The ShanghAI Lectures

人工智能 上海授课

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

Today from the University of Zurich
Switzerland

3 November 2011

欢迎您参与

“来自上海的人工智能系列讲座”

Today's schedule

09.00 - 09.45 Design principles for intelligent systems, Part II

09.45 - 10.00 Development: From locomotion to cognition

10.00 Break

10.05 - 10.30 Guest speaker: Prof. Claude Siegenthaler
"In search of embodied intelligence of markets"

10.35 - 11.00 Guest speaker: Prof. Fabio Bonsignorio
"Embodying disruptive innovation in embodied cognitive systems"

Lecture 5

Design principles for intelligent systems: Part II

3 November 2011

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Today's topics

- short recap
- principle of "cheap design"
- principle of "ecological balance"
- optic flow and its uses
- additional illustrations

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Properties of embodied agents

- subject to the laws of physics
- generation of sensory stimulation through interaction with real world
- affect environment through behavior
- complex dynamical systems
- perform morphological computation

Design principles for intelligent systems

Principle 1: Three-constituents principle

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

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Principle of "cheap design"

The principle of "cheap design" states that if agents are built to exploit the properties of their ecological niche and the characteristics of the interaction with the environment, their design and construction will be much easier, or "cheaper".

examples:

- Swiss robots

- passive dynamic walker, Puppy

- animals, humans (exploitation of passive dynamics)

- Greenpeace

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complementary principle: redundancy (see lecture 4).
There is a trade-off: the more you exploit the ecological niche and the dynamics of the interaction the more you depend on it (see Swiss robots: remove walls around arena, size of Styrofoam cubes, morphology of robot, etc. and it ceases to function).

Metaphorically, the principle of "cheap design" can be transferred to social institutions and business. Greenpeace has a very small marketing budget, but is known to everyone on Earth. They are exploiting existing channels of communication, namely the standard mass media by staging spectacular news-worthy events.

The value principle

The value principle states that intelligent agents are equipped with a value system which constitutes a basic set of assumptions about what is good for the agent.

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On the one hand the value principle is very important because it tells us what is good for the agent. Values typically don't change over the life time of the individual. There is also a frame-of-reference issue. For example, if we, as designers, think that it is a good idea to equip the robots with a certain learning rule (e.g. Hebbian learning which is designed to pick up correlations, see lecture 6), then this constitutes value for the robot (in the eyes of the designer rather than the robot which simply applies the rule). The value principle is also very vague and there is no consensus in the literature of what values should be applied. This is particularly important for development: Why should the agent start engaging in ever more complex activities, for example? (see also, How the body …, pp. 137).

Recall from last week: Principle of "ecological balance"

balance in complexity

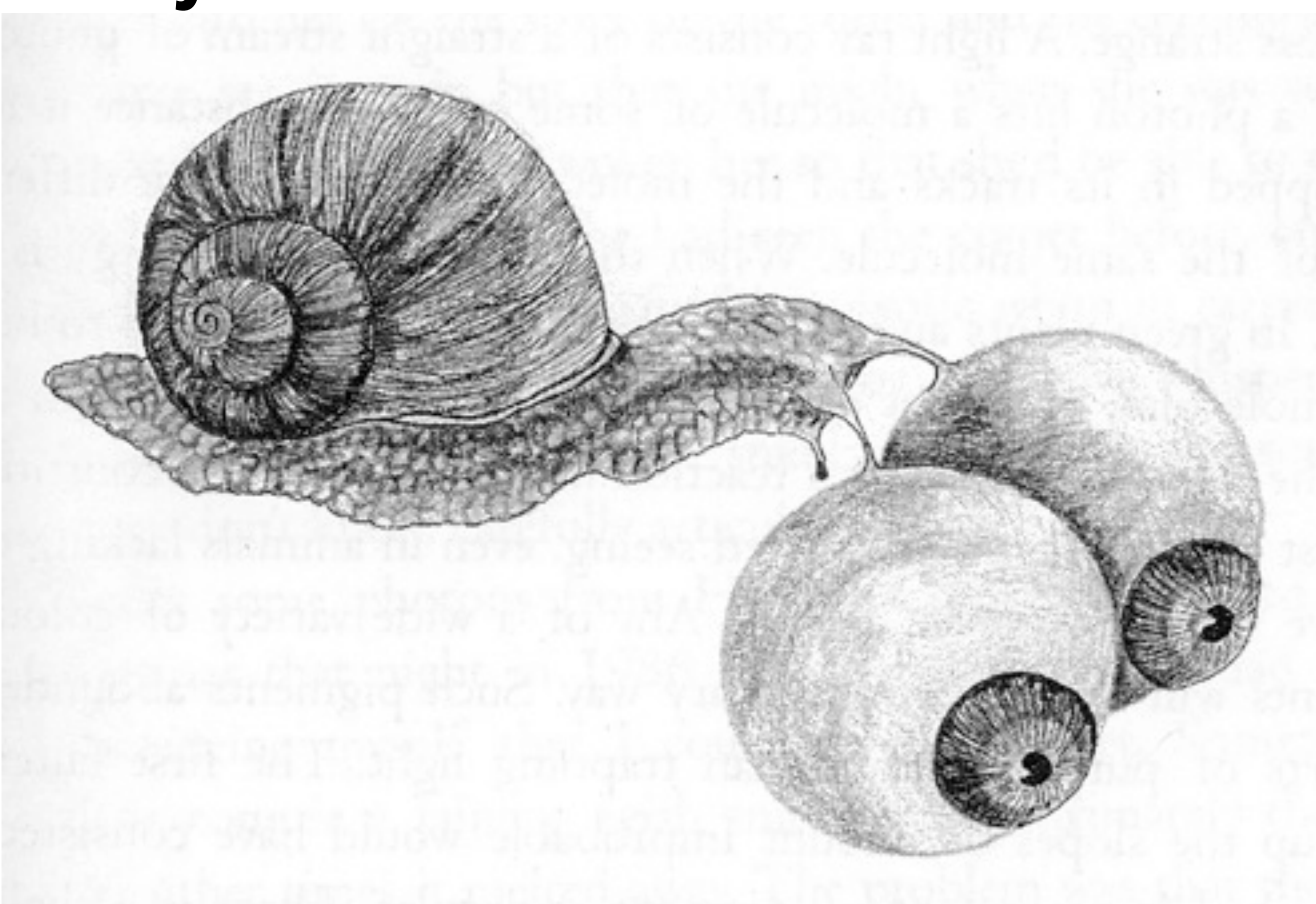
given task environment: match in complexity of sensory, motor, and neural system

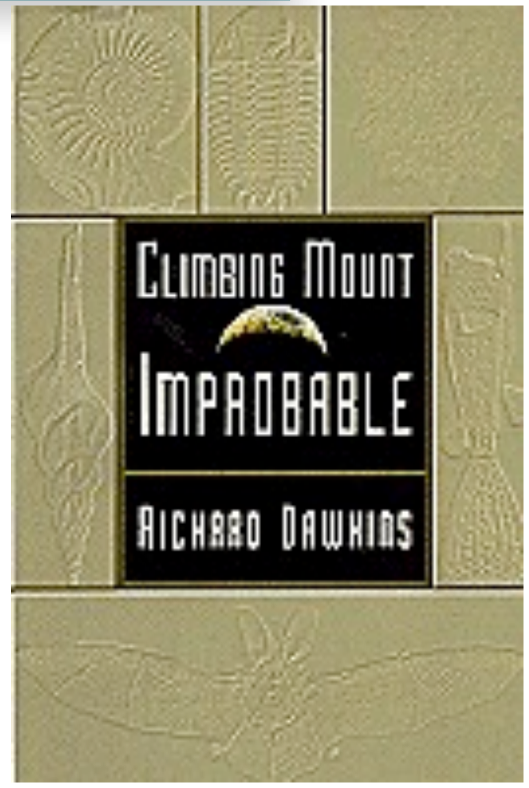
balance / task distribution

brain (control), morphology, materials, and interaction with environment

Recall: Richard Dawkins's snail with giant eyes

ecologically unbalanced system





Author of:
"The selfish gene" and
"The blind watchmaker"

What are such huge eyes good for if the snail cannot move quickly? It's only useless additional weight.

