The ShanghAI Lectures

人工智能

上海授课

Video clips, demonstrations

- Video: Karl Sims's evolved creatures
- Video: Josh Bongard's "Block Pusher"

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Calling on

- Moscow —> can computers be creative?
- Zurich, Switzerland —> solving the puzzle with the three straight lines (through four corners)
- Osaka —> introduction of "Biomorphs" (by Richard Dawkins) and concept"esthetic selection"
- Berlin, Germany —> specifying the neural network for controlling the robot
- Chiba, Japan —> suggestions for fitness function of robot
- Xi'an, China —> how to chose mutation rate (what are the considerations?)
- Karlsruhe —> characterization of "development" in the case of Karl Sims's creatures
- Abu Dhabi —> short comment on the Golem project (is it as revolutionary as claimed?)

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Today's schedule

09.00 - 09.05 Short introduction: University of Madrid, Carlos III, Spain.

09.05 - 09.10 Recap: Artificial Neural Networks

09.05 - 09.55 Artificial evolution and morphogenesis

09.55 Break

10.00 - 10.30 Dr. Francesco Mondada, EPFL, Switzerland

10.30 - 11.00 Prof. Robert Riener, ETH-Zurich - today from USC, The University of Southern Californian, Los Angeles

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

Today from the University of Madrid
Carlos III, Spain
(host: Prof. Fabio Bonsignorio)

17 November 2011

欢迎您参与

“来自上海的人工智能系列讲座”

F-O-R competition: the lucky winner

presented by Prof. Verena Hafner

Marcus Scheunemann

Swiss Chocolate

Should I forget to mention the FOR problem in any of the lectures, the first to discover will get either a box of Swiss chocolate or a bottle of champagne. If there is one idea from the class that everyone should remember, it's the FOR problem.

Lecture 6

Evolution:
Cognition from scratch

15 November 2012

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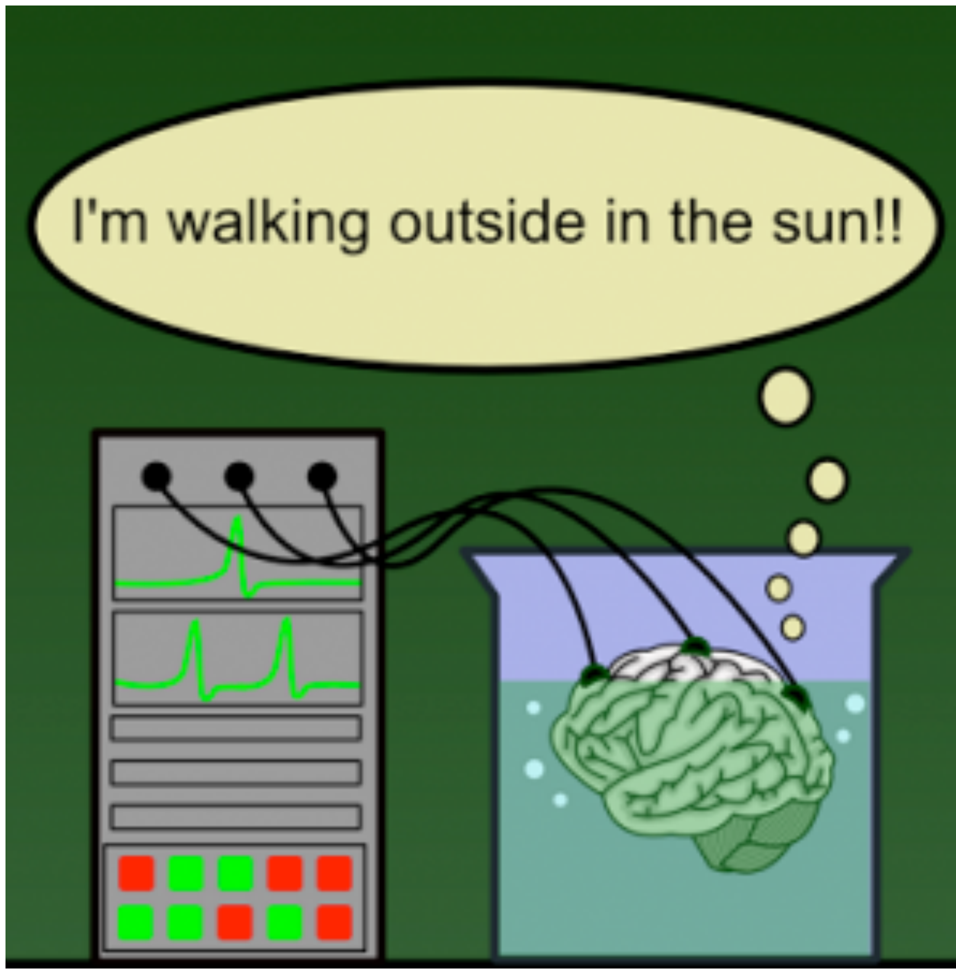
Building brains for bodies

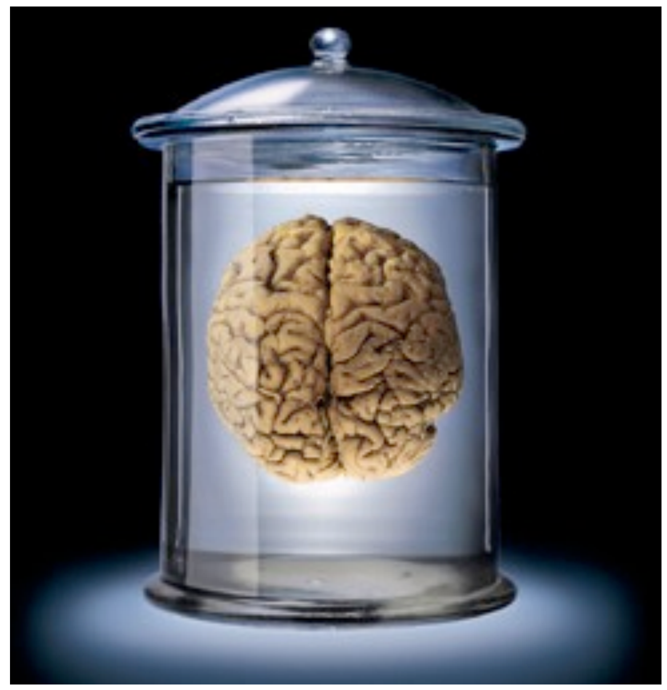
please view recorded video (lecture 6)

“The brain in the vat”

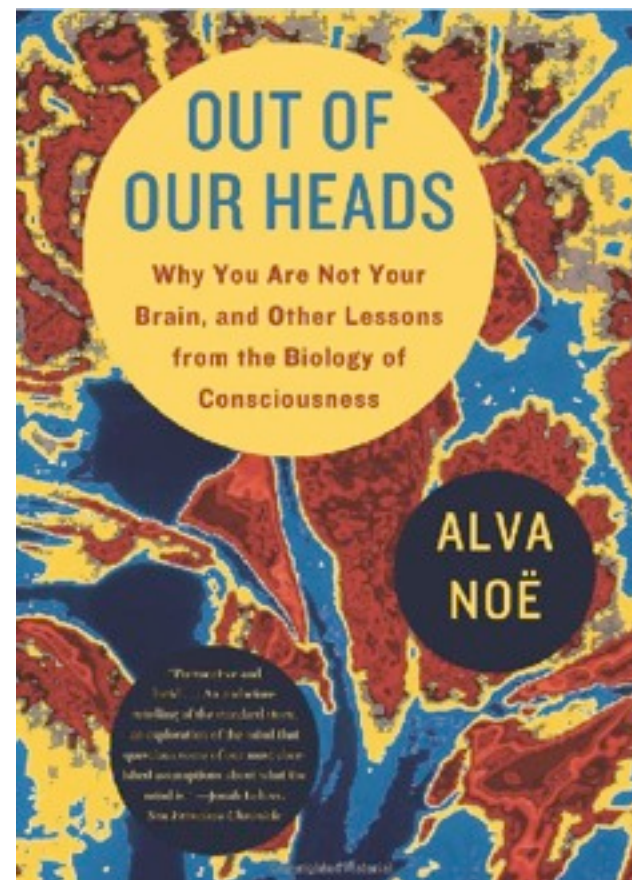


“Brain-in-a-vat”

Alva Noë, “Out of our heads - why you are not your brain”, New York, Hill and Wang, 2009



- **supply energy**
- **flush away waste products**
- **complicated: providing stimulation comparable to that normally provided to a brain by its environmentally situated body**
- **—> vat will have to be something like a living body**



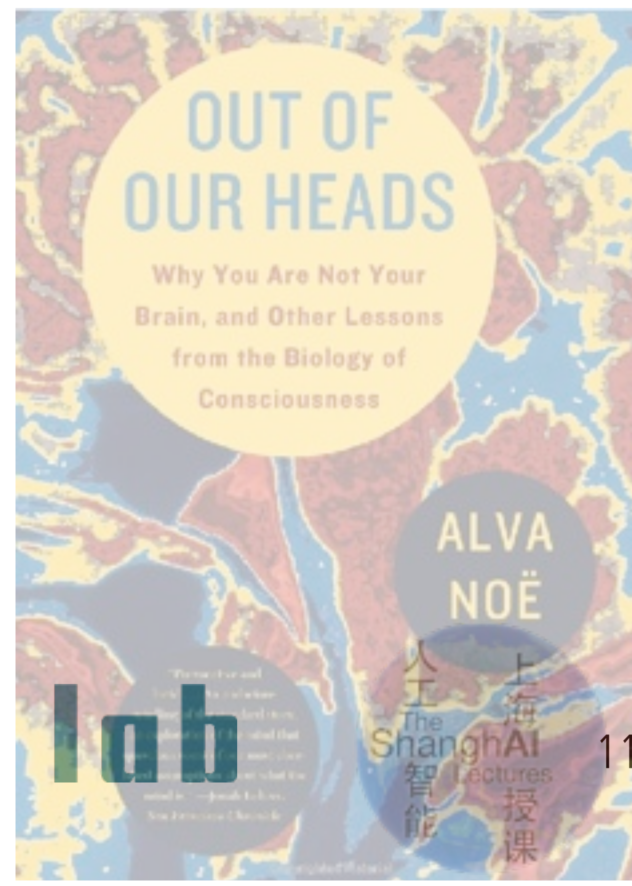
“Consider, first of all, that the vat or petri dish, couldn’t be a mere dish or bucket as Evan Thompson and Diego Cosmelli have discussed in an essay. It would have to supply energy to nourish the cells’ metabolic activity and it would have to be capable of flushing away waste products. The vat would have to be very complicated and specialized in order to control the administration of stimulation to the brain comparable to that normally provided to the brain by its environmentally situated body. If you actually try to think through the details of this thought experiment – this is something scientists and philosophers struck by the brain-in-a-vat idea almost never do – it’s clear that the vat would have to be, in effect, something like a living body.” (Alva Noe, Out of our heads, p. 12/13).

"Brain-in-a-vat"

Alva Noë, "Out of our heads - why you are not your brain", New York, Hill and Wang, 2009

volunteer for short presentation of "Brain-in-a-vat" (22 November 2012)

- supply ene
- flush away
- complicated: providing stimulation comparable to that normally provided to a brain by its environmentally situated body
- —> vat will have to be something like a living body



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Artificial Neural Networks

many excellent books available

class spring term 2013 (UZH, by Rolf Pfeifer)

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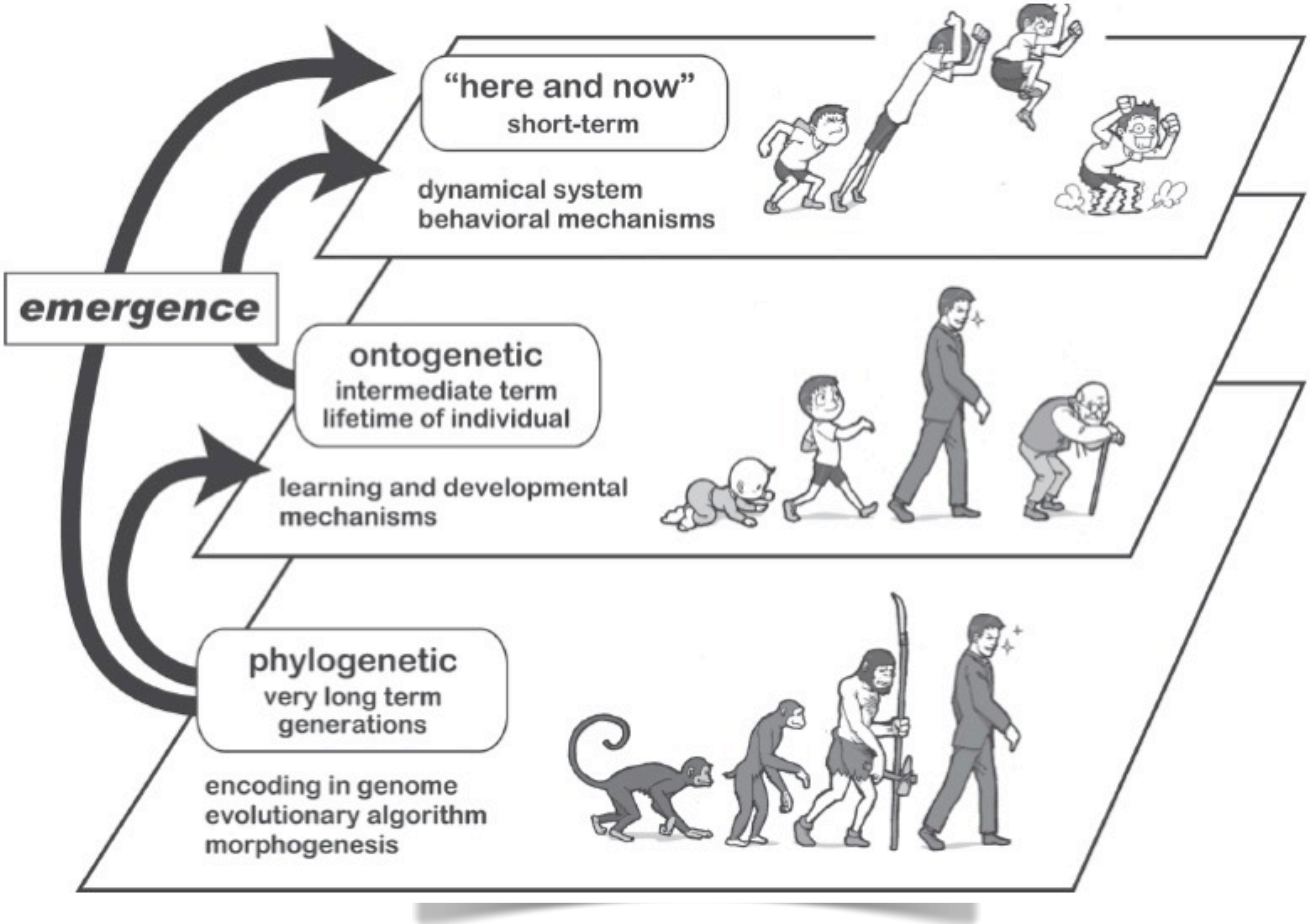
Time perspectives



Time perspectives in understanding and design

state-oriented "here and now" perspective
"hand design"

learning and development "ontogenetic" perspective
initial conditions, learning and developmental processes

evolutionary "phylogenetic" perspective
evolutionary algorithms, morphogenesis

Understanding: **all three perspectives requires**
Design: **level of designer commitments, relation to autonomy**

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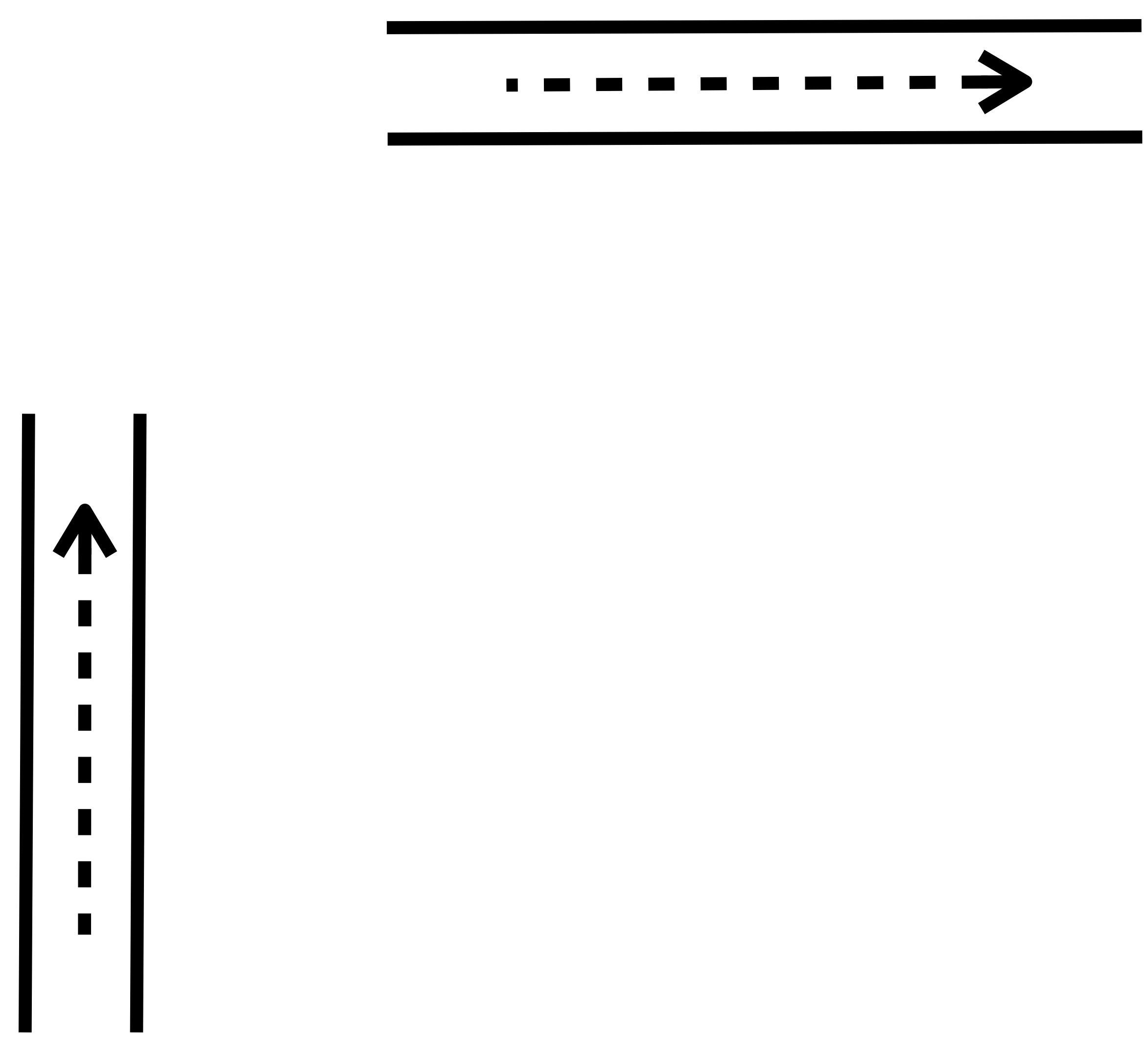
Level of designer commitments:
- state-oriented: everything has to be designed
- learning and development: design initial conditions and learning mechanisms:
- evolutionary: design evolutionary algorithms and processes of morphogenesis

Rechenberg's "fuel pipe problem"



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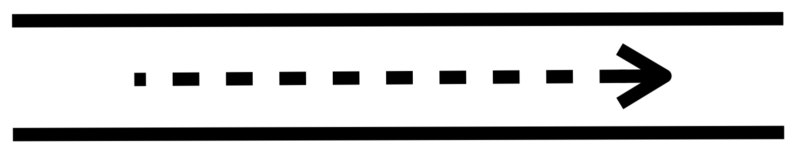
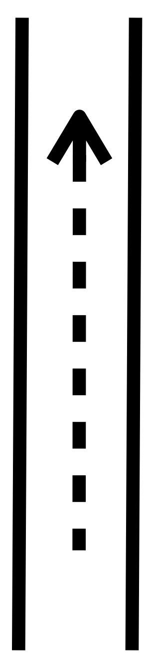
The fluid that enters the system on the left has to be deflected into the horizontal pipe. What is the optimal shape of the connecting piece to minimize turbulence?
Ingo Rechenberg: Technical University of Berlin, in the 1960s.
He found that the optimal shape has a kind of "hunch", rather than being a quarter circle.

