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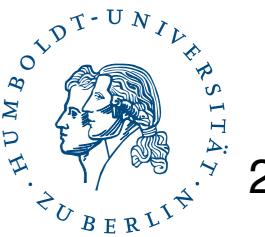
上海  
Lectures

授  
课

# Video clips, demonstrations

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- **Video: Karl Sims' evolved creatures**
- **Video: Josh Bongard's “Block Pusher”**





# The ShanghAI Lectures on Embodied AI

Today from **Humboldt-Universität zu Berlin**, Germany

host:

Verena Hafner  
Adaptive Systems Group, Department of Computer Science  
Humboldt-Universität zu Berlin, Germany



**BERLIN**

# Today's schedule

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**9:00 - 9:05 Short intro from Fabio Bonsignorio (Pisa)**

**9:05 - 9:15 Intro + 2 short presentations (Verena Hafner, HU Berlin)**

**9:15 - 9:55 Lecture 4:  
Evolution: cognition from scratch (Verena Hafner, HU Berlin)**

**9:55 Coffee break**

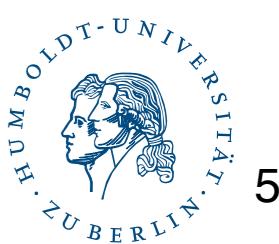
**10:05 Guest lecture "Vision based Micro Intelligent Vehicles" by Ming Yang**

**10:45 Coffee break**

**10:50 Guest lecture "Advanced Materials and Systems for Biohybrid  
Actuators and Sensors" by Arianna Menciassi**

**11:30 Wrap up**

**11:40 End**



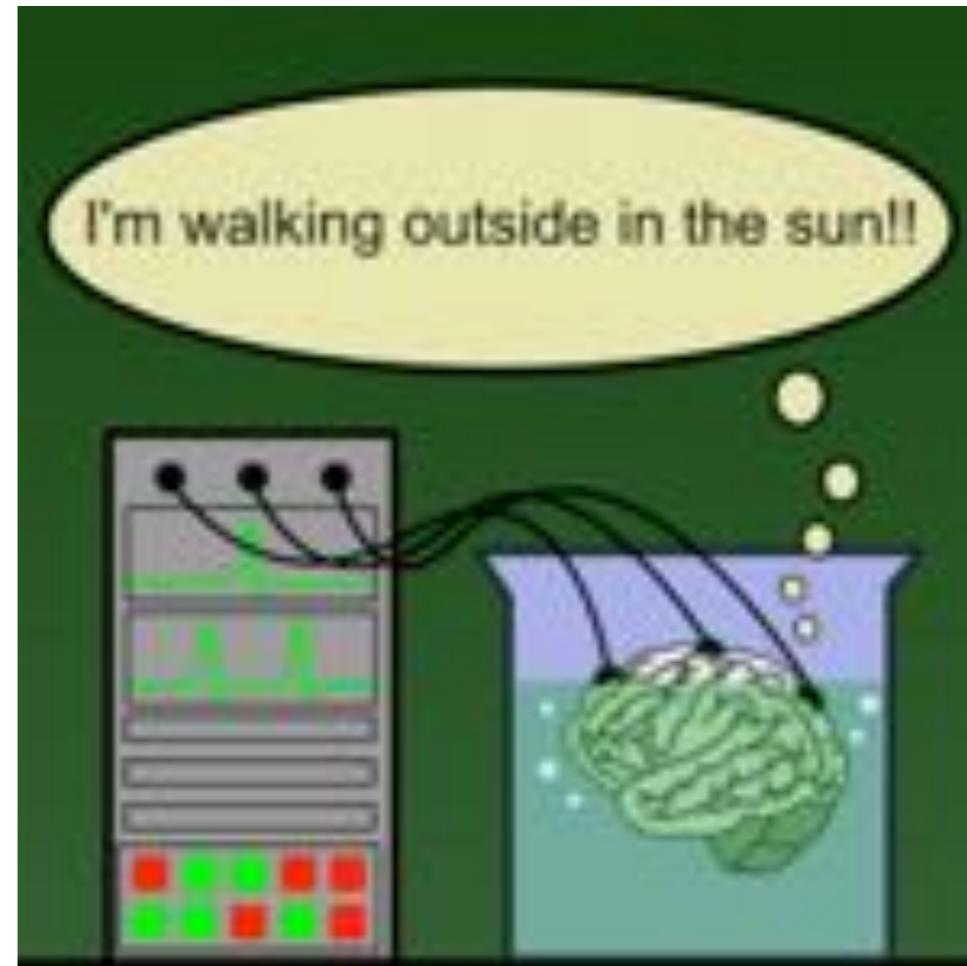
# Building brains for bodies

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**short presentation of “Brain-in-a-vat” (from Moscow, Russia)**

**for a long version  
please view recorded  
videos:**

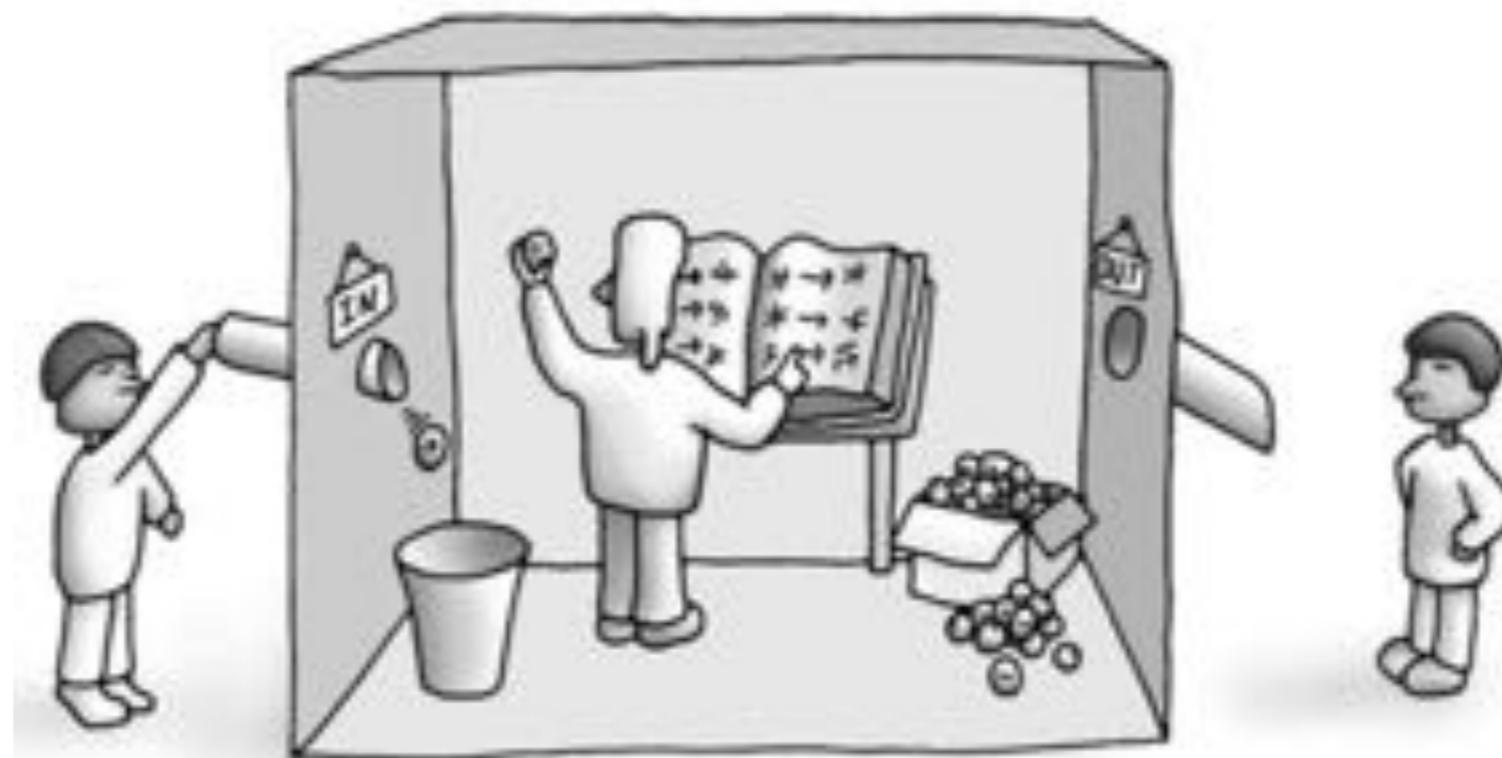
**- e.g. by Olaf Sporns**



# Chinese Room Experiment

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**short presentation from Northwestern, Xian,  
China**

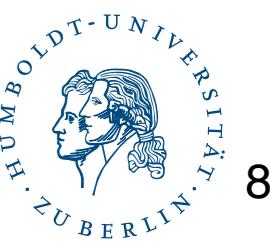


# Lecture 4

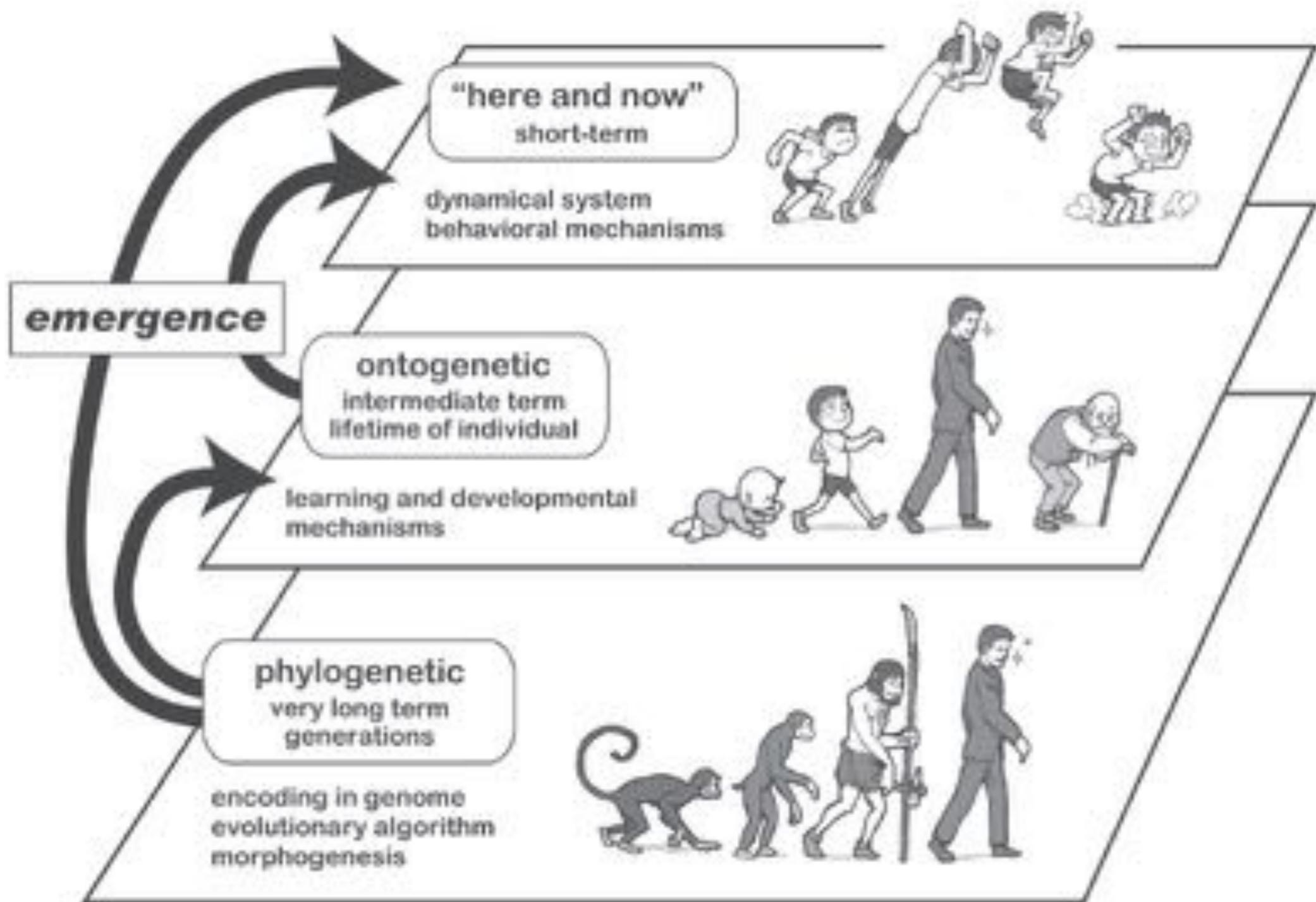
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**Evolution:  
Cognition from scratch**

**6th November 2014**



# Time perspectives



# Time perspectives in understanding and design

state-oriented

**“hand design”**

learning and development

**initial conditions, learning and developmental processes**

evolutionary

**evolutionary algorithms,  
morphogenesis**

“here and now” perspective

“ontogenetic” perspective

“phylogenetic” perspective

Understanding: **all three perspectives required**

Design: **level of designer commitments, relation to autonomy**



# Ontogenetic Perspective

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# Ontogenetic Perspective

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## Artificial Neural Networks:

- many excellent books available
- would exceed the frame of this course



# Ontogenetic Perspective

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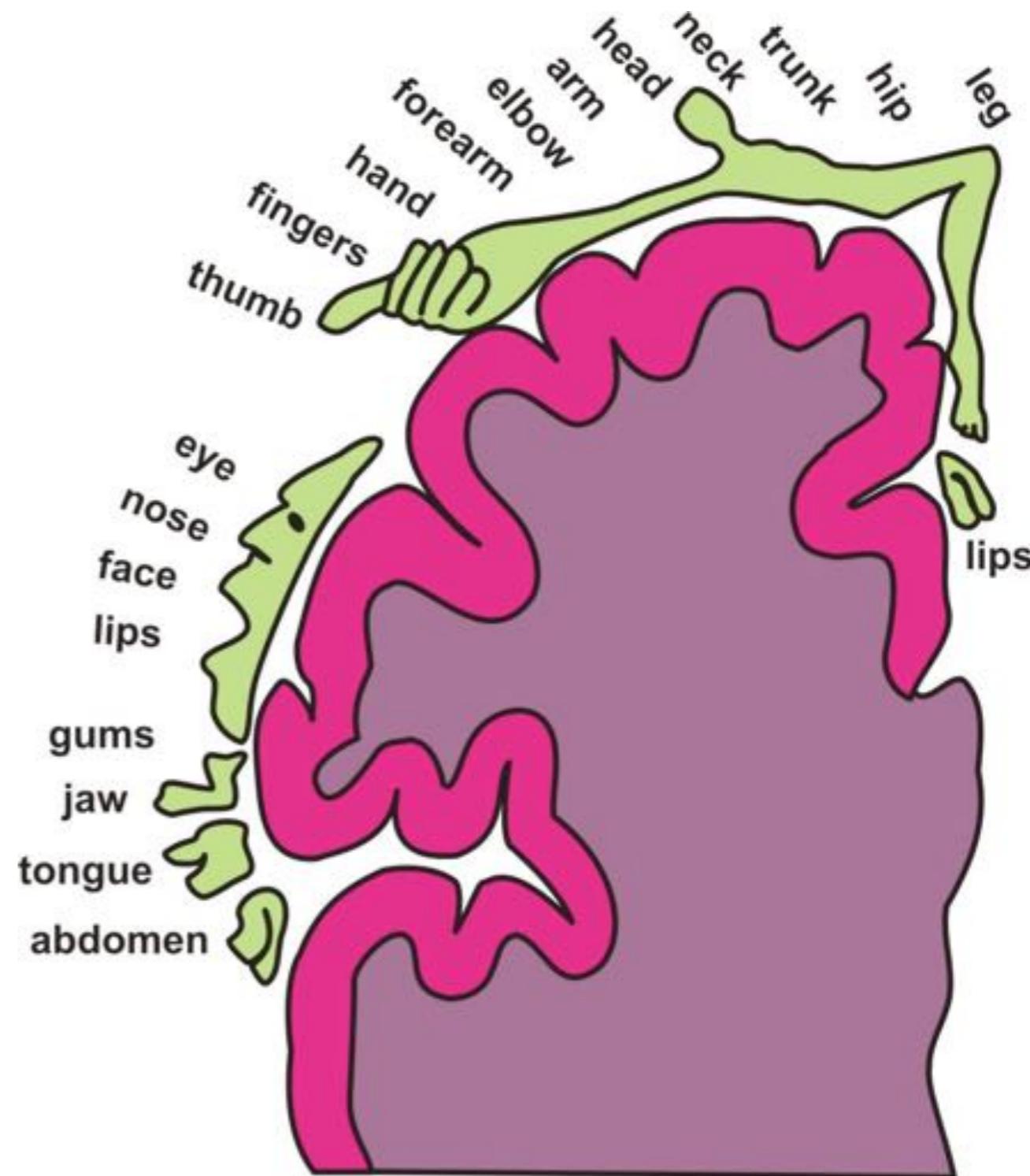
## Developmental Robotics

some examples on body maps, sensorimotor exploration and learning



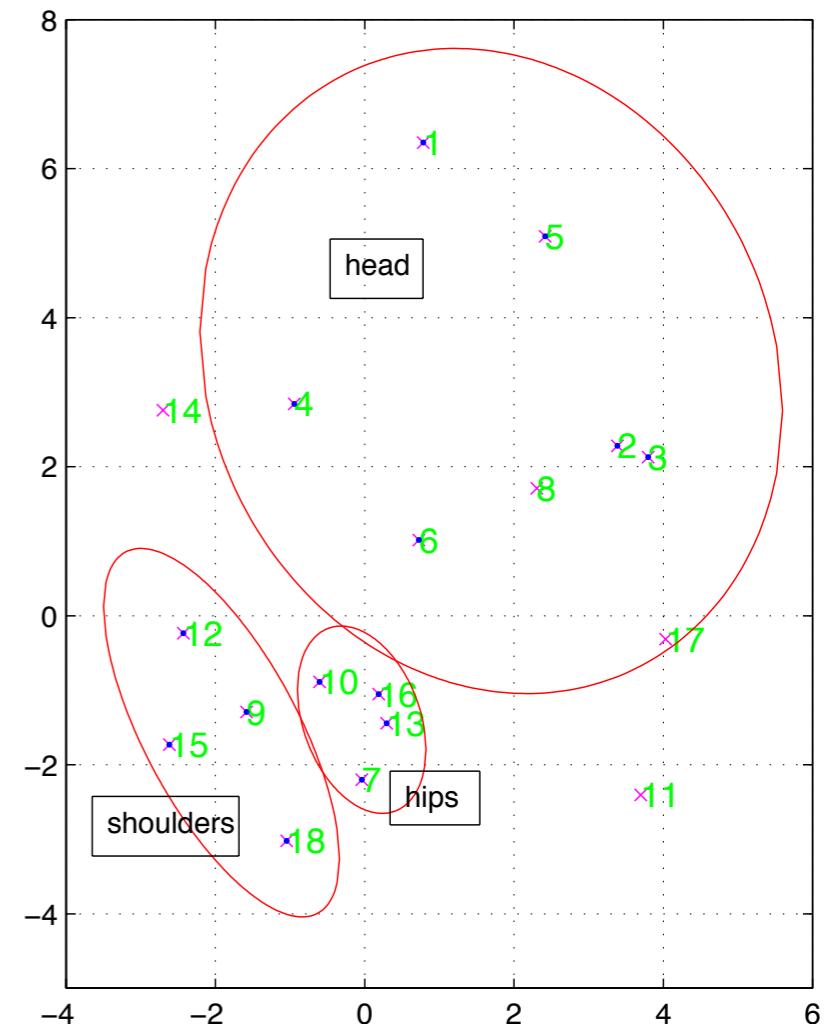
# Body maps

- inspired by somato-sensory maps in human cortex
- dynamic and short term representation of body and behaviour



