ADAPT – UNIZH Past-Present

Morphology, Materials, and Control
"Developmental Robotics"

Rolf Pfeifer, Gabriel Gomez, Martin Krafft,
Geoff Nitschke, NN
Artificial Intelligence Laboratory
Department of Information Technology
University of Zurich
Switzerland

Artificial Intelligence Laboratory
Department of Information Technology

Director
Rolf Pfeifer

Post-docs
Daniel Bisig
Peter Eggenberger
Hansruedi Früh
Charlotte Hemelrijk

Visitors
Hiroshi Yokoi (visiting prof.)
Chris Jones
Robert König
Thomas Uehlinger
Jilles Vreeken
Noel Verdurmen

Staff
Erina Kishida
Rafael Schwarzmann
Clausdia Wirth

PhD students
David Andel
Josh Bongard
Simon Bovet
Raja Dravid
Miriam Fend
Andreas Fischer
Gabriel Gomez
Lorenz Gygax
Verena Hafner
Fumiya Iida
Pascal Kaufmann
Martin Krafft
Hanspeter Kunz
Lukas Lichtensteiger
Massimiliano Lungarella
Kojiro Matsushita
Geoff Nitschke
Chandana Paul
Dale Thomas
Jan Wantia

University of Zurich
Switzerland

Contents

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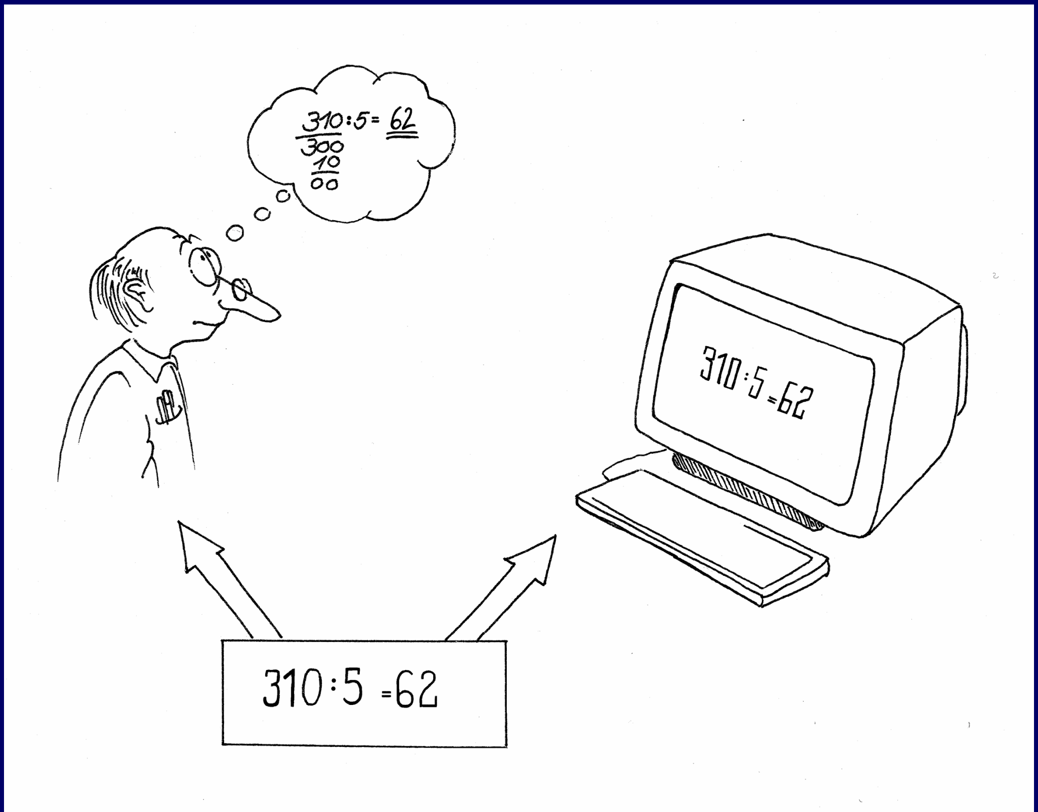
- Introductory comments
- Zurich AI Lab research overview
- The synthetic methodology
- Embodiment – illustrations
- A hard problem in cognitive science: perception in the real world
- The evolution of intelligence: morphogenesis
- The „Zen of robot programming“

The cognitivistic paradigm

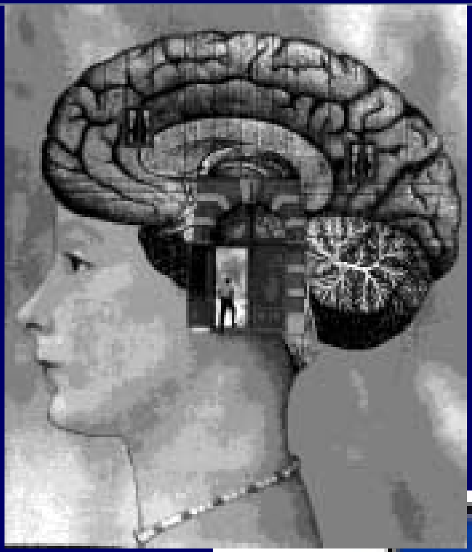


cognition as computation

Artificial intelligence: classical view

Intelligence as:

- centralized in the brain
- as algorithms
- thinking, reasoning, problem solving
- abstraction from physical properties



the computer metaphor

cognition as computation

Classical artificial intelligence – successes

- search engines
- text processing systems
- appliances (dish washers, cameras)
- cars (fuel injection, breaking systems)
- control systems (elevators, subways)
- etc.

Classical artificial intelligence – failures

- vision/perception in the real world
- manipulation of objects
- motor control
- common sense
- everyday natural language
- in general: natural forms of intelligence

→ ***cognitive robotics***

Some problems of classical artificial intelligence

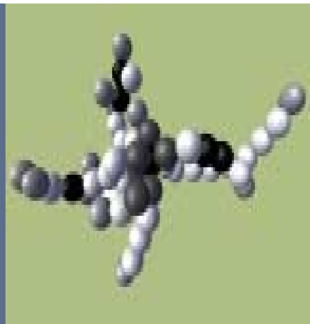
Main problems in a nutshell

- Neglect of fundamental differences of real worlds and virtual (formal) worlds
- Neglect of nature of agent-environment interaction

Embodied artificial intelligence

Rodney Brooks (MIT Artificial Intelligence Laboratory)

- distributed through organism-environment
- complete physical agents interacting with the real world
- acquision of information through sensory system



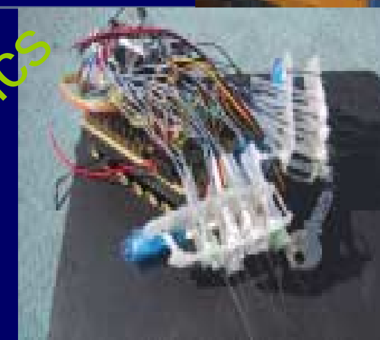
Research at the AI Lab in Zurich

education

locomotion and orientation

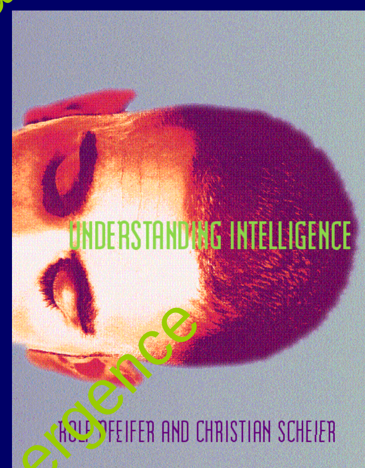
morphology and materials

exploitation of passive dynamics



medicine

collective intelligence



learning, development neural modeling

from structure to growth

designing for emergence

artificial evolution and morphogenesis

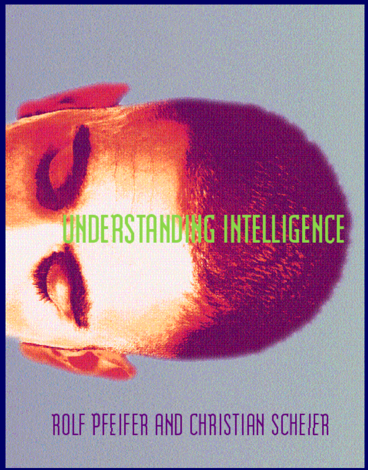
design and art

entertainment

Research at the AI Lab in Zurich

locomotion and orientation

collective intelligence



learning
development
neural modeling

artificial evolution and morphogenesis

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Cognitive robotics

- cognitive vs. non-cognitive (sensory-motor, emotional)
- continuous (not all-or-none)

Cognitive robotics

- cognitive vs. non-cognitive (sensory-motor, emotional)
- continuous (not all-or-none)

—> danger: cognitivistic paradigm lurking!

