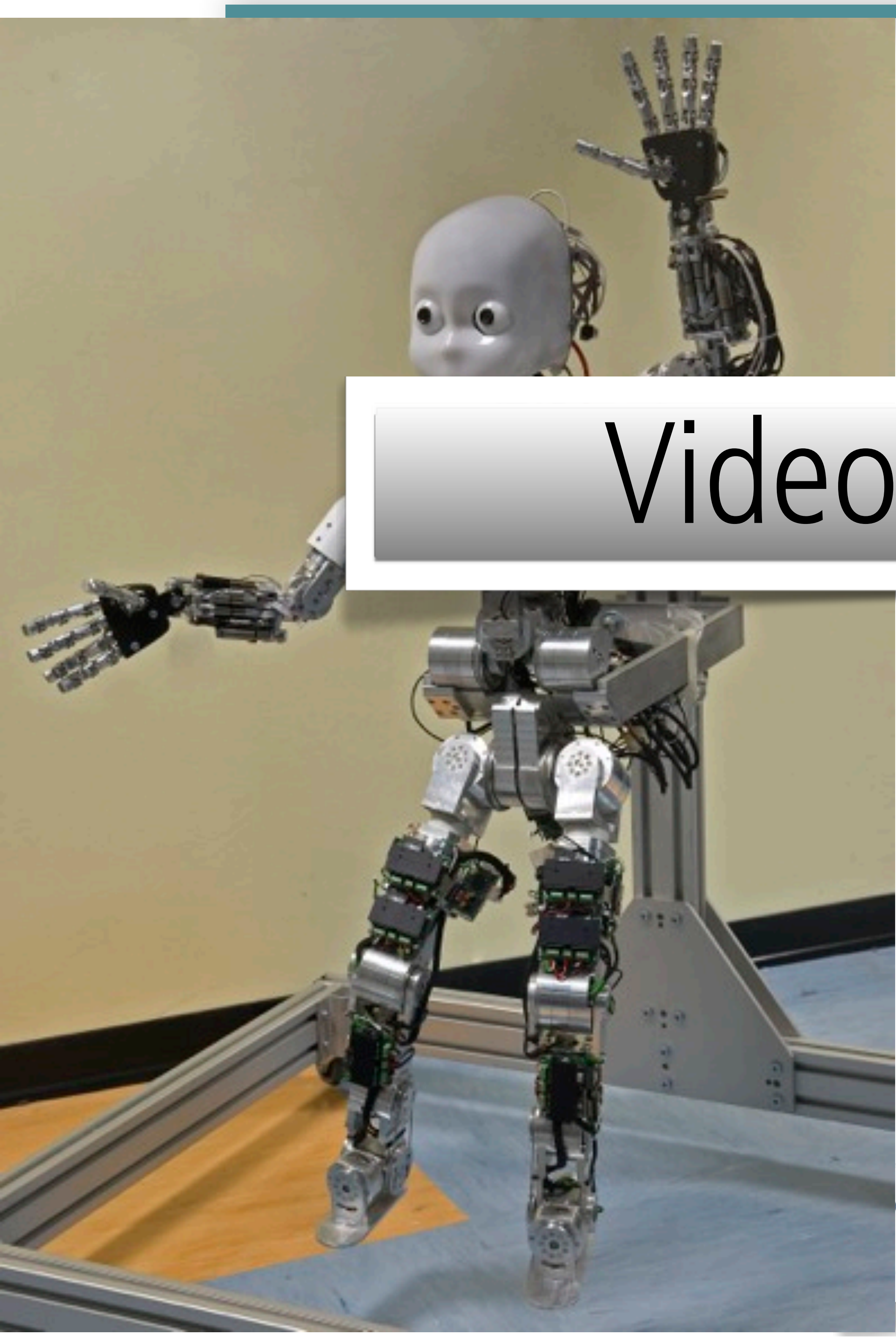
George Lakoff und Rafael Núñez (2000).
Where mathematics comes from: how the embodied mind brings mathematics into being.
New York: Basic Books.

