
人工智能
The ShanghAI Lectures
上海授课

List of videos

1. BongardsBlockPusher.mov
2. bike.mpg.WMV
3. CoffeeBalloonGriperShort.mov
4. growth.mov
5. Kismet.MOV

Summary and conclusions

“How the body shapes the way we think - principles and insights”

Rolf Pfeifer

19 December 2013

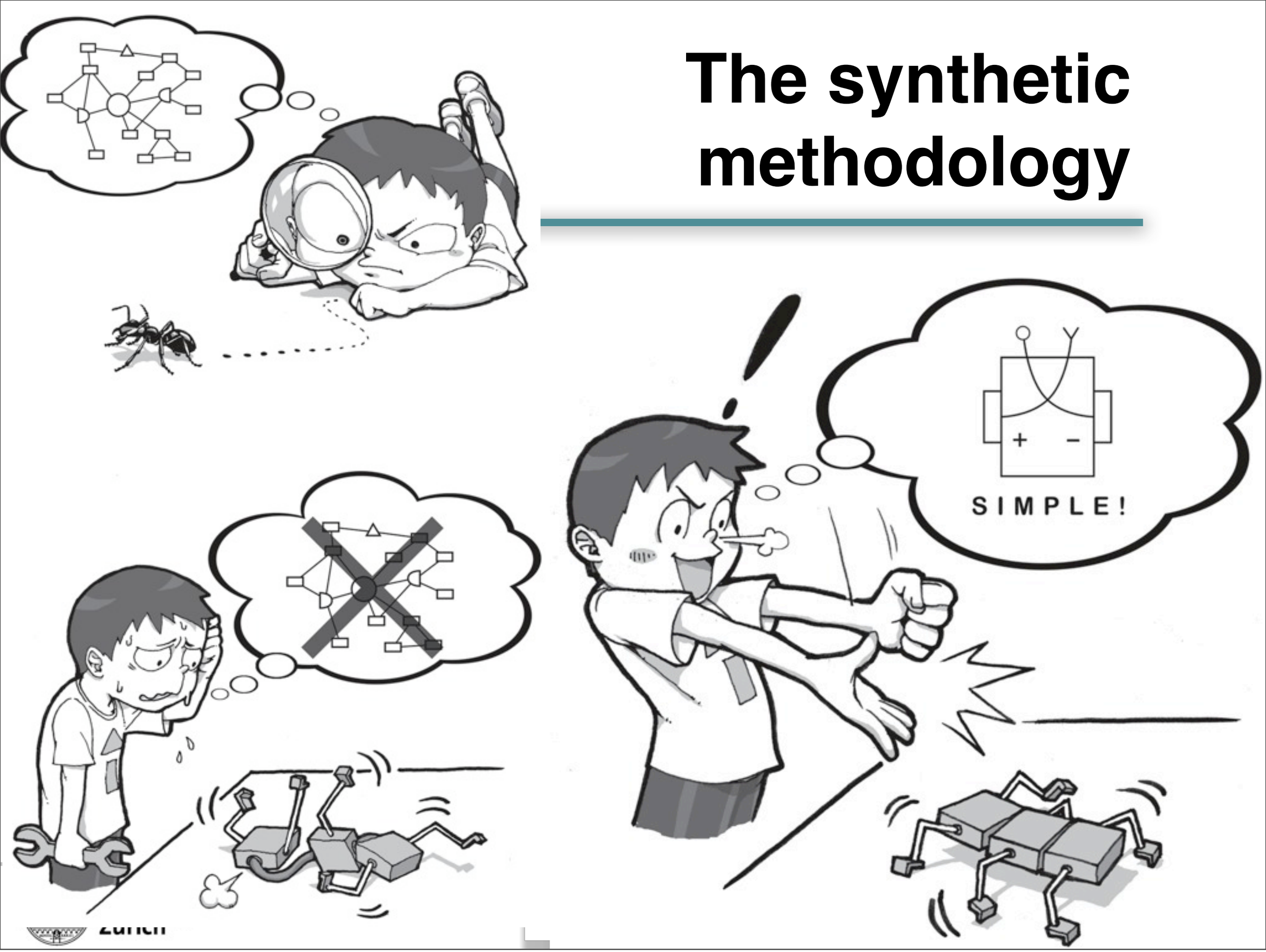
Steps toward a theory of intelligence

- Meta-considerations: “Mind Set”
- Illustration of selected design principles
- Seeing things differently

Meta considerations: “Mind set”

- level of generality and form of theory:
- diversity-compliance:
- **frame-of-reference: ?**
- **synthetic methodology: next slide**
- **time perspectives:**
- **emergence:**

The synthetic methodology



Meta considerations: “Mind set”

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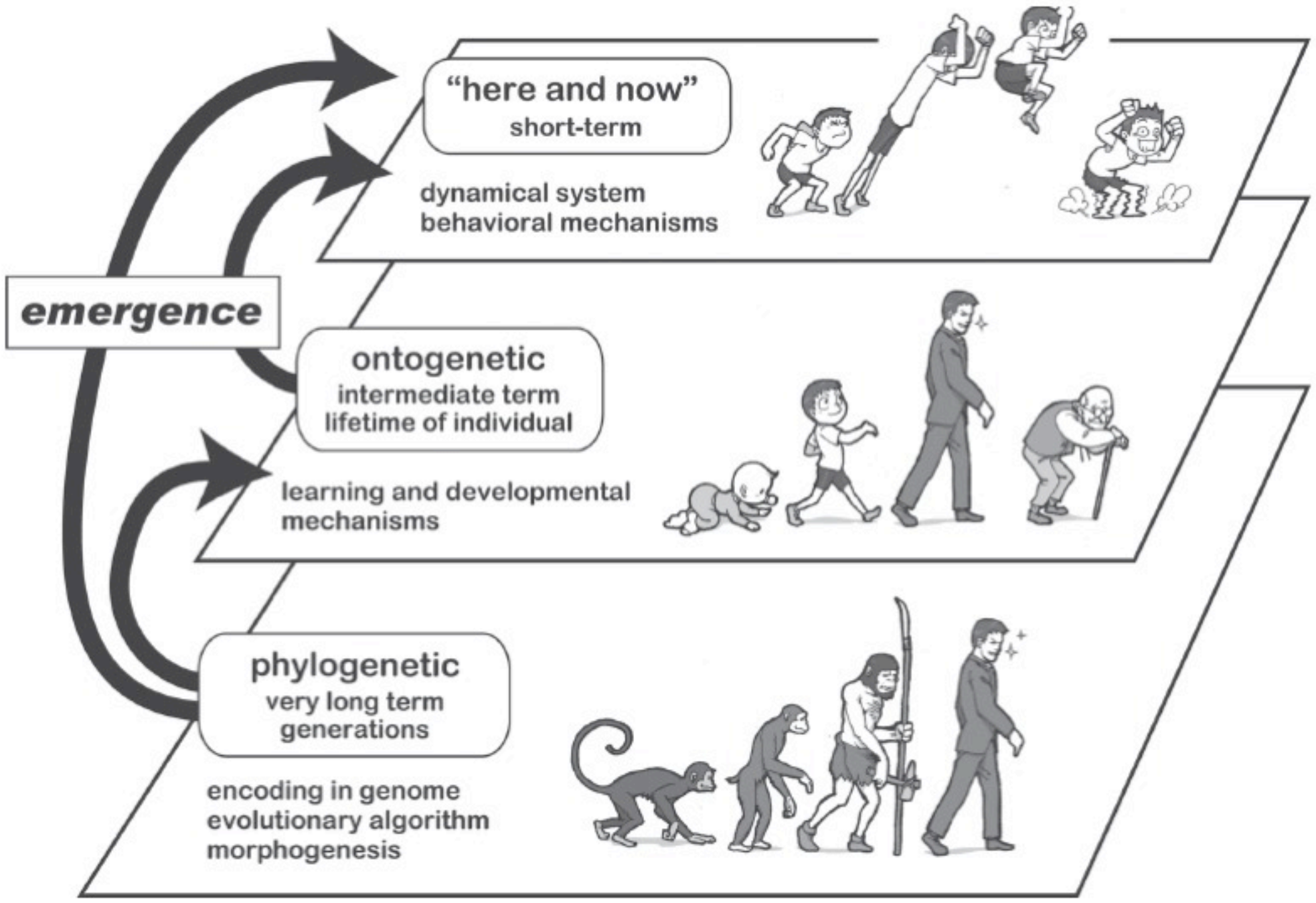
- **time perspectives: ?**
- **emergence:**

Time perspectives

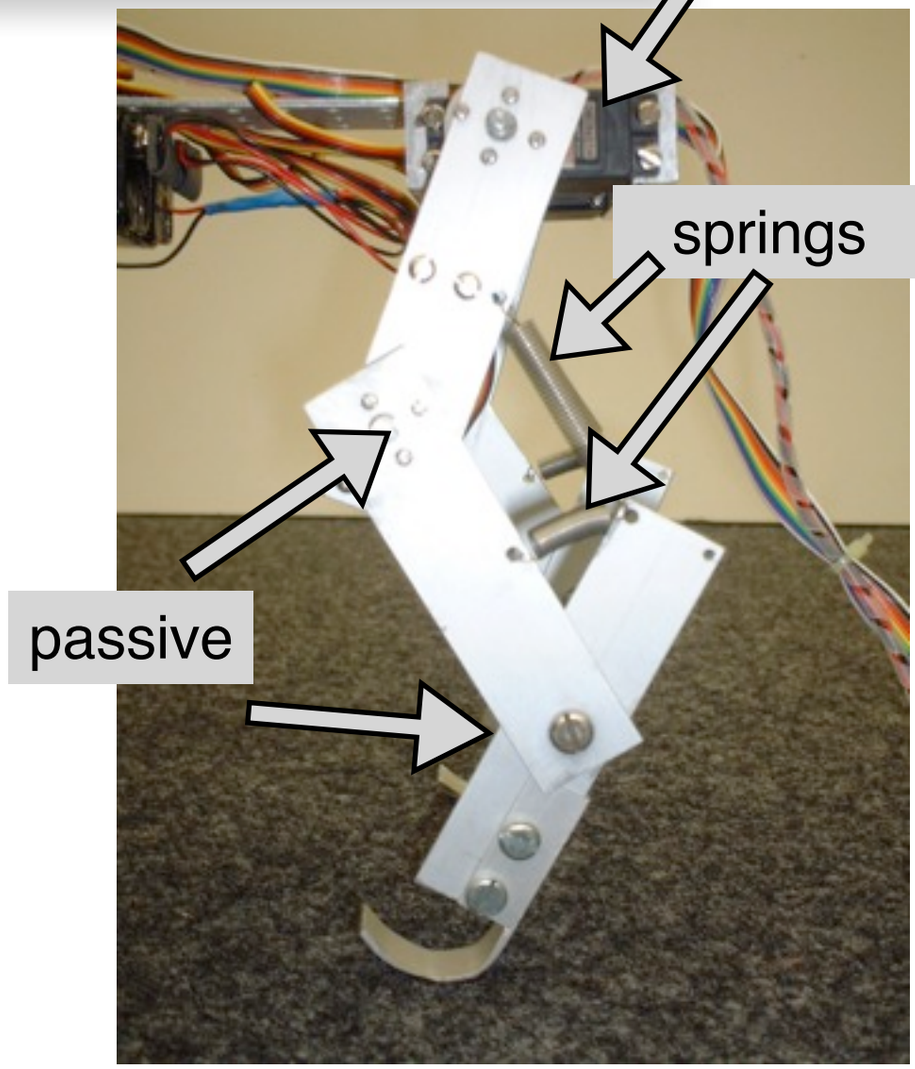


Meta considerations: “Mind set”

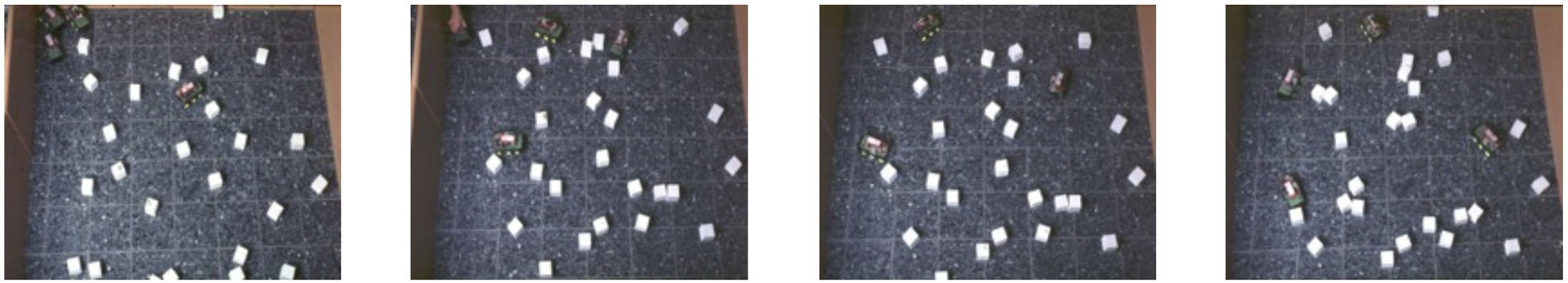
- level of generality and form of theory:
- diversity-compliance:
- frame-of-reference:
- synthetic methodology:
- time perspectives:
- **emergence:**

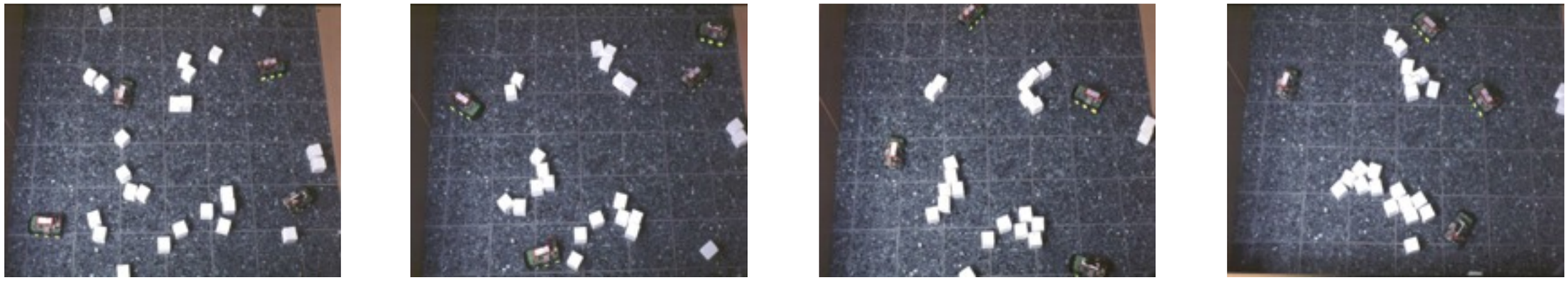
Emergence of stable gait pattern the quadruped “Puppy”

- simple control (oscillations of “hip” joints)
- spring-like material properties (“under-actuated” system)
- self-stabilization, no sensors
- “outsourcing” of functionality



Emergence of clustering ("Swiss Robots")





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

Emergence of global patterns from local rules — self-organization

bee hive

termite mound

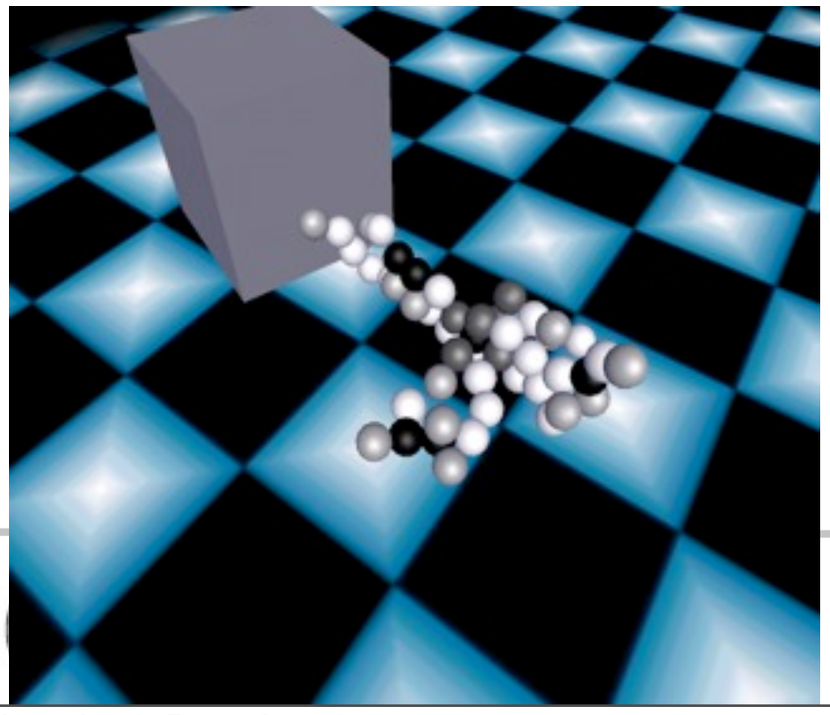
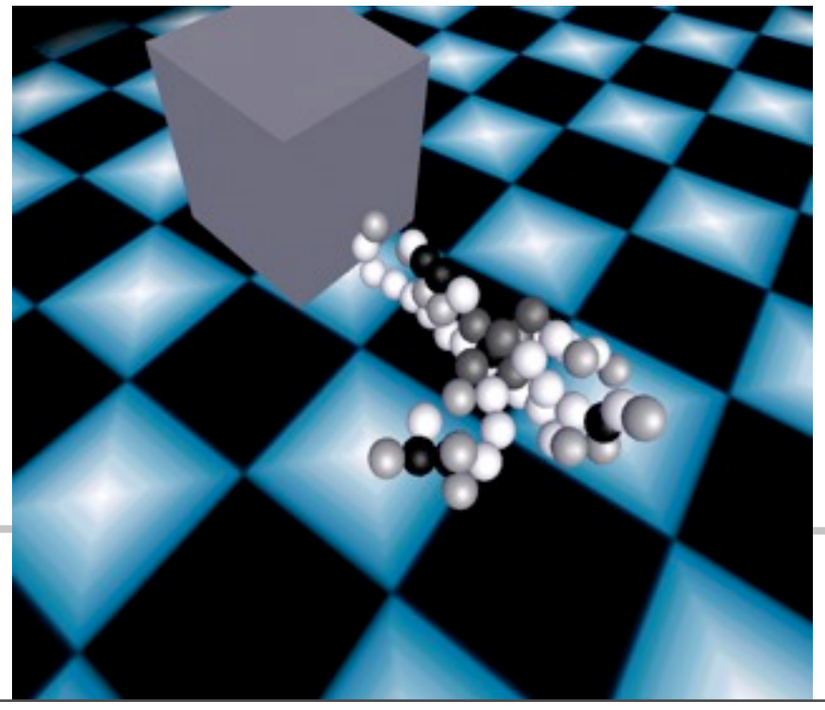
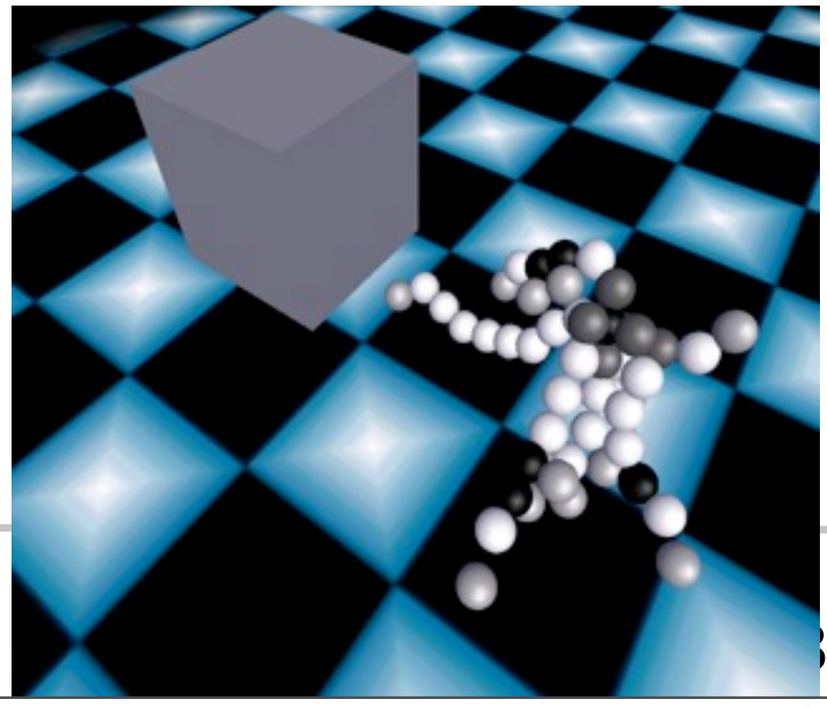
“wave”in stadium

open source development community

Emergence of behavior from time scales: locomotion and pushing

Bongard's "Block Pushers"

