The ShanghAI Lectures

人工智能

上海授课

Video clips / demos

- Swarm behavior in real birds
- Mowgli, the robot “frog”
- iCub attention
- ECCE_Promovideo
- EDSBest Video2010.mov
- roboy_montage_torso.wmv

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

Today from KIT, Karlsruhe Institute of Technology, Germany

6 December 2012

欢迎您参与

“来自上海的人工智能系列讲座”

Calling on

- Shanghai Jiao Tong University: **Ashby's concept of memory**
- HU Berlin: **Reactions, comments on iCub video?**
- SKKU: **recall - structure of water fountain - where is it stored? - relation to human memory?**
- Lodz: **Difference between learning and development?**
- Abu Dhabi: **Entropy and its relation to information**
- Salford: **Why is it important to have correlations in the different sensory channels?**
- RGGU Moscow: **Comments on compliance**
- Chiba: **which is the foveation and which is random? (explanation, why?)**
- University of Tasmania: **Reasons for studying humanoids?**

University of Zurich

robotics Swiss National Centre of Competence in Research

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Today's schedule

09.00 - 09.05 Introduction

09.05 - 10.00 From locomotion/movement to cognition

09.50 Break

10.00 - 10.30 Prof. Ning Lan, Shanghai Jiao Tong University "Cortico-muscular communication of movement information by central regulation of spindle sensitivity"

10.30 - 11.00 Prof. Roland Siegwart: "Design and navigation of wheeled, running, swimming, and flying robots"

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Lecture 9: Guest speaker

Med-X, Shanghai Jiao Tong University

Prof. Ning Lan, Shanghai Jiao Tong University,
"Cortico-muscular communication of movement information by central regulation of spindle sensitivity"

10.00h Zurich time

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Prof. Ning Lan obtained his B.S. degree from the Department of Precision Instruments from SJTU in 1982, and obtained his M.S. and Ph.D. degrees from Biomedical Engineering of Case Western Reserve University in 1985 and 1989, respectively. Currently, he is an Adjunct Associate Professor of University of Southern California. In 1995, he helped organizing the Neural Engineering Committee of the Chinese Society for Neuroscience, and served as its Funding Associate Director. He also served as Assistant Editor of IEEE Trans on Rehabilitation Engineering (now IEEE Trans on Neural Systems and Rehabilitation Engineering), and Associate Editor of Chinese Rehabilitation Theory and Practice. In 2009 he joined the faculty of Med-X research Institute.

Lecture 9: Guest speaker

from the University of Zurich
Switzerland

Prof. Roland Siegwart, Autonomous Systems Lab., ETH Zurich
"Design and navigation of wheeled, running, swimming, and flying robots"

10.30h Zurich time

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Vice president research and corporate relations, ETH Zurich. Prof. of Autonomous Systems.
Research interests:
- Mobile Robot design and navigation; localization and mapping, planning in dynamic environments, human robot interaction, locomotion concepts for rough terrain, walking robots, space rovers, autonomous cars and unmanned aerial vehicles.
- Mechatronics Design and Systems Engineering (smart product design, innovation, creativity).
- Artificial Cognitive Systems (Perception, representations, probabilistic reasoning and planning)

Lecture 9

Ontogenetic development:
From locomotion to cognition

6 December 2012

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Today's topics

- on swarm behavior in real birds: video
- 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

Today’s topics

- on swarm behavior in real birds: video

Video “real birds swarm”

- sensory-motor coordination — information self-structuring
- linking to ontogenetic development
- high-level cognition: the Lakoff-Nunez hypothesis
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- principles for development

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Recall: "Passive Dynamic Walker" Short question

memory for walking?

It is not possible to point a particular address in a microprocessor because the PDW doesn't have any motors and processors. The "memory" for walking is distributed throughout the entire structure, including its materials, shapes, weight distribution, etc.

Ashby’s concept of memory

—> Shanghai Jiao Tong University
  - refresh our memories

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

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

a.

b.

Recall: 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? —> SKKU

shape can be described as structure — just as a memory structure; most likely dynamically generated in interaction with environment (the situated, embodied nature of memory)
shape of water emergent from:
- shape and direction of jets
- pressure at exit
- water surface tension
- gravity

The mere fact that the "output" in memory experiment can be described as a "structure", by no means implies that this is the way in which it is stored (as illustrated by the fountain).

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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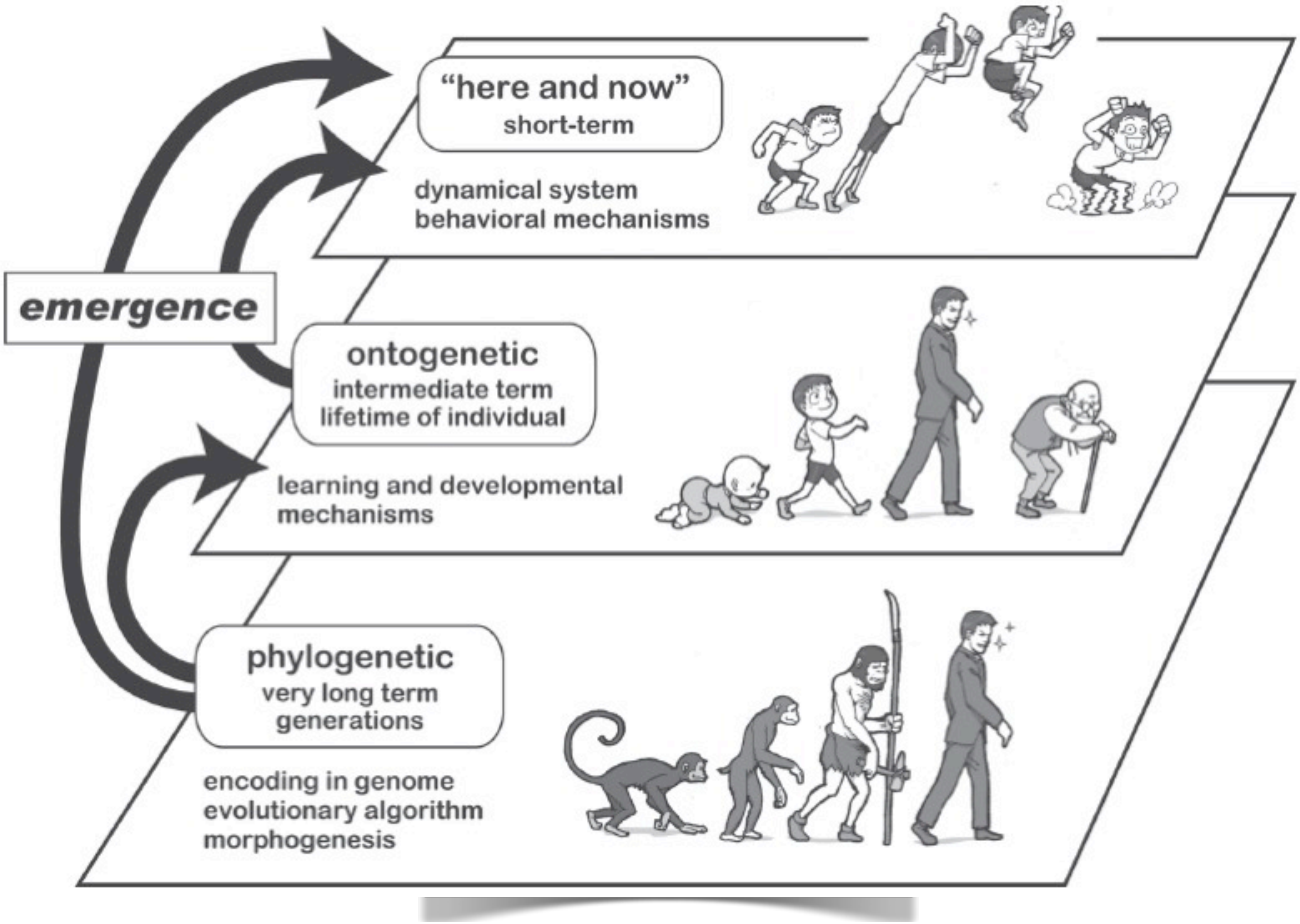
Time perspectives



Remember that a comprehensive explanation of behavior requires all three time perspectives. Also, although the mechanisms at the different levels are of a different nature, they are tightly intertwined.

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

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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)

Motivation for developmental approach

difference between learning and development?

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

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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, vibration, and pain 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"

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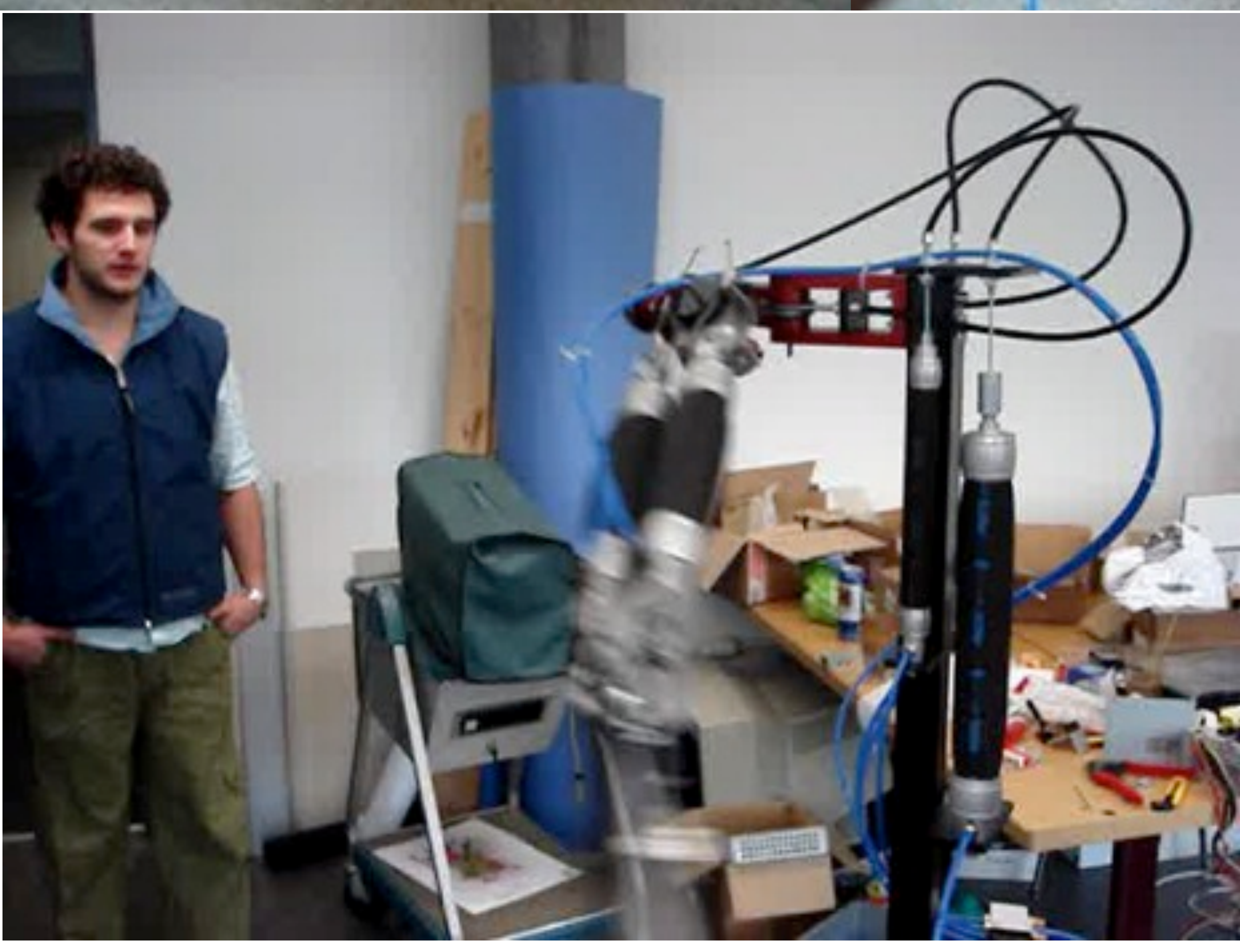
There seems to be an evolutionary predisposition for this kind of movement that makes it on the one hand easy to control, on the other it is very energy-efficient. It is useful for exploring the environment in constrained ways such that the probability of something interesting happening is high (compared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

