Lecture 10: Part 2 - Design Principles

Summary and conclusions

"How the body shapes the way we think - principles and insights"

(slides for self-study)

Rolf Pfeifer

11 December 2012

University of Zurich

ai lab

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

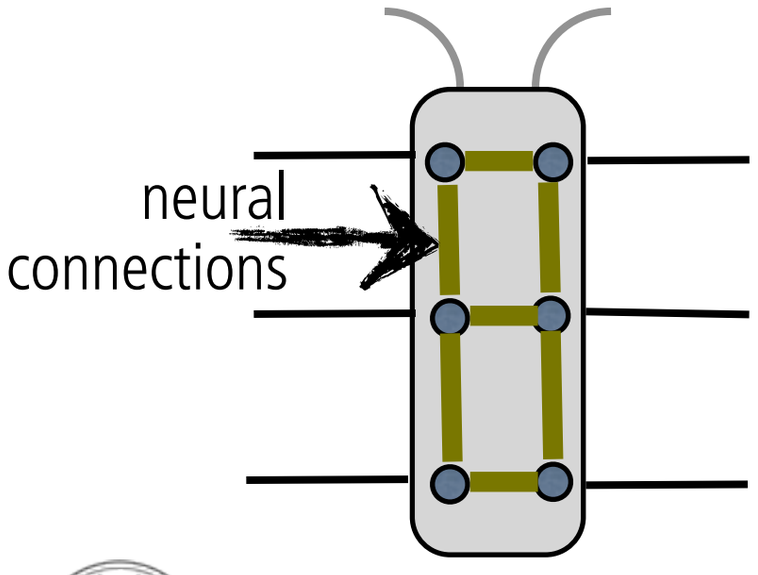
Design principles for collective intelligence

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**



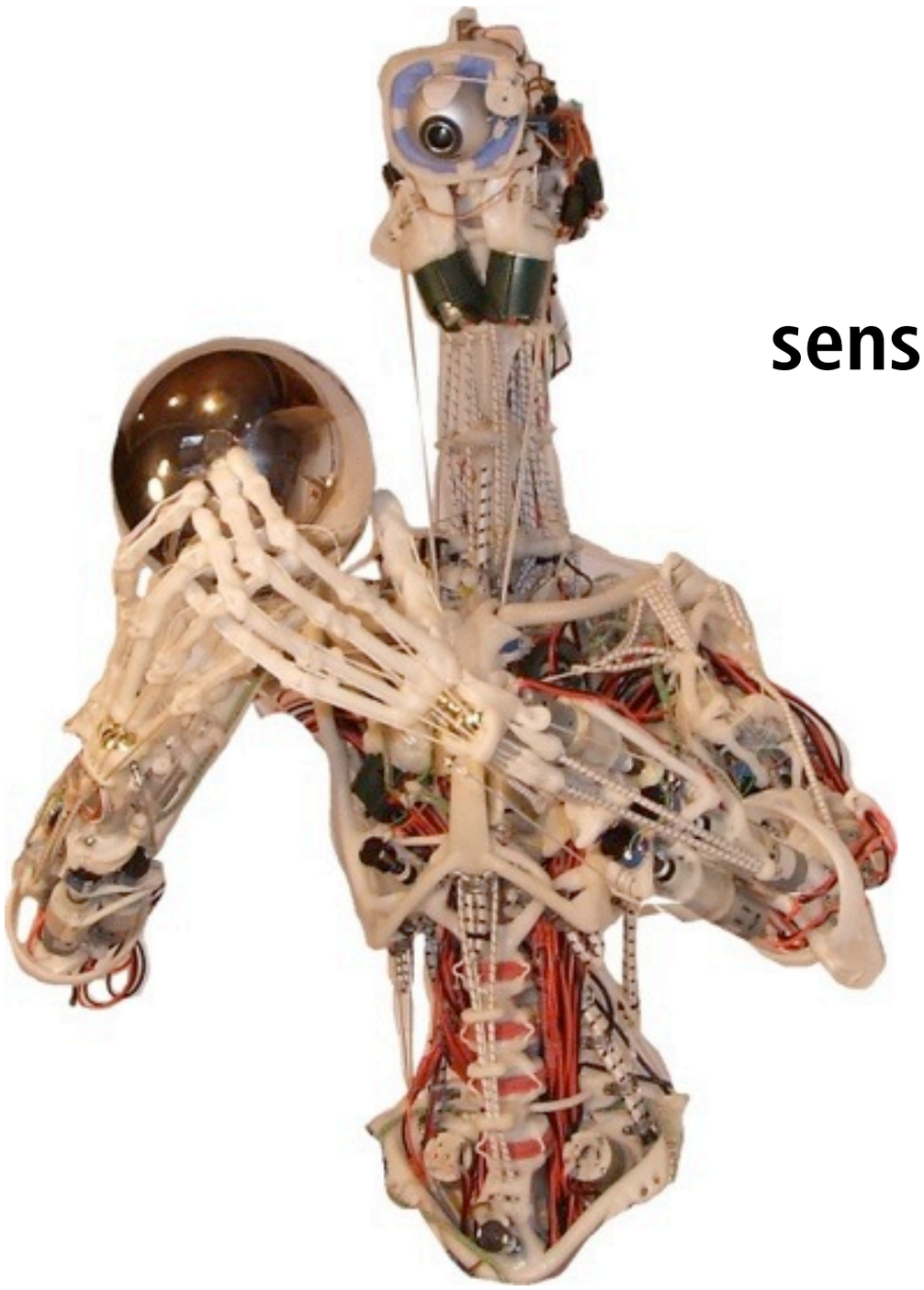
Parallel, loosely coupled processes

coupling through pheromone trails in environment

Pheromone trails enable ants to search for food efficiently: Two ants leave the nest at the same time (top), each taking a different path and marking it with pheromone. The ant that took the shorter path returns first (bottom). Because this trail is now marked with twice as much pheromone, it will attract other ants more than the longer route will.

WARNING: holds not only for ants, but also for humans!!!

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

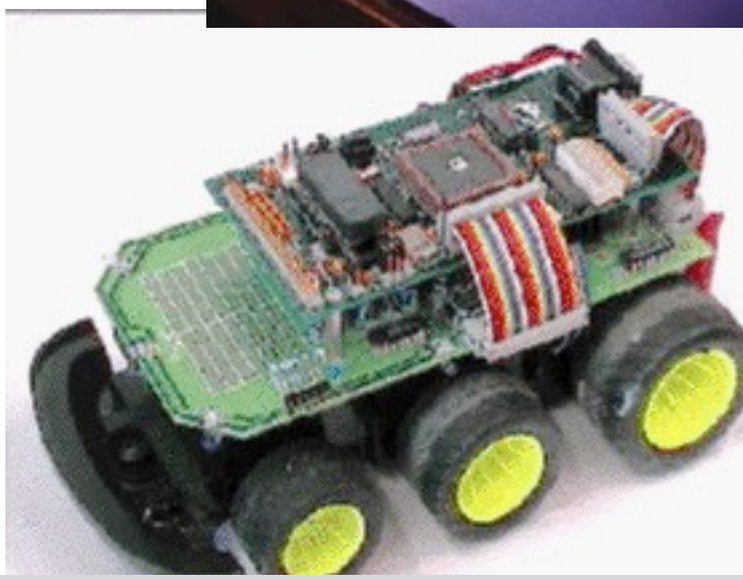
- cross-modal association, learning, concept formation
- identification of mutual information
- prediction
- categorization (fundamental for cognition)

brief explanation of "mutual information"
what is it? example? importance?
—> anyone

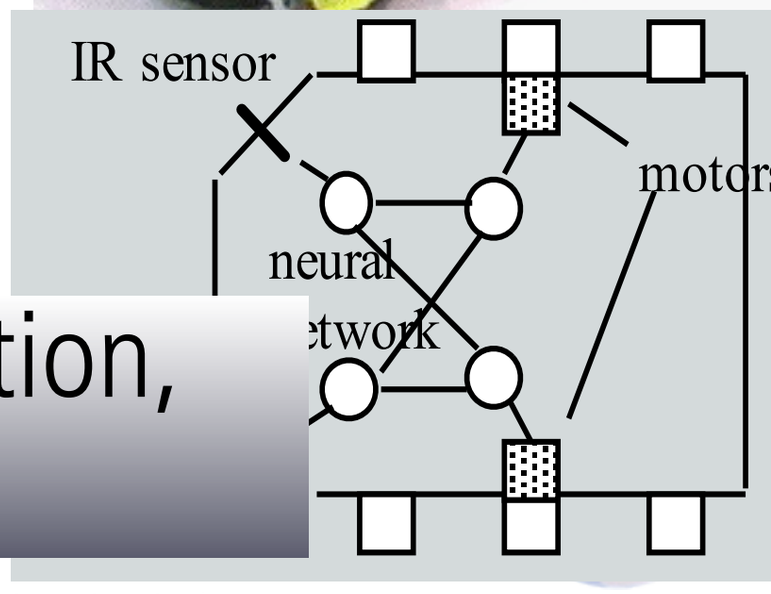
Cheap design exploitation of niche

6x6m arena with Styrofoam cubes

Passive Dynamic Walker



Didabot simple robot for didactial purposes



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

These robots are cleaning up, but that's not what they think they are doing (joke — can the think?)

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

Redundancy
Different physical processes

airplane landing

jet engines
(reverse) propulsion

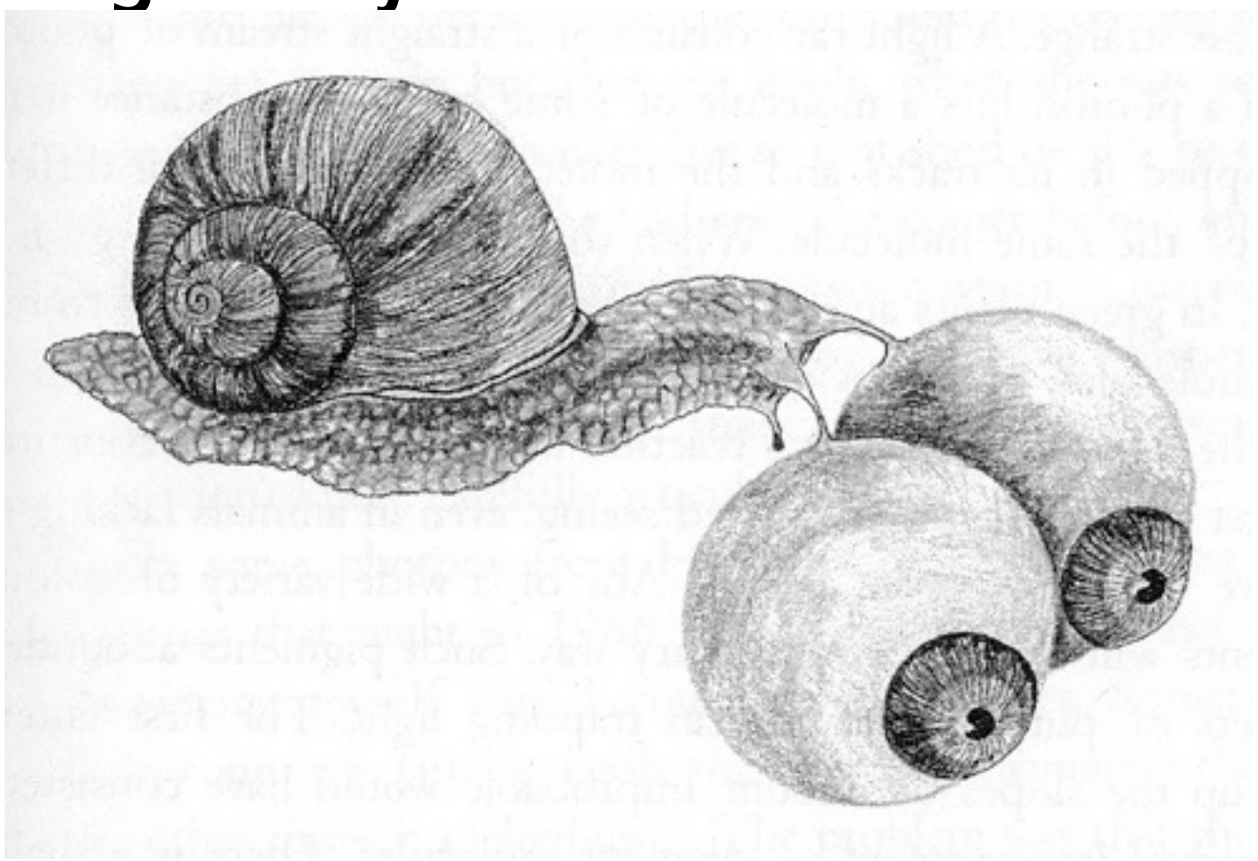
braking systems
partial overlap of functionality