Rechenberg's "fuel pipe problem"





Creative?

—>

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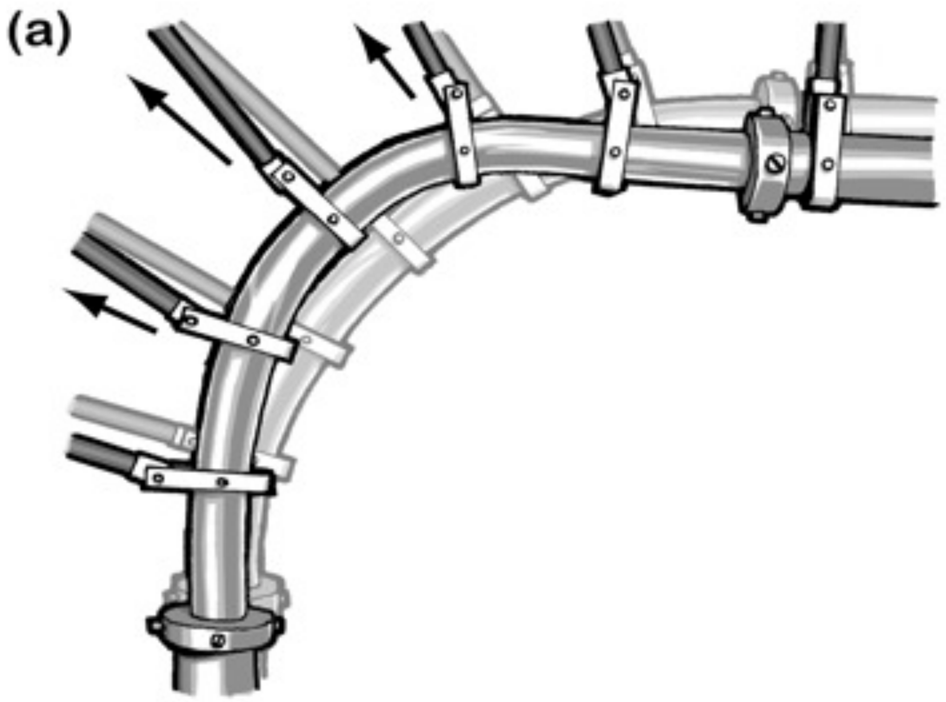
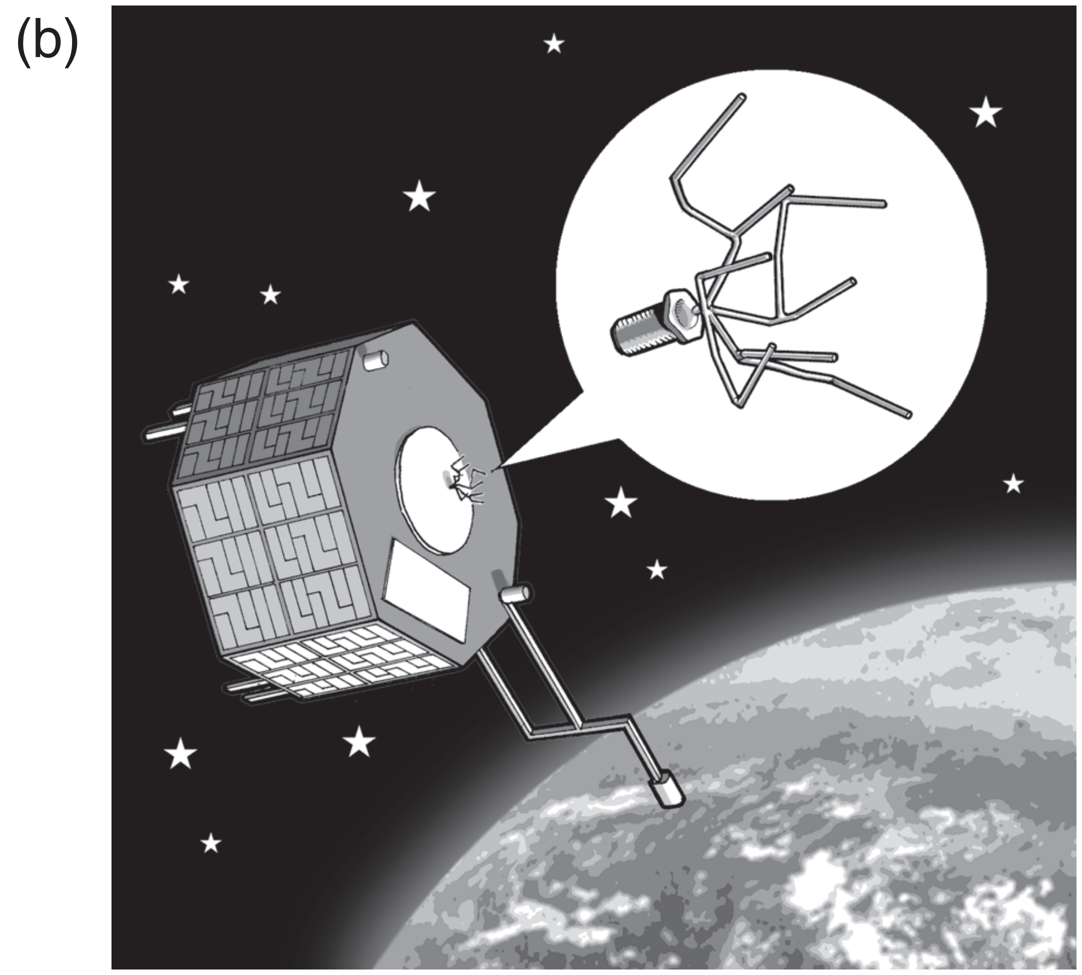
There is the fundamental and very popular question of whether computers or robots can ever be creative. Many engineers that have been dealing with this problem, have not come up with the same solution that GAs have – but still, we don't consider the GA "creative", it's "merely" an algorithm, even though it has produced better solutions than humans (which, in the case of optimization algorithms is usually the case).

On the anecdotal side there is this scene in the movie iRobot where the human says to the robot: a robot could never have written a symphony like Beethoven, and the robot replies: "Could you?".

Evolutionary designs





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

Evolutionary designs

GECCO
(Genetic and Evolutionary Computation Conference)

Human-competitive design

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

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It turned out that the antenna "designed" by the GA had in fact better characteristics than the ones designed by humans. They are now being used by NASA.

Connecting corners of square

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

x x

x x

—> Zurich

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Artificial evolution

- John Holland
- Ingo Rechenberg
- John Koza

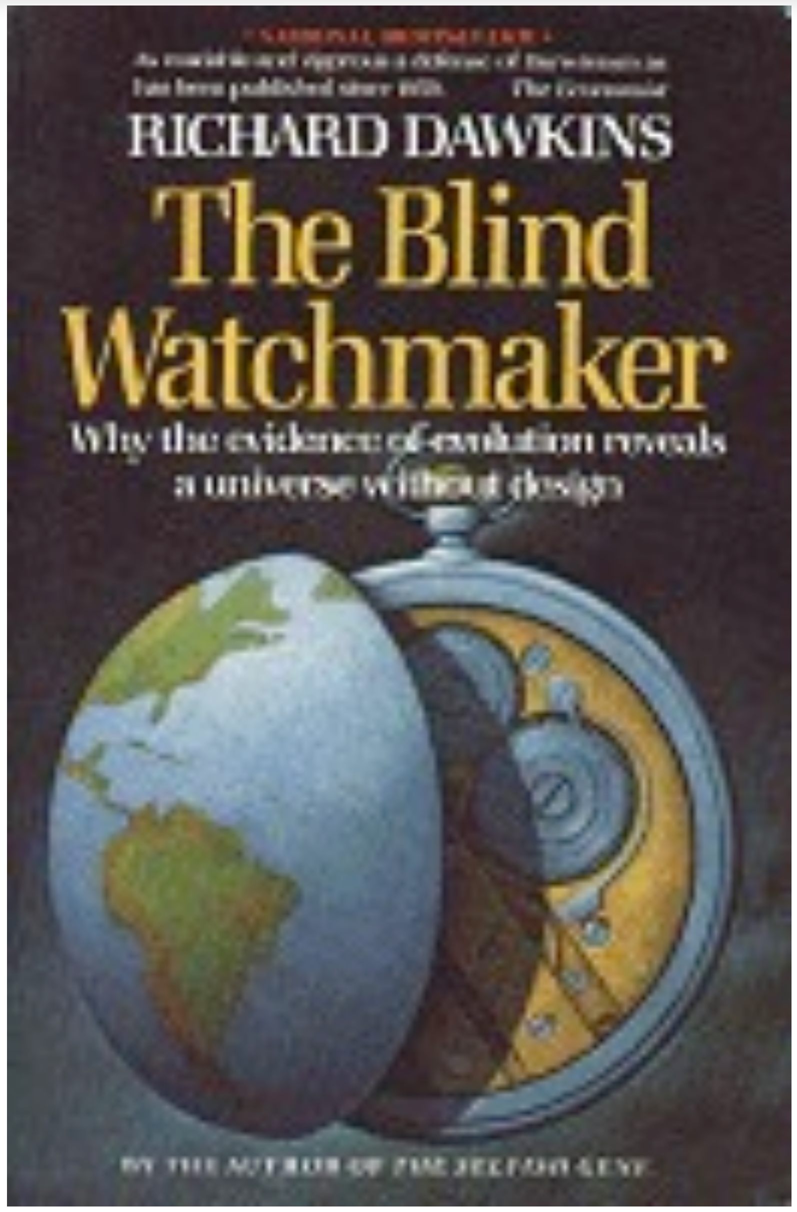
Artificial evolution

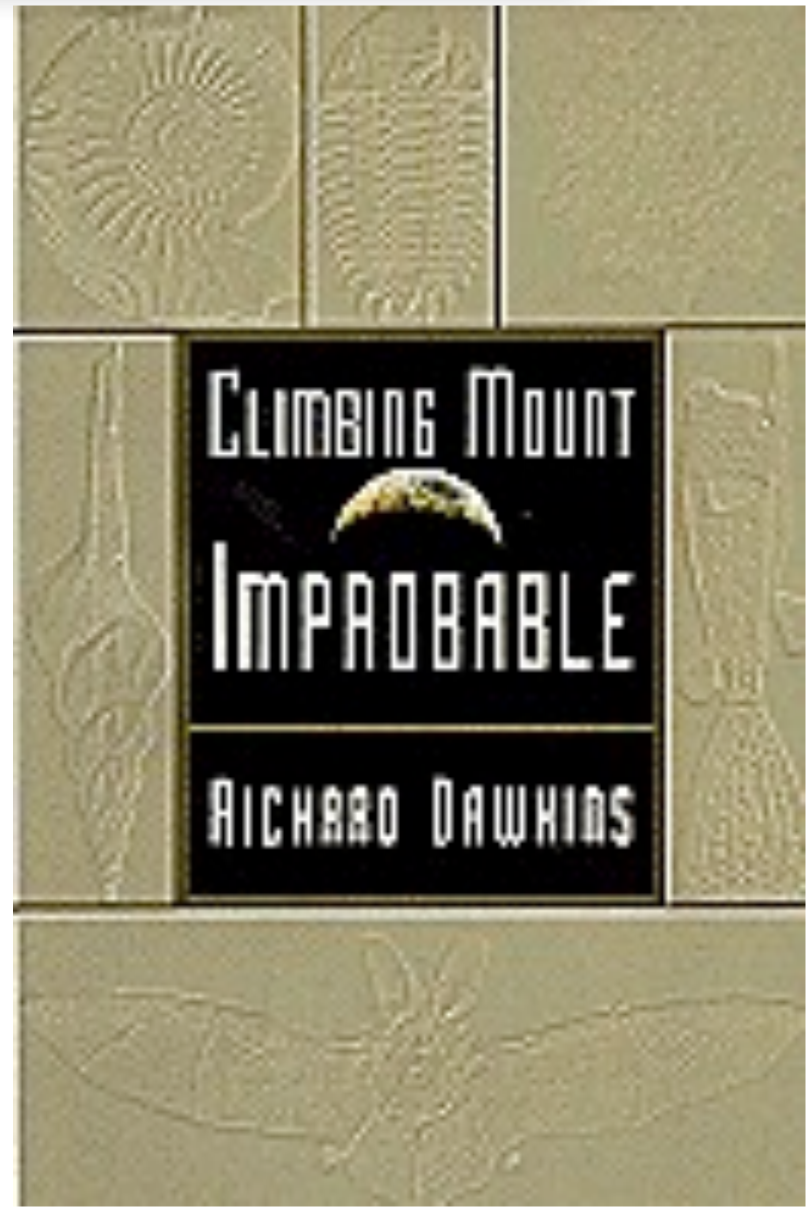
- John Holland: Genetic Algorithm, GA
- Ingo Rechenberg: Evolution Strategy, ES
- John Koza: Genetic Programming, GP

Goal: exploiting evolution for the design of intelligent agents

Cumulative selection

Richard Dawkins (author of "The selfish gene")





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Watch out!!

the creationists!?!!!

Richard Dawkins:
very outspoken against creationism

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)**

http://suhep.phy.syr.edu/courses/mirror/biomorph/

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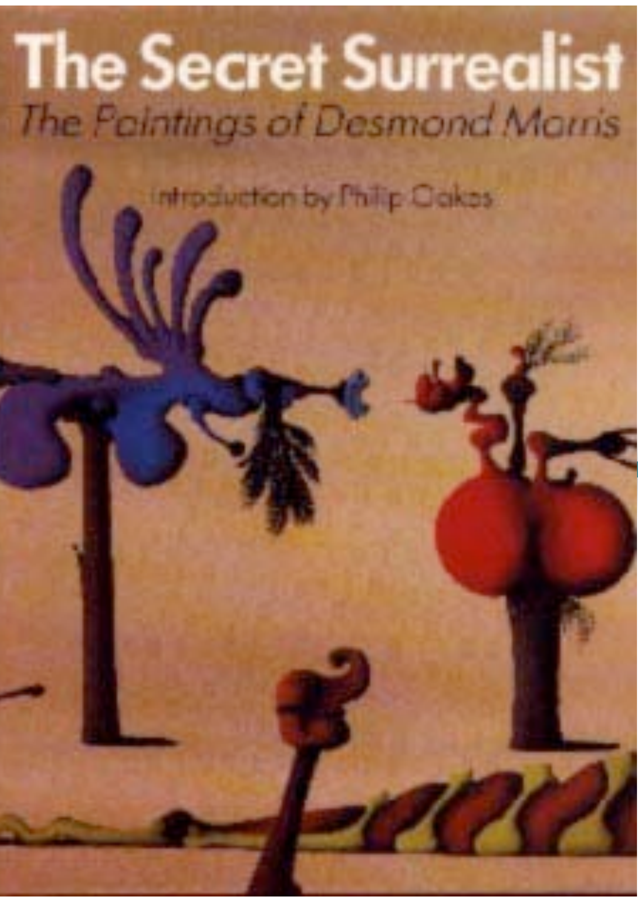
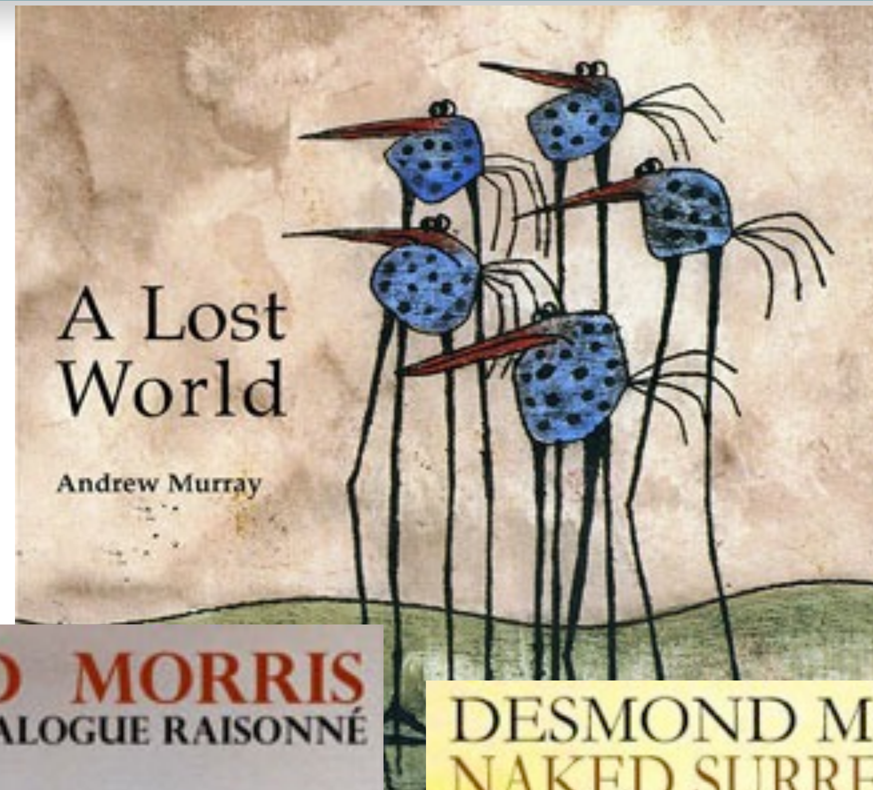
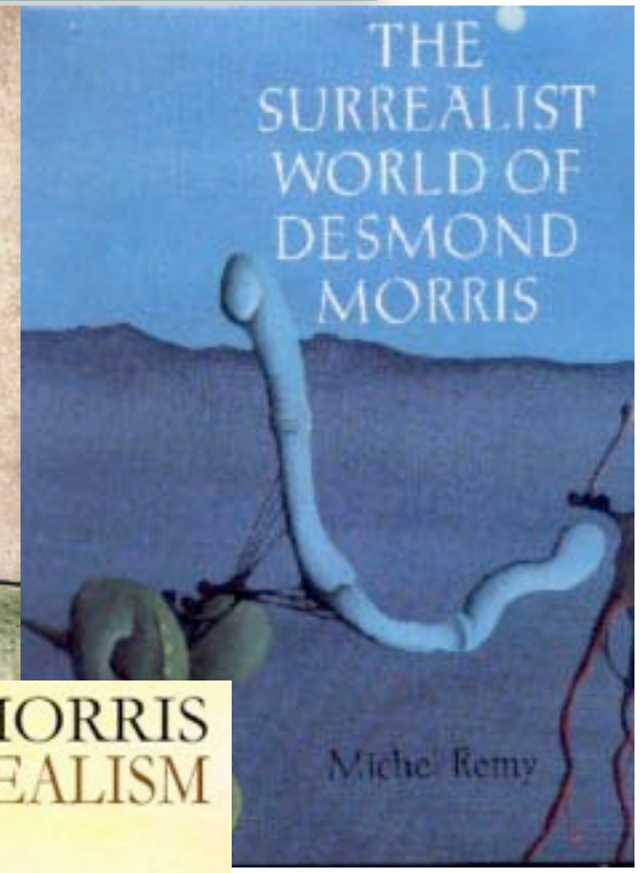
encoding "creature" in genome (string of numbers): **genotype**
expression of "genes": **phenotype**
esthetic selection designates the process by which a user selects an object that he "likes" and evolution proceeds from there)