Compliance

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

—> Comment: RGGU Moscow

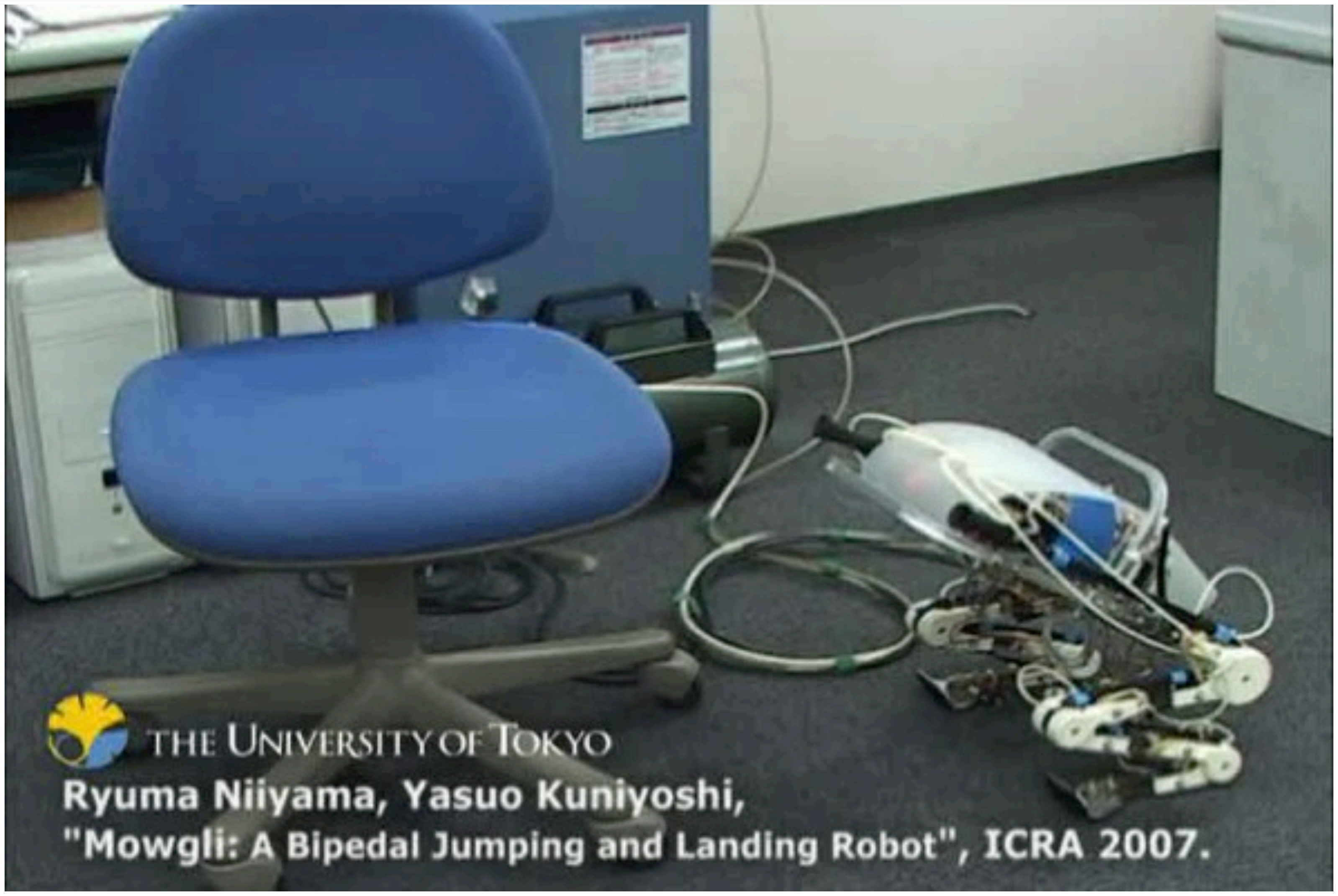
Anthropomorphic arm with pneumatic actuators



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, they have a certain elasticity, a bit 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).

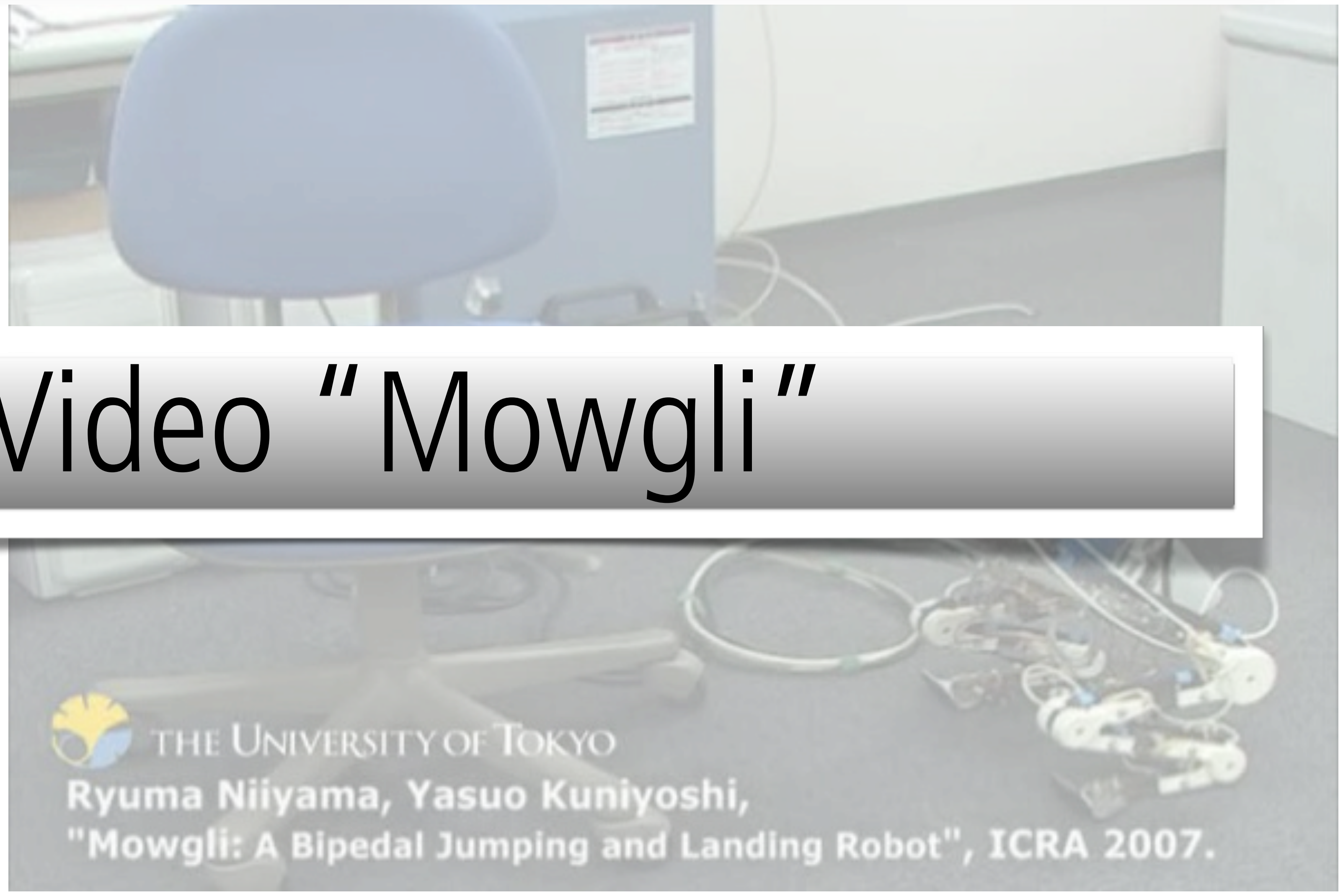
Robot Frog "Mowgli" driven by pneumatic actuators



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

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



Video "Mowgli"

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 (correlations)
- 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

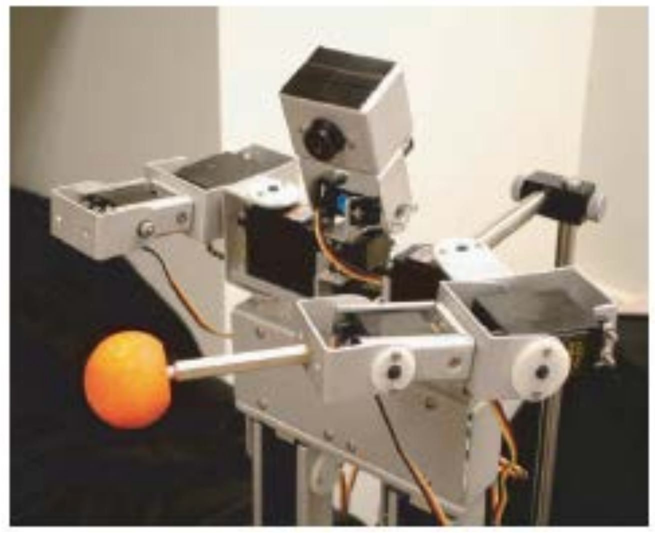
- cross-modal association, learning, concept formation
- extraction of mutual information → prediction
- categorization (fundamental for cognition)

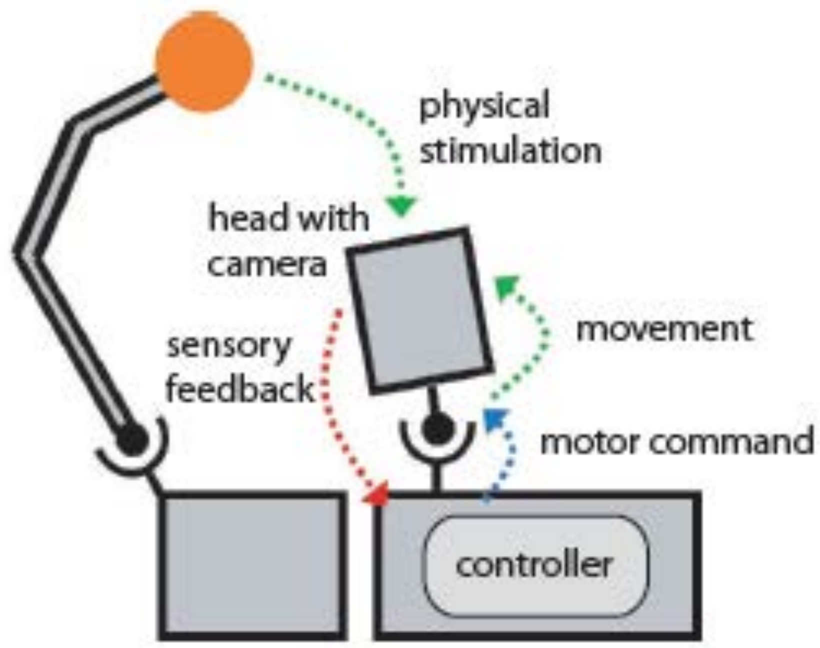
Quantification of information structure

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

—> NYU, Abu Dhabi: Entropy and its relation to 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