Cognition defined

- „A broad (almost unspecifiably so) term which has been tradtionally used to refer to such activites as thinking, conceiving, reasoning, etc.“ *The Penguin Dictionary of Psychology*
- „The act or process of knowing in the broadest sense, including both awareness and judgment.“ *Mirriam Webster‘s*
- „Cognition refers to all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used (including) terms as sensation, perception, imagery, retention, recall, problem solving, and thinking.“ *Ulrich Neisser*
- „Cognition is the collection of mental processes and activities used in perceiving, remembering, thinking, and understanding, as well as the act of using those processes.“ *Mark H. Ashcraft*

Cognition defined

- „The most widespread use is as a descriptive term for the large class of so-called higher-level processes, that is, processes not directly driven by the sensory and motor systems.“ *Understanding Intelligence*

--> not all-or-none, but continuous

Cognitive robotics

approaches:

- „hand design"
- developmental robotics, epigenetic robotics
- evolutionary robotics

--> embodiment perspective

Cognitive robotics

approaches:

- „hand design“ (here and now)
- developmental robotics, epigenetic robotics (ontogenetic)
- evolutionary robotics (phylogenetic)

--> embodiment perspective

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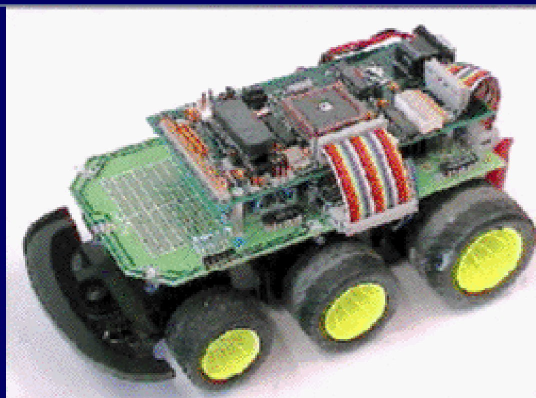
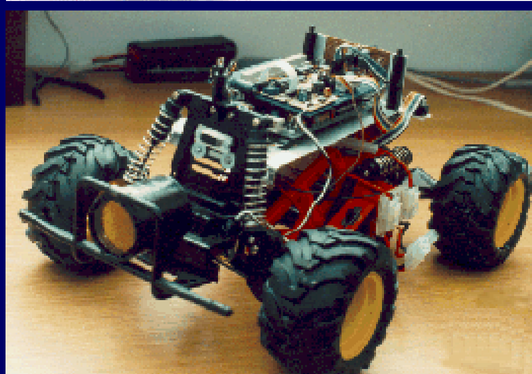
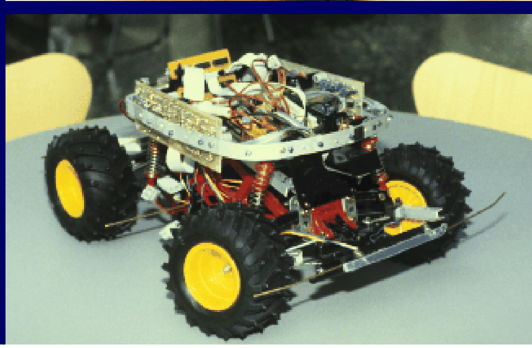
Zurich AI Lab robots



Didabot

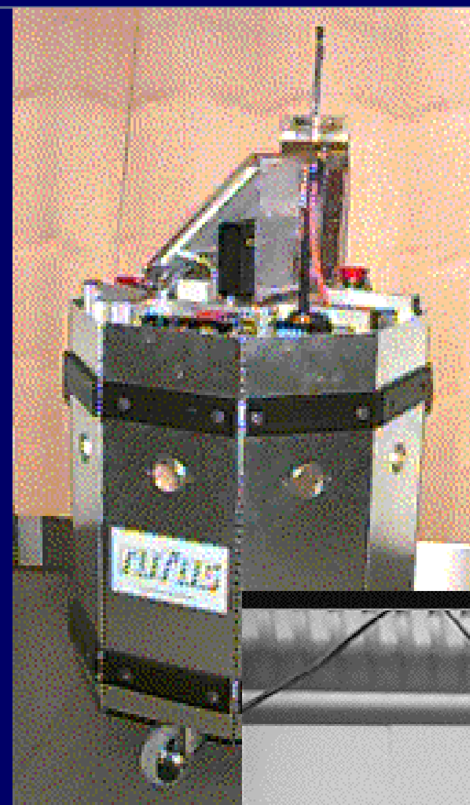


Famez

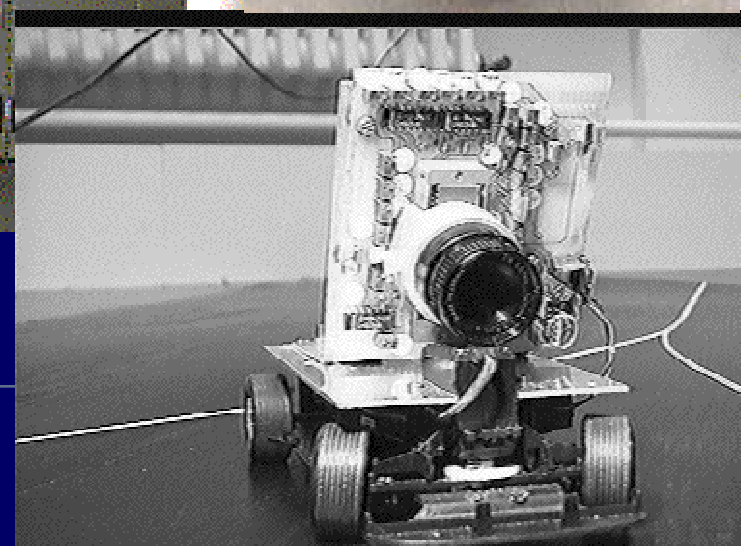


Sita

Rufus T. Firefly



Ms. Gloria Teasdale



Morpho

Zurich AI Lab robots

- Amouse
- Sahabots
- Melissa
- Tripp
- Samurai
- Analogrob
- Dexterolator
- Stumpy
- Eyebot
- Mindstorms
- Kheperas
- Mitsubishi
- Forkleg

Why build robots?

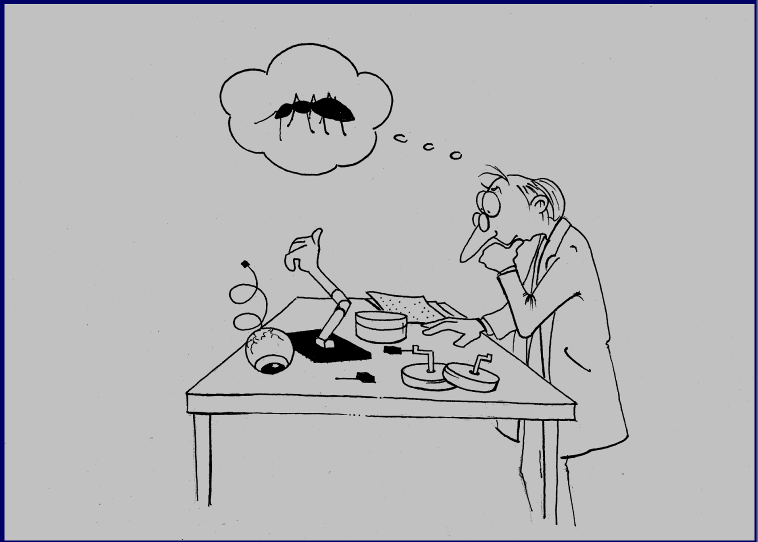
Why build robots?

--> synthetic methodoogy

Synthetic methodology

"Understanding by building"

- modeling behavior of interest
- abstracting principles

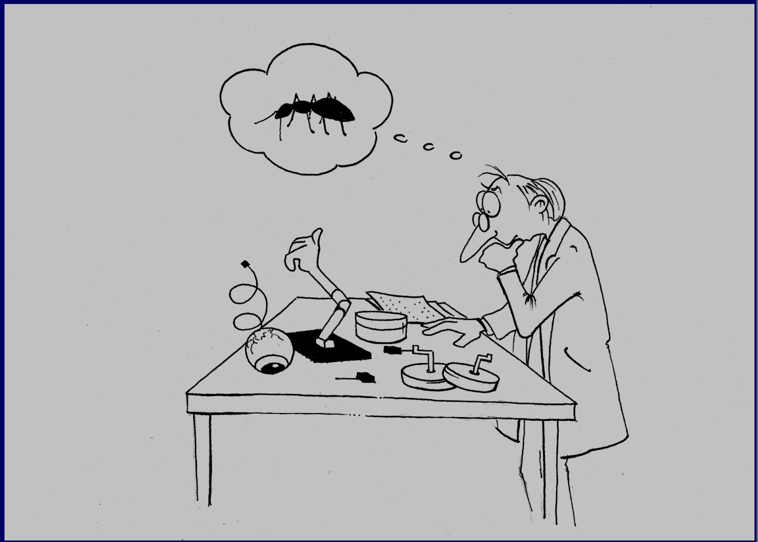


Synthetic methodology

"Understanding by building"

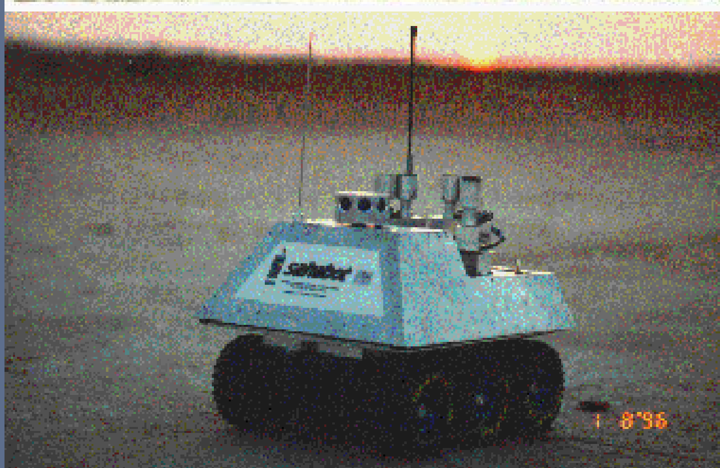
- modeling behavior of interest
- abstracting principles