Task distribution

between brain, morphology, materials, and environment

extreme case: Passive Dynamic Walker

Puppy, Stumpy

Animals, humans: dynamic change of muscle stiffness

Loosely swinging arm (see below)

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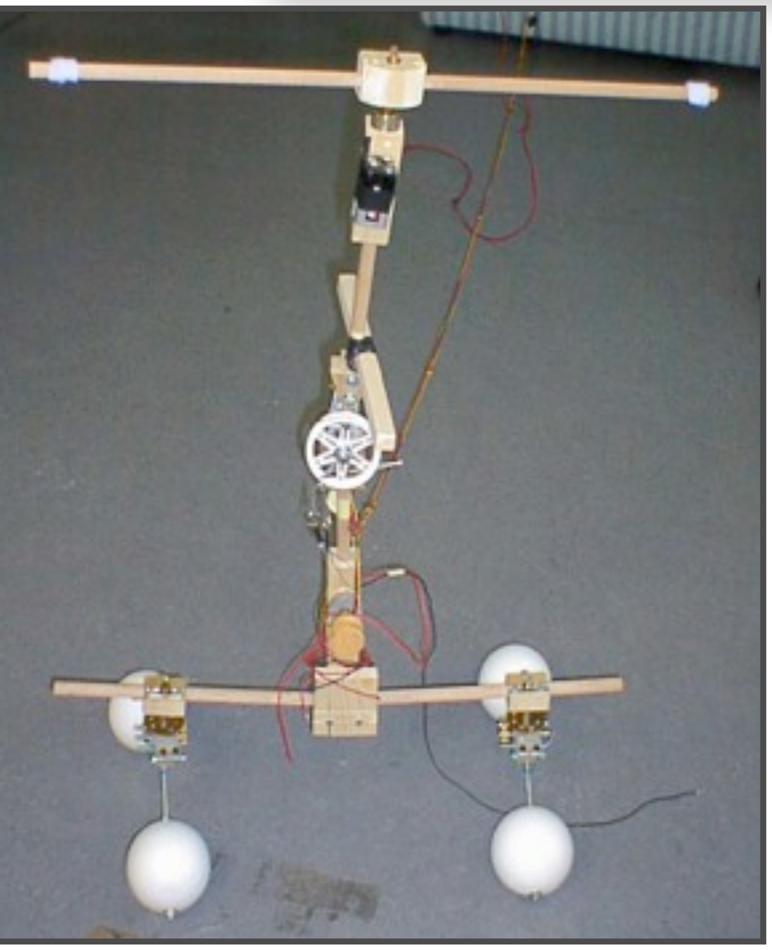
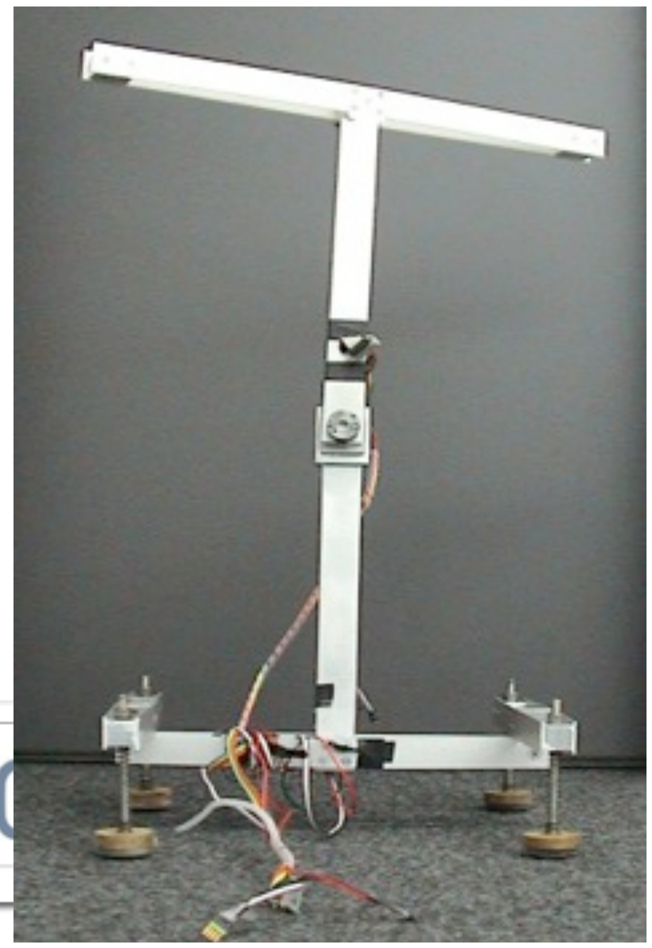
Various functions, in movement and locomotion can at least partially be outsourced to morphological and material characteristics of the system; there is a kind of "trading space". Examples that we have seen are "Puppy" and the passive dynamic walker. Next, we will look at morphological computation in visual systems, in particular insect eyes.

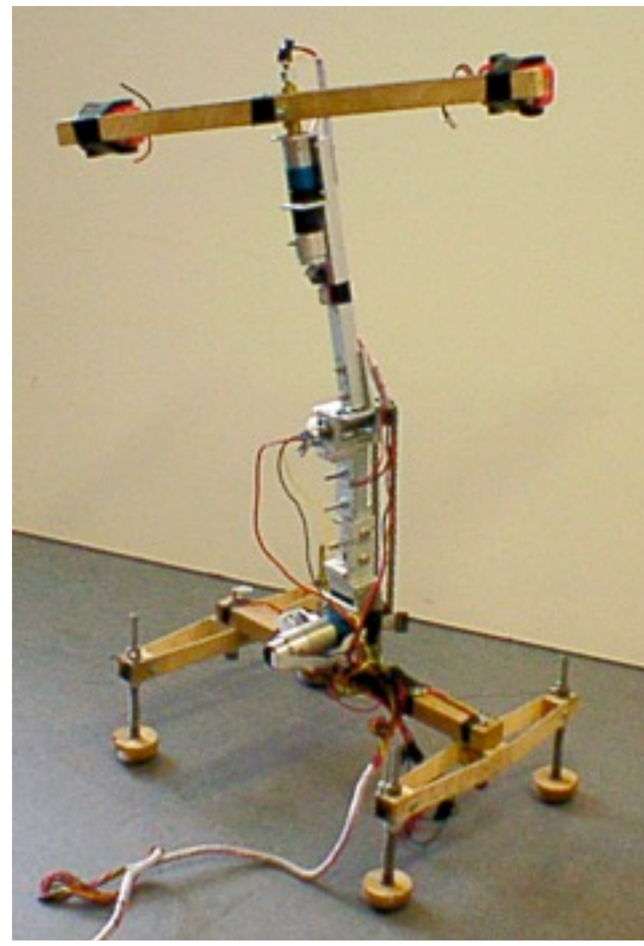
"Stumpy": task distribution



almost brainless: 2 actuated joints
springy materials
surface properties of feet

Design and construction: **Raja Dravid, Chandana Paul, Fumiya Iida**





self-stabilization

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"Stumpy" only has 2 DOFs of actuation, hip and shoulder. By varying the amplitude, frequency, and phase (between the two joints), roughly twenty different gaits can be achieved.

The dancing robot "Stumpy"

Collaboration with Louis-Philippe Demers, Nanyang Technological University, Singapore

Movie:
Dynamic Devices and AILab, Zurich

Raja Dravid
Max Lungarella

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Choreography with 12 Stumpies (by Raja Dravid and Max Lungarella)

Task distribution

between brain, morphology, materials, and environment

extreme case: Passive Dynamic Walker

Puppy, Stumpy —> “choreography”

Animals, humans: dynamic change of muscle stiffness

Loosely swinging arm (see below)