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

complexity: co-existence of local and global structure

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

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

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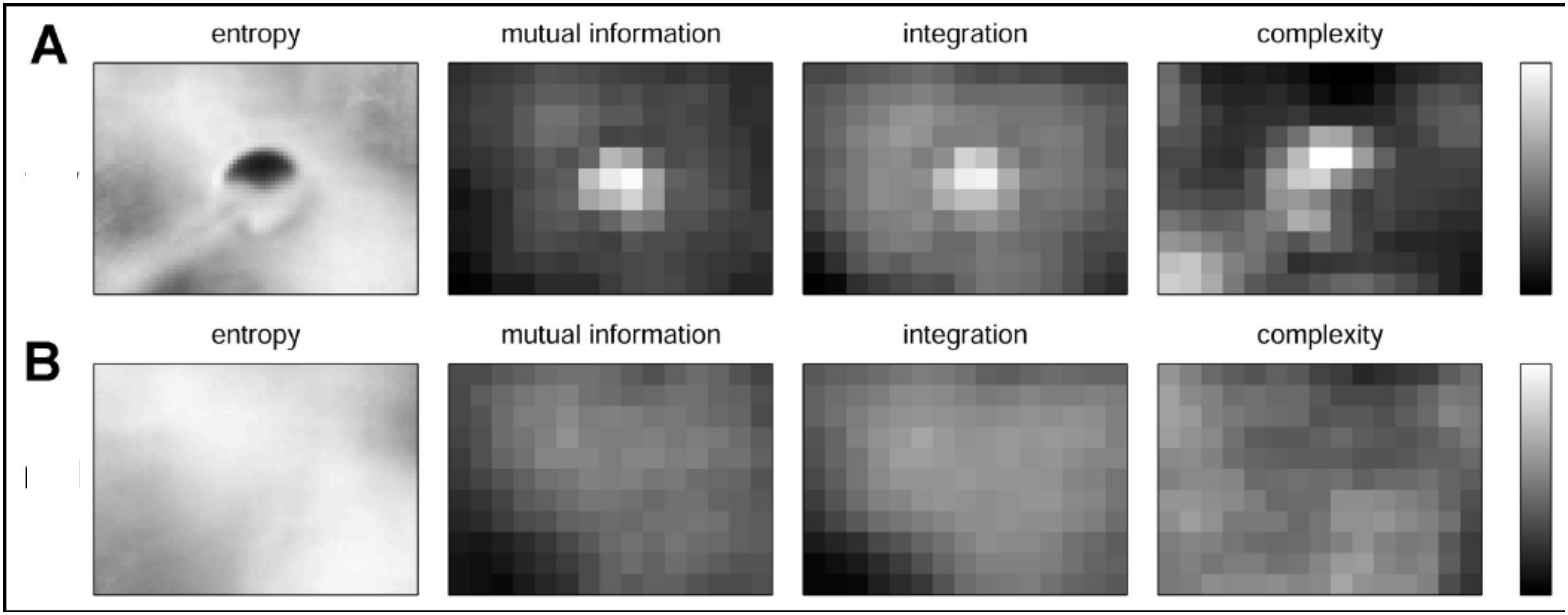
Taken from measures of brain complexity by Tononi, Sporns, and Edelman, 1994, 1996.
Intuitively: mutual information – give example of vision and touch. Both provide good spatial information, so there is an information overlap. Recall the redundancy principle: different modalities based on different physical processes make the system more adaptive.

Results: random vs. foveation

which is which? why? —> Chiba



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

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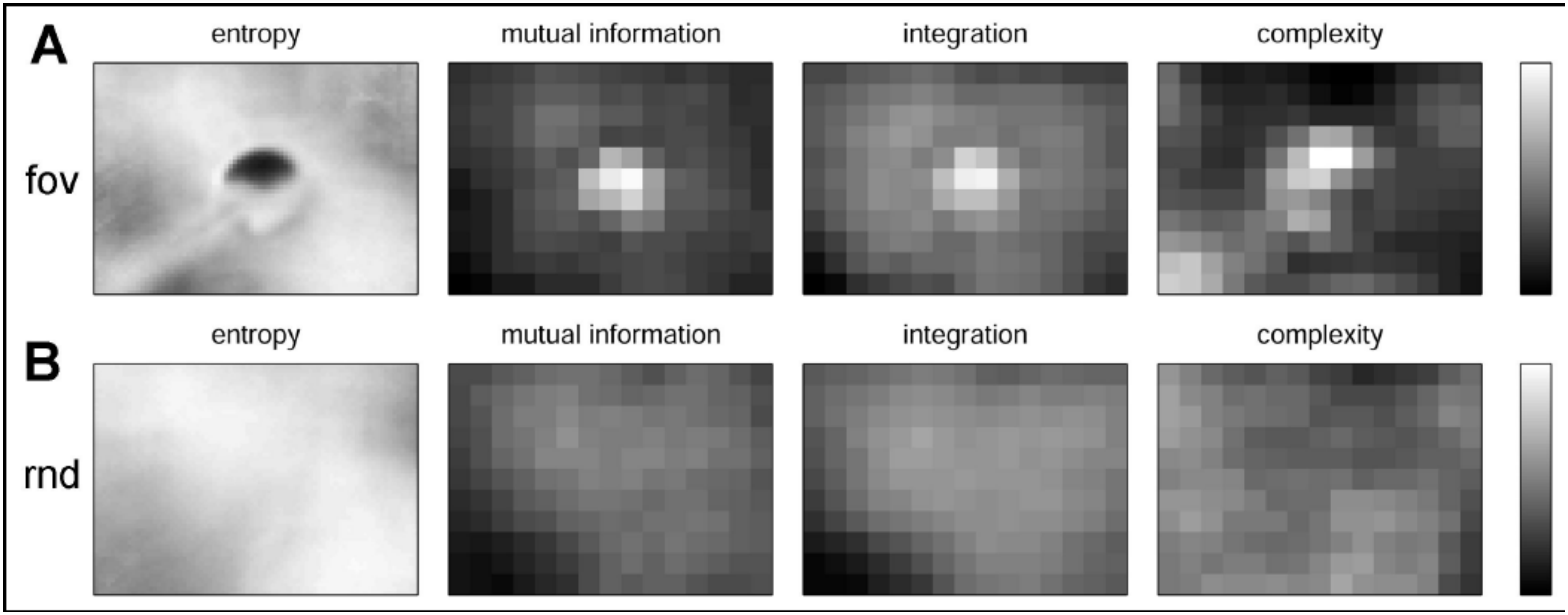
Results: foveation vs. random



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

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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

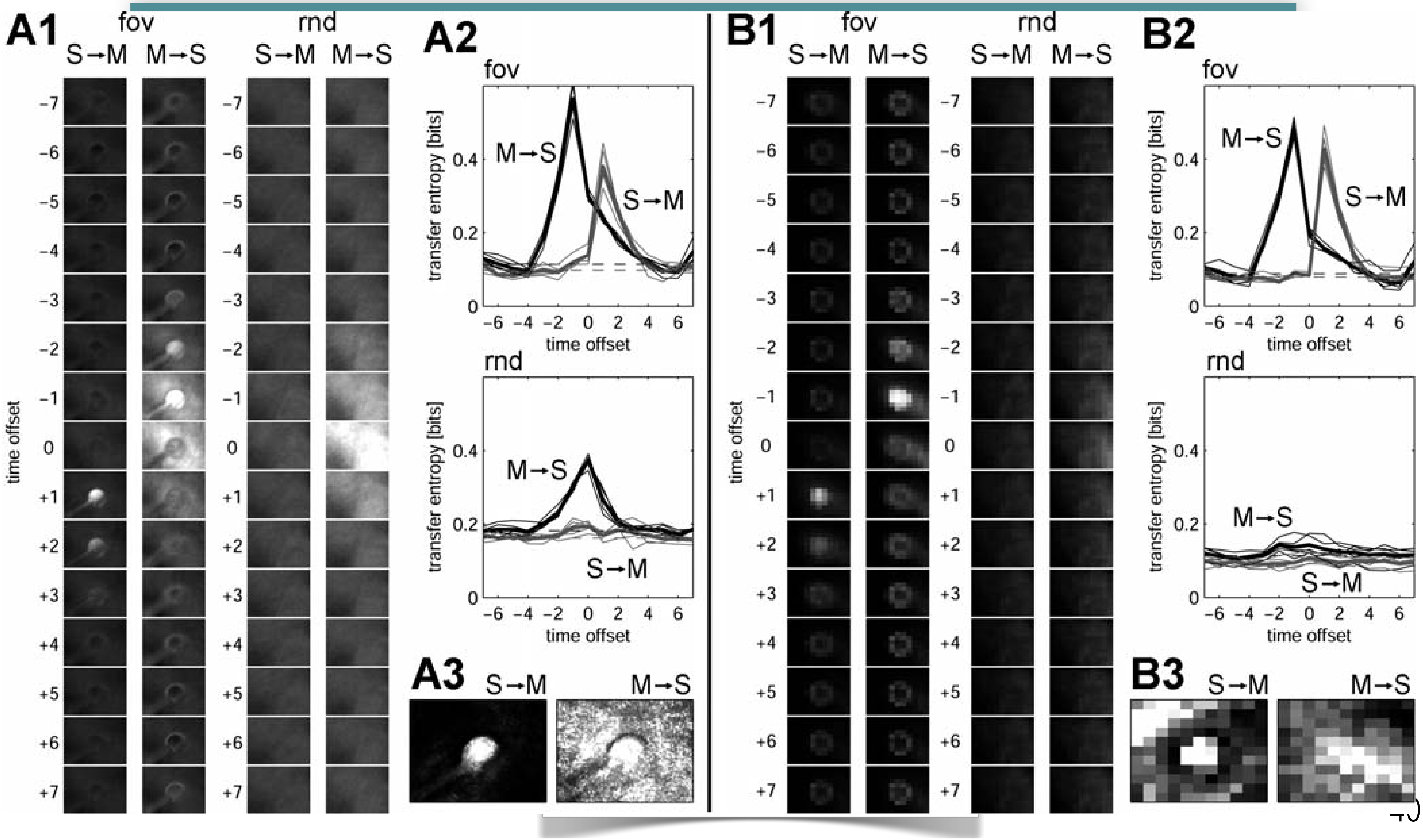
Measuring "causality"

Transfer entropy: derived from Kullback-Leibler Entropy

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

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)

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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)

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

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

Induction of information structure: effect (principle of "information self-structuring)

foundation of learning and development

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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)