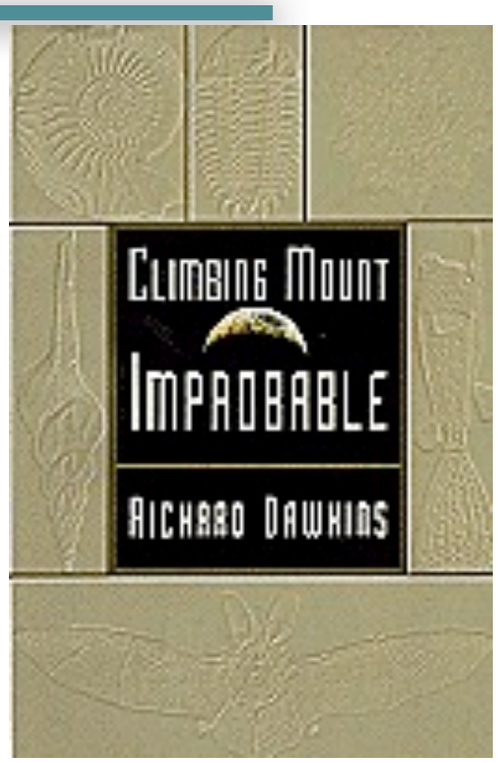
parachutes
mechanical

wheels (friction)
runway conditions

Ecological balance matching complexity

ecologically unbalanced system: Richard Dawnkins's snail with giant eyes

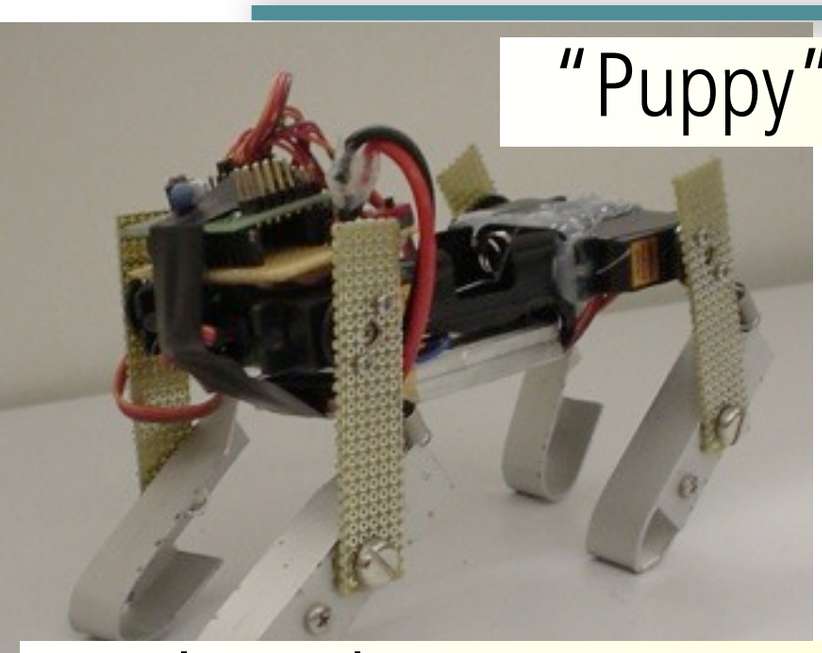




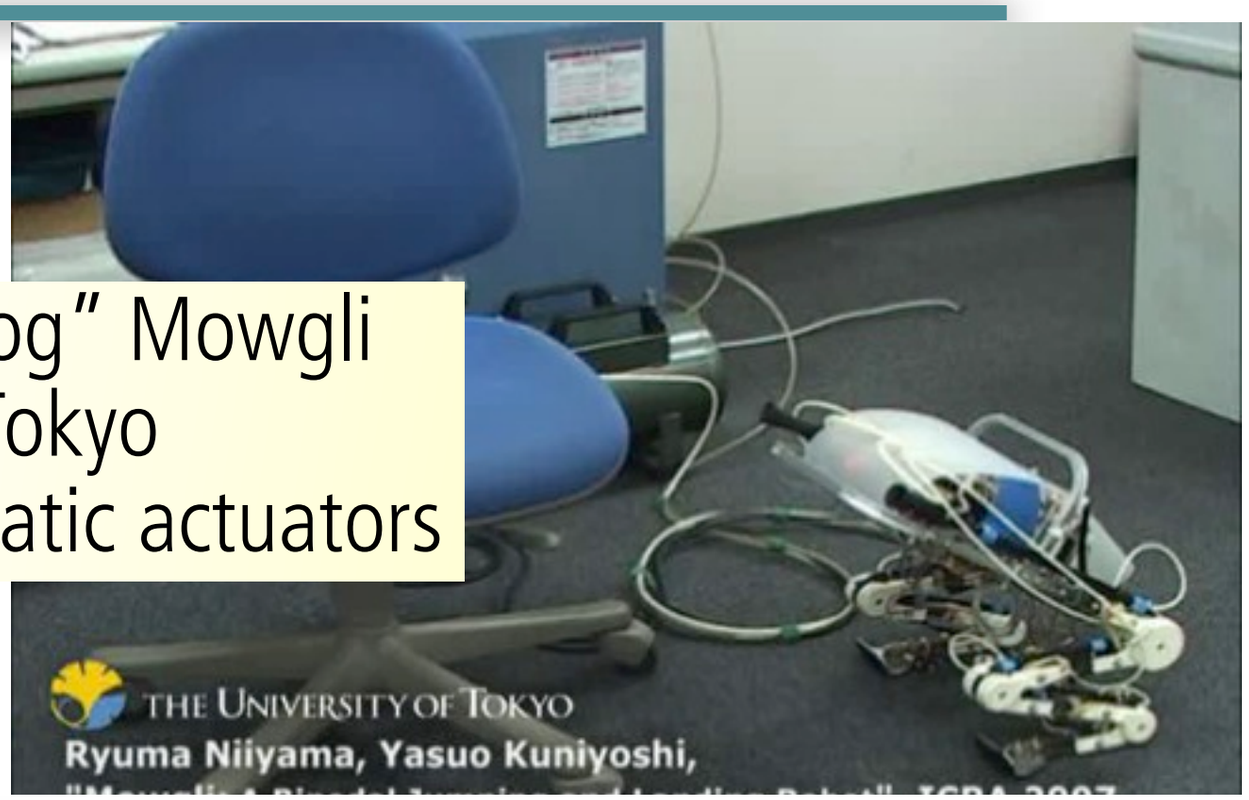
Author of:
"The selfish gene" and
"The blind watchmaker"

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

Ecological balance: task distribution morphology, materials, control

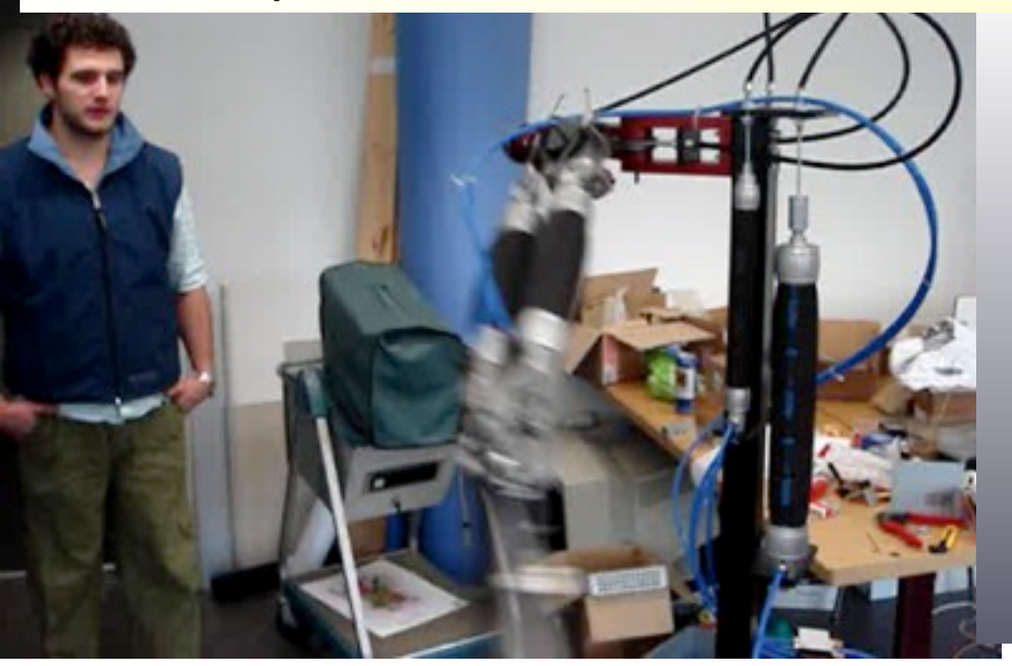


"Puppy" with springs



Robot "frog" Mowgli
U-Tokyo
with pneumatic actuators

loosely swinging arm
with pneumatic actuators



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

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Bernstein's problem: Development as an incremental process

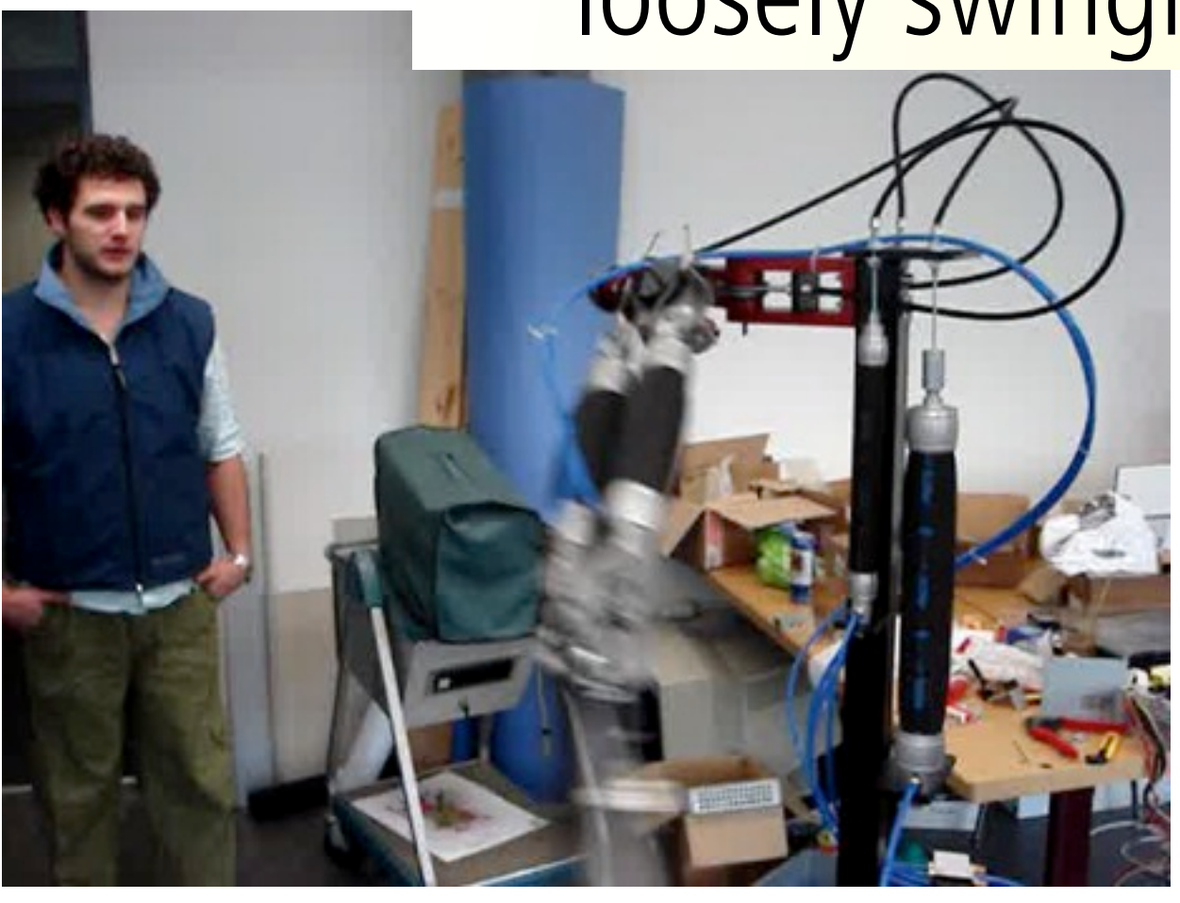
learning to control high DOF body: freezing and freeing DOFs