# Maps based on Information Distances

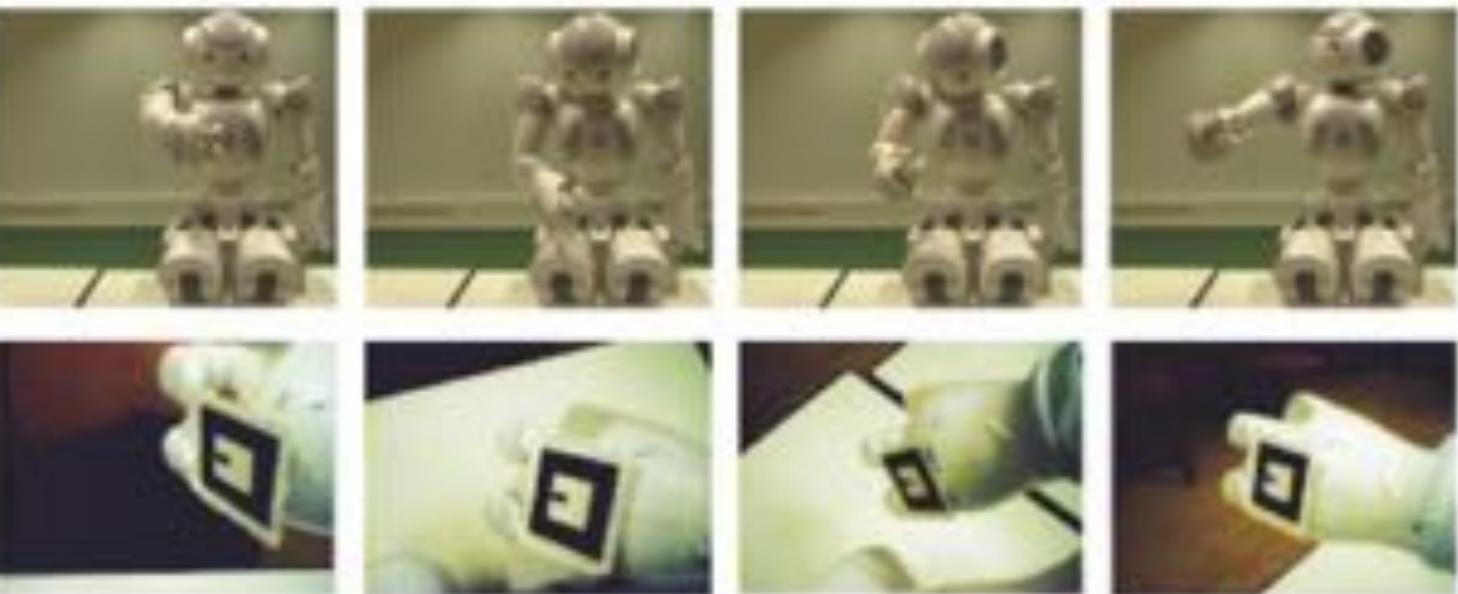
- informationally close sensors are also close on the map
- maps function as body schema



Hafner, V.V. and Kaplan, F. (2008), Interpersonal Maps: How to Map Affordances for Interaction Behaviour, In: E. Rome et al. (Eds.):Affordance-Based Robot Control, LNAI 4760, pp. 1-15, Springer-Verlag Berlin Heidelberg

# Sensorimotor Exploration

exploration strategies



# Exploration Strategies

- Random motor babbling
- Goal-directed
- Intrinsic motivation



Rolf, M., and M. Asada, "Autonomous Development of Goals: From Generic Rewards to Goal and Self Detection", IEEE Int. Conf. Development and Learning and on Epigenetic Robotics, Genoa, 10/2014.

Oudeyer, P.-Y., Kaplan, F., **Hafner, V.V.** (2007), Intrinsic Motivation Systems for Autonomous Mental Development, IEEE Transactions on Evolutionary Computation, Special Issue on Autonomous Mental Development, 11:2, pp. 265-286

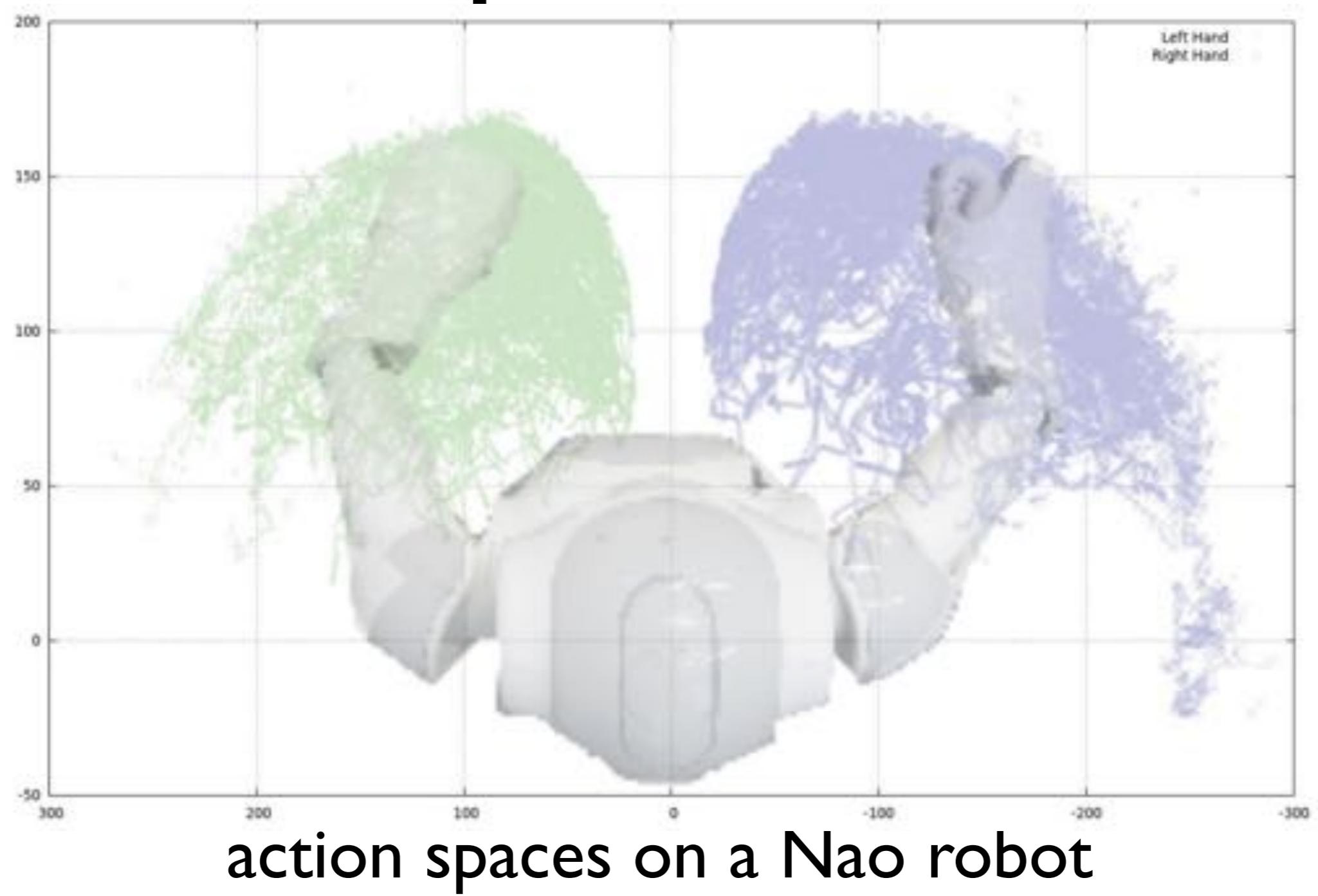
# Exploration Strategies



The Playground Experiment  
(intrinsic motivation,  
maximise learning  
progress)

Oudeyer, P.-Y., Kaplan, F., **Hafner, V.V.** (2007), Intrinsic Motivation Systems for Autonomous Mental Development, IEEE Transactions on Evolutionary Computation, Special Issue on Autonomous Mental Development, 11:2, pp. 265-286

# Sensorimotor Exploration



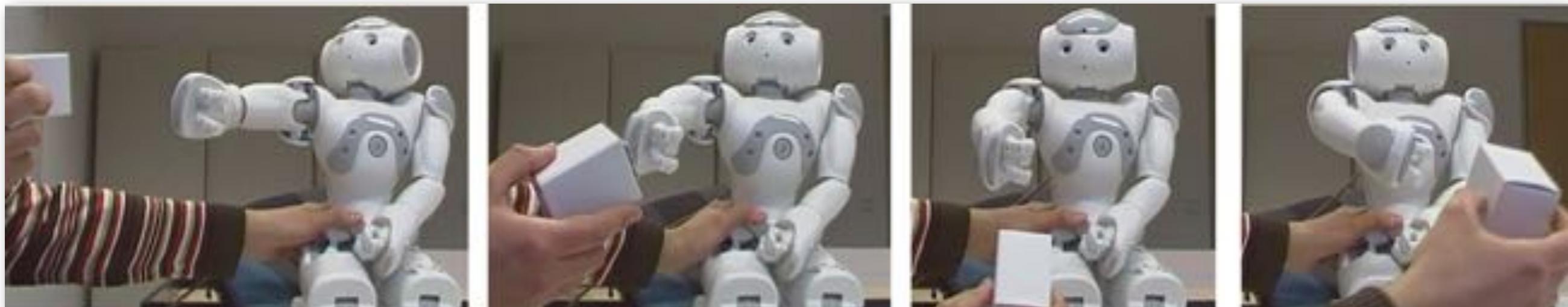
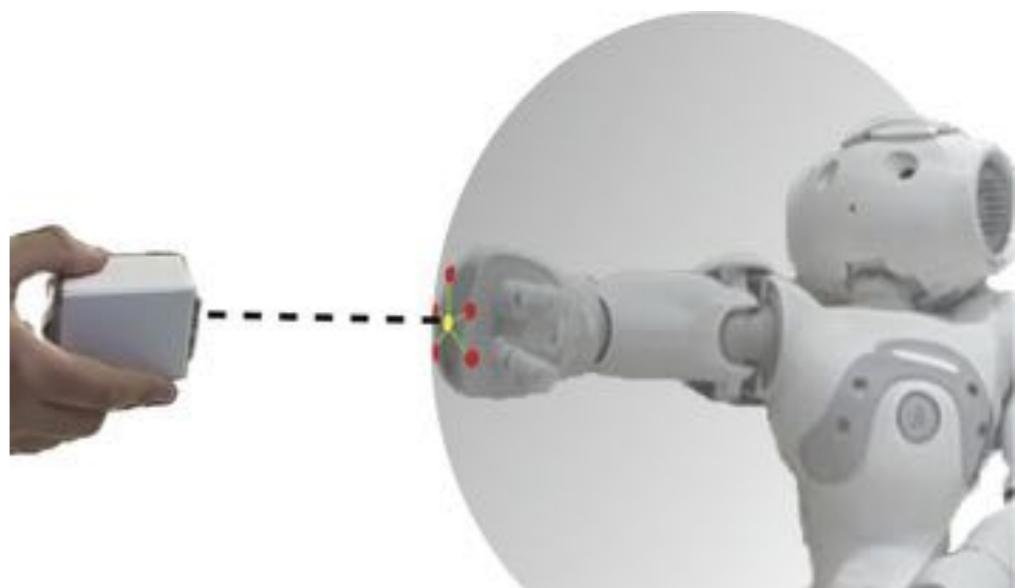
# Could pointing emerge from grasping?



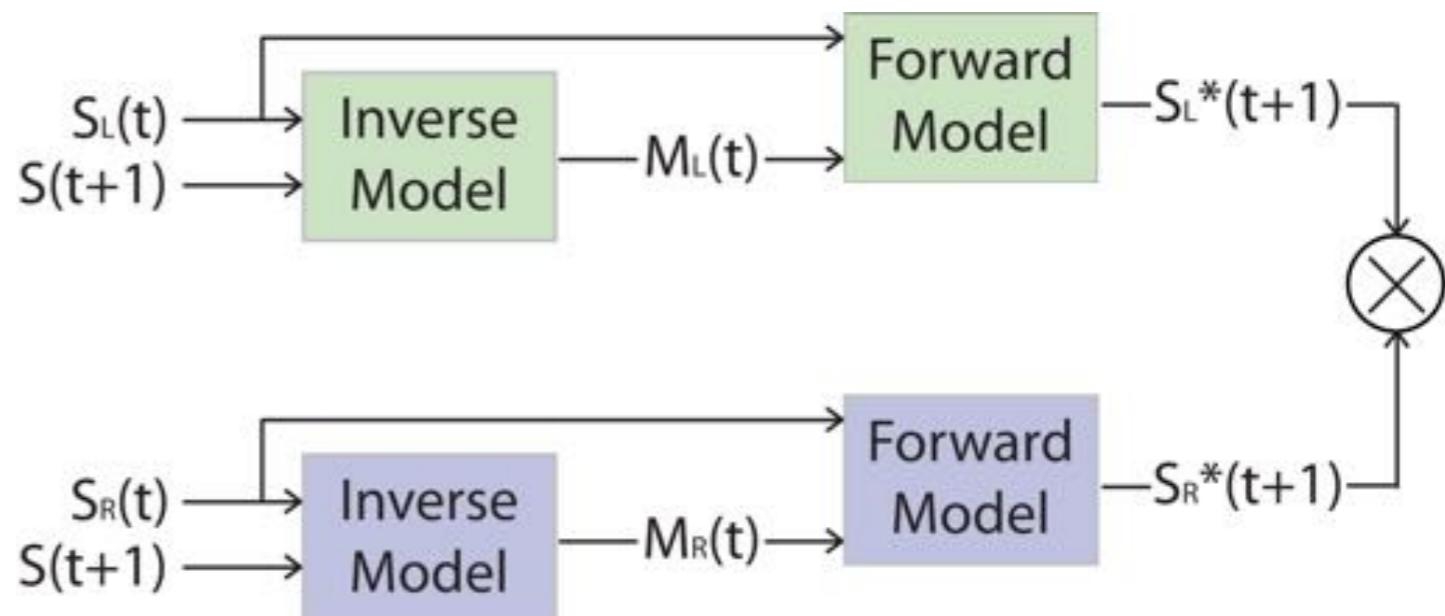
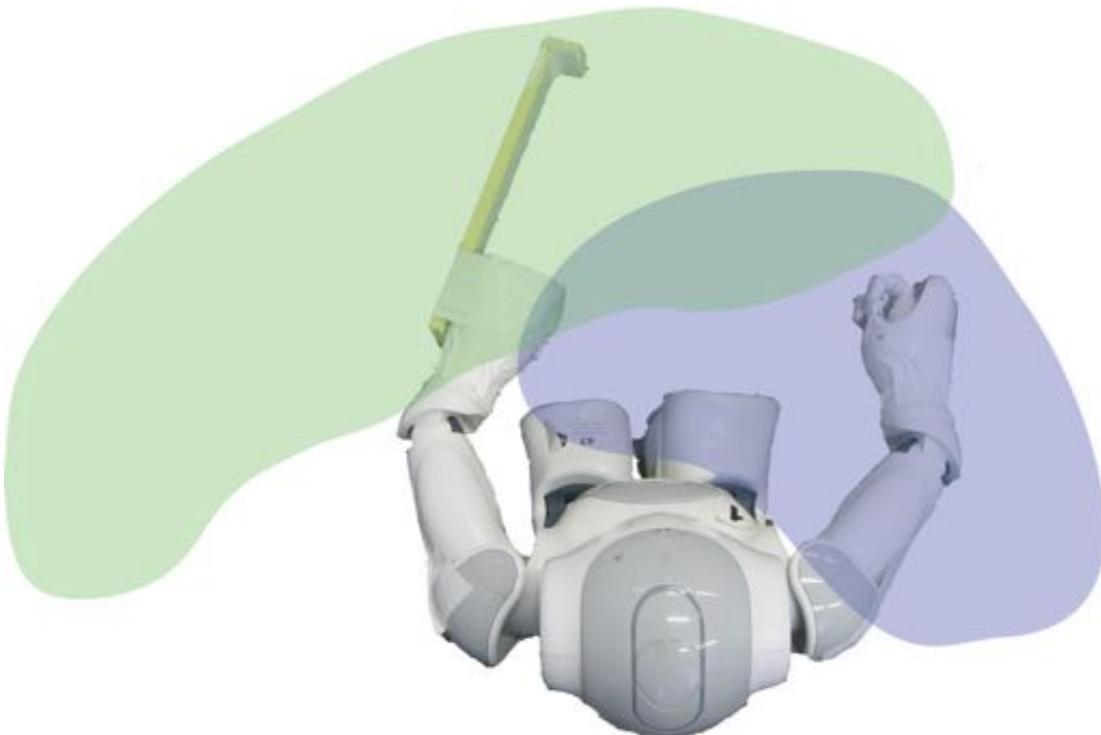
**Hafner, V.V. and Schillaci, G. (2011),** From field of view to field of reach - could pointing emerge from the development of grasping? *Frontiers in Computational Neuroscience, Conference Abstract: IEEE ICDL-EPIROB 2011.*