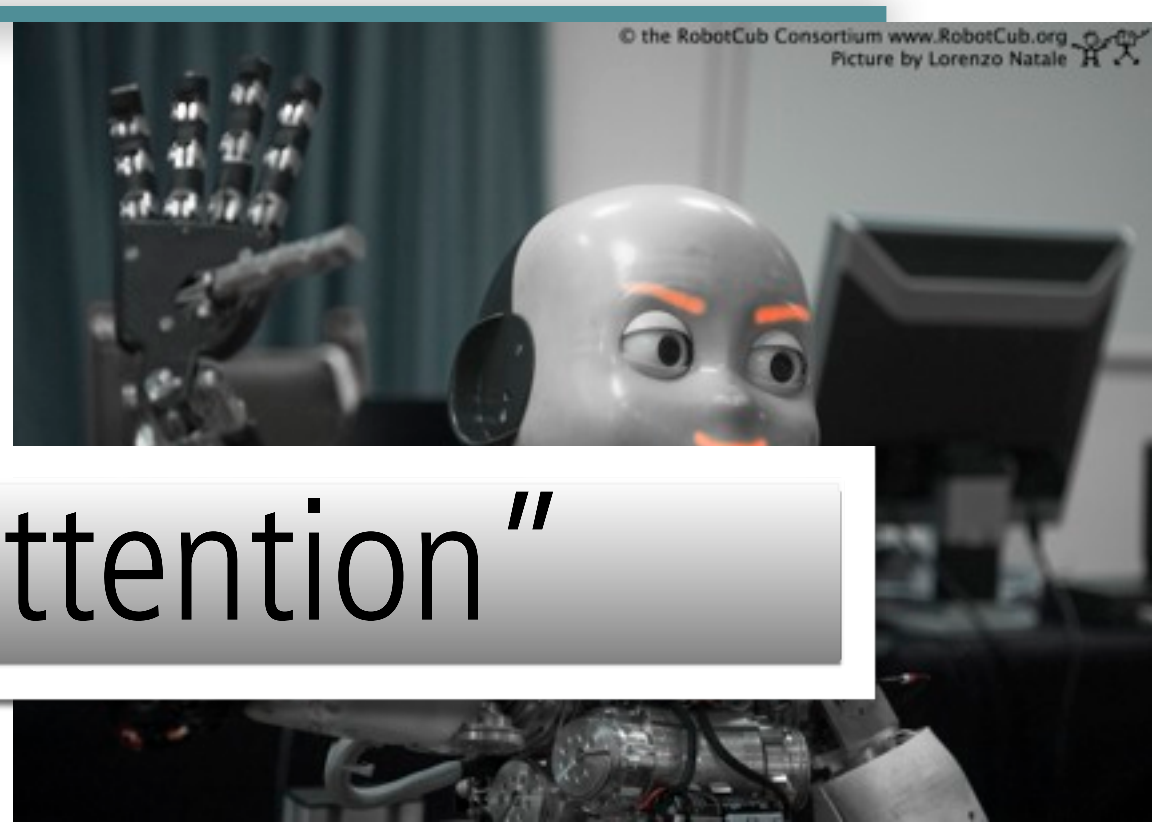
# Robots for studying development: Why humanoids

- **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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The robot iCub (Cognition, Understanding, and Behavior) was developed in the context of a large European project. It is an open platform that is currently used in about 15 research laboratories in Europe to perform experiments on development. The video demonstrates iCub's attentional abilities. In spite of the simplicity of the attentional system, the observer get's a strong feeling that the iCub is behaving intelligently (watch out for the F-O-R problem).

# Adding sensors: generation of sensory stimulation through action

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

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Adding sensors to make robots more intelligent is the obvious thing to do. What's important here is that each action has a consequence in terms of sensory stimulation (see also John Dewey's quote, below). And this is one of the fundamental differences to a computer which, in essence, "waits" for input, i.e. for someone to push a key or click a mouse button. Also: extremely impoverished sensory system.