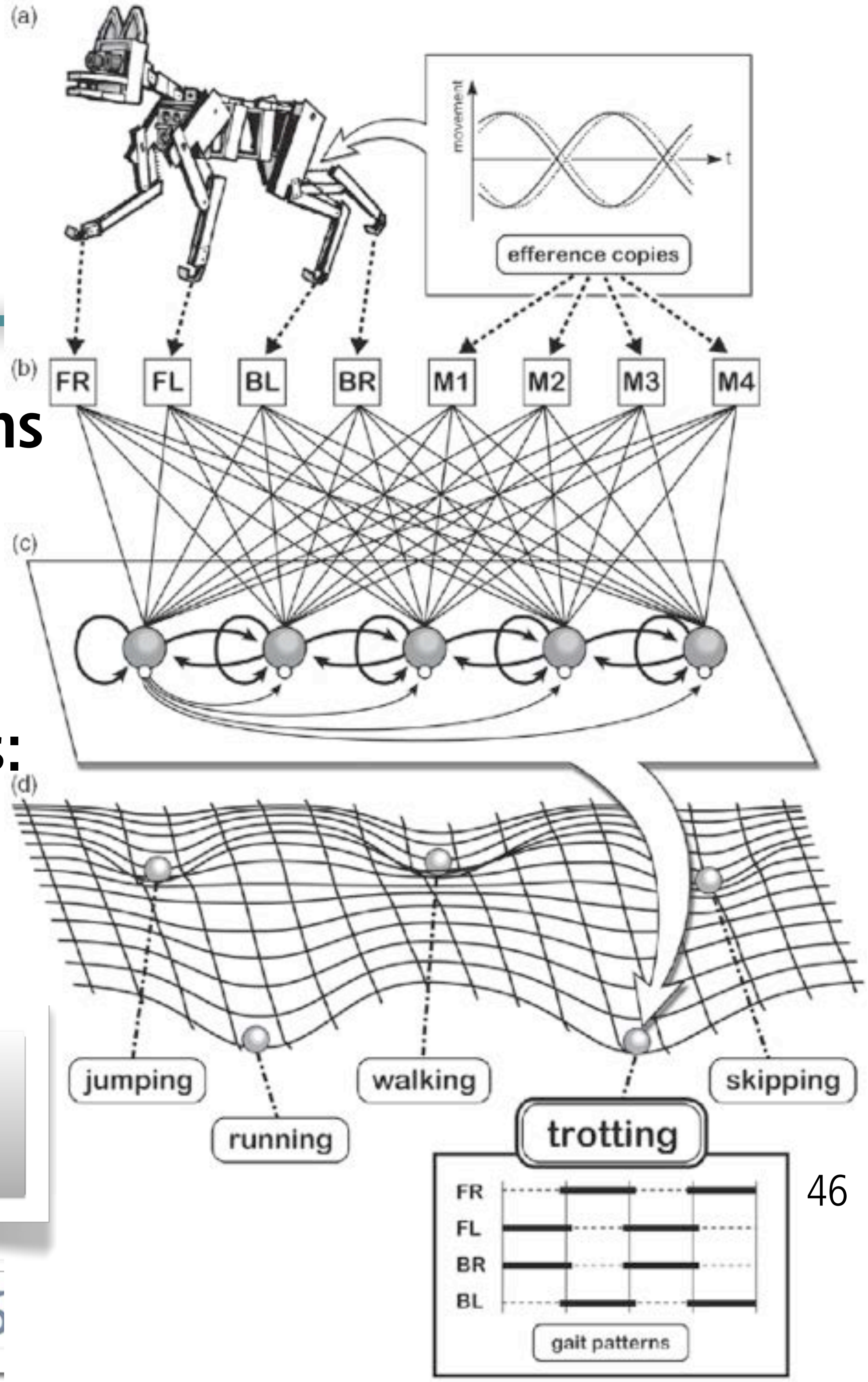
Building grounded cognition

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.

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Interesting experiment by famous developmental psychologist Linda Smith on an embodied notion of transitivity that can easily be understood by children. Give them a container. Give them a somewhat smaller container: they will put it into the larger container. Give them a yet smaller container, they will put it into the medium-sized container and they will immediately realize that the smallest container is also contained in the biggest one.

Robots for studying development: Why humanoids?

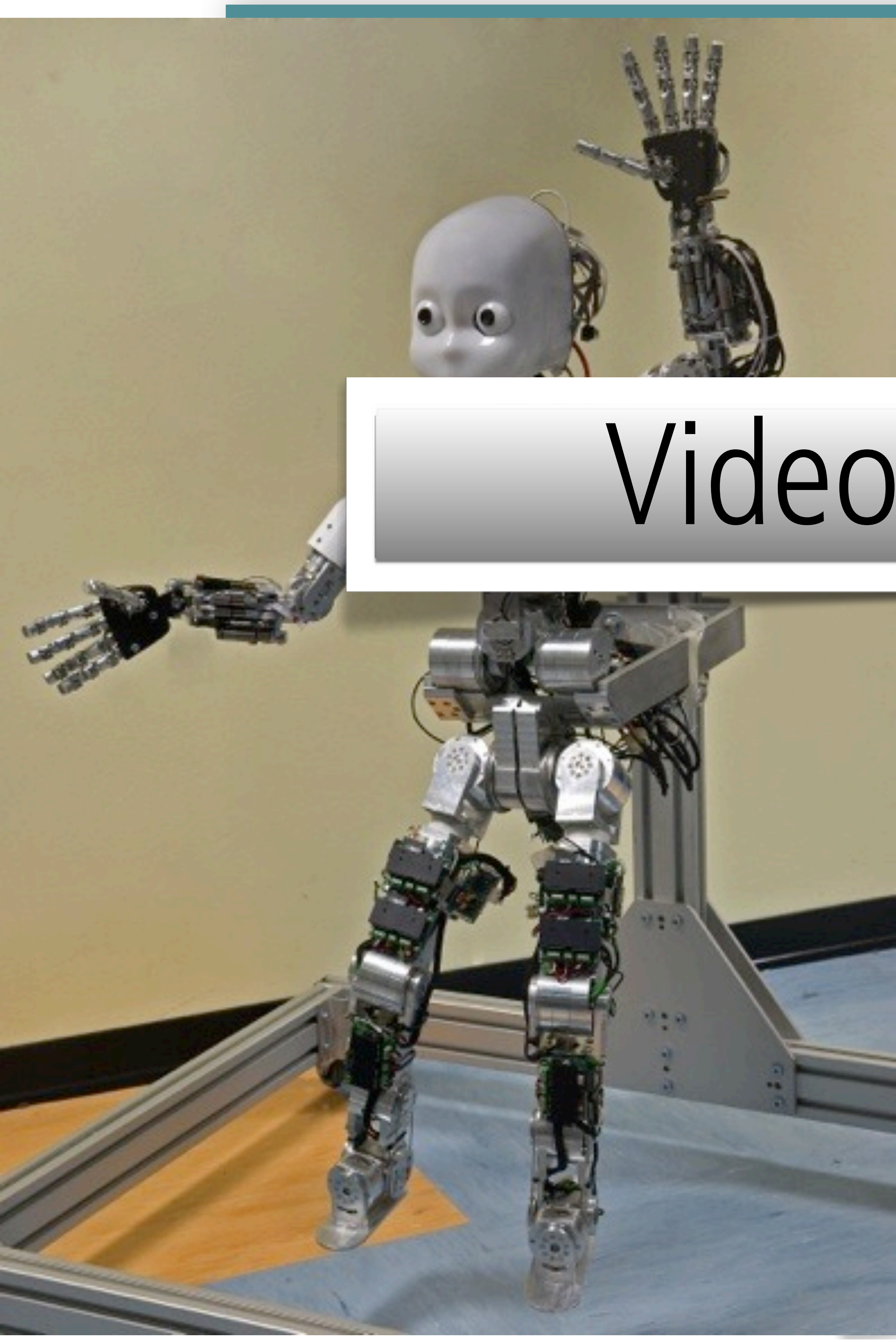
Reasons?
—> University of Tasmania (Australia)

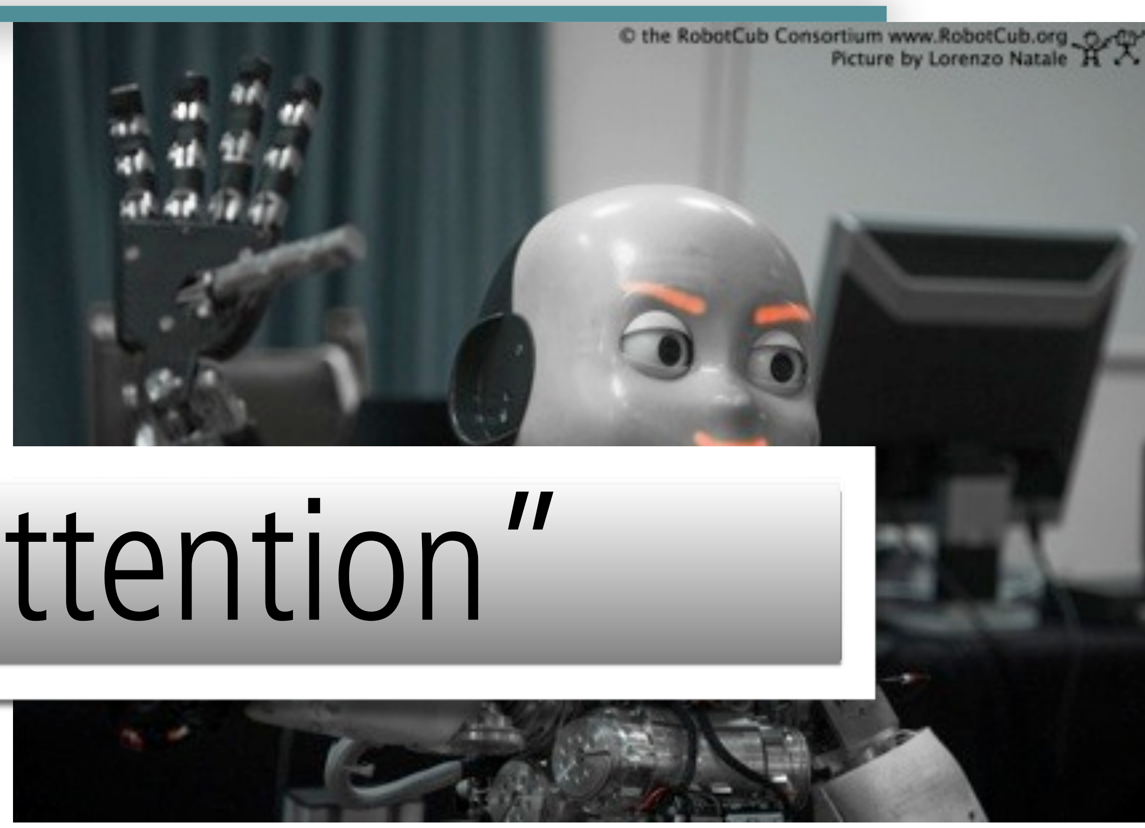
Robots for studying development: Why humanoids?

