

人
工
智
能

The
ShanghaiAI
Lectures

上
海
授
课

Mittwoch, 6. November 13

Video clips, demonstrations

- **Video: Josh Bongard's “Block Pusher”**

The ShanghAI Lectures

An experiment in global teaching

From the University of Zurich
by Rolf Pfeifer

7 November 2013

Lecture 6

Evolution: Cognition from scratch

7 November 2013



“The brain in the vat”



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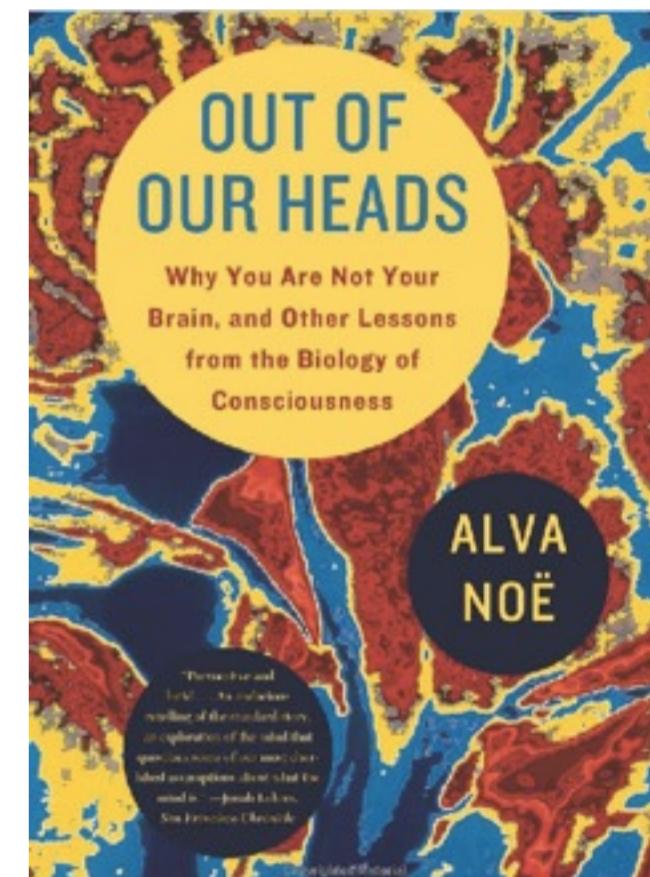
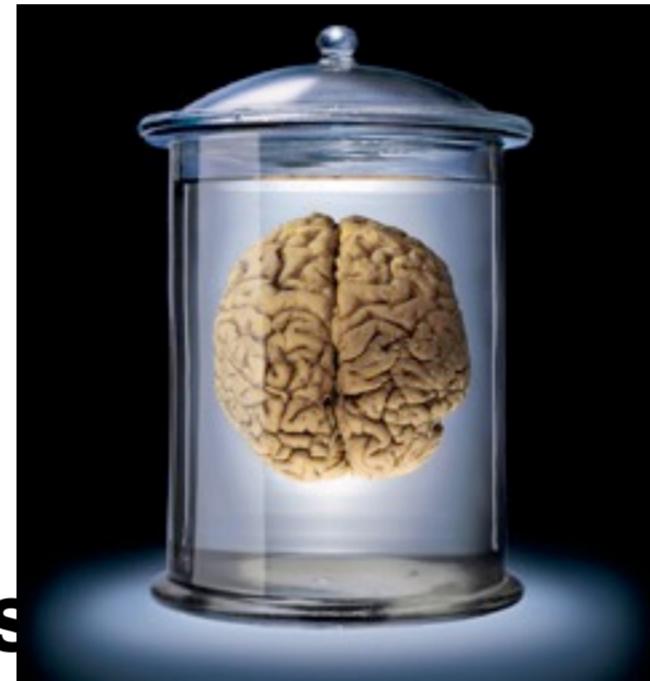
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Mittwoch, 6. November 13

“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**

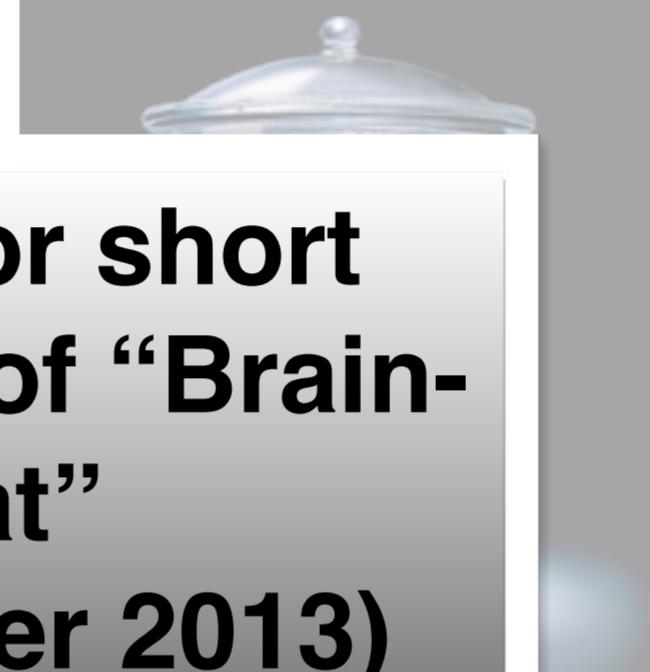
Mittwoch, 6. November 13

“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).

I'm walking outside in the sun!!

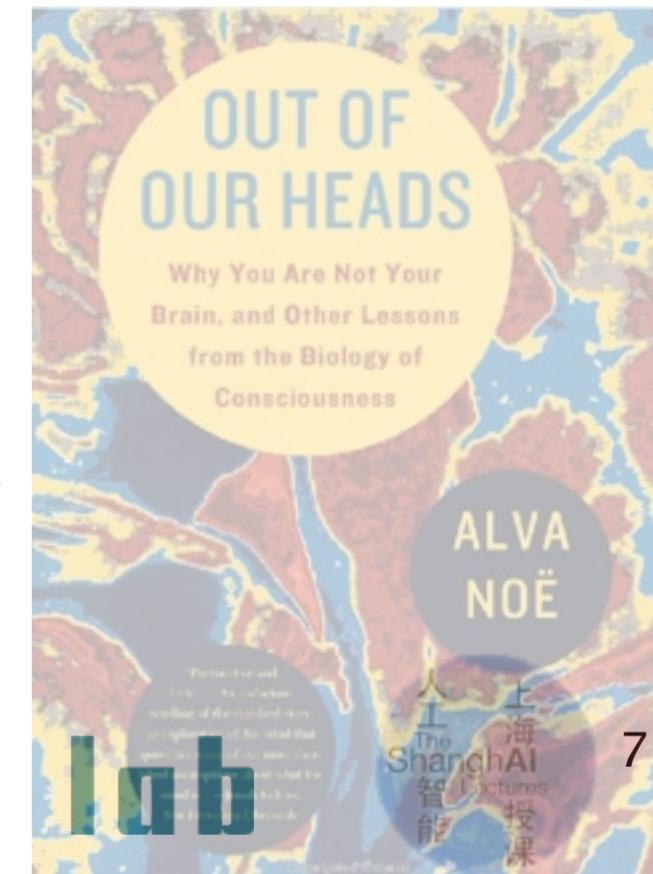
“Brain-in-a-vat”