# Physical dynamics and information structure

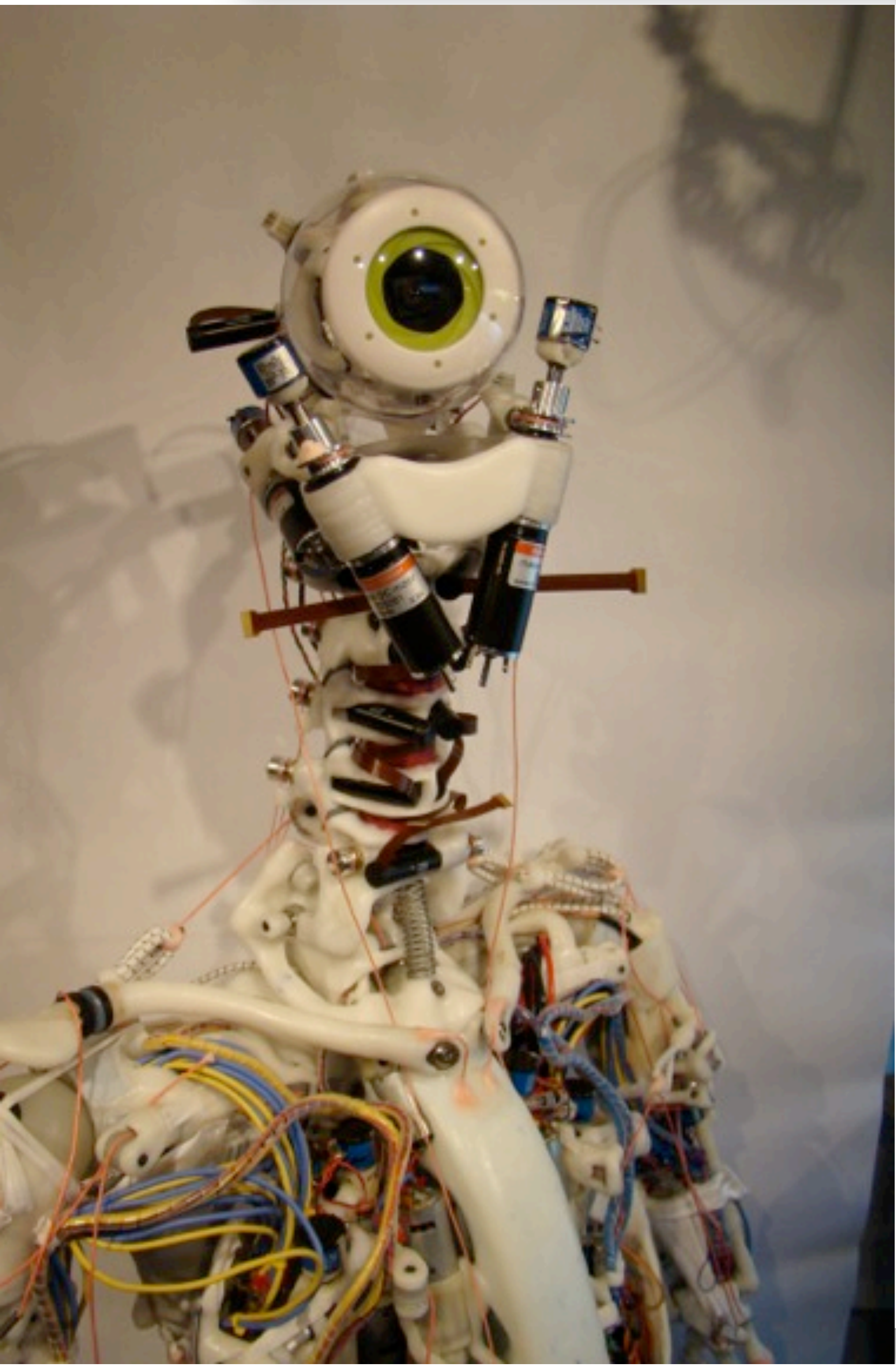
Induction of patterns of sensory stimulation through physical interaction with environment →

raw material for information processing of brain (control) →

induction of correlations (information structure)