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

beware: **anthropomorphization ...**

Robots for studying development: iCub





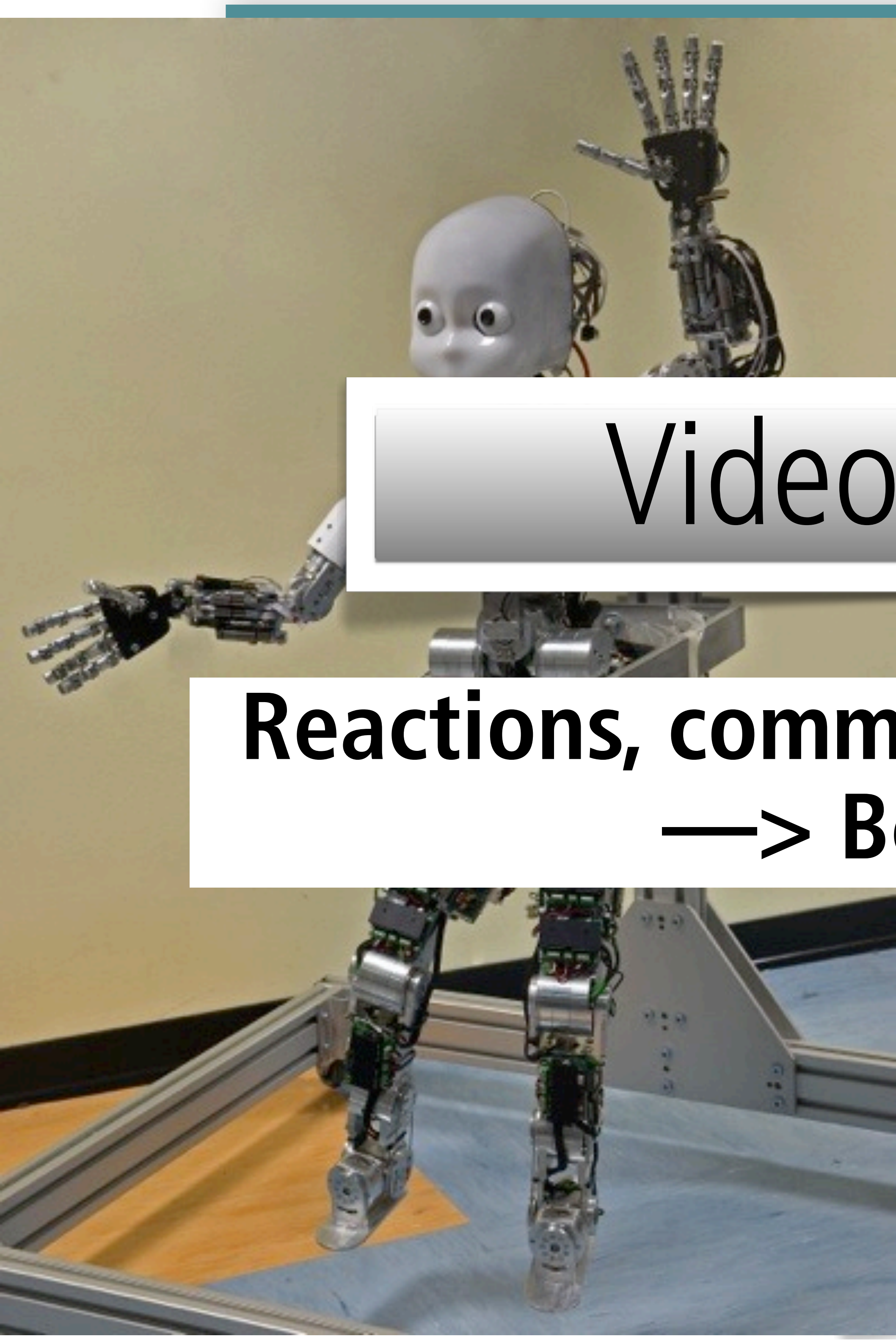
Video “iCub attention”

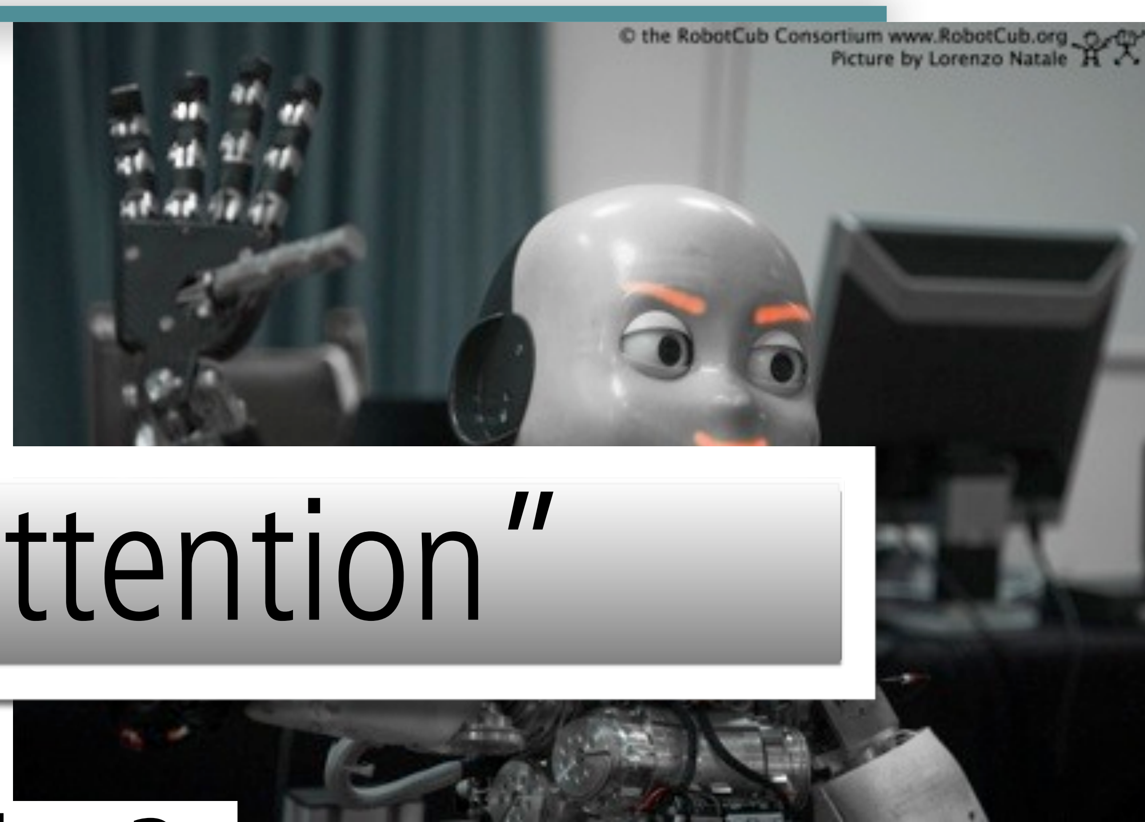
The iCub project by
Giorgio Metta and Giulio Sandini

robotics Swiss National Centre of Competence in Research

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).

Robots for studying development: iCub





Video “iCub attention”

Reactions, comments on video?
—> Berlin

ct by
Giorgio Metta and Giulio Sandini

robotics Swiss National Centre of Competence in Research

A research platform for sensori-motor development

Adding sensors: generation of sensory stimulation through action

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

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)

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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)

why is it important to have correlations in the different sensory channels? (e.g. visual and haptic)

—> Salford

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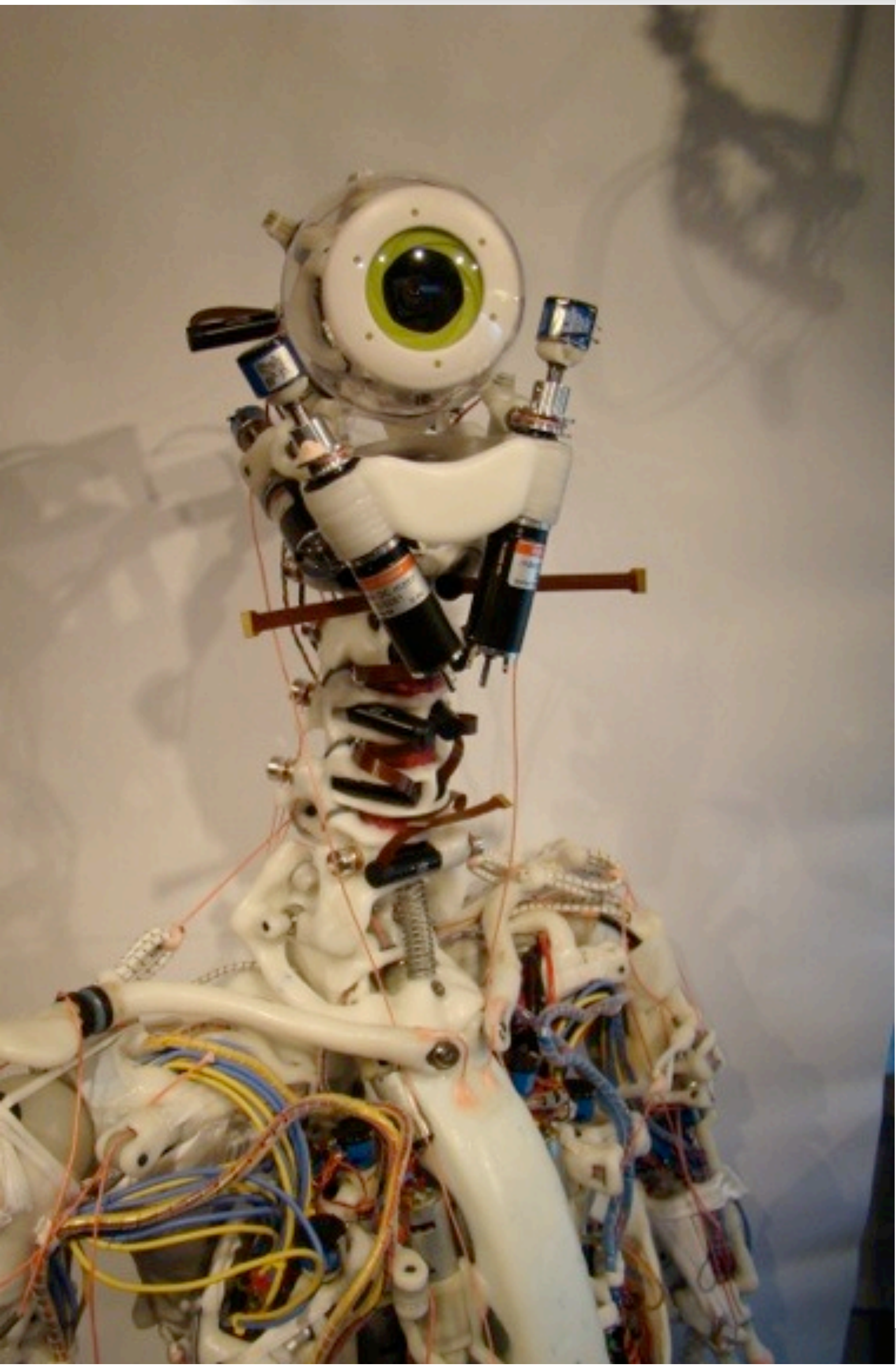
The super-compliant, "soft", robot ECCE for development