# Could pointing emerge from grasping?

object outside the field of grasp

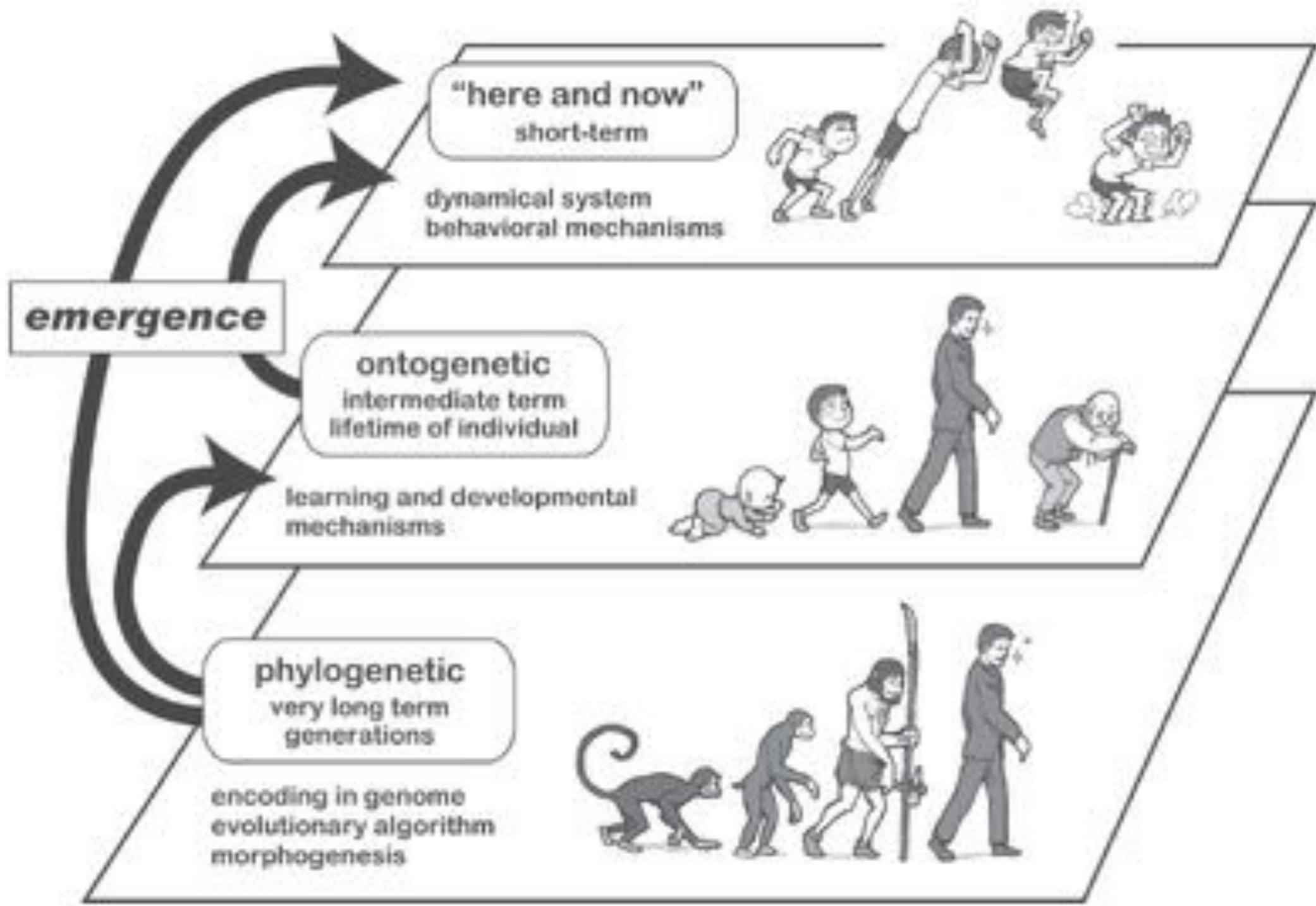


# ...Tool-use and Internal Models



Schillaci, G., **Hafner, V. V.**, Lara, B. (2012), Coupled Inverse-Forward Models for Action Execution Leading to Tool-Use in a Humanoid Robot, *Proceedings of the 7th ACM/IEEE International Conference on Human-Robot Interaction (HRI 2012)*, pp. 231-232, Boston, USA.

# Time perspectives



# Phylogenetic Perspective

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## Evolution



# Artificial evolution

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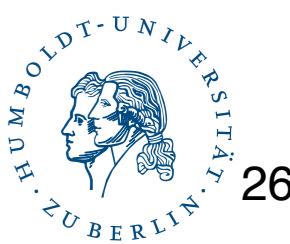
- John Holland
- Ingo Rechenberg
- John Koza



# Artificial evolution

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- **John Holland: Genetic Algorithm, GA**
- **Ingo Rechenberg: Evolution Strategy, ES**
- **John Koza: Genetic Programming, GP**





# Bionics



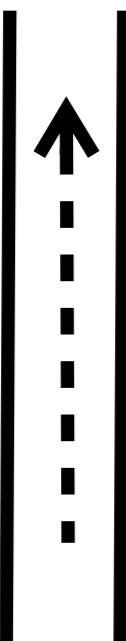
TU Berlin (Ingo Rechenberg)

<http://lautaro.bionik.tu-berlin.de/institut/s2foshow/>



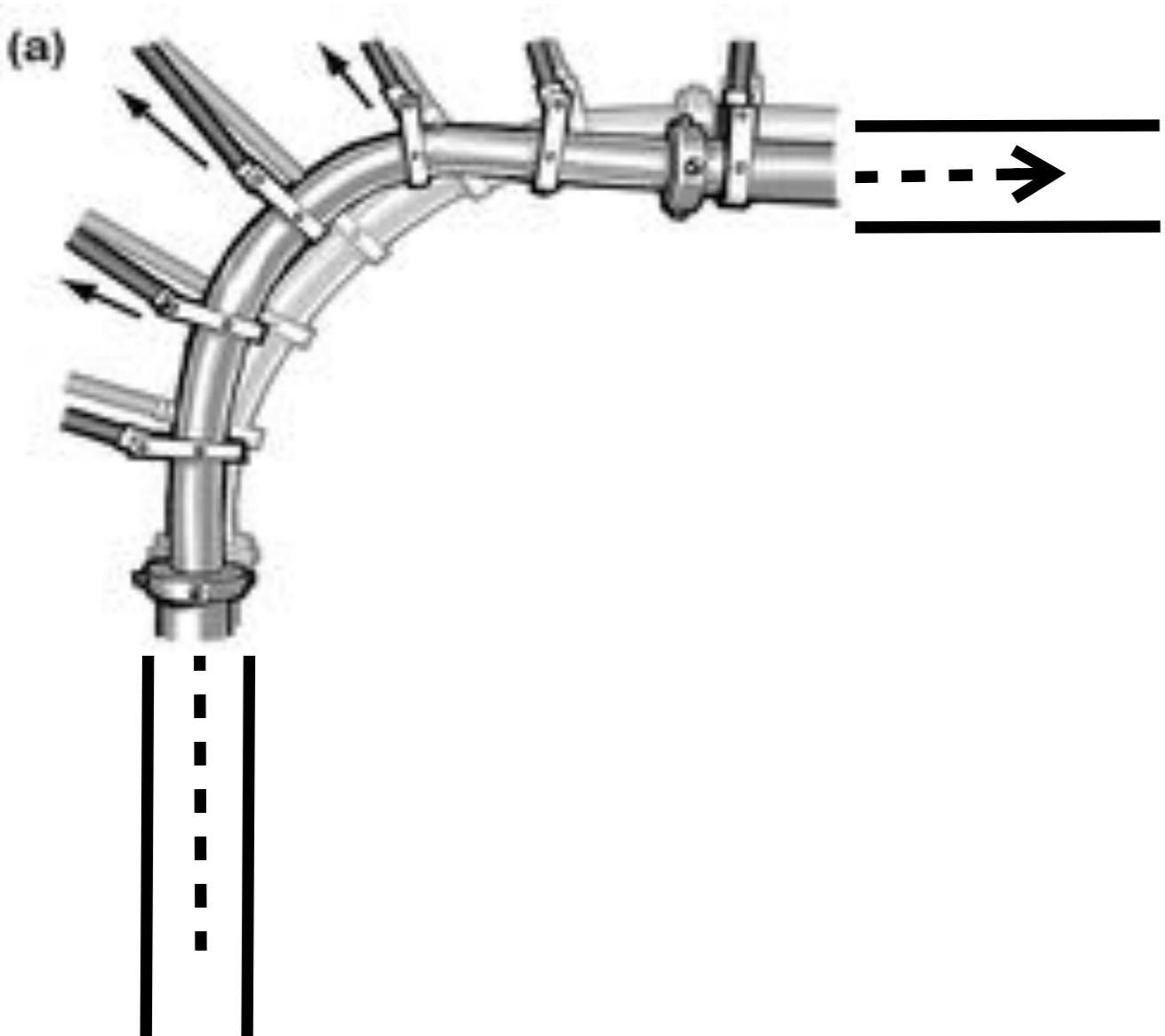
# Rechenberg's “fuel pipe problem”

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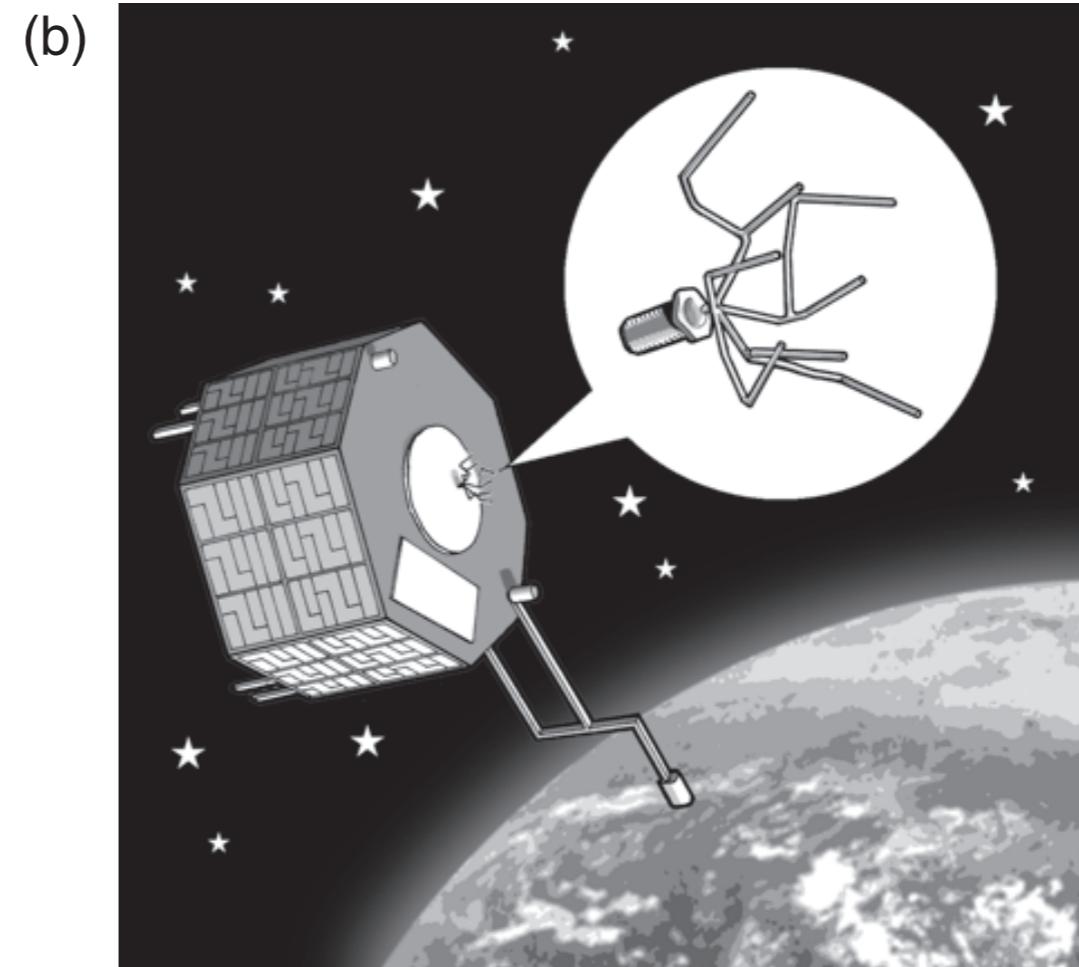
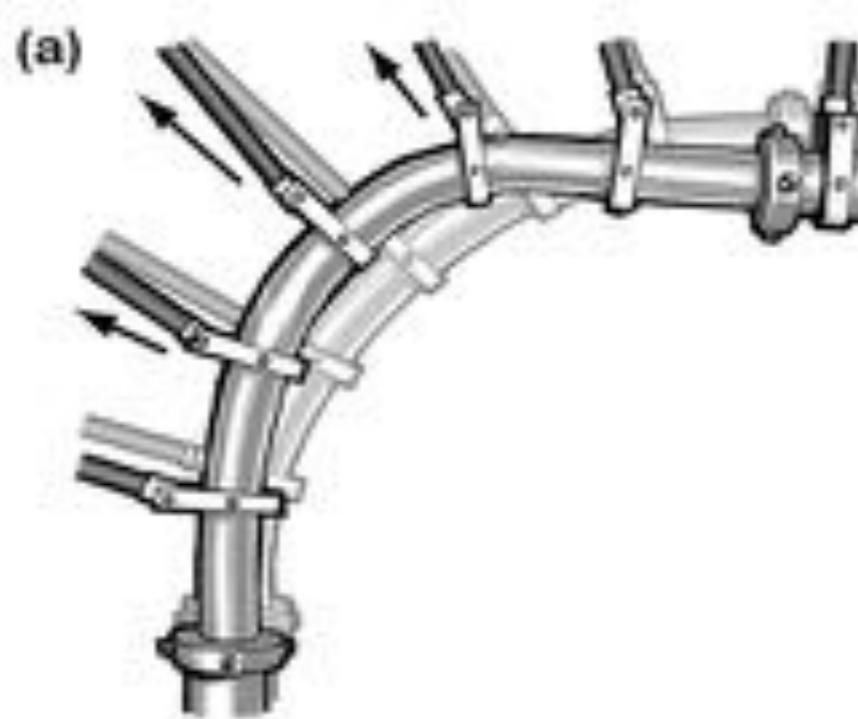