- development (morphogenesis) embedded into evolutionary process, based on GRNs
- testing of phenotypes in physically realistic simulation

Emergence of behavior from time scales: locomotion and pushing

Video “BongardsBlockPushers.mov”

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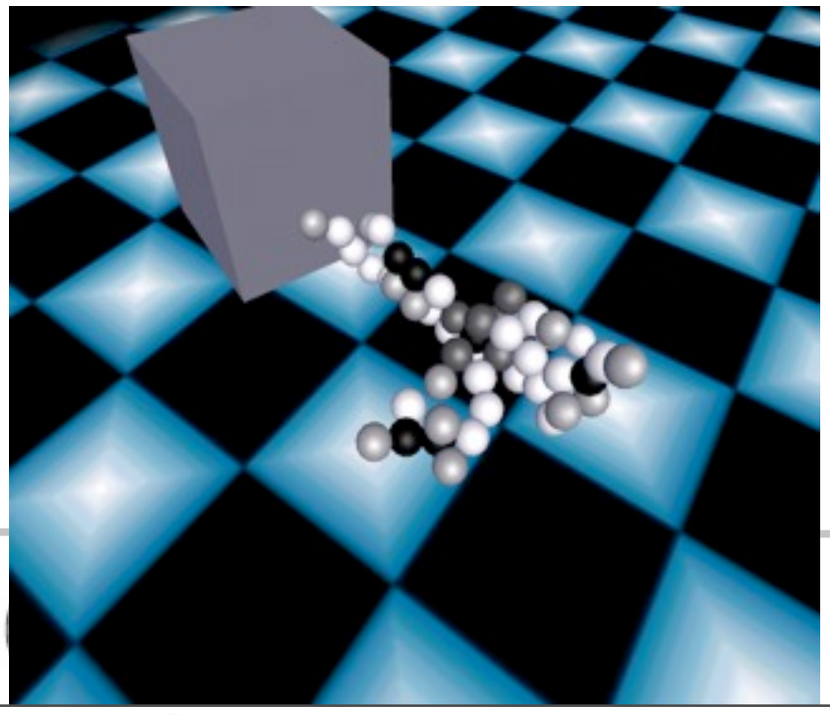
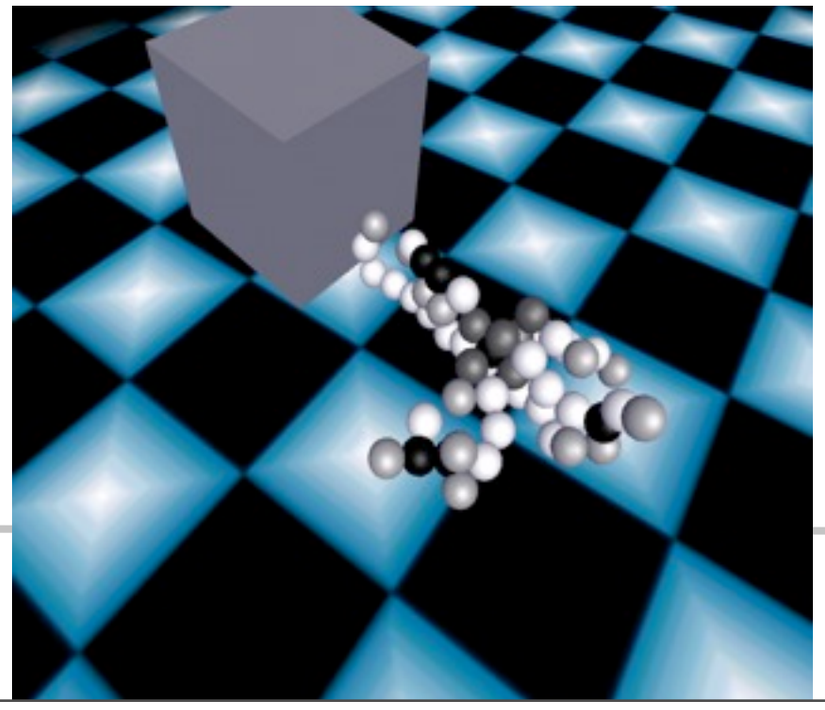
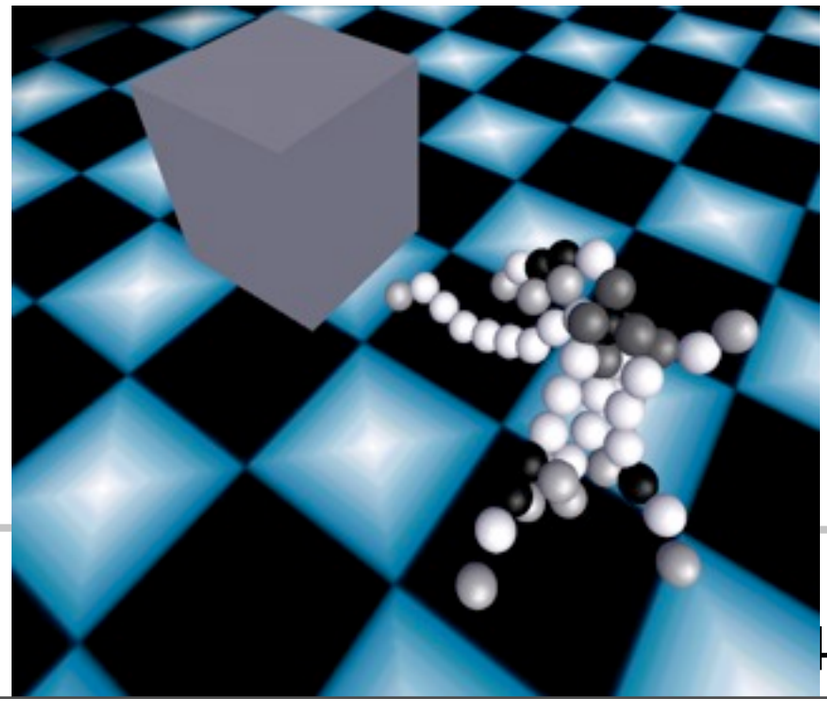




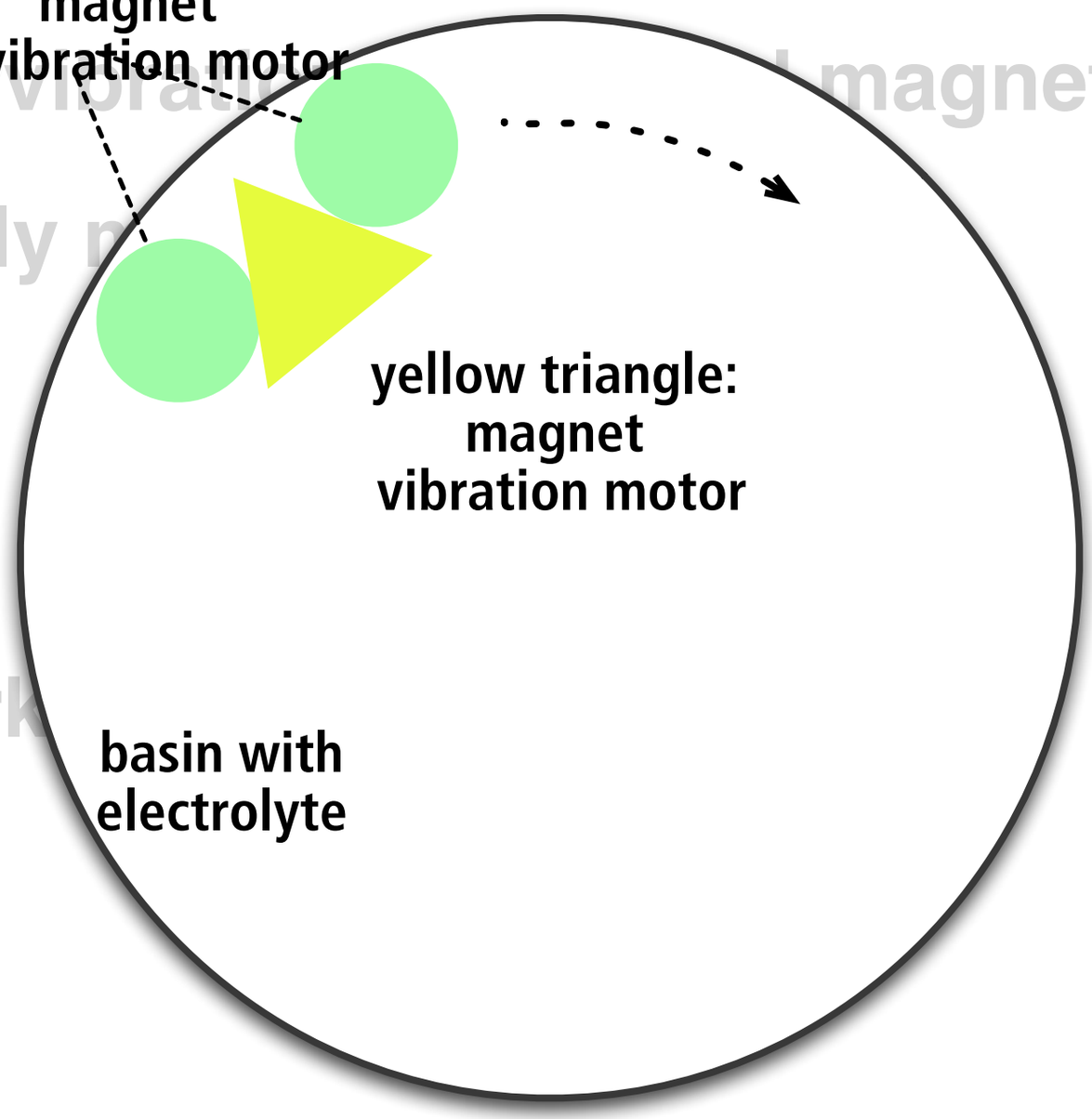
Design for emergence: a “bicycle” following the wall

emergent functionality (not self-assembly)

yellow triangle: vibration motor + magnet

green discs: only m

how does it work



Morphological Computation: self-assembly and emergent functionality

“The self-assembled, emergent bicycle”

Video “bike4.mpg.WMV”

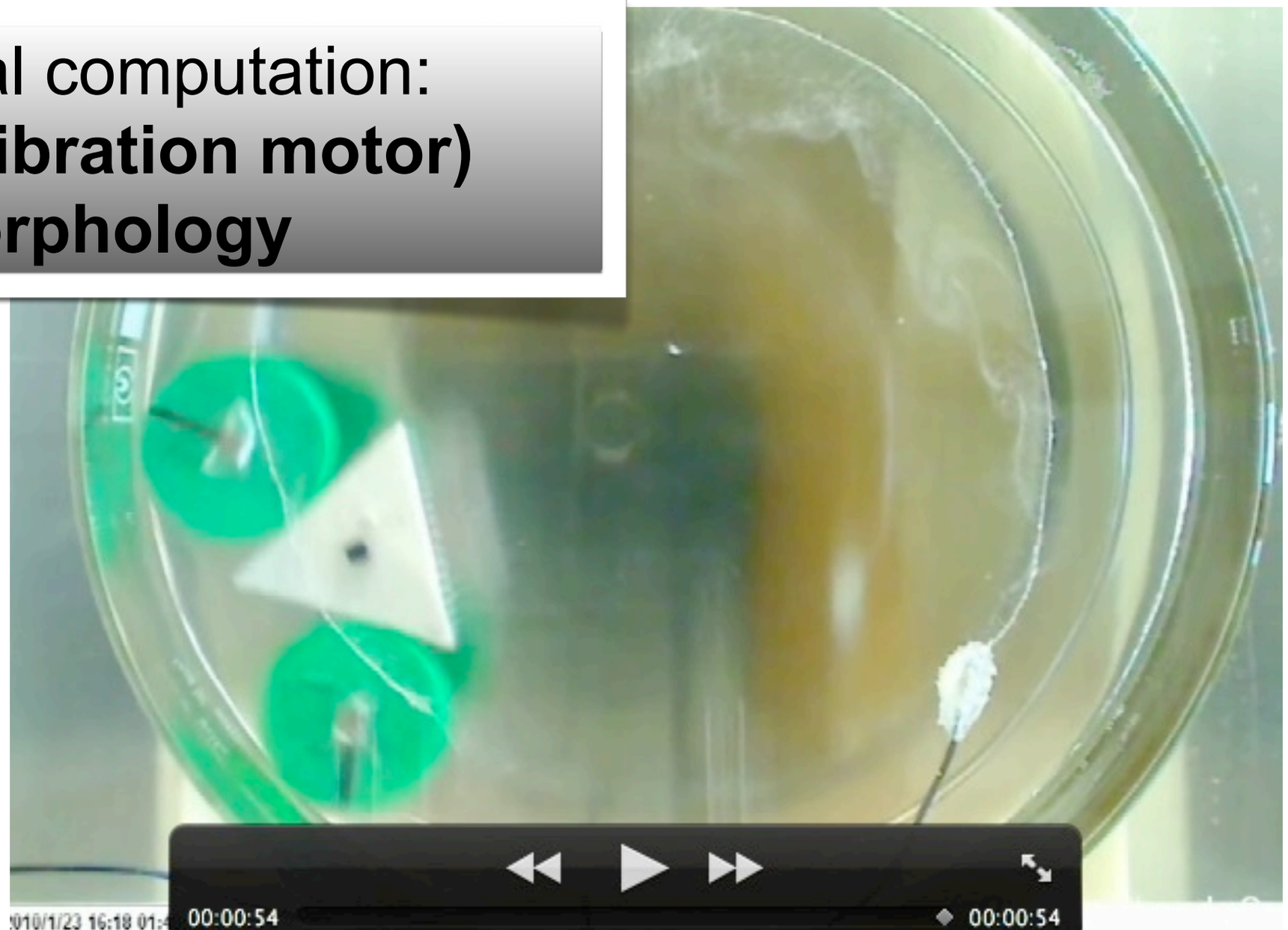
Design and construction:
Shuhei Miyashita

University of Zurich[UZH]

Morphological Computation: self-assembly and emergent functionality

“The self-assembled, emergent bicylce”

morphological computation:
no control (vibration motor)
only morphology



Design and construction:
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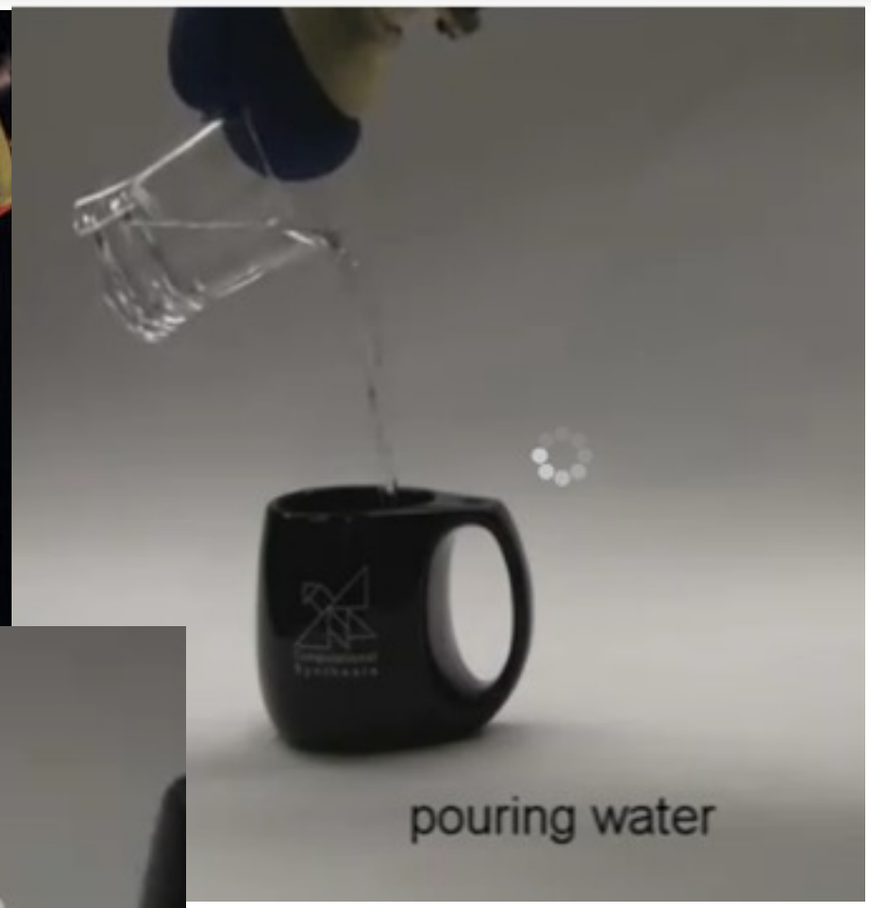
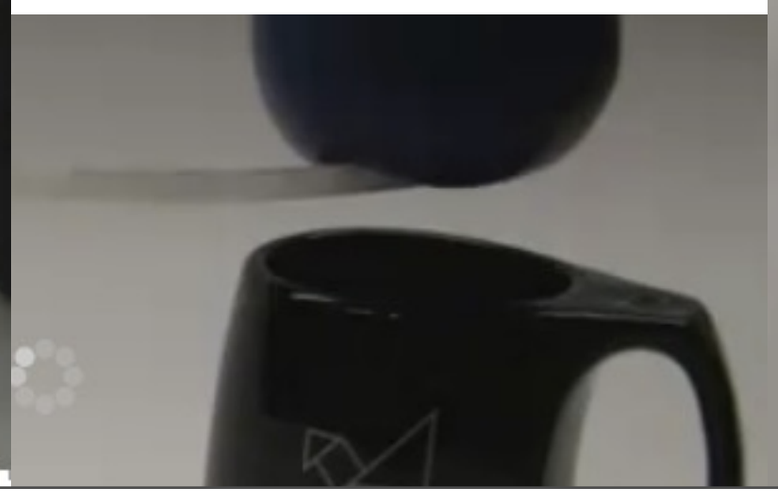
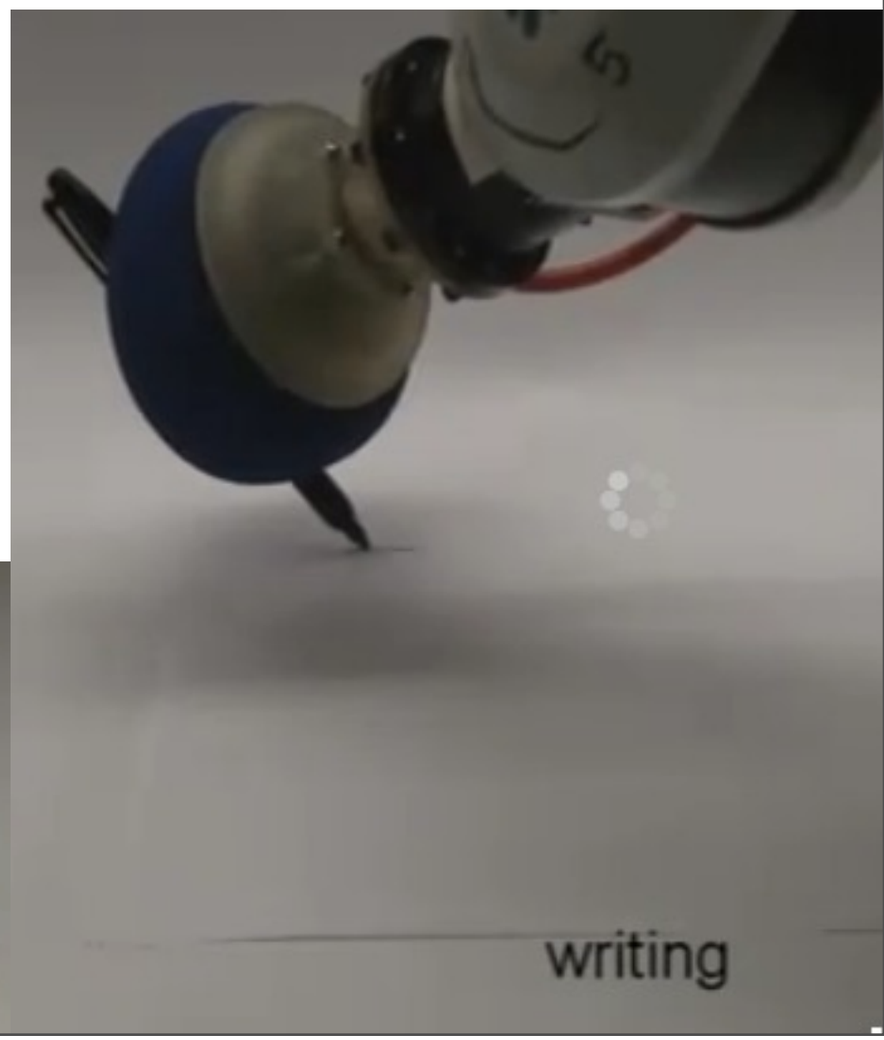
Emergence of adaptive behavior from materials