# Compliance, “softness”: the next steps

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



**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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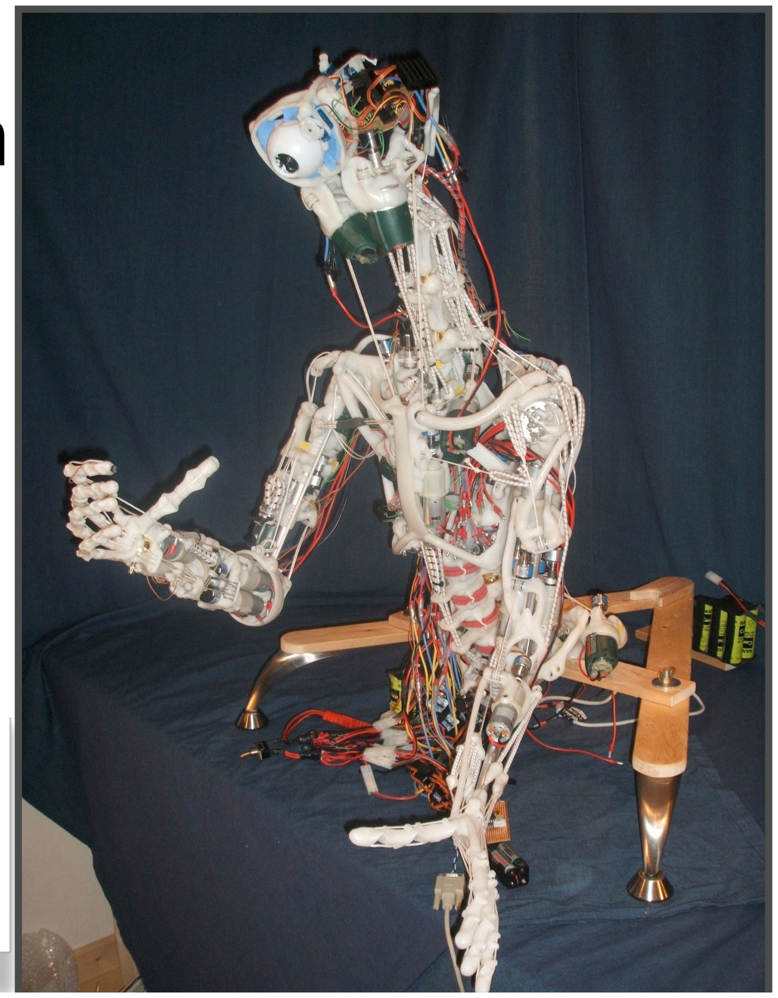
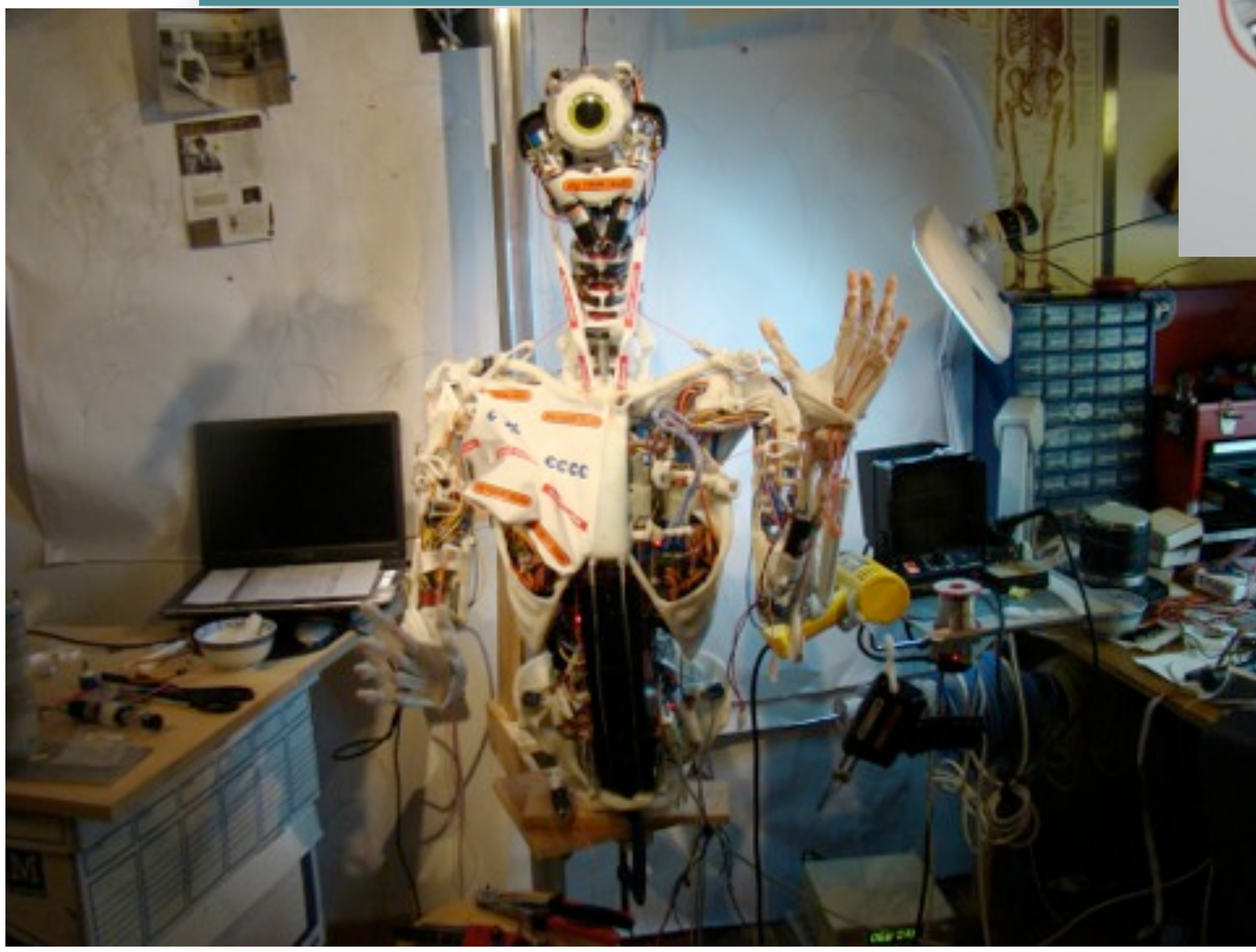
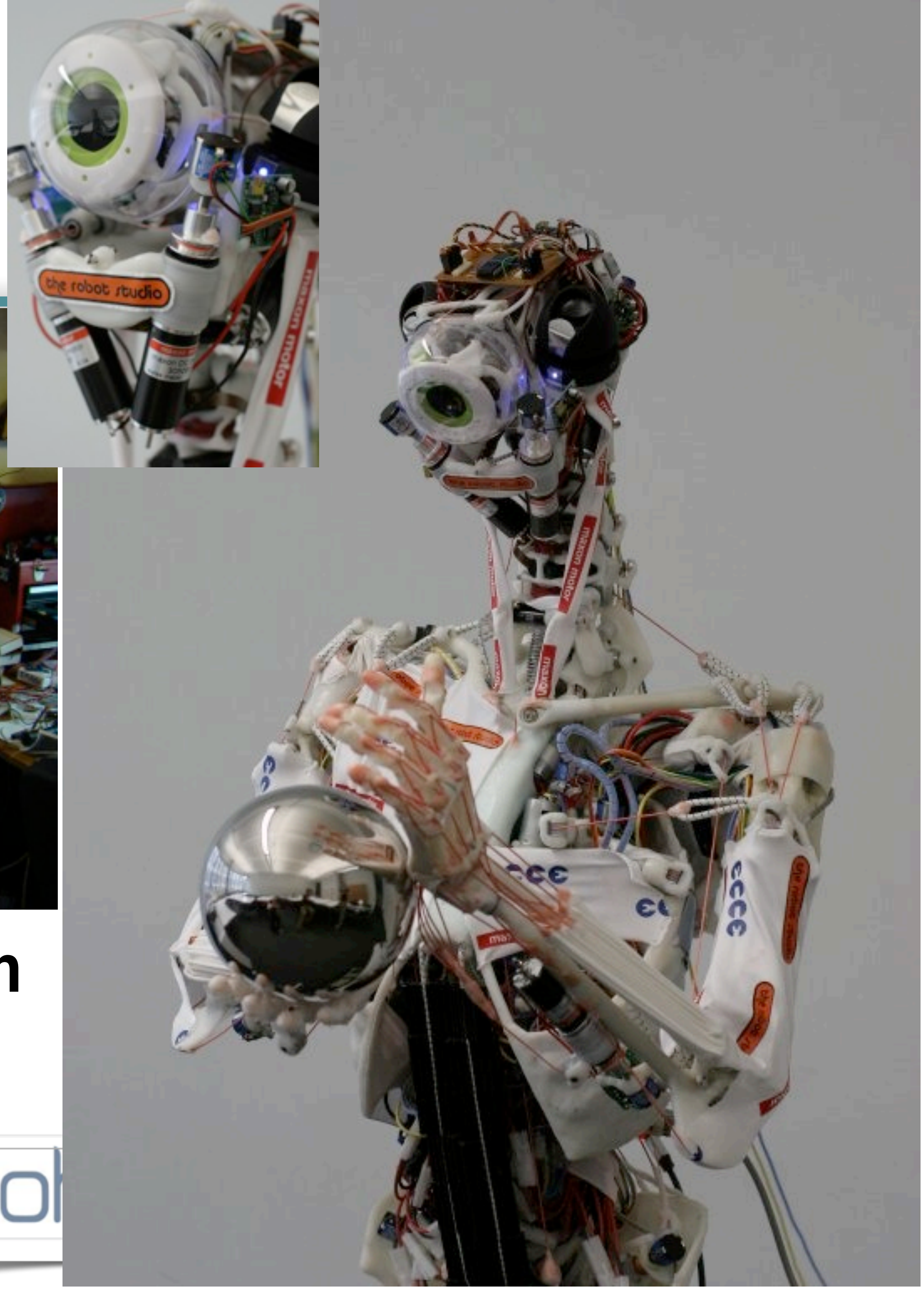