Discover, learn from real world
The best exploration strategies

only possible through embodiment

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

"loosely swinging arm"



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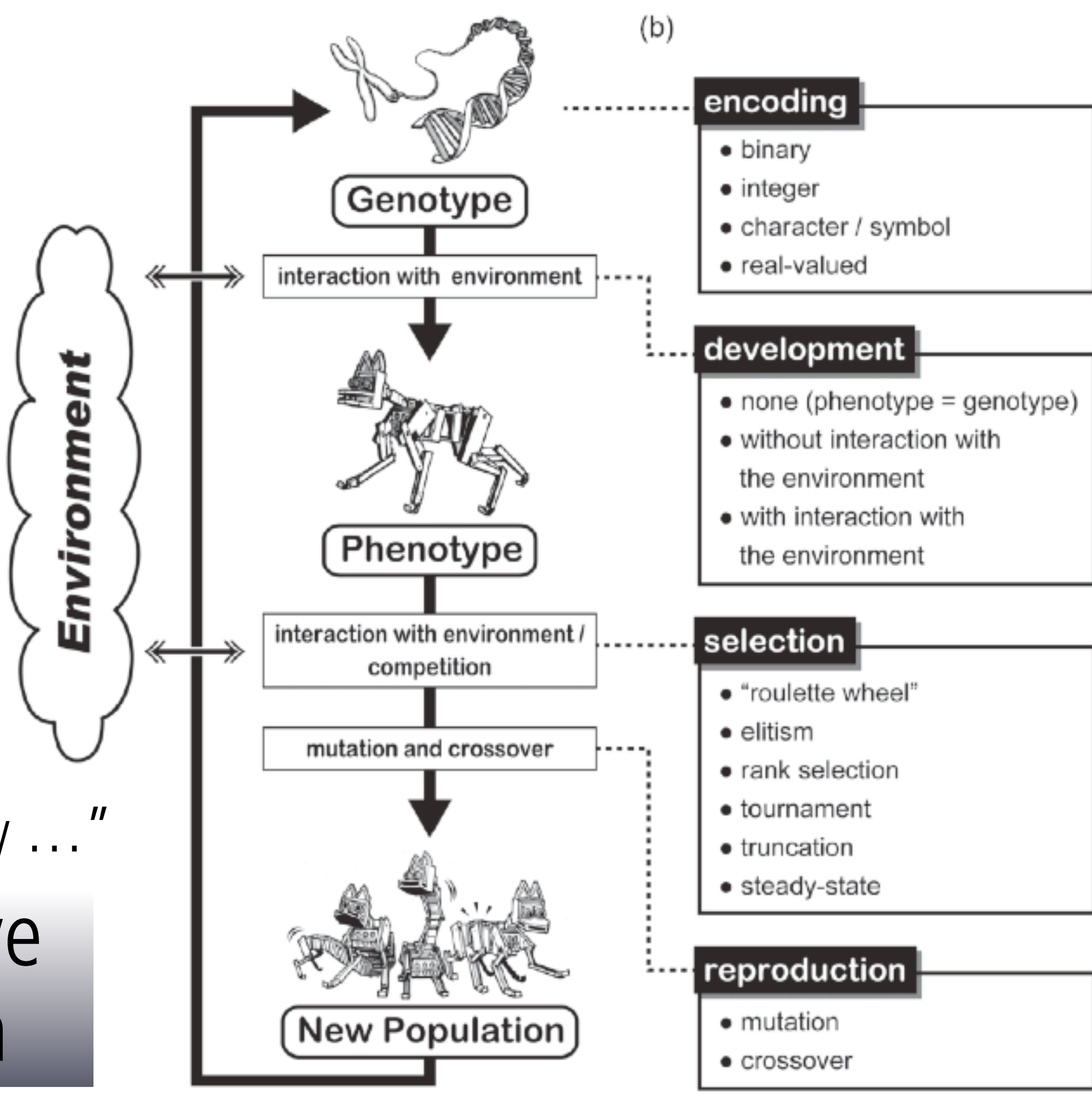
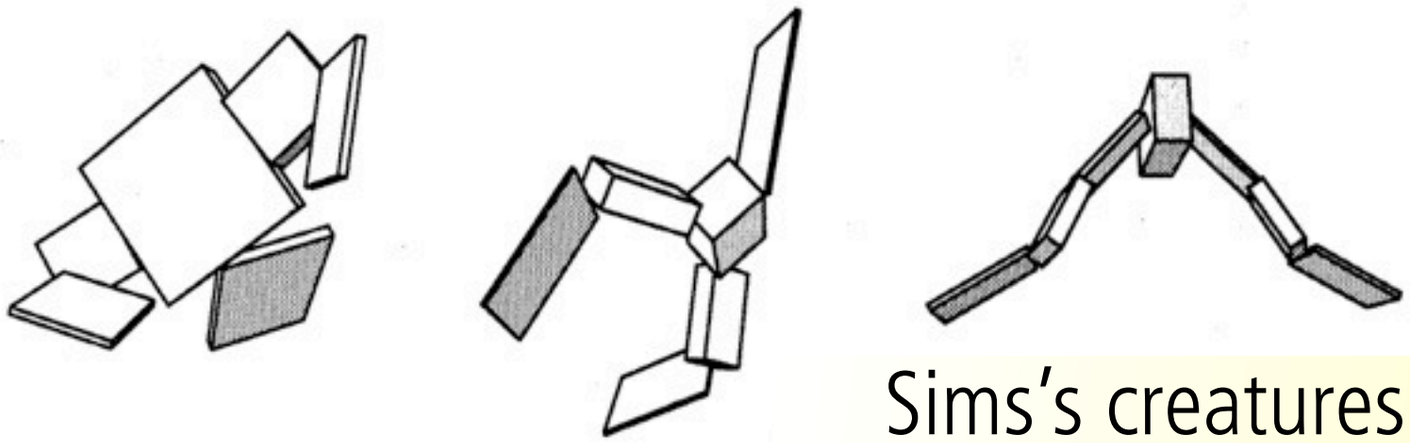
Basic cycle for artificial evolution

from
"How the body …"

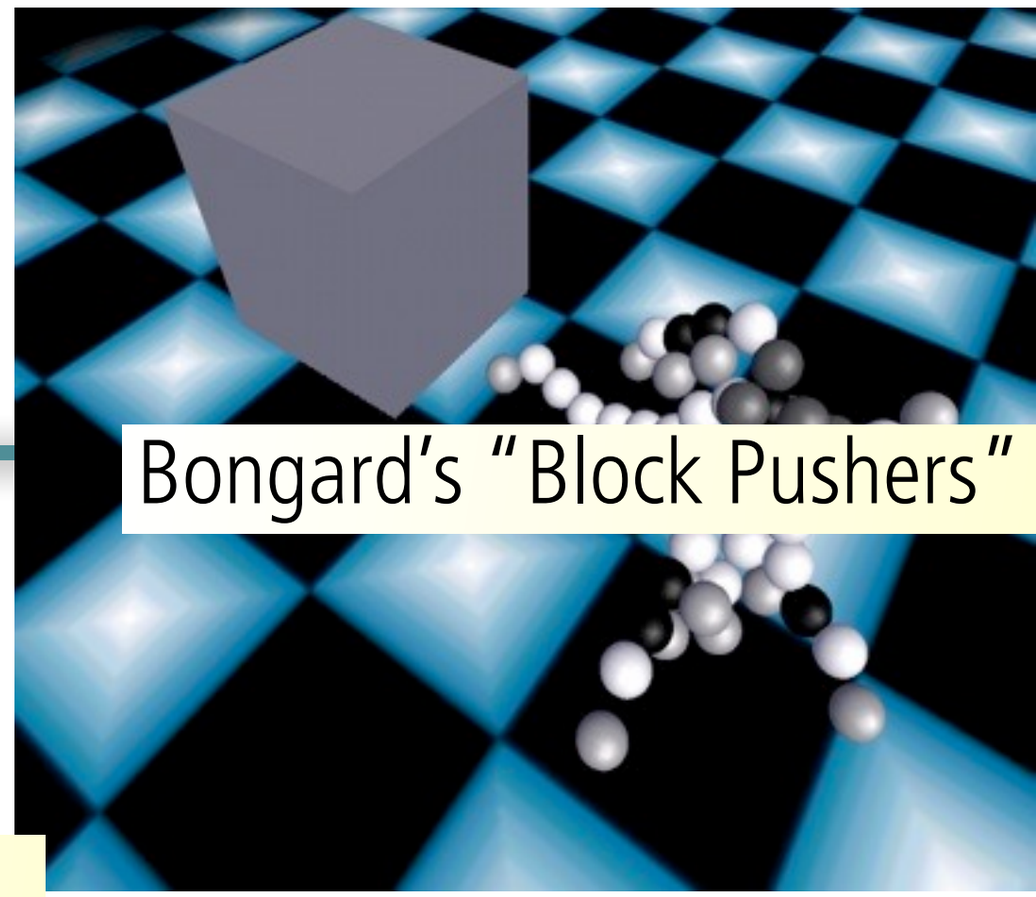
cumulative selection



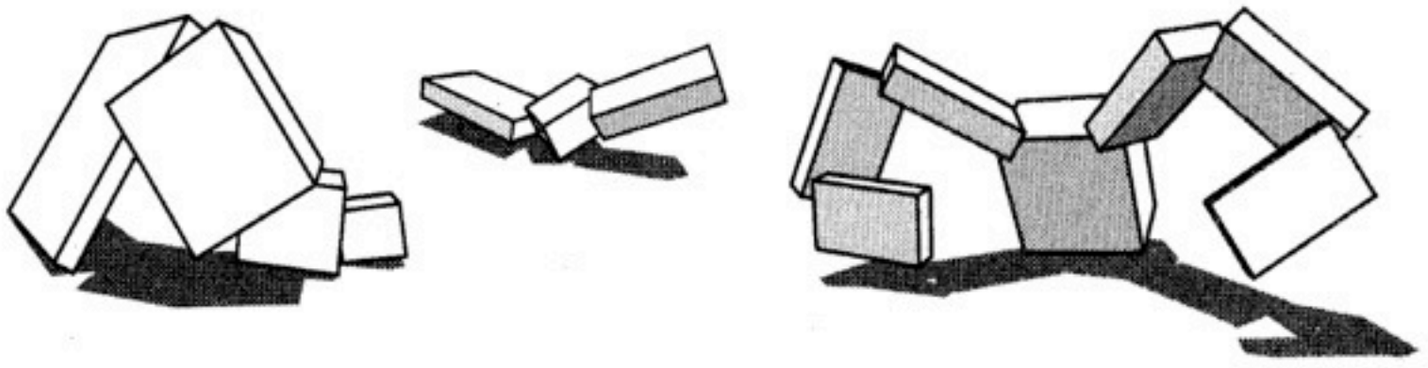
Brain-body co-evolution



Sims's creatures



Bongard's "Block Pushers"