The “Jaeger/Lipson coffee balloon griper”

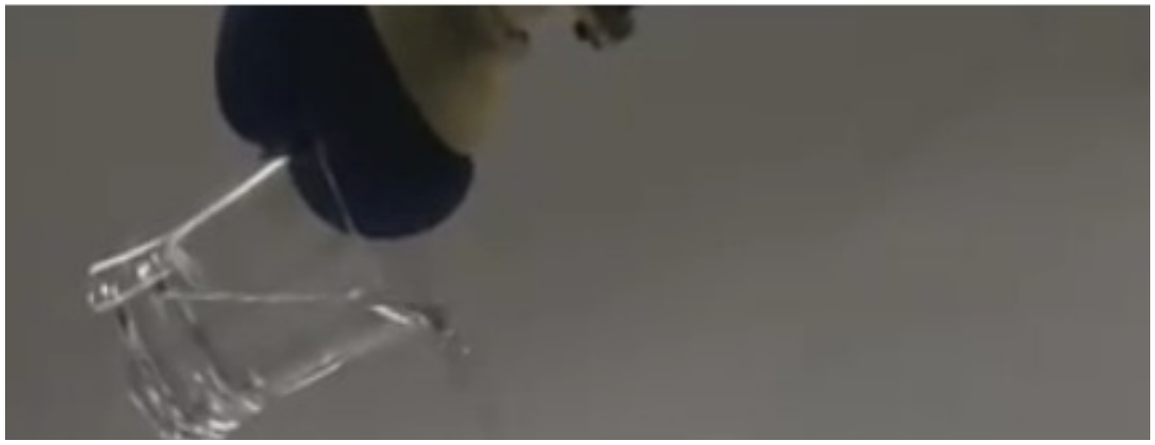
Jaeger/Lipson “coffee balloon gripper”



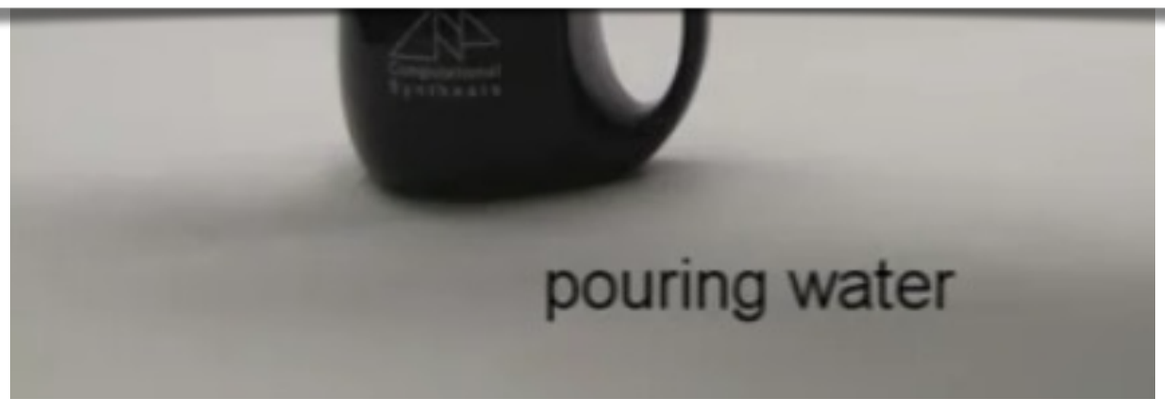




Jaeger/Lipson “coffee balloon gripper”

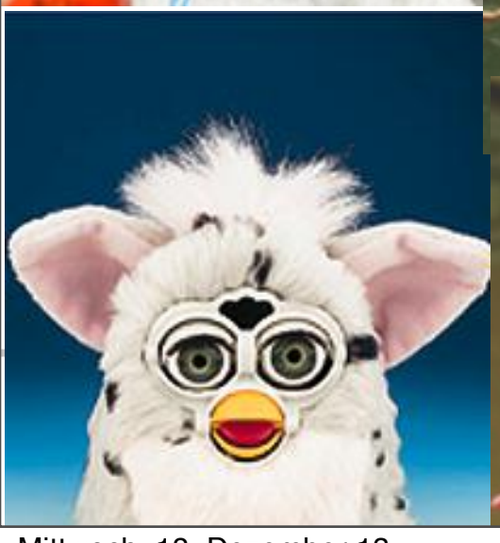


Video “CoffeeBalloonGripperShort.mov”

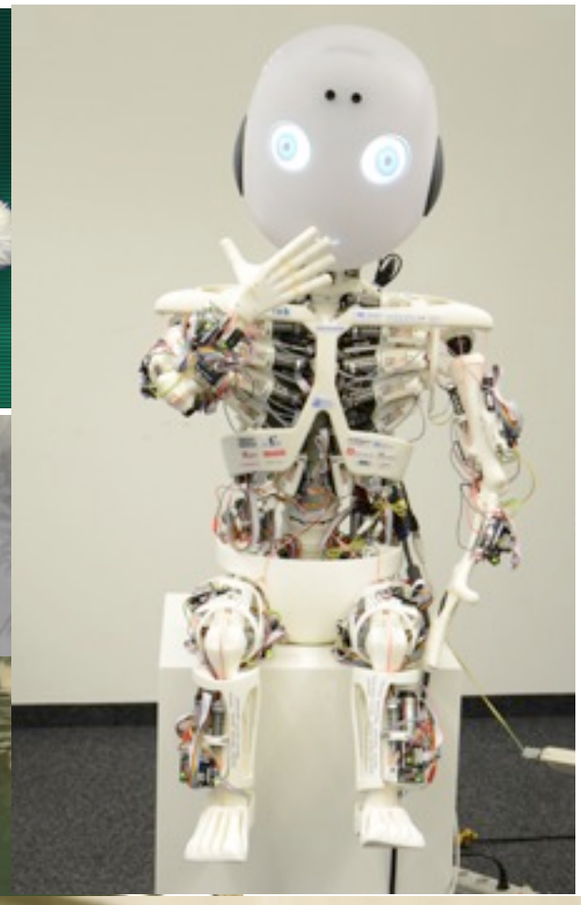


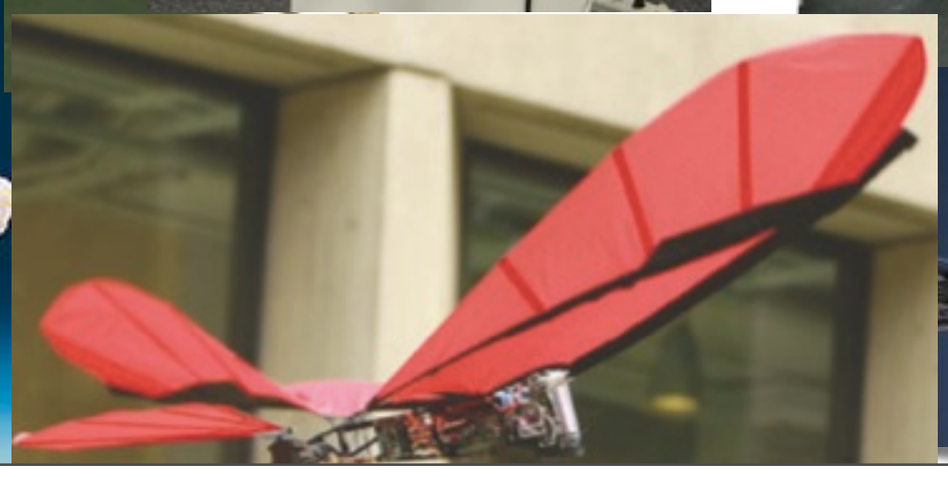
“Soft Robotics”

Soft to touch

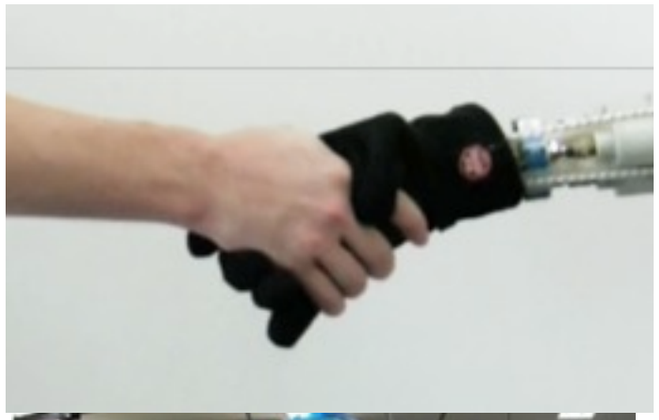


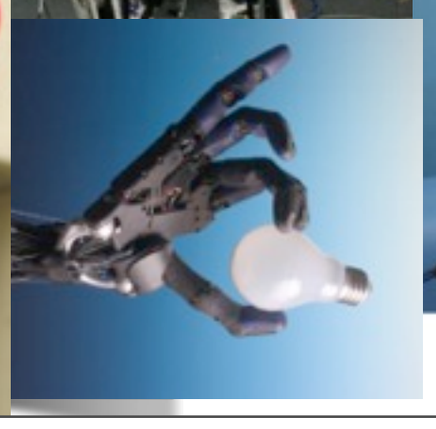
Soft movement

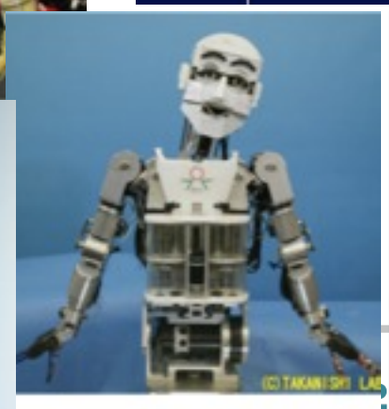




Soft interaction







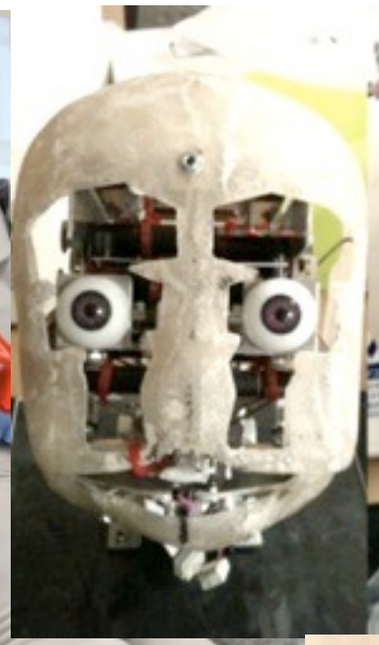
happy

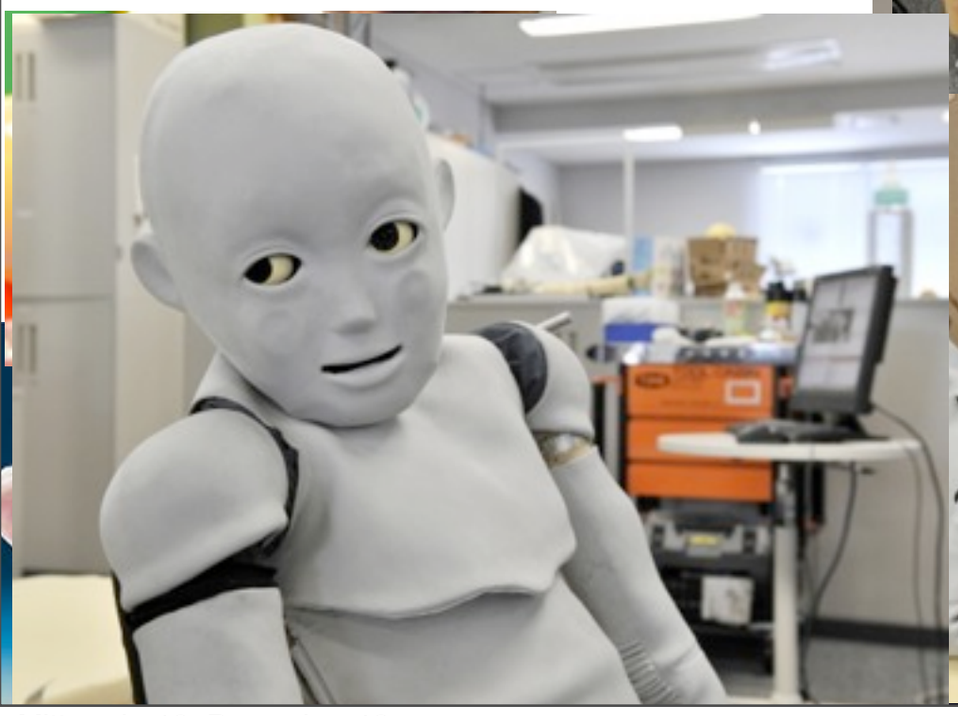
angry

“Soft Robotics”

(Osaka University)

Soft to touch **Soft movement** **Soft interaction**





Mittwoch, 18. Dezember 13

Expansion of design space: trading spaces and trade-offs

- morphologies (physical structure, distribution of sensors, actuators)

- must understand “trading space”: morphology - computation/control

- trade-offs: morphology/materials - flexibility (but changeable properties)

Morphology and computation: “trading spaces”

increasing dominance of morphology and materials
decreasing dominance of control

informational computation

control and behavior less separable
increased reliance on self-organization

morphological computation

control dominant

morphology and materials dominant
“guided self-organization”

pure algorithm

computer (running algorithm)

industrial robot (centralized control

Asimo (and similar robots)

ECCE (compliant, tendon-driven)

Octopus (soft, continuous)

“Robot Frog” (variable compliance)

Jaeger-Lipson coffee-balloon gripper

PDW (exploiting morphology)

cells molecules “Tribolons”

control dominant

morphology and materials dominant

Emergence as a continuum

Properties of physically embodied agents, e.g. “Puppy”

Characteristics of real-world environments

Characteristics of real-world environments

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

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Herbert Simon's concept of "bounded rationality"

Steps toward a theory of intelligence

- Meta-considerations: “Mind Set”
- **Illustration of selected design principles**
- **Seeing things differently**

Agent design principles

Agent design principles	**Description**
Three constituents	ecological niche, behaviors/tasks, and agents
Complete agent	complete agent, not only isolated components
Parallel, loosely coupled processes	parallel, asynchronous, processes, largely coupled through interaction with environment
Sensory-motor coordination	behavior sensory-motor coordinated with respect to target; self-generated sensory stimulation
Cheap design	exploitation of niche and interaction; parsimony
Redundancy	partial overlap in functionality based on different physical processes
Ecological balance	Balance in complexity of sensory-motor and neural system; task-distribution: morphology, materials, control, environment
Value	driving forces, developmental mechanisms, self-organization

Design principles for development

Principles for development	**Description**
Integration of time scales	many time scales need to be integrated into one agent
Development as an incremental process	start simply, build successively on top of what has already been learned
Discover	agent must have ability to explore and evaluate, which implies that agent can discover through its own activites
Social interaction	sensory-motor coordination together with social interaction provides most powerful engine for development
Motivated complexity	why complexity increases during ontogenetic development (driving force)

Design principles for evolution

Principles for evolution	**Description**
Population	Population is the prerequisite for evolution to function
Cumulative selection and self-organization	Cumulative selection will produce interesting results only if evolutionary process exploits processes of self-organization
Brain-body co-evolution	"Brain" (neural control) and body must be evolved simultaneously
Scalable complexity	In order for complex organisms to emerge, the ontogenetic developmental processes must be encoded in the genome
Evolution as a fluid process	Agents should be modeled with a large number of cells: evolution should make only small modifications (at the genome)
Minimal designer bias	Design as little as possible and let evolution do as much work as possible

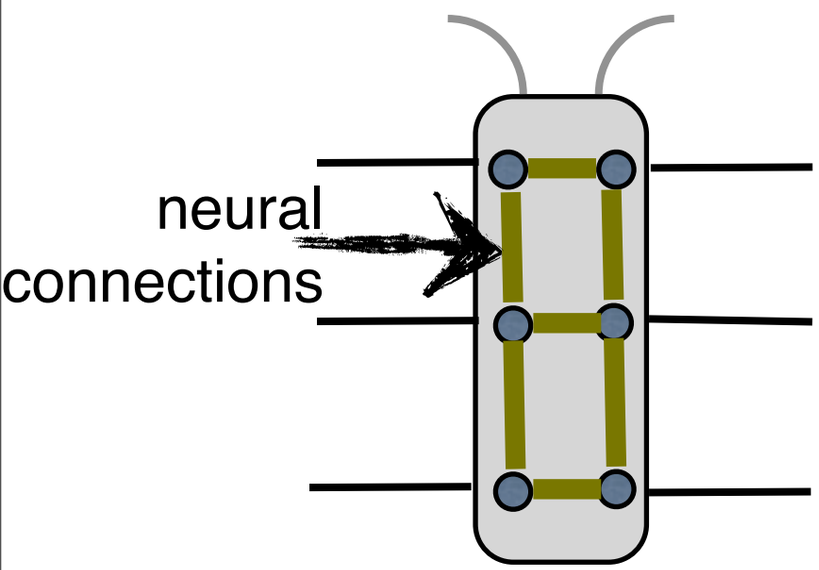
Design principles for collective intelligence