# Rechenberg's “fuel pipe problem”

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# Evolutionary designs



**evolutionary designs: (a) Rechenberg's “fuel pipe”, (b) antenna for satellite**

# Creativity: Connecting corners of square

---

x

x

**connect four corners  
of square with three  
straight lines, ending up  
in the starting corner**

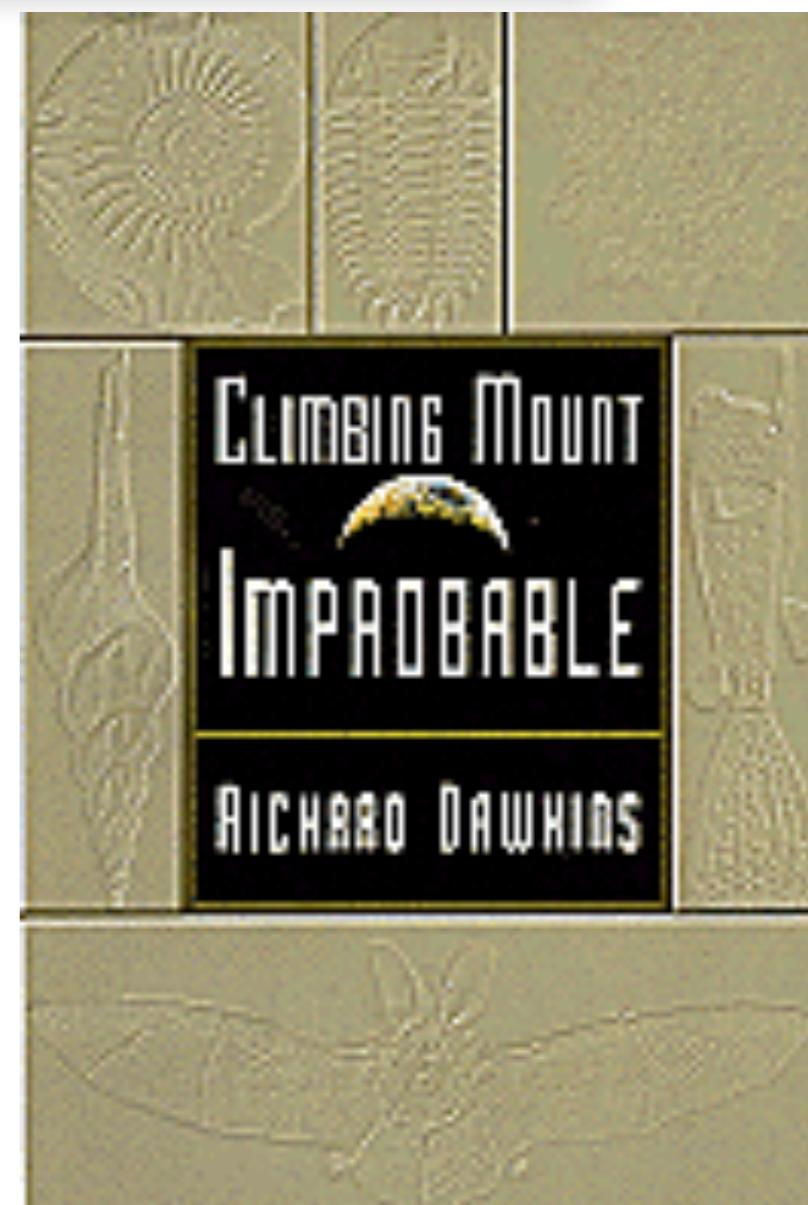
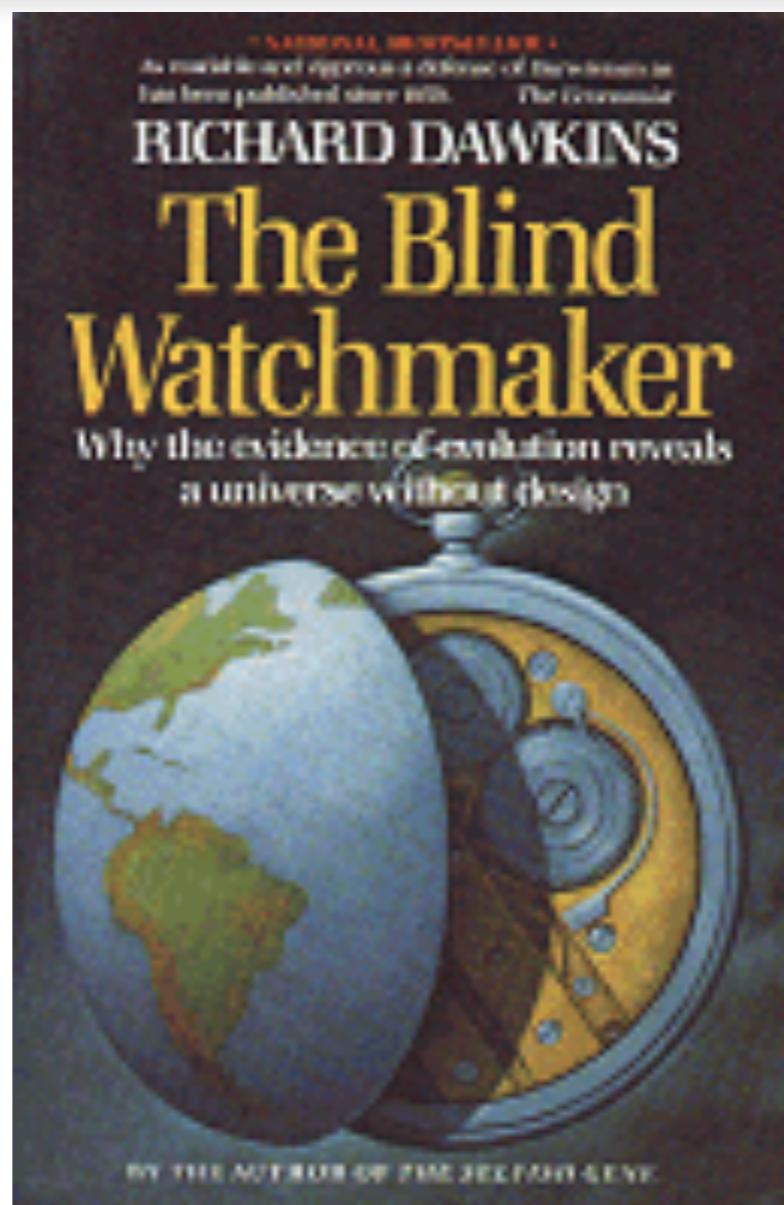
x

x



# Cumulative selection

**Richard Dawkins**  
(author of “The  
selfish gene”)



# Cumulative Selection: Example by Richard Dawkins

## Monkey typing Shakespeare

Hamlet: Do you see yonder cloud that's almost in shape of a camel?

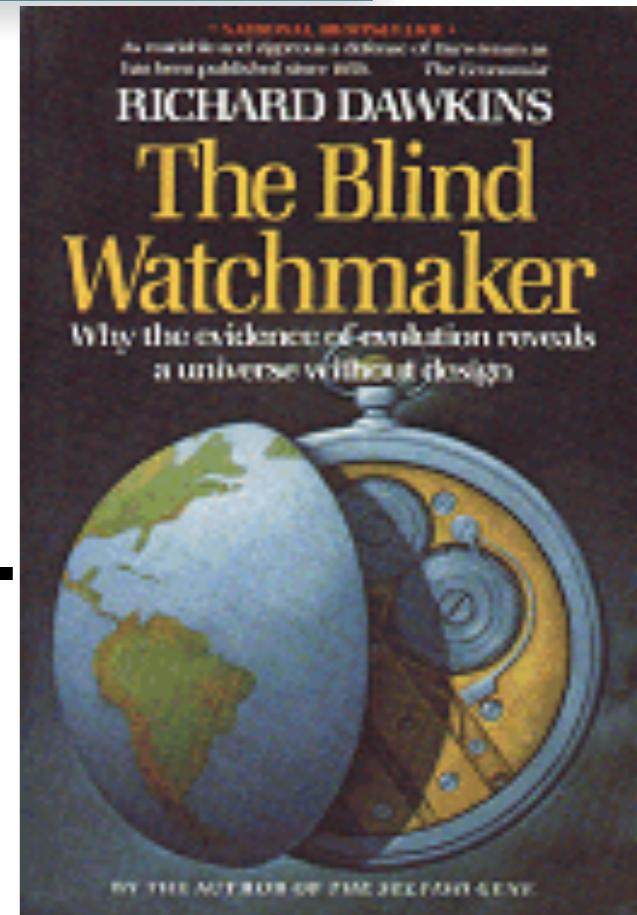
Polonius: By the mass, and 'tis like a camel, indeed.

Hamlet: Methinks it is like a weasel.

Polonius: It is backed like a weasel.

Hamlet: Or like a whale?

Polonius: Very like a whale.



# Cumulative Selection: Example by Richard Dawkins

Hamlet: Do you see yonder cloud that's almost in shape of a camel?

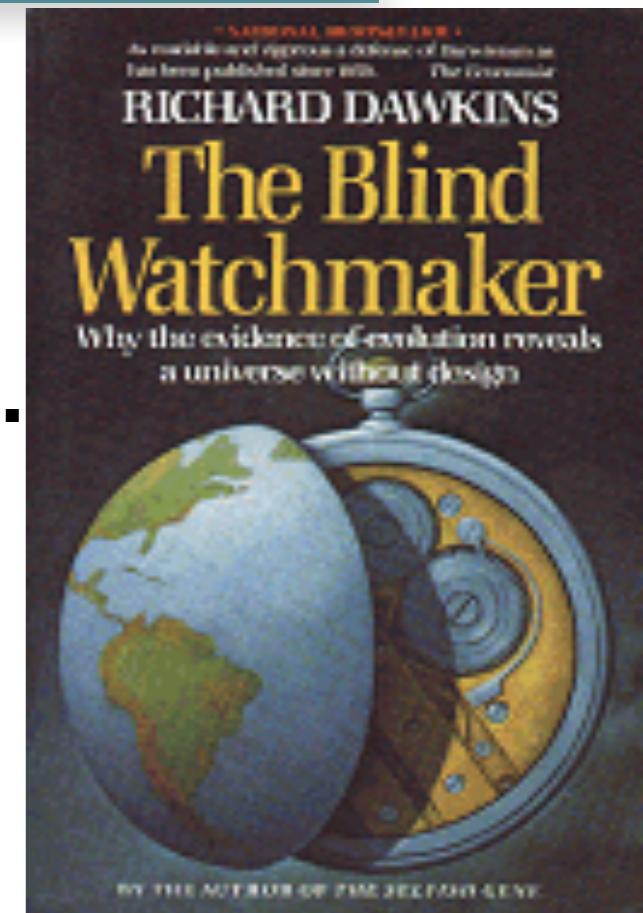
Polonius: By the mass, and 'tis like a camel, indeed.

Hamlet: Methinks it is like a weasel.

Polonius: It is backed like a weasel.

Hamlet: Or like a whale?

Polonius: Very like a whale.



How many possible arrangements?



# “Methinks it is like a weasel” (cumulative selection)

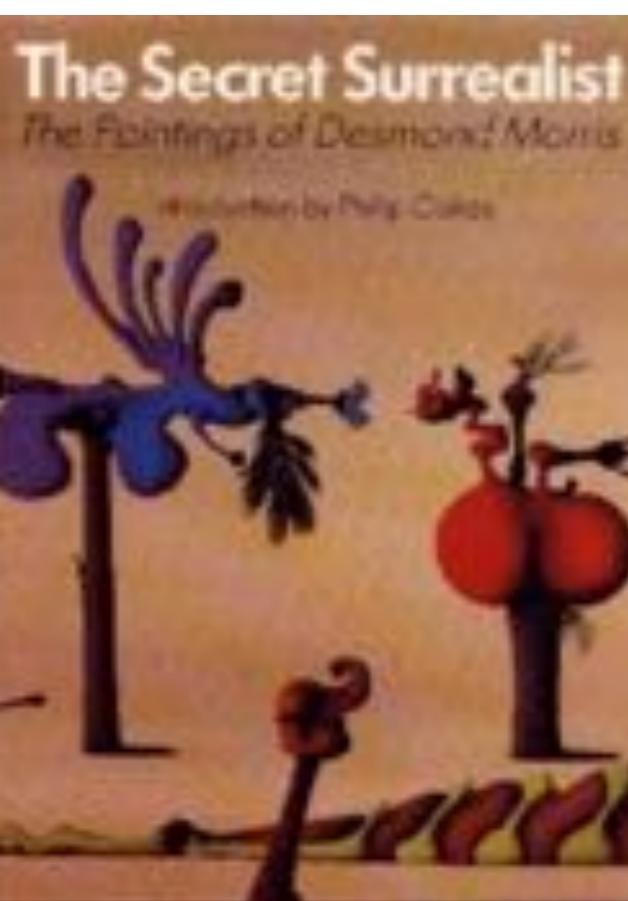
generation	winner sentence	dist. to target
0	WDLDMNLT DTJBKWIRZREZLMQVOP	25
10	WDLDMNLT DTJB SWIRZREZLMQVOP	24
20	WDLDMNLS ITJISWHRZREZ MECS P	20
30	MELDINLS IT ISWPRKE Z WECSEL	8
40	METHINGS IT ISWLIKE B WECSEL	4
43	METHINKS IT IS LIKE A WEASEL	0

# Biomorphs

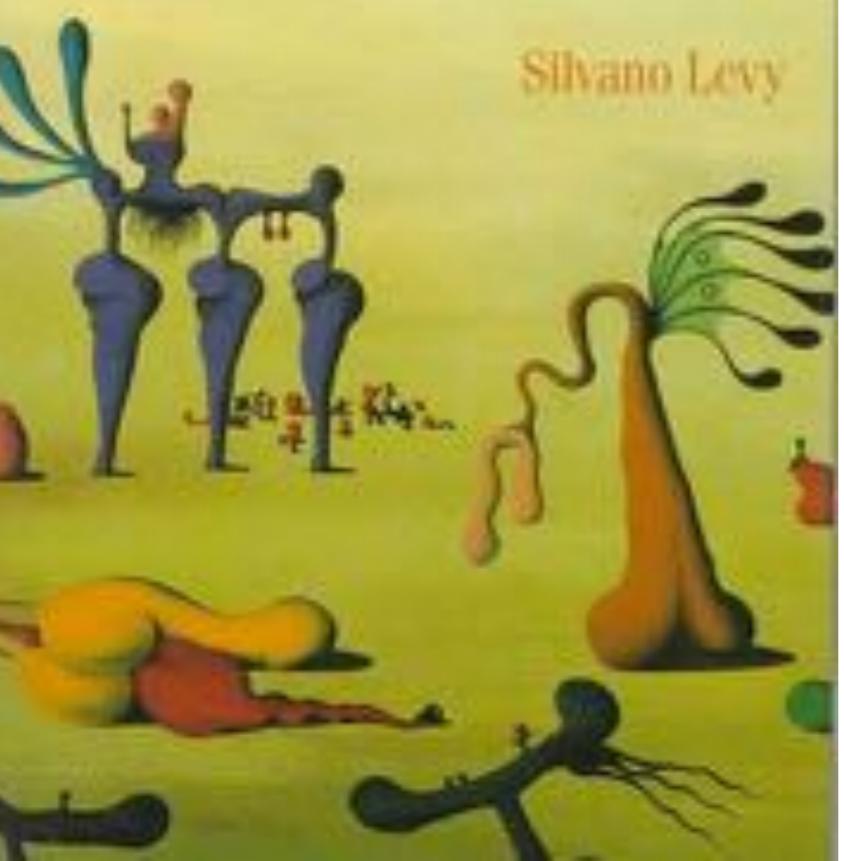
## The power of esthetic selection

- encoding “creature” in genome (string of numbers)
- expression of “genes” (graphical appearance):
- selection of individuals for “reproduction” (based on “fitness” – esthetic appeal)

“reproduction” (with mutation)