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”
(14 November 2013)**

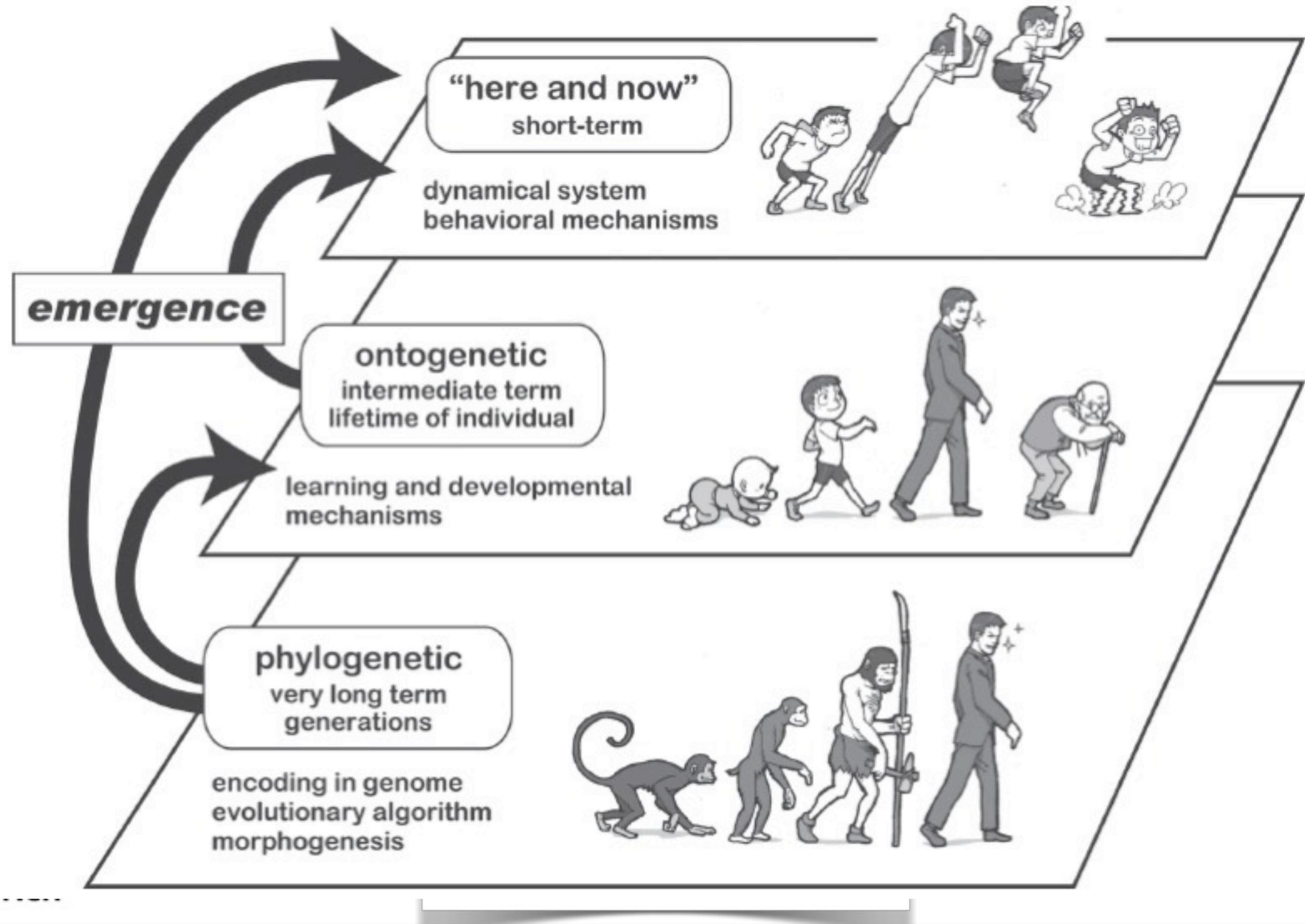
- supply energy
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Mittwoch, 6. November 13

“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).

Time perspectives



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Time perspectives in understanding and design

state-oriented
“hand design”

“here and now”
perspective

learning and
development
initial conditions,
learning and
developmental
processes

“ontogenetic” perspective

evolutionary
evolutionary

“phylogenetic”
perspective

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



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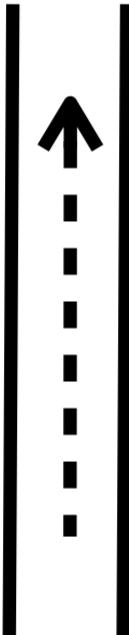
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Level of designer commitments:

- 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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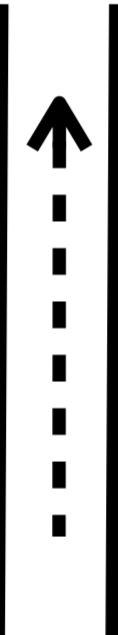
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The fluid that enters the system on the left has to be deflected into the horizontal pipe. What is the optimal shape of the connecting piece to minimize turbulence?

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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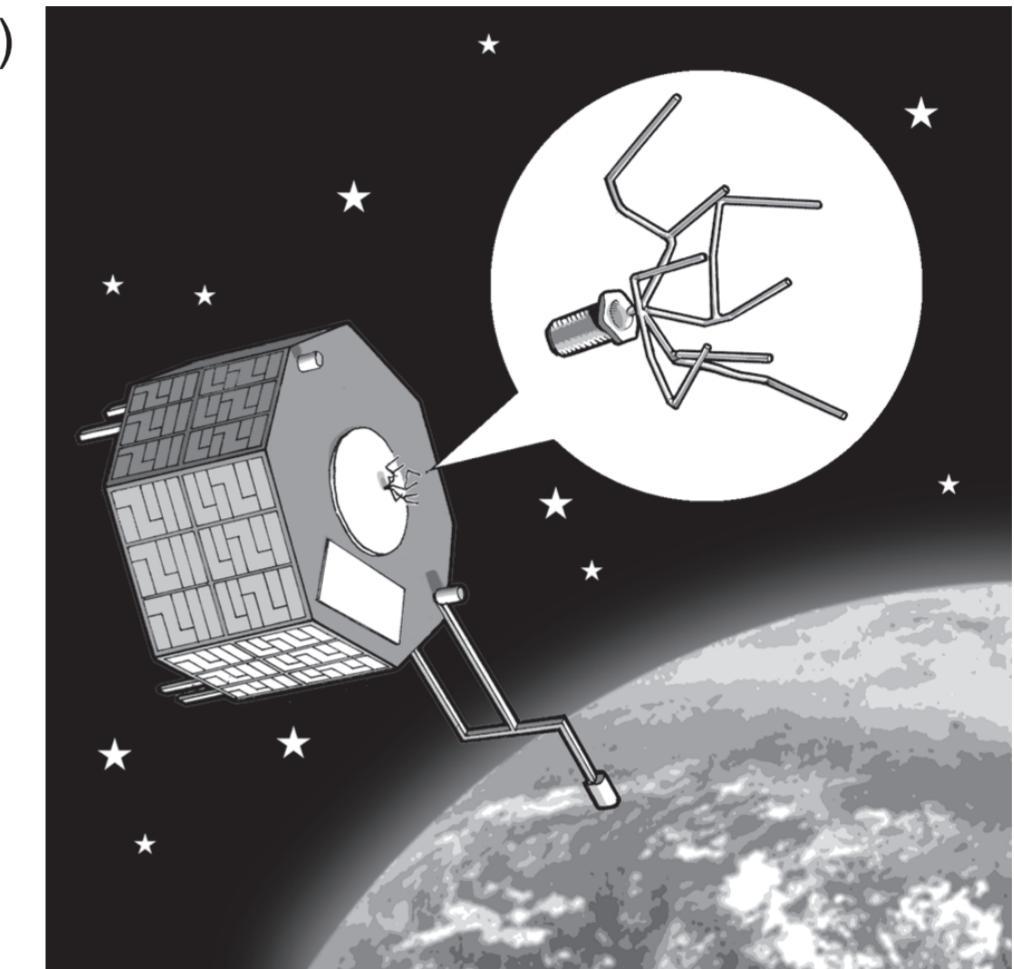
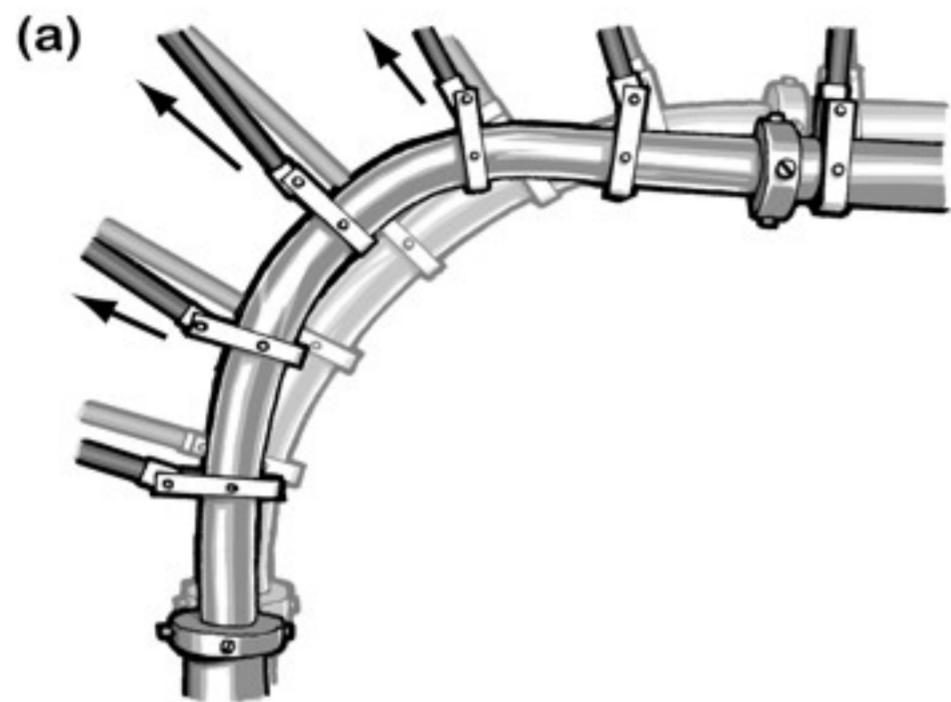
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There is the fundamental and very popular question of whether computers or robots can ever be creative. Many engineers that have been dealing with this problem, have not come up with the same solution that GAs have - but still, we don't consider the 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