Optic flow and morphological computation

- **amazing navigational skills**
- **fast obstacle avoidance**
- **learning**

photos courtesy
Rüdiger Wehner

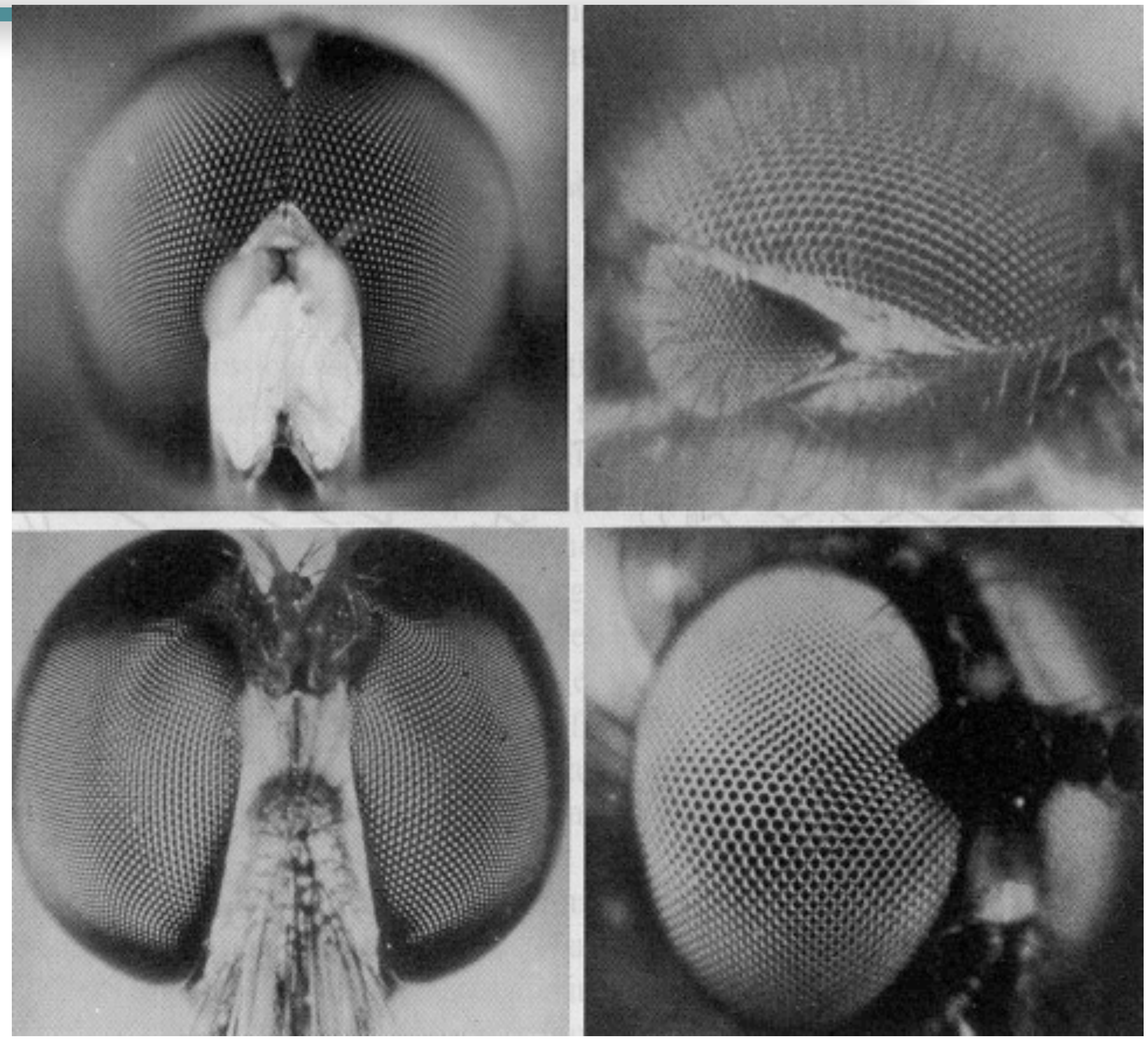
photo
P.O. Gustavson

Ecological niche of the desert ant Cataglyphis; salt pan near Maharès in Southern Tunisia. These ants leave the nest around noon (when it's really hot) in a zig-zag line, and when they found some food they move back to the nest in an almost straight line. This ability is achieved by maintaining a "home vector", a vector that always points back in the direction of the nest and its length is proportional to the distance from the nest. At each step, this "home vector" is updated. In order to do this, the ant needs two measurements: direction and distance. Direction is achieved by a special kind of compass based on perceiving polarization patterns in the sky. Distance can be determined either by counting steps or via optic flow (see below).

Different morphologies of insect eyes

housefly

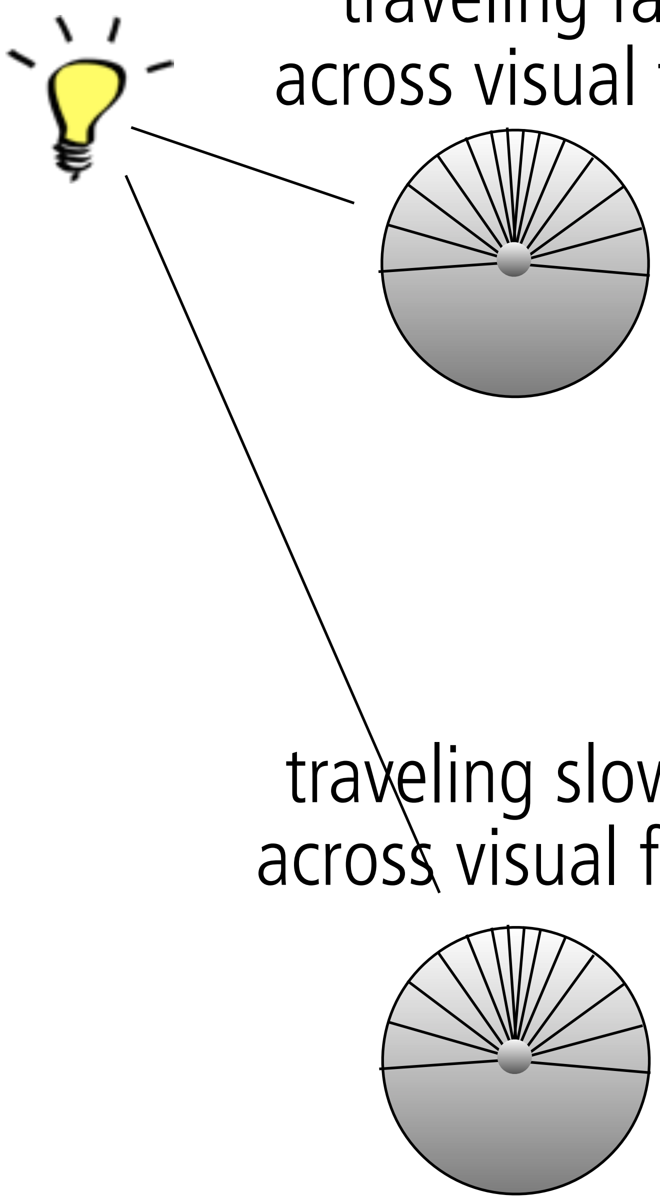
large variation of shapes



honey bee

The arrangement of the facets or ommatidia in the compound eye of insects looks very homogeneous, but in fact it isn't. Also, depending on the location in the eye, they have different functionalities.

Motion parallax and sensor morphology

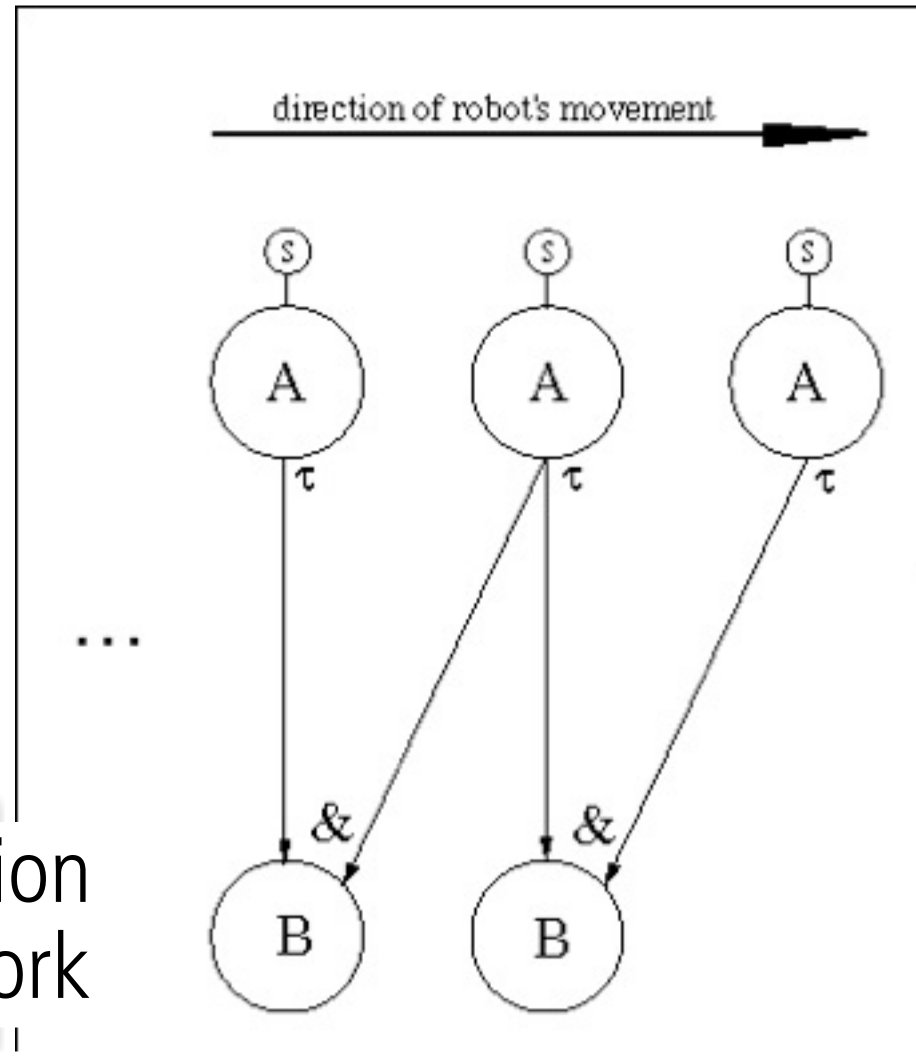


lateral optic flow ~
angular velocity

non-homogeneous arrangement of facets: higher density in front

"pre-processing" through physical arrangement of facets: compensation of motion parallax