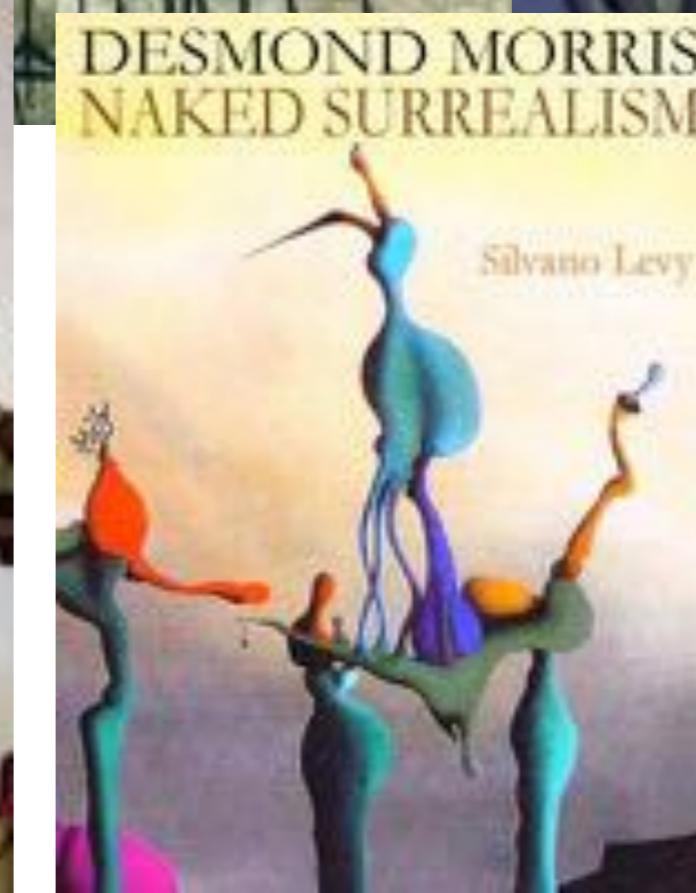
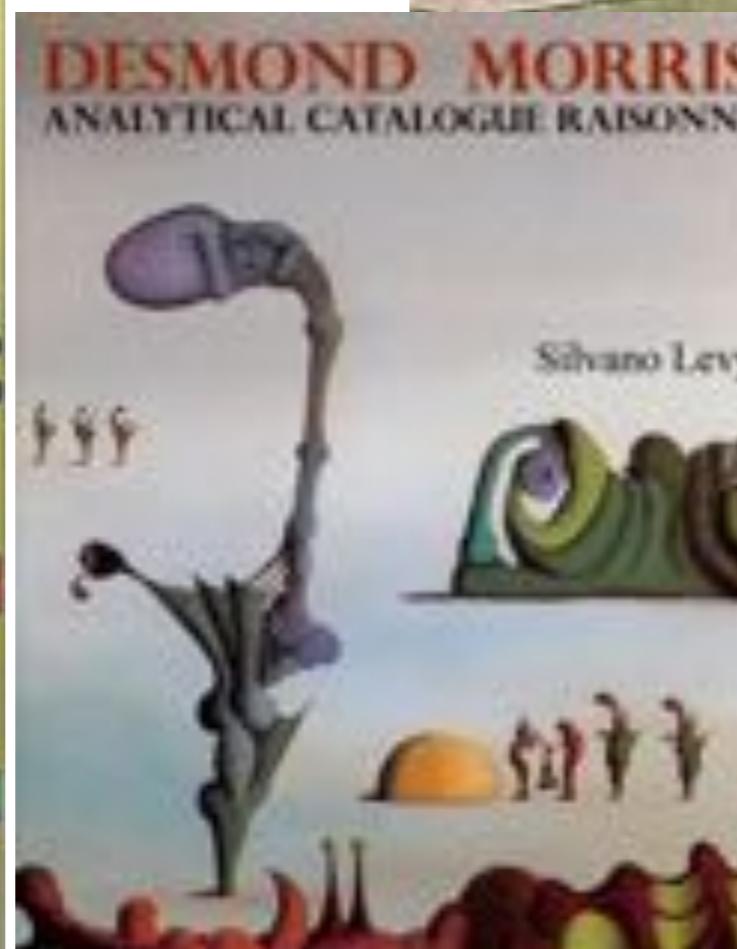
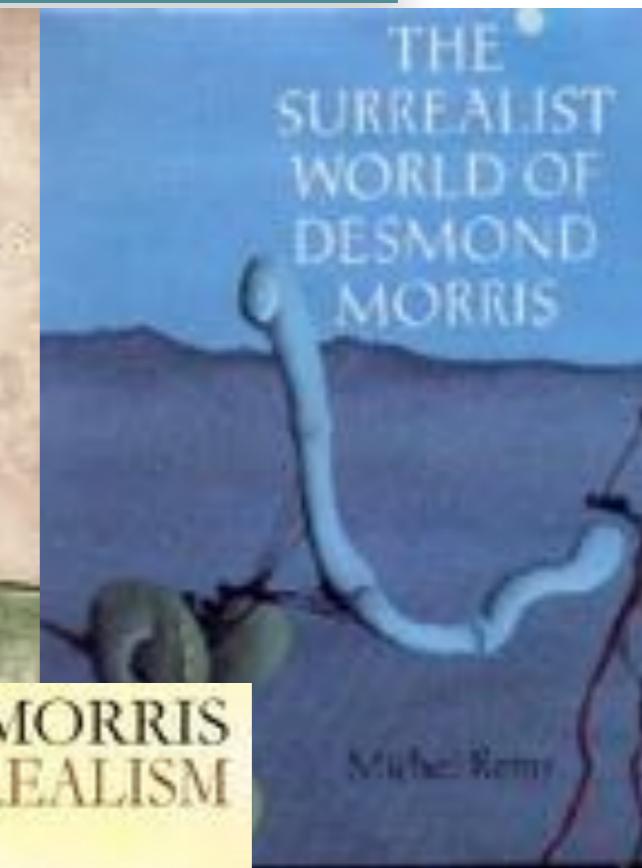
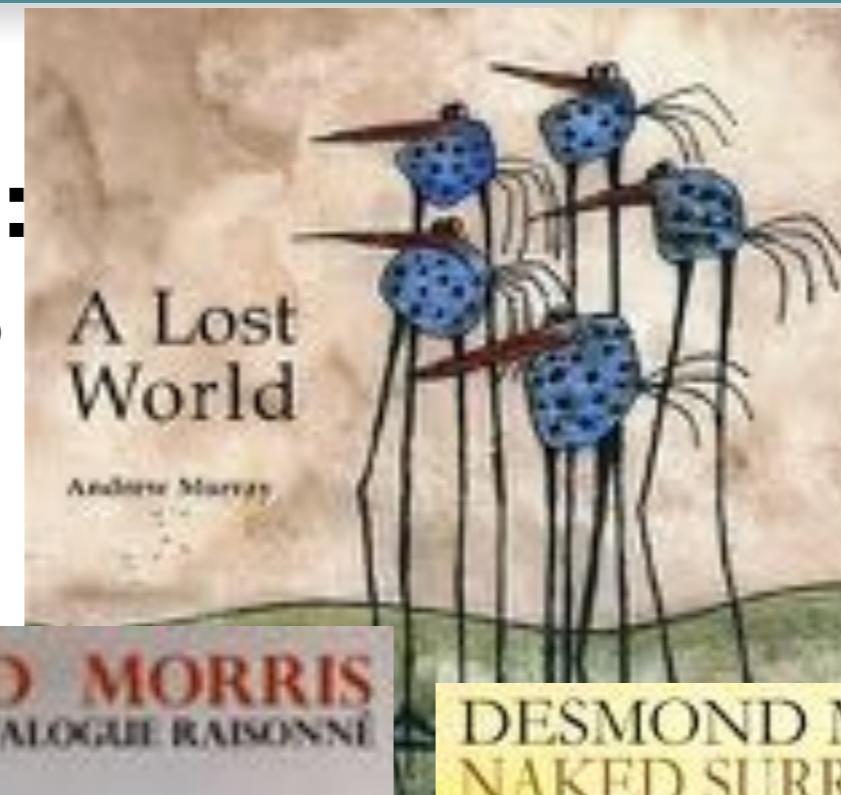


DESMOND MORRIS  
50 YEARS OF SURREALISM



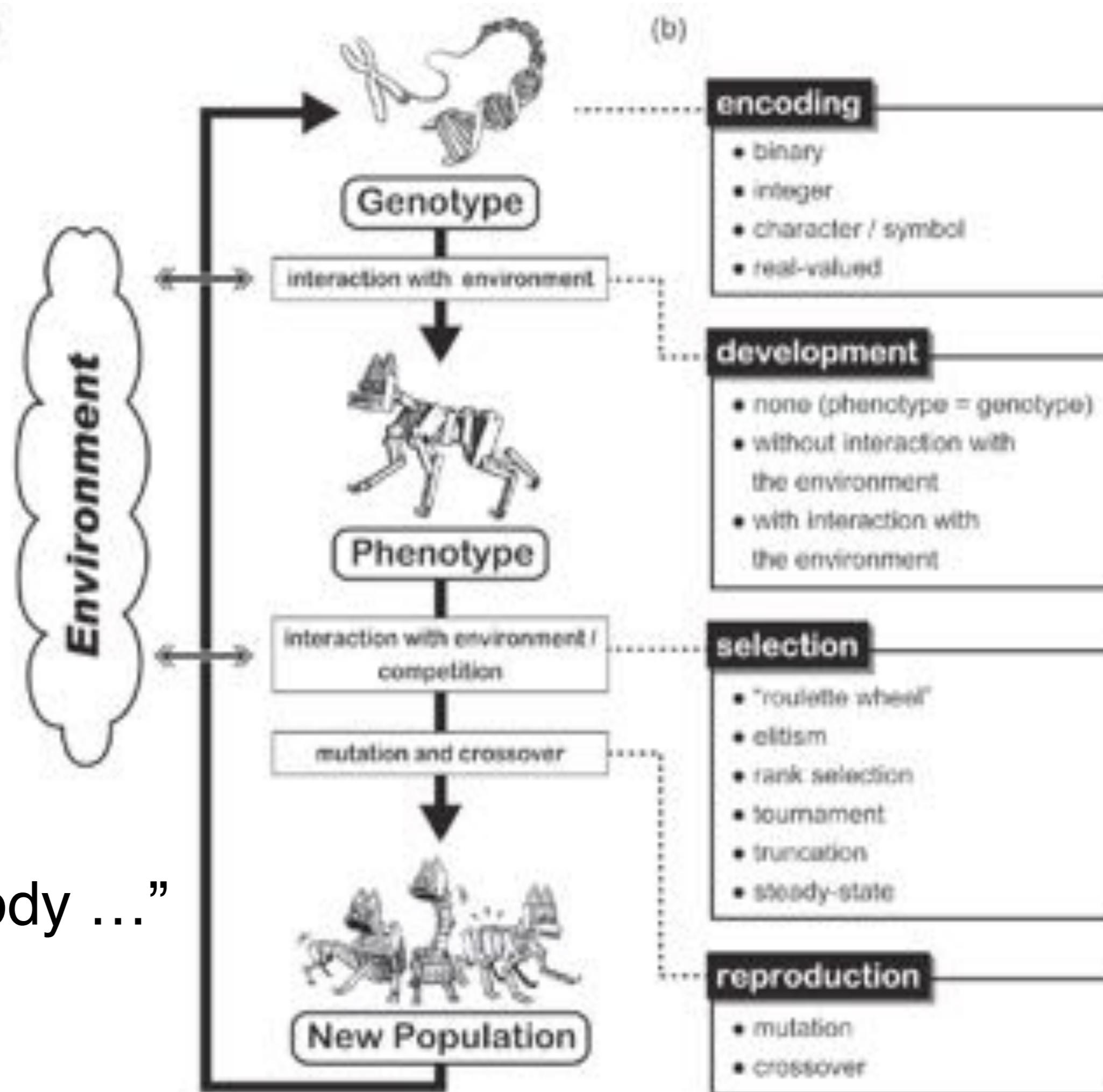
# Biomorphs: by surrealist painter Desmond Morris

exhibitions:  
1948 - 2008

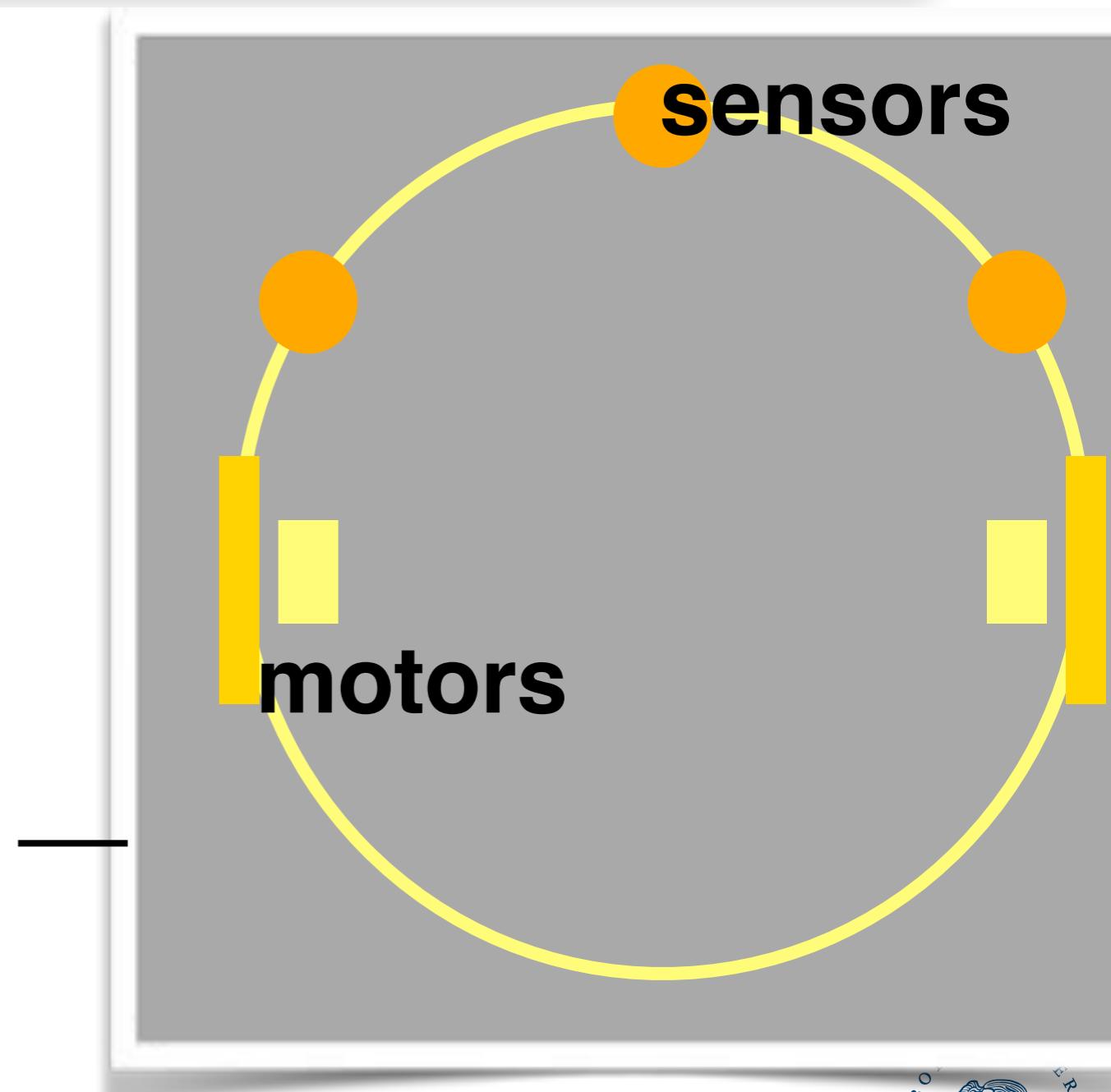


# Basic cycle for artificial evolution

from  
“How the body ...”



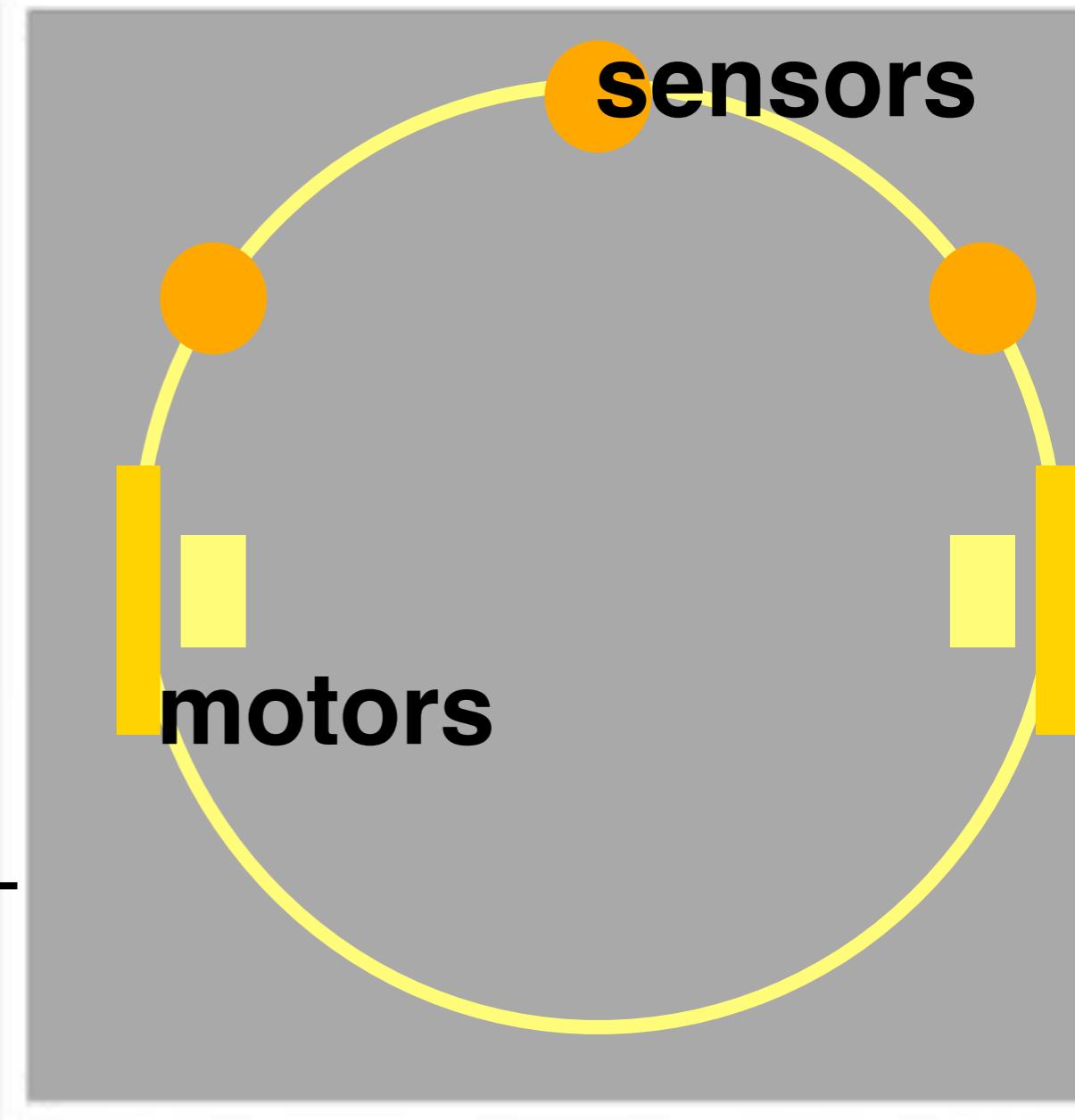
# Evolving a neural controller



# Evolving a neural controller

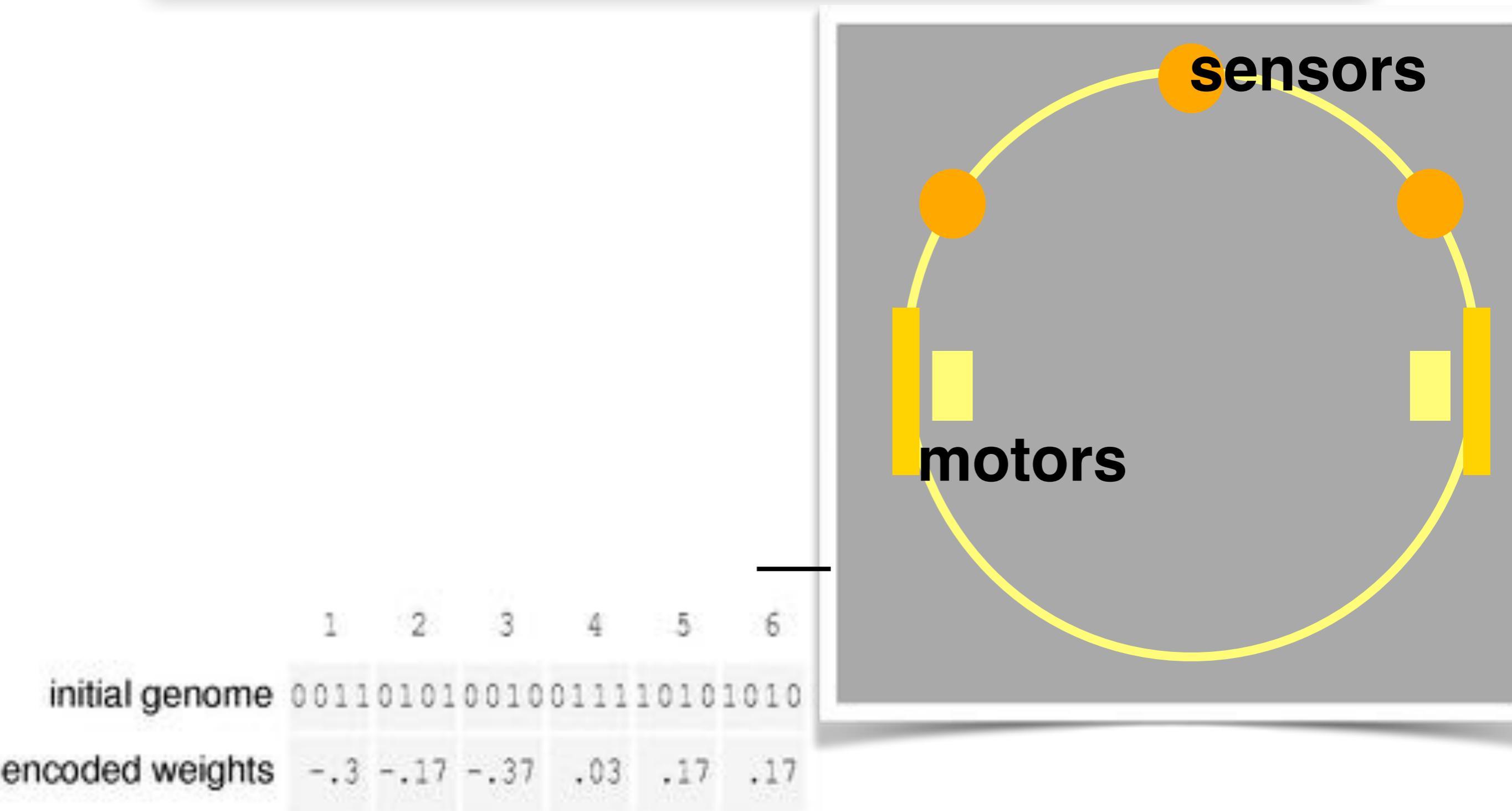
What do we need to specify?