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Evolutionary designs



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

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

anyone?

x

x

Artificial evolution

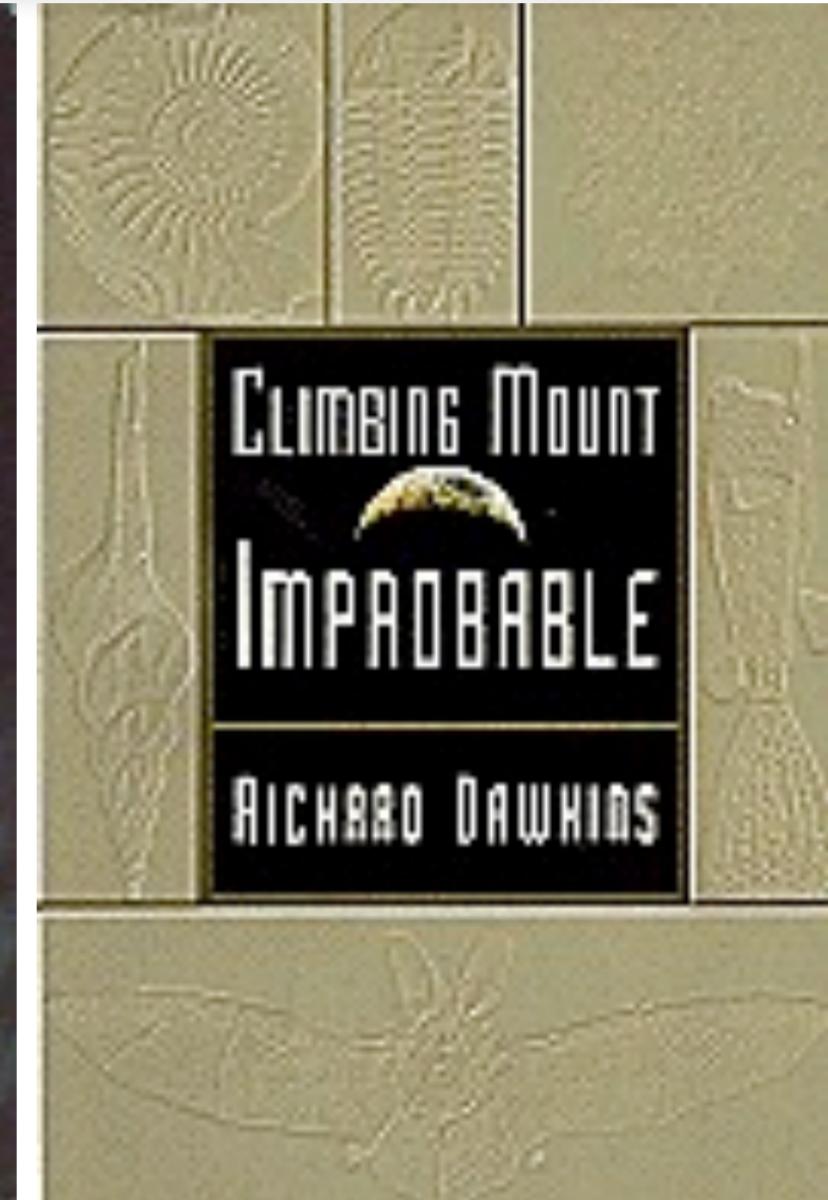
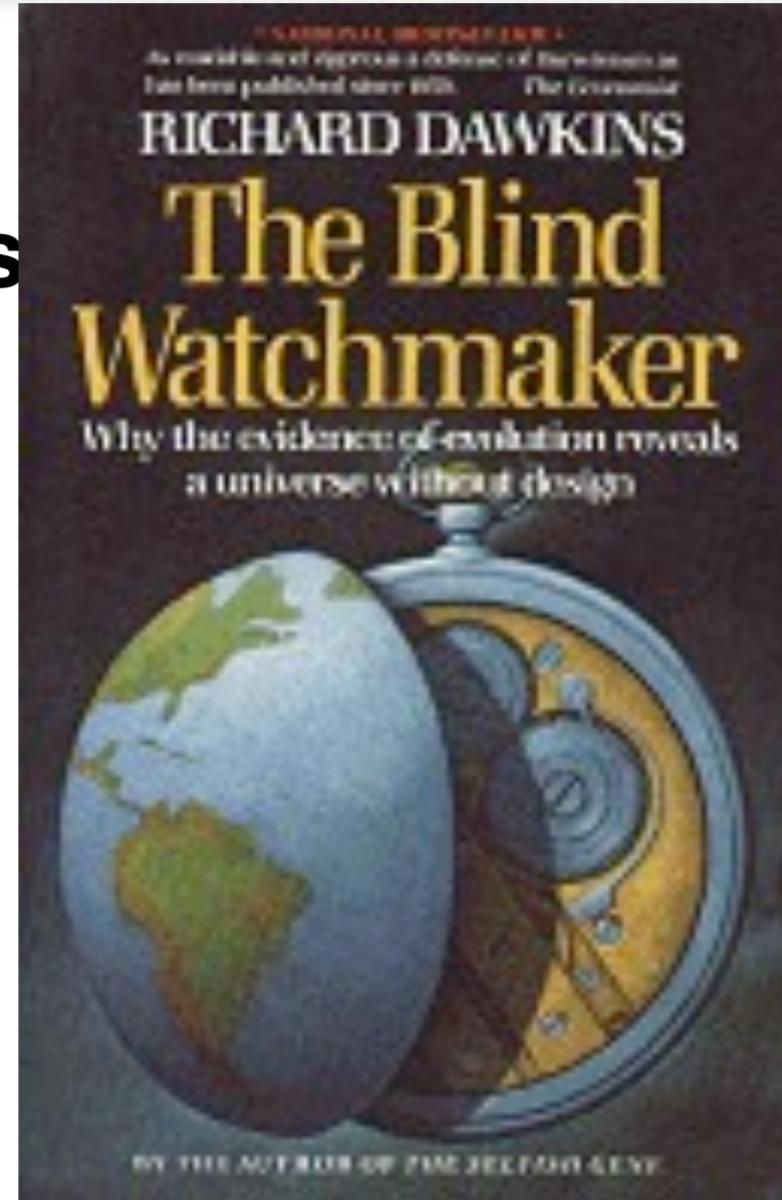
- John Holland
- Ingo Rechenberg
- John Koza

Artificial evolution

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

Cumulative selection

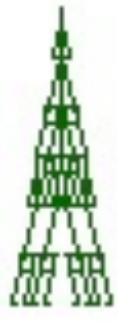
Richard Dawkins
(author of “The selfish gene”)



Watch out!!

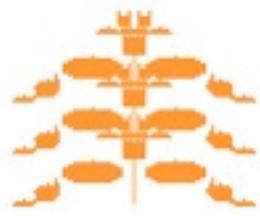
the creationists!?!?