→ *robots as useful artifacts*
→ *robots as cognitive tools*



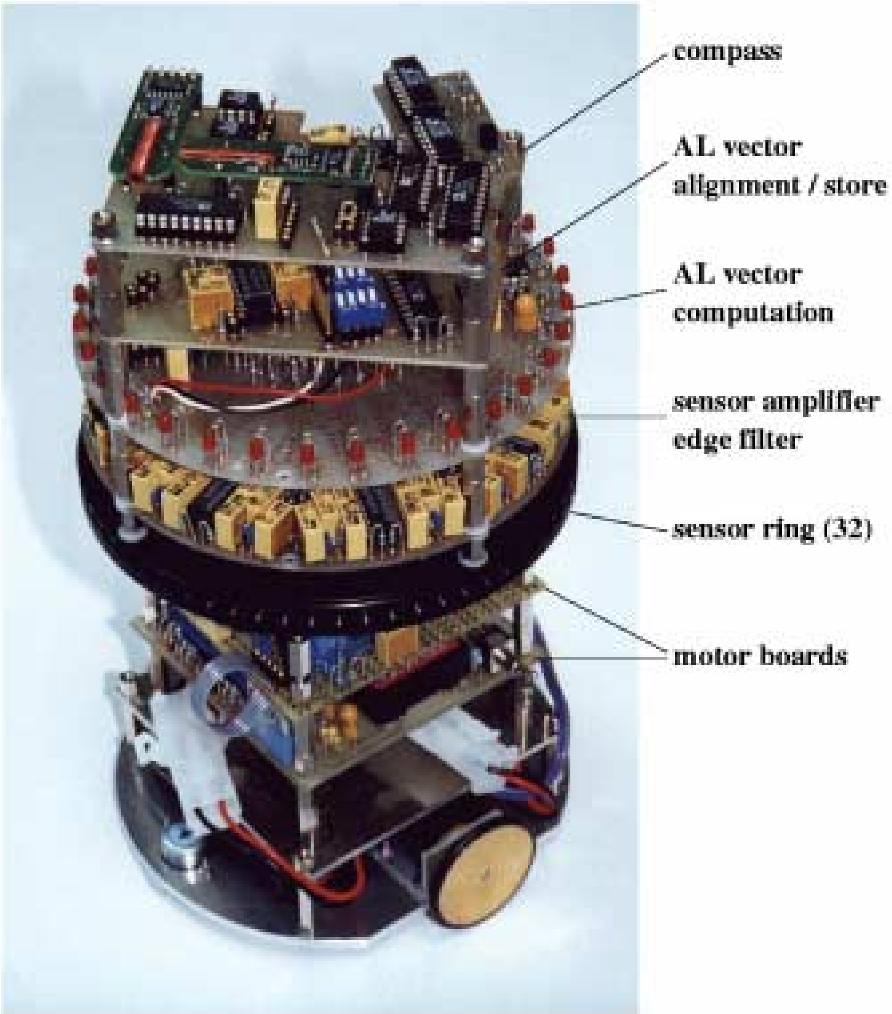
Sahabot I and II

navigation behavior of the desert ant *Cataglyphis*



Design and construction:
Hiroshi Kobayashi, Dimitri Lambrinos, Ralf Möller, Marinus Maris

Analog robot



visual navigation behavior of the desert ant *Cataglyphis*

Design and construction: Ralf Möller

The “Eyebot”

morphology of insect eyes

Design and construction:
Lukas Lichtensteiger and
Peter Eggenberger

The flying robot “Melissa”

navigation behavior of flying insects

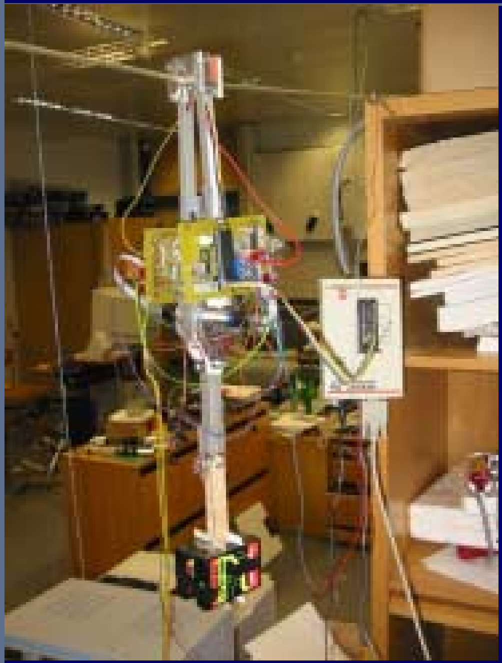
gondola with omnidirectional camera

Design and construction:
Fumiya Iida

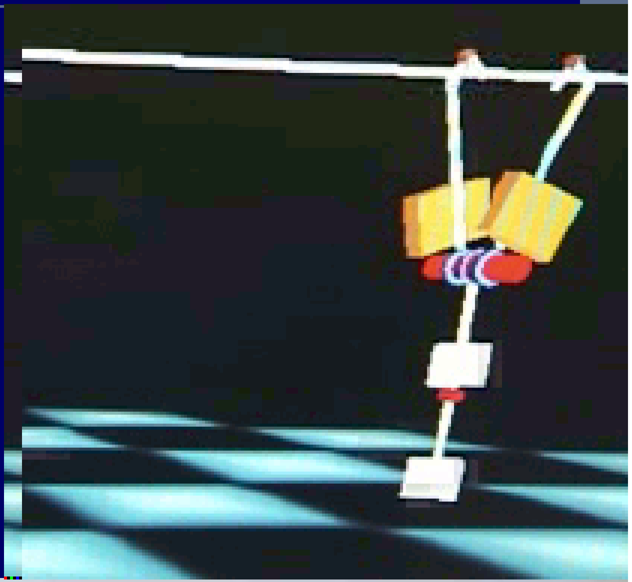
Main train station in Zurich

explaining embodiment
to public at large

The “Monkey robot”

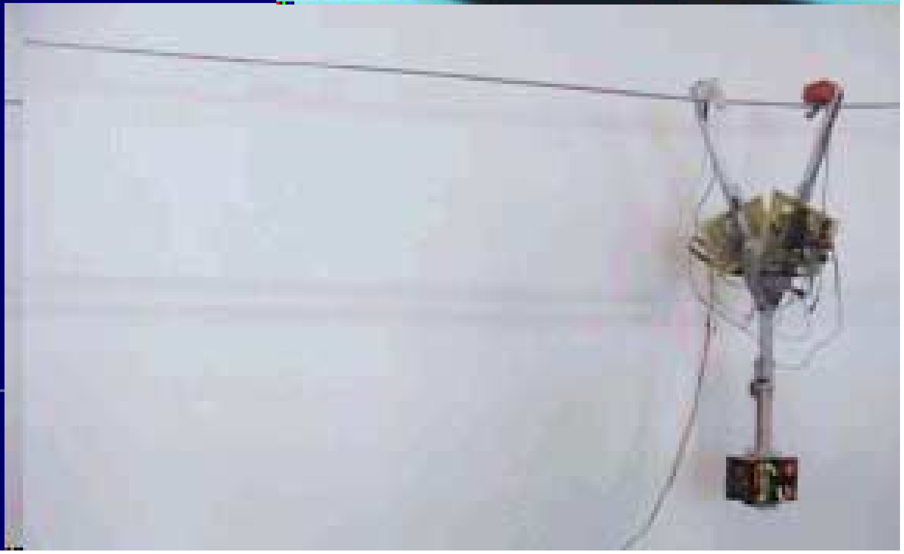


Design and construction:
Dominique Frutiger



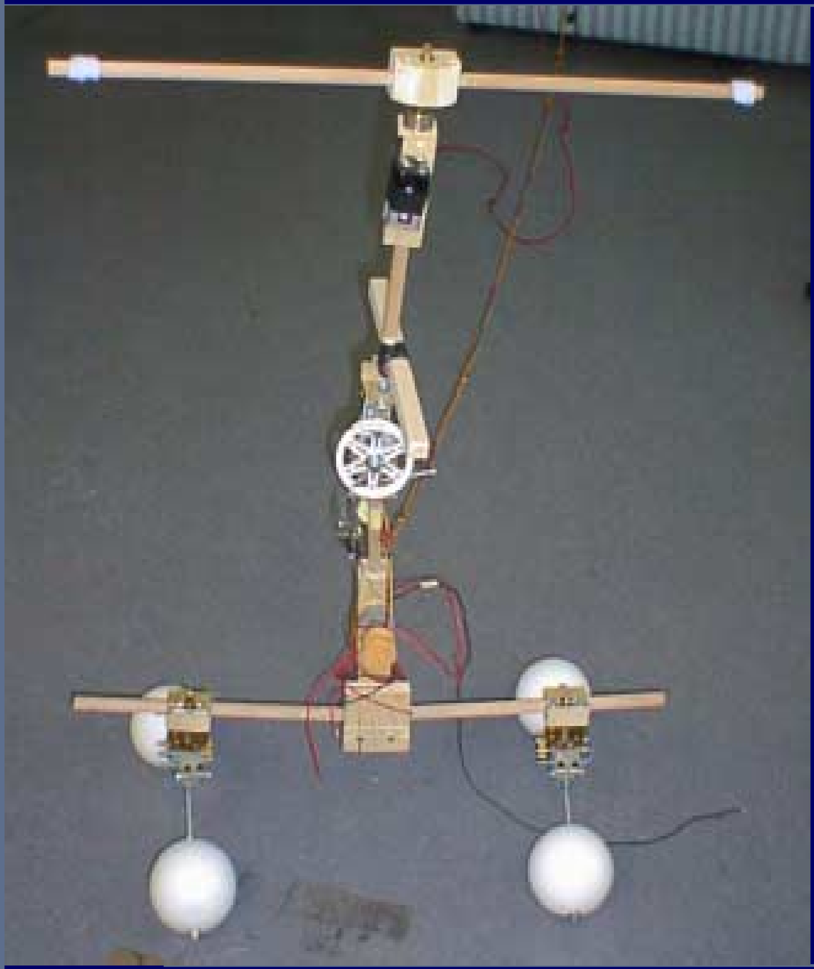
simulation

dynamics of brachiation



robot

The dancing robot “Stumpy”