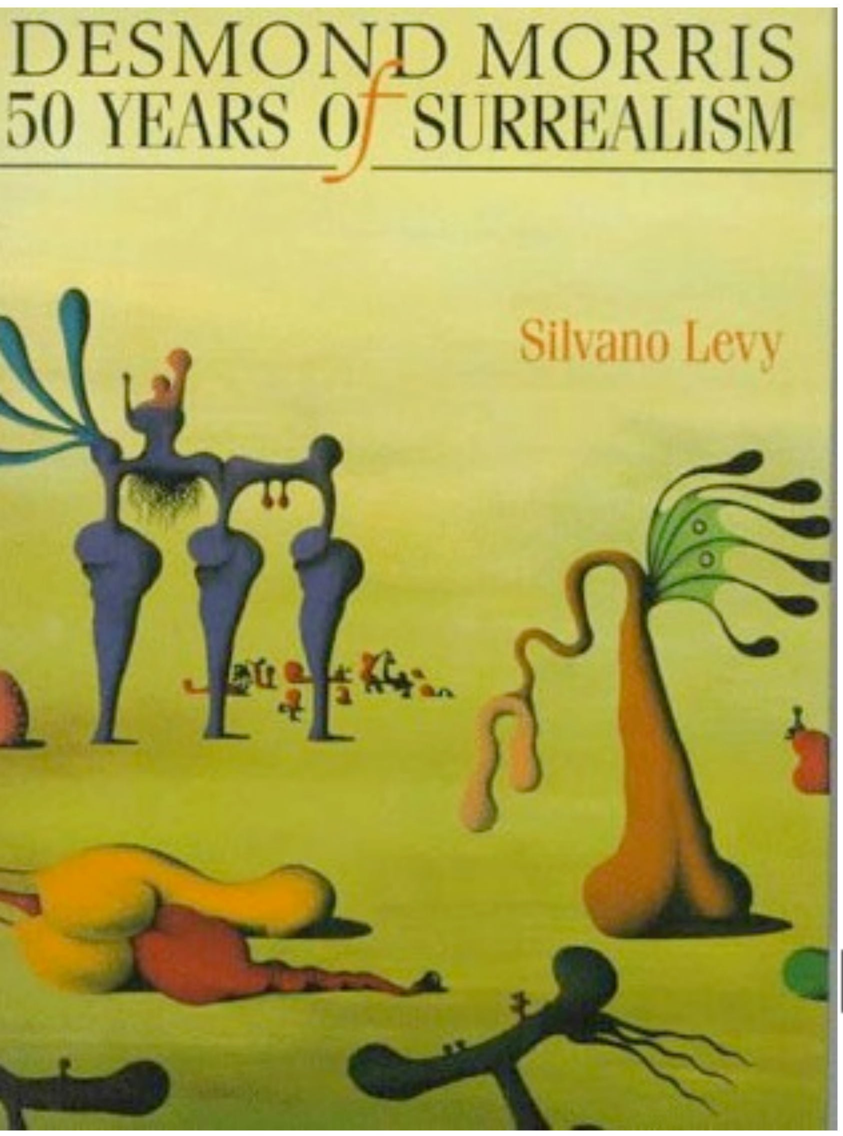


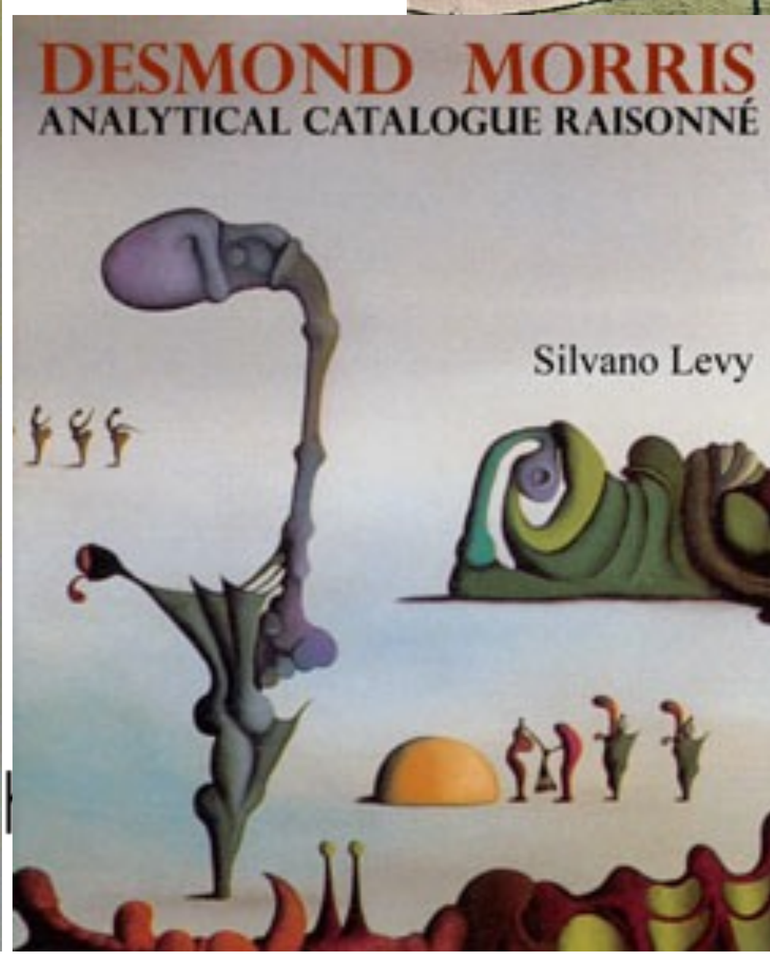
Biomorphs: by surrealist painter Desmond Morris

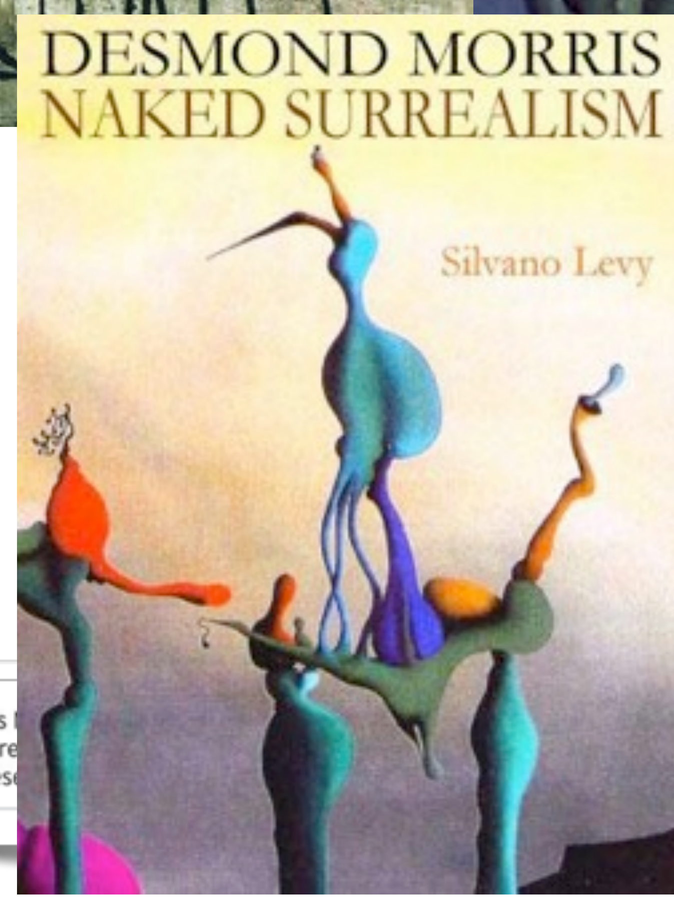
exhibitions: 1948 - 2008







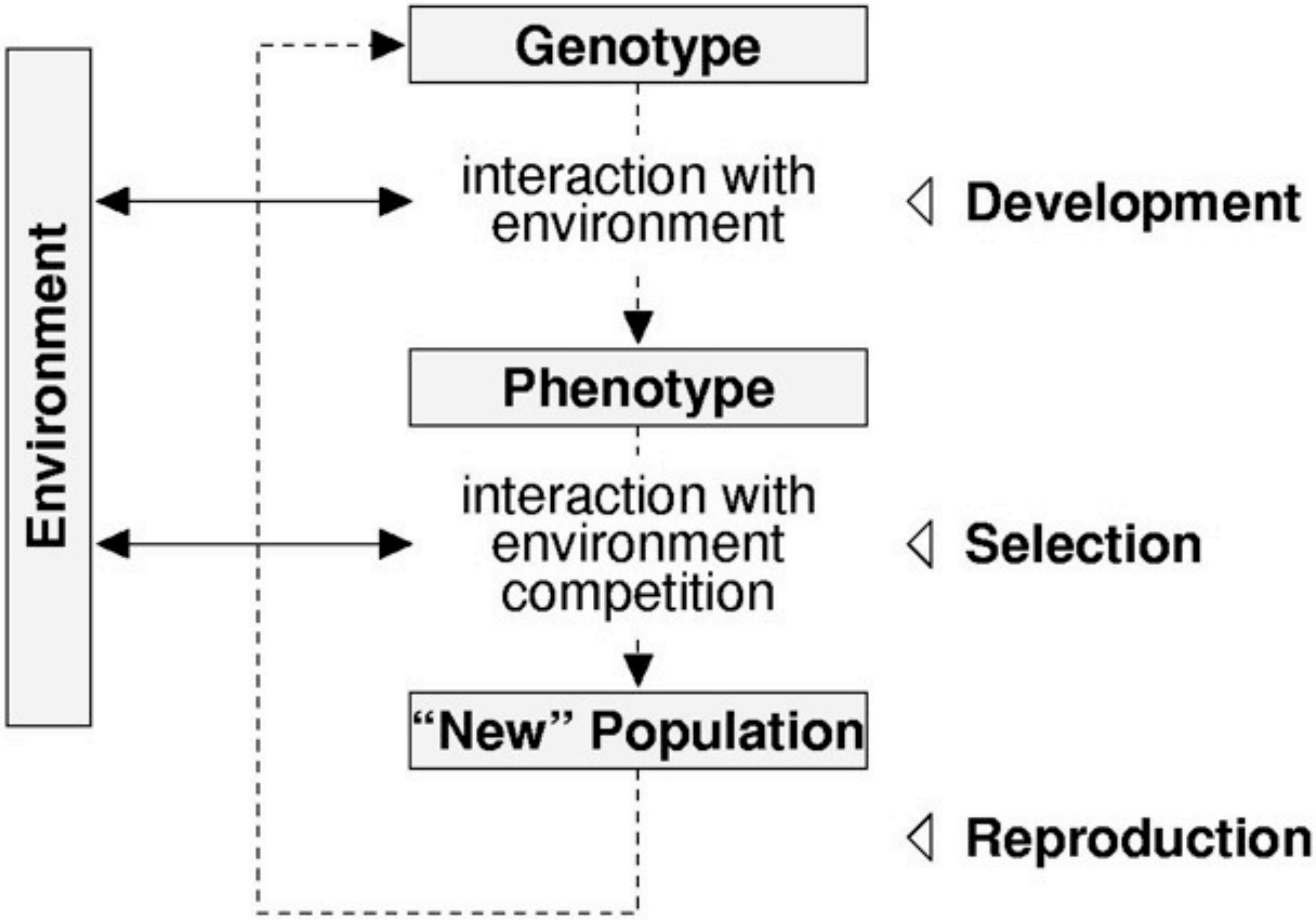




Biomorphs
Encoding in genome

- “genes” 1-8: control of overall shape (direction, length of attachment)
- “gene” 9: depth of recursion
- “genes” 10-12: color
- “gene” 13: number of segmentations
- “gene” 14: size of separation of segments
- “gene” 15: shape for drawing (line, oval, rectangle, etc.)

The "grand evolutionary scheme"

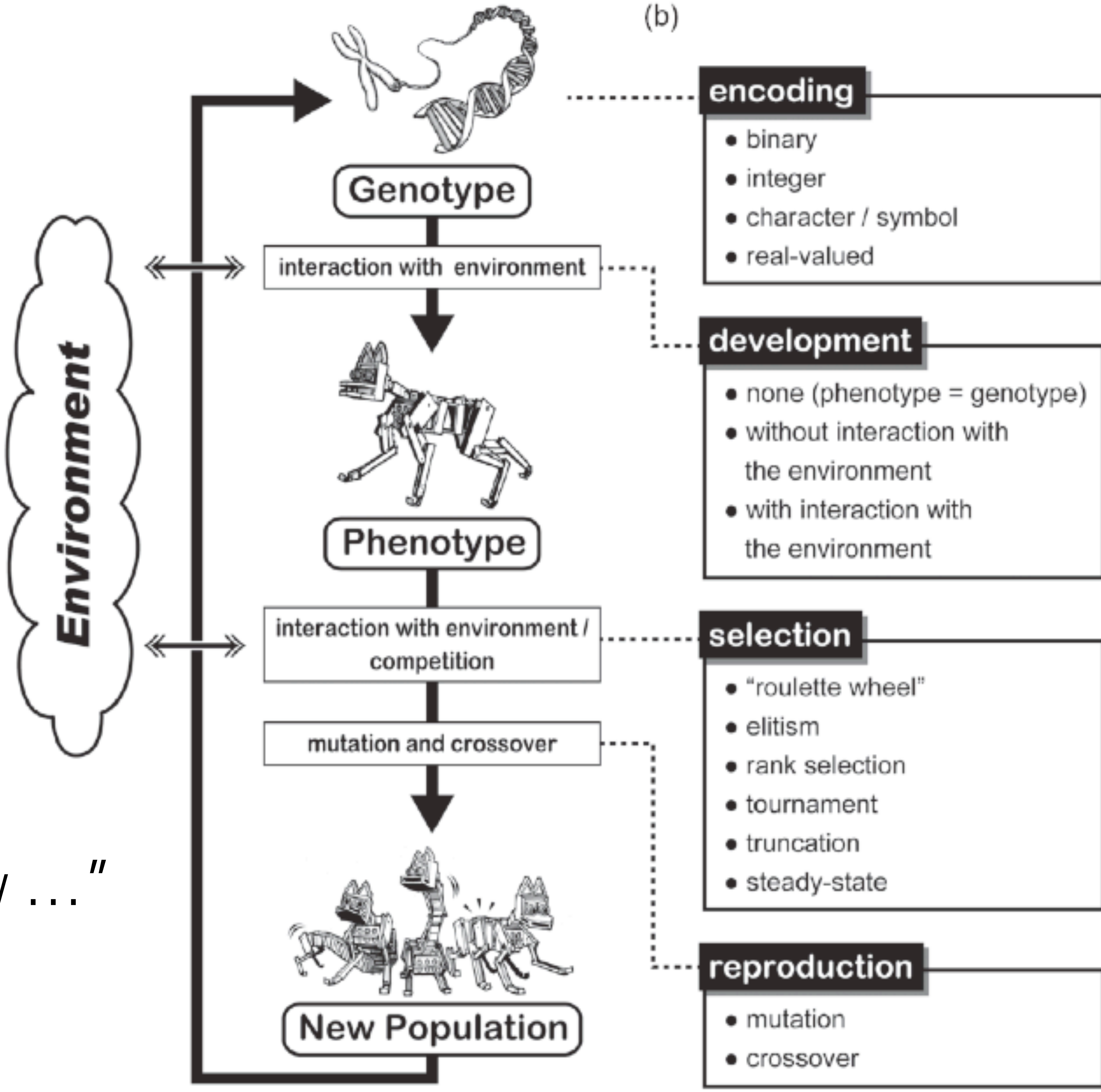


encoding	development	selection	reproduction
• binary • many-character • real-valued	• no development (phenotype = genotype) • development with and without interaction with the environment	• "roulette wheel" • elitism • rank selection • tournament • truncation • steady-state	• mutation • crossover

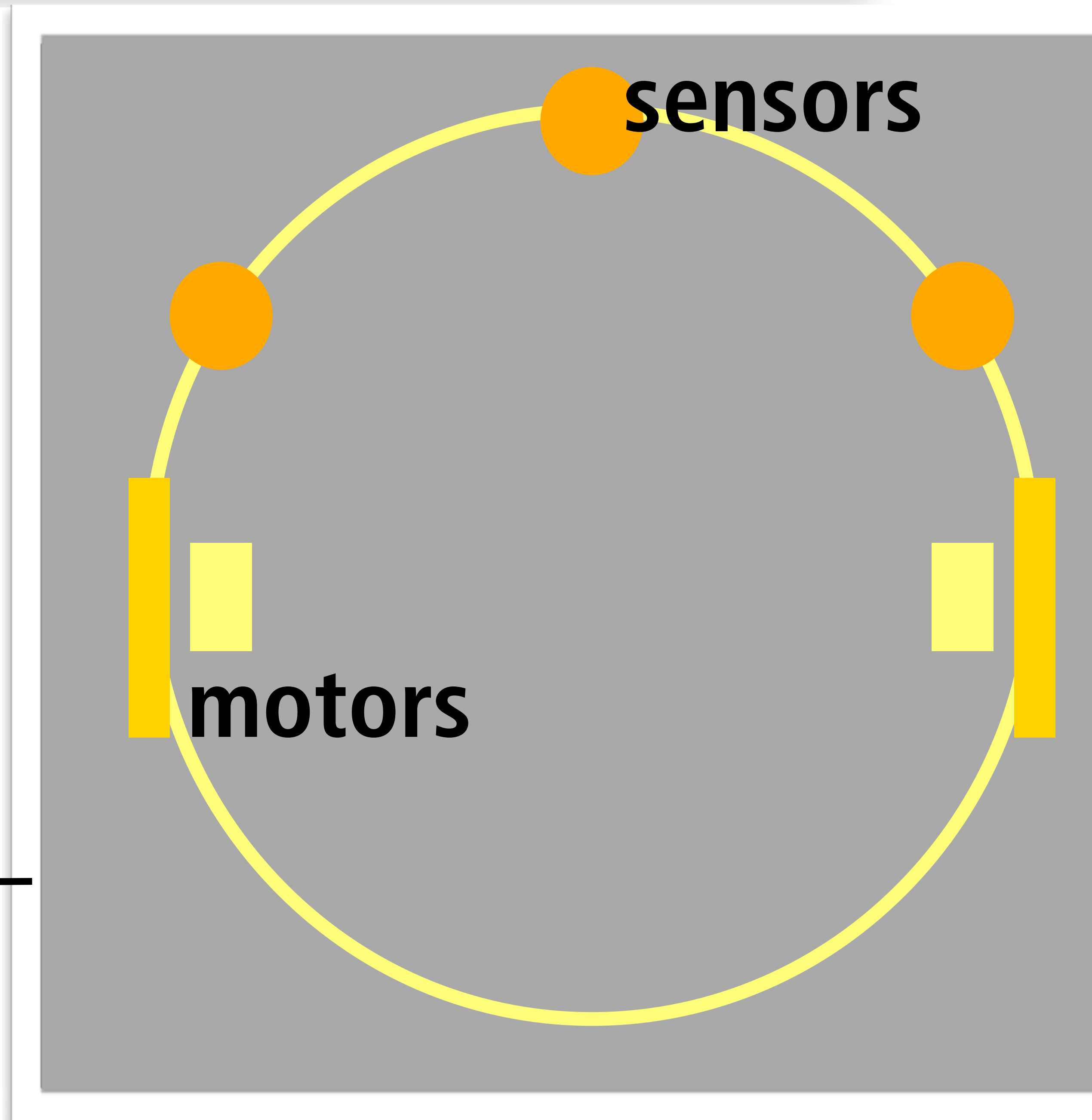
Basic cycle for artificial evolution

from
"How the body …"