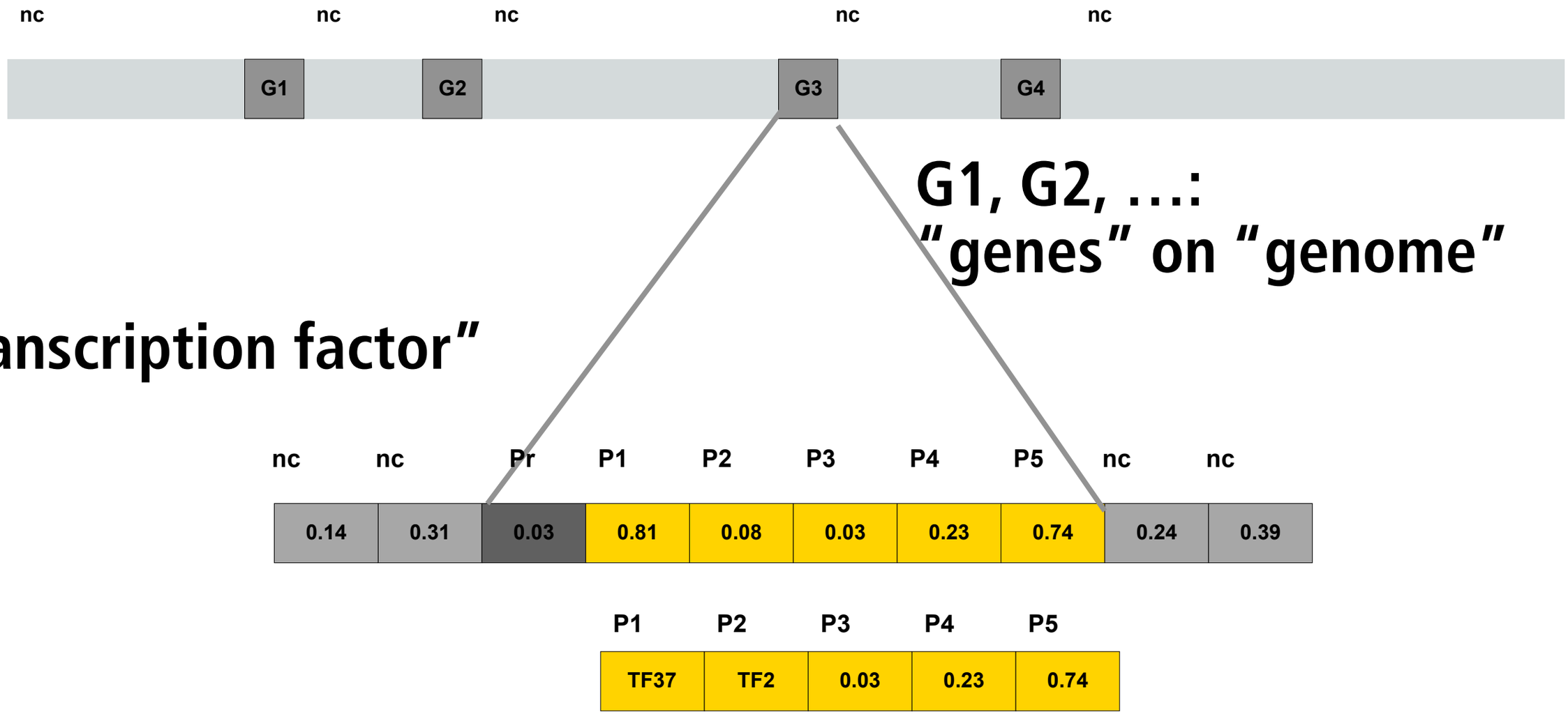
Lipson's creatures
"Golem" project

Encoding of developmental processes in genome

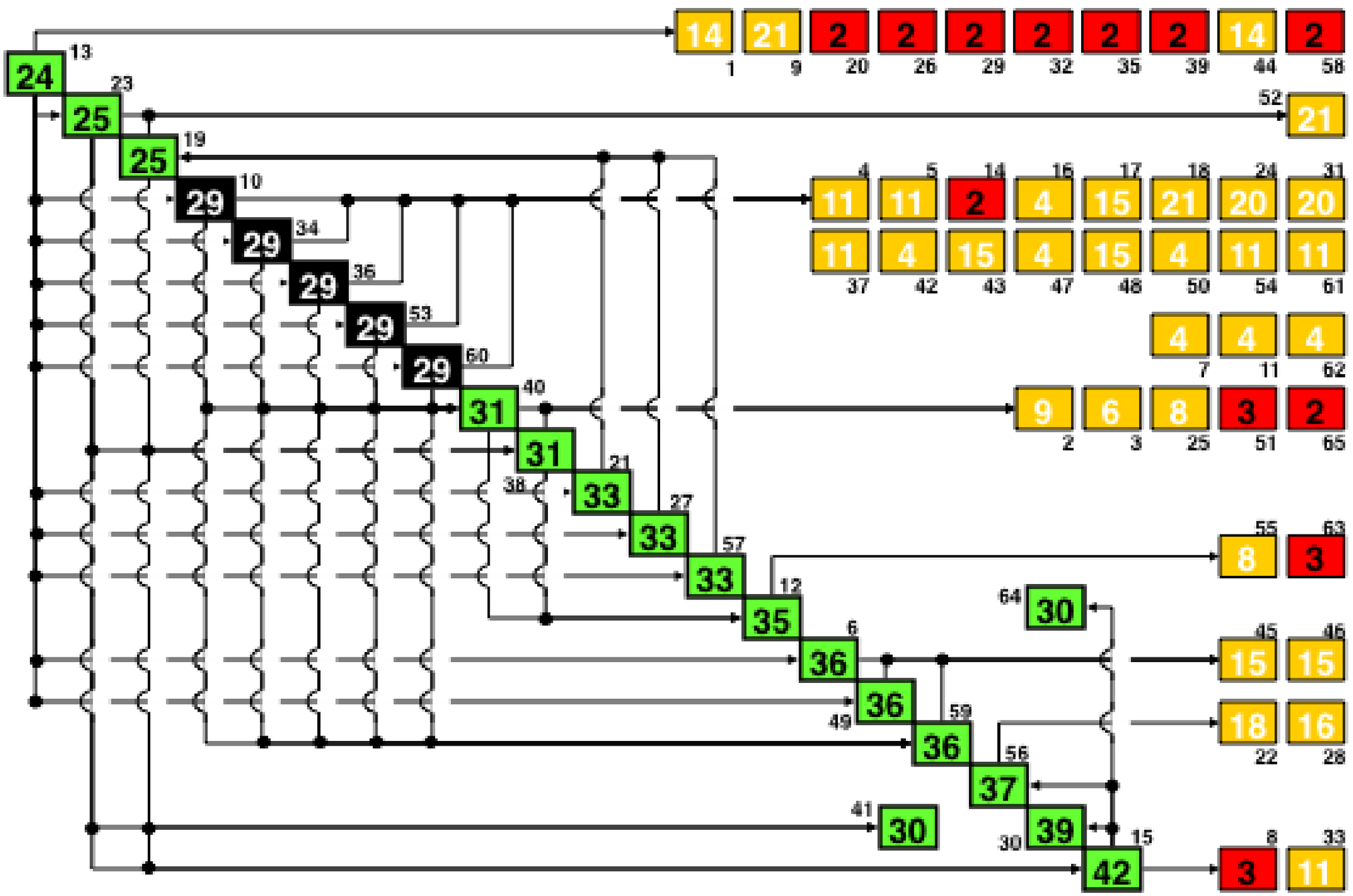
rather than the structure of the organism

Encoding developmental processes
Representation of "gene"

nc: "non-coding region"



GRN for evolved creature (Josh Bongard)



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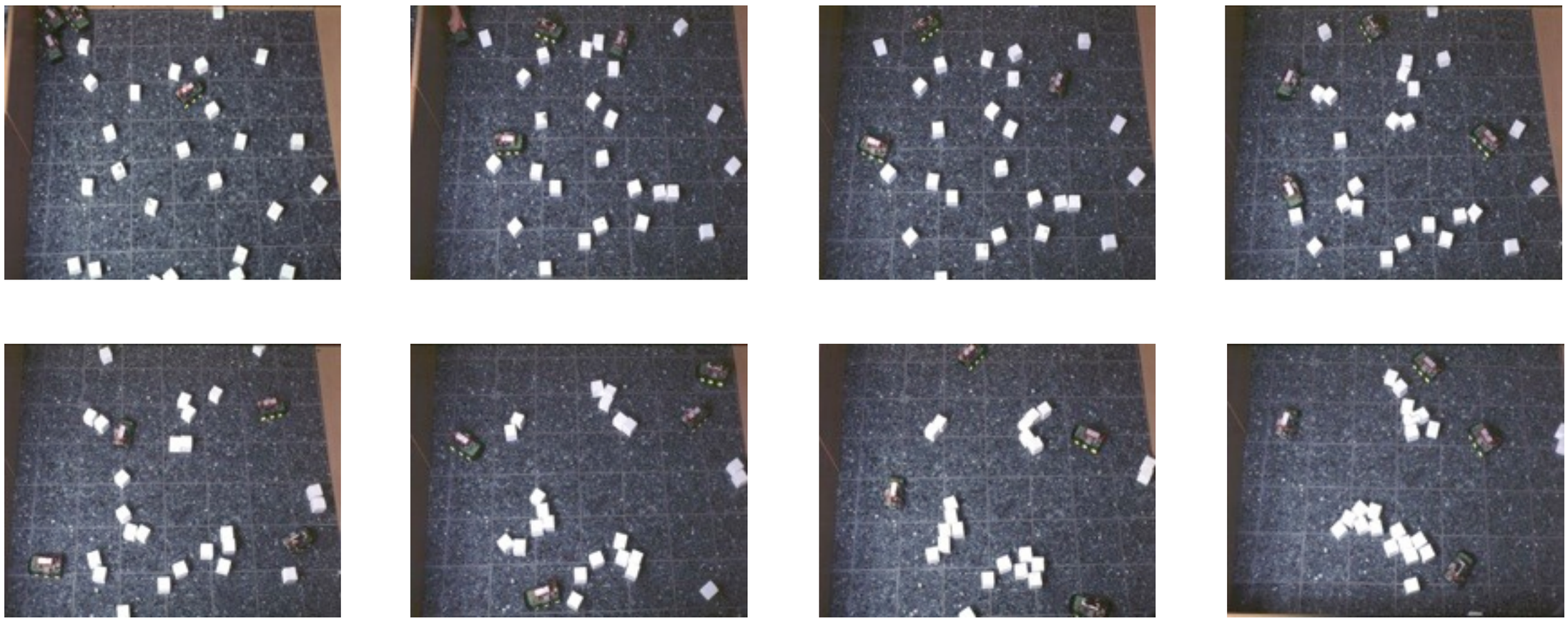
Design for emergence: cleaning an arena



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

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

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.
Requires quite sophisticated perceptual skills on the part of the robots (recognizing a cube from different angles and distances, recognizing a cluster). Some elementary motor skills for grasping and dropping. locomotion skills.