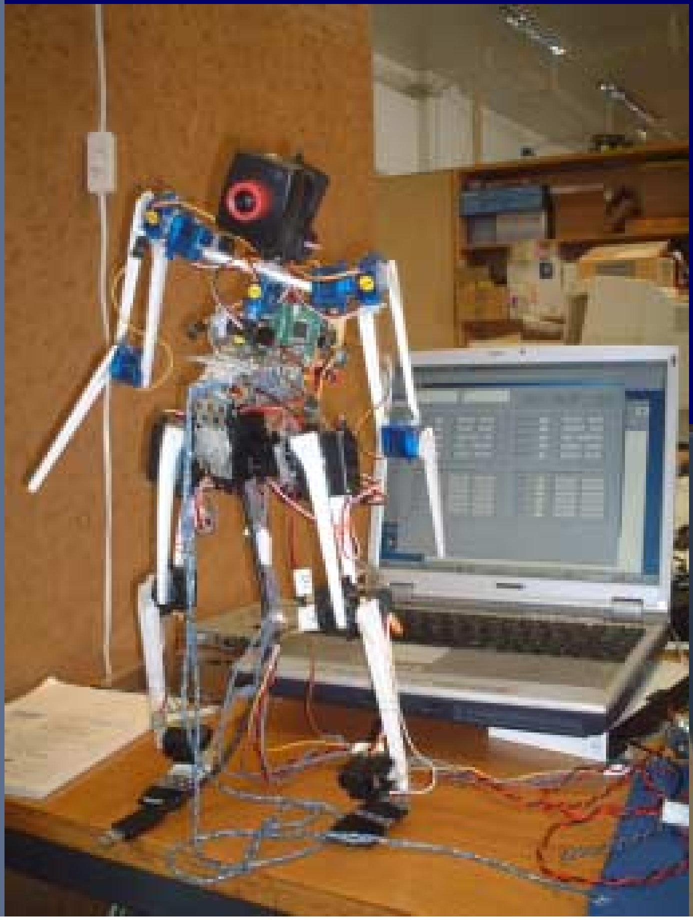
exploring ecological balance

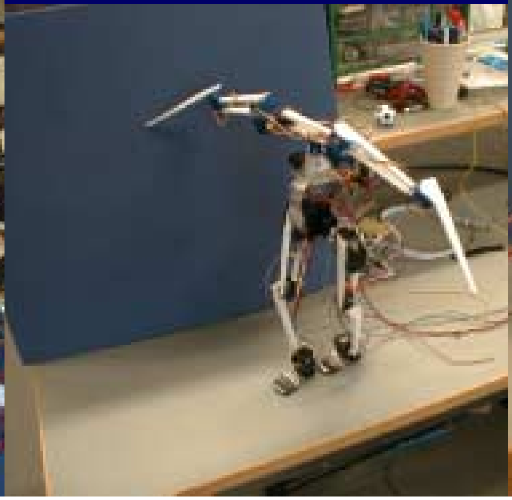
Design and construction:
Raja Dravid, Fumiya Iida
Max Lungarella, Chandana Paul

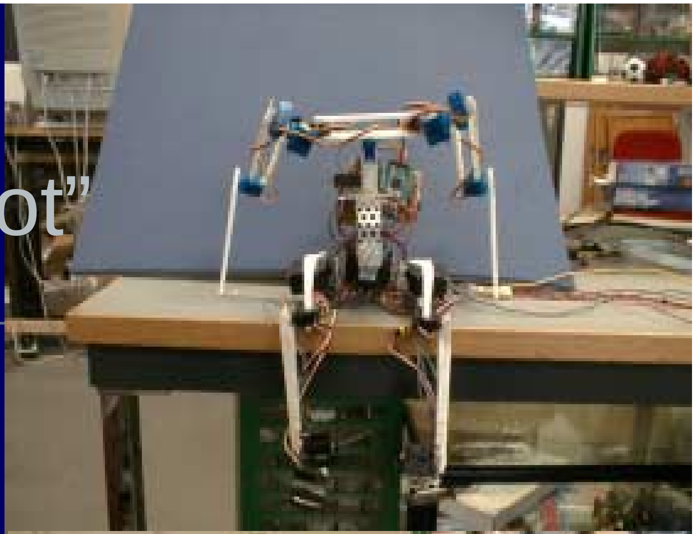
Der “Forkleg robot”

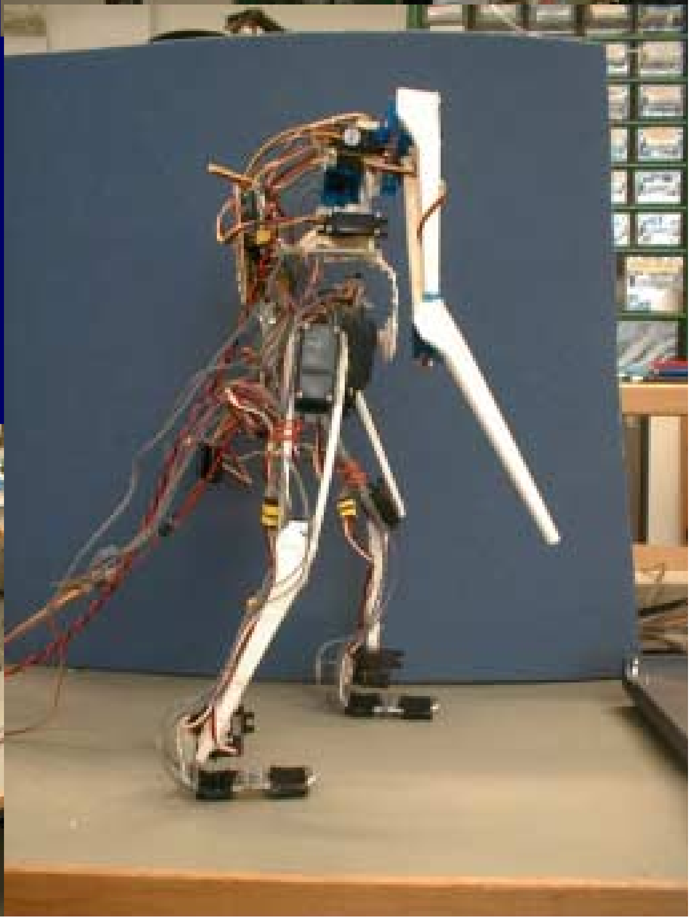
dynamics of biped walking

Design and construction: Hiroshi Yokoi and Kojiro Matsushita

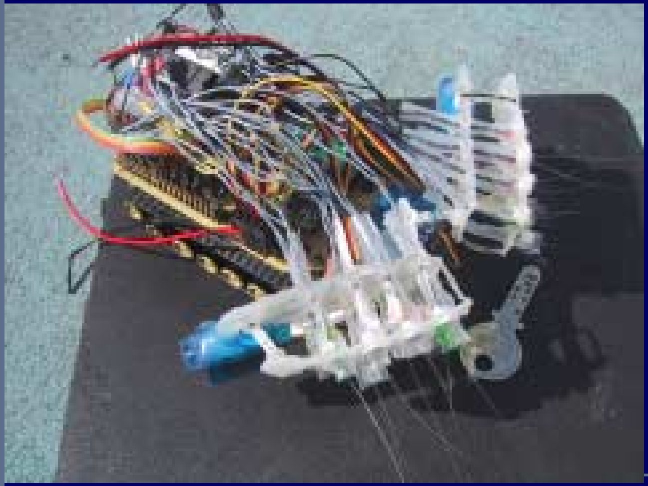








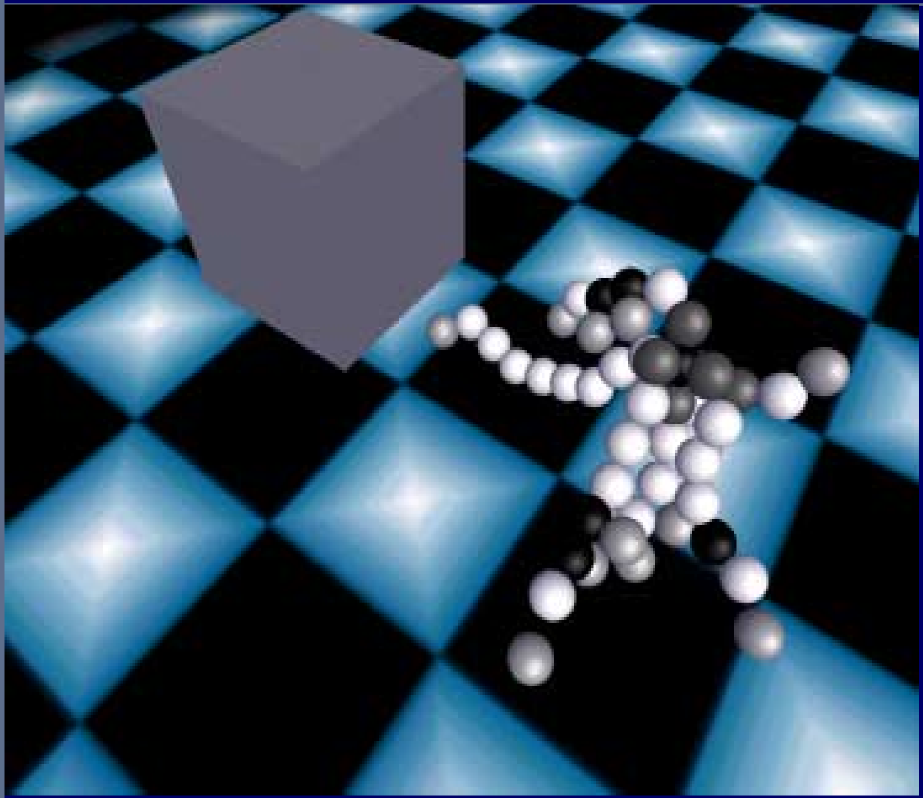
AMOUSE, the artificial mouse



Design and construction:
Verena Hafner, Miriam Fend and Hiroshi Yokoi

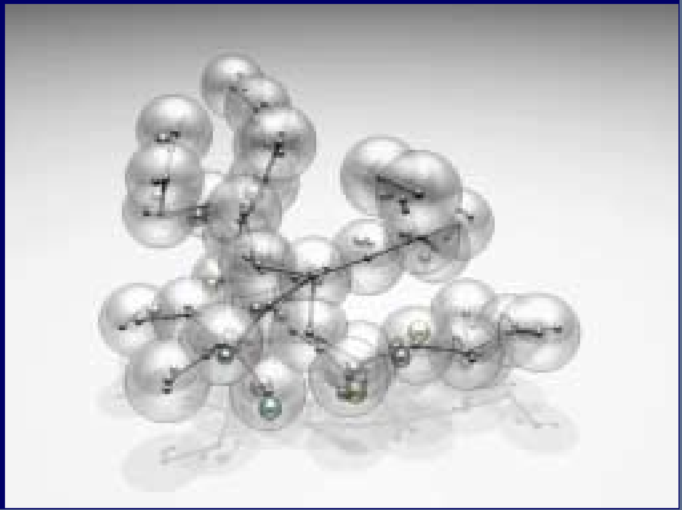
function of whisker systems in rodents

The “Block Pusher”



task distribtion between morphology, materials, and neural substrate

“life as it could be”