**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/>

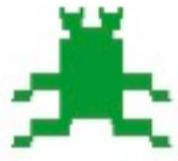
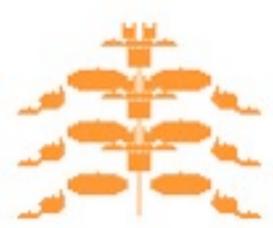
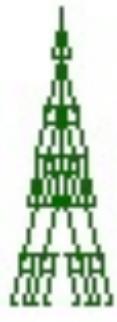
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encoding “creature” in genome (string of numbers): **genotype**

expression of “genes”: **phenotype**

esthetic selection designates the process by which a user selects an object that he “likes” and evolution proceeds from there)

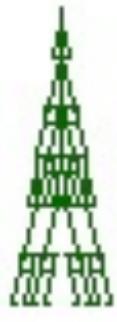


Biomorphs

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- encoding “creature” in genome (string of numbers):
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- “reproduction” (with mutation)

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



Biomorphs

The power of esthetic selection



- encoding “creature” in genome (string of numbers):

- expression of “genes” (graphical appearance):

Please study the “Blind Watchmaker Applet”

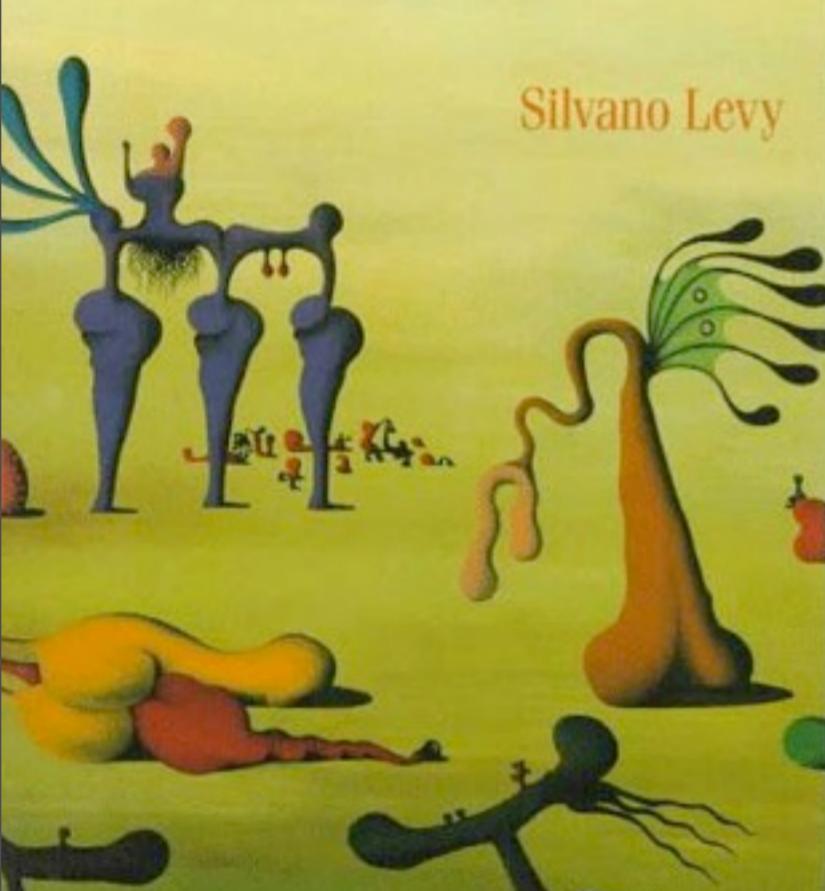
esthetic appeal)

- “reproduction” (with mutation)

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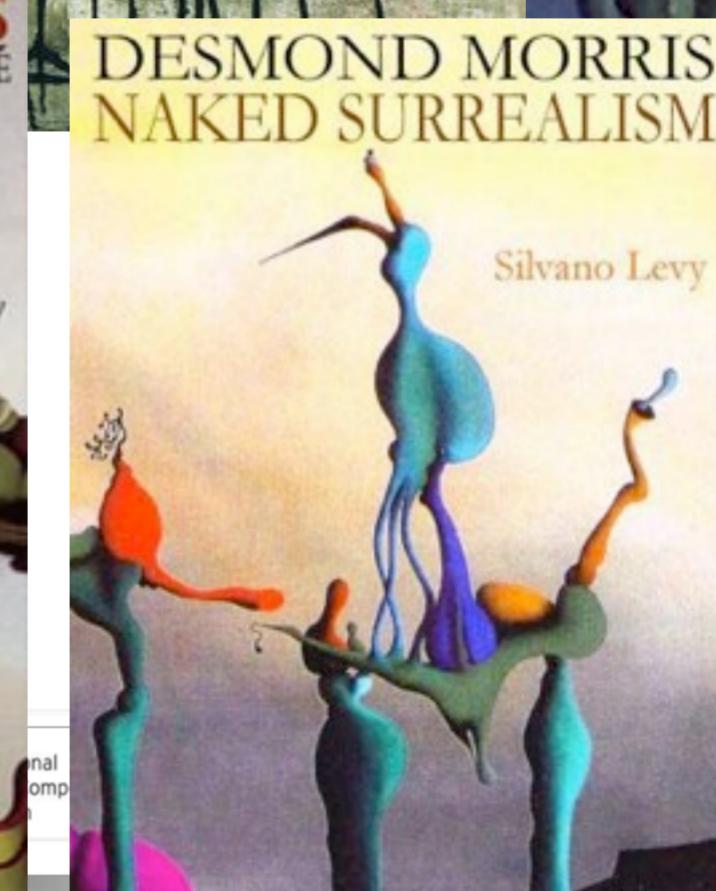
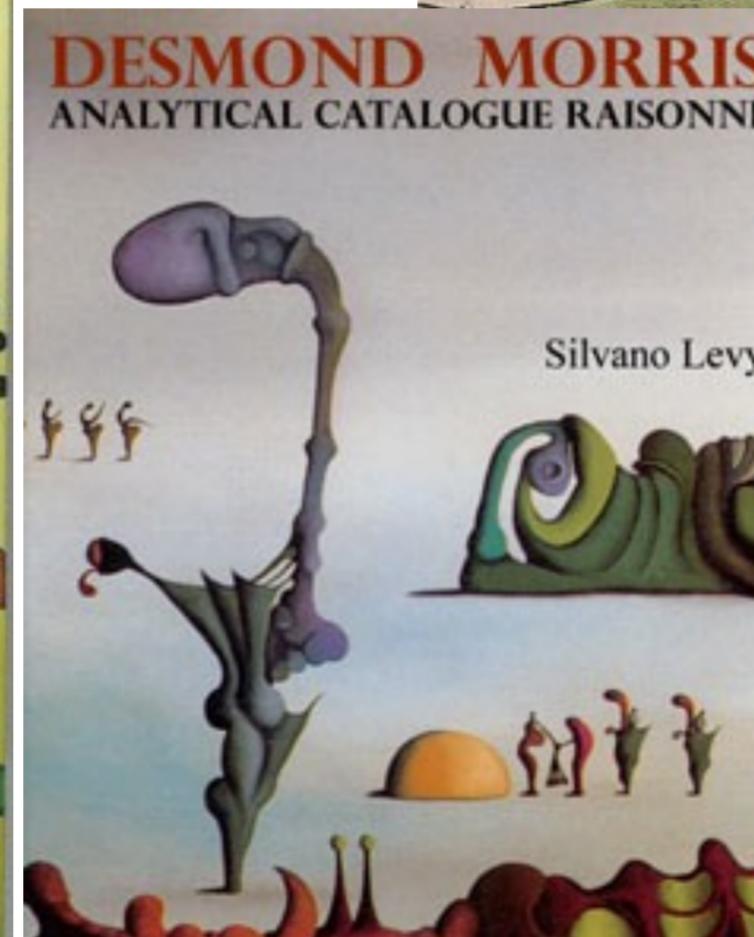
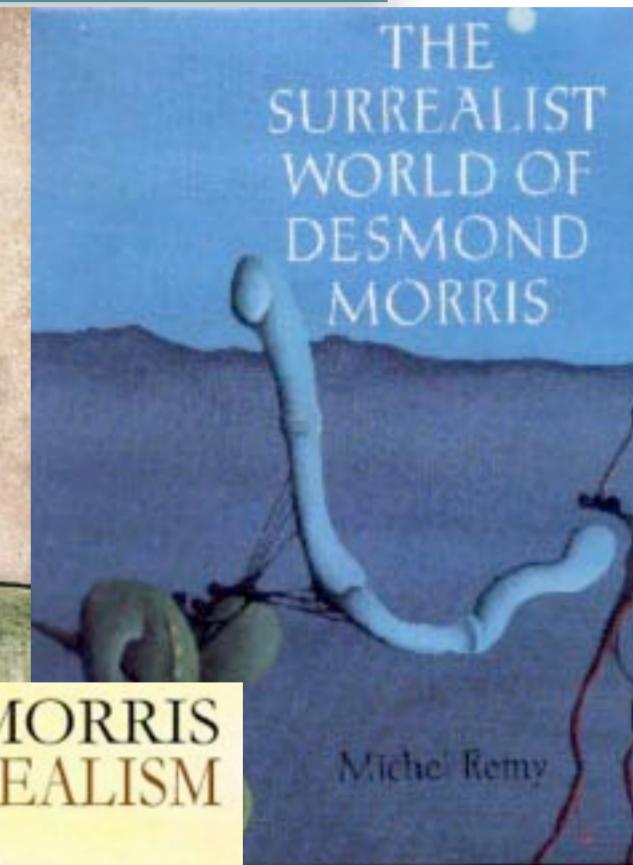
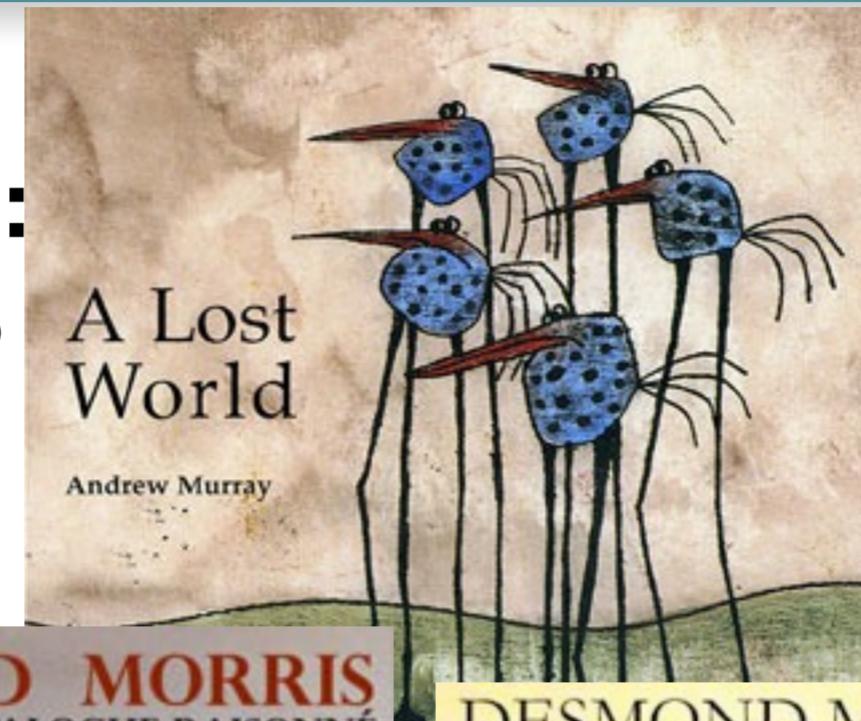