University

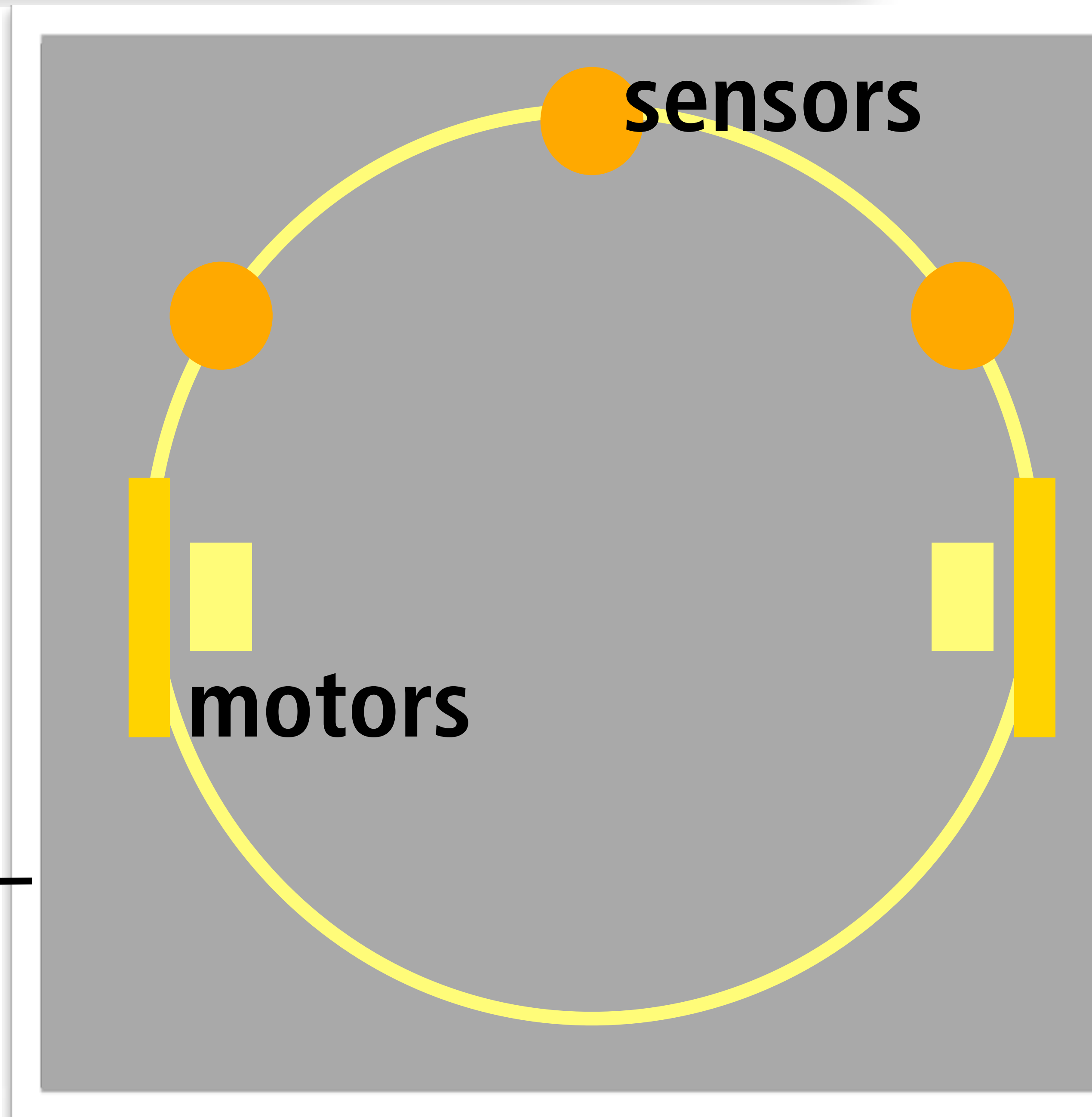


Evolving a neural controller



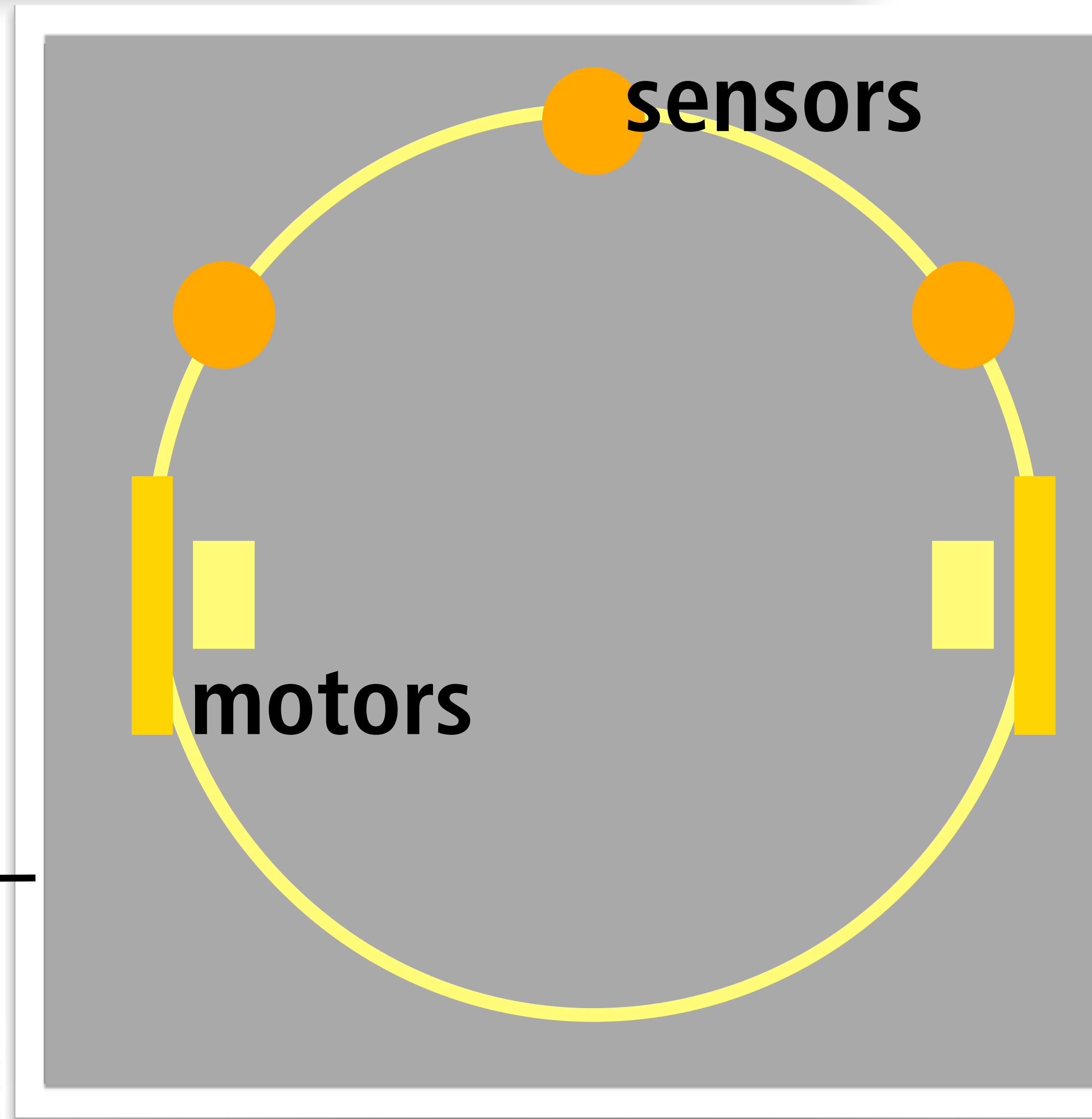
Evolving a neural controller

What do we need to specify?
—>
Humboldt University
(encoding in genome?)



Need to define the five basics: embedding, node characteristics, connectivity, propagation rule, and learning rule. Here we try to find proper weights through evolution. This is the classical approach to artificial evolution where the robot (with its morphology) is given and the control (in this case a neural network) is evolved.

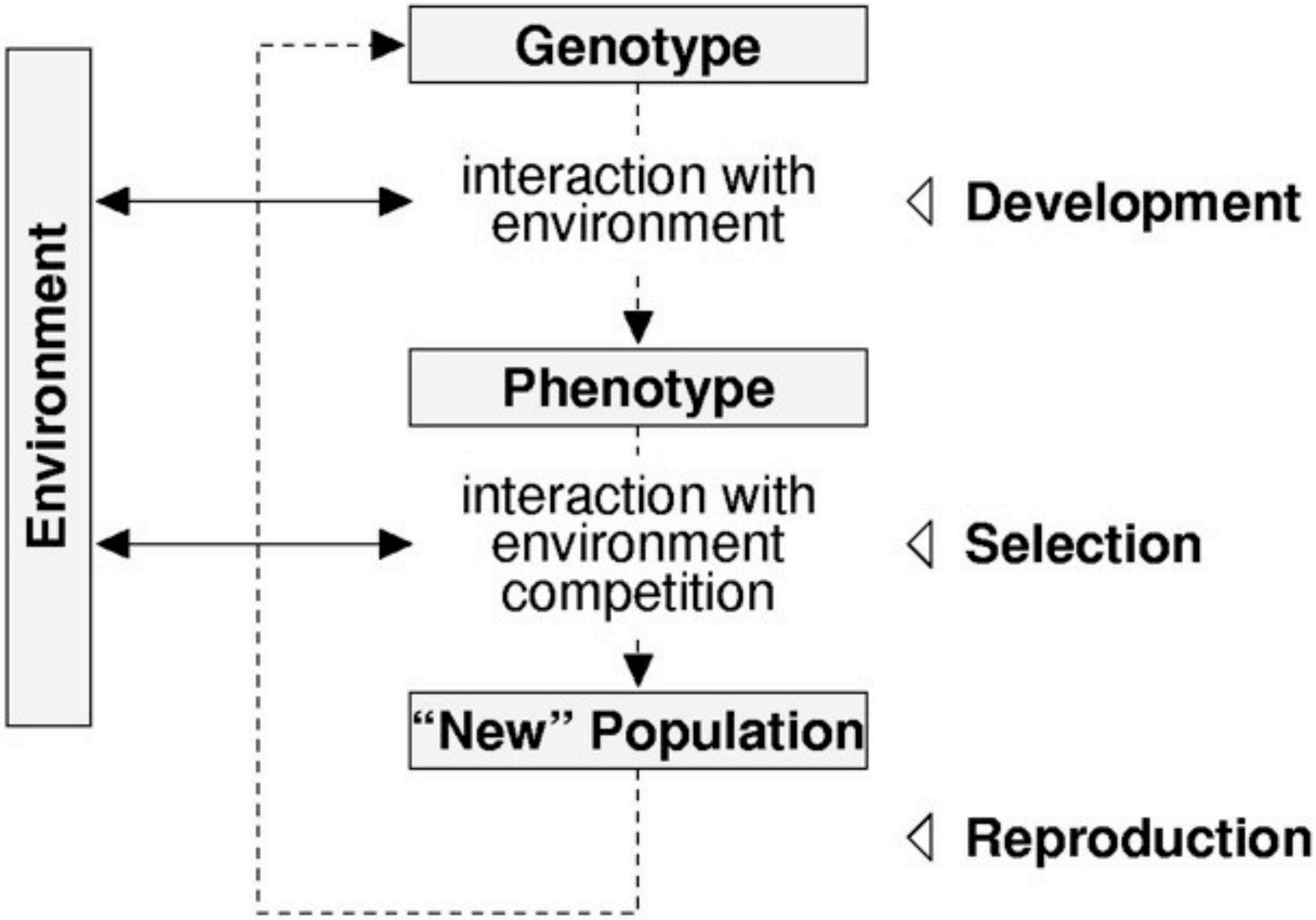
Encoding in genome



	1	2	3	4	5	6
initial genome	0011	0101	0010	0111	1010	1010
encoded weights	-.3	-.17	-.37	.03	.17	.17

process of “development” is trivial in this case: the weights are calculated as follows: v/15 – .5, where v is the value of the bit string of the gene. This yields values between –.5 and +.5

The "grand evolutionary scheme"



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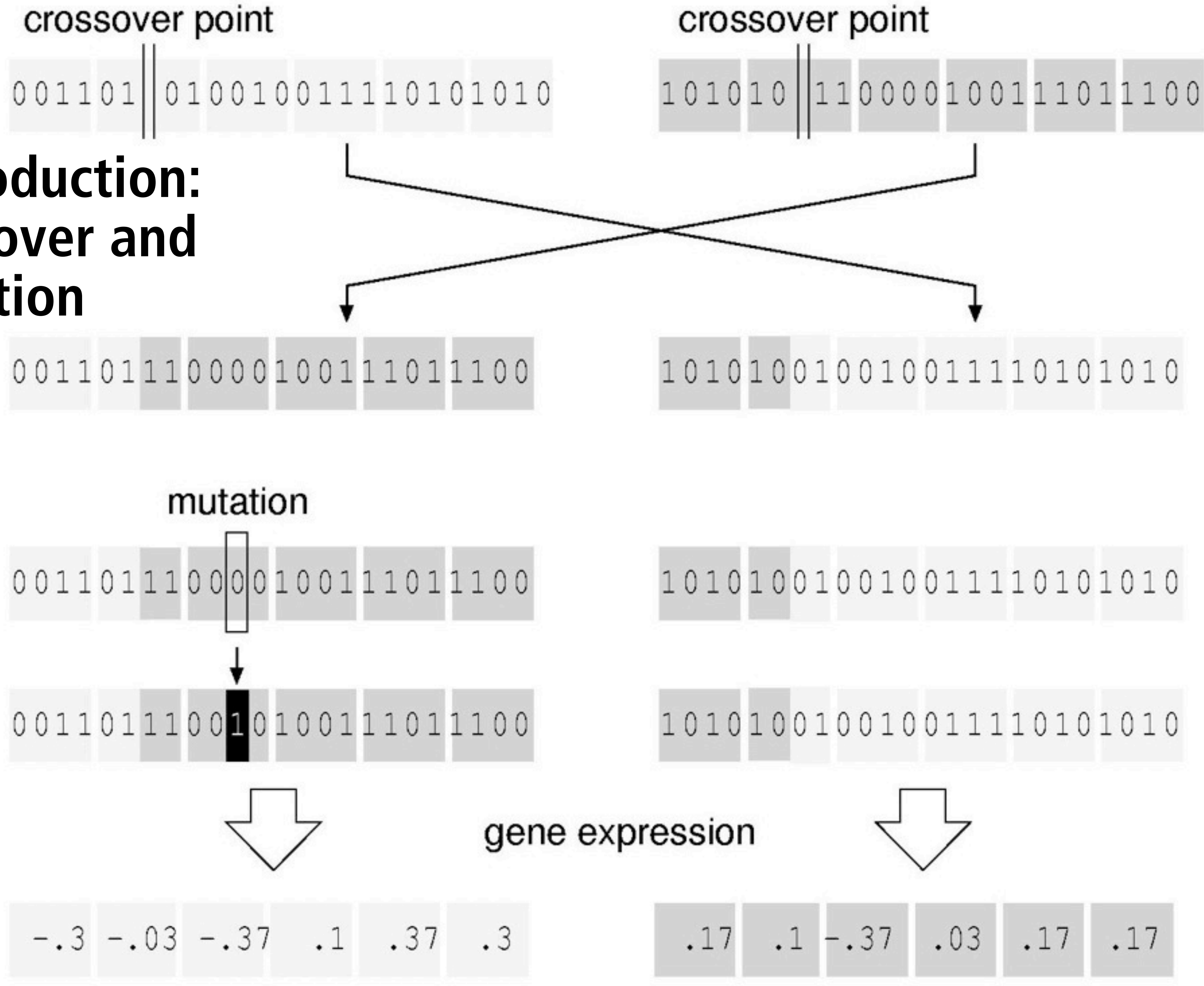
Fitness function and selection

suggestions? —> Chiba

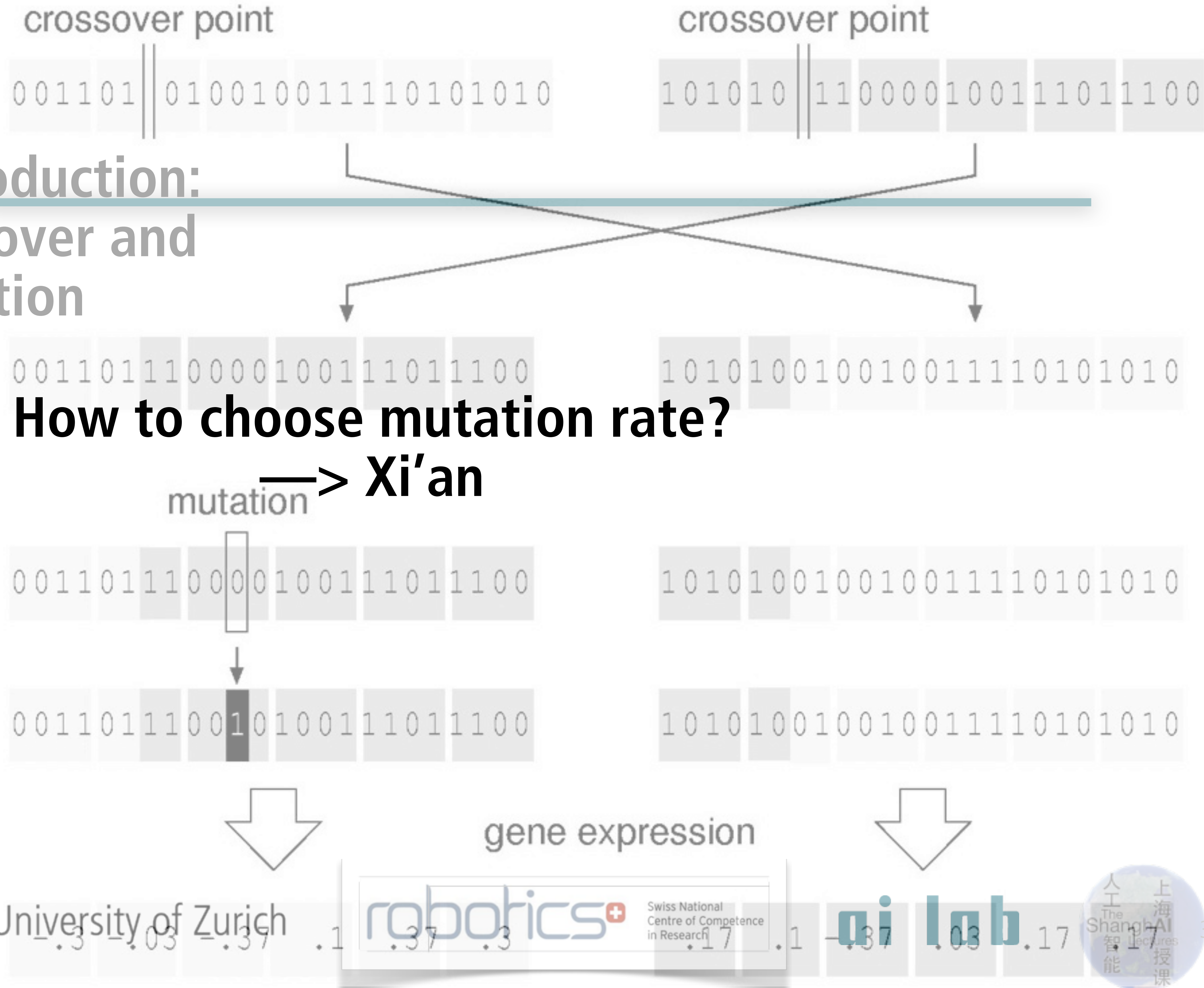
encoding	development	selection	reproduction
• binary • many-character • real-valued	• no development (phenotype = genotype) • development with and without interaction with the environment	• "roulette wheel" • elitism • rank selection • tournament • truncation • steady-state	• mutation • crossover

Fitness function: two components
1. speed —> positive
2. collisions —> negative

Reproduction: crossover and mutation



Reproduction: crossover and mutation



How to choose mutation rate?
—> Xi'an

University of Zurich

Choice of mutation rate: too large —> random search; too small: organism will evolve too slowly.