morphological computation



very simple motion
detector network

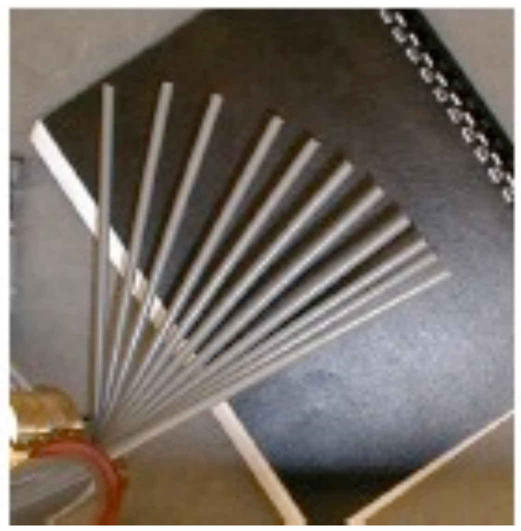
Non-homogenious arrangement of facets (ommatidia) --> compensates motion parallax.

Adaptive behavior through morphology change

"Eyebot"

Video "Eyebot"

output from three different runs



Design and construction:
Lukas Lichtensteiger and Peter Eggenberger,
AI Lab, UZH

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The "facets" which are tubes with a light-sensitive cell at the end, can be moved individually by electrical motors. The task of the robot was to maintain a fixed lateral distance to a light source. An evolutionary algorithm (see lecture 6) was run that modified the angular positions of the "facets". The "brain" of the robot, i.e. the controller in the form of a neural network was not changed; the robot had to solve the problem by changing its morphology. If the robot managed to solve the task, nothing was changed, if not, the angular positions of the "facets" were changed ("mutation"). Because of motion parallax, this is a hard problem. The output from three different runs shows that the resulting arrangements are all non-homogeneous, with densities higher in the front.

Motion parallax and sensor morphology: summary

- **must know embedding of "brain" (neural ciruit) in physical organism**
- **morphology (physical arrangement of facets): part of "computation" (pre-processing)**
- **fast, "free"**

→ morphological computation

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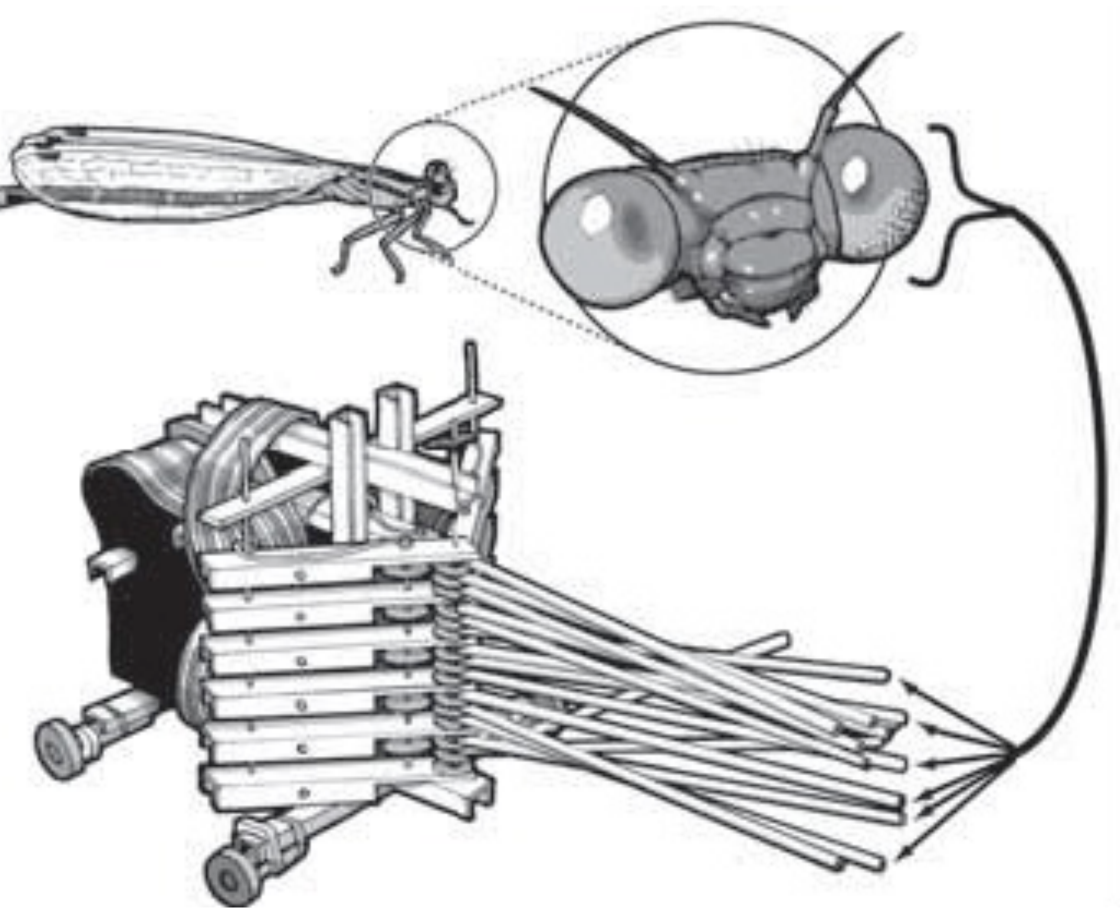
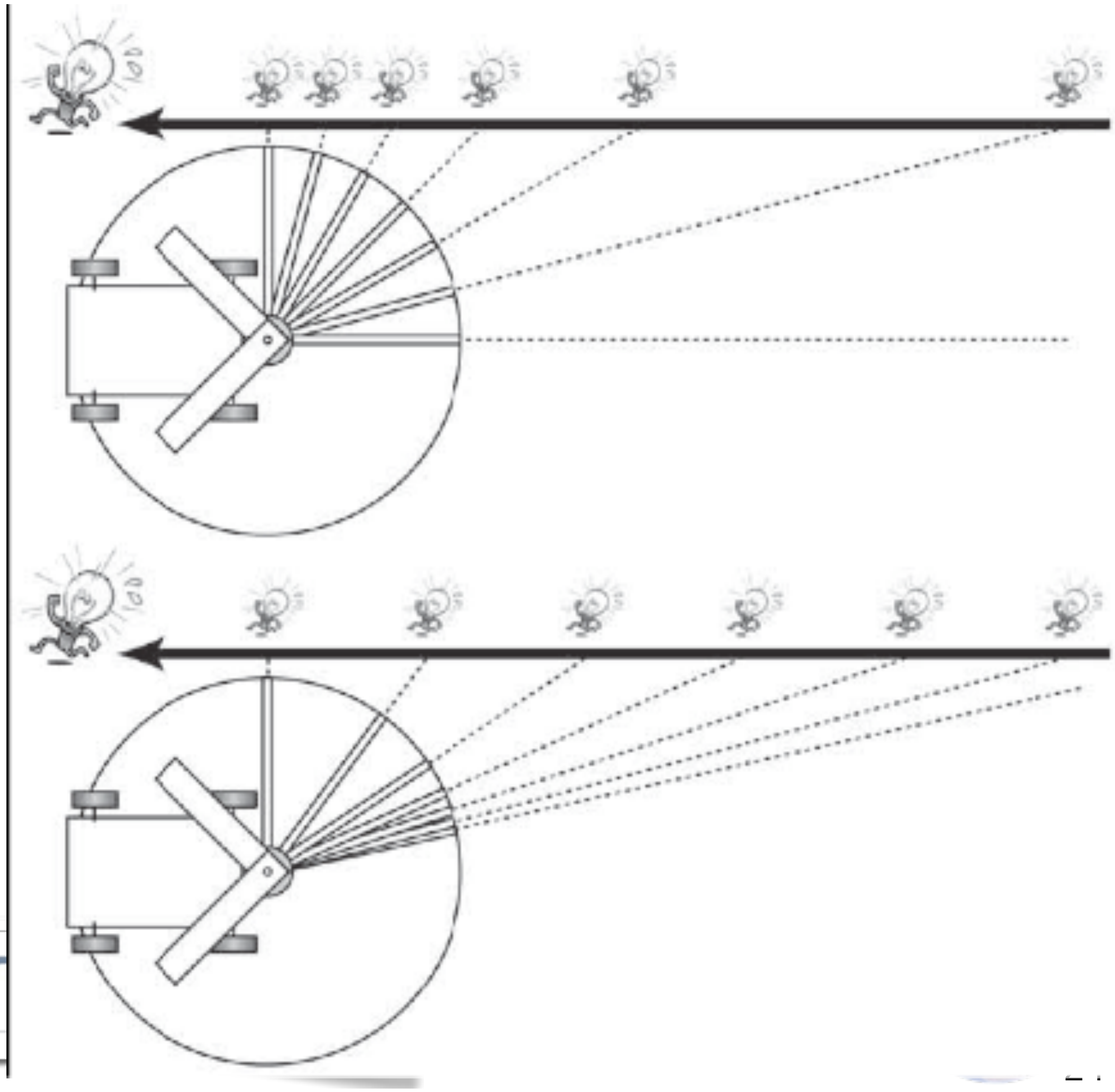
It can also be shown that there is a dependence of learning speed on morphology (because the environment is sampled differently; described in Lukas Lichtensteiger's PhD thesis, a former PhD student of the AI Lab in Zurich)