Design and programming:
Josh Bongard

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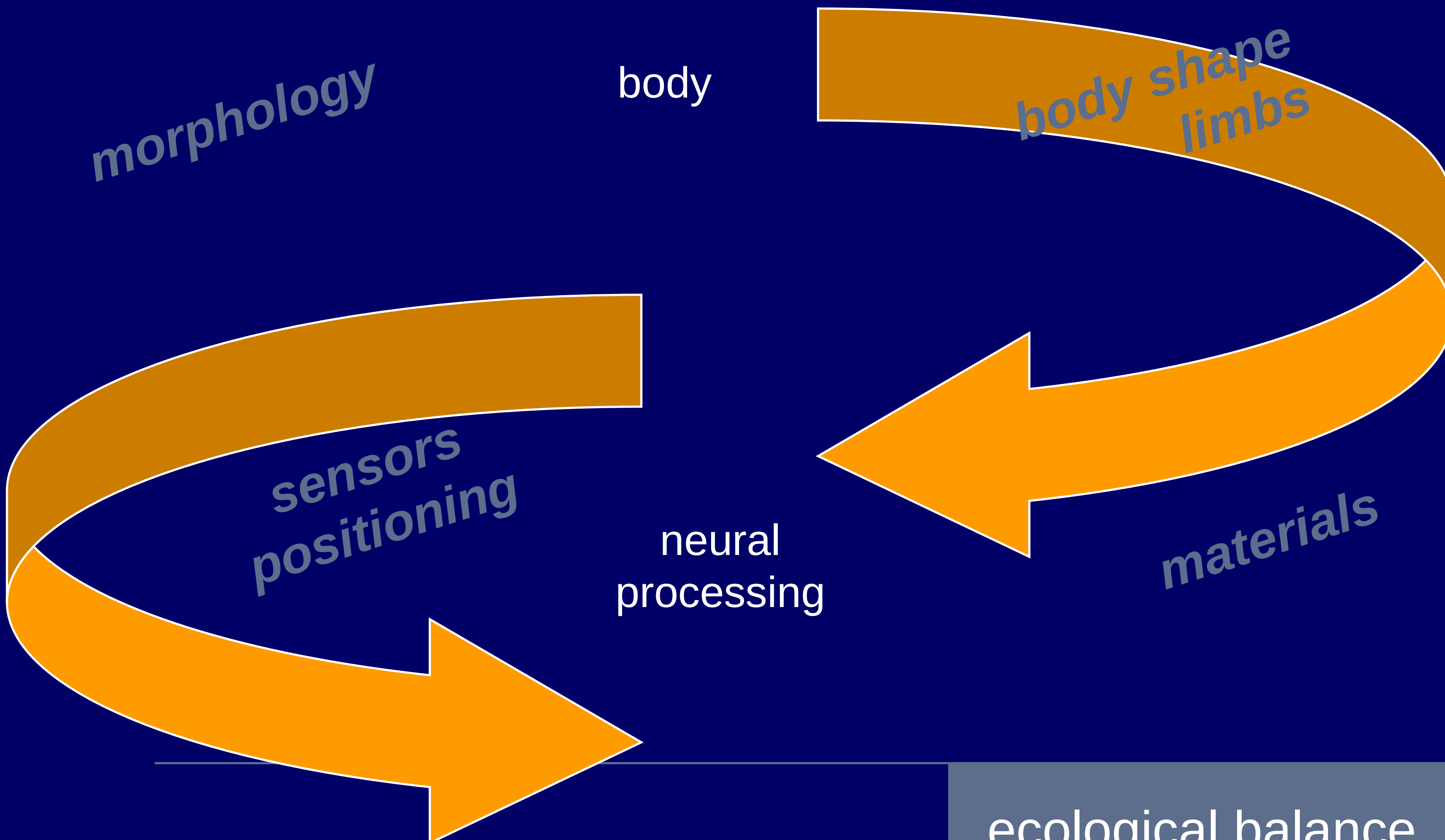
Embodiment

intelligence must have a body → trivial

non-trivial meaning →

Embodiment



ecological balance

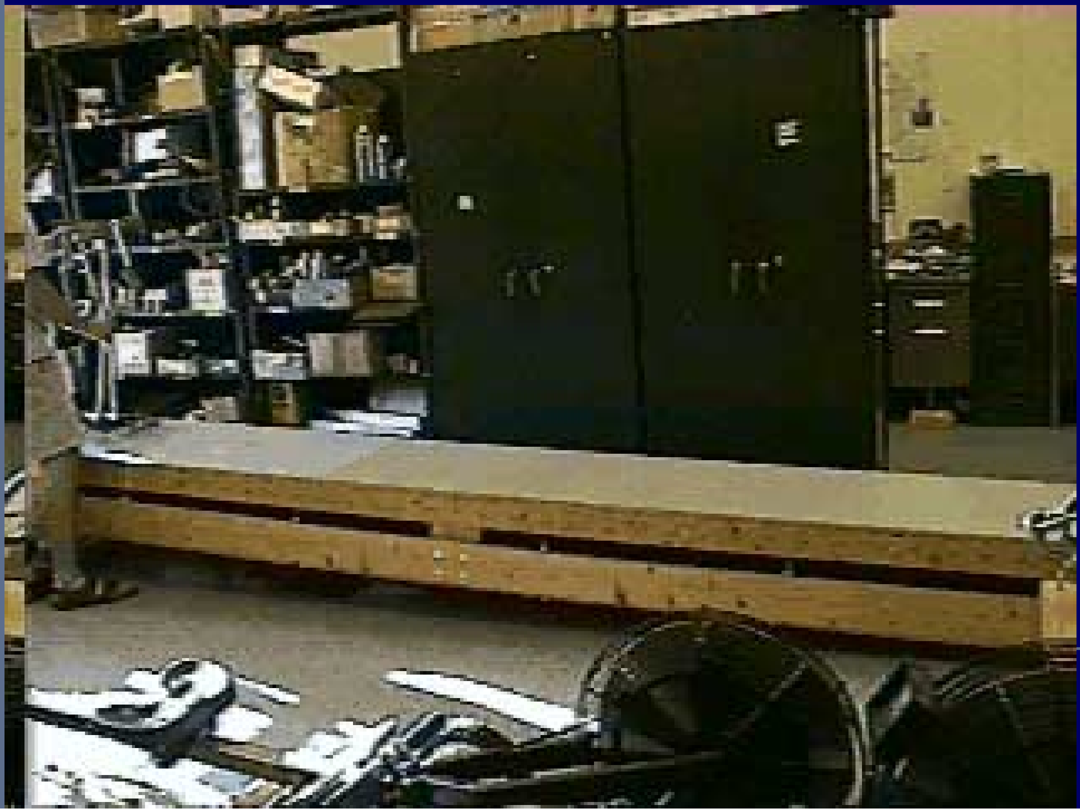
Morphology and motor system

Goal: natural walking

"Passive Dynamic Walker" – the brainless robot

walking without control

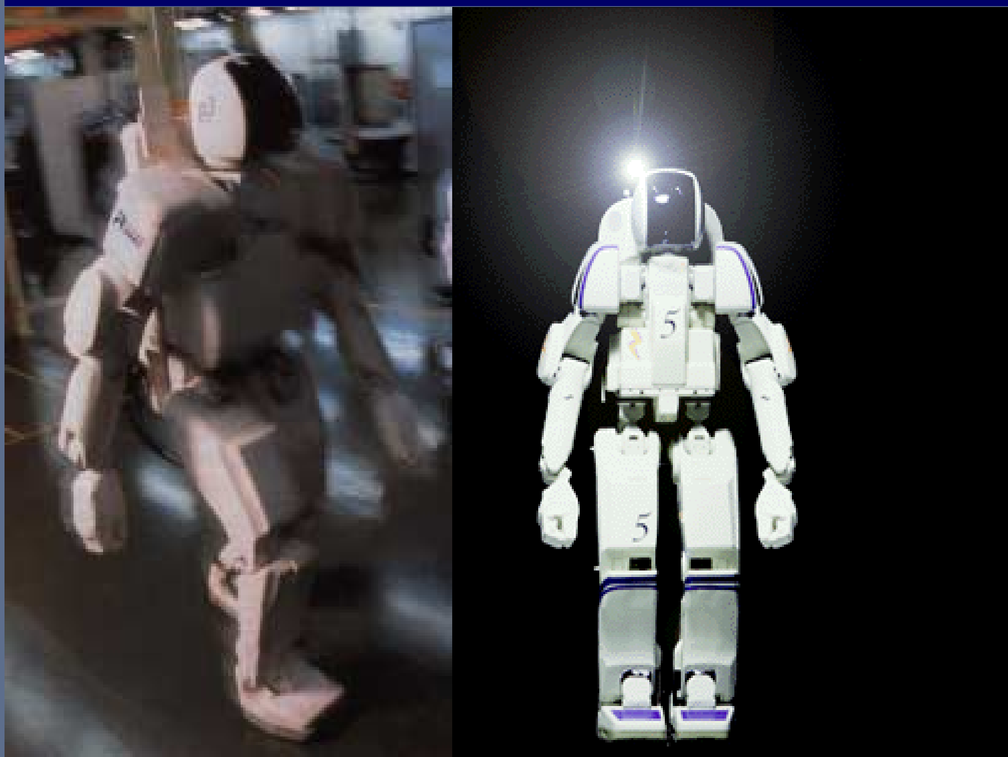
design and construction
Steve Collins, Cornell University



morphology:
- wide feet
- elastic heels
- counterswing of the arms
- properties of the feet

dynamically stable
statically unstable

Asimo (Honda) and H-7 (Univ. of Tokyo)



Asimo

H-7
design and construction
S. Kagami, Univ. of Tokyo

Conclusions from walking study

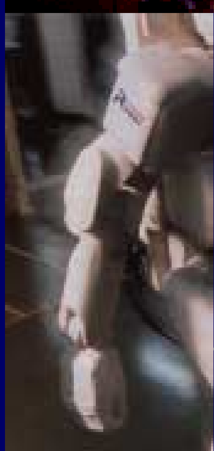
appropriate morphology and materials
exploitation of dynamics / physics
→ minimal control effort
→ energy-efficient walking
→ natural walking

and vice versa:

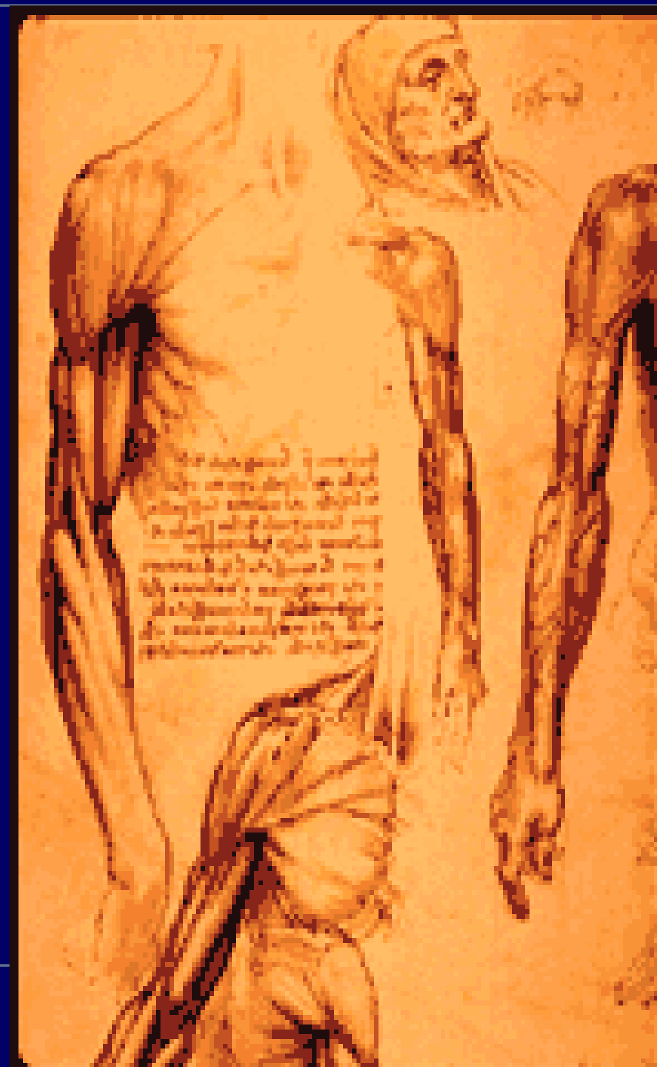
- hard materials
  no exploitation of dynamics
  → large effort for control

Humanoid robot epidemic

Control from materials



traditional robot arms:
- hard materials
- electrical motors



human hand-arm-shoulder system:
- elasticity
- stiffness
- damping

Properties of the muscle-tendon system

- grasping an object
- winding a spring
  → energy expenditure
- release
  → turning back without control
- exploited by the brain

"good control"
- decentralized -- little effort of the brain required
- "free" – exploitation of physical properties

Control from materials

- spring-like behavior
- stiffness and elasticity
- damping properties

("computational properties" of materials)

robots with artificial muscles
→ exploitation of the dynamics of the (artificial) muscle-tendon system

Robots with artificial muscles

The service robot ISAC

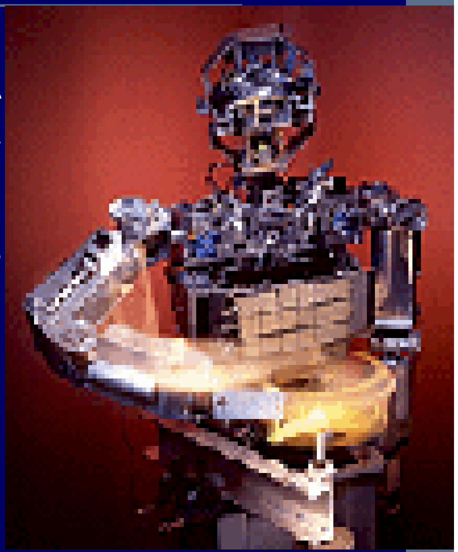
pneumatic actuators

by Alan Peters
Vanderbilt University

COG

series elastic actuators

by
Rodney Brooks
MIT AI Lab



artificial hand

pneumatic actuators

by Lee and Shimoyama
University of Tokyo

Humanoid robot

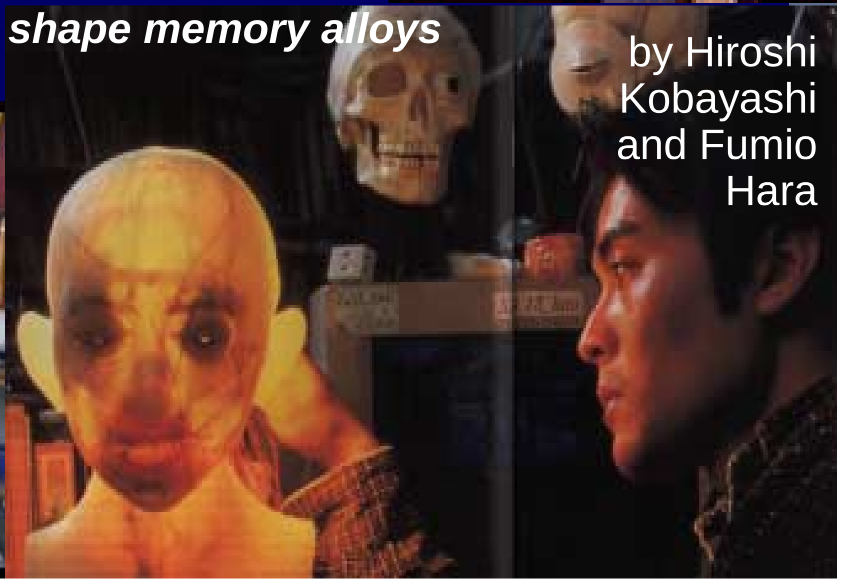
pneumatic actuators

by Rudolf Bannasch, TU Berlin

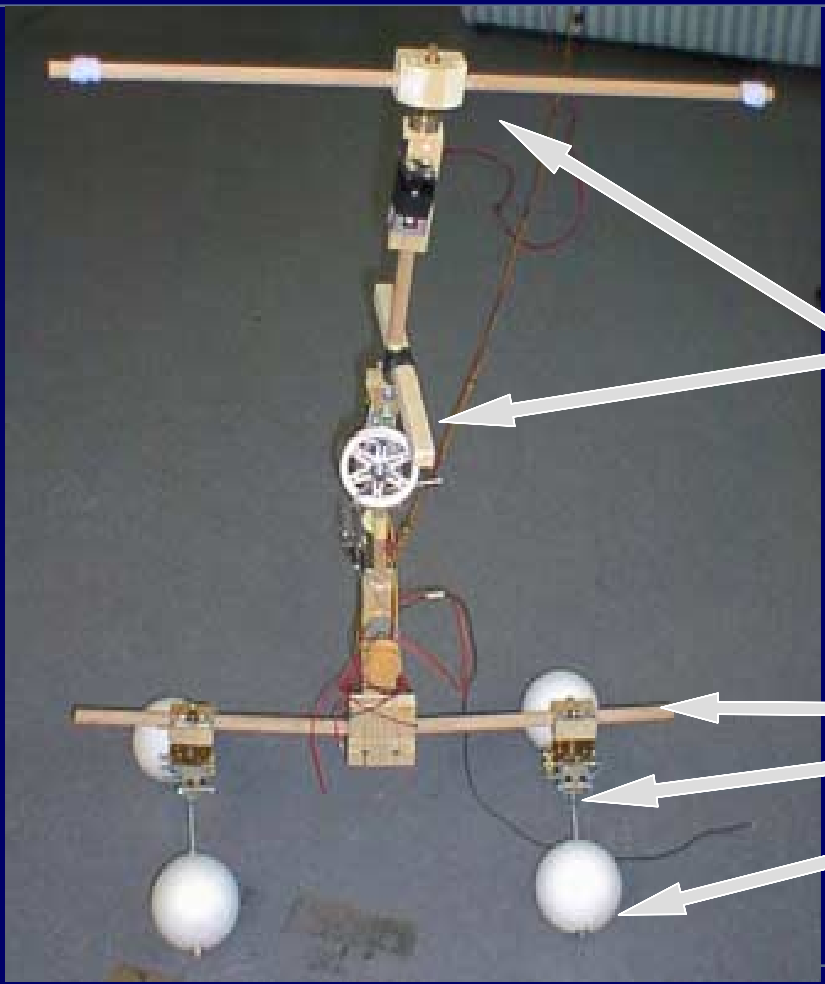
The Face Robot

shape memory alloys

by Hiroshi Kobayashi and Fumio Hara



The dancing robot “Stumpy”



virtually “brainless” (simple control)
two motors

joints

elastic materials

surface properties

Design and construction:
Raja Dravid, Fumiya Iida, Max Lungarella, Chandana Paul

The dancing robot "Stumpy"

“Stumpy”: Summary

- Exploitation of dynamics
  - spring-like properties
  - natural elasticity and damping of materials
  - surface properties of the feet
- many behaviors with two joints
- self-stabilization

good control through morphology and materials

Principle of “ecological balance”

balance / task distribution between

- morphology
- materials
- neuronal processing (nervous system)
- environment (scaffolding)

Interest of locomotion and orientation for cognitive robotics

- grounding of cognition in sensory-motor patterns
- “body schema”
- spatial abilities essential
- body as basis for metaphors (Lakoff, Johnson)

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Categorization in the real world: fundamental to cognition

categorization:

- ability to make distinctions in real world
- fundamental to any intelligent system
- closely intertwined with perception

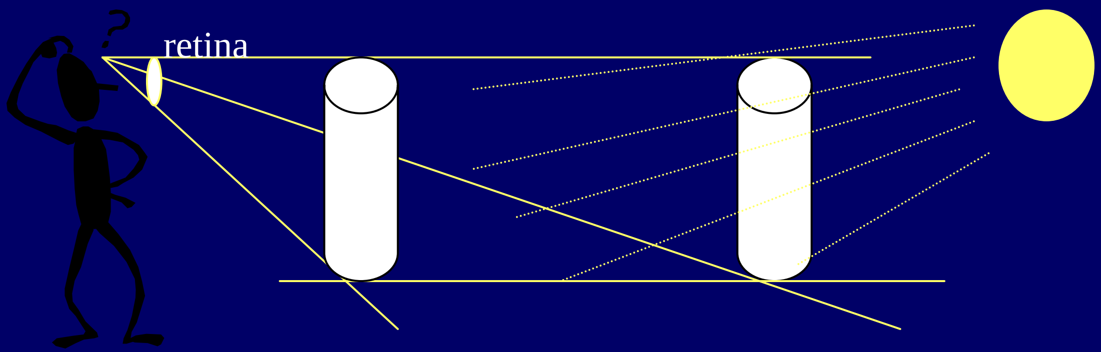
careful!