The solution: simple rules

behavioral rule:

sensory stimulation on left: turn right

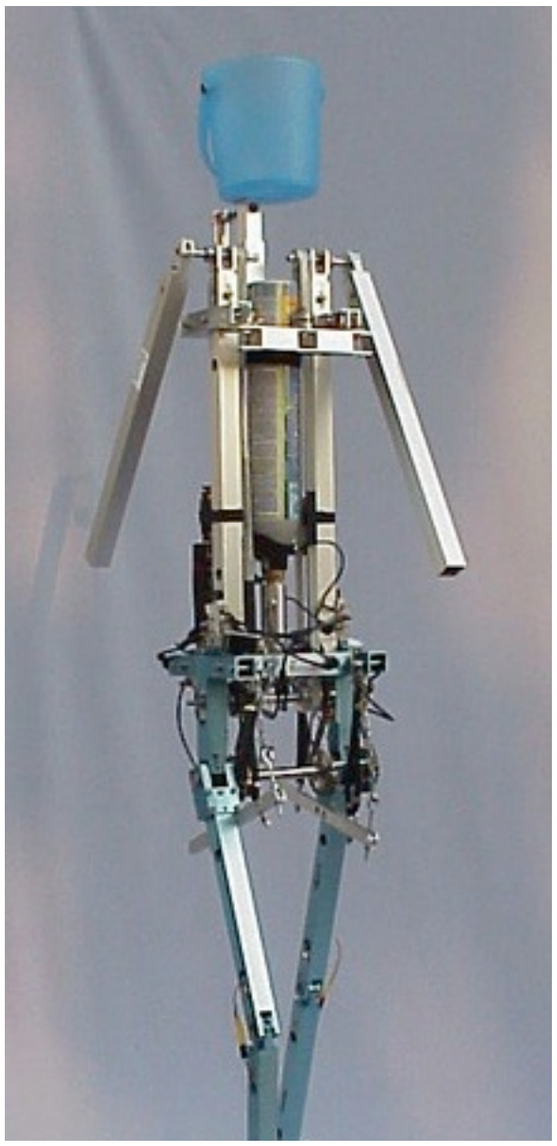
sensory stimulation on right: turn left

(obstacle avoidance)

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

Walking without control?

The solution:
The “Passive Dynamic Walker”

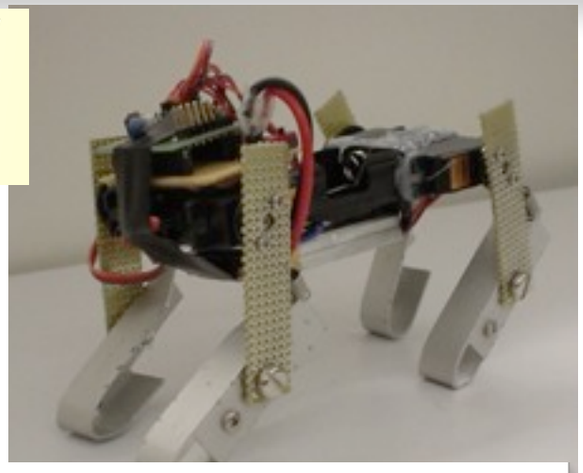


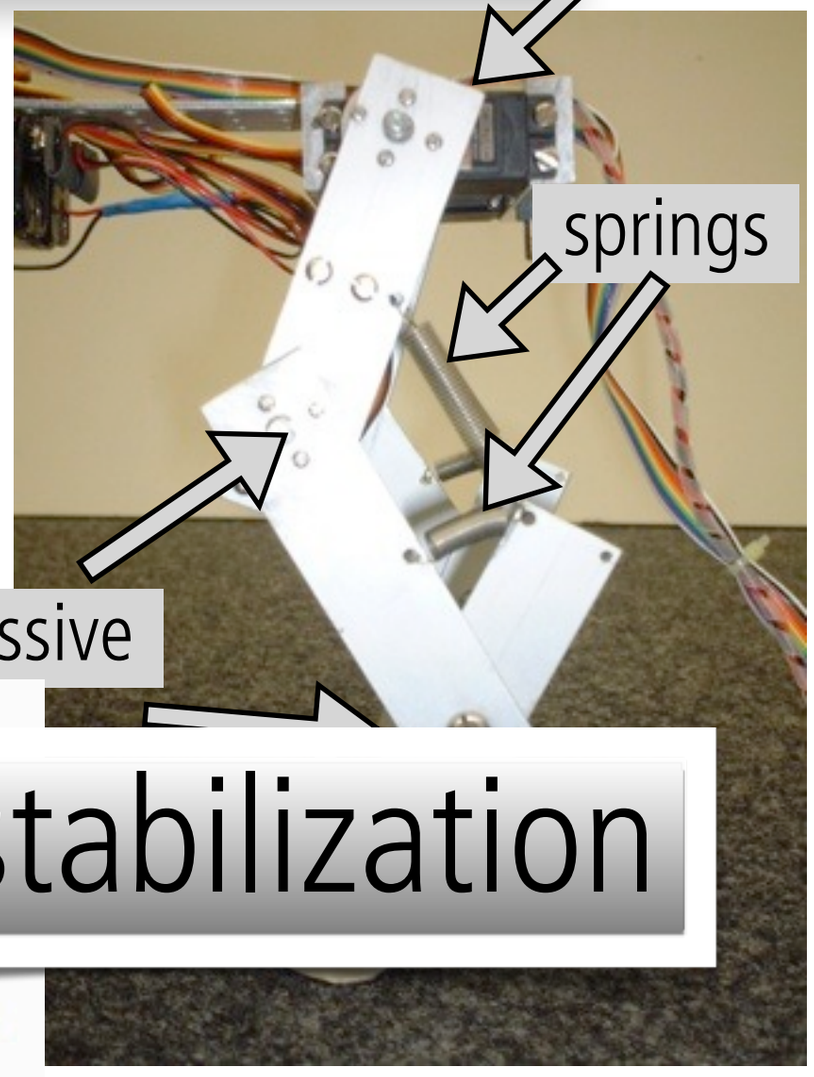
“Denise”
no control for balance

Rapid locomotion with slow electronics/brains?

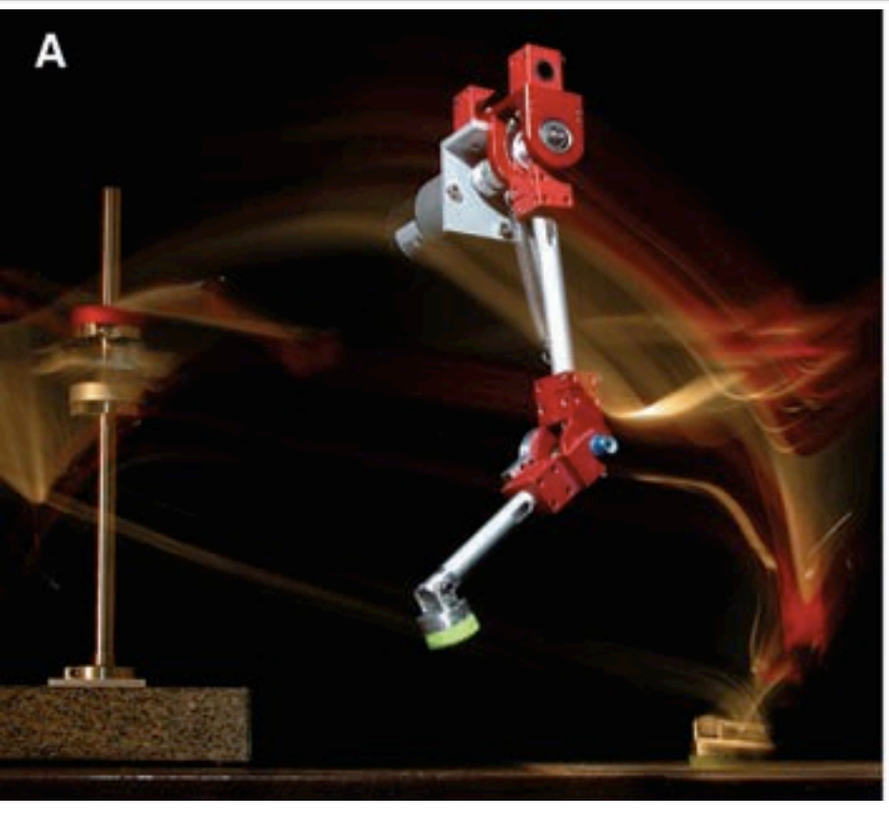
The solution: "Exploitation of morphology and materials"

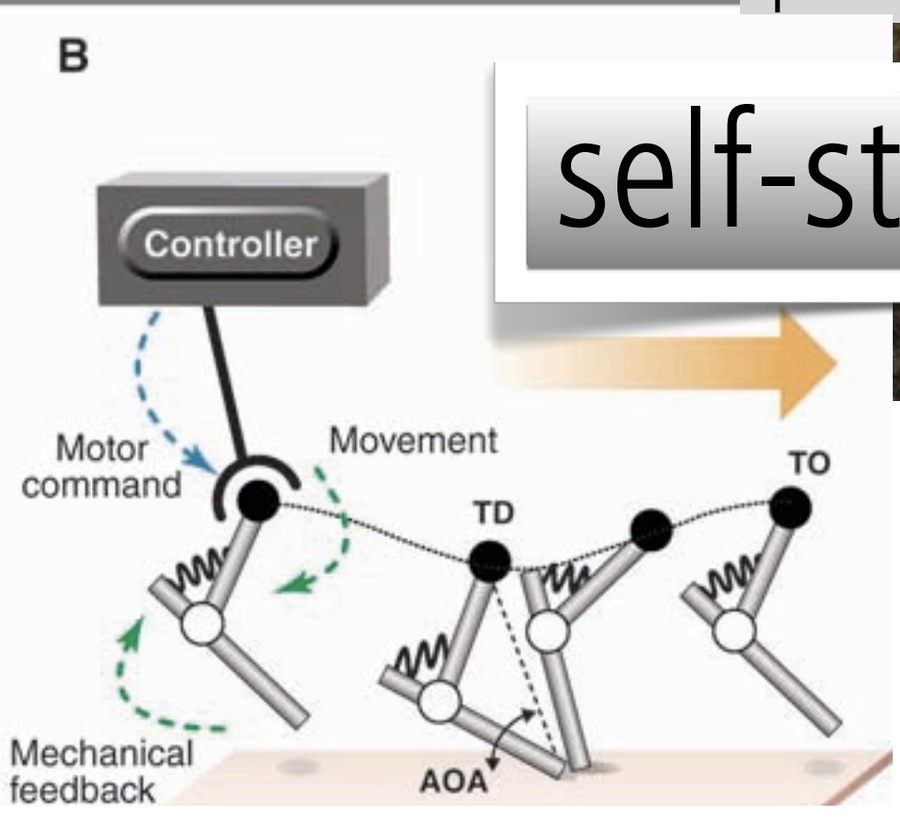
"Puppy"