The “Eyebot” and motion parallax

read details in:
“How the body…” p. 131

Cartoons by
Shun Iwasawa





Uses of optic flow

- obstacle avoidance
- visual odometry (measuring distance)
- centering
- saliency detection
- landing

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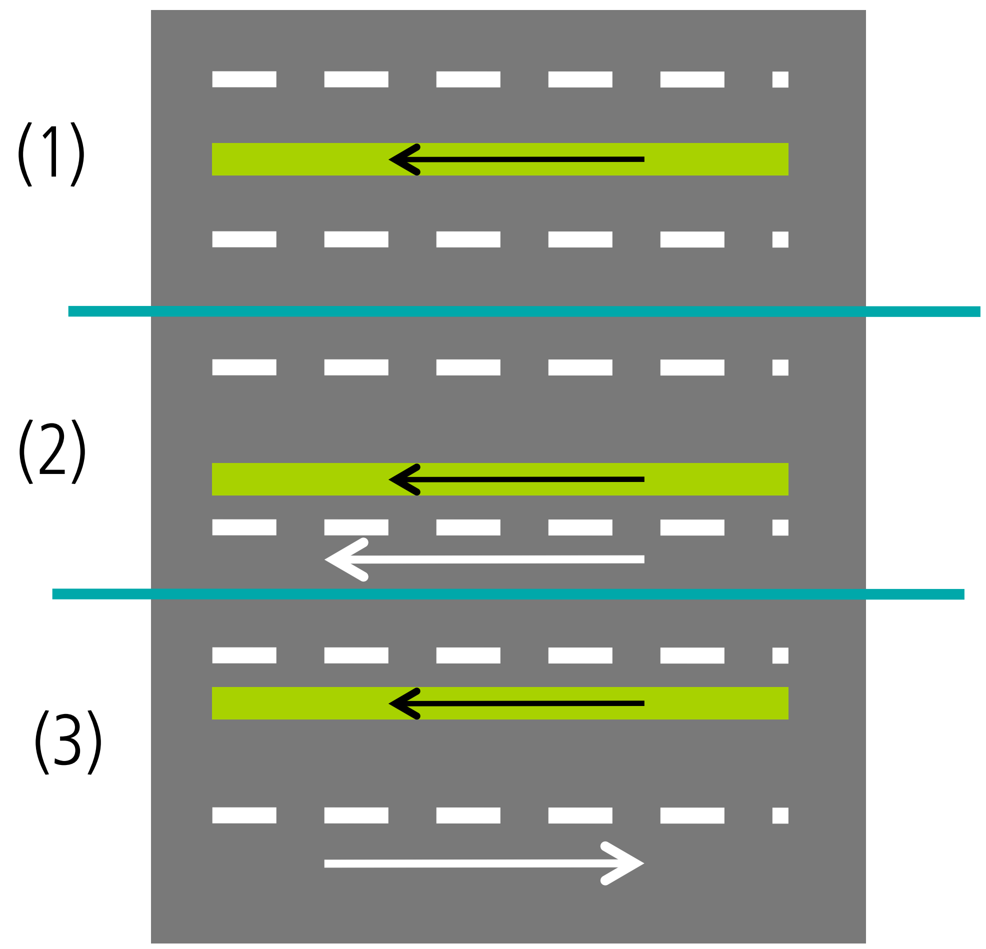
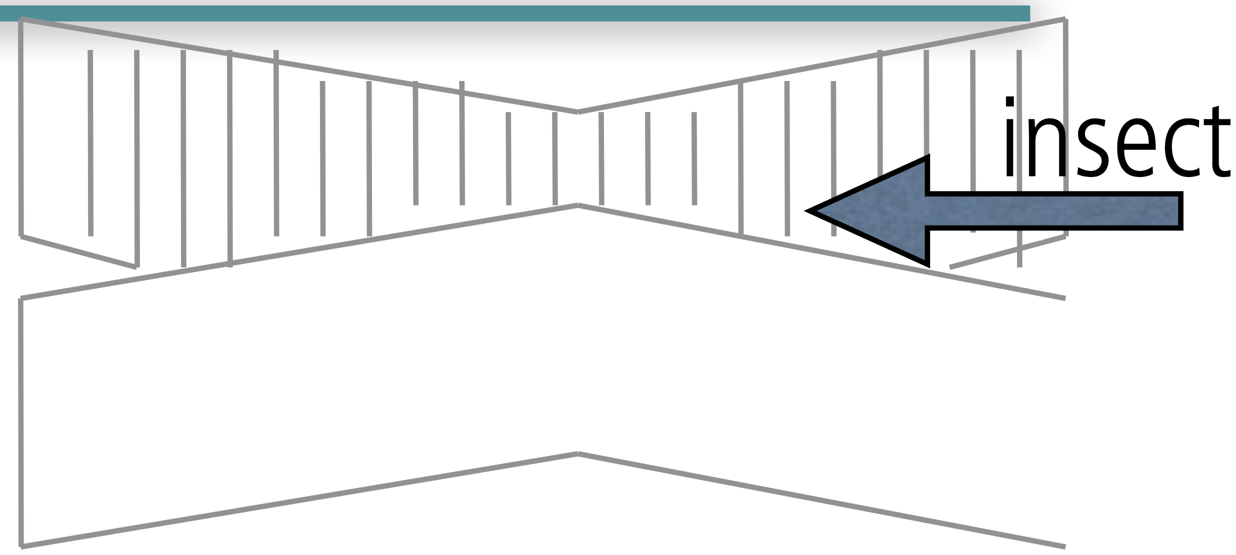
Optic flow is widely used in nature. Note that most natural systems don't have distance sensors, because what is relevant is not distance but "time to collision."
Optic flow is a good indicator of "time to collision."
Note: optic flow from horizontal rotation is independent of distance