Principles for collective systems	**Description**
Level of abstraction	Proper level of abstraction must be chosen, and the implications (of abstraction) important
Design for emergence	Find local rules of interaction that lead to desired global behavioral patterns (holds also for individual agents)
From agent to group	Agent design principles often applicable to collective systems (e.g. parallel, loosley coupled processes)
Homogeneity-heterogeneity tradeoff	Find compromise between systems using only one type of module/robot and systems emplying several specialized types

Parallel, loosely coupled processes

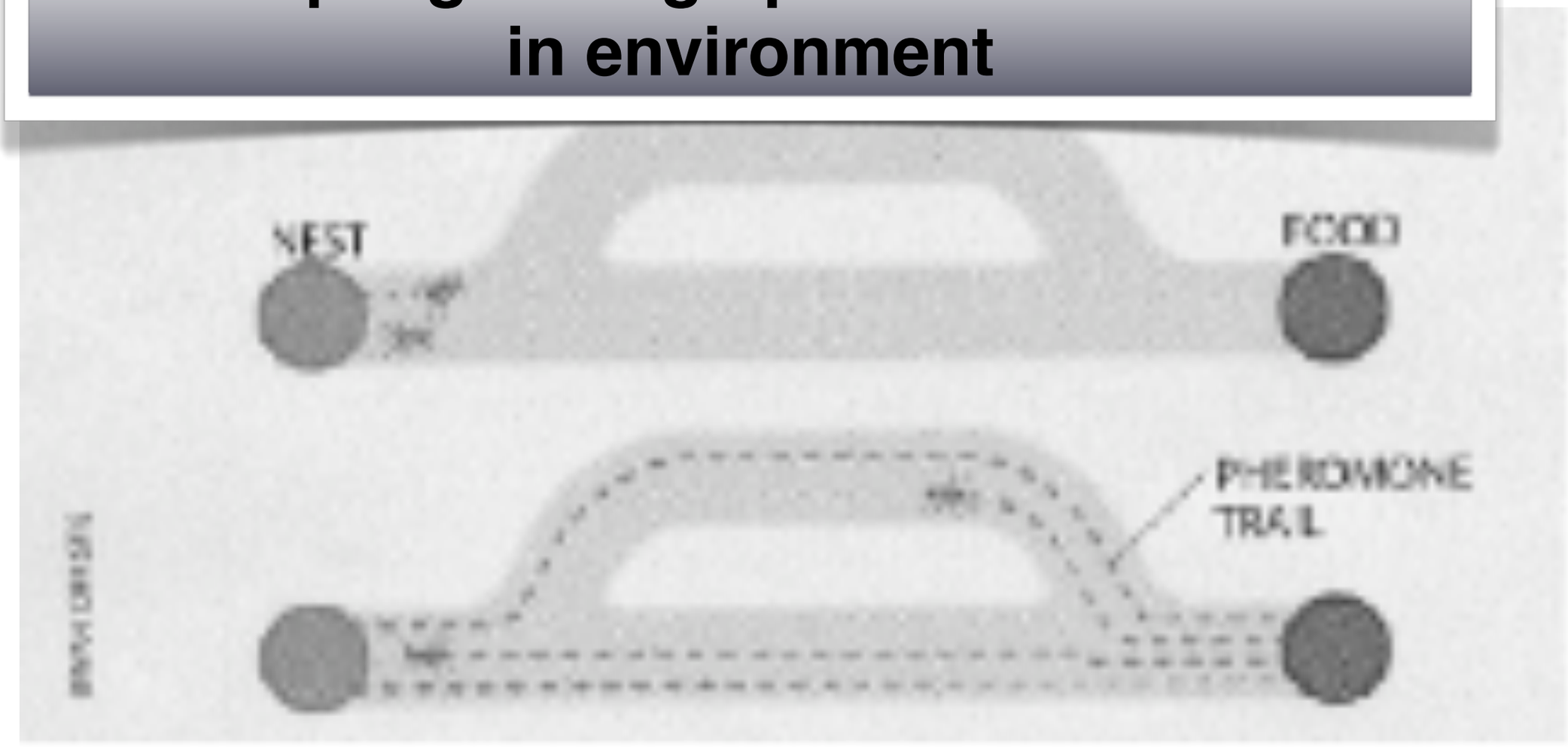
Holk Cruse, German biologist

- **no central control for leg coordination**
- **only communication between neighboring legs**
- **global communication/coupling: through interaction with environment**



Parallel, loosely coupled processes

coupling through pheromone trails in environment



Sensory-motor coordination Information self-structuring

induction of patterns of sensory stimulation containing information structure through sensory-motor coordinated interaction (e.g. grasping, foveating)

The “story”: physical dynamics and information processing

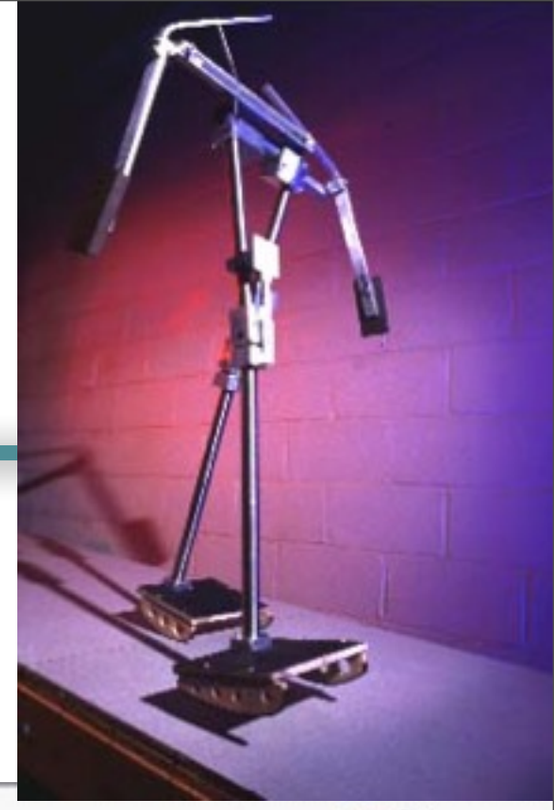
- morphology and materials
- exploration
- preferred trajectories from biomechanical constraints
- induction of patterns of sensory stimulation
- sensory-motor coordination --> induction of information structure
- good “raw material” for brain

The “story”: physical dynamics and information processing

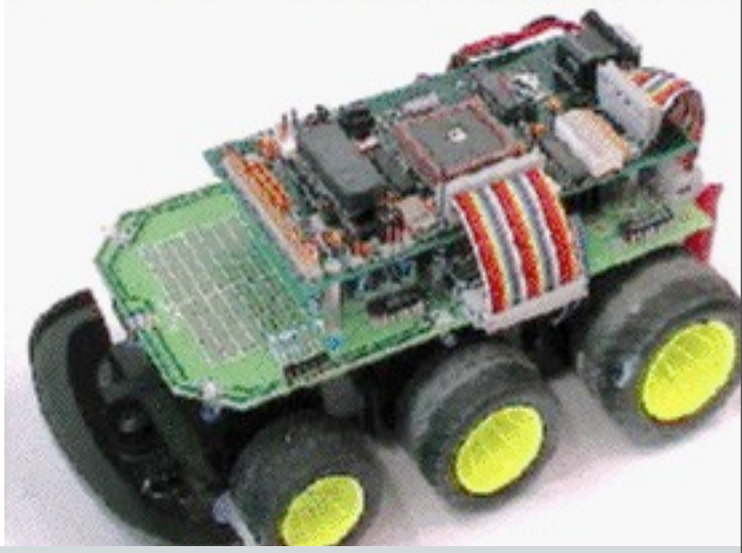
- cross-modal association, learning, concept formation
- extraction of mutual information --> prediction
- categorization (fundamental for cognition)

Cheap design exploitation of niche

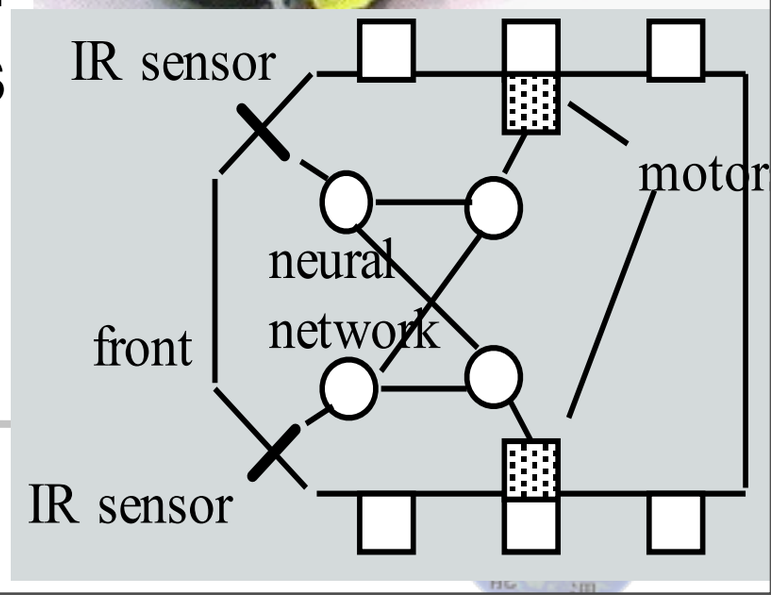
6x6m arena with Styrofoam cubes



Passive Dynamic Walker



Didabot simple robot for didactial purposes



Cheap design
simple mechanism

behavioral rule:

sensory stimulation on left: turn right

sensory stimulation on right: turn left

(obstacle avoidance)

exploiting: borders, shape, weight, friction, morphology, weight distribution

Cheap design
simple mechanism

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understanding the trade-offs

Redundancy
Different physical processes

airplane landing

jet engines
(reverse) propulsion

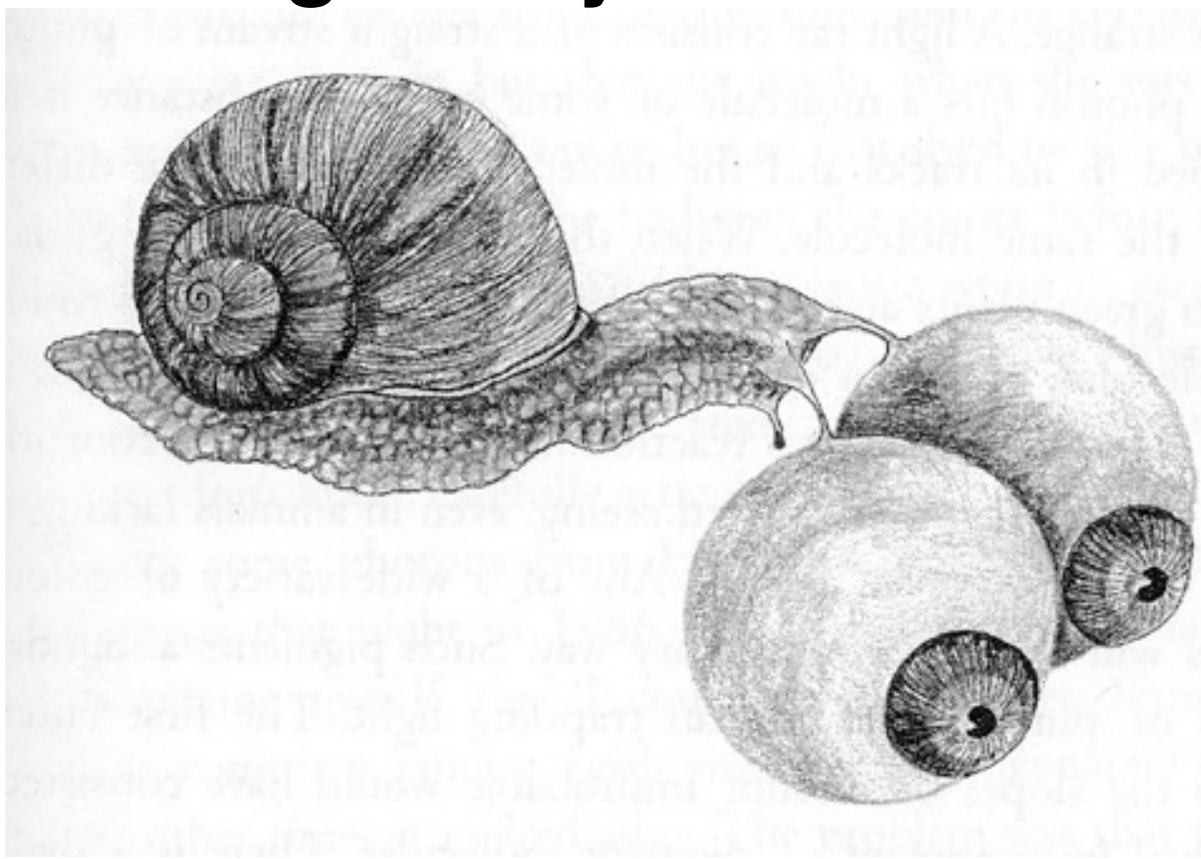
braking systems
partial overlap of functionality

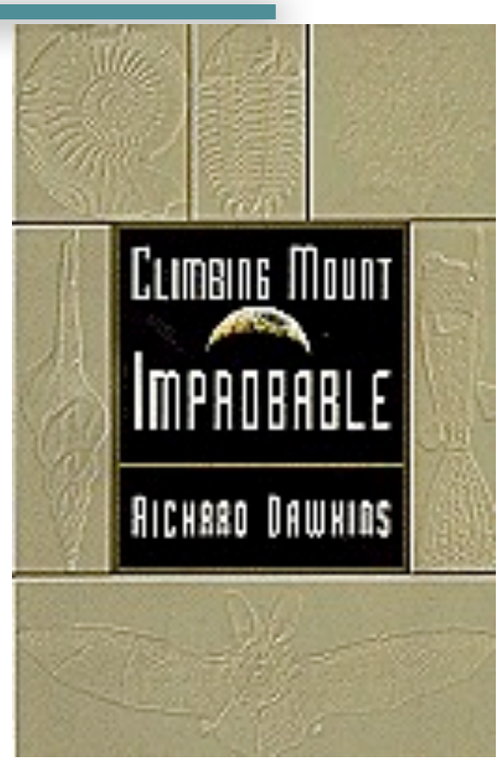
parachutes
mechanical

wheels (friction)
runway conditions

Ecological balance matching complexity

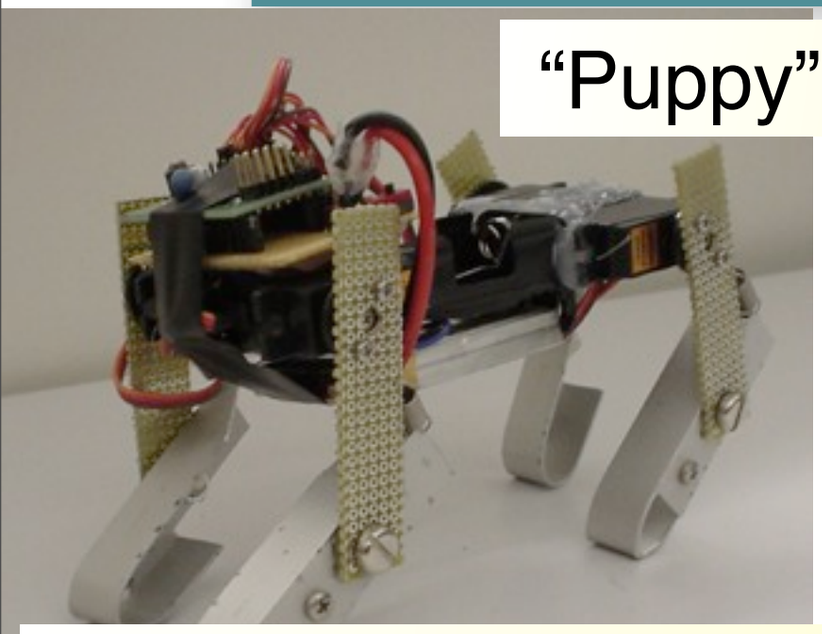
ecologically unbalanced system: Richard Dawnkins' snail with giant eyes





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

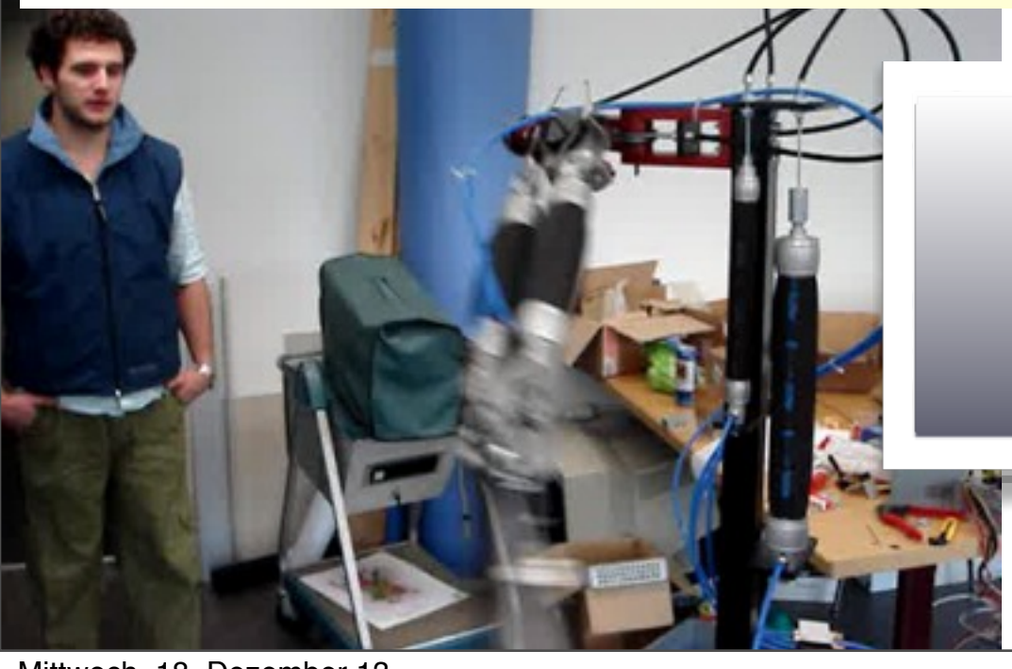
Ecological balance: task distribution morphology, materials, control



"Puppy" with springs

Robot "frog" Mowgli
U-Tokyo
with pneumatic actuators

loosely swinging arm with pneumatic actuators



control partially "outsourced" to properties of springs, pneumatic actuators

robotics Swiss National Centre of Competence in Research

ai lab

The ShanghAI Lectures

Design principles for development

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Motivated complexity	why complexity increases during ontogenetic development (driving force)