ECCE is a fully tendon-driven robot with tendons that incorporate a soft element.

# The super-compliant “soft” robot ECCE






fully tendon-driven

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robo

# ECCE at Chinese Academy of Science, Shanghai, 2009

University of

2nd from left: Prof. Weidong Chen, Shanghai Jiao Tong University

# Techfest 2011, IIT Bombay

**Embodied Intelligence**
**Switzerland**


University of

# i-Days, Lucerne Switzerland September 2010

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Not everybody seems to be happy about ECCE

# Hannover Fair, ICT Brussels, Science Fair St. Agrève, France




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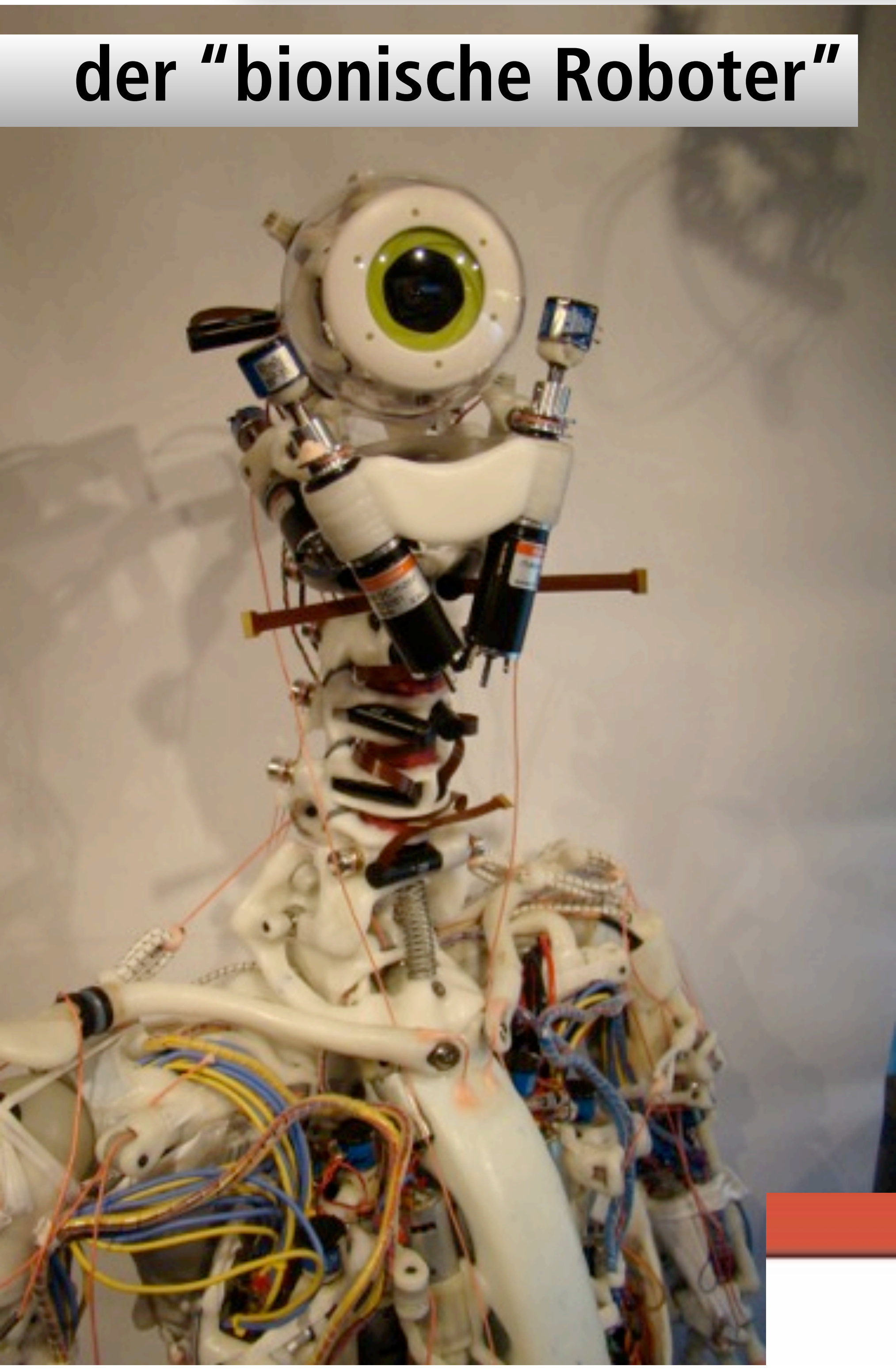
# ECCE with former president of Switzerland: Innovation Fair 2010