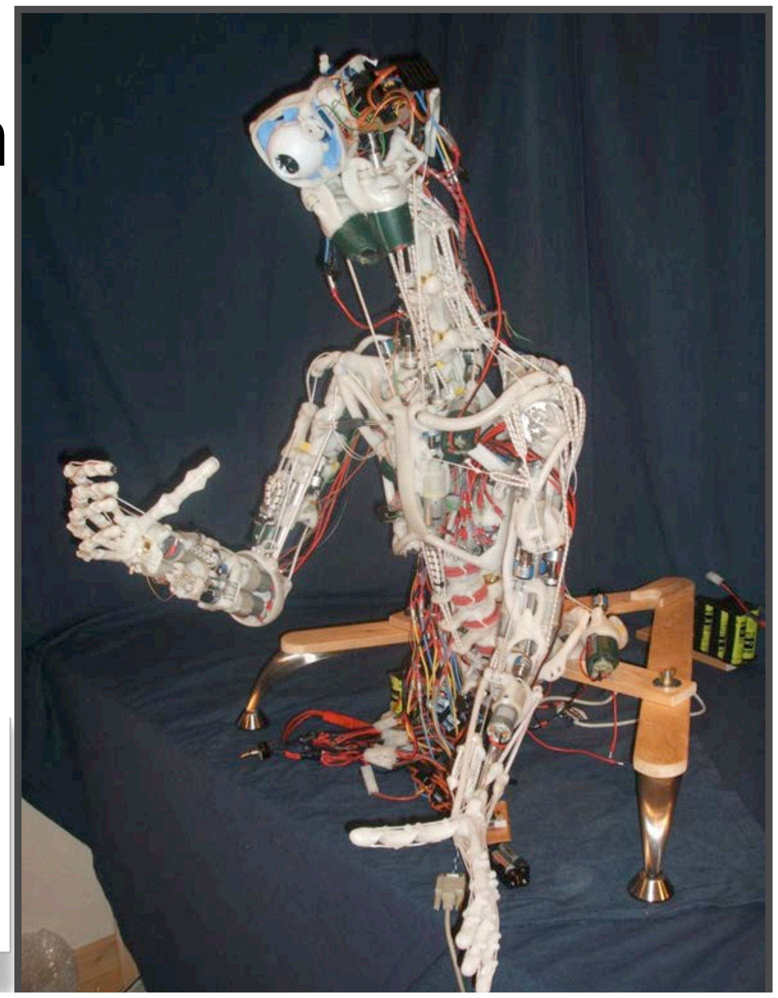


Design and construction:
Rob Knight — robotstudio, Geneva
Richard Newcombe — Imperial College
Owen Holland — Essex/Sussex University
Hugo Marques, Cristiano Alessandro, Max Lungarella — UZH, experiments

ECCE — Embodied Cognition in a Compliantly Engineered Robot

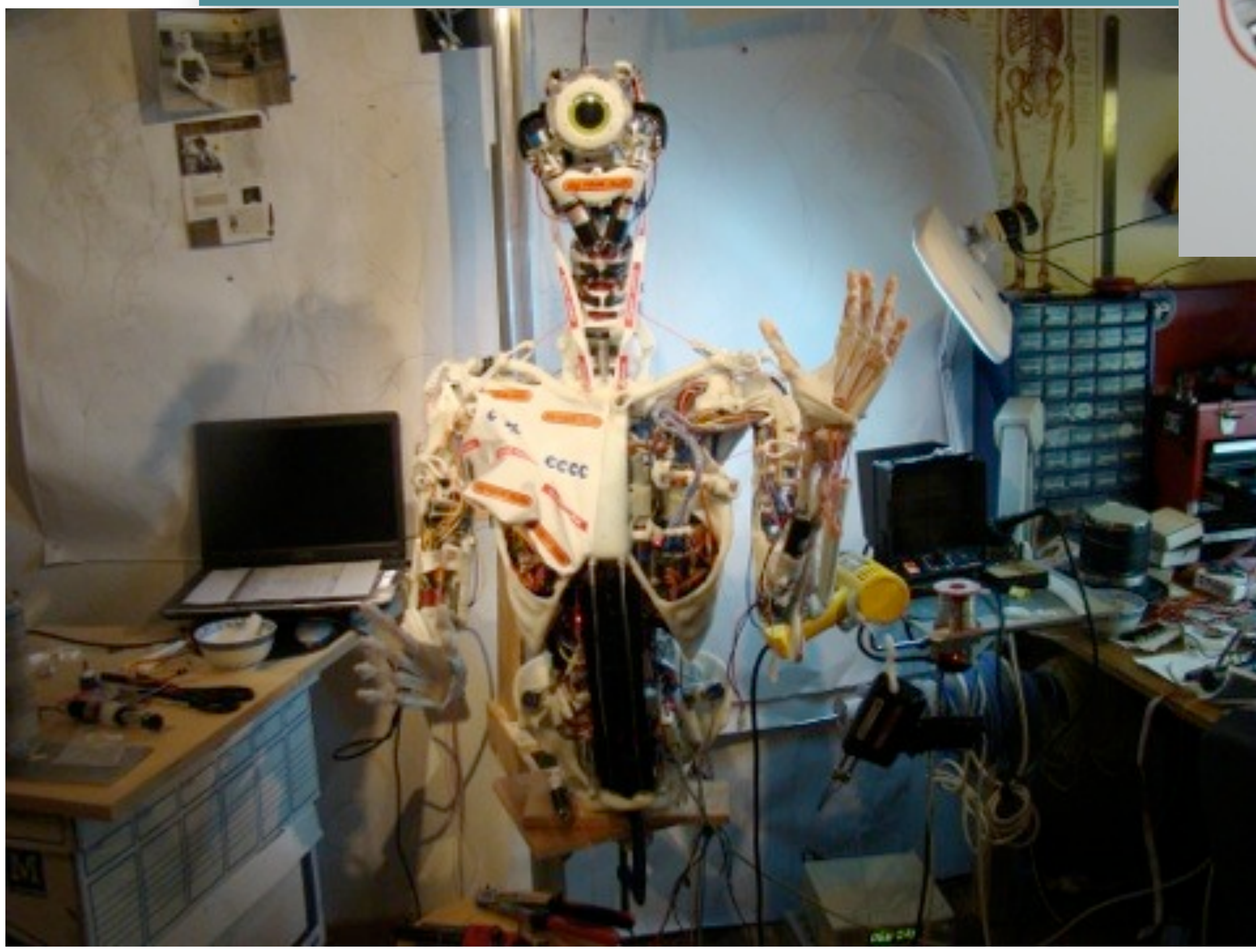
Anthropomorphic design

robotics Swiss National Centre of Competence in Research



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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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

University of Zurich

Not everybody seems to be happy about ECCE

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

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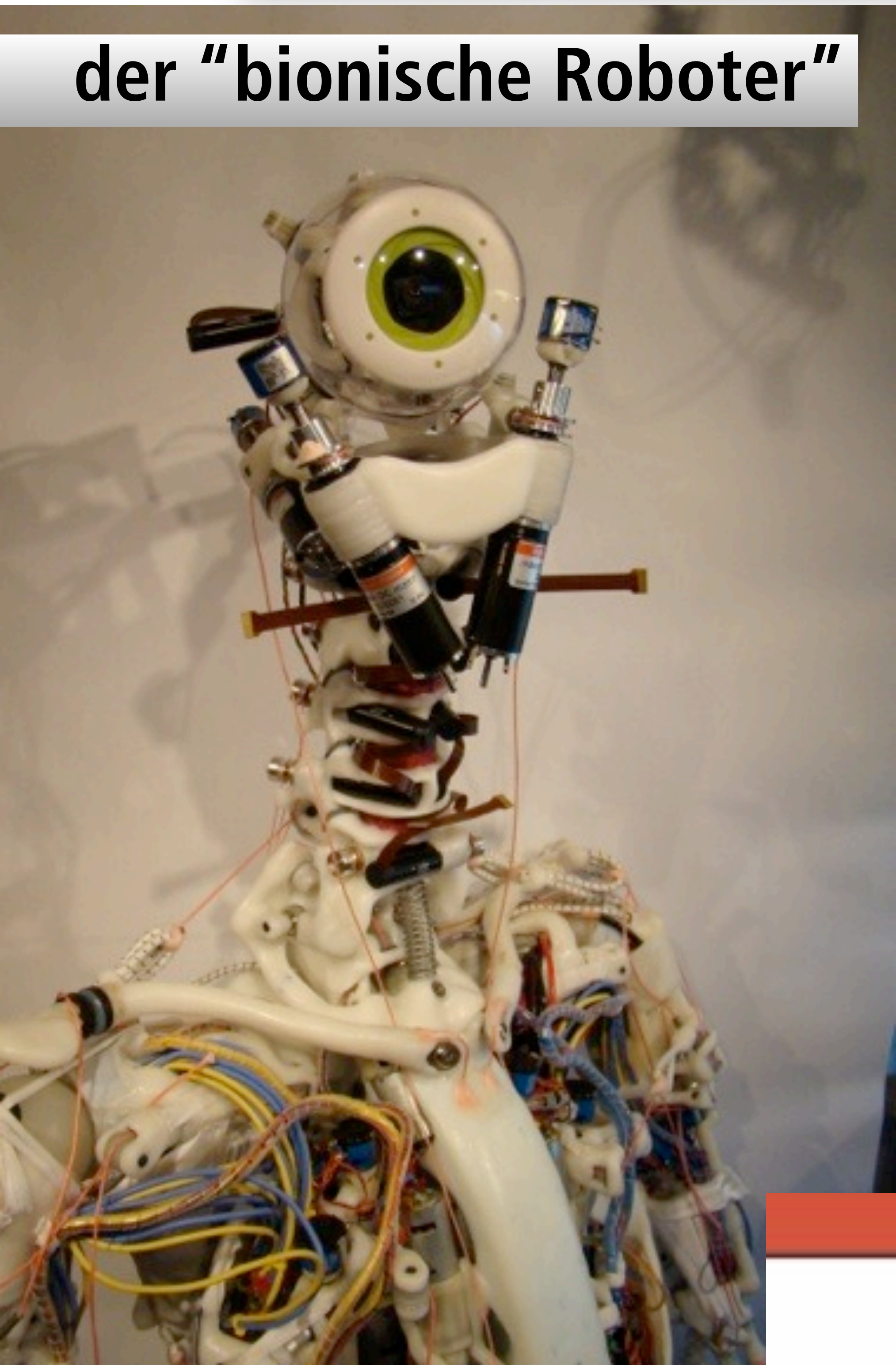
ECCE with former president of Switzerland: Innovation Fair 2010