DESMOND MORRIS
50 YEARS OF SURREALISM



Biomorphs: by surrealist painter Desmond Morris

exhibitions:
1948 - 2008

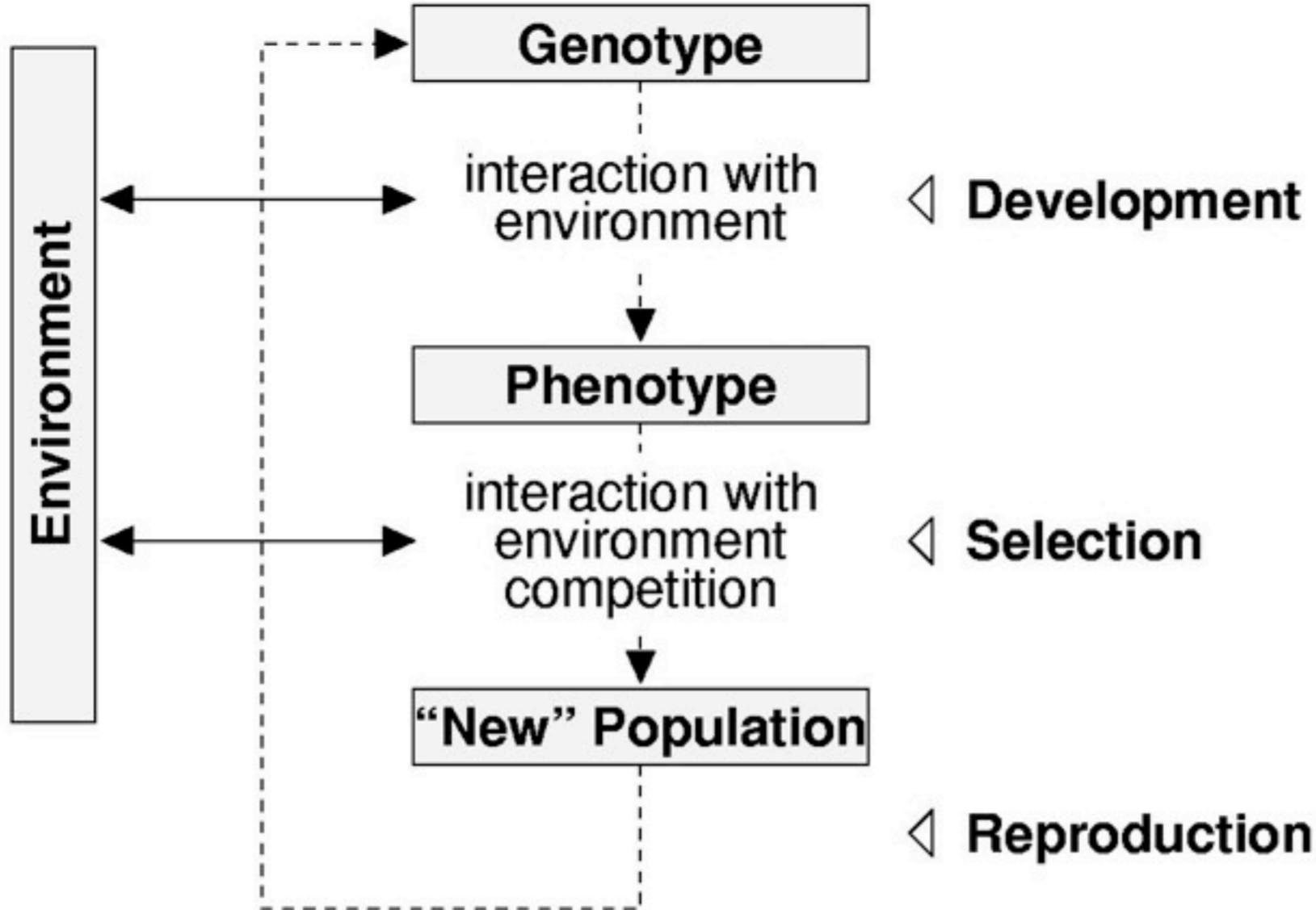


Biomorphs

Encoding in genome

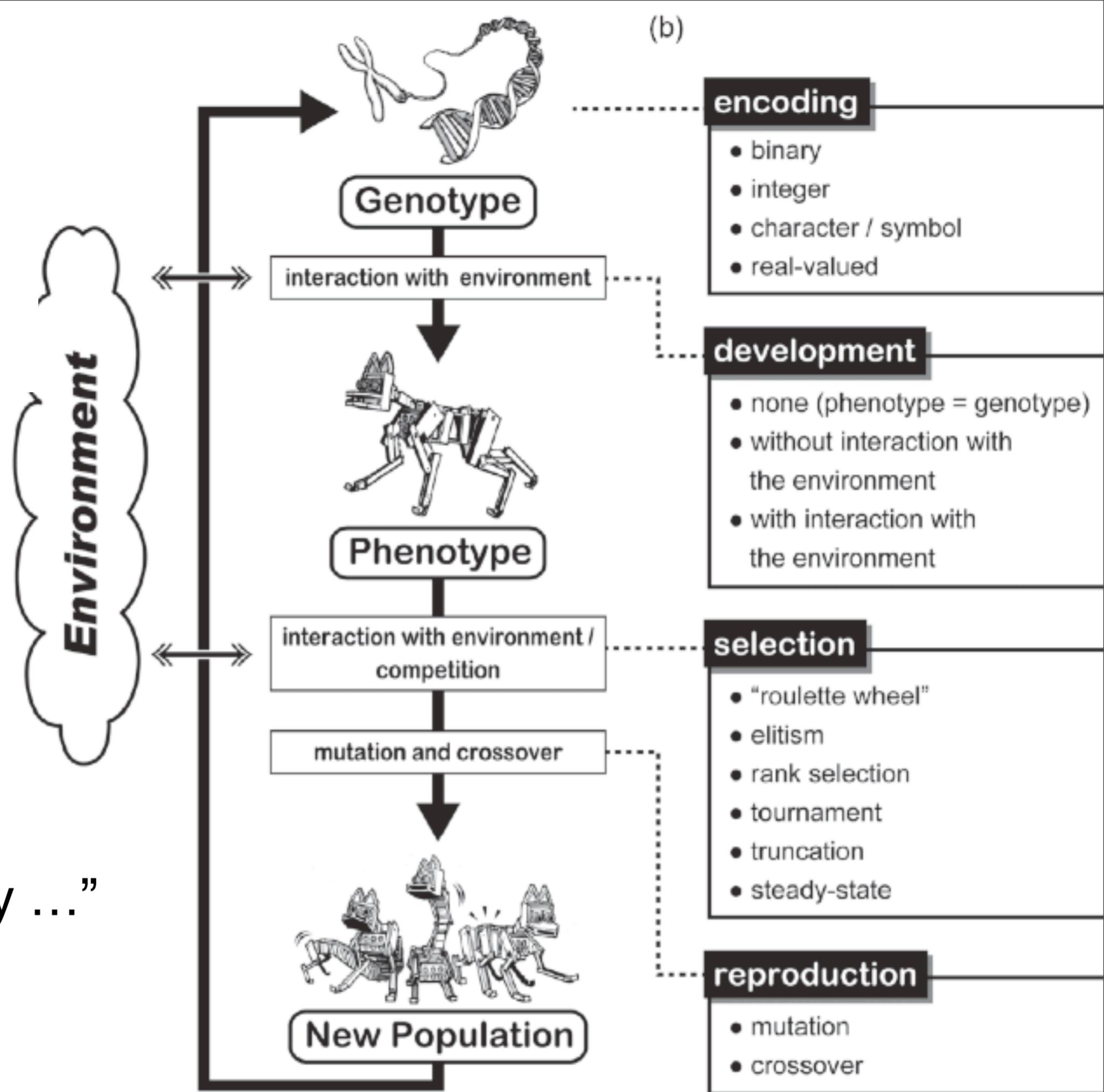
- “genes” 1-8: control of overall shape (direction, length of attachment)
- “gene” 9: depth of recursion
- “genes” 10-12: color
- “gene” 13: number of segmentations
- “gene” 14: size of separation of segments
- “gene” 15: shape for drawing (line, oval, rectangle, etc.)