Anthropomorphic design

Doris Leuthard, former president of Switzerland, shaking hands with ECCE

# Bernstein's problem

- highly complex system: number of redundant DOFs in compl tem
- how to control/orchestrate?

research opportunity

complexity barrier

(Nikolai Bernstein, Russian physiologist, 1896-1966)

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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 p[illegible]blem

research opportunity

- acquisition of own body schema (n[illegible] characteristics of body)
- expected patterns of sensory stimulation

# Implementation of learning in embodied systems

important approach:

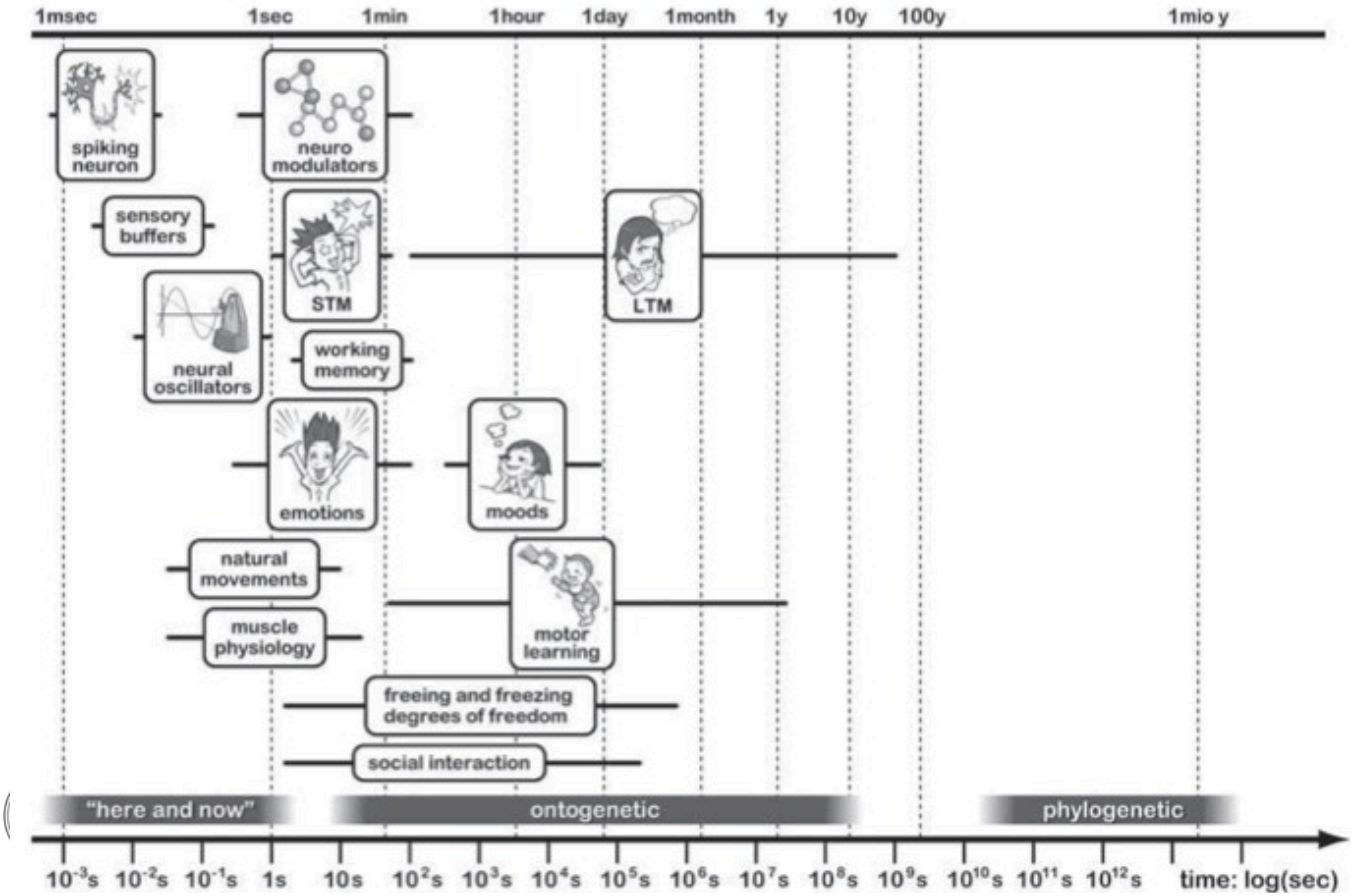
"Artificial Neural Networks"

see lecture 6

# 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



imitation learning: important
mirror neurons
prerequisite for imitation: shared or joint attention
scaffolding: holding child by hand