Approaches to evolutionary robotics

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

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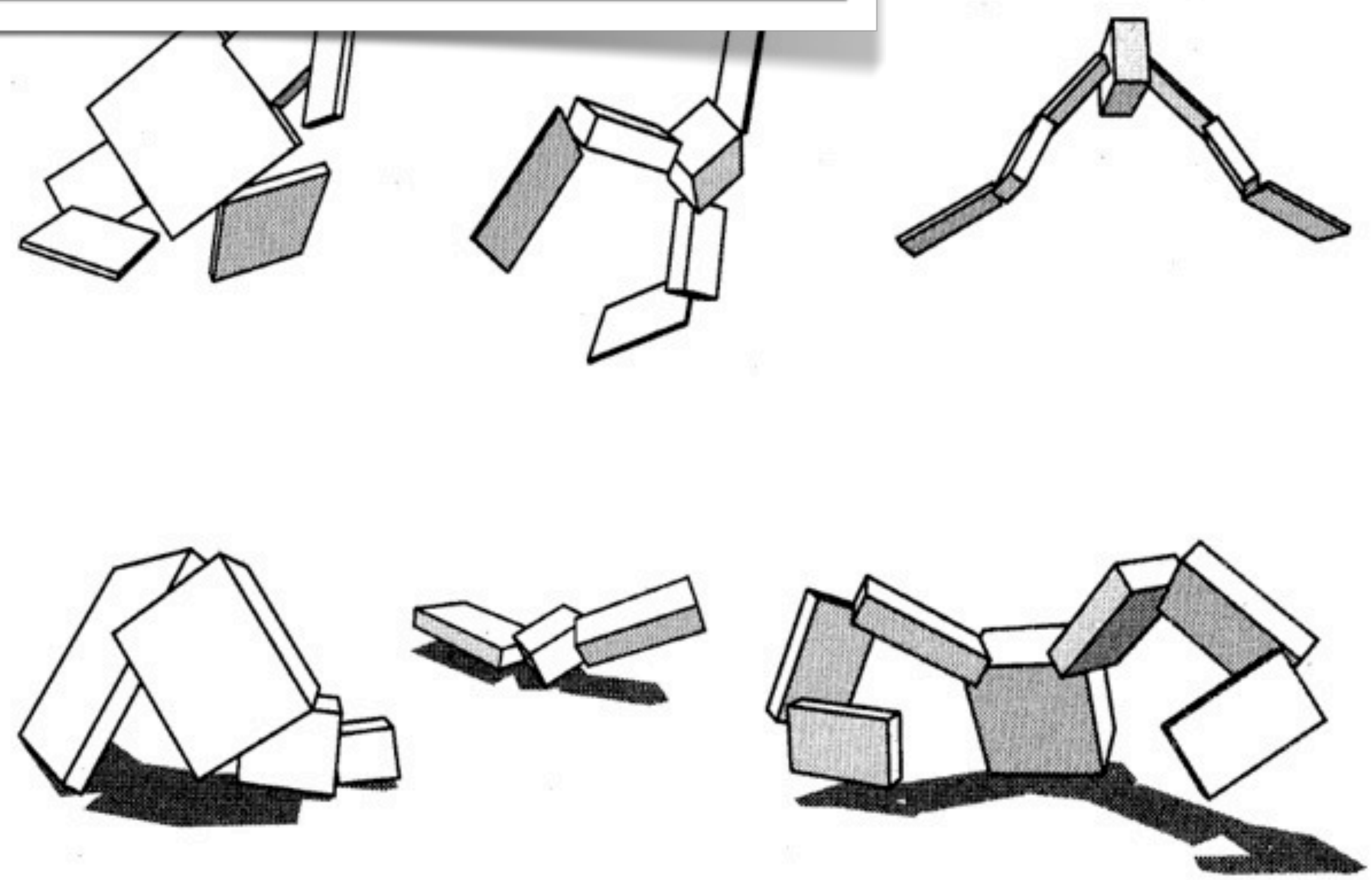
embodied approach:
1. parameterization —> Sims, Lipson and Pollack, Komosinski and Ulatowski
2. GRNs —> Eggenberger, Bongard

Evolving morphology and control: Karl Sims's creatures

Video "Karl Sims's evolved creatures"



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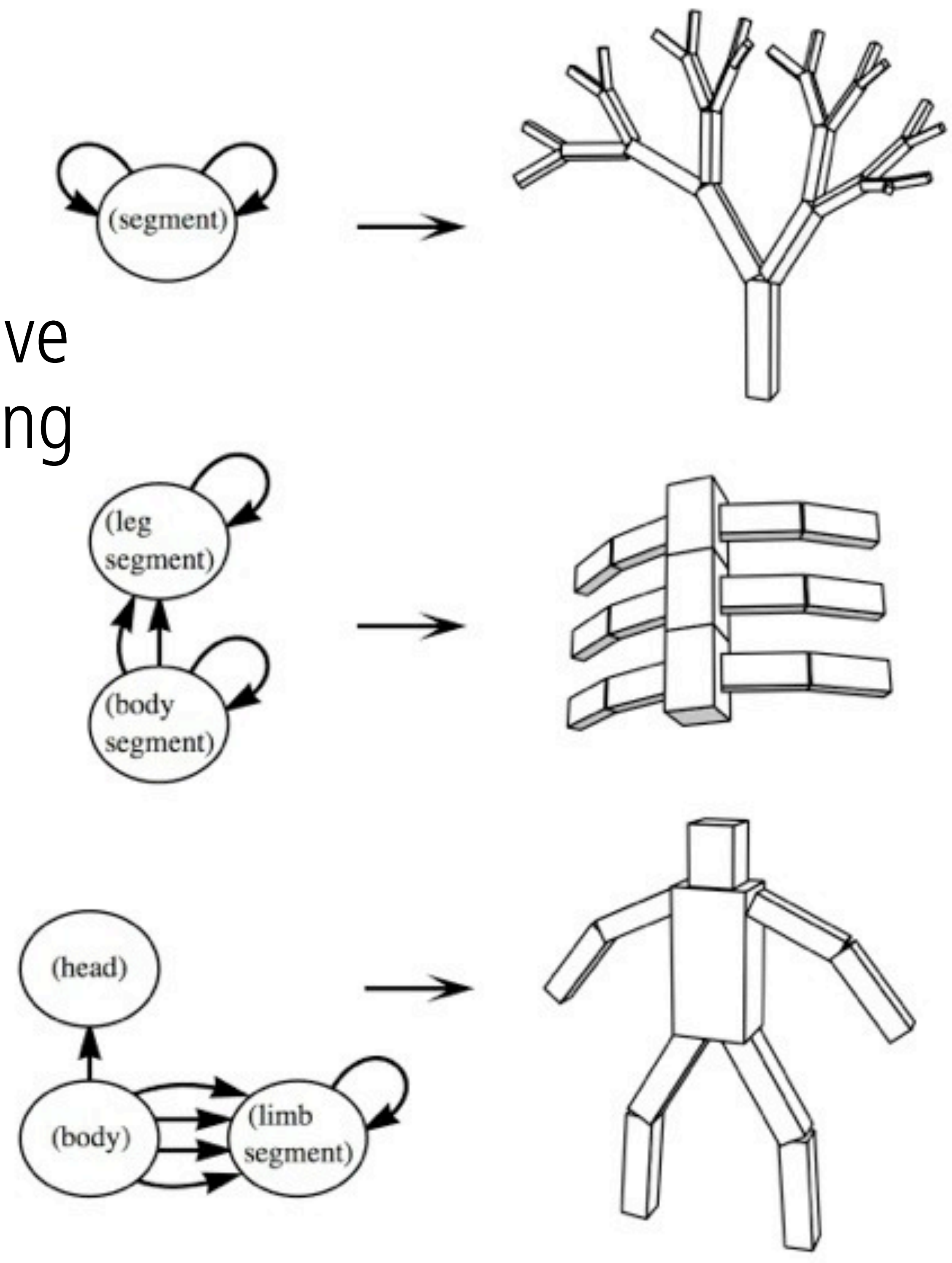
Parameterization of morphology

encoding in genome "genotype"

development

embodied agent "phenotype"

recursive encoding



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Parameterization of morphology

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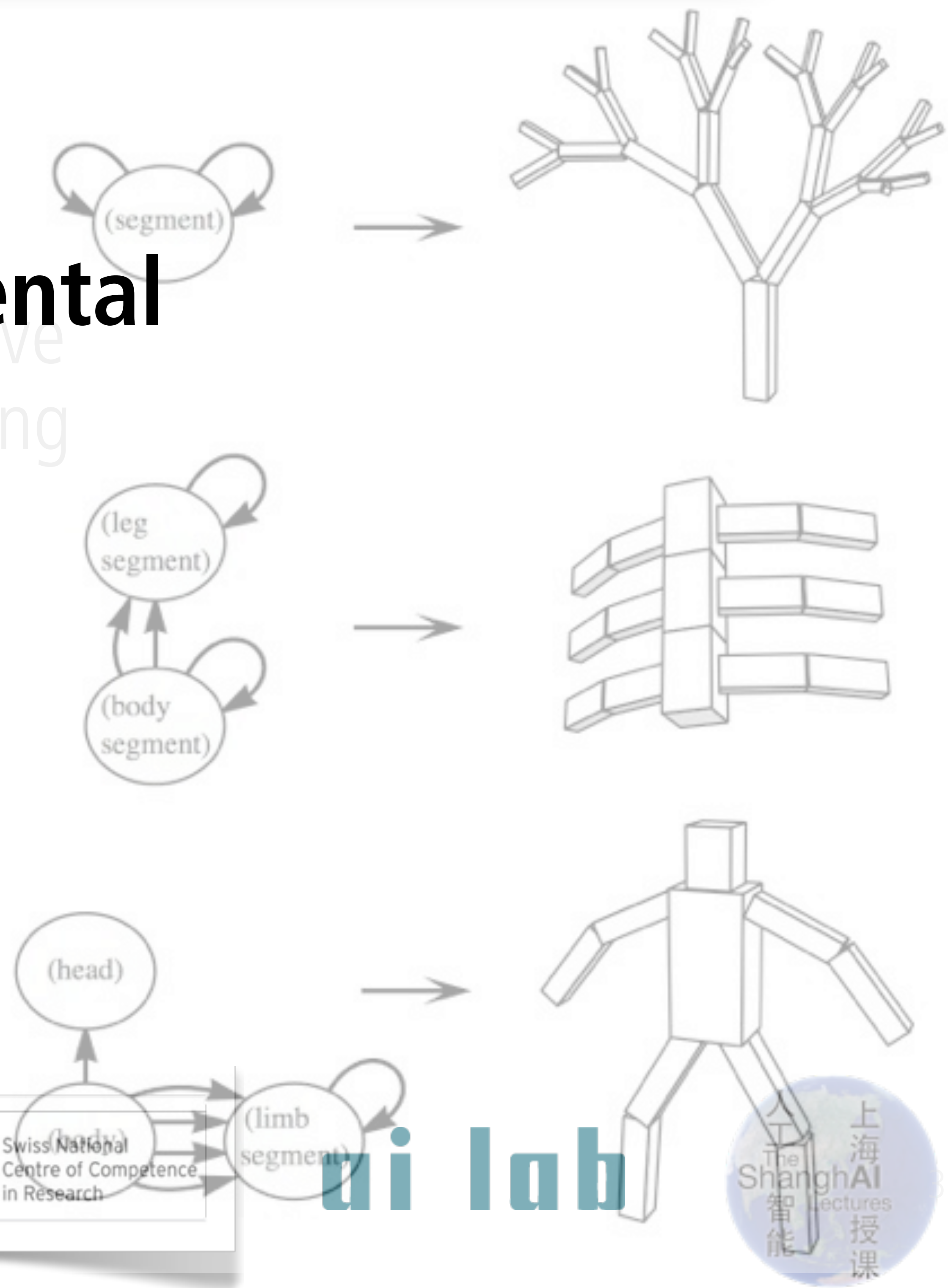
recursive encoding



characterizing the “developmental process”

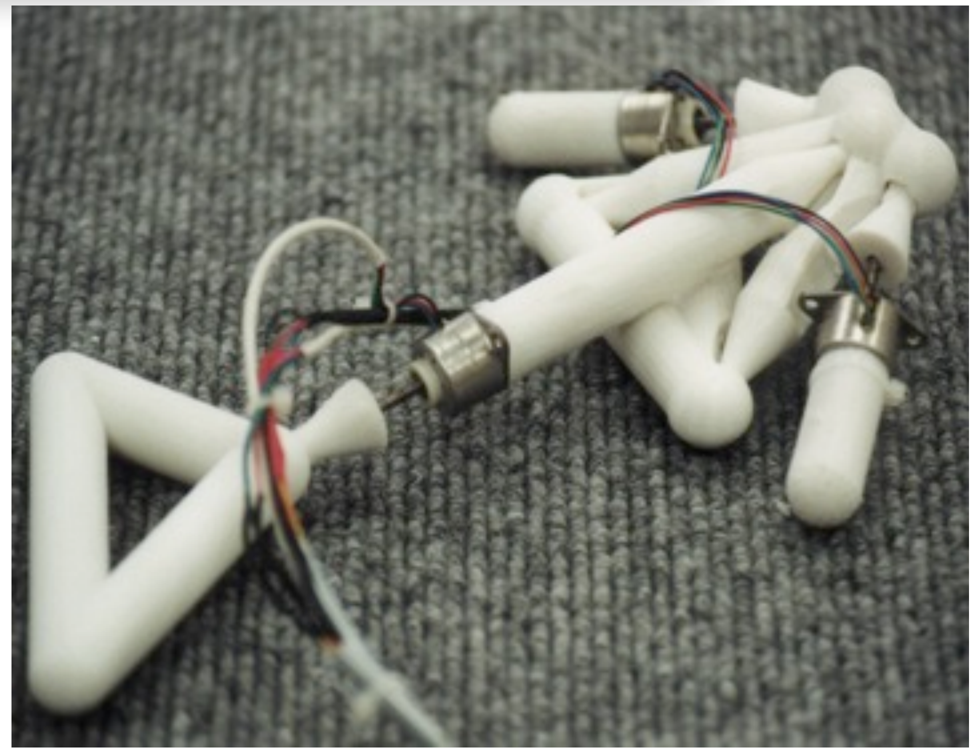
—> Karlsruhe

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)



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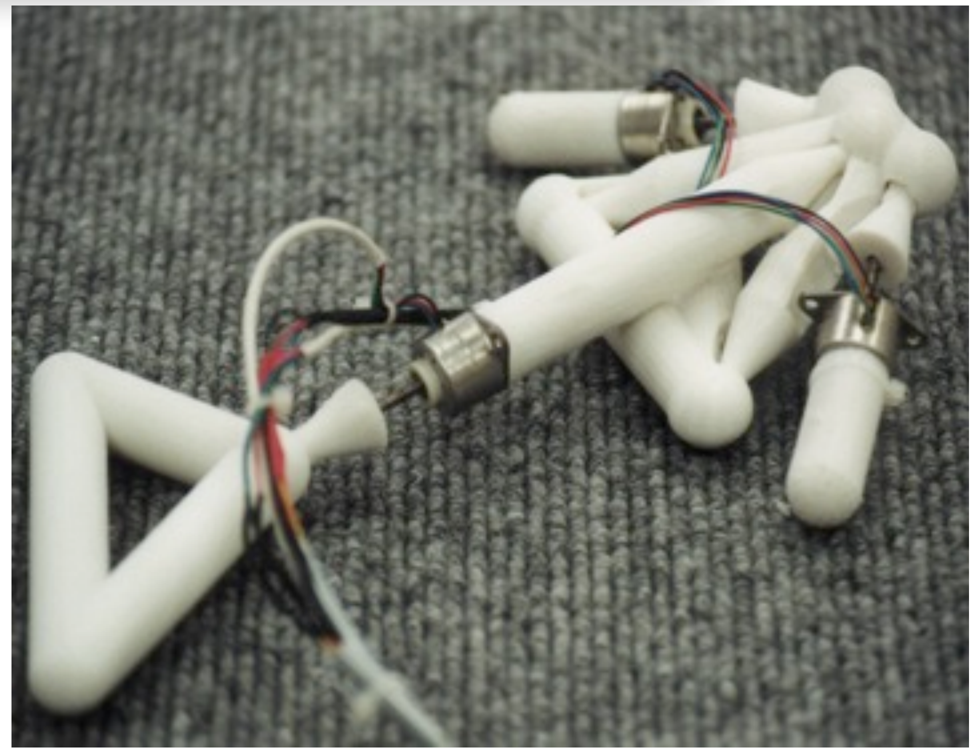
(recursive encoding)