morphological computation



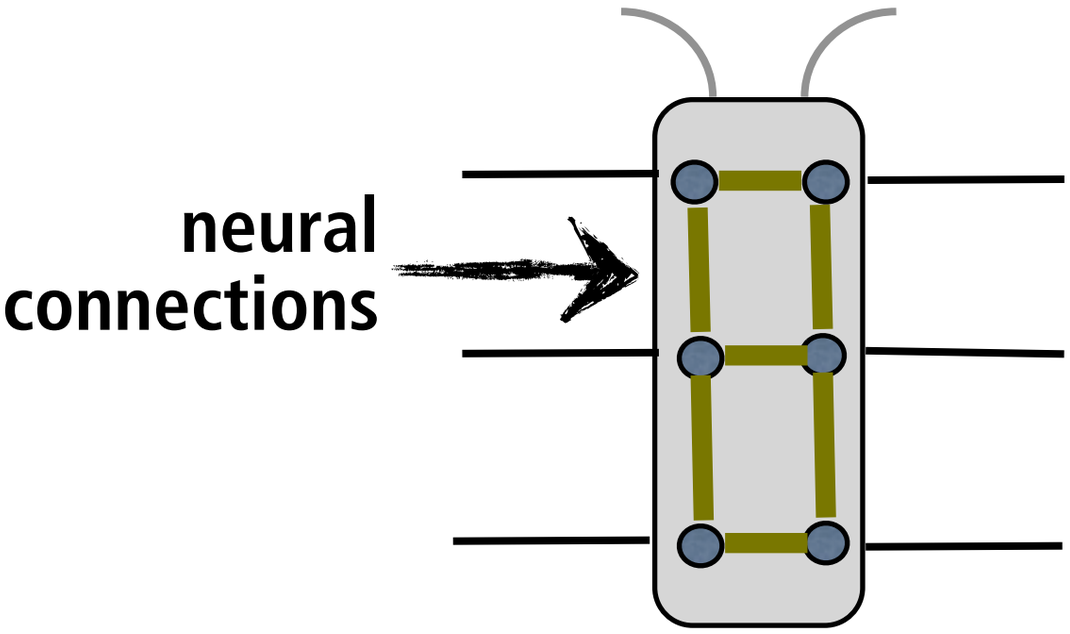


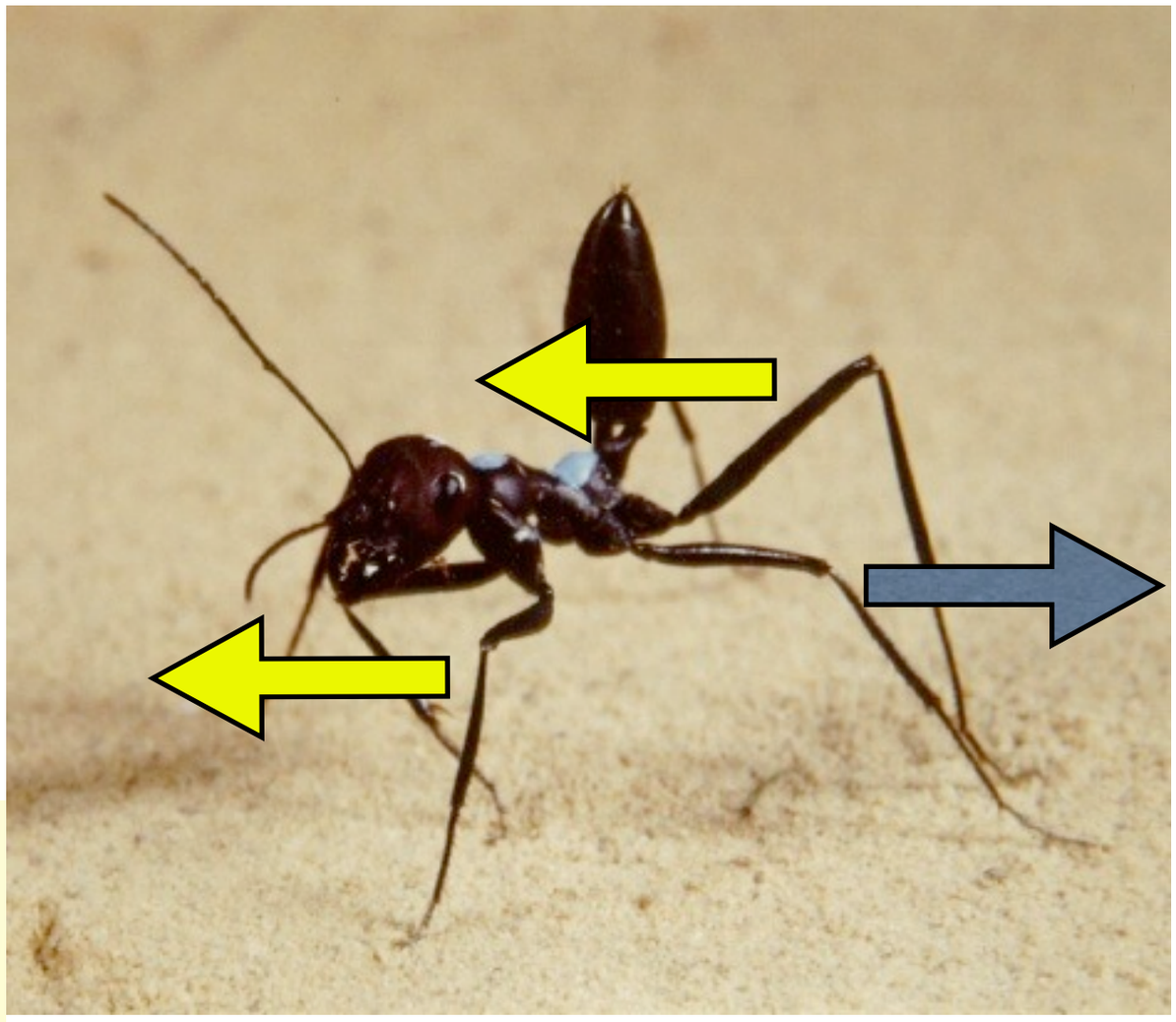
self-stabilization

Jena
monoped

Leg coordination without central control?

The solution: global communication through interaction with real world

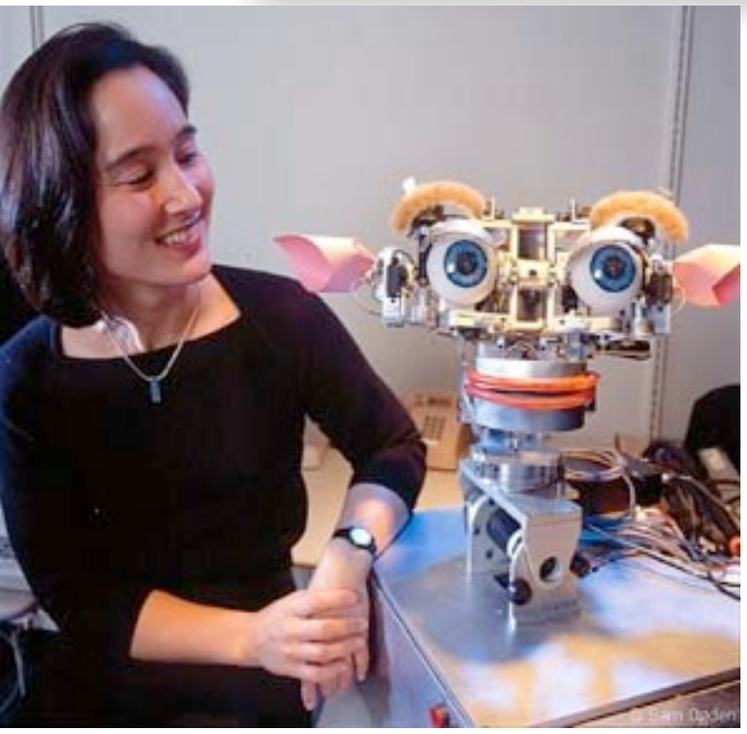




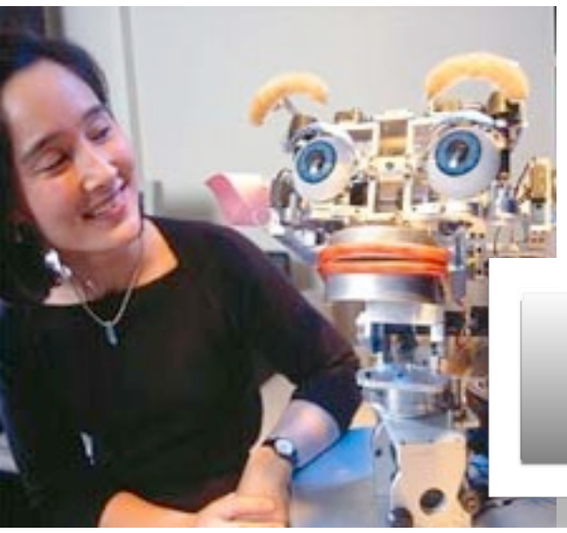
"parallel, loosely coupled processes"

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

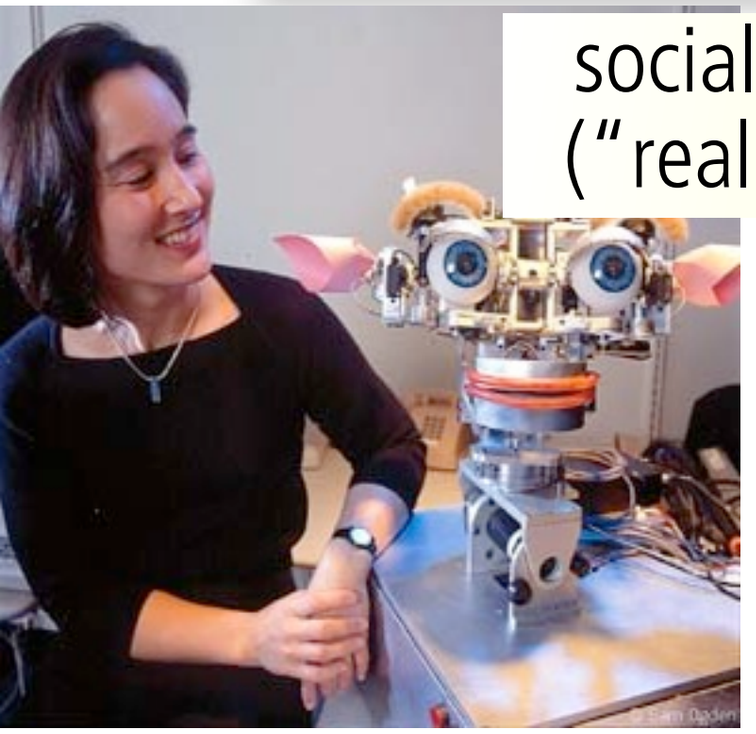
visual tracking of slow objects

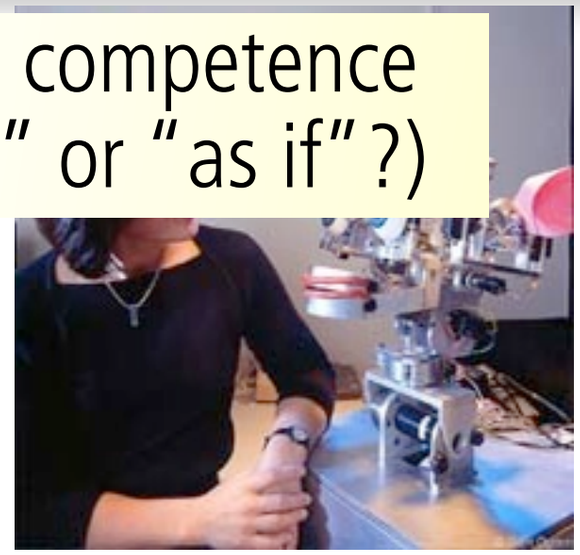
habituation

Video “Kismet.mov”

Social competence without high-level cognition?