Bernstein's problem: Development as an incremental process

learning to control high DOF body: freezing and freeing DOFs

robotics Swiss National Centre of Competence in Research

ai lab

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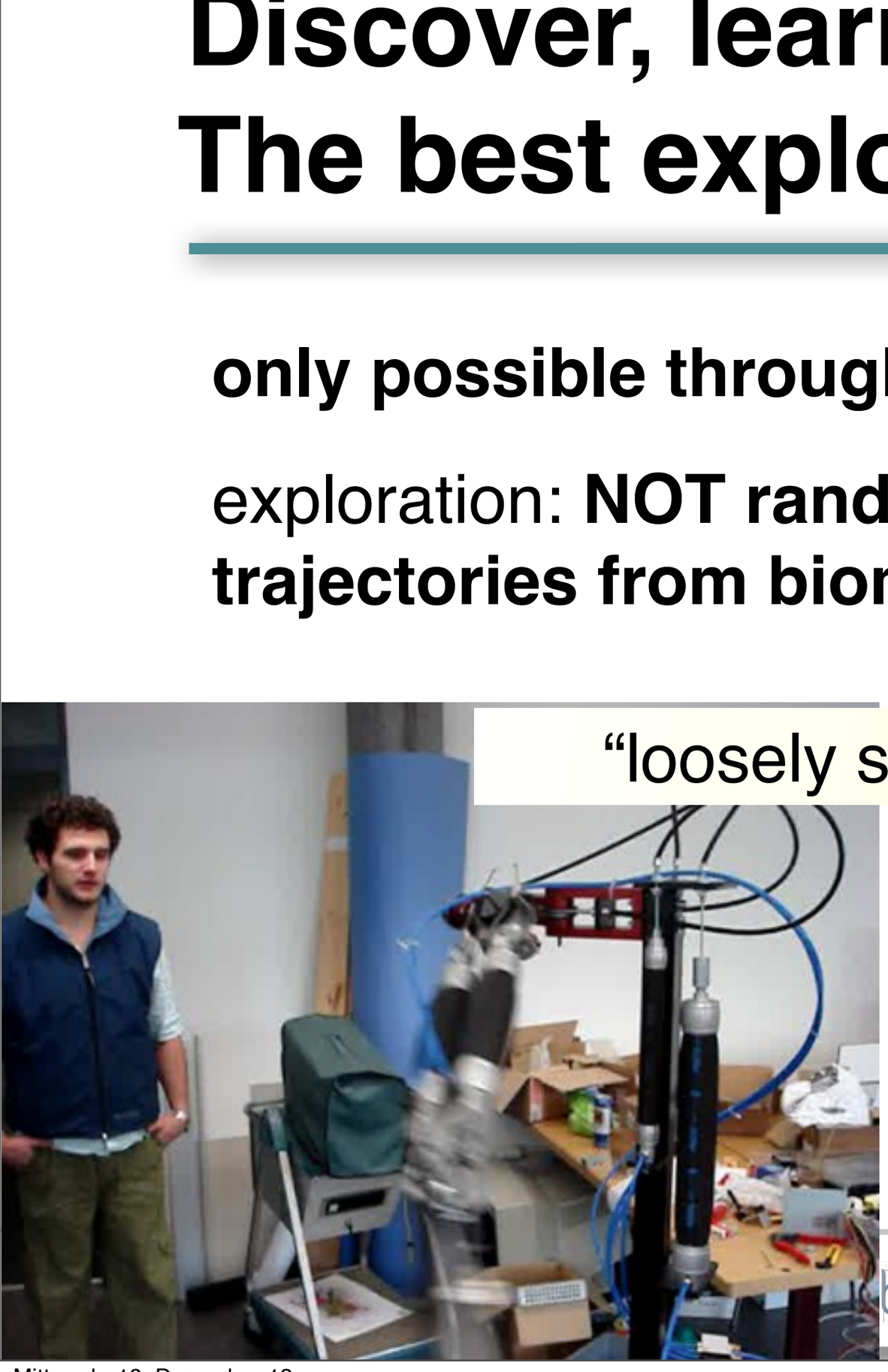
Discover, learn from real world
The best exploration strategies

only possible through embodiment

exploration: **NOT random! —> preferred trajectories from biomechanical constriaints**



“loosely swinging arm”

Design principles for evolution

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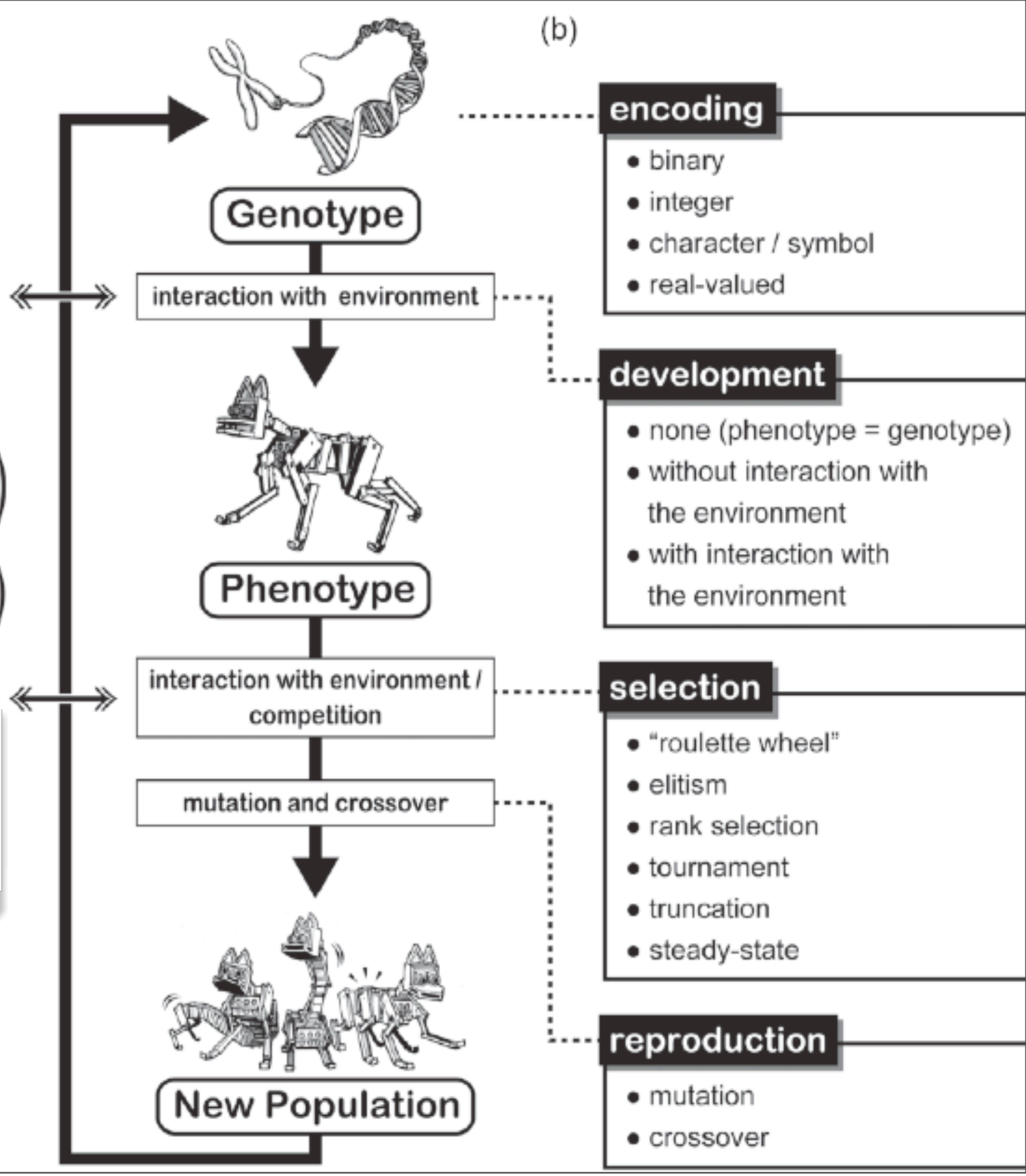
Basic cycle for artificial evolution

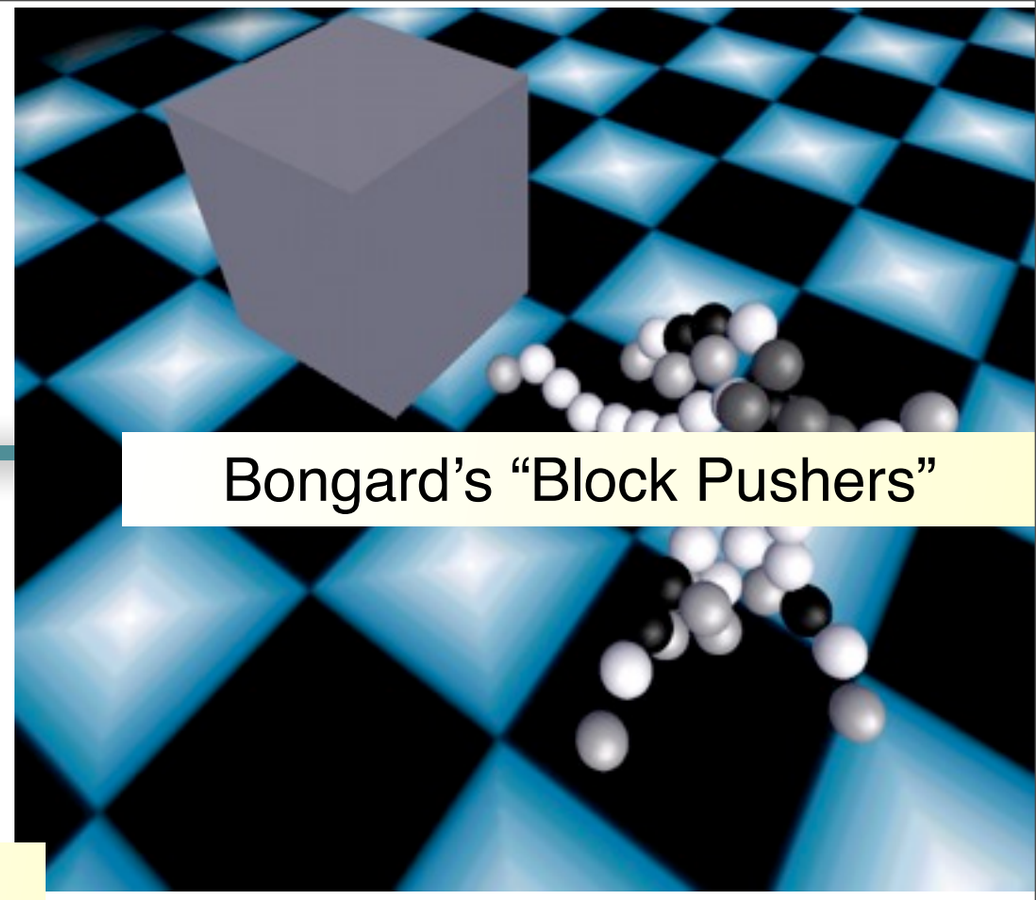


cumulative selection

from
"How the body …"

University of Zurich[UZH]

Brain-body co-evolution

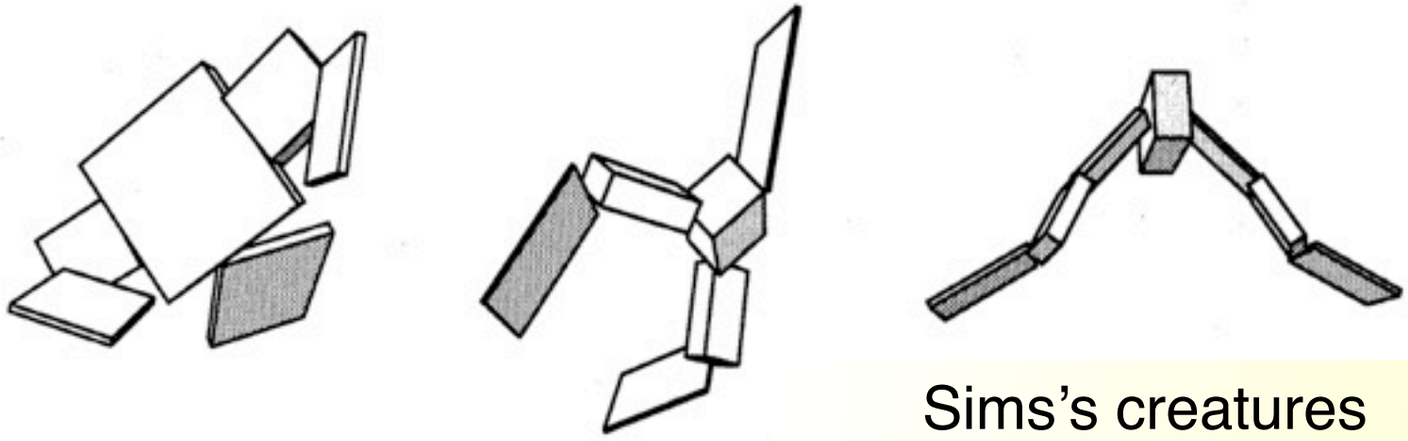


Bongard's "Block Pushers"

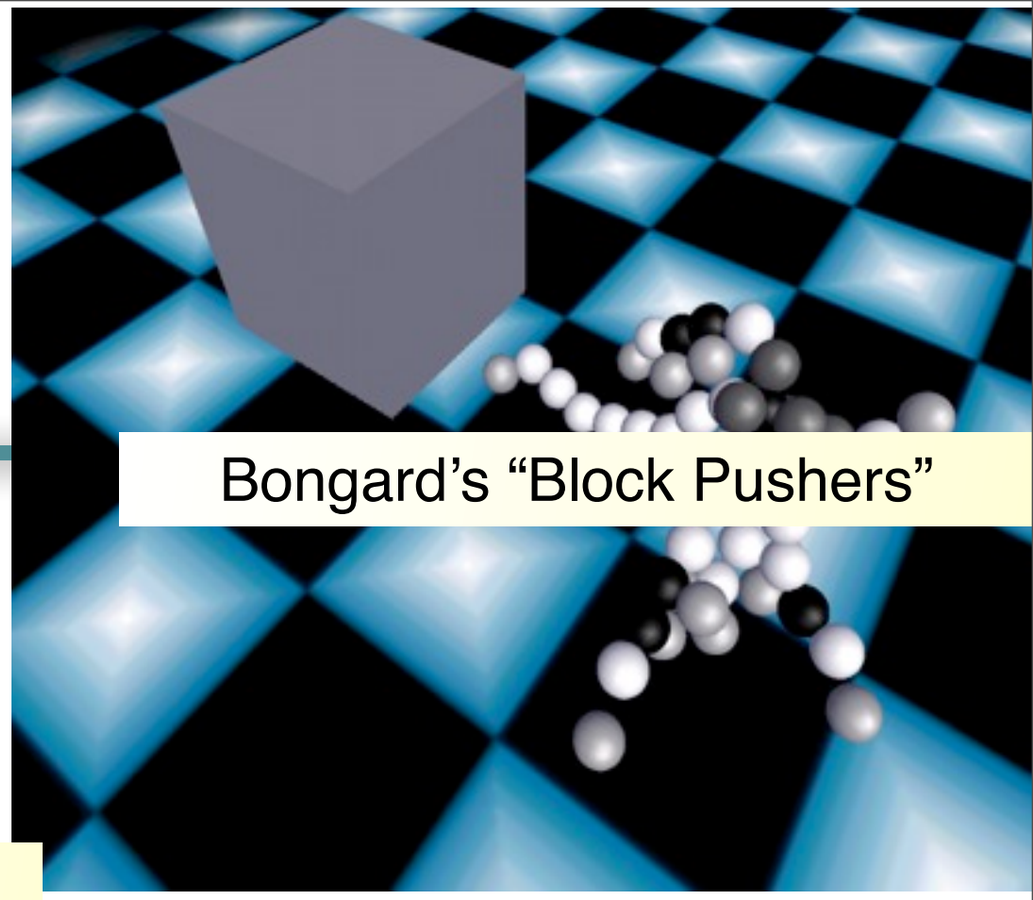
Sims's creatures

Lipson's creatures
"Golem" project

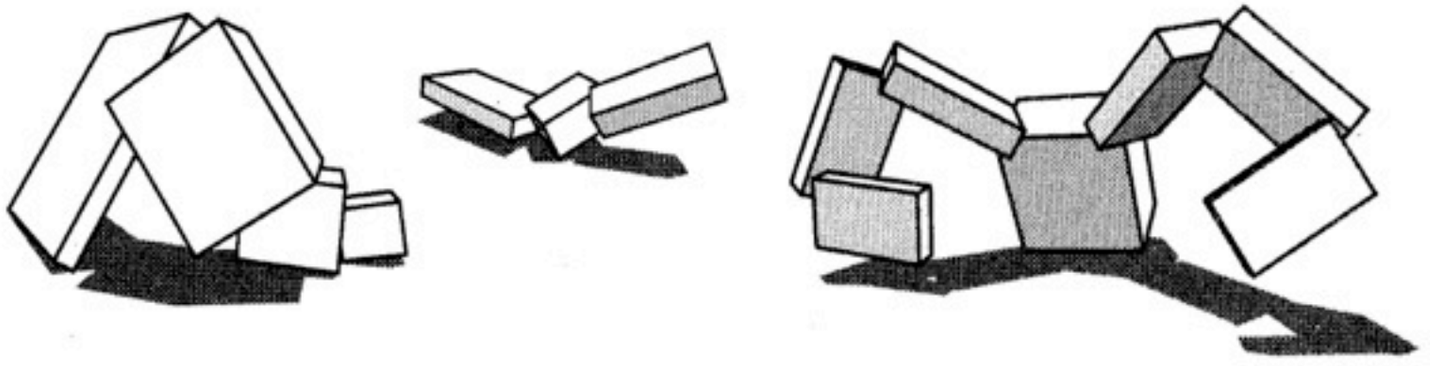
Brain-body co-evolution



Sims's creatures



Bongard's "Block Pushers"