Golem as the first self-evolving machine in history
—> NYU, Abu Dhabi



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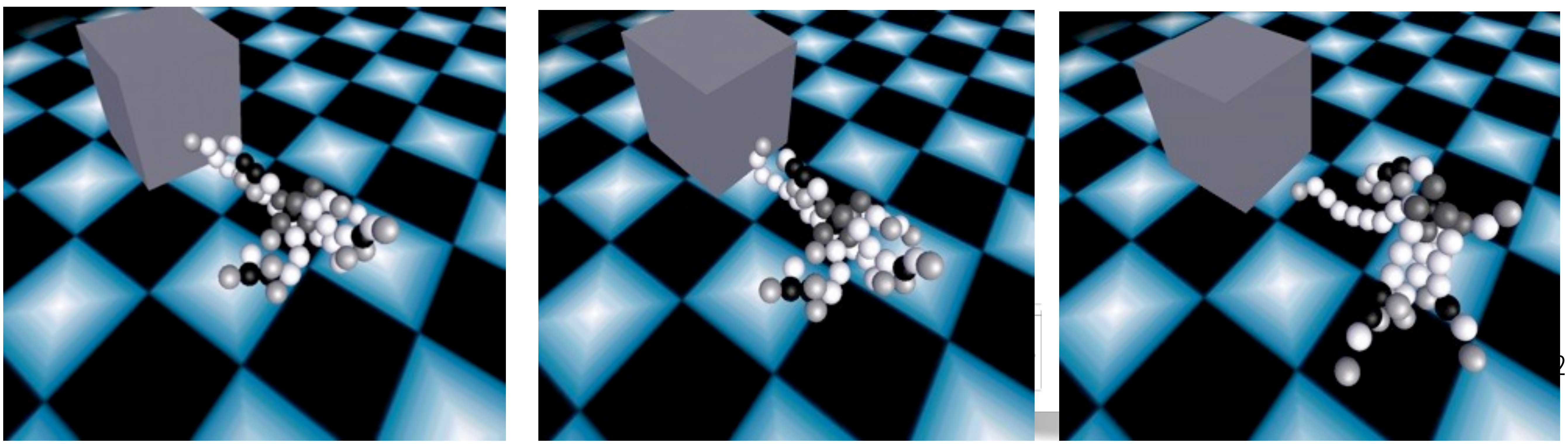
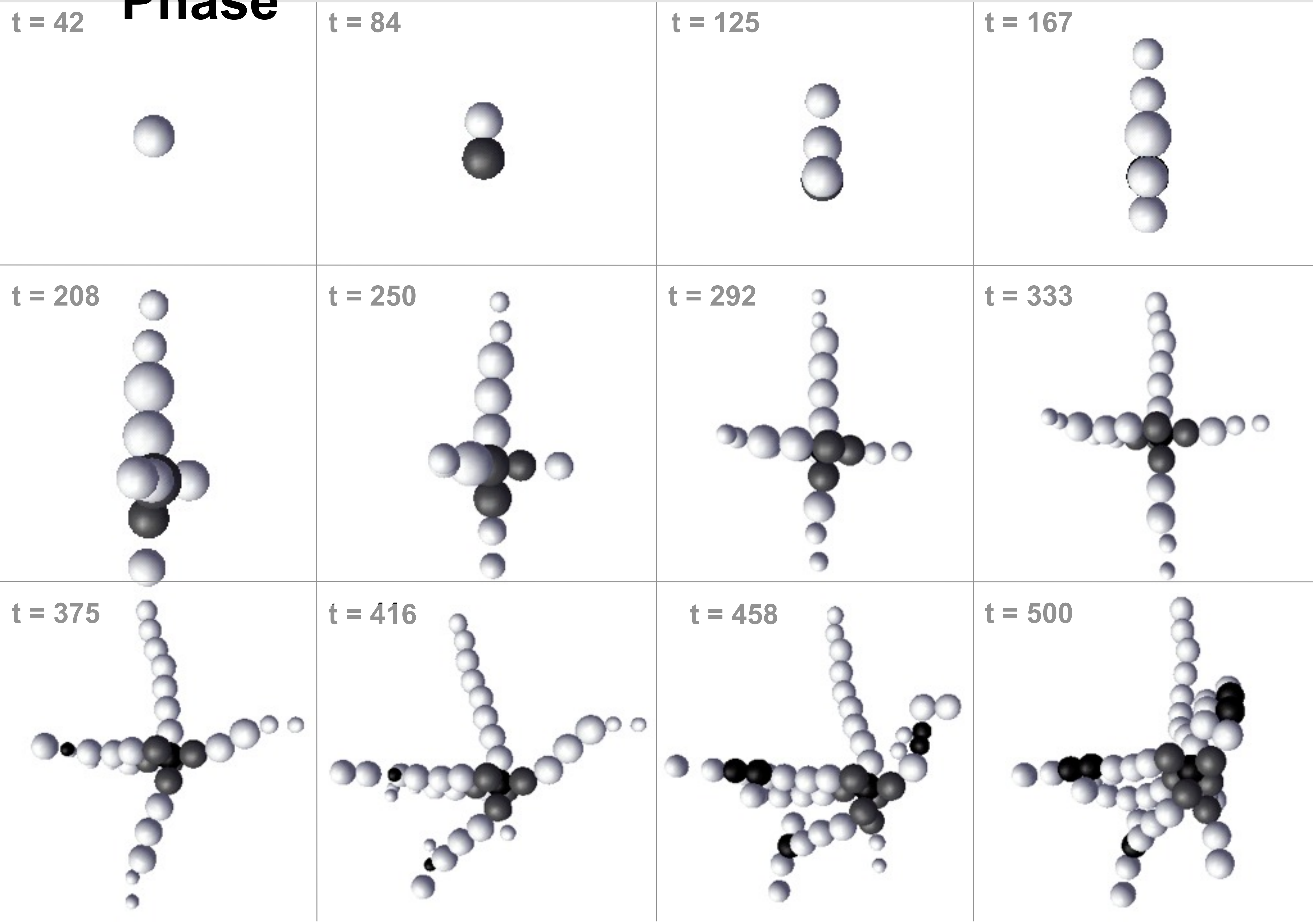
Genetic Regulatory Networks (GRNs): Bongard's "block pushers"

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



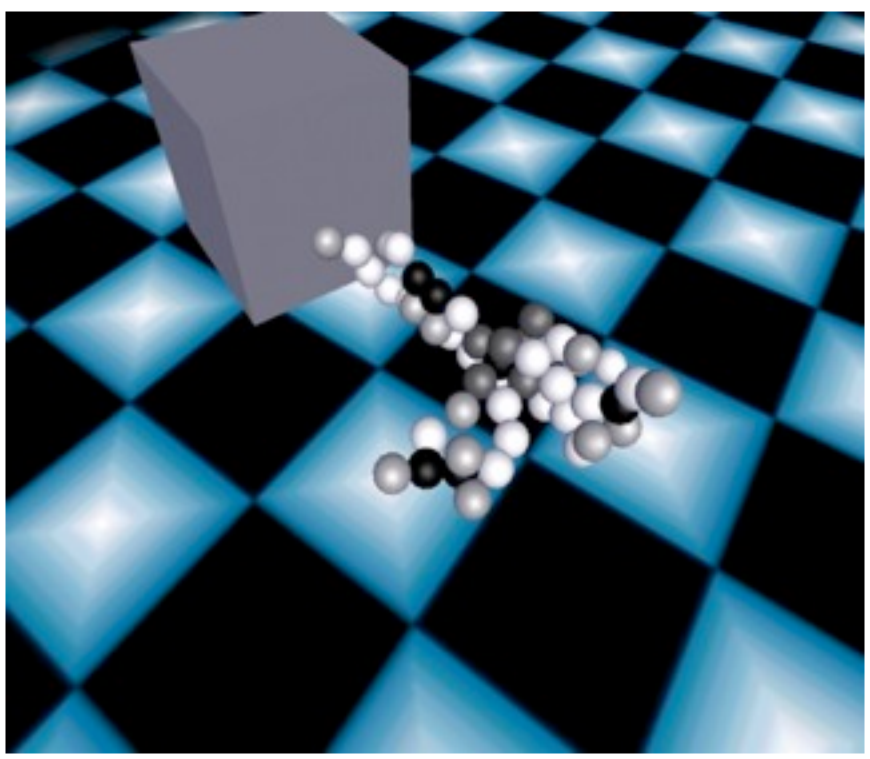
The Growth Phase

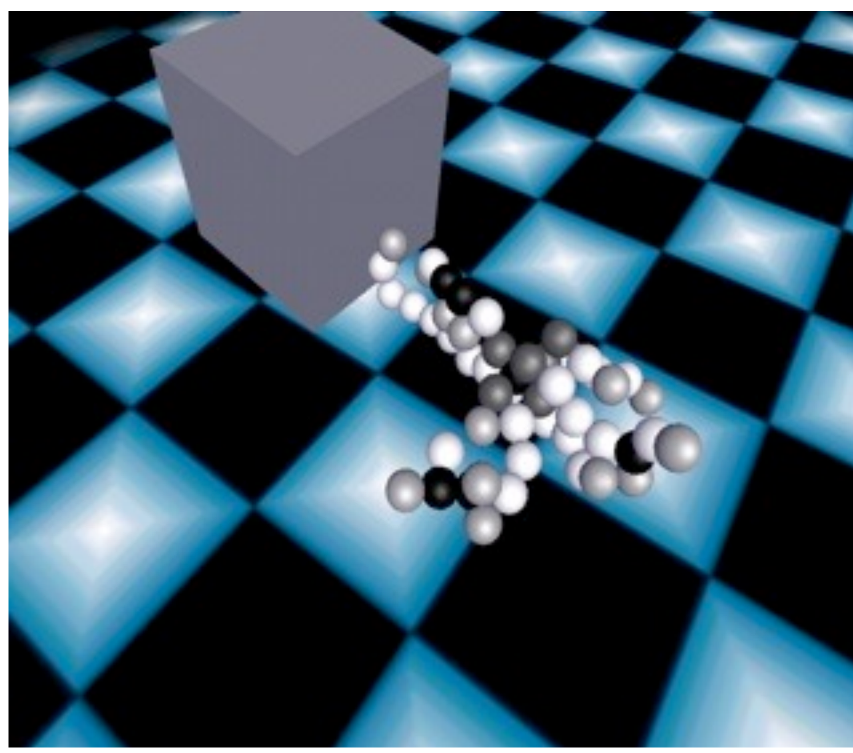


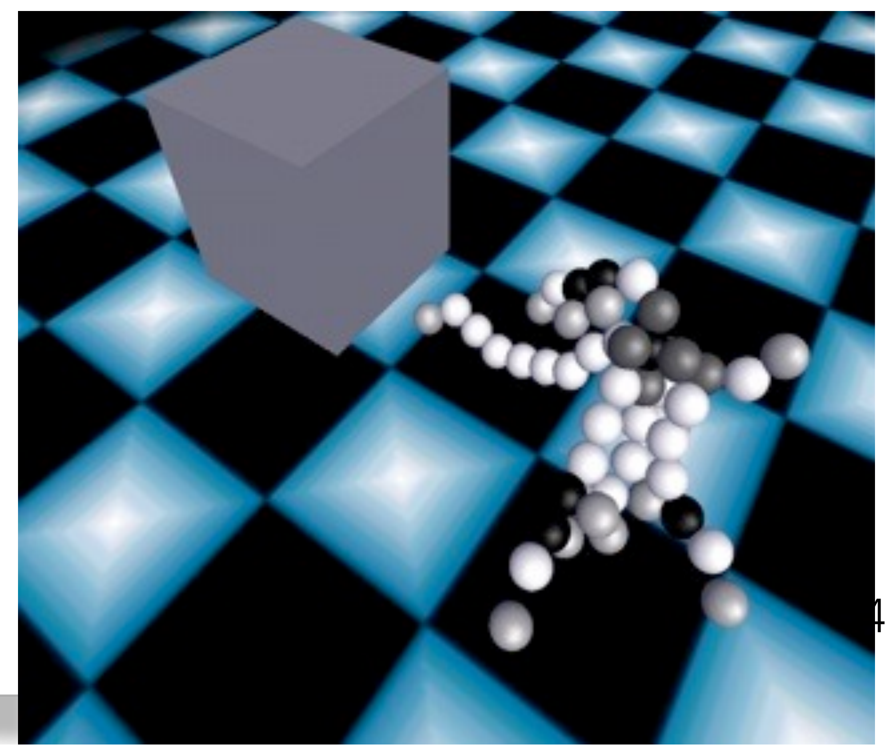
Evolution of a “block pusher” (“Artificial Ontogeny”)

- development (morphogenesis) embedded
-

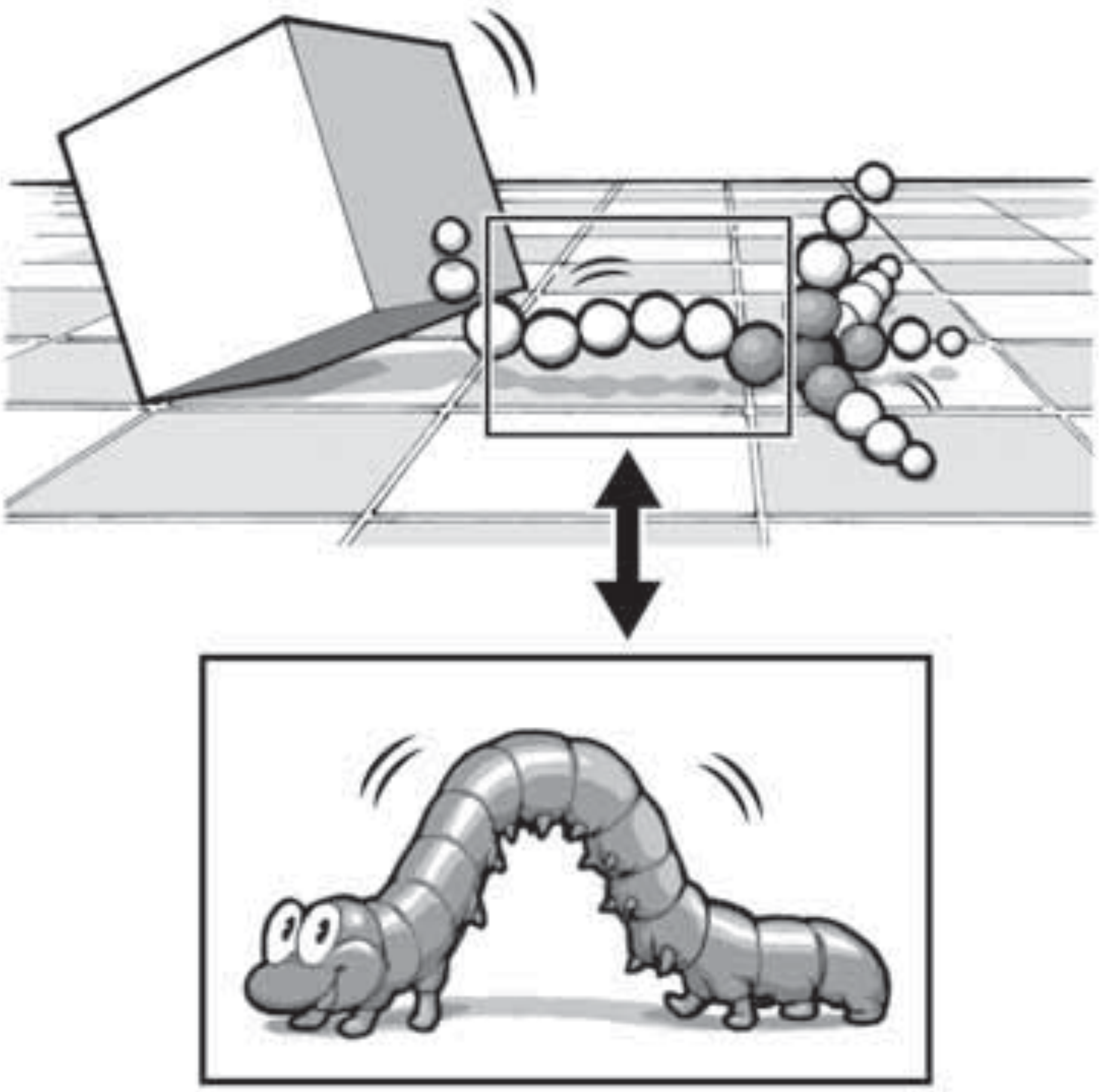
Video “Evolution of block pushers”

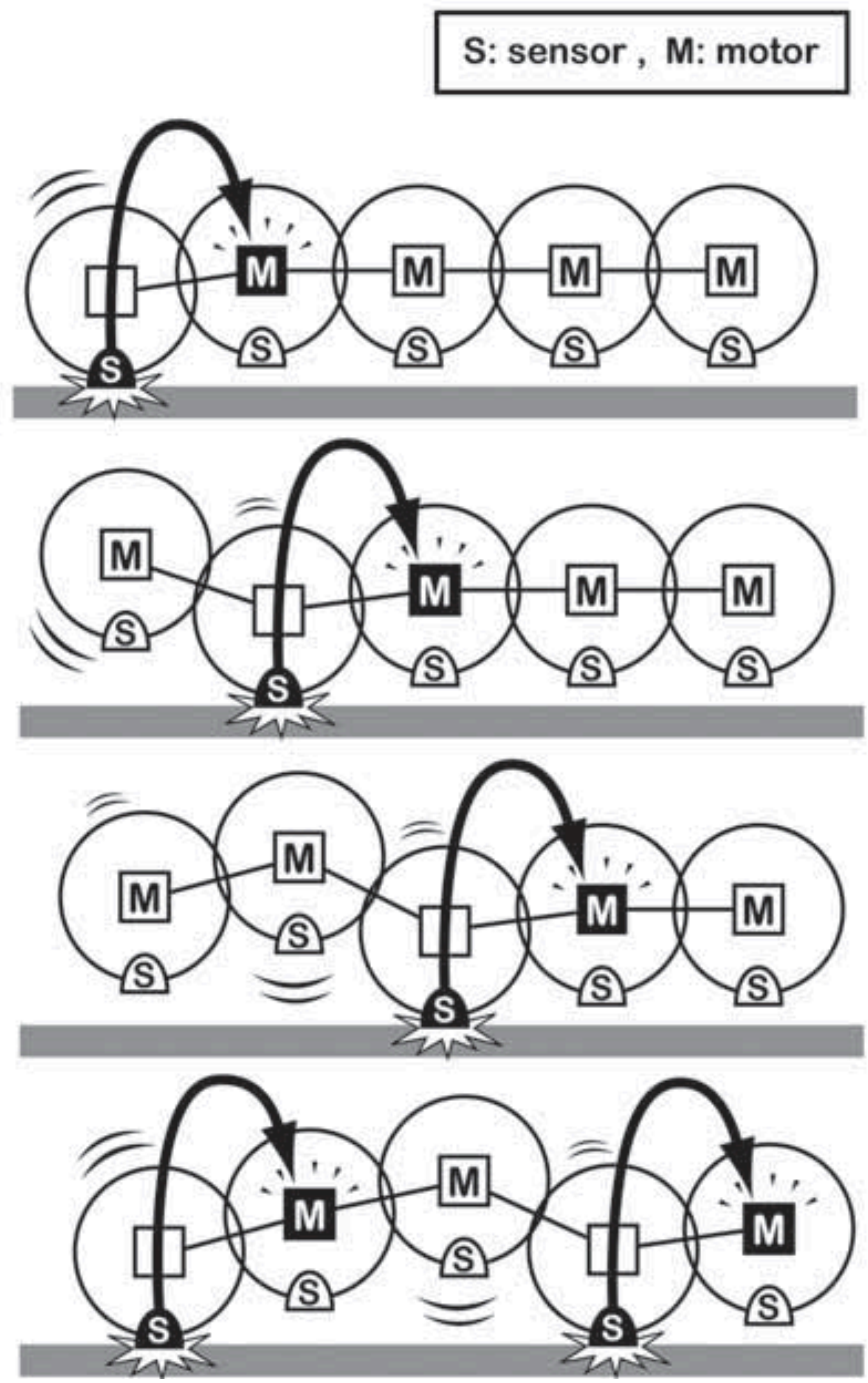






Inchword method of locomotion





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Emergence of locomotion:The block pusher. (*a*) the actual block pusher. (*b*) The inchwormlike locomotion of the block pusher.A sensor, S, in one cell is connected to a motor,M, in a neighboring cell.Whenever S touches the ground, it will actuate the motor M, which subsequently will lift up the cell containing S. This reflex propagates through the entire creature and causes the locomotion behavior. (*c*) The pattern of motion is reminiscent of how an inchworm moves: waves travel along the animal’s body in order to move it forward.