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





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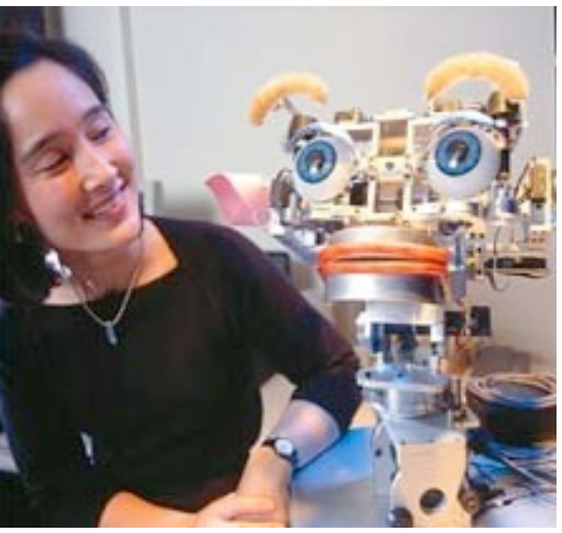


reflexes:

turn towards sound

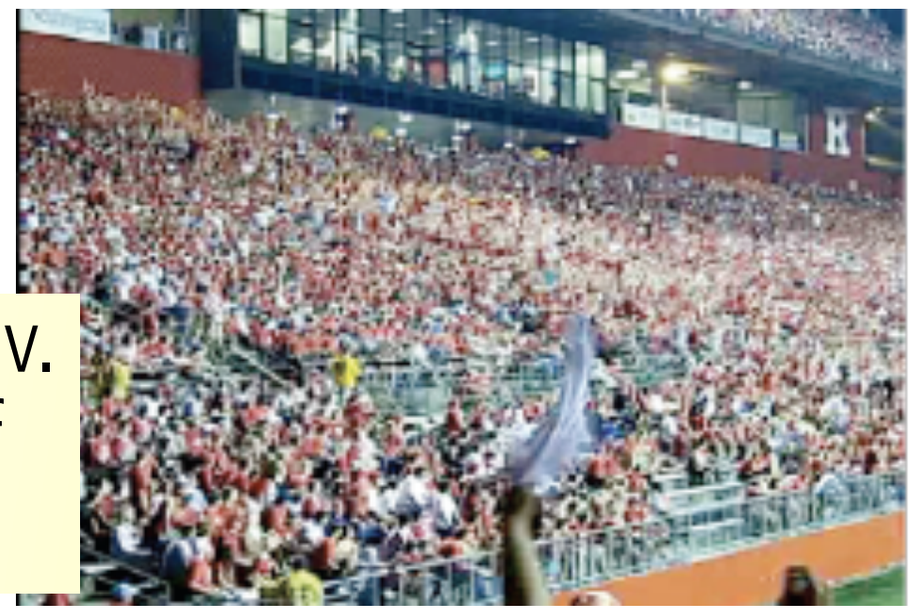
turn towards moving objects

visual tracking of slow objects

habituation

Rodney Brooks, MIT:
"What do you mean — 'as if'? This **IS** social competence"

Social behavior through simple reflexes?



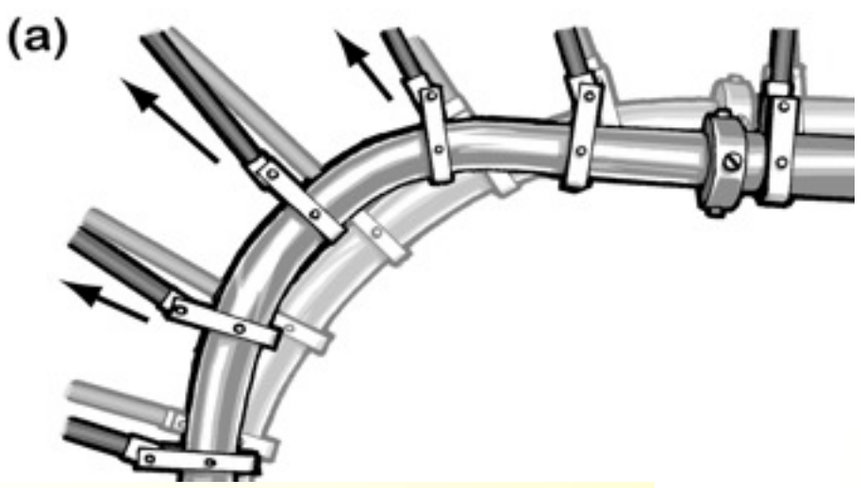
John Bargh, Psychologist, Yale Univ.
"The unbearable automaticity of being", 1999

Finding shortest paths without measuring, storing, comparing?

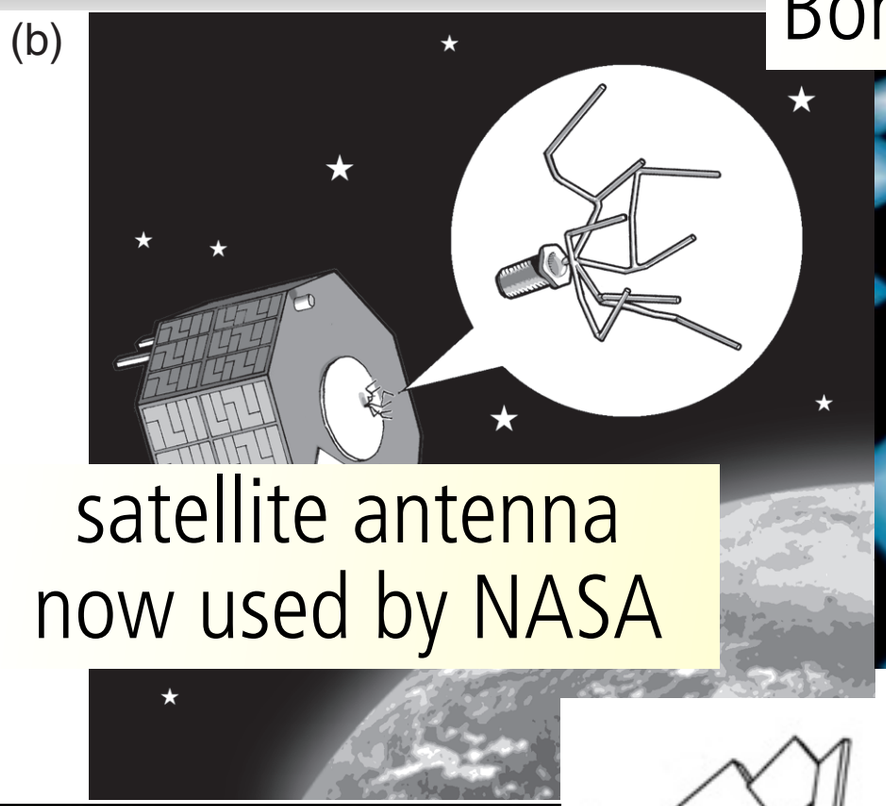
Creative computers, robots?

- "Computers can never be creative — they can only reproduce what you program into them"
- From the movie "I, Robot". Human to robot (my transcription): "Robots could never be creative, they could never write a symphony like Beethoven!" Robot to human: "Could you?"

Solution: Artificial evolution and morphogenesis



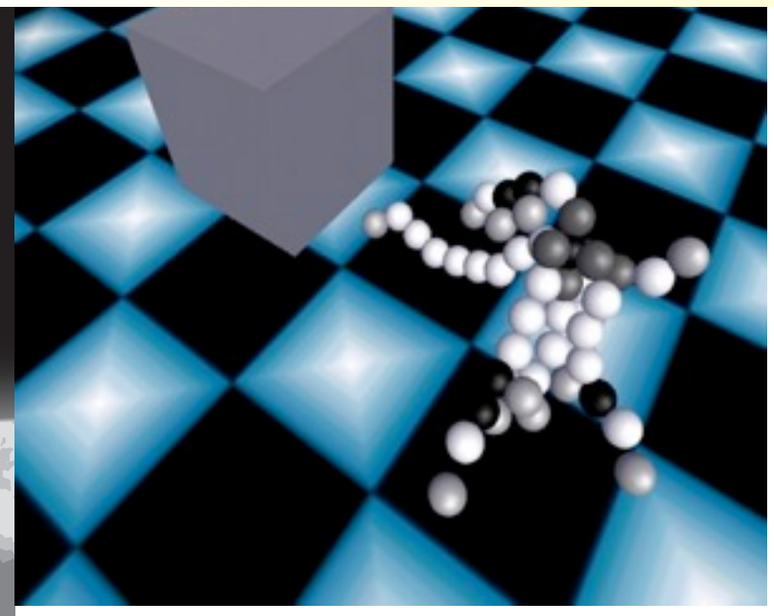
Rechenberg's "hunched" fuel pipe solution

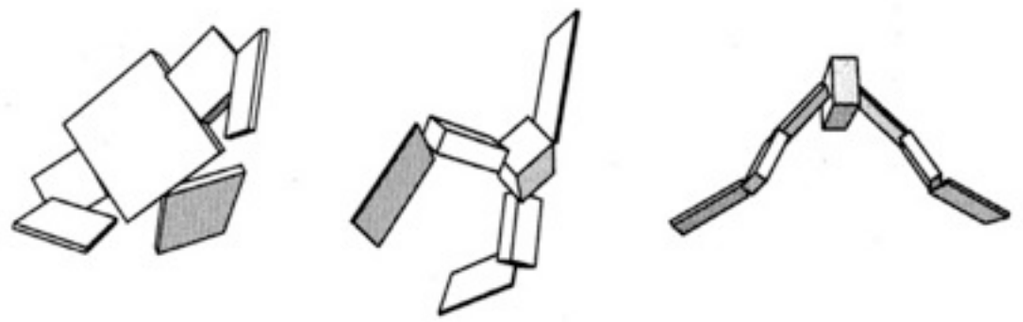


satellite antenna now used by NASA

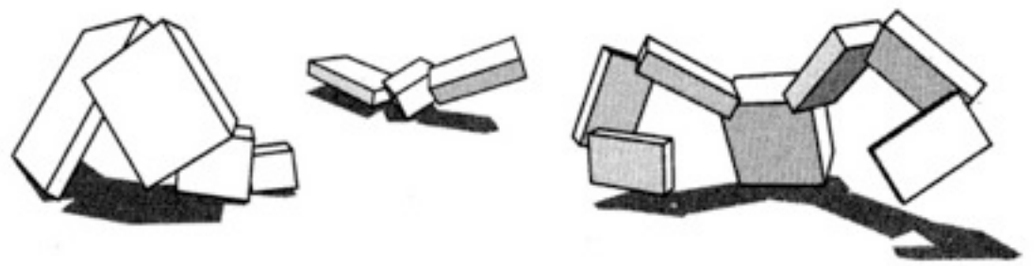
Lipson's creatures "Golem" project

Bongard's "Block Pushers"





Sims's creatures



Morphogenesis (Bongard and Bisig, 2001)

Video “growth.mov”

Problem solved?

Epilogue

David Payne *Confessions of a Taoist on Wall Street*
Sun I: little boy growing up in monastery
Wu: chef (cook) of monastery and Sun I's mentor

The little boy, Sun I, is born of a Chinese mother and an American fighter pilot in China. His mother dies at birth and his father returns home to the United States; he is left alone and grows up in a monastery. His mentor and teacher is the chef, Wu, who takes good care of him. The monastery is on a high rock upon a river. One of their daily chores is to carry water from the river to the monastery up a rocky path. The boy remembers that whenever they arrived at the top of the rock his buckets were empty, all the water spilled, whereas Wu's were always full.

Courtesy Purdue University Libraries, Archives and Special Collections

Yoke with water buckets

ai lab

The ShanghAI Lectures 上海人工智能授课

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.)