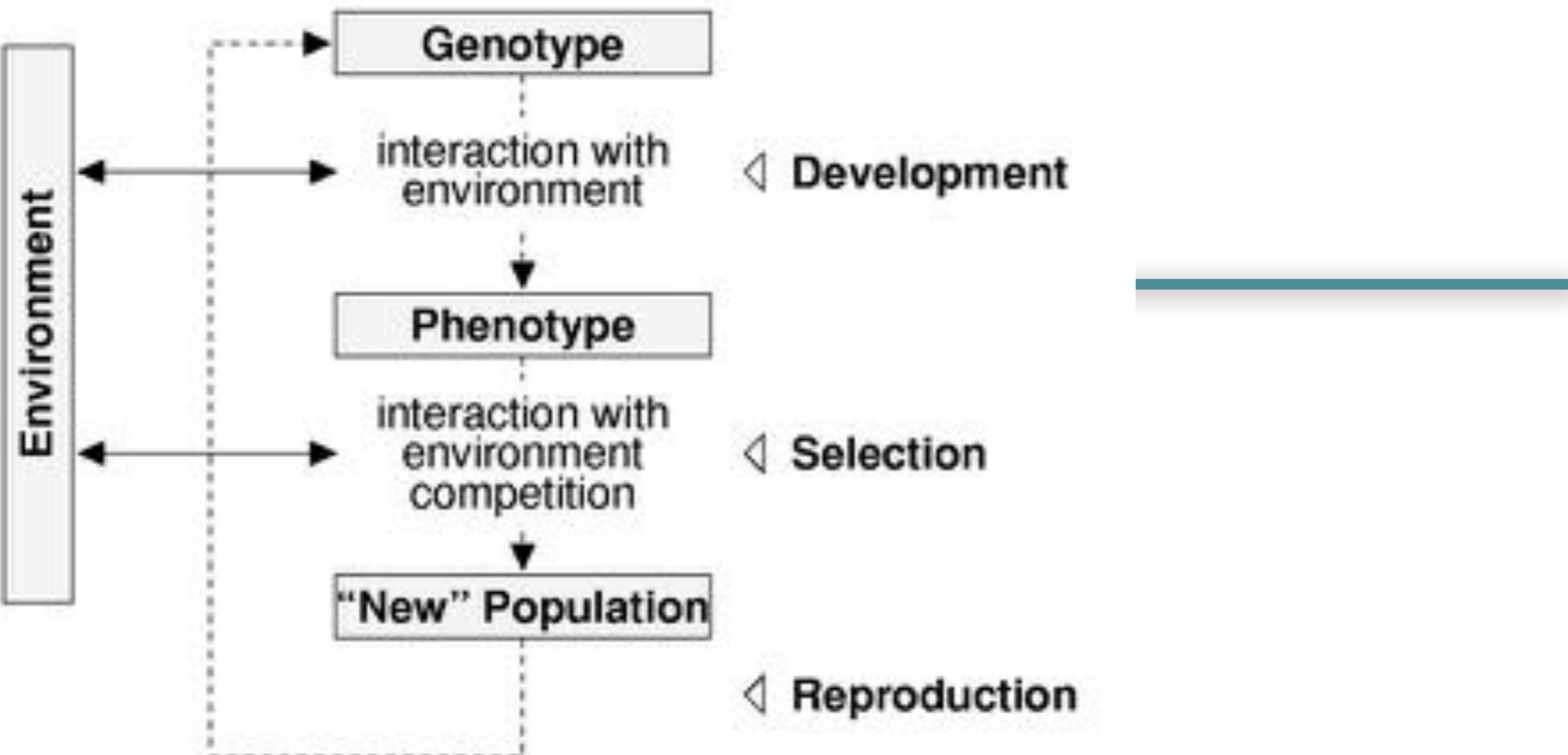
(encoding in genome?)



# Encoding in genome

---





encoding	development	selection	reproduction
<ul style="list-style-type: none"> <li>• binary</li> <li>• many-character</li> <li>• real-valued</li> </ul>	<ul style="list-style-type: none"> <li>• no development (phenotype = genotype)</li> <li>• development with and without interaction with the environment</li> </ul>	<ul style="list-style-type: none"> <li>• "roulette wheel"</li> <li>• elitism</li> <li>• rank selection</li> <li>• tournament</li> <li>• truncation</li> <li>• steady-state</li> </ul>	<ul style="list-style-type: none"> <li>• mutation</li> <li>• crossover</li> </ul>

# Fitness function and selection

---

## suggestions?

encoding	development	selection	reproduction
• binary	• no development (phenotype = genotype)	• “roulette wheel”	• mutation
• many-character	• development with and without interaction with the environment	• elitism	• crossover
• real-valued		• rank selection • tournament • truncation • steady-state	

crossover point

001101|01001001110101010

crossover point

101010|110000100111011100

## Reproduction: crossover and mutation

001101110000100111011100

10101001001001110101010

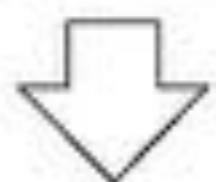
mutation

001101110000100111011100

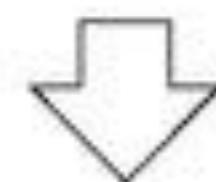
10101001001001110101010

001101110010100111011100

10101001001001110101010



gene expression



-.3 -.03 -.37 .1 .37 .3

.17 .1 -.37 .03 .17 .17

crossover point



crossover point

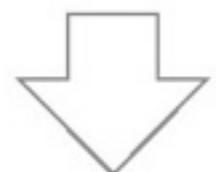
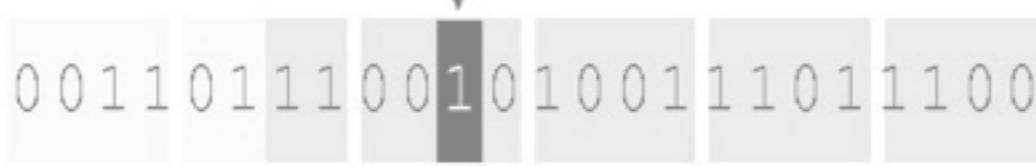
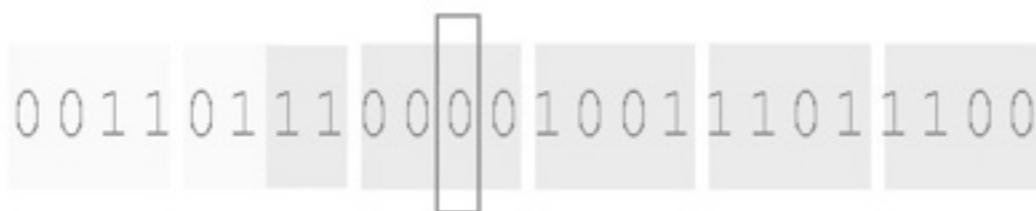


## Reproduction: crossover and mutation



## How to choose mutation rate?

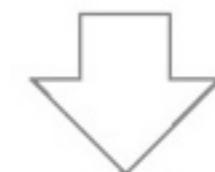
mutation



gene expression

-.3 -.03 -.37 .1 .37 .3

.17 .1 -.37 .03 .17



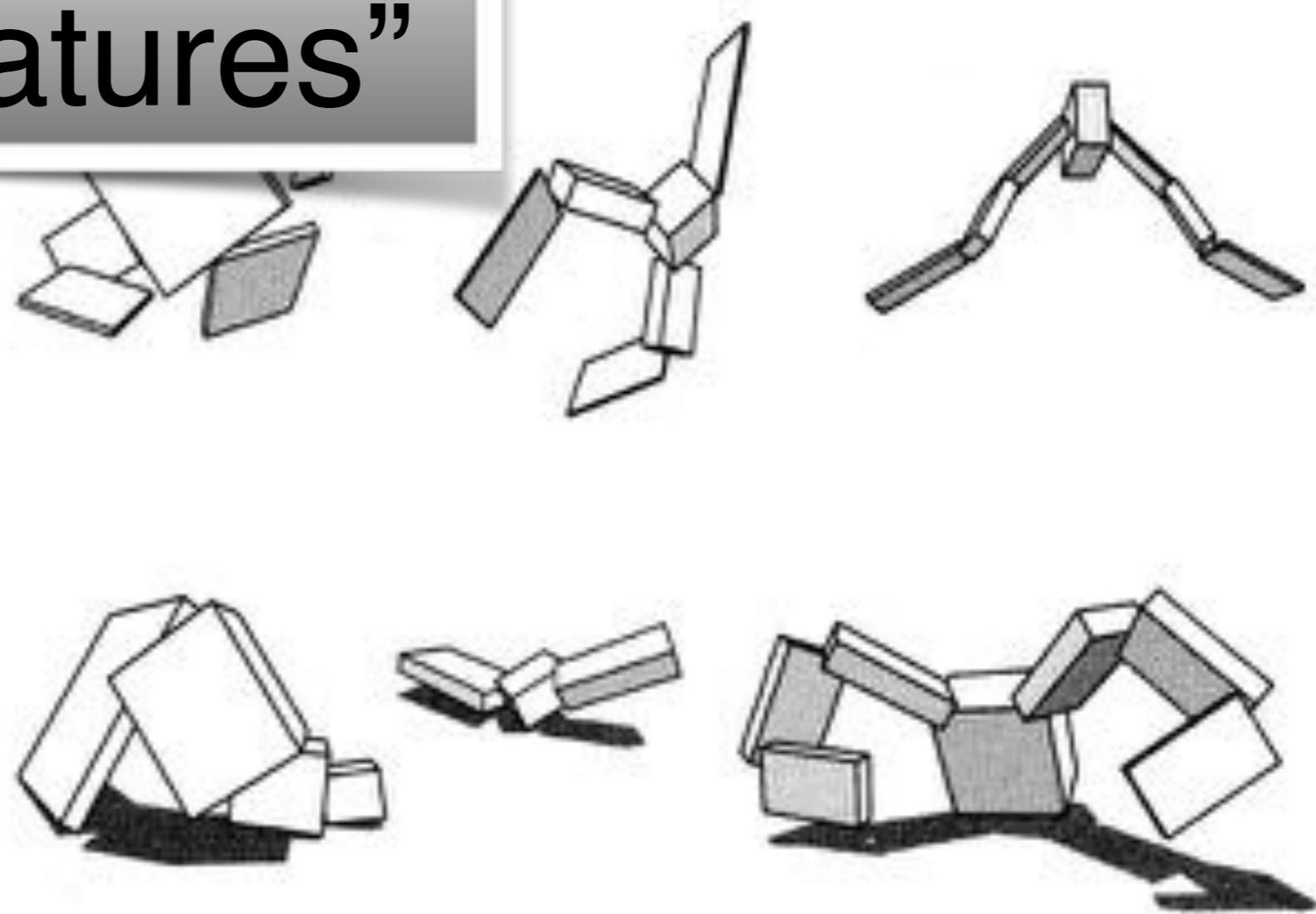
# Approaches to evolutionary robotics

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- given robot → evolve control  
(neural network)
- embodied approach → co-evolution of morphology and control

# Evolving morphology and control: Karl Sims' creatures

Video “Karl Sims’ evolved creatures”



# Parameterisation of morphology

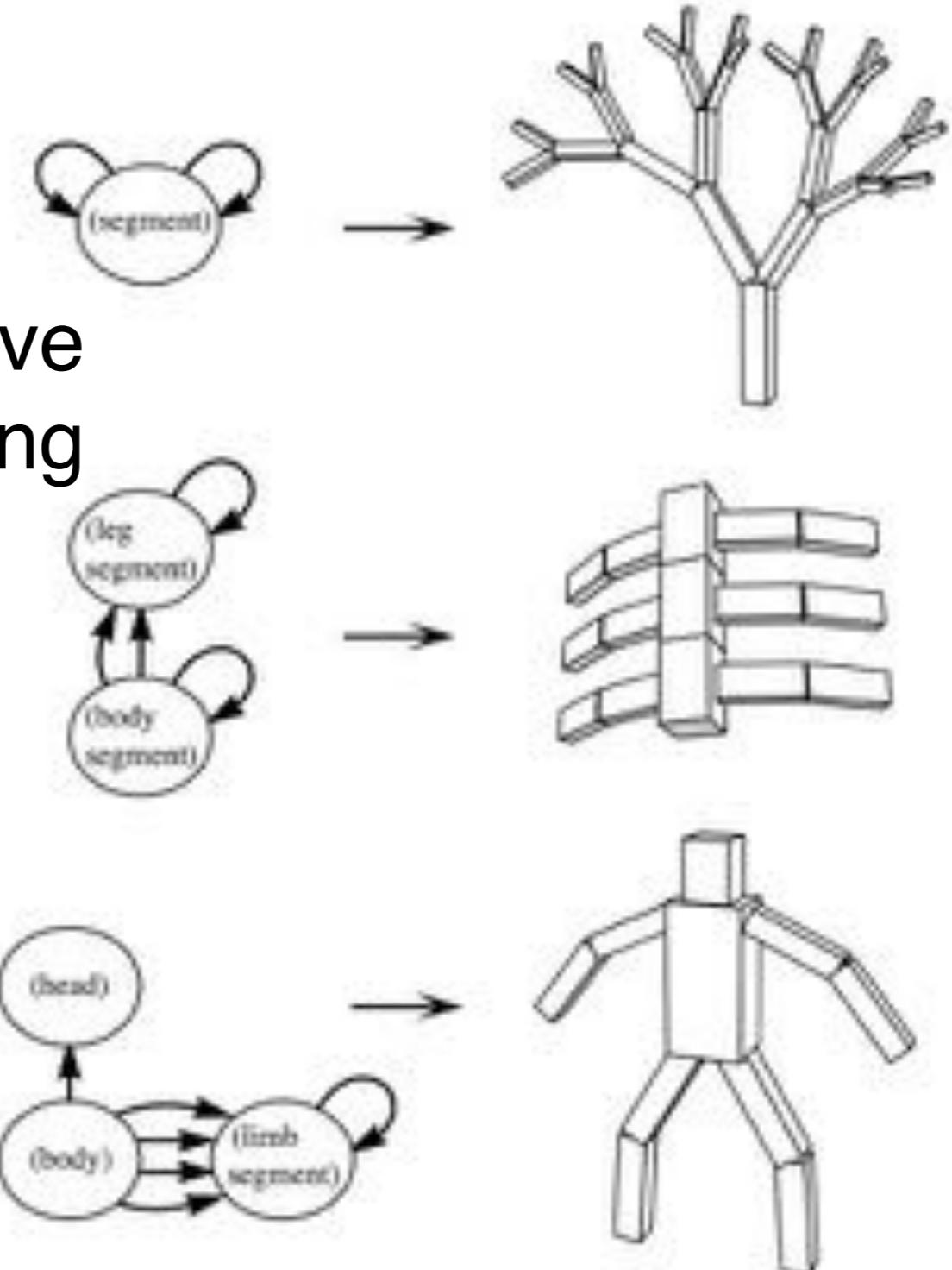
encoding in  
genome  
“genotype”

development



embodied  
agent  
“phenotype”

recursive  
encoding

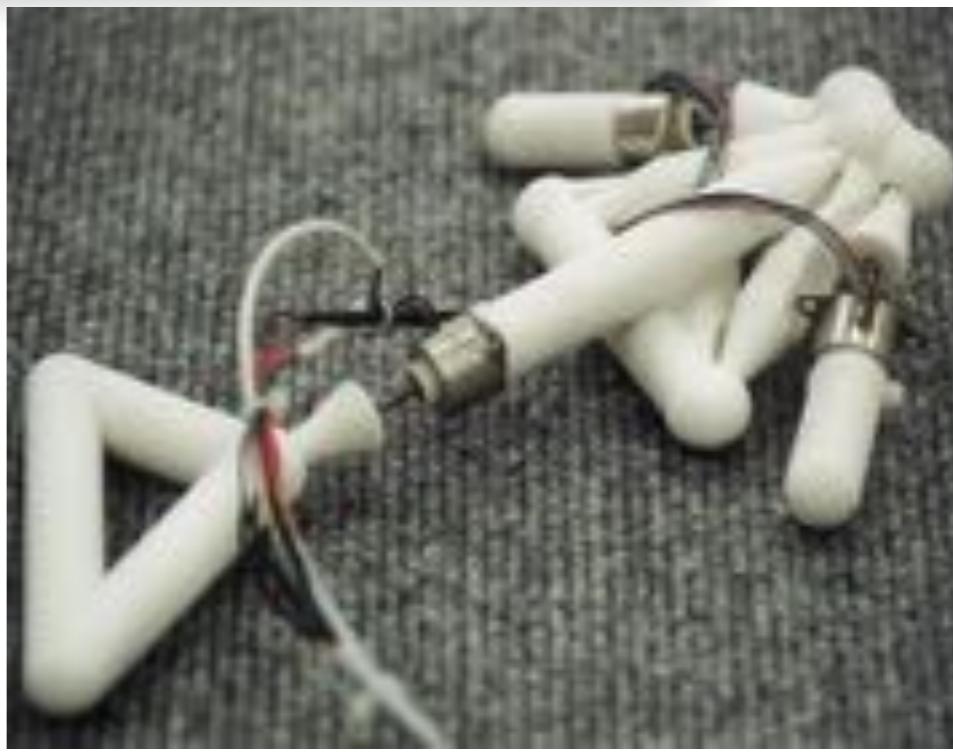


# New version: Golem (Lipson and Pollack)

representation of morphology  
in genome

- **robot: bars, actuators, neurons**
- **bars: length, diameter, stiffness, joint type**
- **actuators: type, range**
- **neurons: thresholds, synaptic strengths**