Insect navigation strategies: exploiting optic flow



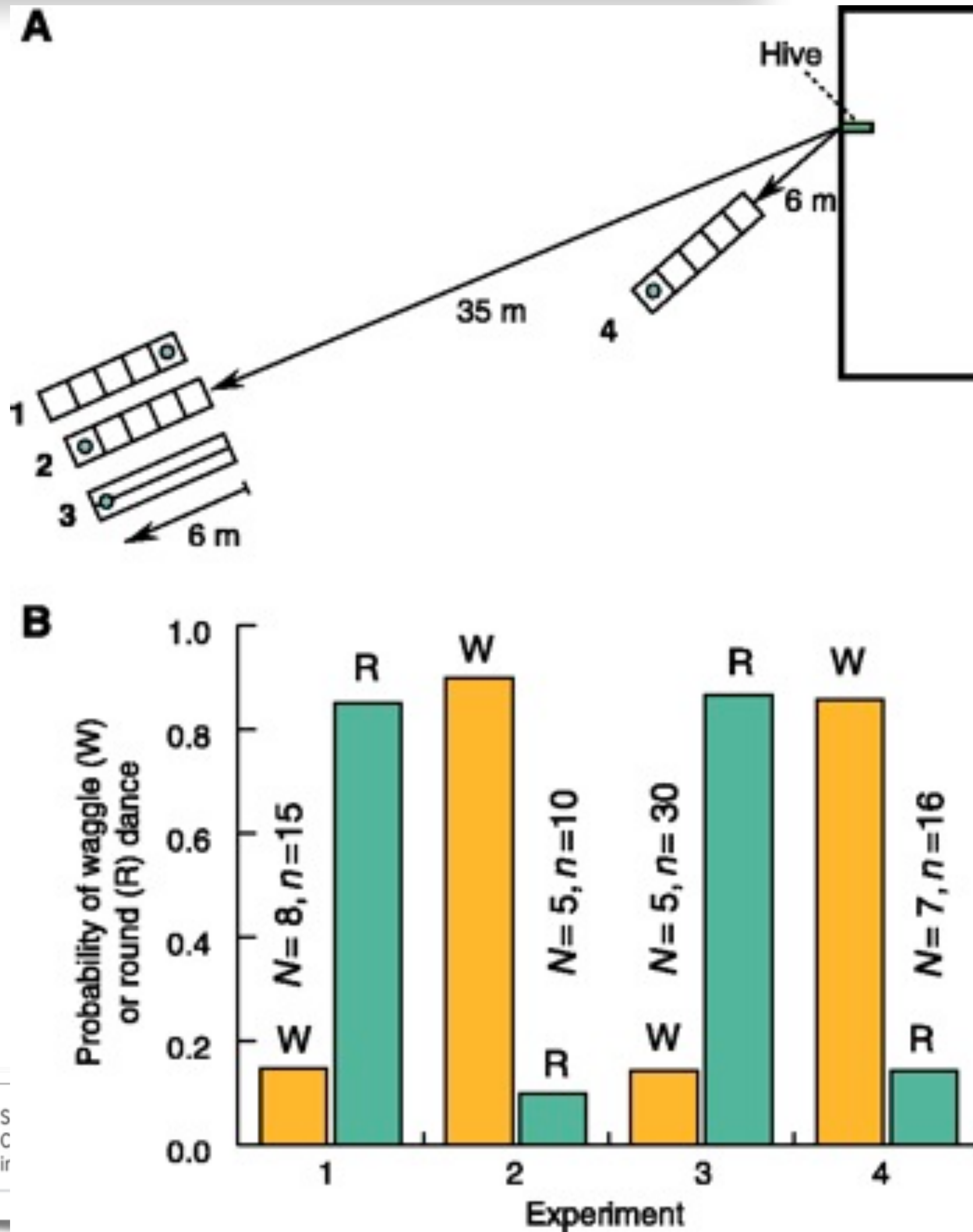


- obstacle avoidance and centering: control strategy?
- motion parallax: close objects --> high optic flow
- speed profile?
- landing?
- distance sensors?

Experiment 1: walls not moving, experiment 2: left wall moving in direction of flight, experiment 3: left wall moving in opposite direction of flight

Optic flow-based odometry in bees

Srinivasan's fascinating experiments (2000)



(A) Layout for experiments using tunnels. Each tunnel represents a separate experiment (1, 2, 3, or 4). The dot in the tunnel shows the position of the feeder in each case. (B) Probability of waggle (W) round (R) dance for experiments 1 to 4. N and n represent the numbers of bees and dances analyzed, respectively in each experiment. Science, 287, p. 852, 2000.

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In experiments 1, 2, 4 there is a patterned tunnel, i.e. one that induces optic flow, whereas tunnel 3 is without patterns.

Design principles for intelligent systems

Principle 1: Three-constituents principle

Principle 2: Complete-agent principle

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The principle of sensory-motor coordination

induction of structured sensory stimulation through sensory-motor coordinated action

principle of information self-structuring: effect

(leads into development)

There is essentially an F-O-R issue: if the interaction is sensory-motor coordinated, more information structure is induced, and because this is induced through the agent’s own actions, we talk about “information self-structuring”.

In order to better understand this, a digression is required.

Physical dynamics and information processing

Recall: agent characteristic: induction of patterns of sensory stimulation through physical interaction with environment. Take grasping as an example.

Grasping an object

- many ways
- winding spring (effort)
- release
- exploitation by brain
  - "cheap design", exploitation of material properties, "free"
  - "ecological balance": outsourcing of functionality to morph. and material characteristics

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Grasping an object

- **induction of sensory stimulation**
- **dependence on**
  - **morphology: high density of touch, temperature, vibration sensors in hand**
  - **actuation: sensory-motor coordination**
  - **induction of correlations**

→ "raw material" for information processing of brain

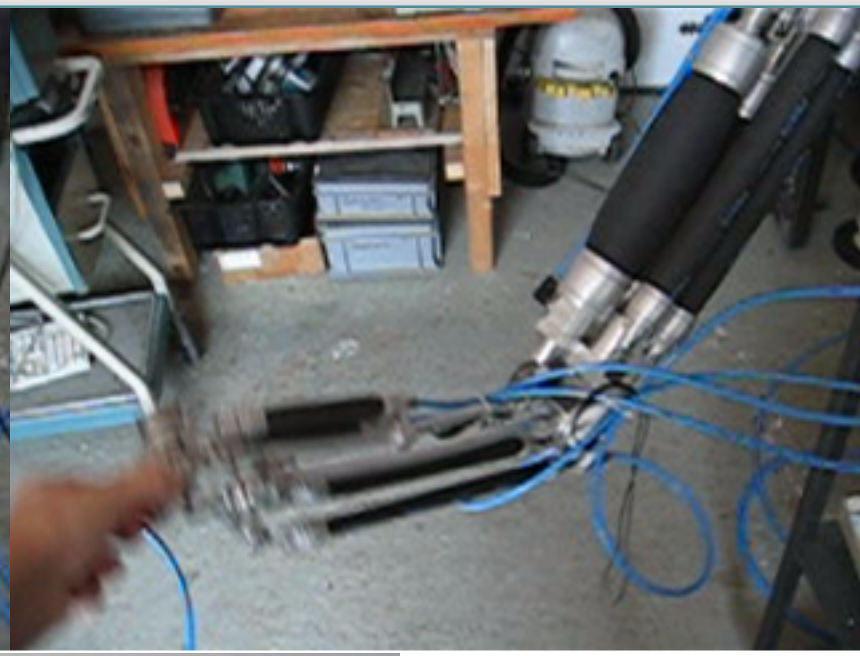
Loosely swinging arm

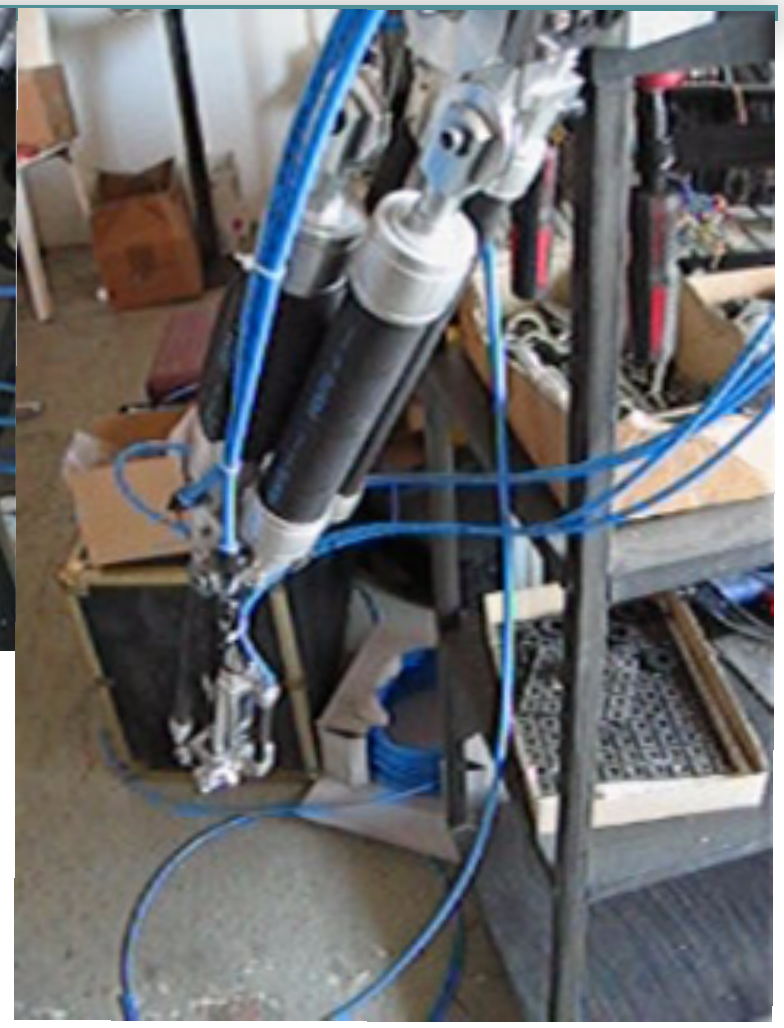
- complex trajectory of hand
- simple control (“cheap design”, “ecological balance”)
- exploitation of morphology/ materials (biomechanical contraints)