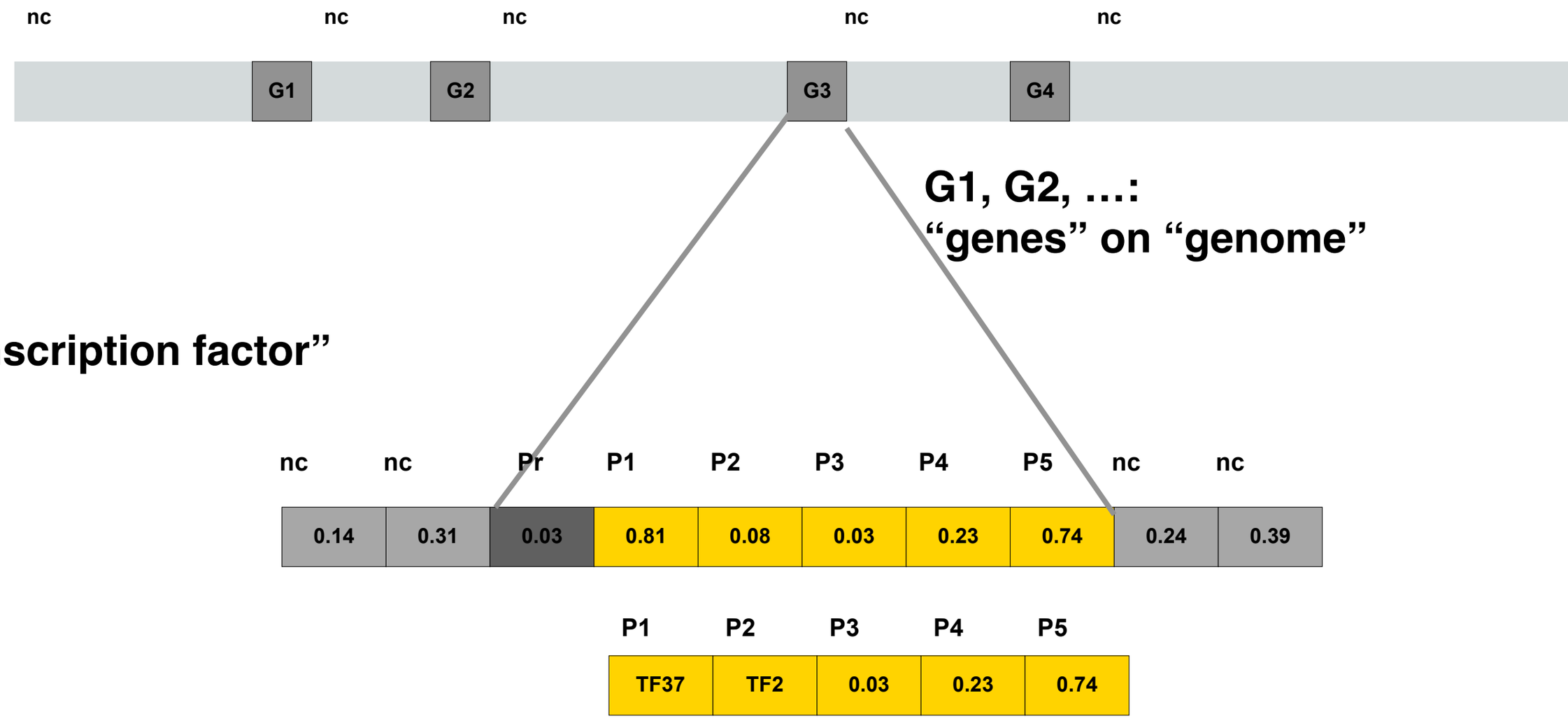
Lipson's creatures
"Golem" project

Encoding of developmental processes in genome

rather than the structure of the organism

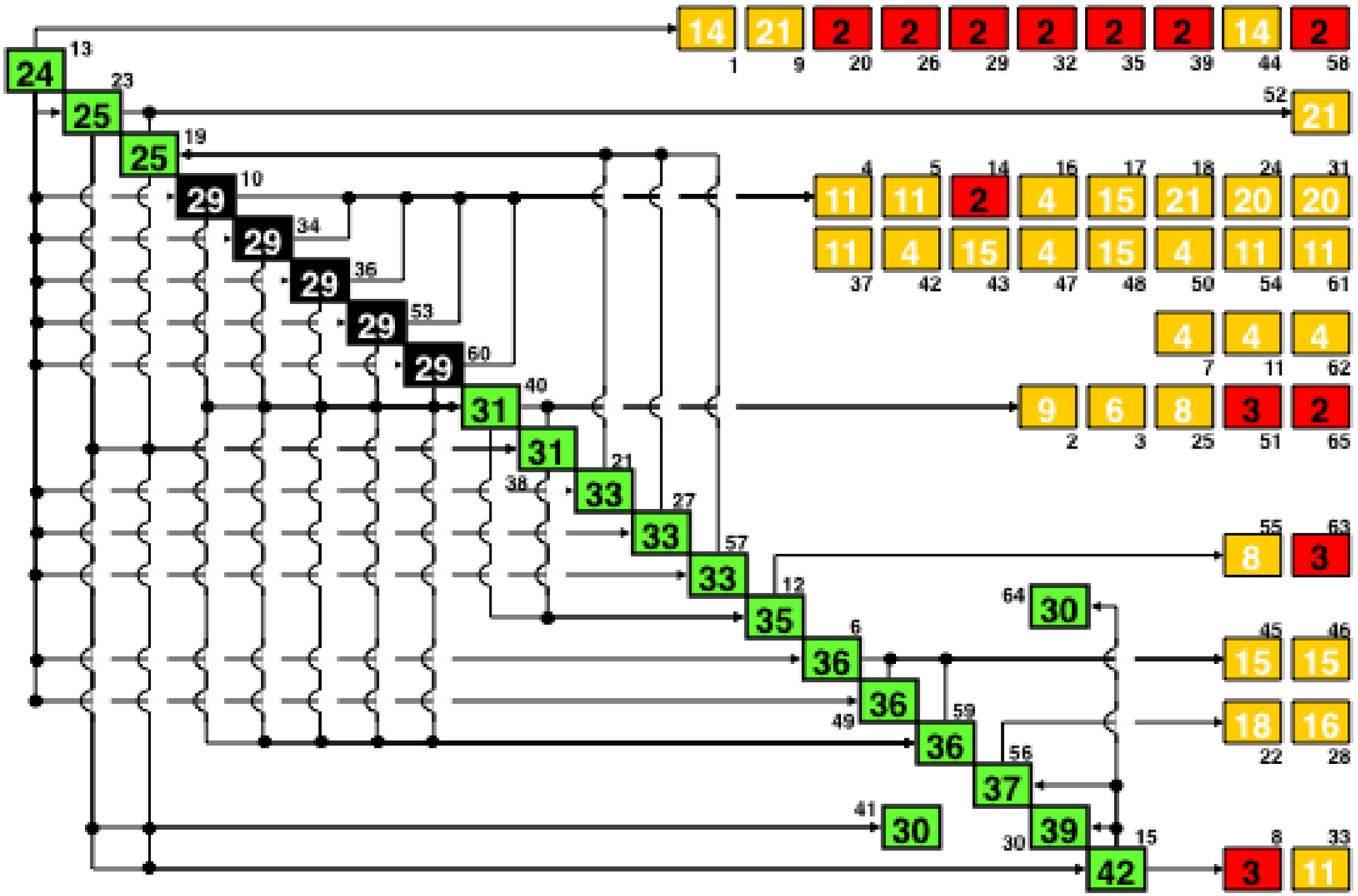
Encoding developmental processes
Representation of “gene”

nc: “non-coding region”



TF: “transcription factor”

GRN for evolved creature (Josh Bongard)



Steps toward a theory of intelligence

- Meta-considerations: “Mind Set”
- Illustration of selected design principles
- **Seeing things differently**

Seeing things differently

- “Cleaning up”, the “Swiss robots”
- Walking without control
- Rapid locomotion with “slow” electronics
- Coordination through interaction with world
- Social interaction as “reflexes”
- Optimization without cognition
- Creative computers

Activities involved in clustering: standard solution

6x6m arena with Styrofoam cubes

- Look for cube, if possible, the nearest one).
- Pick up cube (somehow).
- Look for nearest cluster.
- Go to cluster.
- Deposit cube.
- Look for new cube, etc.

sophisticated perceptual skills required

The solution: simple rules

behavioral rule:

sensory stimulation on left: turn right

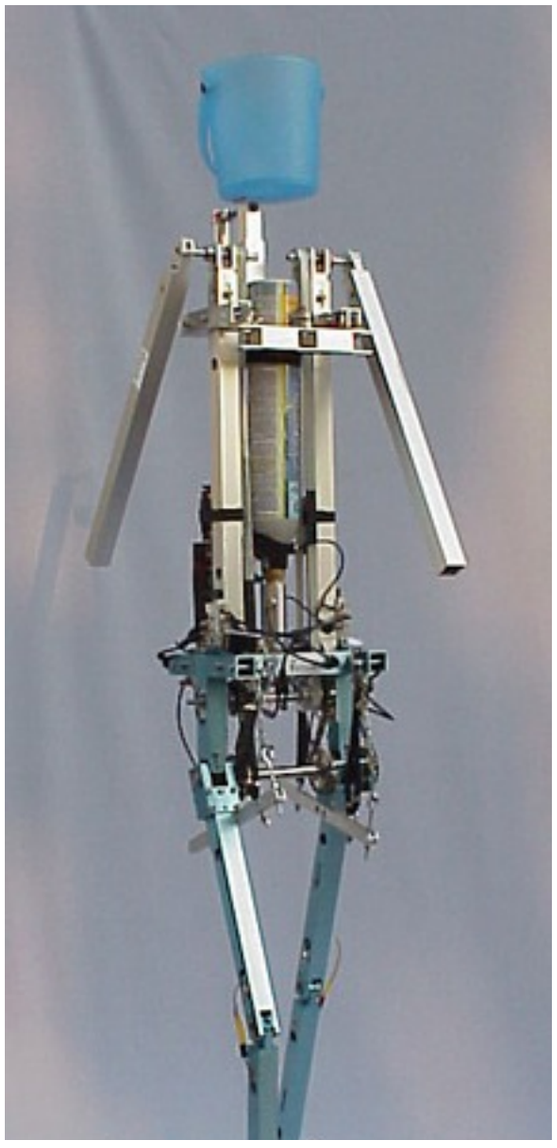
sensory stimulation on right: turn left

(obstacle avoidance)

situated perspective (from the agent's point of view)

Walking without control?

The solution:
The “Passive Dynamic

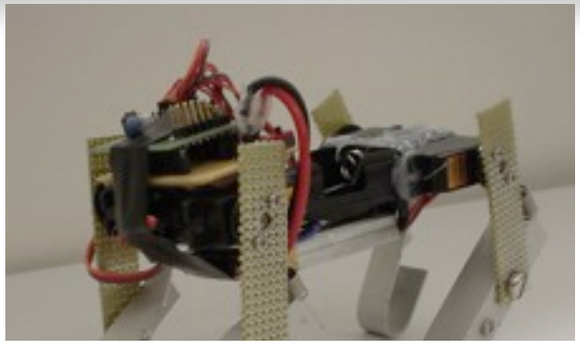


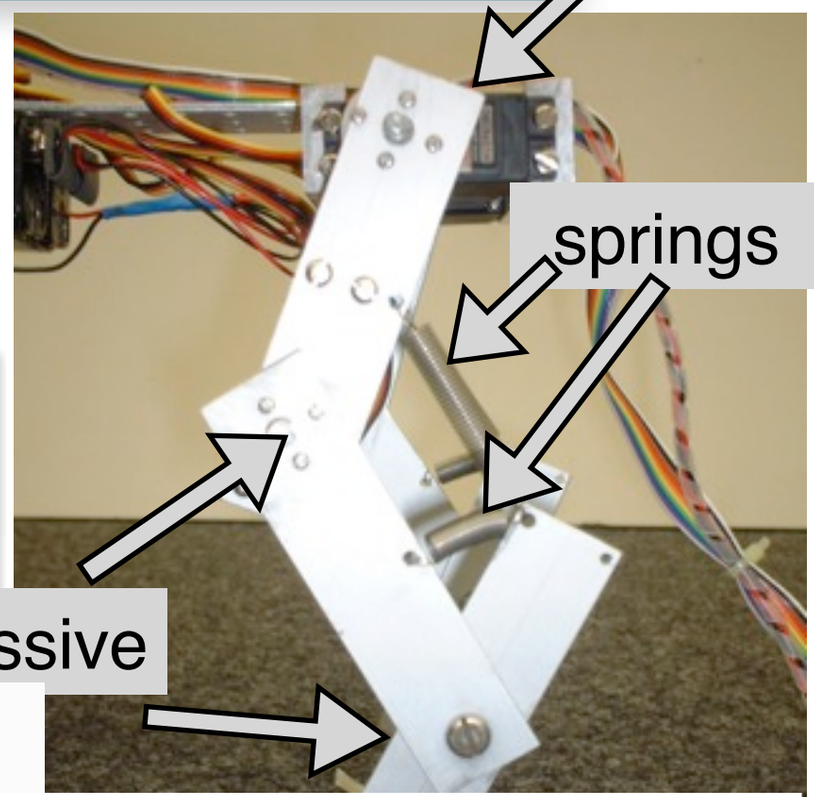
“Denise”
no control for
balance

Rapid locomotion with slow electronics/brains?

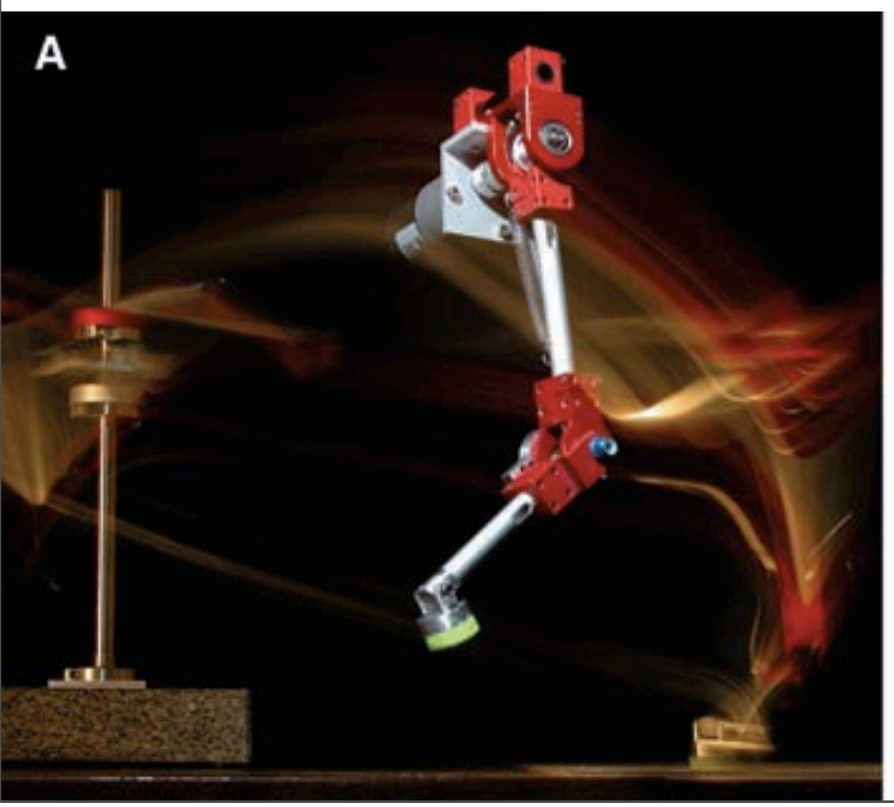
The solution: “Exploitation of morphology and materials”

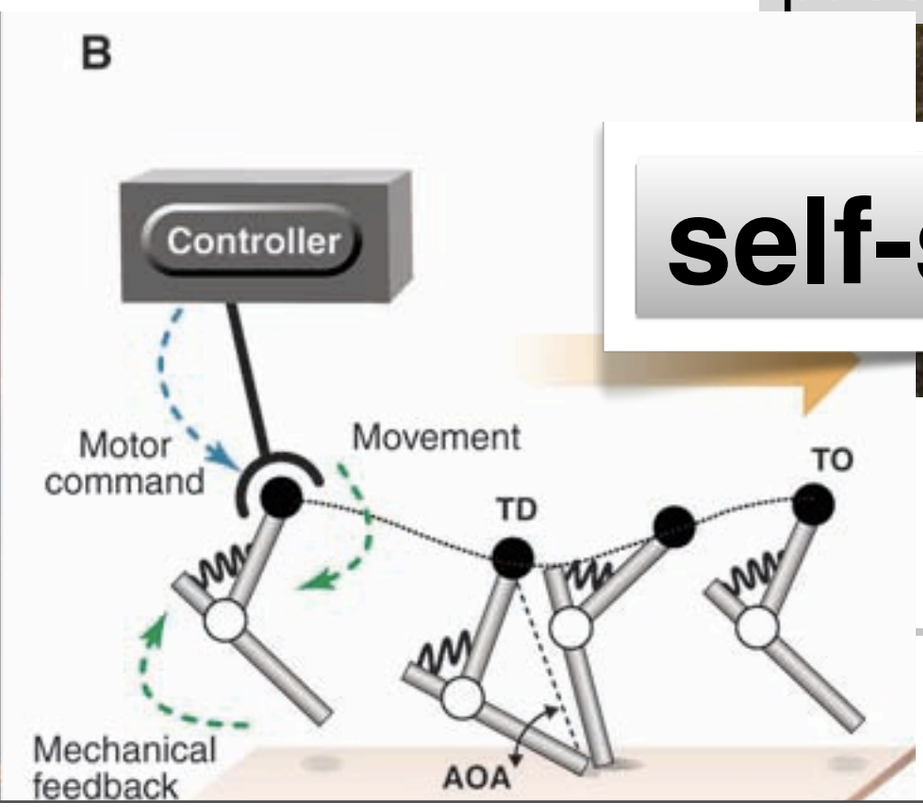
“Puppy”





morphological computation



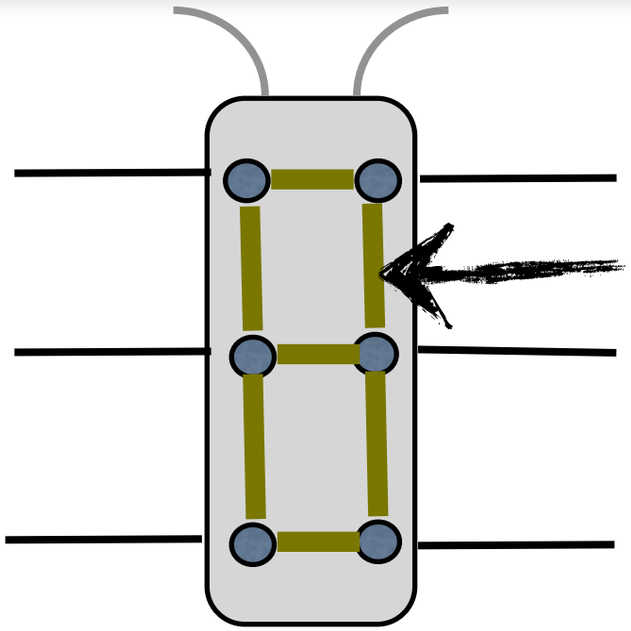


self-stabilization

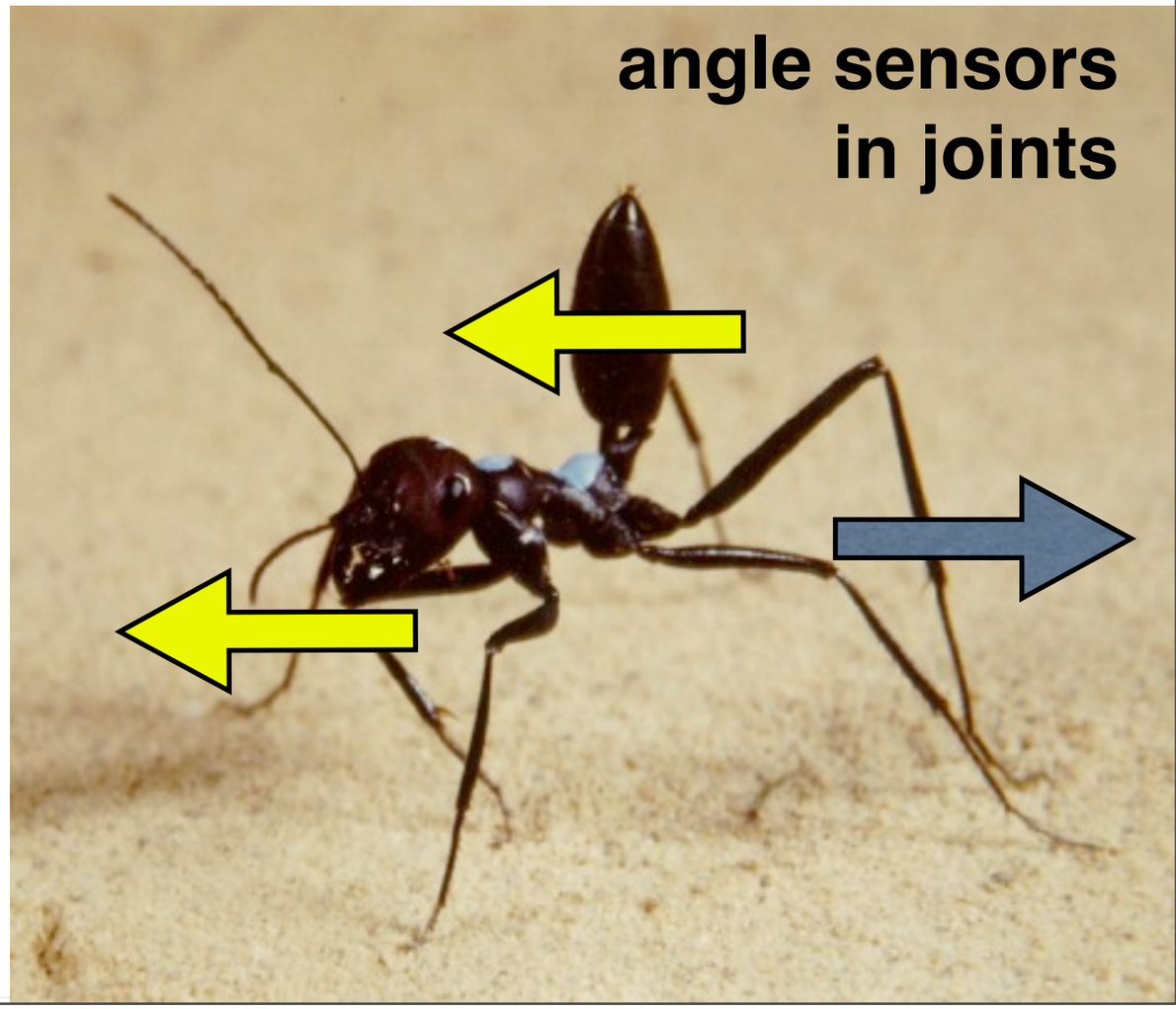
Jena monoped

Leg coordination without central control?