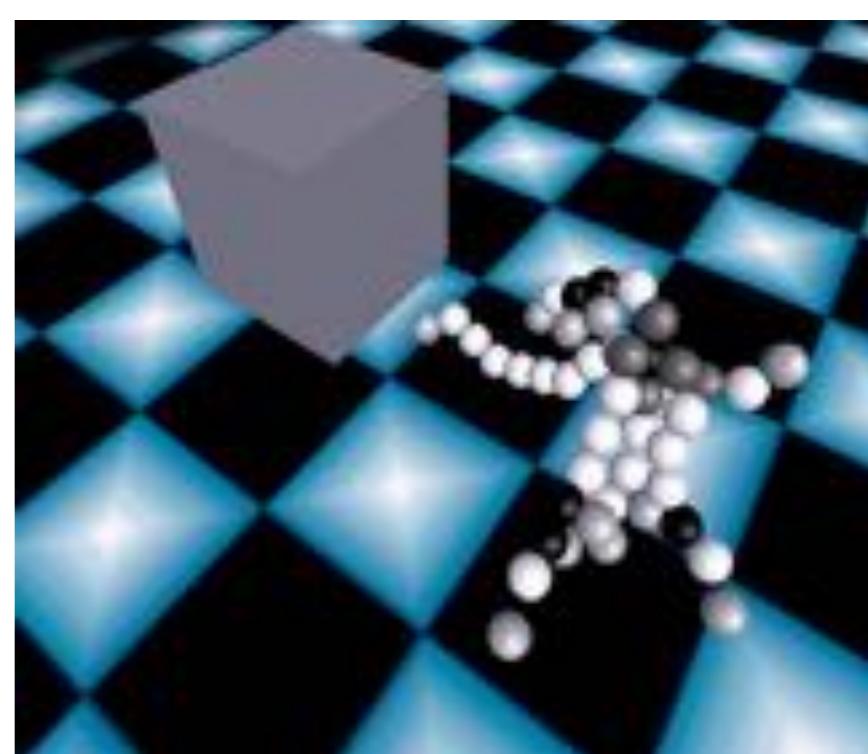
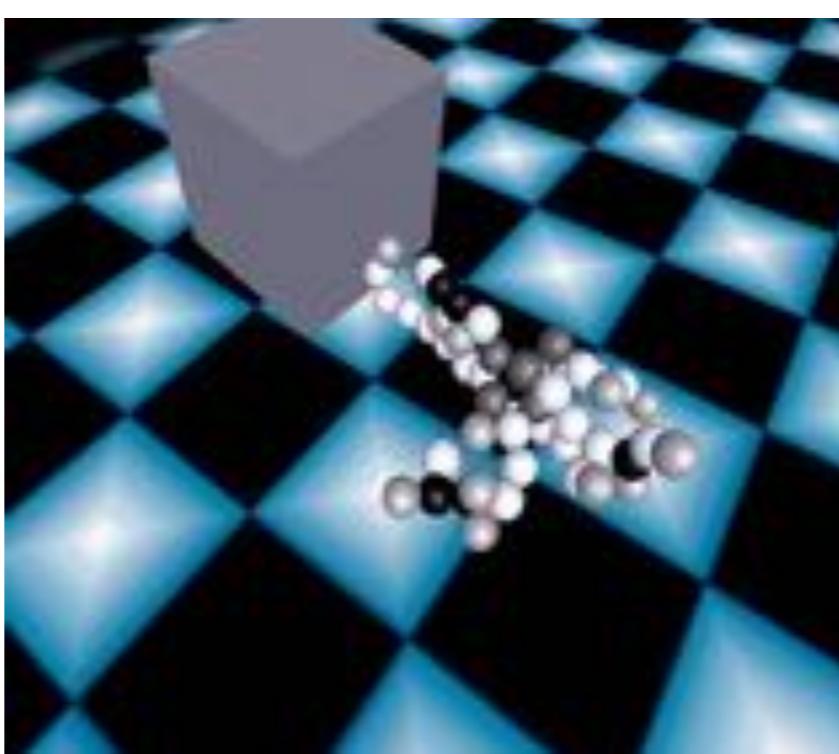
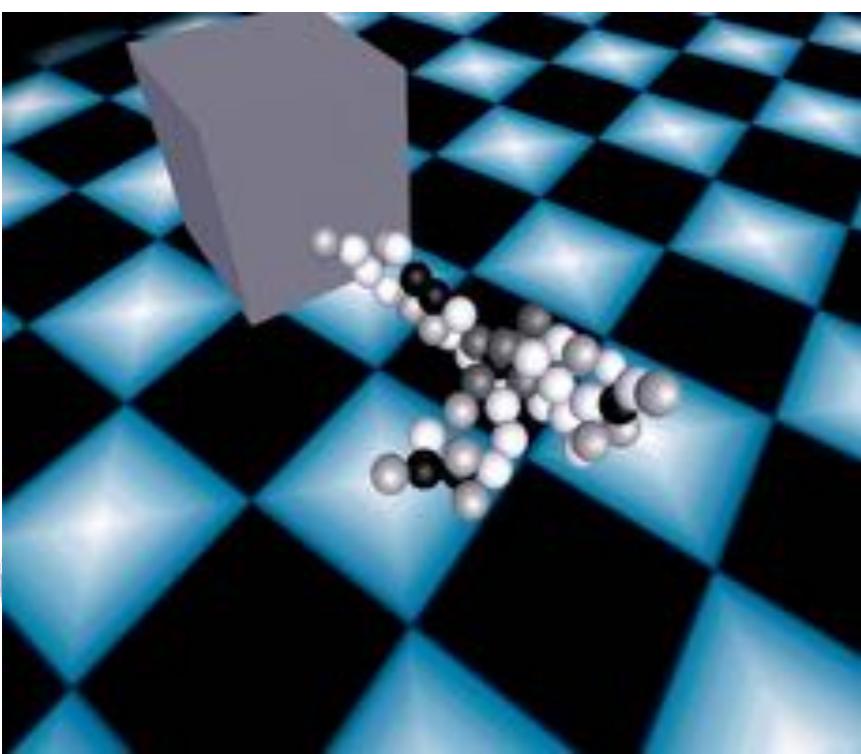
(recursive encoding)



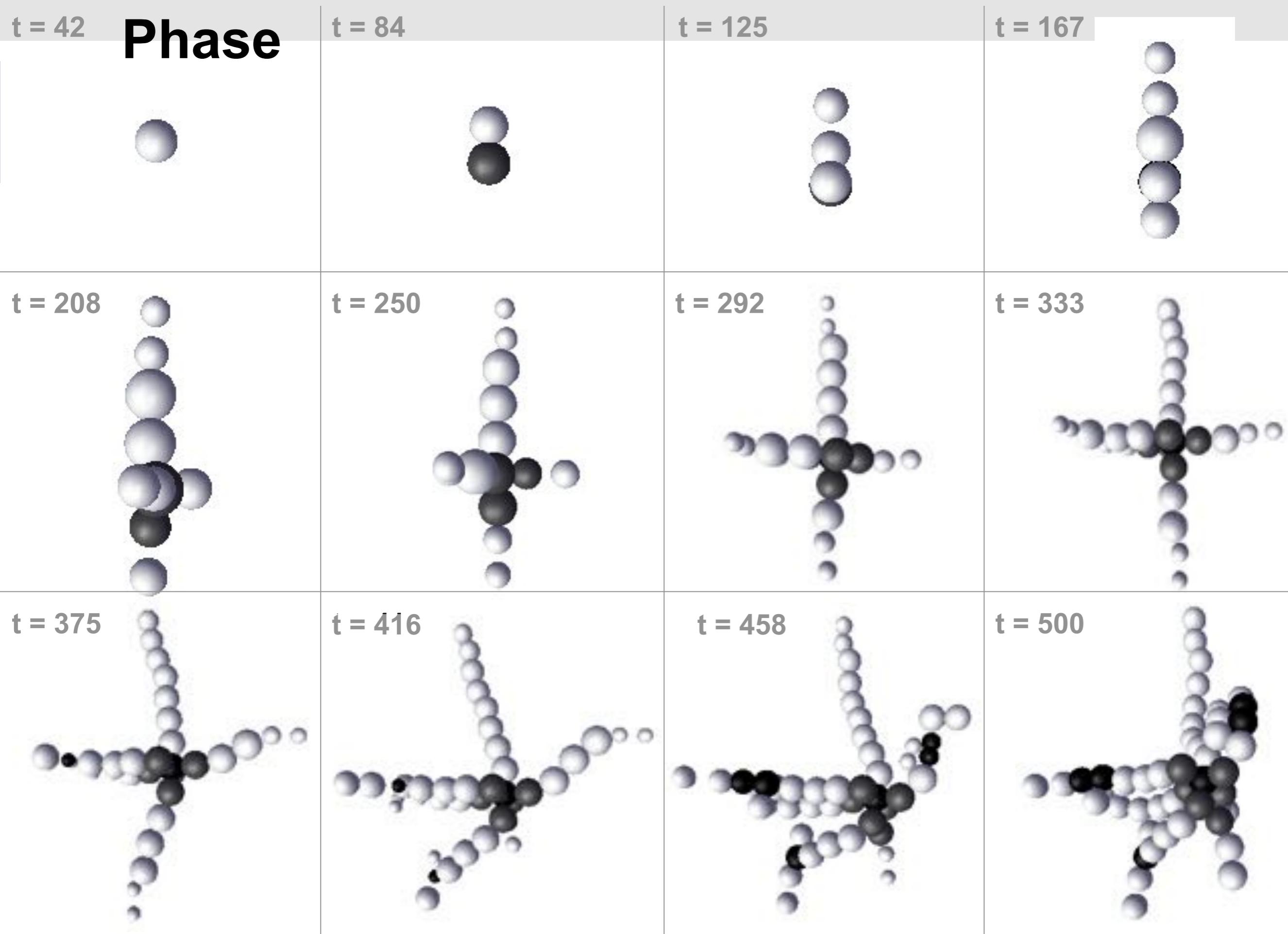
# Genetic Regulatory Networks (GRNs): Bongard's “block pushers”

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



# The Growth Phase

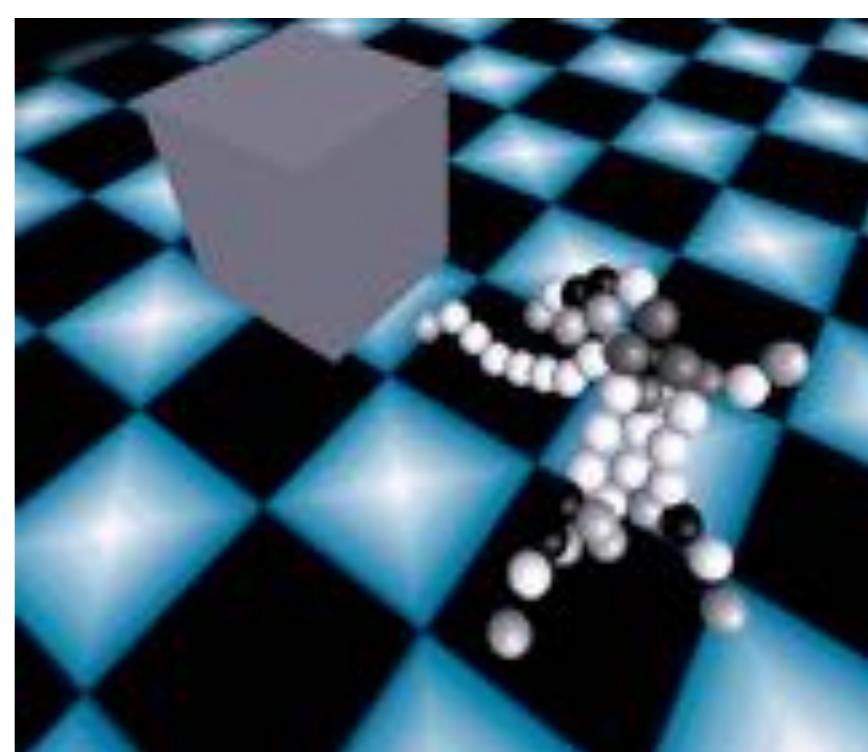
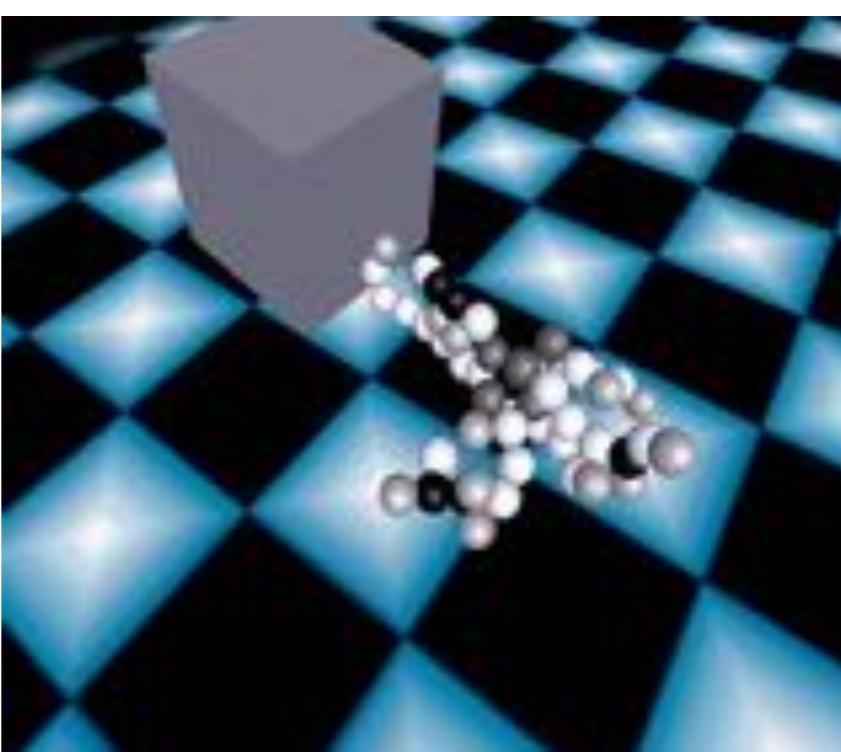
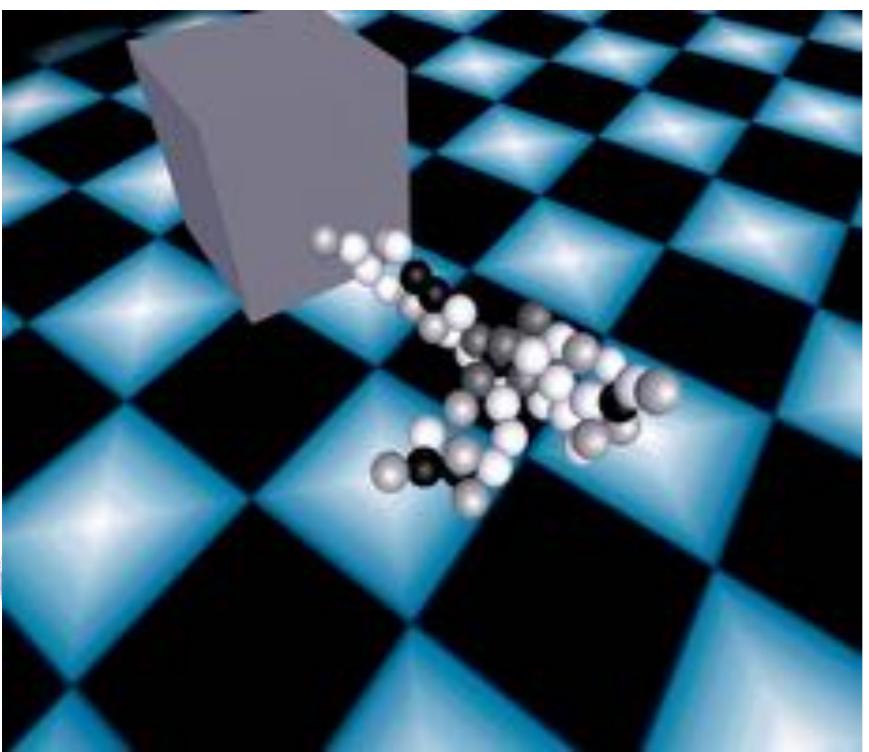