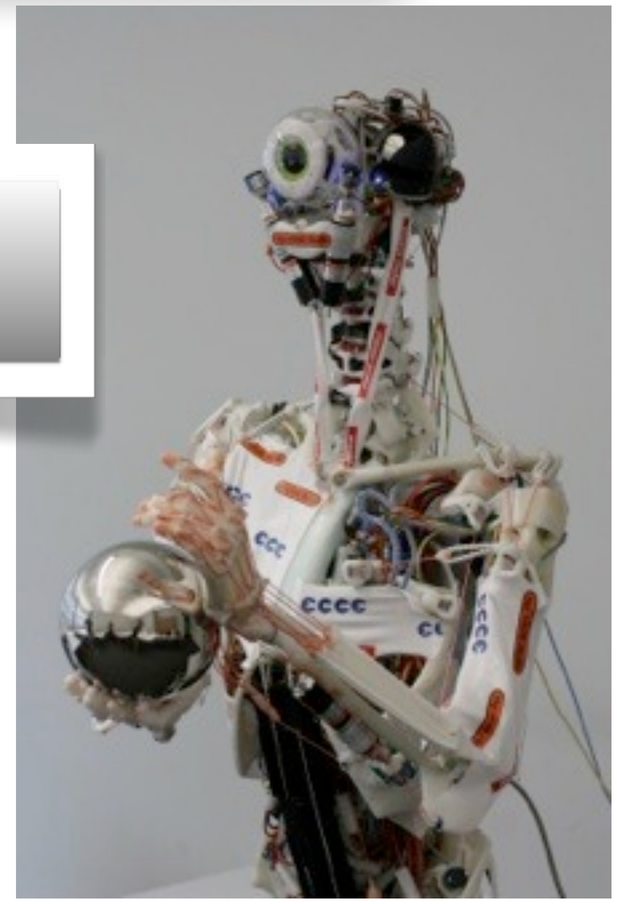
Anthropomorphic design

maxon motor
driven by precision

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

The super-compliant, “soft”, robot ECCE

Video “ECCE_Promovideo”



Anthropomorphic design

→ **must have learning**

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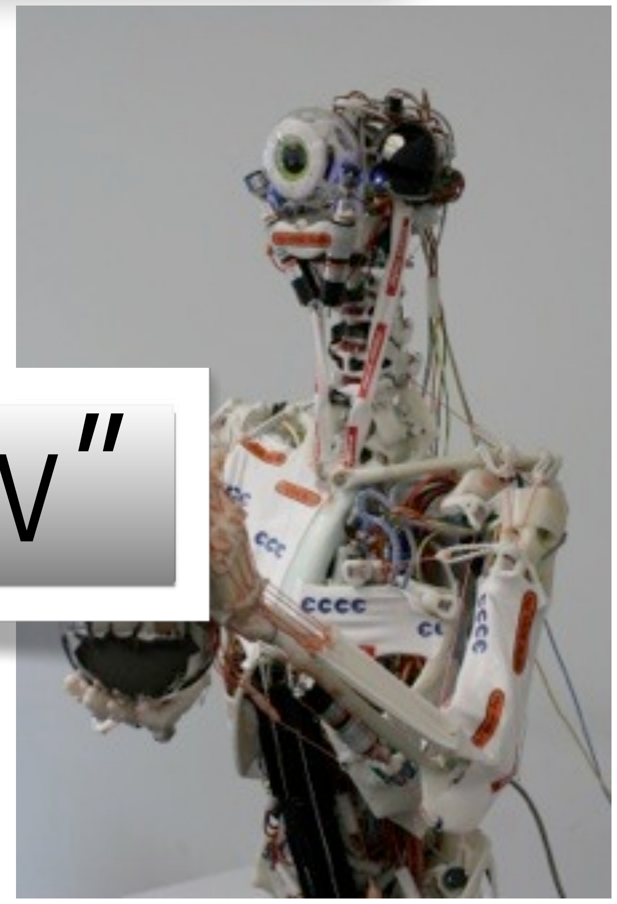
The super-compliant "soft" robot ECCE

Video "EDS Best Video2010.mov"



Anthropomorphic design

cf. also: Inaba's Kojiro

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Neue Plattform: Roboy

(in - schneller - Entwicklung: Ziel Februar 2013)

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

head needs to be replaced - use facebook for voting

benutzerfreundlich?
Emotionen?
funktioniert es?
sedax
design
engineering
technology

1

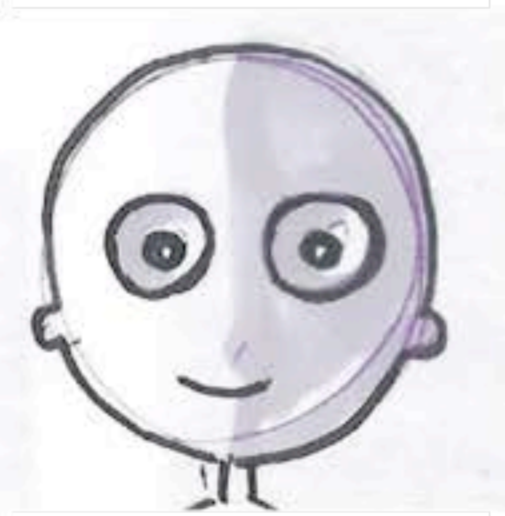
2

3

4

5

6



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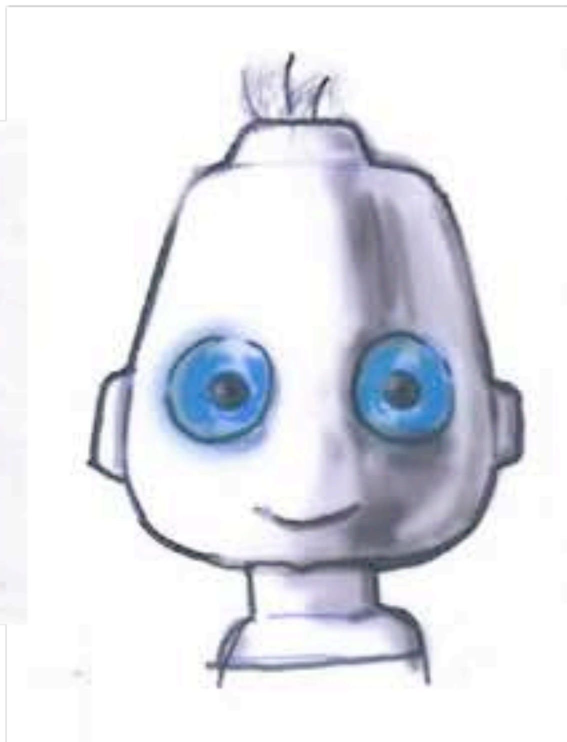

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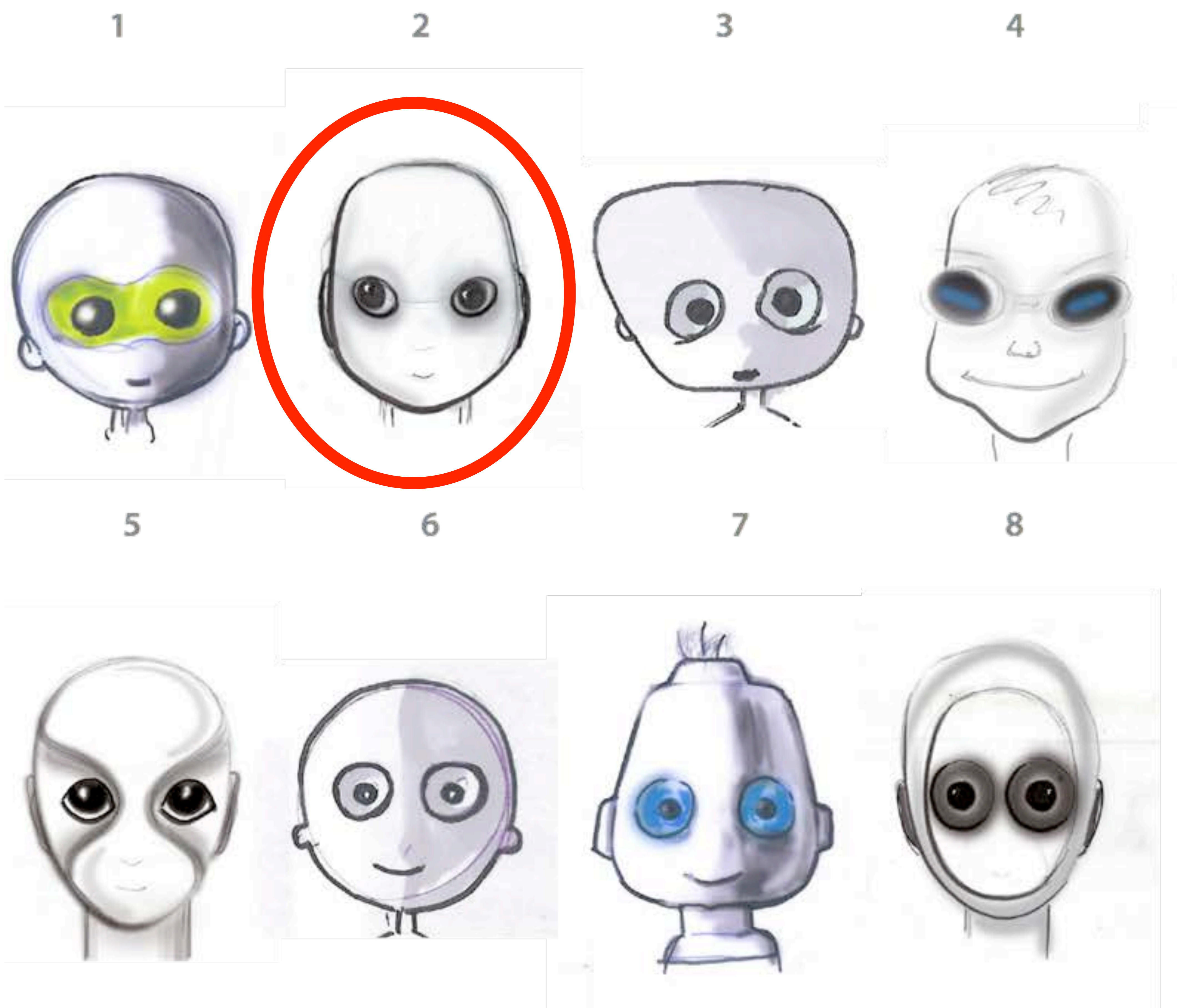
1
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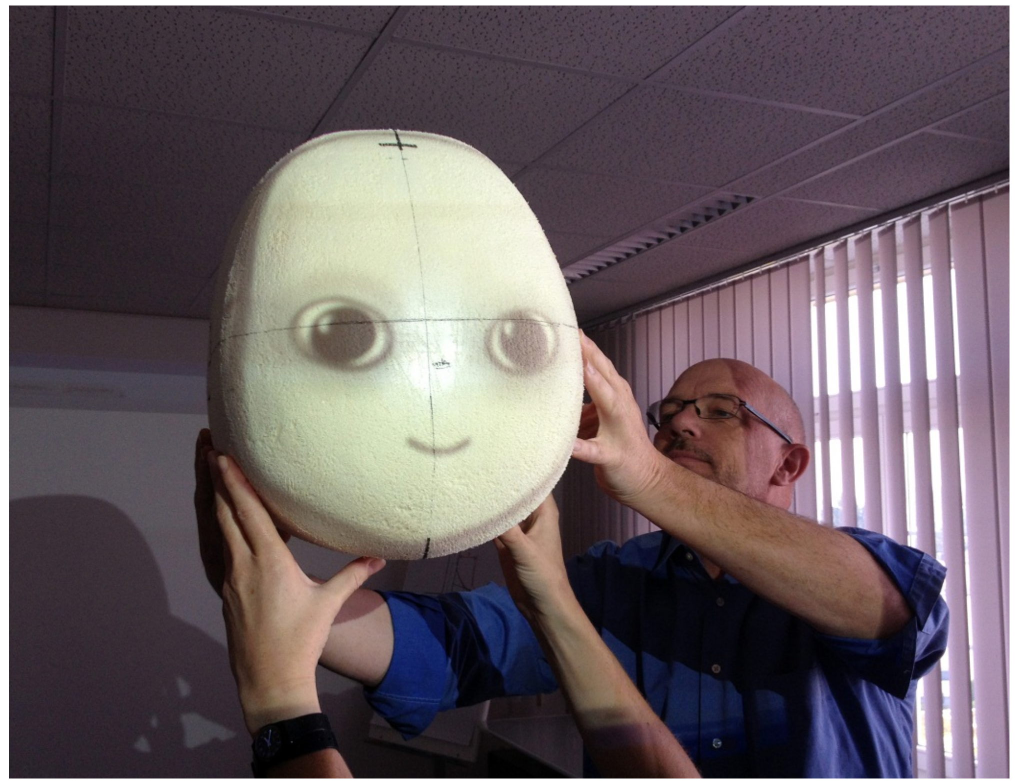
Kopf Proportionen