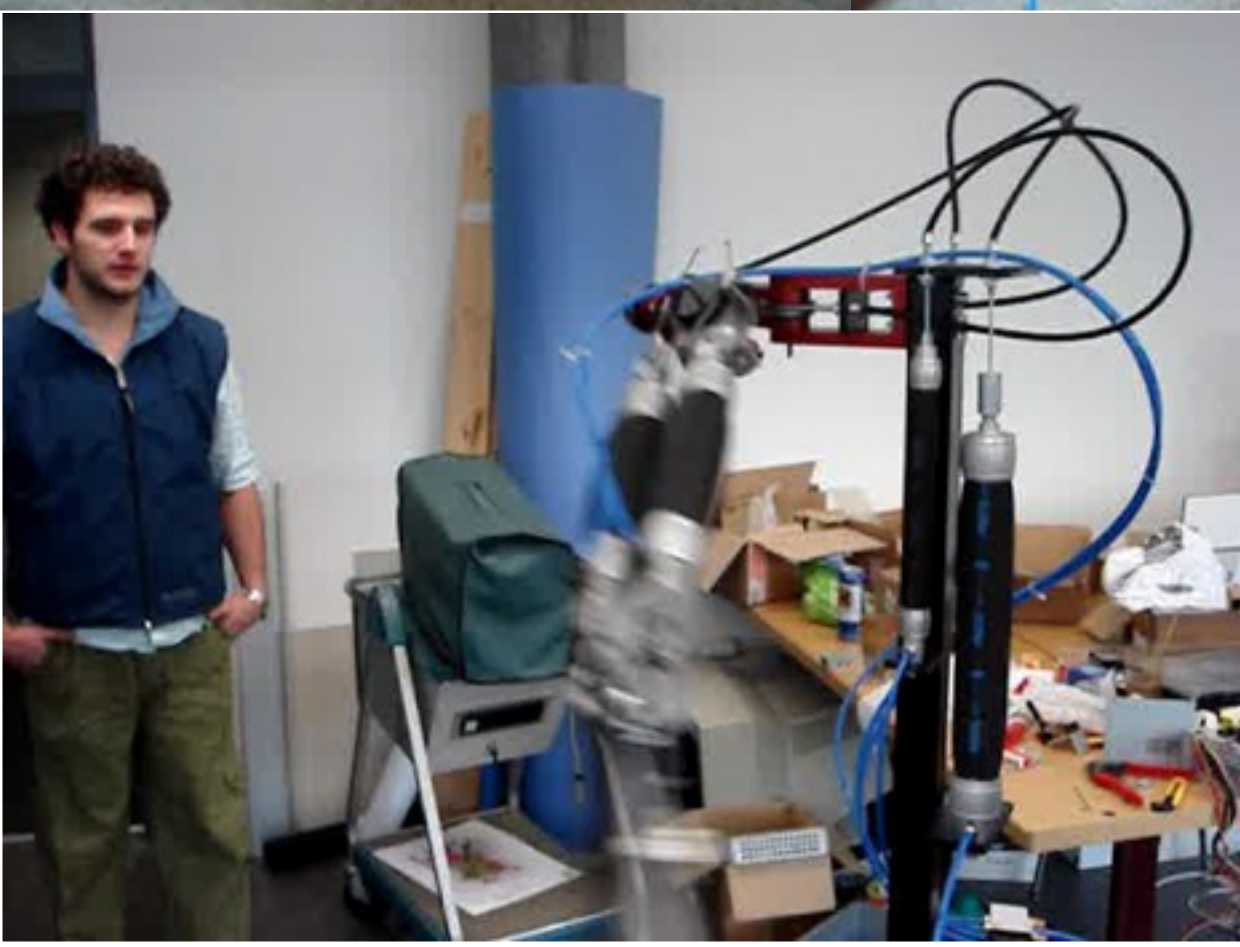
→ control “decentralized” “free”

this is part of a bigger story about how behavior and learning are “orchestrated”

Anthropomorphic arm with pneumatic actuators



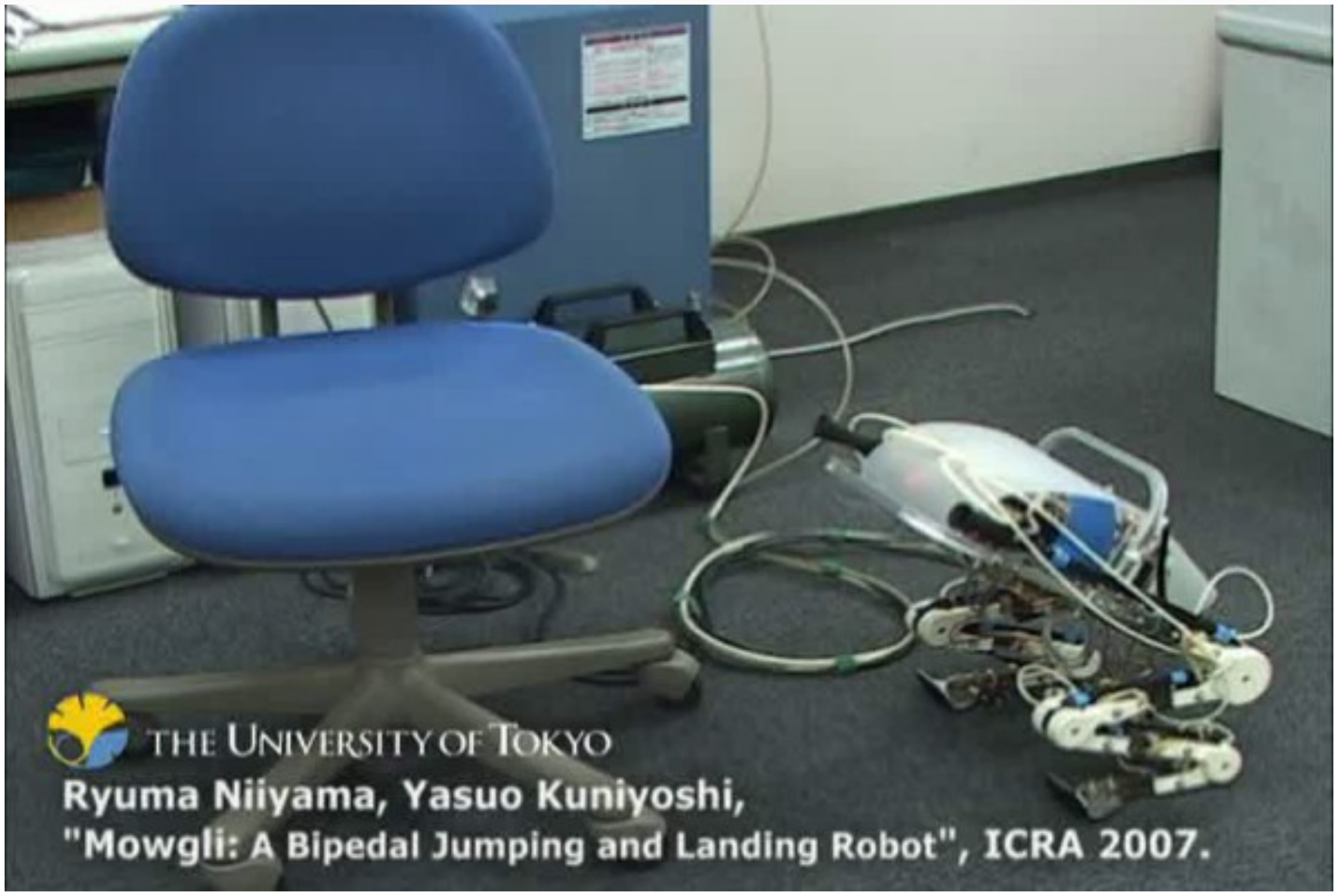




Design and construction:
Raja Dravid, Max Lungarella, Juan Pablo Carbajal, AI Lab, Zurich

Pneumatic actuators: also called “air muscles”. Rubber tubes with incorporated braided fabric: when air pressure is applied, the contract and because of the rubbery materials, pneumatic actuators and the compressability of the air, they are elastic, resembling the human muscle-tendon system. By applying air pressure, the muscle contracts and its stiffness increases.