The “grand evolutionary scheme”



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

Basic cycle for artificial evolution

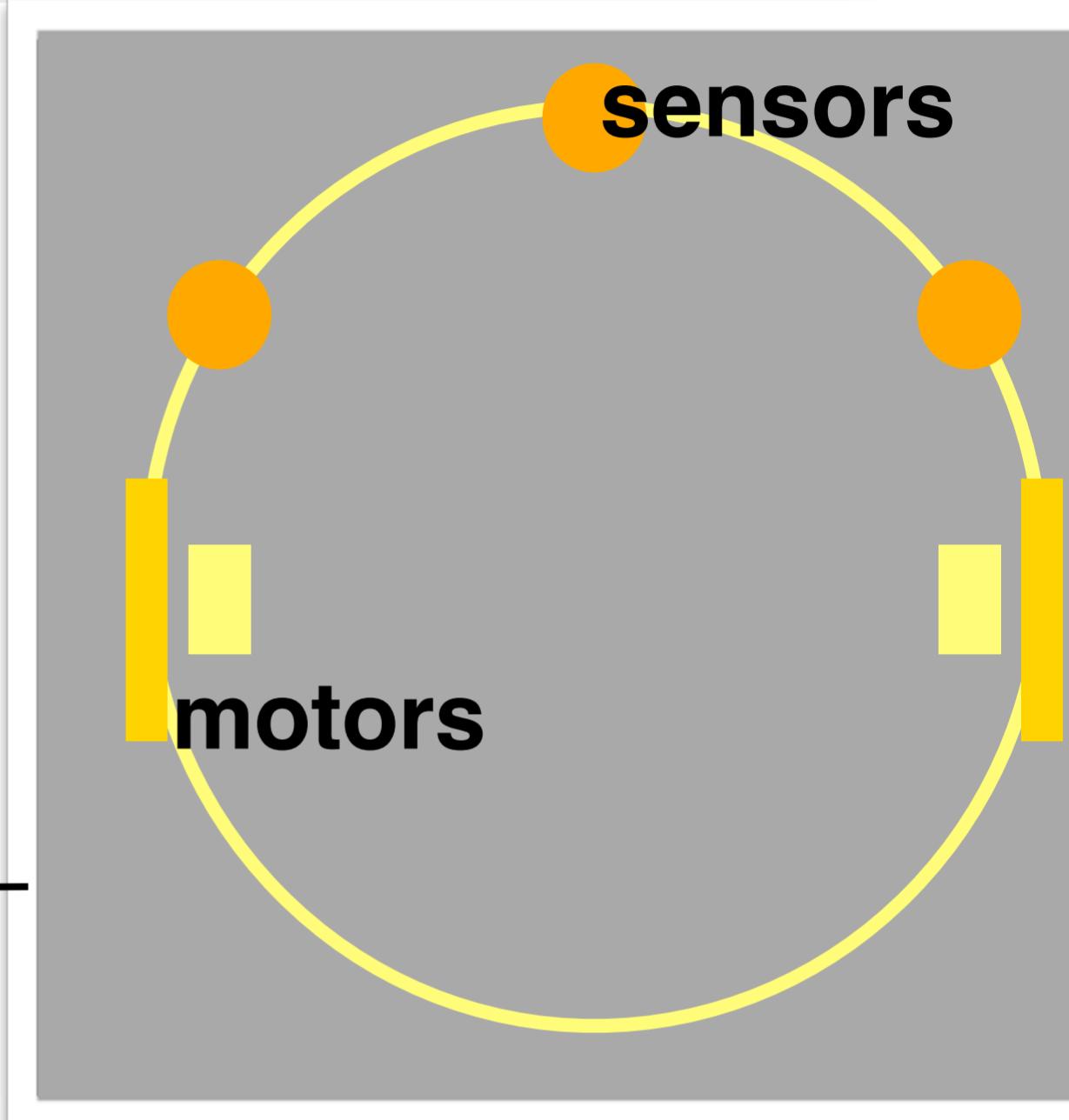


from
“How the body ...”



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Evolving a neural controller