- frame-of-reference (behavior vs. internal representation)

Perception in the real world

Hard problem in real world:

- continuously changing sensory stimulation
- sensory stimulation varies greatly depending on distance, orientation and lighting conditions



Perception in the real world

Hard problem in real world:

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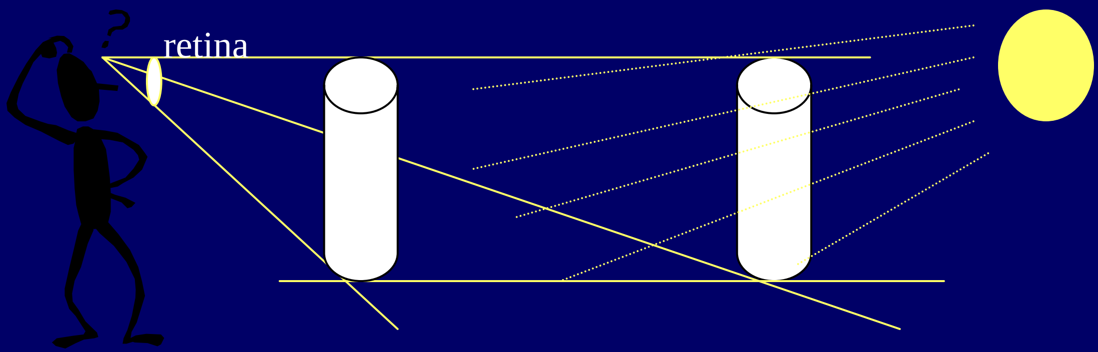
Idea 1:
sensory-motor coordination



The principle of sensory-motor coordination

intelligent behavior: sensory-motor coordination/ coupling

leads to:

- structuring of sensory stimulation
- generation of correlations in sensory data (“good data”)

examples:

- foveation
- reaching, grasping
- perception, categorization

inspiration
— John Dewey, 1896 (!)
— Edelman and co-workers
— developmental studies; Thelen and Smith

Perception in the real world

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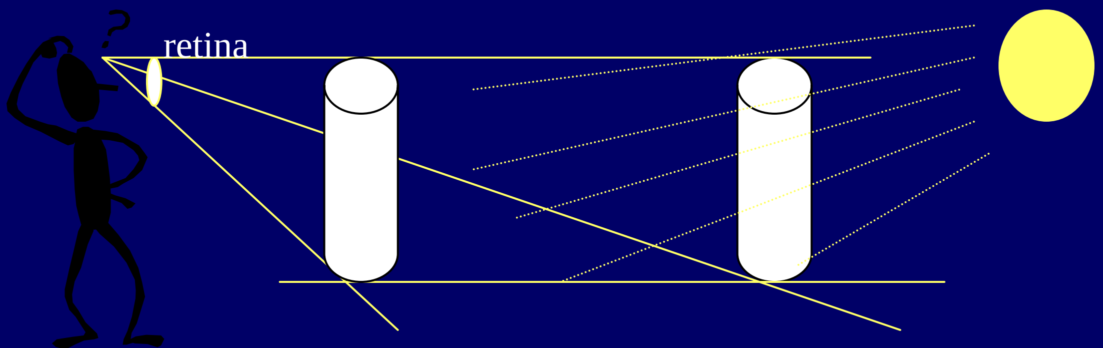


Sensory-motor coordination:

- serves to structure sensory input
- provides correlations in different sensory channels

--> enables learning and concept formation

Categorization as sensory-motor coordination

“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“.

(John Dewey, 1896)

Complexity reduction through sensory-motor coordination

Complexity reduction through sensory-motor coordination

it can be shown: sensory-motor coordination leads to

- dimensionality reduction (sensory data)
- induction of correlations in different sensory channels

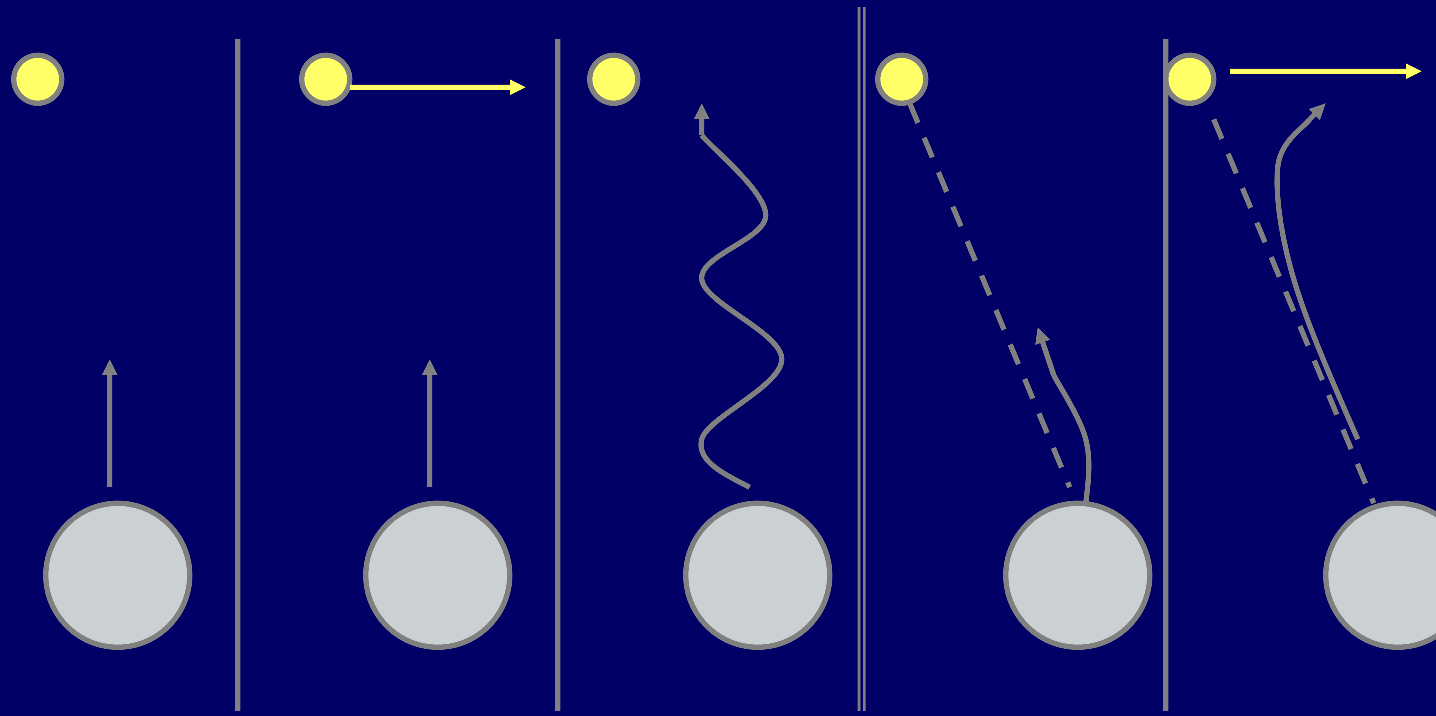
$\rightarrow$ *information theoretic reason for sensory-motor coordination*

$\rightarrow$ *basis for learning*

(experiments by Max Lungarella, Gabriel Gomez, and Rene te Boekhorst Dimensionality reduction through sensory-motor coordination)

Experiments – Idea

comparing not sensory-motor coordinated behavior with sensory-motor coordinated behavior



not sensory-motor coordinated   sensory-motor coordinated

Perception in the real world

Hard problem in real world:

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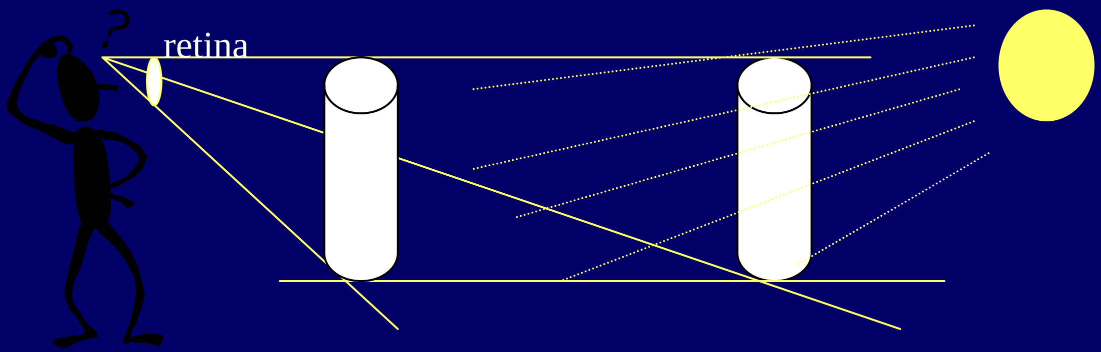


Idea 1:
sensory-motor coordination

Idea 2:
development

„Developmental robotics“

- robot interacting with the environment over extended periods of time → individual history
- advantage of robots: record internal and sensory-motor states → analyze time series
- goals:
  - learning categorization/perception
  - „body schema“ / „body self-image“
  - „sense of presence“