The solution: global communication through interaction with real world



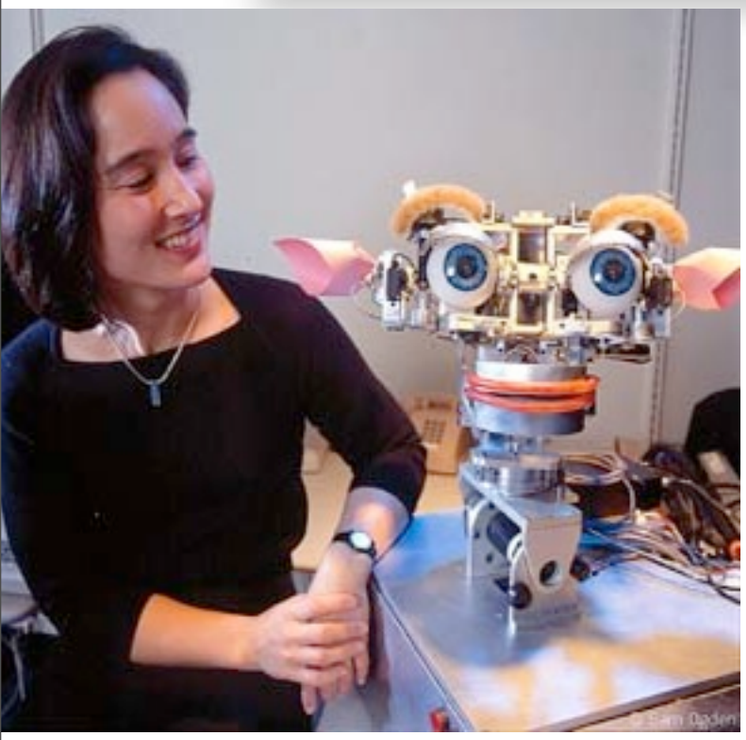
neural connections



“parallel, loosely coupled processes”

Social competence without high-level cognition?

Social competence without high-level cognition?



Cynthia Breazeal, MIT Media Lab

reflexes:

turn towards sound

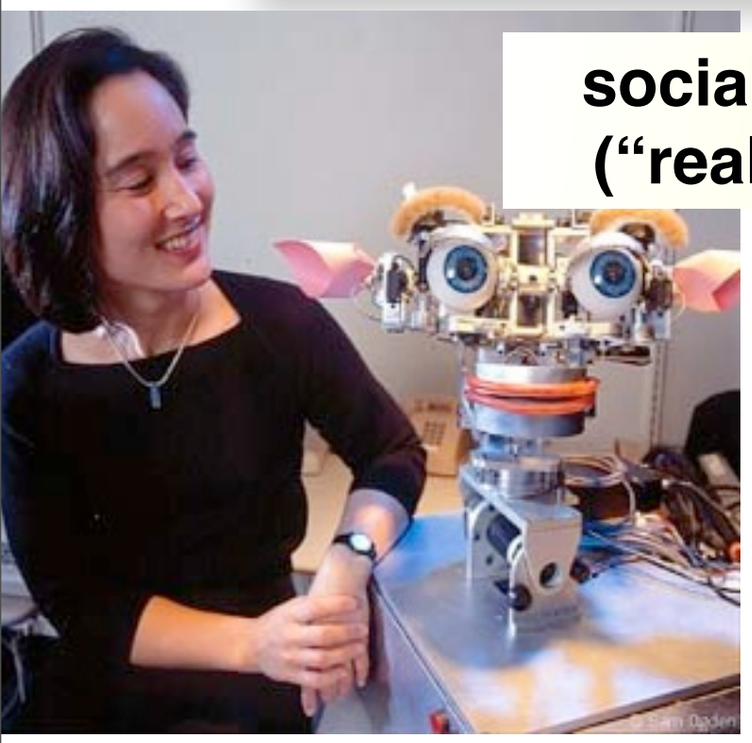
turn towards moving objects

visual tracking of slow objects

habituation

Video “Kismet.mov”

Social competence without high-level cognition?



social competence ("real" or "as if"?)

Cynthia Breazeal, MIT Media Lab

reflexes:

turn towards sound

turn towards moving objects

visual tracking of slow objects

habituation

Rodney Brooks, previously MIT, now ReThink Robotics:
"What do you mean — 'as if'? This IS social competence"

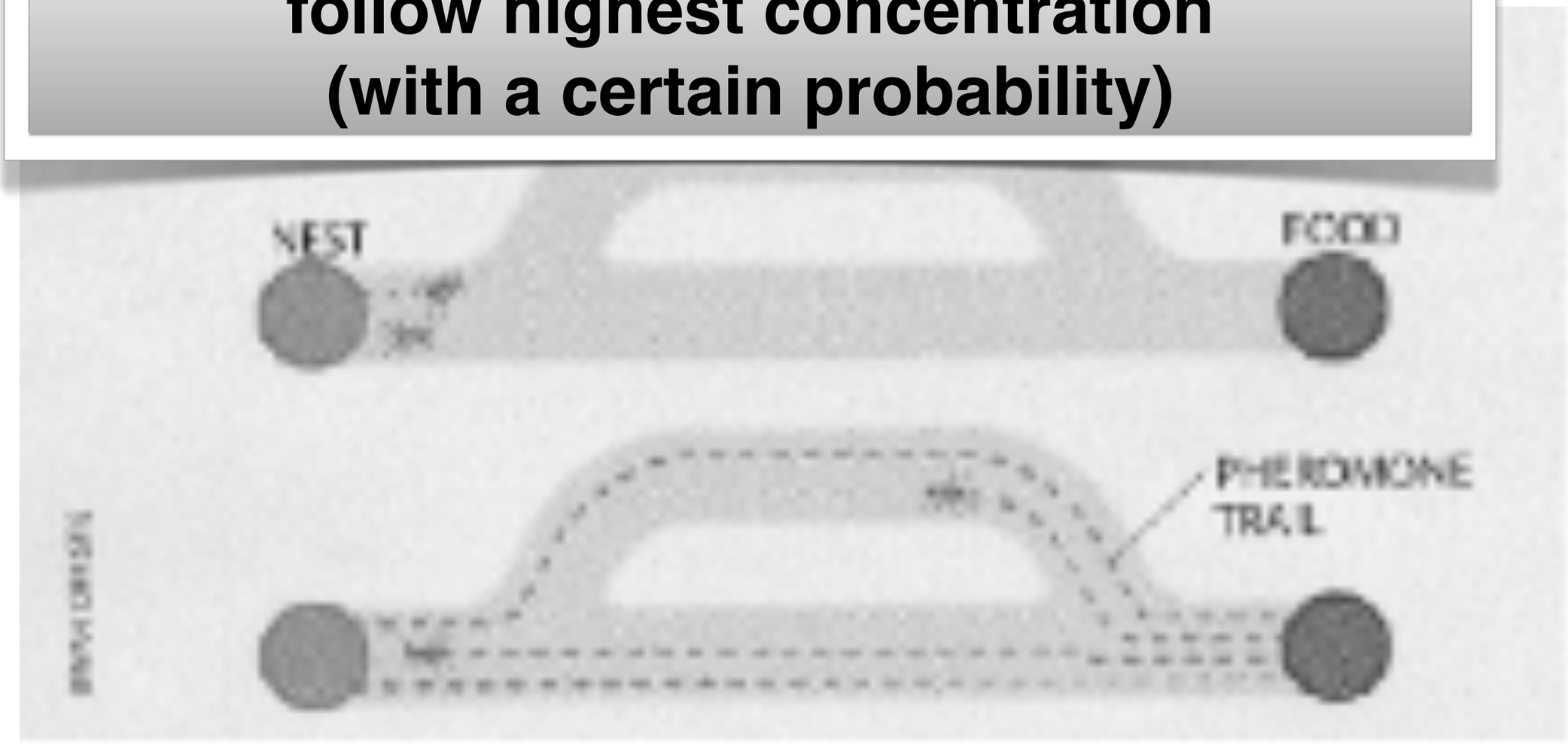
Social behavior through simple reflexes?

John Bargh, Psychologist, Yale Univ. “The unbearable automaticity of being”, 1999

Finding shortest paths without measuring, storing, comparing?

Finding shortest paths without measuring, storing, comparing?

deposit phermone
follow highest concentration
(with a certain probability)



Creative computers, robots?

The myth:
“Computers can never be creative — they can only reproduce what you program into them”

Don’t overestimate yourself:

From the movie I-Robot

From the movie I-Robot

From the movie I-Robot

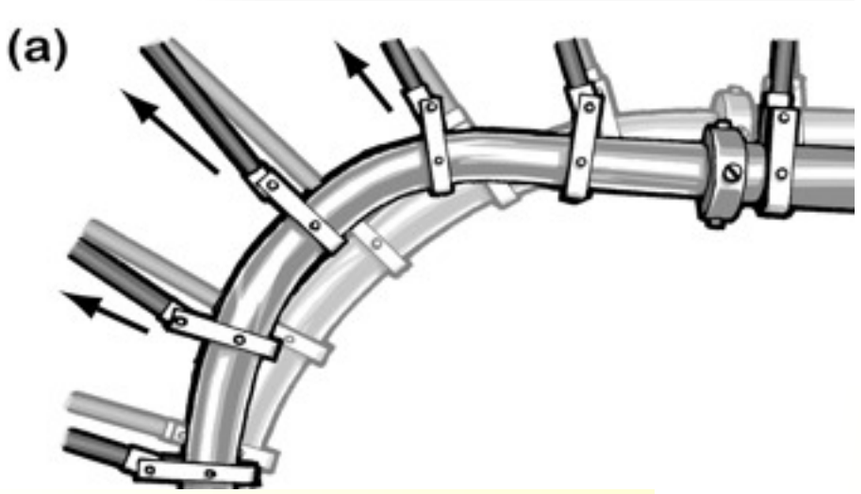
But a robot could never write a symphony like Beethoven!

From the movie I-Robot

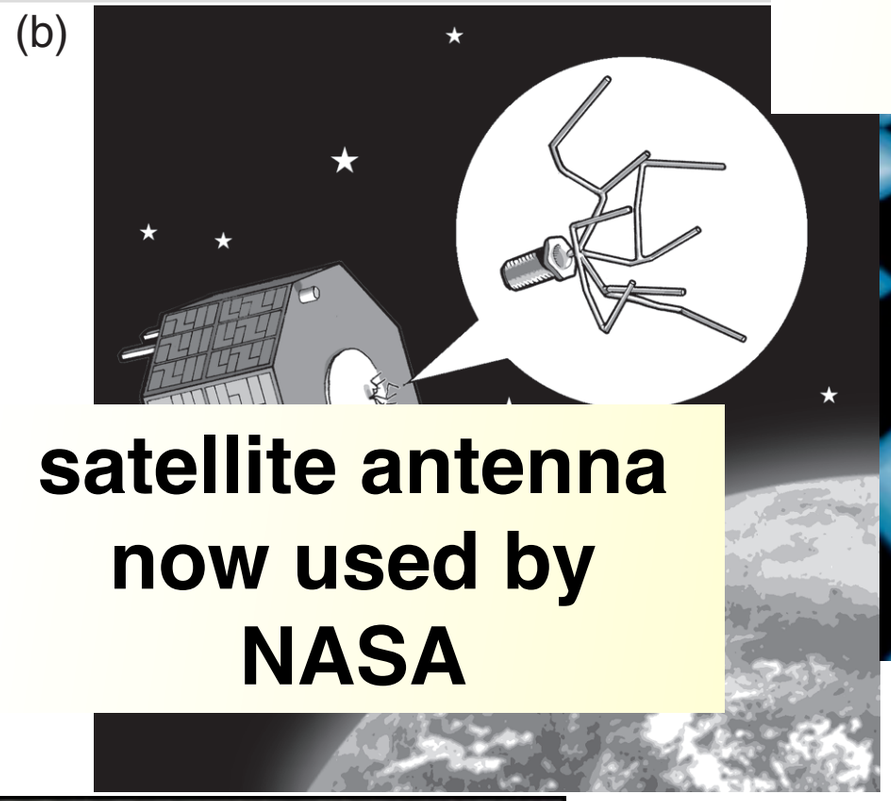
But a robot could never write a symphony like Beethoven!

Could you?

Solution: Artificial evolution and morphogenesis

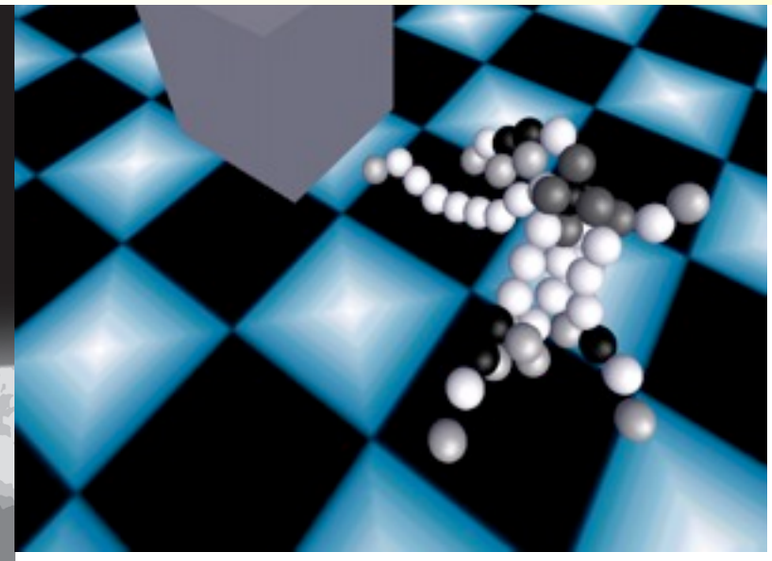


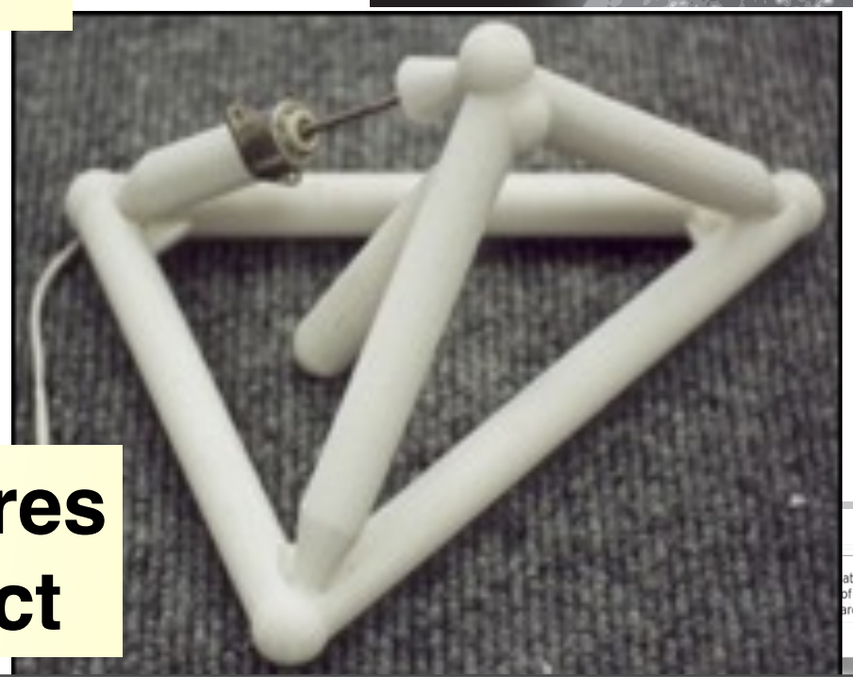
Rechenberg's "hunched" fuel pipe solution



satellite antenna now used by NASA

Bongard's "Block Pushers"

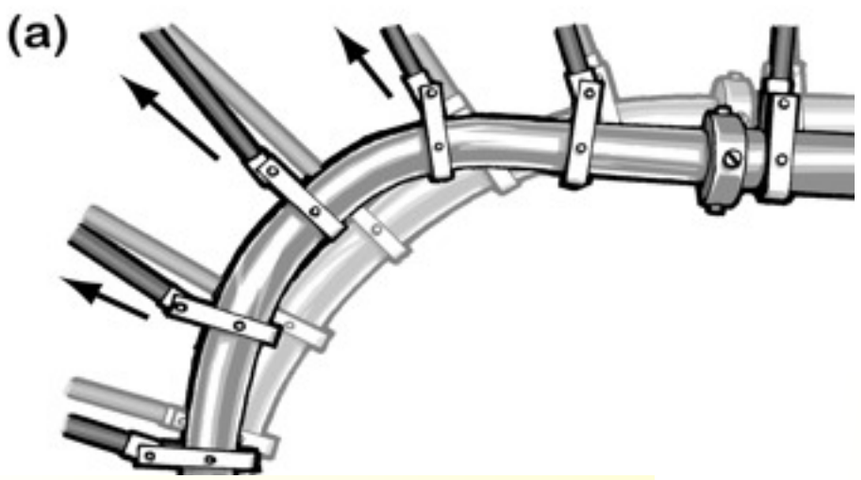




Lipson's creatures "Golem" project

Sims's creatures

Solution: Artificial evolution and morphogenesis



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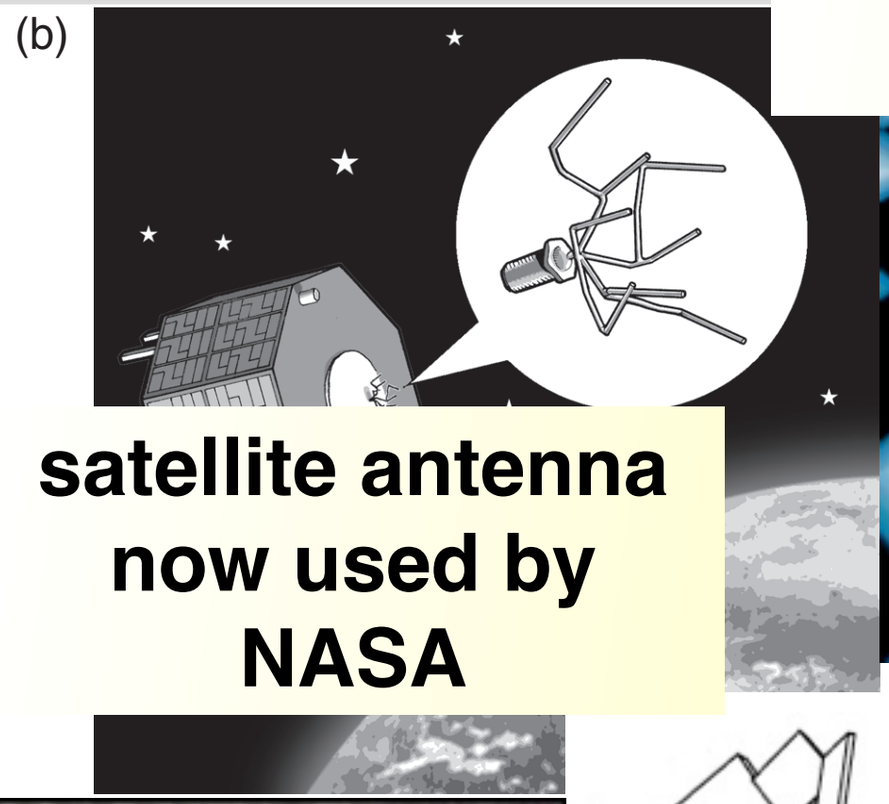