Bongard's evolutionary scheme

genotype:
parameters of genetic regulatory network

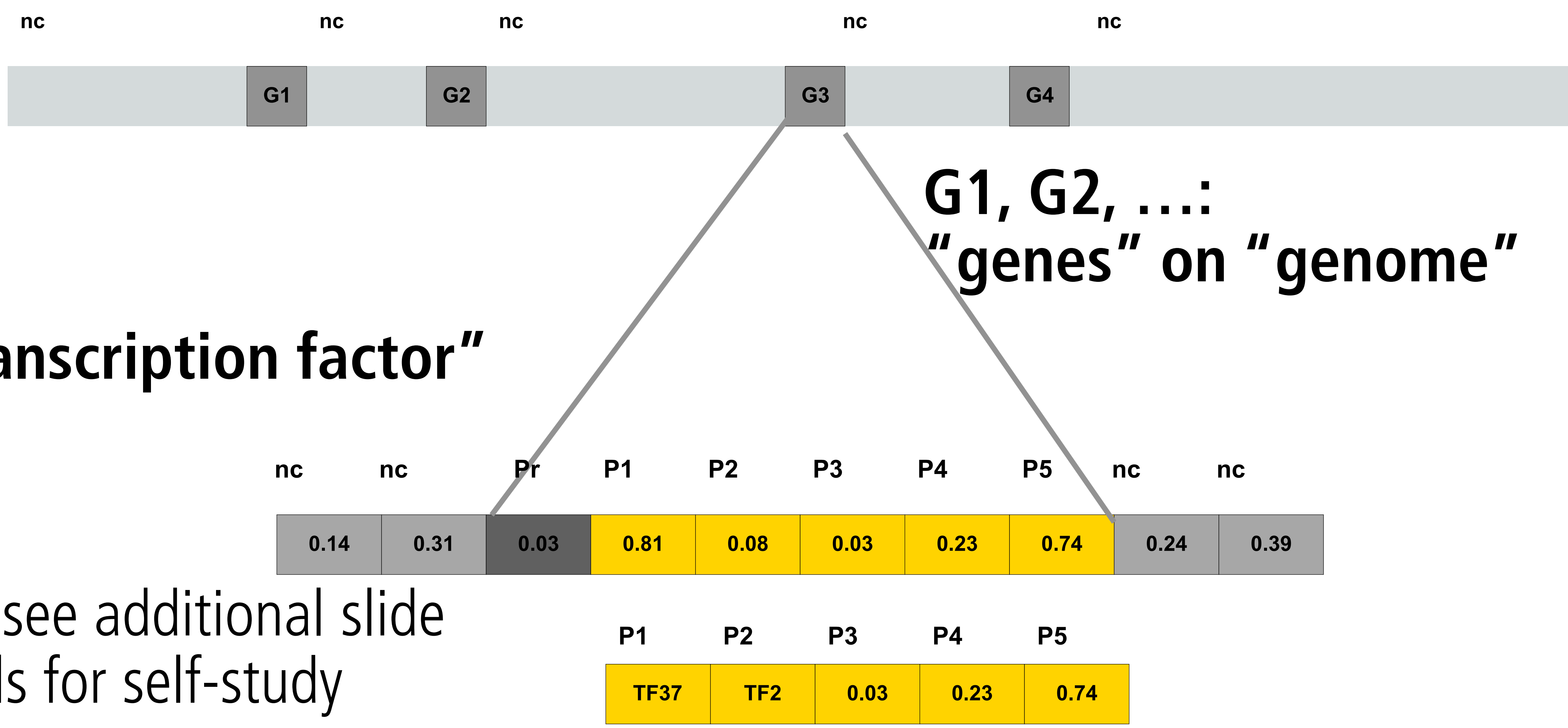
ontogenetic development:
"transcription factors"

phenotype selection:
physically realistic simulation

reproduction:
mutation and recombination

Representation of "gene"

nc: "non-coding region"



G1, G2, …:
"genes" on "genome"

TF: "transcription factor"

Details: see additional slide materials for self-study

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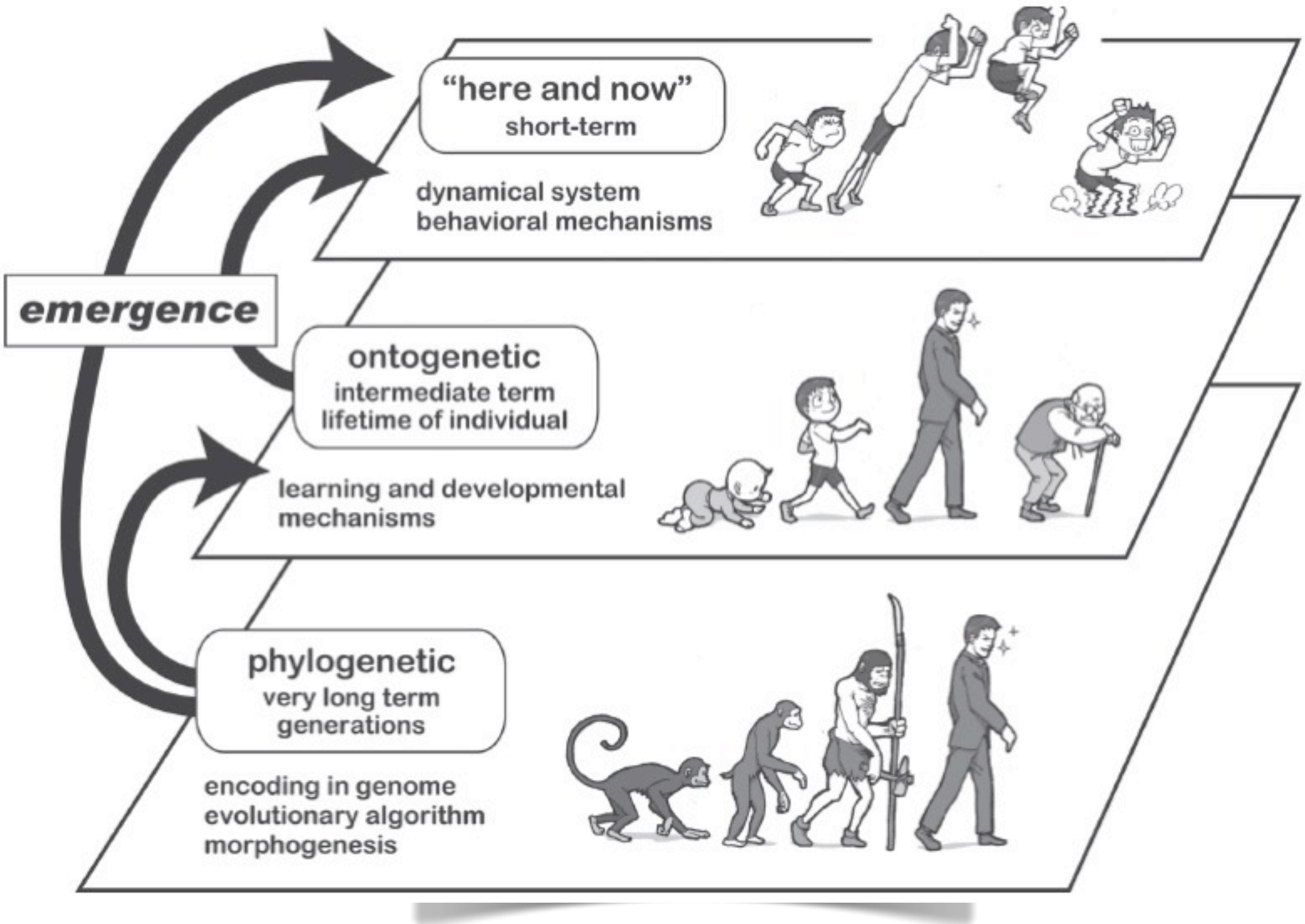
What is evolved in this case are the parameters of the genetic regulatory network, rather than the structure of the organism. The GRNs characterize (enable, constrain) the developmental process.

Time scales tightly intertwined



Design principles for artificial evolution

Principle 1: Population

Principle 2: Cumulative selection and self-organization

Principle 3: Brain-body co-evolution

Principle 4: Scalable complexity

Principle 5: Evolution as a fluid process

Principle 6: Minimal designer bias

Assignments for next week

- Read chapter 6 of "How the body …"
- Additional slide materials for self-study
- Assignments - volunteers?

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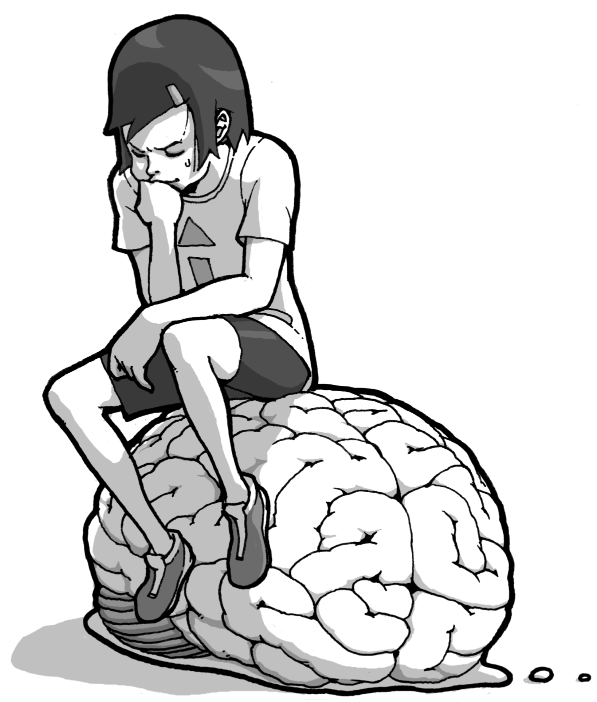
End of lecture 6

Thank you for your attention!

stay tuned for guest lectures

on artificial evolution, and on “soft robotics”



Lecture 6: Guest speaker

from Lausanne, EPFL, Switzerland

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Dr. Francesco Mondada, EPF-Lausanne, Switzerland
"Towards Robots for Daily Life"

10.00h Zurich/CET

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Lecture 6: Guest speaker

from USC, The University of Southern California, Los Angeles

Prof. Robert Riener, ETH Zurich, Sensory-Motor Systems Laboratory, Dpt. of Health Sciences and Technology: "Design principles for intelligent rehabilitation robots"

10.30h Zurich (CET) time, 1.30h am in Los Angeles (!) - Thank you Robert :-)

End of lecture 6

Thank you for your attention!

stay tuned for lecture 7

“Collective intelligence: Cognition from interaction”

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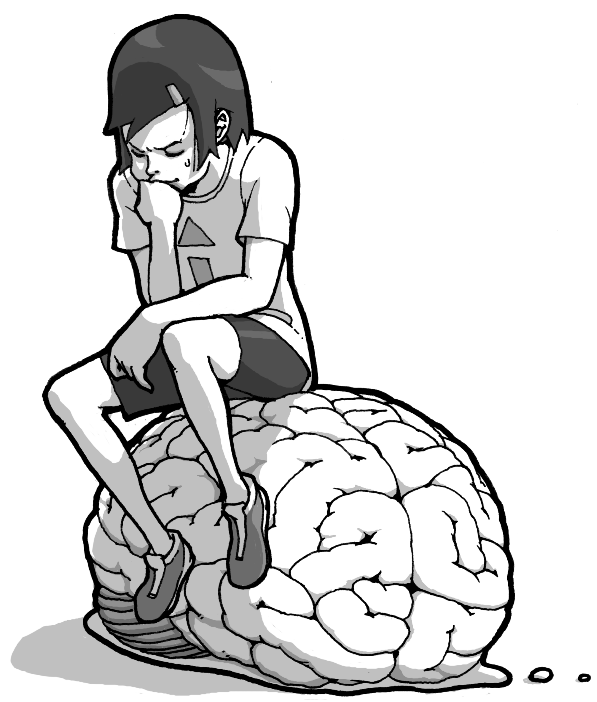
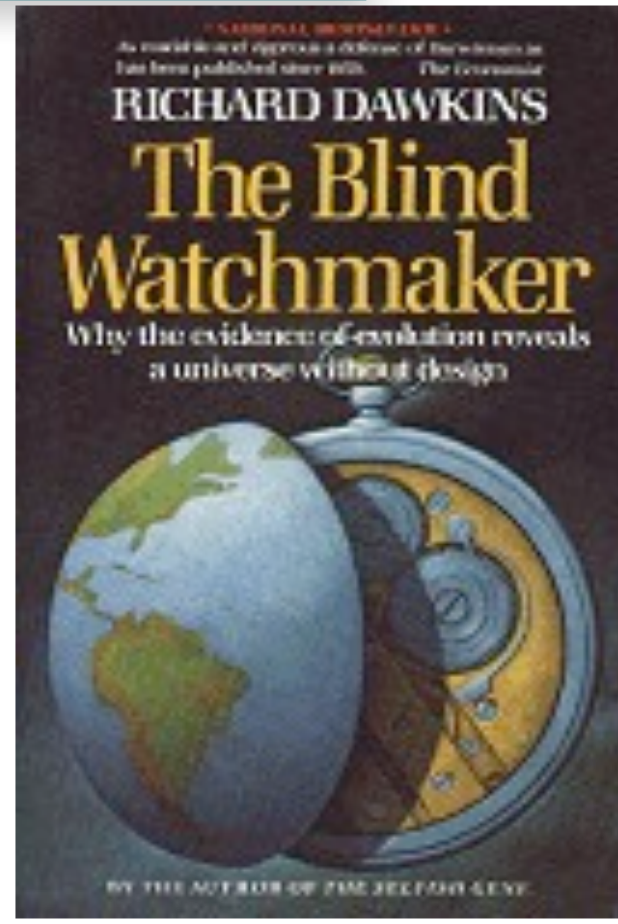


Additional slide materials for self-study

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.**

Imagine a monkey sitting in front of a kyeboard randomly typing. There is a certain — extremely low — probability that at some point, he will have written Shakespeare's Hamlet. To make matters a bit more easy and slightly more probable, let's just look at one sentence from Hamlet's dialogue with Polonius, in old English, "Methinks it is like a weasel."

Cumulative Selection: Example by Richard Dawkins

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

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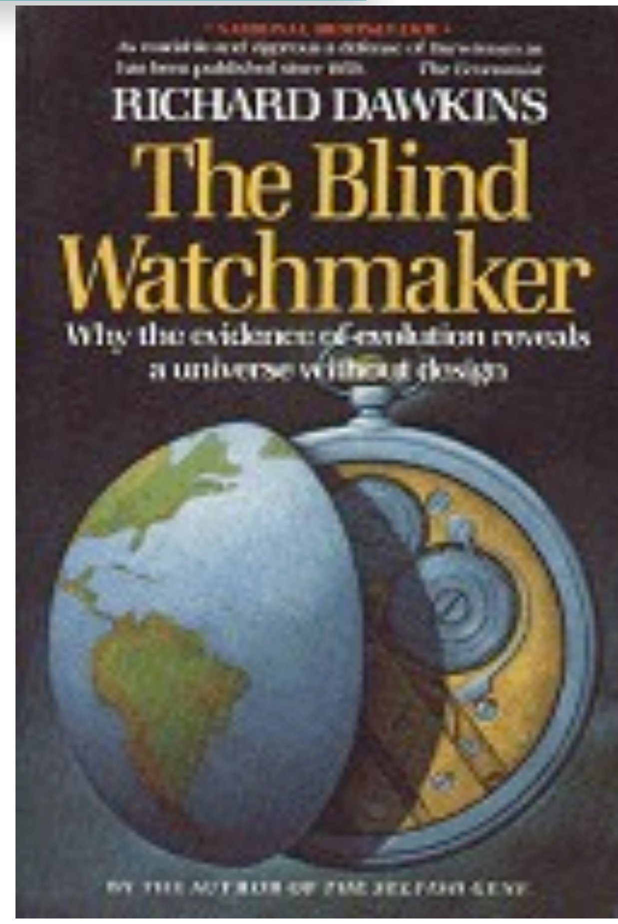

How many possible arrangements?

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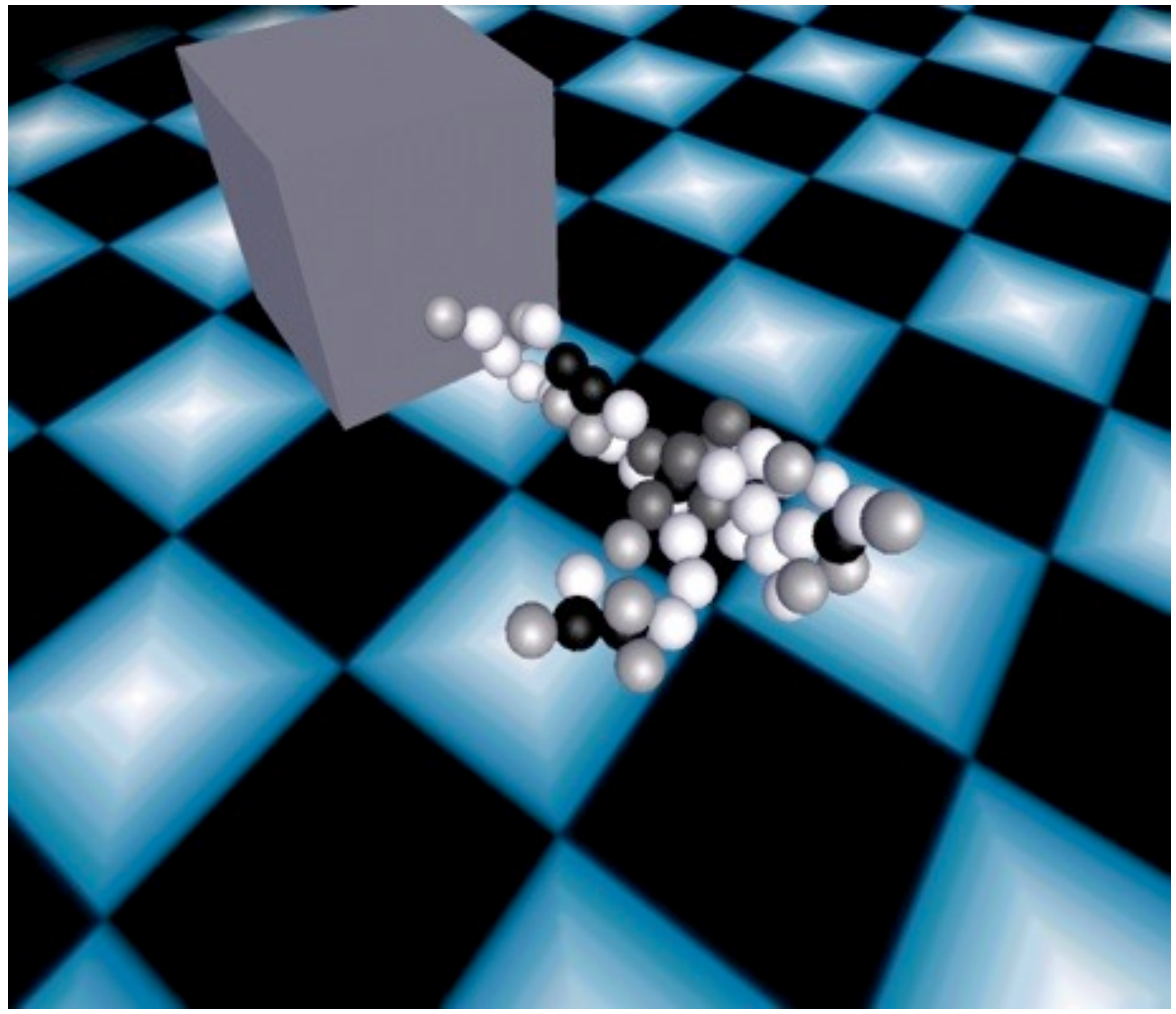
To increase the probability that a solution can be found, only one sentence is chosen from the entire text (but "in principle" the argument also applies to the entire text of Shakespeare's Hamlet (it'as actually fun think about it.