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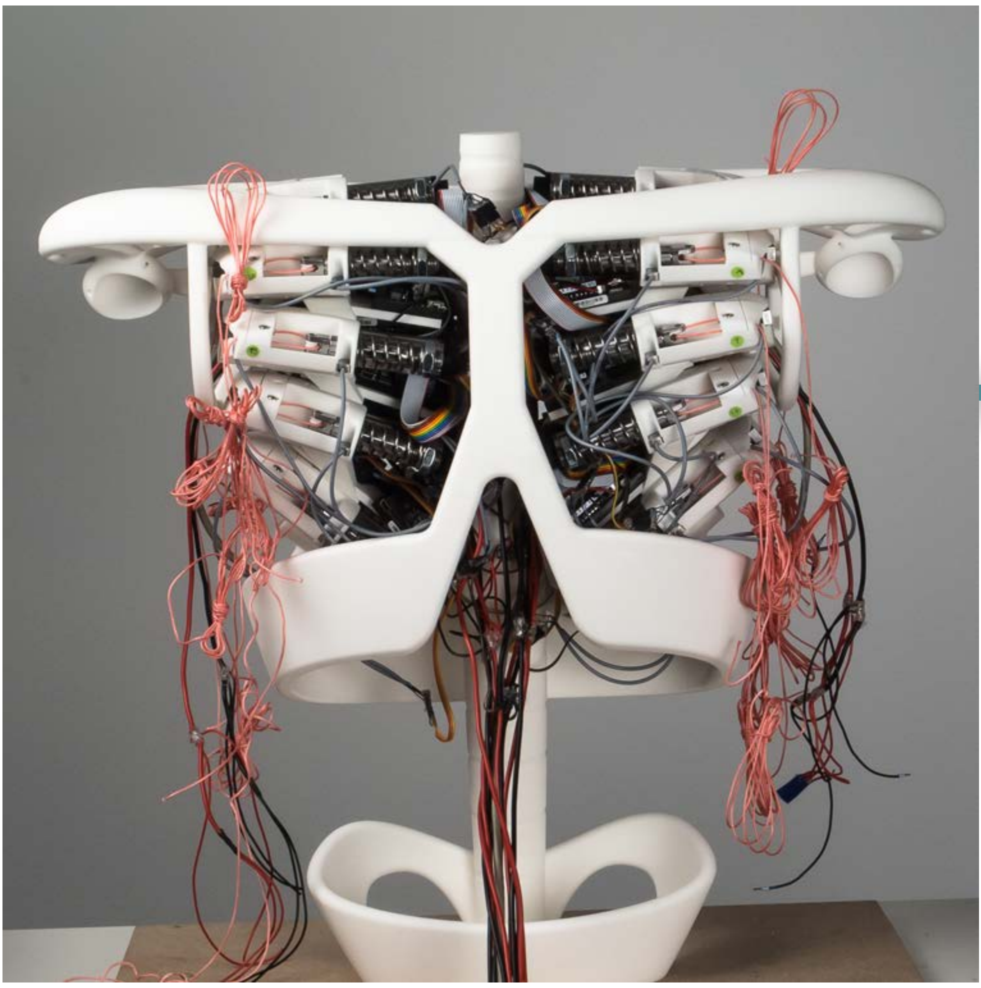

Torso Konstruktion

video:
roboy_montage_torso.wmv

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Visit:

become friends with “Roboy” on facebook!

http://www.robotsontour.com/en/

“Robots on Tour”
9 March 2013
Zurich, “Puls 5”

ROBOTS ON TOUR

World Congress and Exhibition of Robots, Humanoids, Cyborgs and more

START BESUCHER ROBOTER PROGRAMM REFERENTEN LOCATION INFOS TICKETS KONTAKT ENGLISH

“On the occasion of the 25th anniversary of the Artificial Intelligence Laboratory, Dept. of Informatics, University of Zurich”

World Congress and Exhibition of Robots, Humanoids, Cyborgs and more am 9. März 2013 in Zürich

Aktuelle News

31.07.2012: Nun ist es offiziell: Das AI Lab arbeitet an einem neuen Roboter! Mehr zu Roboy erfahren Sie auf www.roboy.org.

Univ
Zuri

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START BESUCHER ROBOTER PROGRAMM REFERENTEN ... AKT ENGLISH

save the date!

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Bernstein's problem

- highly complex system: ... number of redundant DOFs in compl... ...em
- 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)

Bernstein's p blem

research opportunity

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

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Implementation of learning in embodied systems

important approach:

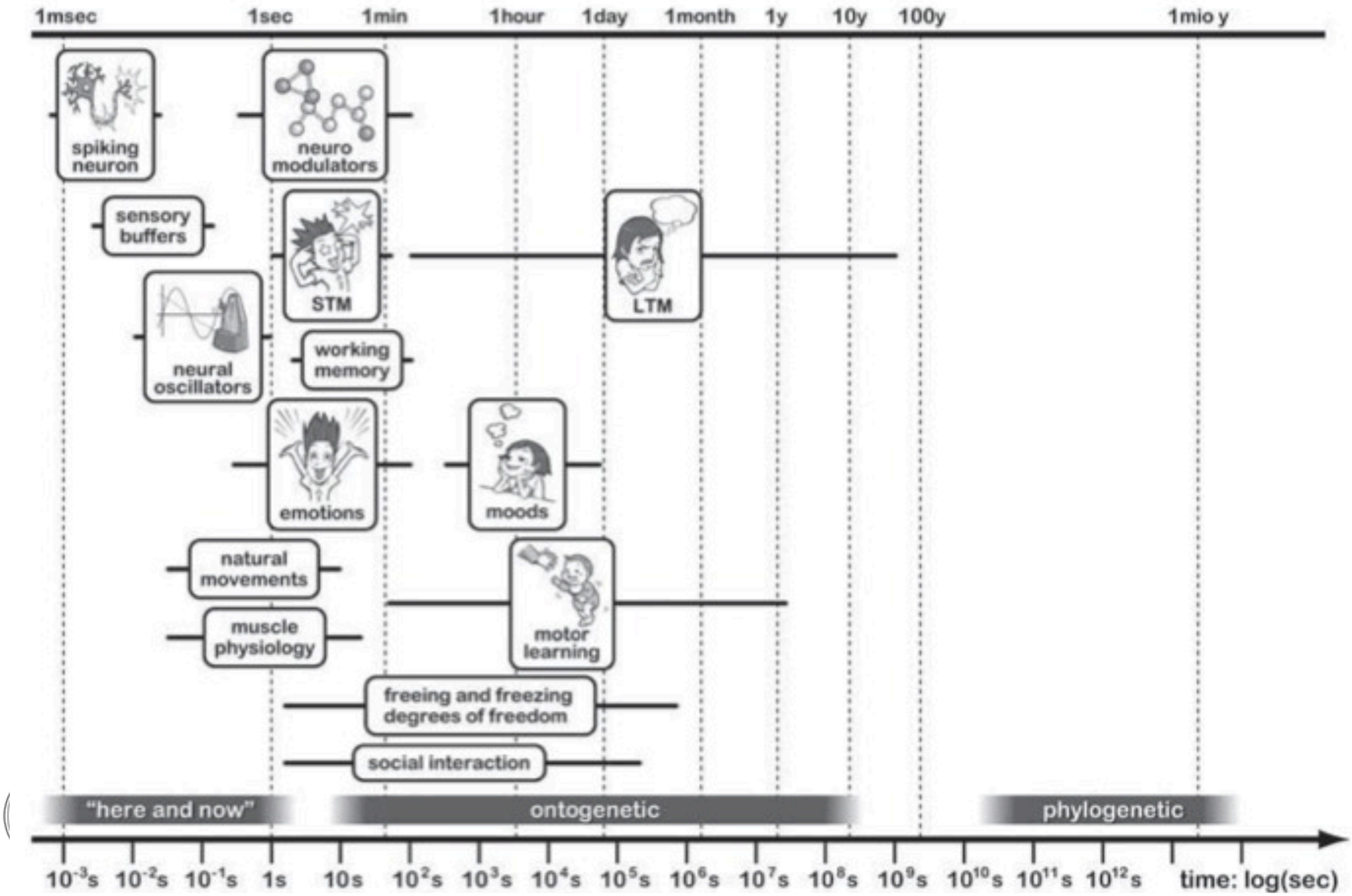
“Artificial Neural Networks”

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 (on development), and all the remaining chapters of "How the body …"**

End of lecture 9

Thank you for your attention!

stay tuned for guest lectures

Prof. Ning Lan

Prof. Roland Siegwart

University of Zurich

lab

人工智能 上海授课 The ShanghAI Lectures

Lecture 9: Guest speaker

Med-X, Shanghai Jiao Tong University

Prof. Ning Lan, Shanghai Jiao Tong University,
"Cortico-muscular communication of movement information by central regulation of spindle sensitivity"

10.00h Zurich time

University of Zurich

robotics Swiss National Centre of Competence in Research

ai lab

The ShanghAI Lectures 人工智能 上海授课

Prof. Ning Lan obtained his B.S. degree from the Department of Precision Instruments from SJTU in 1982, and obtained his M.S. and Ph.D. degrees from Biomedical Engineering of Case Western Reserve University in 1985 and 1989, respectively. Currently, he is an Adjunct Associate Professor of University of Southern California. In 1995, he helped organizing the Neural Engineering Committee of the Chinese Society for Neuroscience, and served as its Funding Associate Director. He also served as Assistant Editor of IEEE Trans on Rehabilitation Engineering (now IEEE Trans on Neural Systems and Rehabilitation Engineering), and Associate Editor of Chinese Rehabilitation Theory and Practice. In 2009 he joined the faculty of Med-X research Institute.

Lecture 9: Guest speaker

from the University of Zurich
Switzerland

Prof. Roland Siegwart, Autonomous Systems Lab., ETH Zurich
"Design and navigation of wheeled, running, swimming, and flying robots"

10.30h Zurich time

University of Zurich

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The ShanghAI Lectures 人工智能 上海授课

Vice president research and corporate relations, ETH Zurich. Prof. of Autonomous Systems.
Research interests:
- Mobile Robot design and navigation; localization and mapping, planning in dynamic environments, human robot interaction, locomotion concepts for rough terrain, walking robots, space rovers, autonomous cars and unmanned aerial vehicles.
- Mechatronics Design and Systems Engineering (smart product design, innovation, creativity).
- Artificial Cognitive Systems (Perception, representations, probabilistic reasoning and planning)

End of lecture 9

Thank you for your attention!

stay tuned for lecture 10

Summary and conclusions (Rolf)

Future trends (various guest lectures)