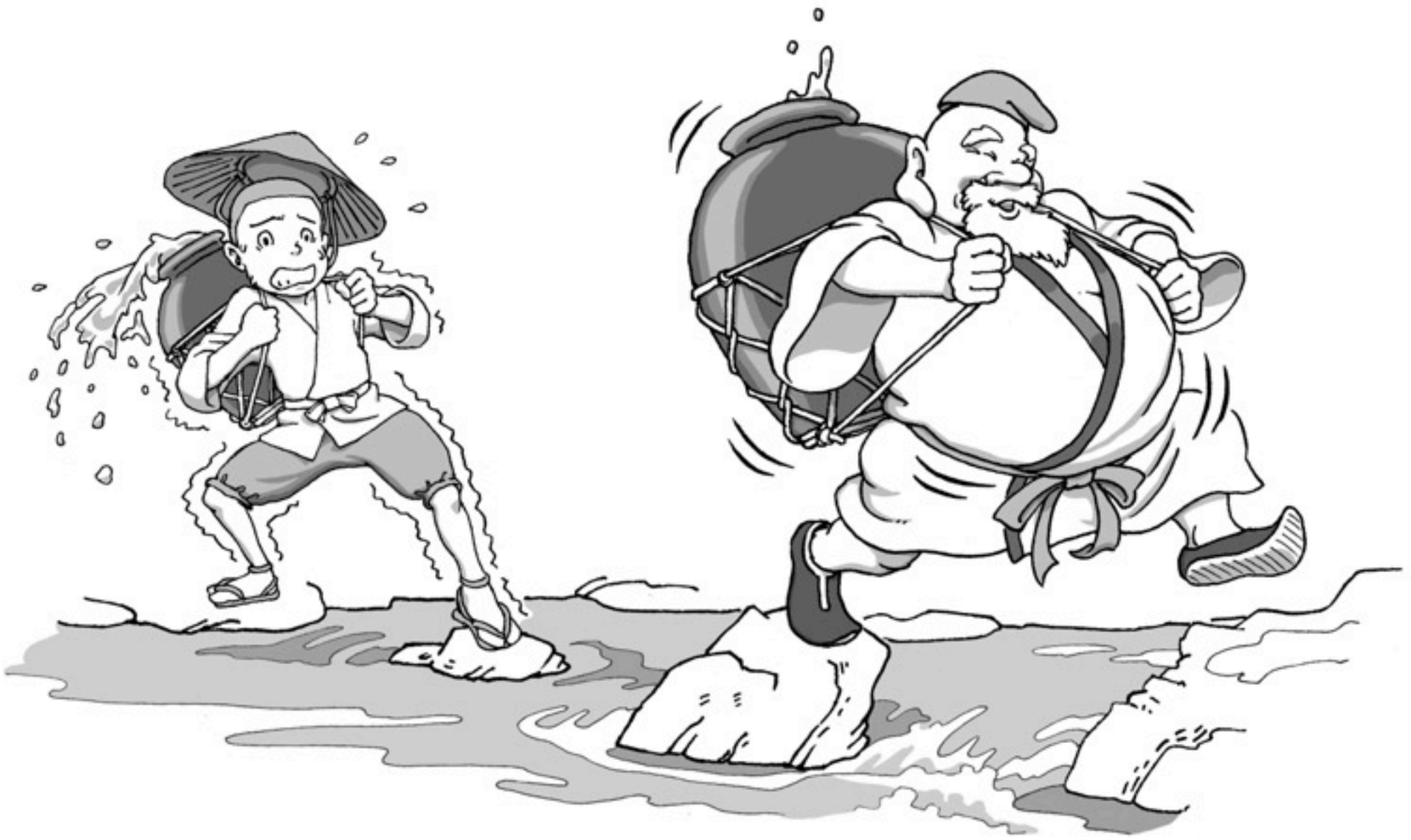
"I don't understand it," I confessed to him. "You must know some kind of trick. Explain your method." ...

"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)

Conversation between Sun I and Wu



Cartoon: **Shun Iwasawa, Studio Ghibli, Tokyo, Japan**

That's it!

Thank you for your attention!

stay tuned for

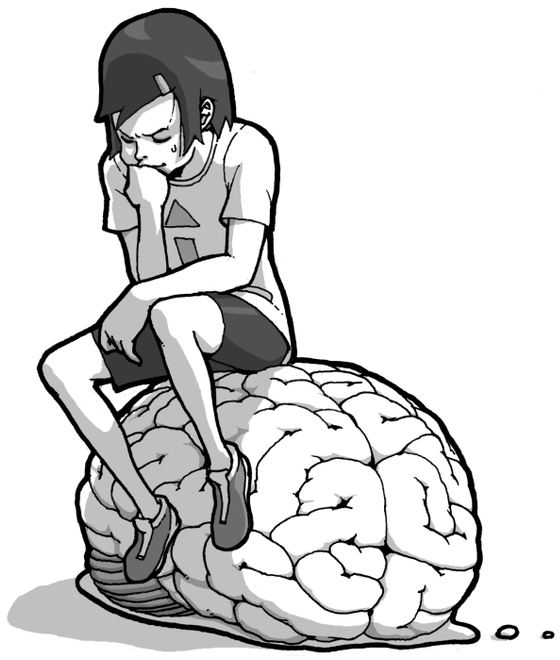
Tamas Haidegger
Aude Billard
Jamie Paik

End of week 11 Q&A session

Thank you for your attention!

Now, enjoy: "Future Trends"

(with various guest speakers)



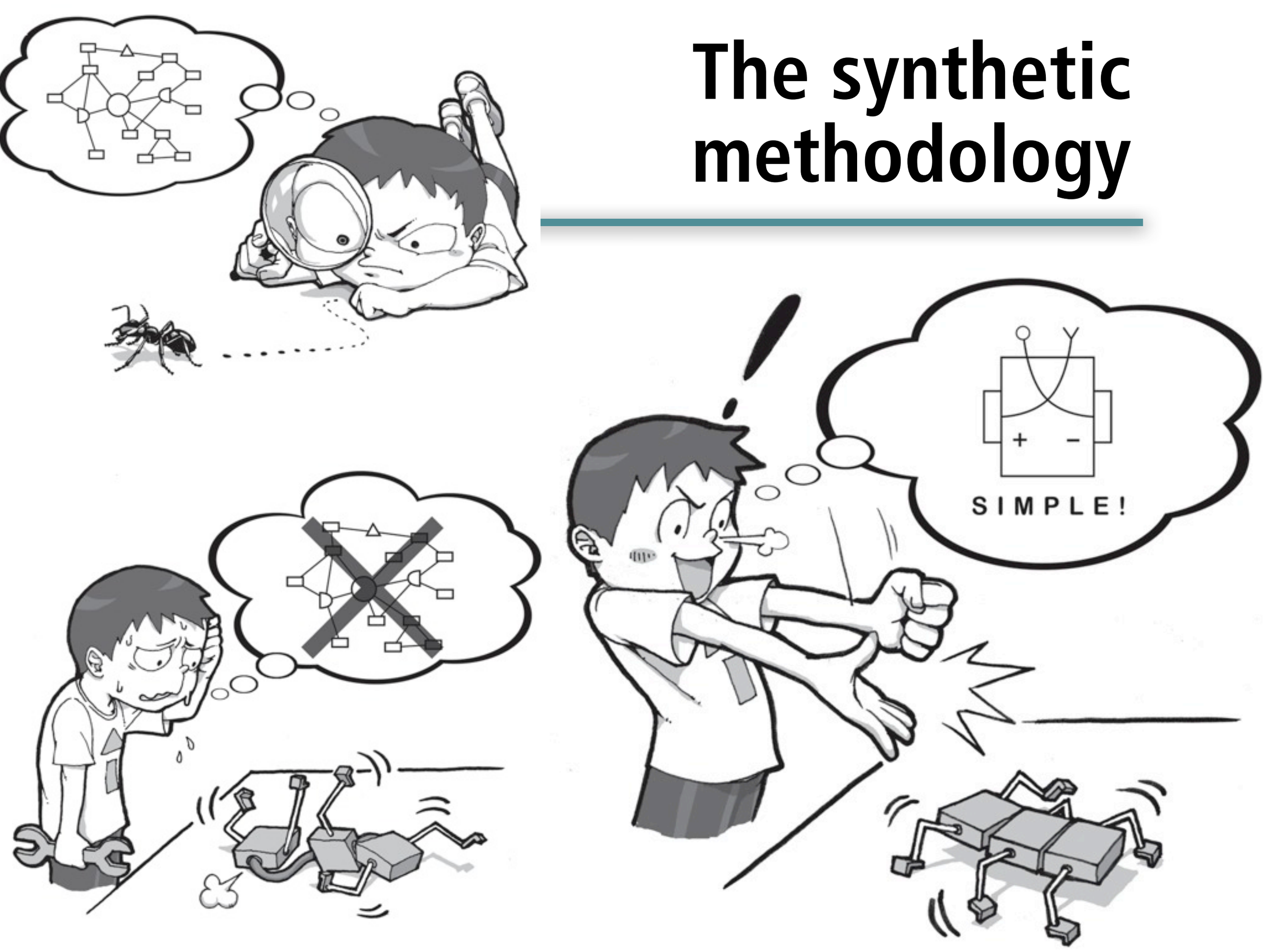
University of Zurich

lab

Selected highlights

Through engineering to science

The synthetic methodology



Information self-structuring through sensory-motor coordination

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

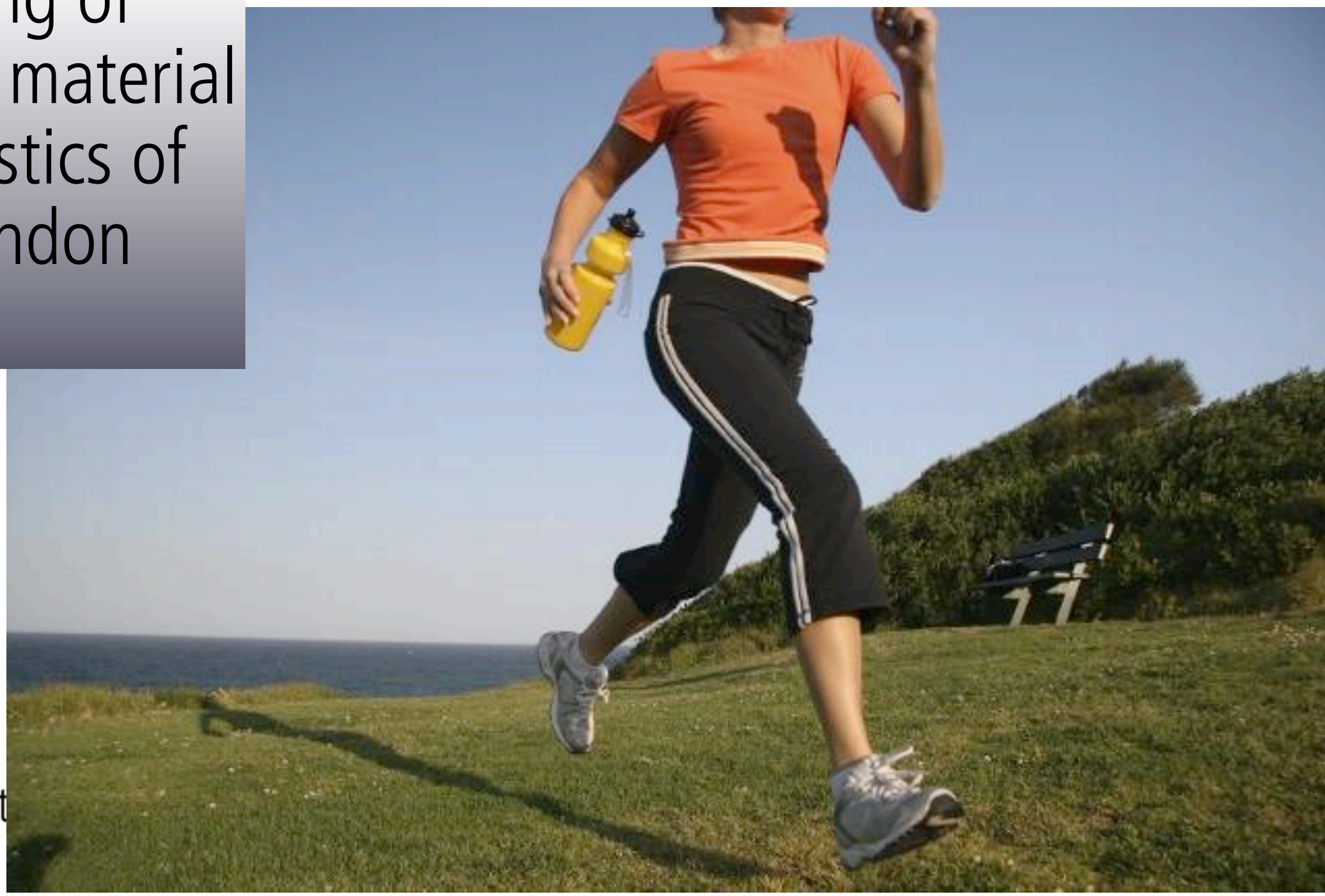
- cross-modal association, learning, concept formation
- extraction of mutual information → prediction
- categorization (fundamental for cognition)

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



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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