Robot Frog "Mowgli" driven by pneumatic actuators



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

Control is very simple - again outsourced to morphological and material characteristics of the "frog" (the shape of the legs; the damped spring properties of the pneumatic actuators.

The "story": physical dynamics and information processing

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

The "story": physical dynamics and information processing

- good "raw material" for brain
- cross-modal association, learning, concept formation
- extraction of mutual information —> prediction (expectations: crucial for motor control)
- categorization (fundamental for cognition)

The brain uses the motor signal to predict the expected pattern of sensory stimulation, which can then be used to assess whether the action has been successful.

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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We can see that the ideas are not new - they date back all the way to 1896 (i.e. the century before last) to John Dewey in his seminal paper entitled “The reflex arc concept in psychology”. An early champion of embodiment in philosophy is Maurice Merleau-Ponty, a later champion is George Lakoff (see below).

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)

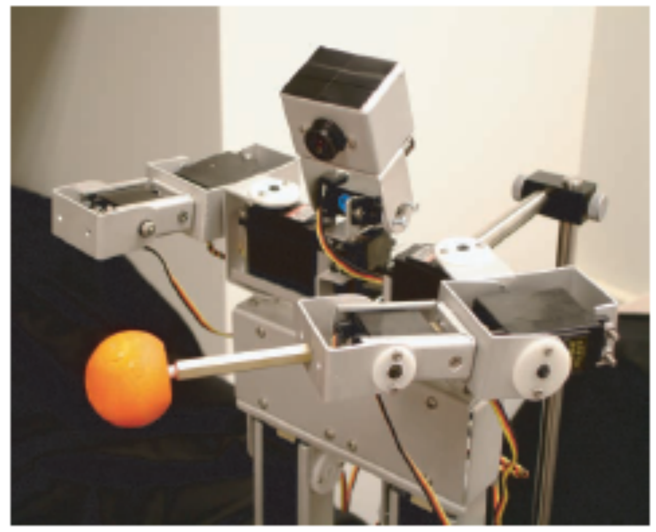
Interestingly, Dewey's quote reads like an argument against the computer metaphor.

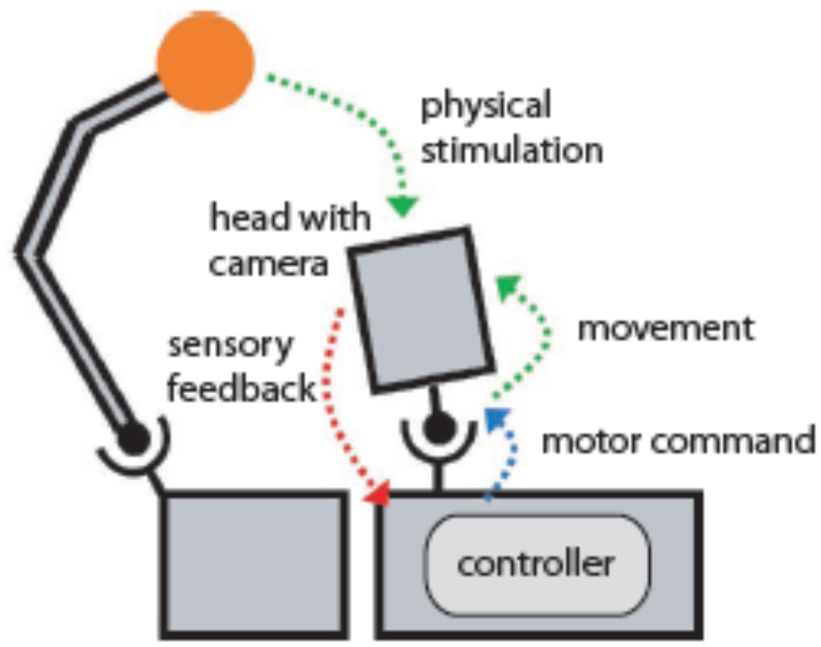
Quantification of information structure

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 independent from each other, and sensory-motor coordinated, i.e. robot (camera) 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

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

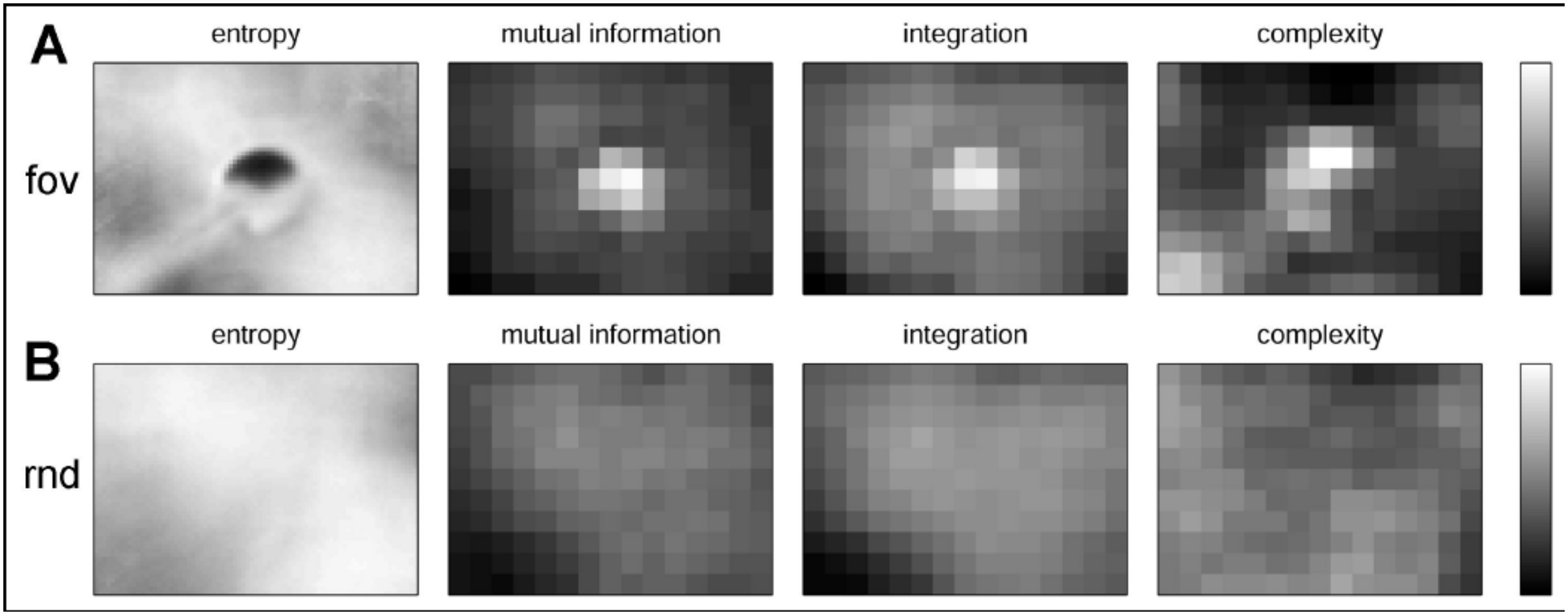
complexity: co-existence of local and global structure

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

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

Taken from a paper on measures of brain complexity by Tononi, Sporns, and Edelman;
no need to learn the formulas ;-)

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

Development: From locomotion to cognition

- Please read chapter 5 in "How the body …"

End of lecture 5

Thank you for your attention!

stay tuned for our guest lectures

Prof. Claude Siegenthaler and Prof. Fabio Bonsignorio

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Lecture 5: Guest speaker

from Zurich, Switzerland

Prof. Claude Siegenhaler, Univ. of St. Gallen (CH)
and Hosei University, Tokyo
Founder of many companies
Winner of numerous awards

"In search of embodied intelligence of markets"

Today, 10.05 Central European Time (09.05 UK time; 17.05 Shanghai time; 18.05 Japan time)

Lecture 5: Guest speaker

from Madrid, Spain

Prof. Fabio Bonsignorio, Univ. Carlos III, Madrid, Spain
"Embodying disruptive innovation in embodied cognitive systems"

Today, 10.35 Central European Time (09.35 UK time; 17.35 Shanghai time; 18.35 Japan time)

End of lecture 5

Thank you for your attention!

stay tuned for lecture 6

"From locomotion to cognition: developmental science"

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