"Methinks it is like a weasel" (cumulative selection)

generation	winner sentence	dist. to target
0	WDLDMNLT DTJBKWIRZREZLMQVOP	0.25
10	WDLDMNLT DTJBSWIRZREZLMQVOP	0.24
20	WDLDMNLS ITJISWHRZREZ MECS P	0.20
30	MELDINLS IT ISWPRKE Z WECSEL	0.80
40	METHINGS IT ISWLIKE B WECSEL	0.40
43	METHINKS IT IS LIKE A WEASEL	0.00

try one of the applets on the net

Additional materials on Bongard's GRNs



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Observations on Bongard's "block pushers"

- size of organism
- no direct relation between length of genome and fitness of phenotype
- means of locomotion: no global neuronal coordination
- specialization of cells (black, dark gray, light gray, white)

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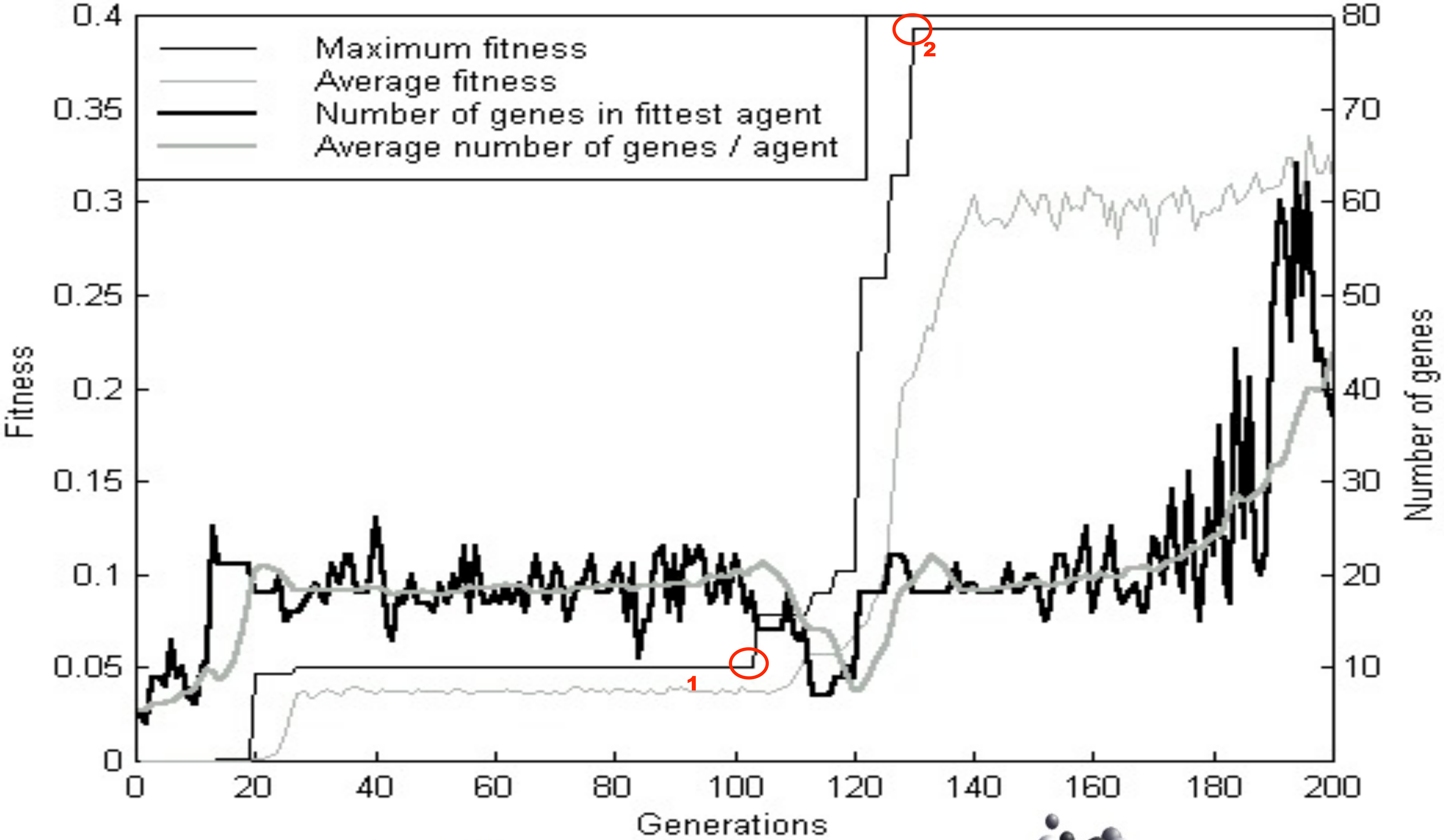
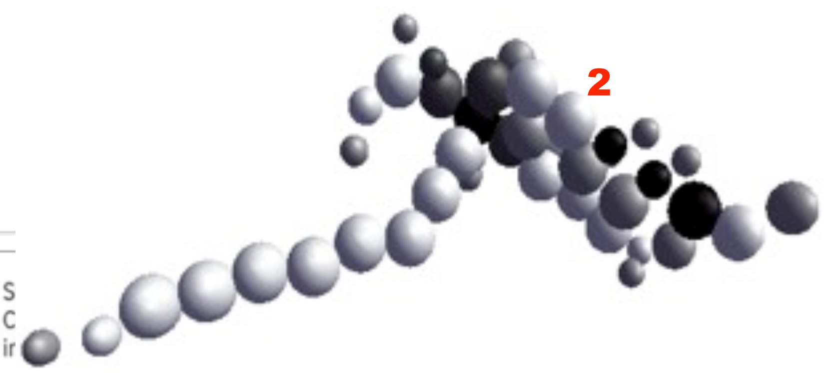
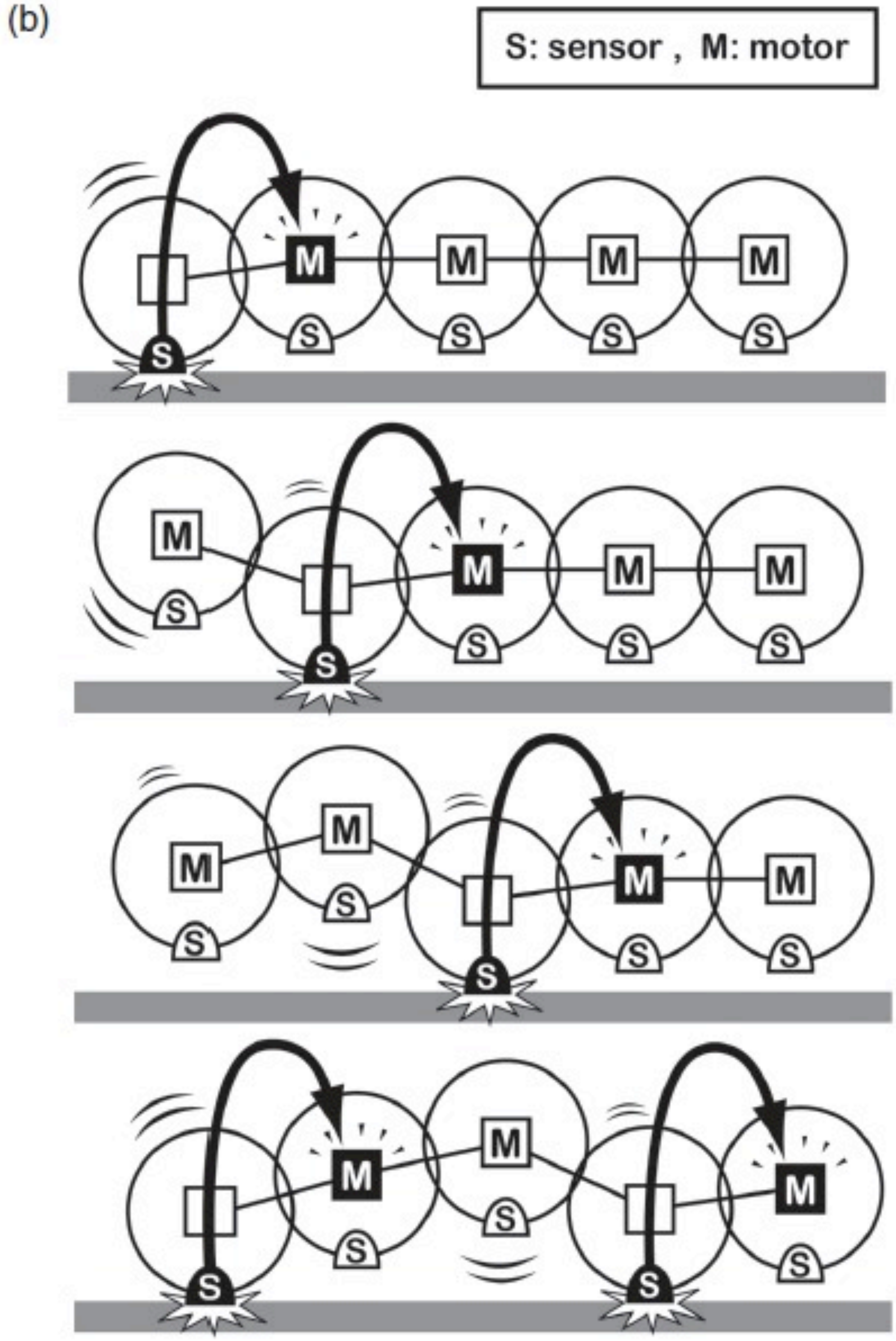
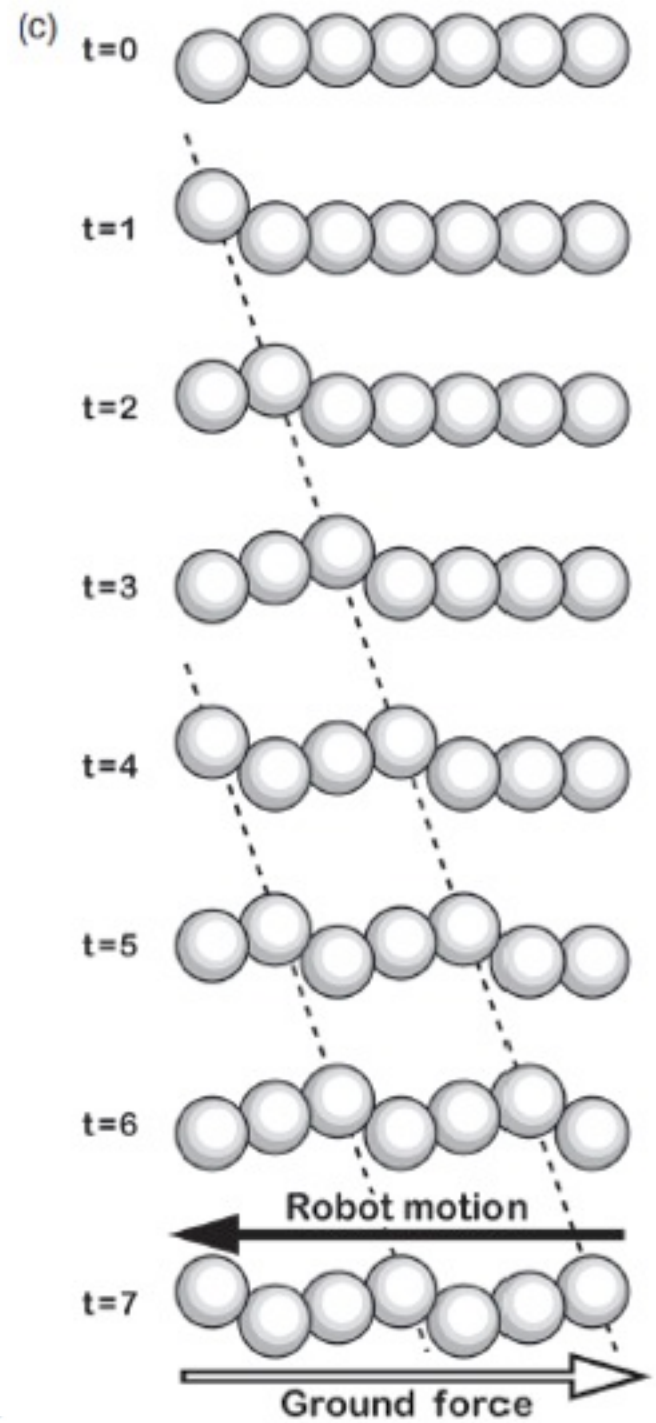

Maximum fitness
Average fitness
Number of genes in fittest agent
Average number of genes / agent
Fitness
Number of genes
Generations
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160
180
200
1
2


1


2

Emergence of locomotion through local reflexes

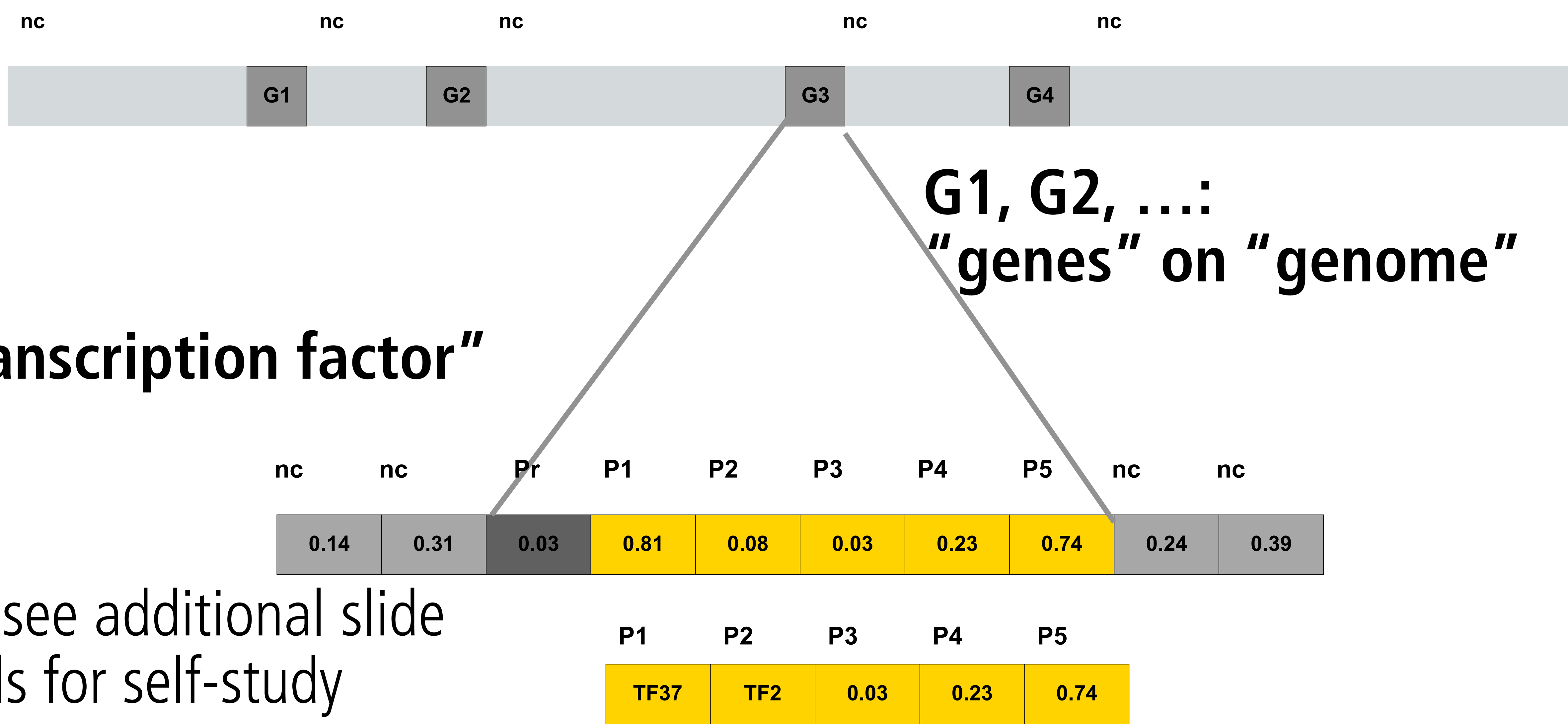




from “How the body …”

Representation of "gene"

nc: "non-coding region"



G1, G2, …: "genes" on "genome"

TF: "transcription factor"

Details: see additional slide materials for self-study

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Representation of “gene”

Parameters of “gene”:
nc: non-coding region
TF: “transcription factor”
Pr: start of promotor region
P1:TF regulating expression of this gene
P2: TF emitted by gene when expressed
P3: quantity of TF emitted
P4, P5: lower and upper bound of concentration range between which gene is expressed
when expressed: gene emits one of 42TFs, 20 regulatory, 22 structural (morphology and neural network

For more detail, see, for example:

Bongard, J., and Pfeifer, R. (2003). Evolving complete agents using artificial ontogeny. In F. Hara, and R. Pfeifer (eds.). Morpho-functional machines: The new species. Designing embodied intelligence. Tokyo: Springer, 237-258.

TFs for growth process (examples)

TF0: splitting of cell
TF1, TF2: attachment of cell with angle
TF3: joint type
...
TF6: create neuron
TF7, TF 8: position of neuron in cell
TF9: delete neuron
TF10: create synapse
TF11: delete synapse
TF12: split synapse into two branches
…
TF40: produced by touch
TF41: produced by torque on hinge joint

For more detail, see:
Bongard, J. (2003). Incremental approaches to the combined evolution of a robot's brain and body. Unpublished doctoral dissertation. University of Zurich.

End of additional materials for self-study

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