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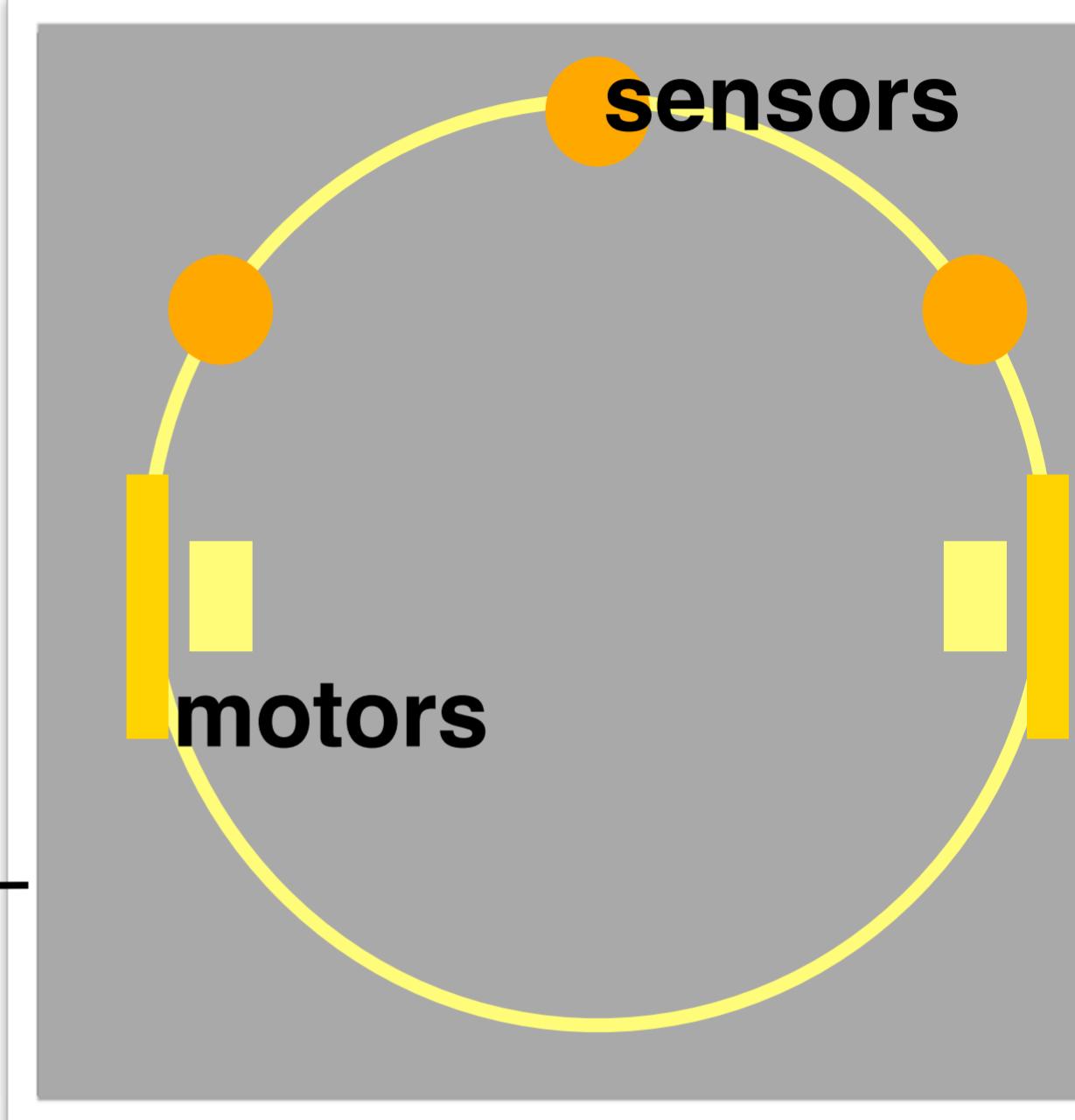
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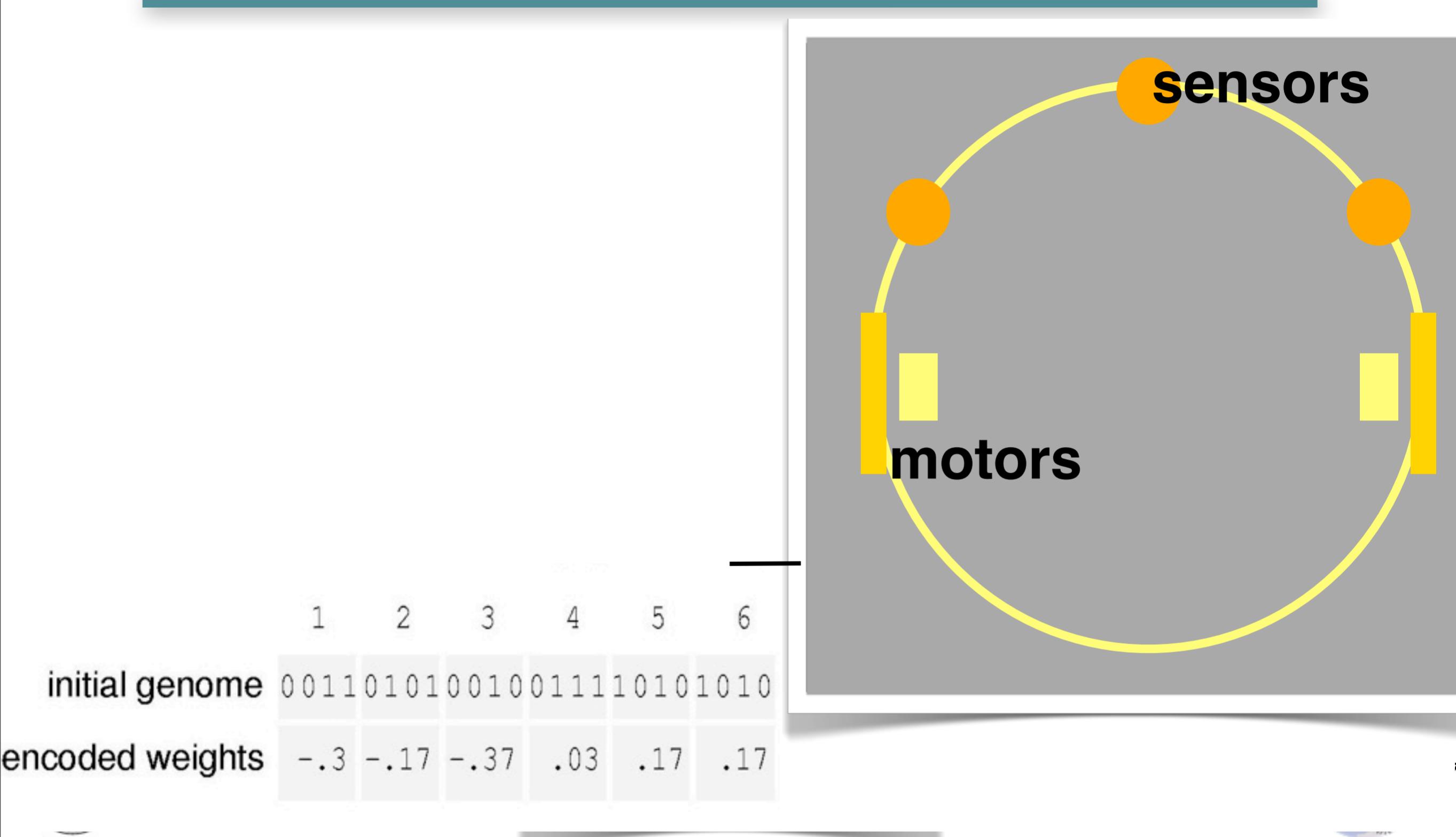
Evolving a neural controller

What do we need to specify?
→
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.

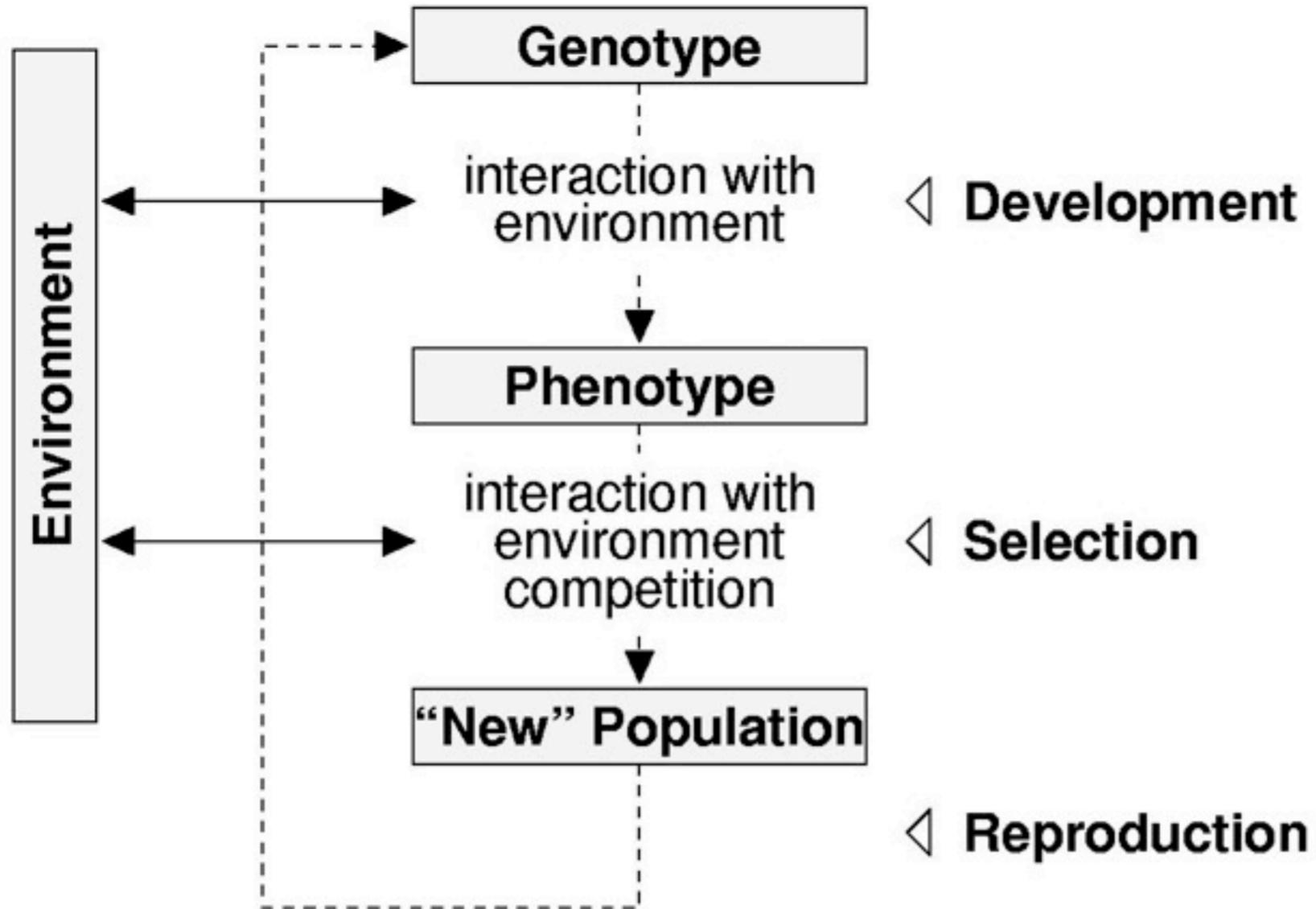
Encoding in genome



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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”



encoding	development	selection	reproduction
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Fitness function and selection

suggestions?