# Assignments for next week

- **Read chapter 5 of "How the body …" on development**

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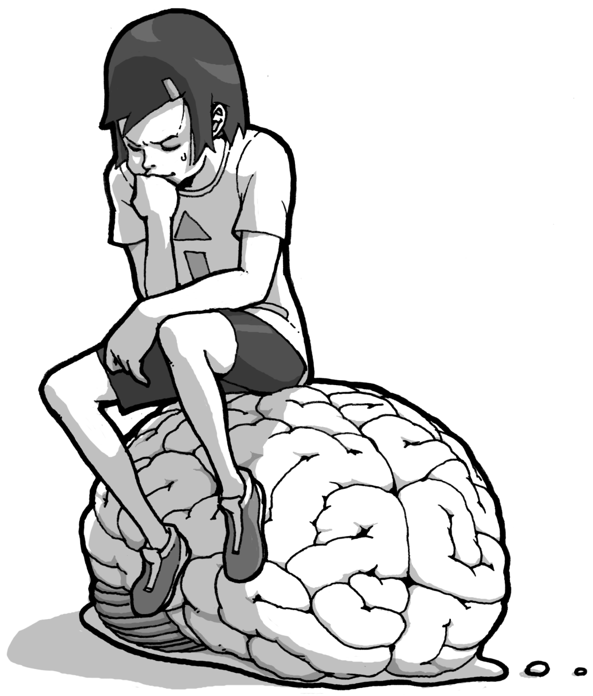
# End of lecture 10

**Thank you for your attention!**

**stay tuned for guest lectures**

**Prof. Barbara Webb**

**Dr. Tamas Haidegger**



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# Lecture 10: Guest speaker

Laboratory of Biomedical Engineering, Budapest University of Technology and Economics

Austrian Center for Medical Innovation and Technology, Vienna

CEO and CTO, Clariton Ltd.

**Dr. Tamas Haidegger, Budapest**
**“Humans-robots-humans: who is operating who ”**

**10.30h Zurich time (17.30h Xi’an time)**



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# Lecture 10: Guest speaker

from Edinburgh, UK (Scotland)
Institute for Perception, Action, and Behaviour

**Prof. Barbara Webb, University of Edinburgh**
**“AI - Artificial Insects”**

**10.00h Zurich time, 09.00 UK time (17.00h Shanghai time, 18.00 Tokyo time)**



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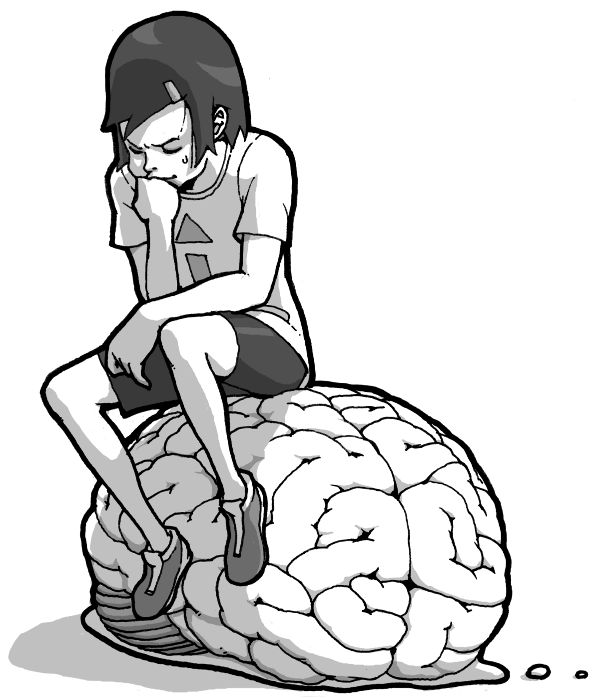
# End of lecture 10

**Thank you for your attention!**

**stay tuned for lecture 11**

**Summary and conclusions (Rolf)**

**Future trends (various guest lectures)**





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