# Evolution of a “block pusher” (“Artificial Ontogeny”)

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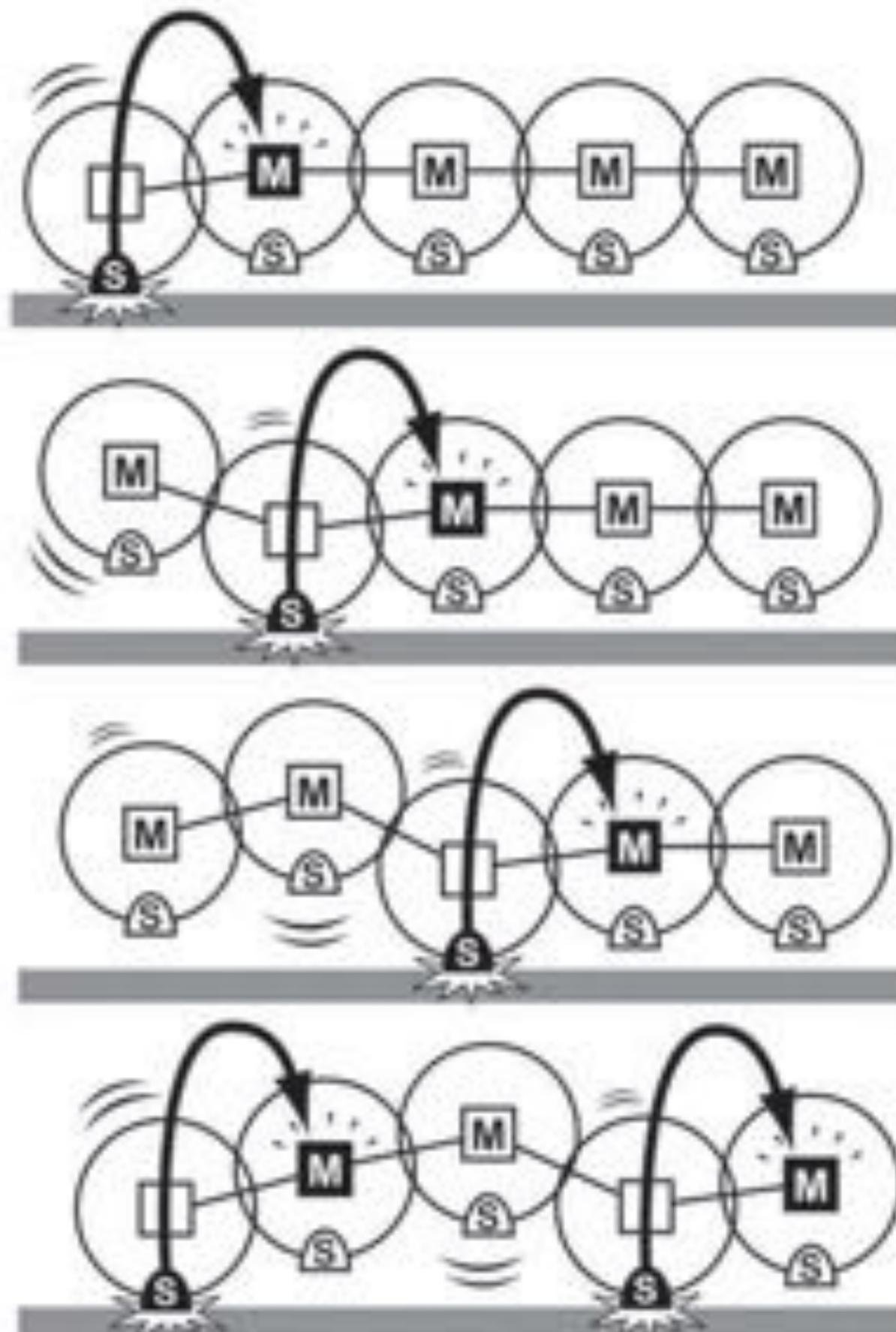
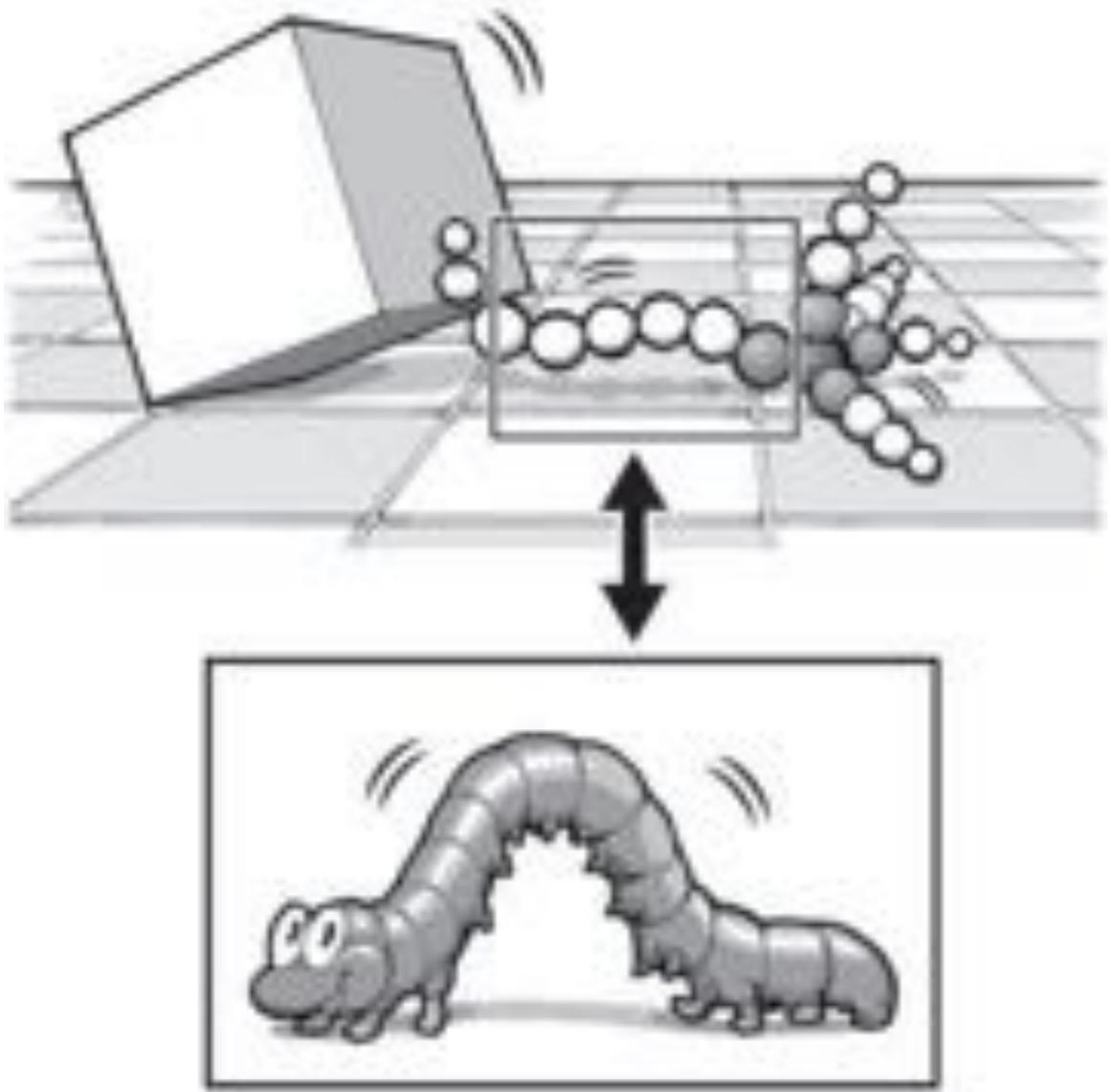
- Video “Evolution of block pushers”

↓ Click here to download ↓

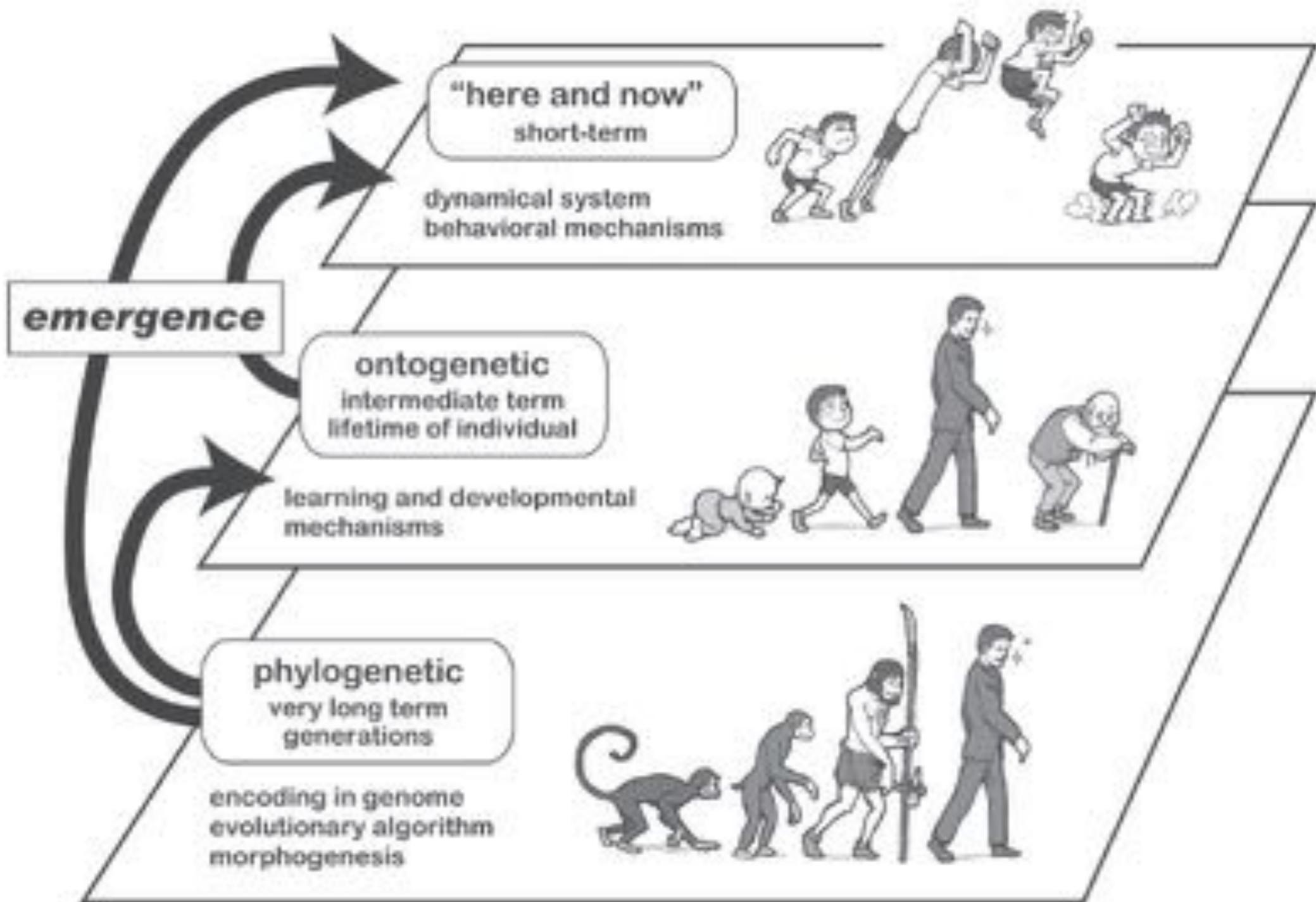


# Inchworm method of locomotion

S: sensor , M: motor



# Time scales tightly intertwined



# Assignments for next week

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- **Read chapter 6 of “How the body ...”**
- **Assignments - volunteers?**

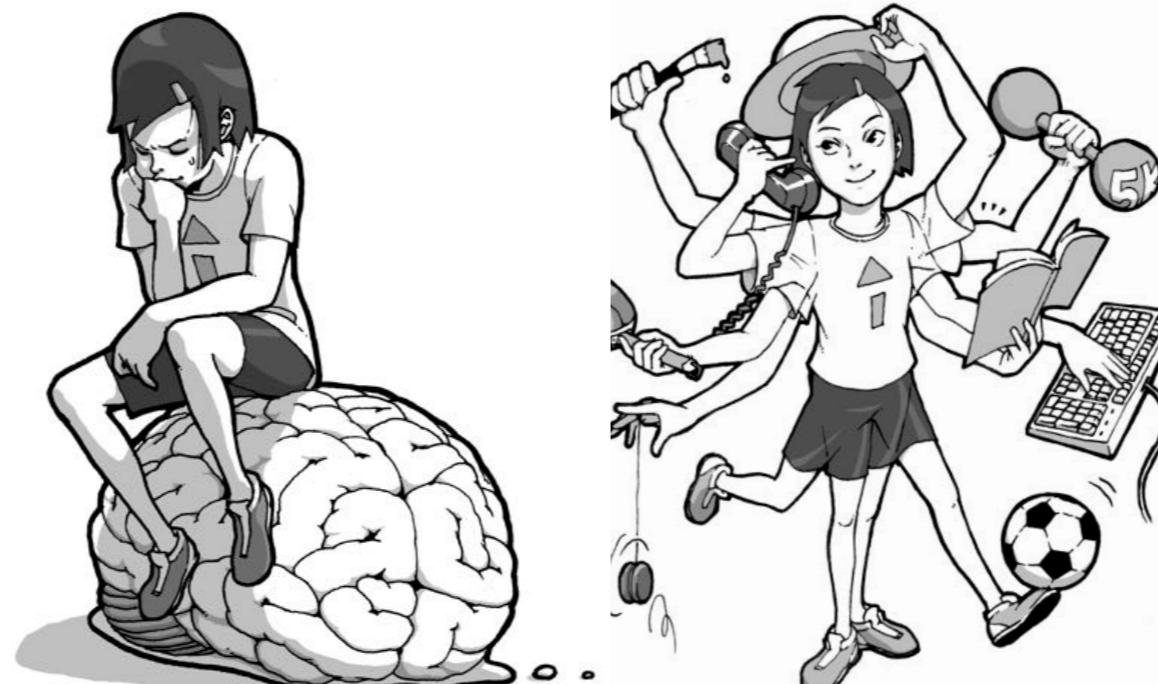


# End of lecture 4

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**Thank you for your attention!**

**stay tuned for guest lectures**



# Lecture 4: Guest speaker

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**Guest lecture “Vision based Micro Intelligent Vehicles”  
by Ming Yang, Shanghai Jiao Tong University, China**

# Lecture 4: Guest speaker

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**Guest lecture "Advanced Materials and Systems for Biohybrid Actuators and Sensors" by Arianna Menciassi, Scuola Superiore Sant'Anna, Pisa, Italy**

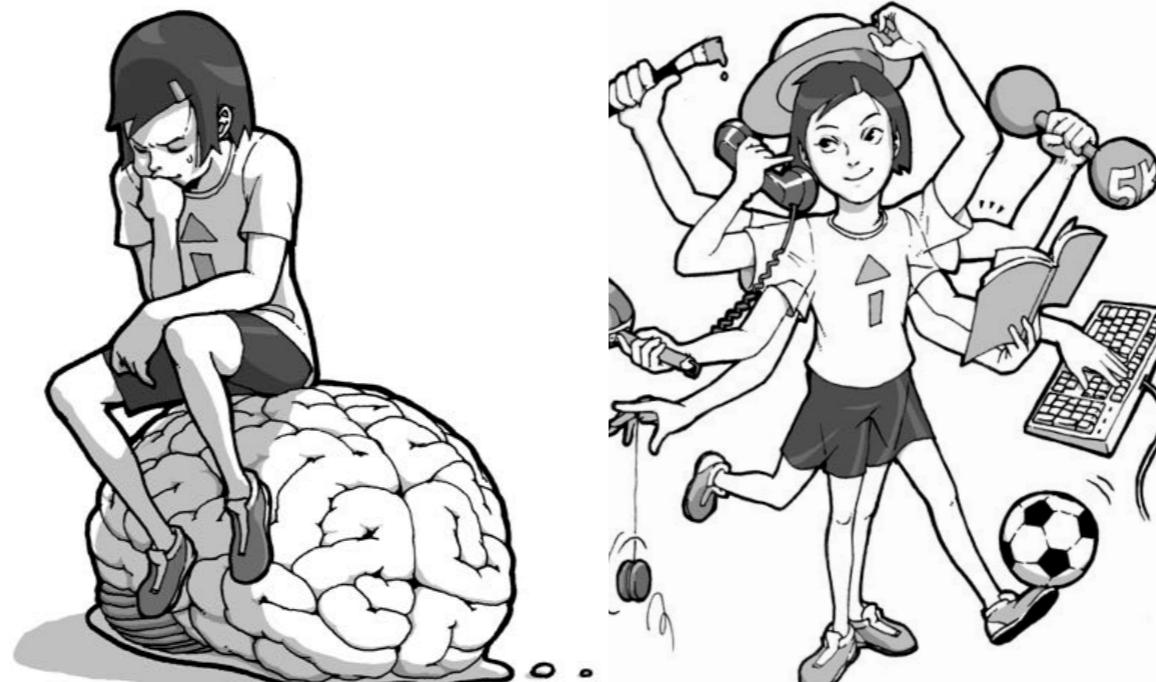
# End of lecture 4

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**Thank you for your attention!**

**stay tuned for lecture 5**

**“Soft Robotics and Bioinspiration”**



# Thank you.

<http://adapt.informatik.hu-berlin.de/>

Local organisers:

- Damien Drix
- Andreas Goroncy
- Christian Blum