→ *robots as cognitive tools*

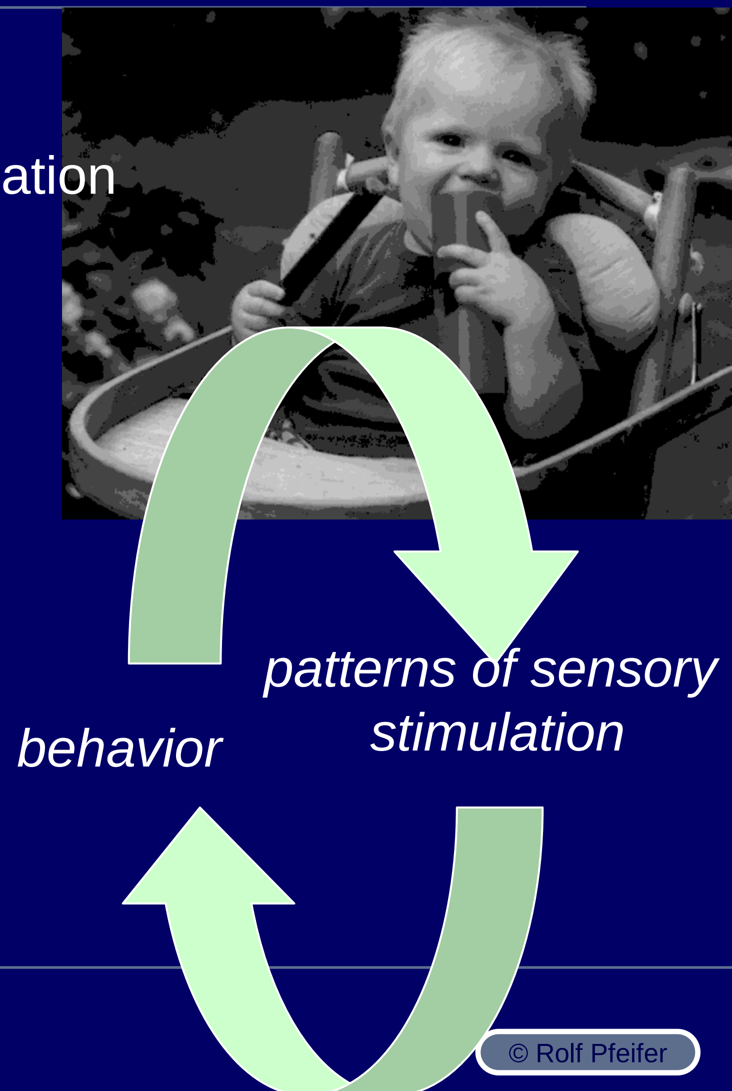
Facilitation through morphology and materials

- constraining movements
  - generating rich sensory stimulation
  - inducing correlations

$\rightarrow$ enables cross-modal associations

example:

random neural stimulation



Bootstrapping „high-level cognition“

→ sensory-motor coordination

→ cross-modal associations

→ basic categorization behavior

→ gradual decoupling from sensory-motor level

→ same neural structures involved (mirror neurons)

→ new types of mechanisms?

Technological requirements

- complex sensory and motor systems
- bendable high-density touch sensors
- artificial muscles
- soft materials

Currently in place/in progress:

- binocular active vision system (Gabriel Gomez, Hiroshi Yokoi)
- robot arm (Mitsubishi)
- experiments with neumatic actuators (Raja Dravid)
- experiments with spring-like muscle-tendon systems (Hiroshi Yokoi)

„Developmental robotics“: Research directions

- sensory-motor coordination (foveation, visual tracking, grasping) (Brooks, Sandini, Metta, Schaal, Pfeifer)
- social interaction and communication (Breazeal, Kuniyoshi, Steels)
- learning by imitation (Kuniyoshi, Schaal, Dautenhahn, Berthouze, Gaussier, Sandini, Metta)
- reinforcement learning (Asada)

also: robots learning by imitating humans (Schaal, Metta)

„Developmental robotics“: Activities

- EDEC-workshop: Emergence and Development of Embodied Cognition
- DECO-workshop: Development of Embodied Cognition
- Epigenetic robotics workshop
- Cognitive robotics workshop (AAAI) (careful!)

Contents

Artificial evolution and morphogenesis

not only “life as it is”

but “life as it could be” (Chris Langton)

Implication of embodiment:

Co-evolution of morphology and neural control

exploring “ecological balanced”

Contents

- Some terminology
- The synthetic methodology
- Embodiment – illustrations
- A hard problem in cognitive science: perception in the real world
- The evolution of intelligence: morphogenesis
- The „Zen of robot programming“

The "Zen of robot programming"

- relax, the real world is there
- it's your friend, not your enemy — exploit
- not everything needs to be controlled — physics is for free

Rodney Brooks, MIT Artificial Intelligence Laboratory

Summary

- cognitive robotics — robots as cognitive tools
- embodiment — implications: ecological balance
- categorization and perception: sensory-motor coordination and developmental robotics

Related projects

- Explorations in embodied cognition (Swiss National Science Foundation)
  Goals: similar to ADAPT
- AMOUSE – Artificial Mouse (EU)
  Goals: multi-modal exploitation (whisker system, visual system)

Papers

- te Boekhorst, R., Lungarella, M., and Pfeifer, R. (submitted). Dimensionality reduction through sensory-motor coordination.
- Lungarella, M., and Berthouze, L. (2002). Adaptivity through physical immaturity.
- Lungarella, M., and Berthouze, L. (2002). Adaptivity via alternate freeing and freezing of degrees of freedom.
- Lungarella, M., and Pfeifer, R. (2002). Robots as cognitive tools: information theoretic analysis of sensory-motor data. *Humanoid Robotics Conference.*
- Eggenberger, P., Gomez, G., and Pfeifer, R. (2002). Evolving the morphology of a neural network for controlling a foveating retina - and its test on a real robot.
- Pfeifer, R. (several). On the role of morphology and materials in the emergence of cognition.

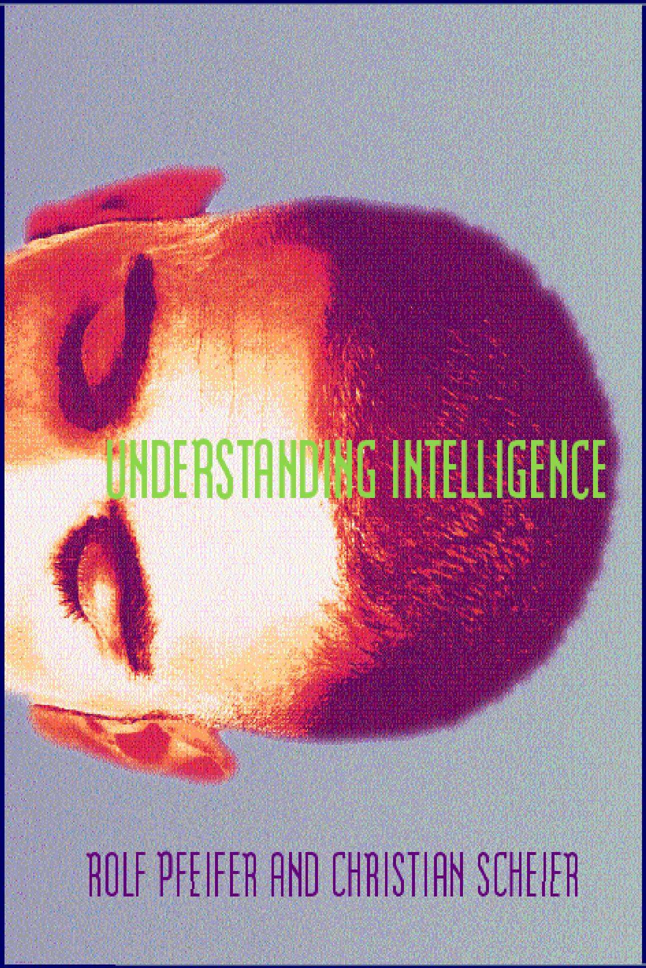
Recruiting: PhD students for ADAPT project

Want to know more?

Visit us in Zurich!

Artificial Intelligence Laboratory
Department of Information Technology

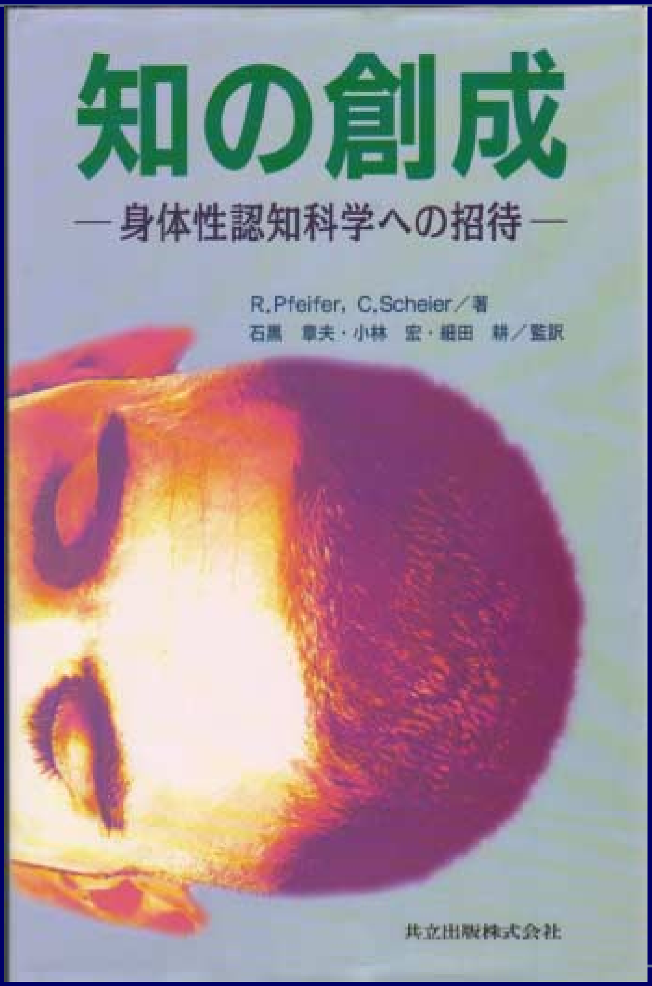
or read:



MIT Press
November 1999
(2nd printing 2000, paperback edition)

"*Understanding Intelligence* is a comprehensive and highly readable introduction to embodied cognitive science."
– **Arthur B. Markman**, *Science*

or in Japanese



translated by: Koh Hosoda. Akio Ishiguro and Hiroshi Kobayashi
with a preface by: Minoru Asada

Comparison

Felix, Regula and Exuperantius

the three saints of the city of Zurich

Grossmünster

Legend??

→ *"passive dynamic walkers"*