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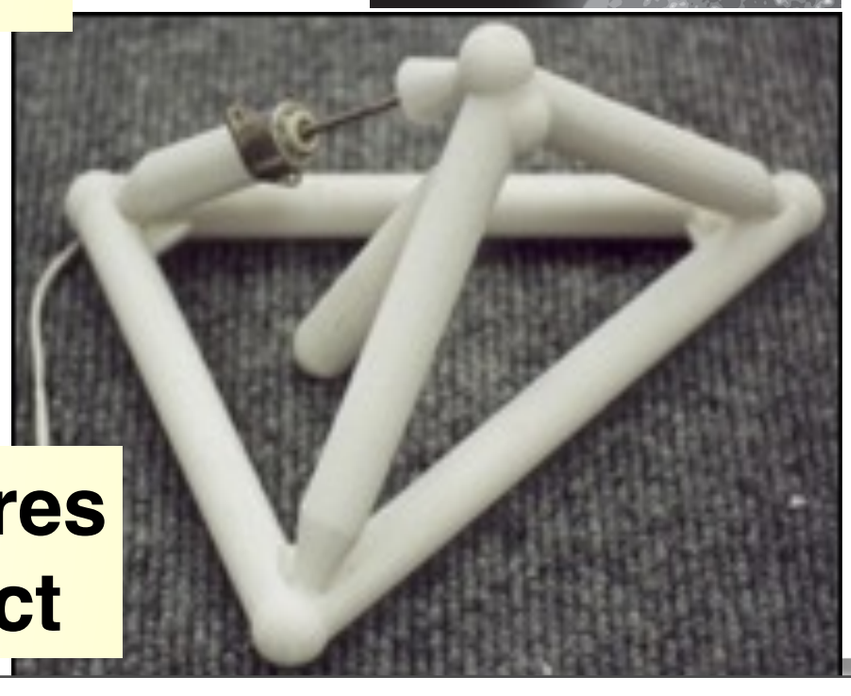
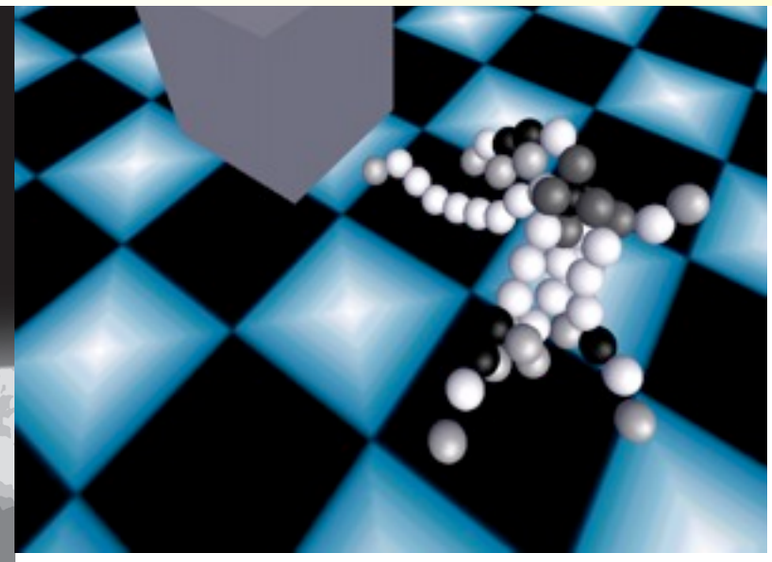
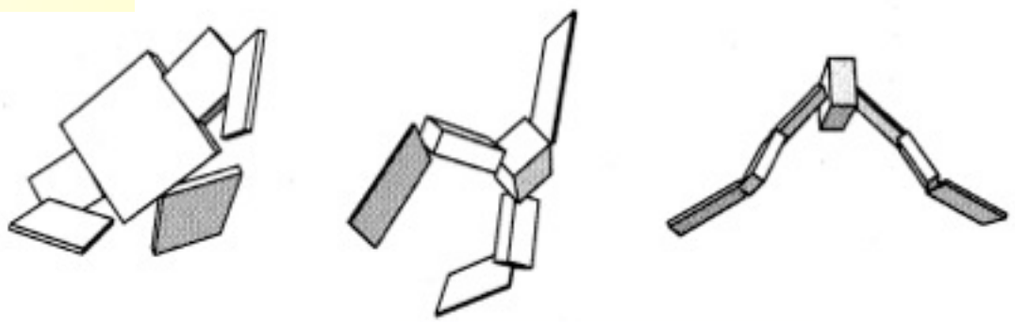


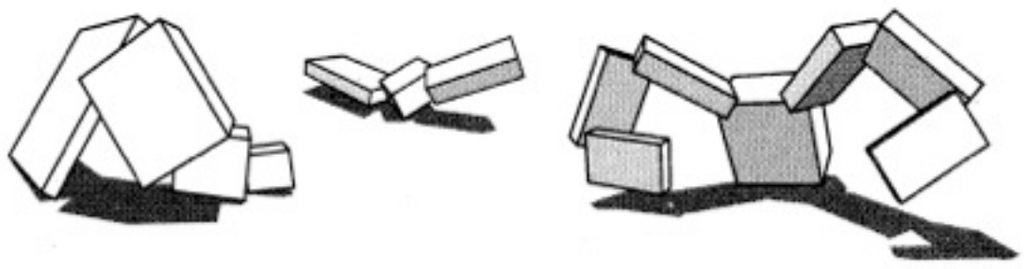
Lipson's creatures "Golem" project

Bongard's "Block Pushers"





Sims's creatures



Morphogenesis (Bongard and Bisig, 2001)

Creatures "from scratch"

Video "growth.mov"

Epilogue

Sun I, son of a Chinese mother and American fighter pilot. Mother dies at birth, father returns to US. Sun I grows up in monastery, Wu, the chef (cook), is his mentor. One of the chores: carrying water in buckets from the river to the monastery, which was situated on a high rock. When they arrived at the top, Sun I's buckets were always empty (spilling), Wu's always full.

Listen to the following conversation:

Sun I and Wu carrying water buckets

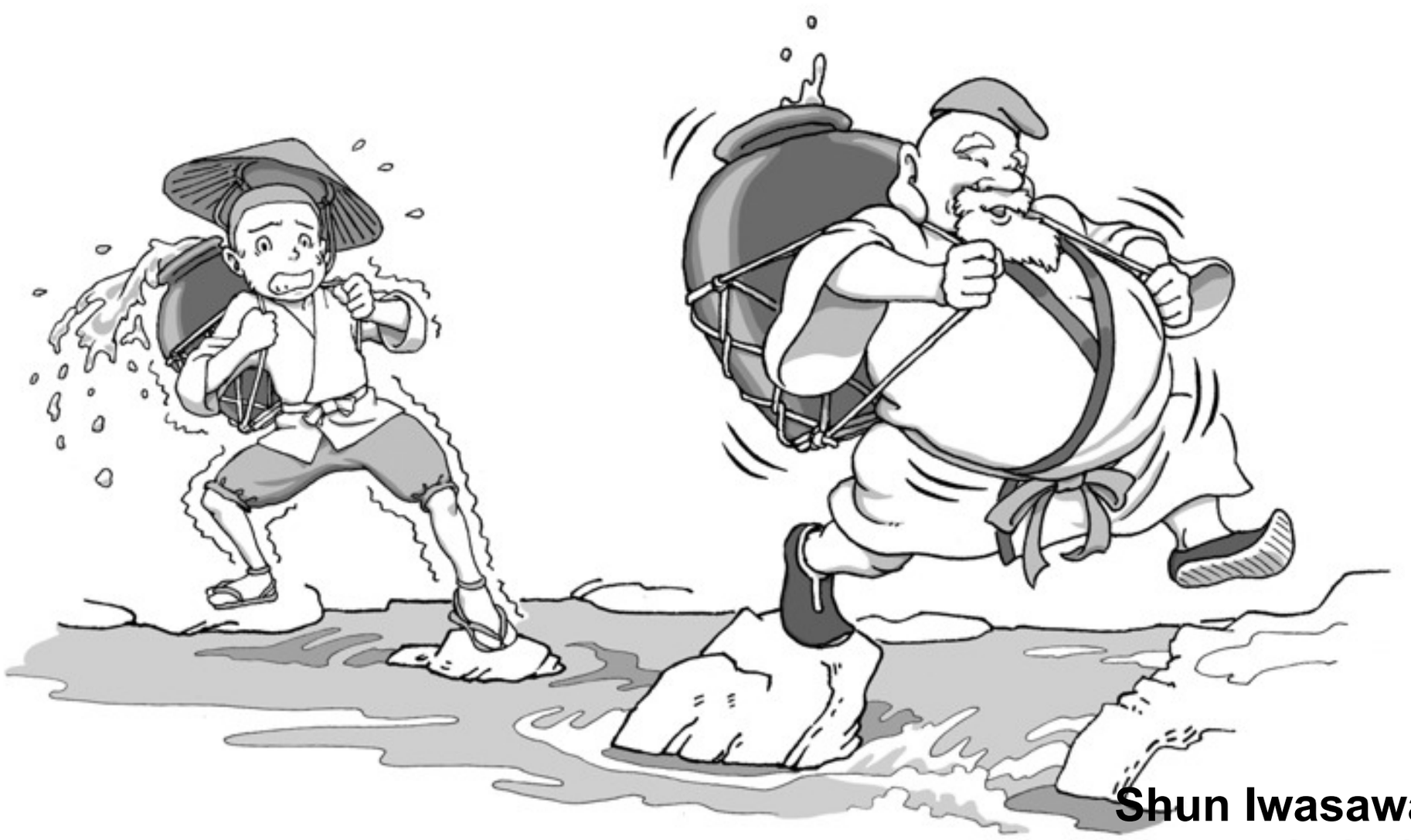


Illustration:
Shun Iwasawa, Studio Ghibli, Tokyo from Pfeifer/Pitti: “La révolution de l’intelligence du corps”, 2012.”

Conversation between Sun I and Wu

It was true. By some extraordinary luck or skill Wu never seemed to lose a drop, though he hurried along the treacherous stair at twice my pace. (I tried to cut my losses by moving slowly, plotting my course in advance and picking each footrest with deliberate care.)

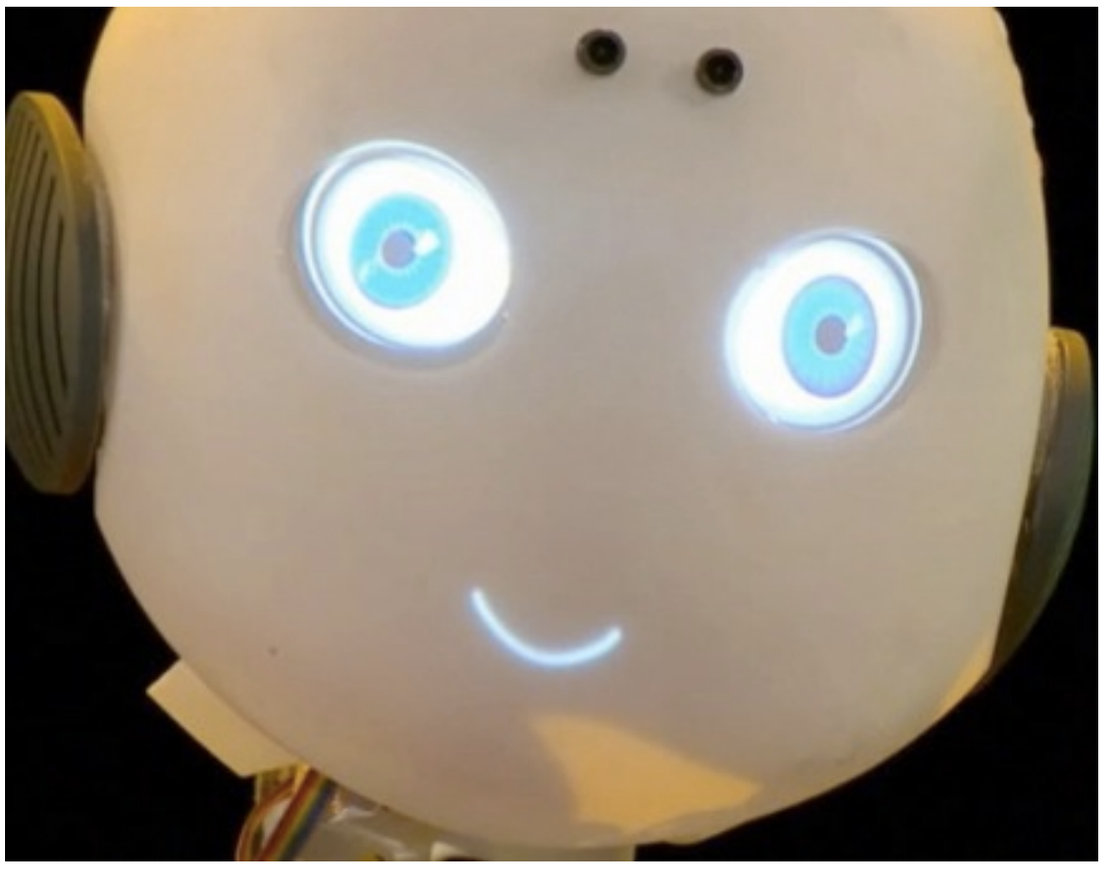
"I don't understand it," I confessed to him. "You must know some kind of trick. Explain your method." ...

"You haven't yet caught on. It's precisely this—excess of method—that confounds you, leaves the buckets nearly empty …"

"If you're so smart, how do you do it then?"

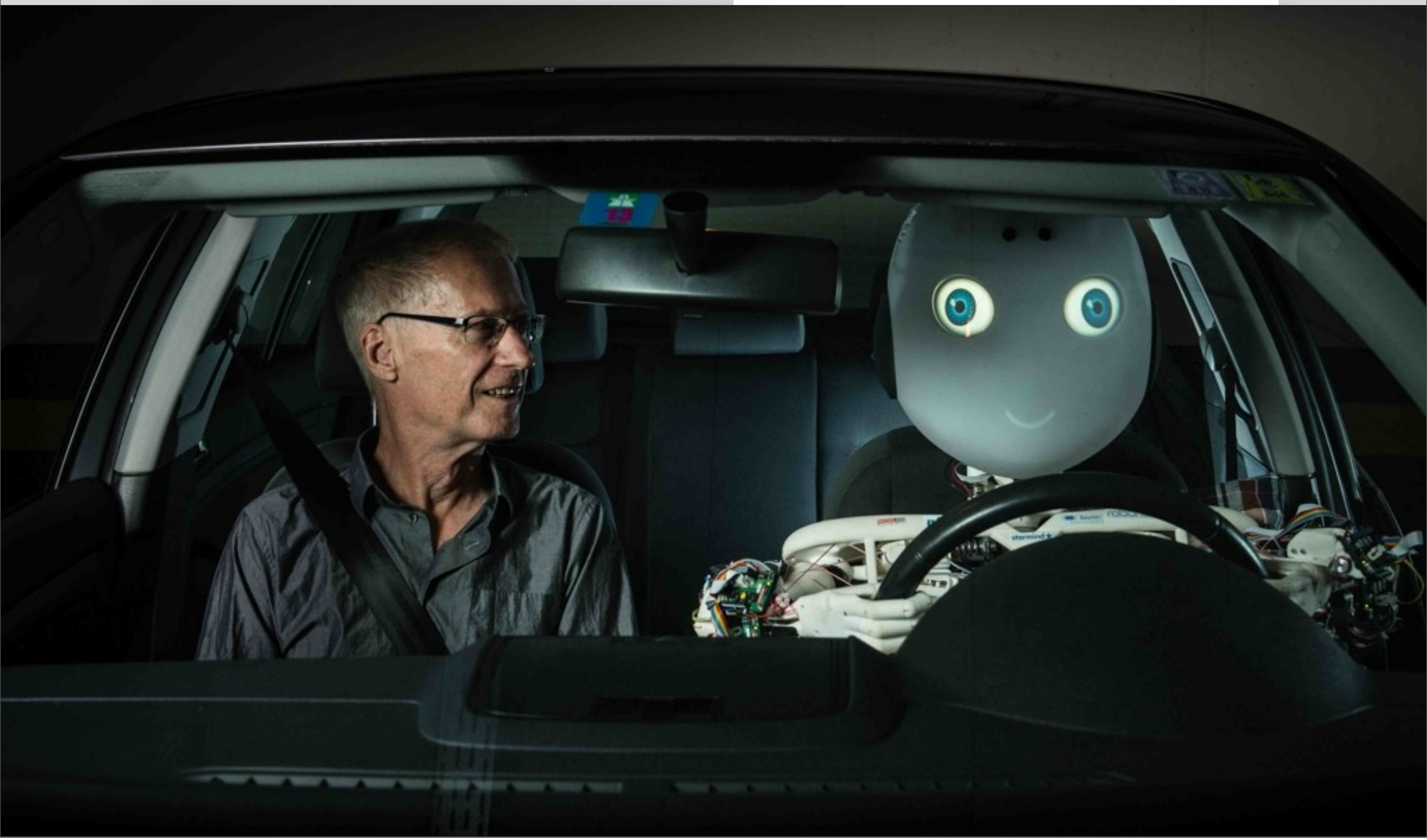
"How do I do it? . . . I close my eyes and think of nothing. My mind is somewhere else. My legs find their way without me, even over the most uneven ground. How can I tell you how I do it? . . . I can't even remember myself!" (Payne, 1984, pp. 18–19)

That’s it!



Thank you for your attention!

The future?



Selected highlights

Through engineering to science

Information self-structuring through sensory-motor coordination

Exploiting morphological computation

“outsourcing” control functions into morphological and material properties

Dealing with impact while running

Outsourcing of control to material characteristics of muscle-tendon system

The big humiliations of mankind forcing a different view

- **The Copernican turn (1473 - 1543)**
- **Charles Darwin's theory of natural selection (19th Century)**
- **Sigmund Freud's psychoanalytic theory of neurosis —> behavior not under conscious control; free will?**
- **Watson-Crick: DNA — mechanism for life's hereditary information (Nobel Prize, 1962) (just as flatworm and yeast)**
- **Human Genome Project: 20'000 to 25'000 genes, instead of expected over 100'000, similar to flatworm** C.elegans
- **Humans as machines? as robots?**

End of selected highlights