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

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Fitness function: two components

1. speed → positive
2. collisions → negative

crossover point

001101||010010011110101010

crossover point

101010||110000100111011100

reproduction:
**crossover and
mutation**

001101110000100111011100

10101001001001110101010

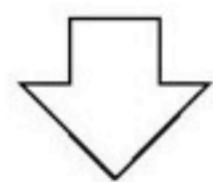
mutation

001101110000100111011100

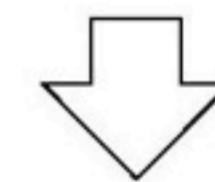
10101001001001110101010

001101110010100111011100

10101001001001110101010



gene expression



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

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

Approaches to evolutionary robotics

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

embodied approach:

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

Evolving morphology and control: Karl Sims's creatures



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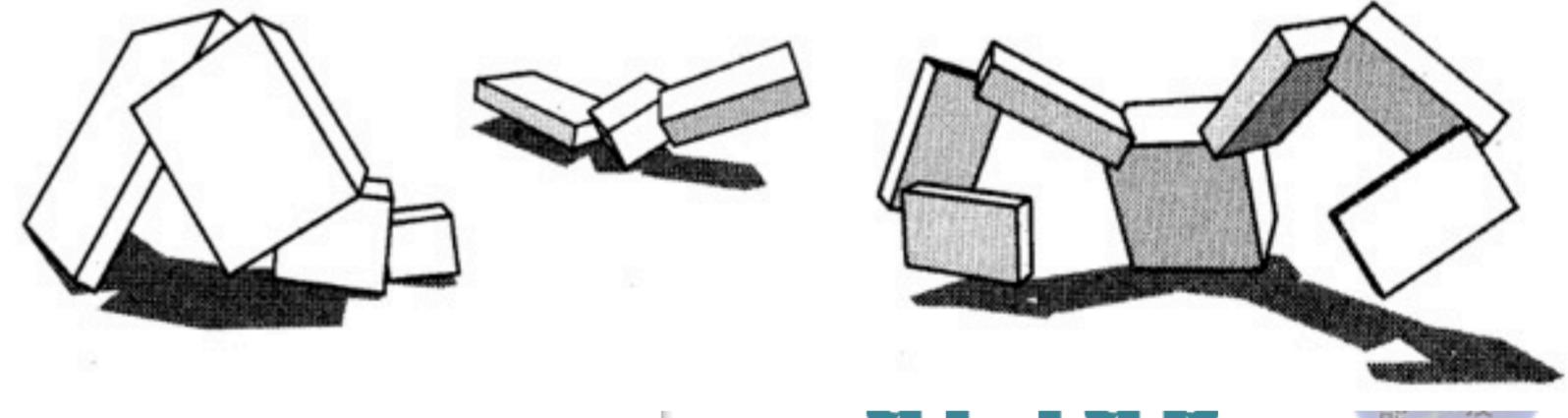
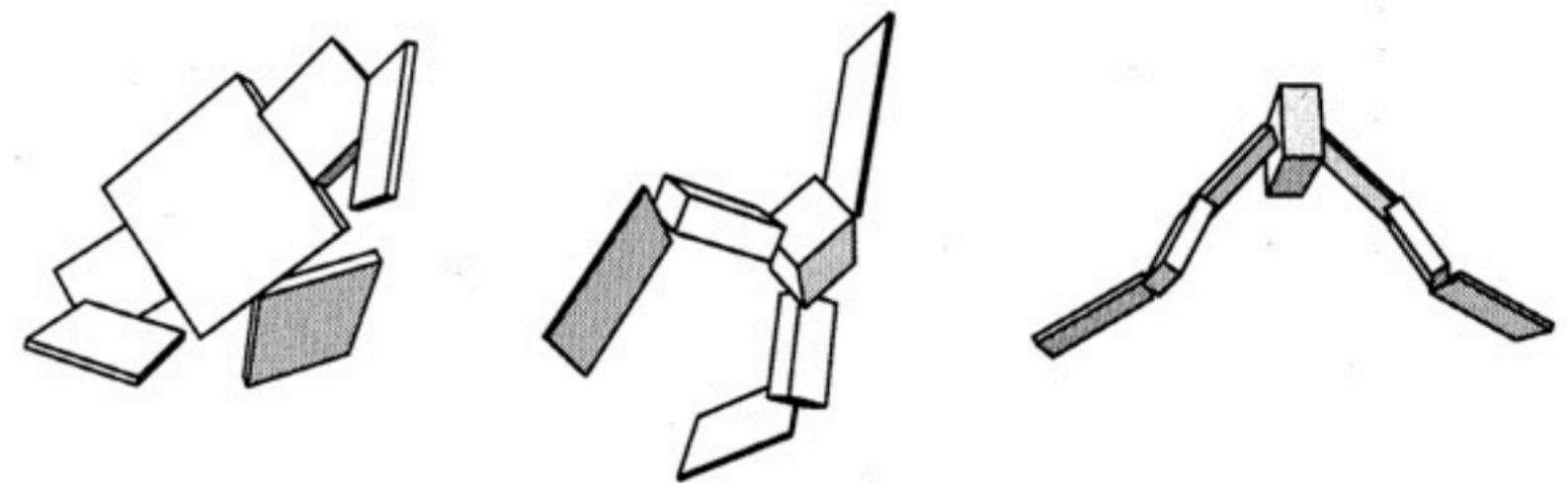
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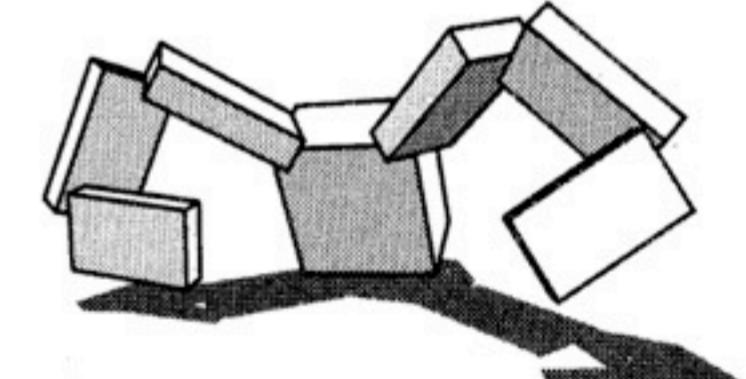
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Evolving morphology and control: Karl Sims's creatures

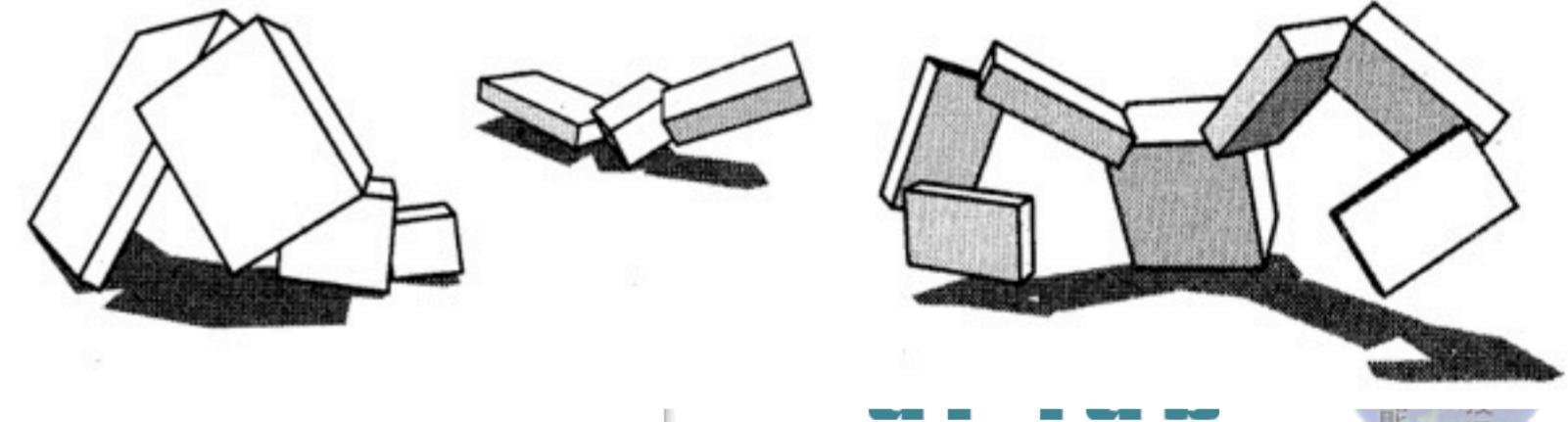
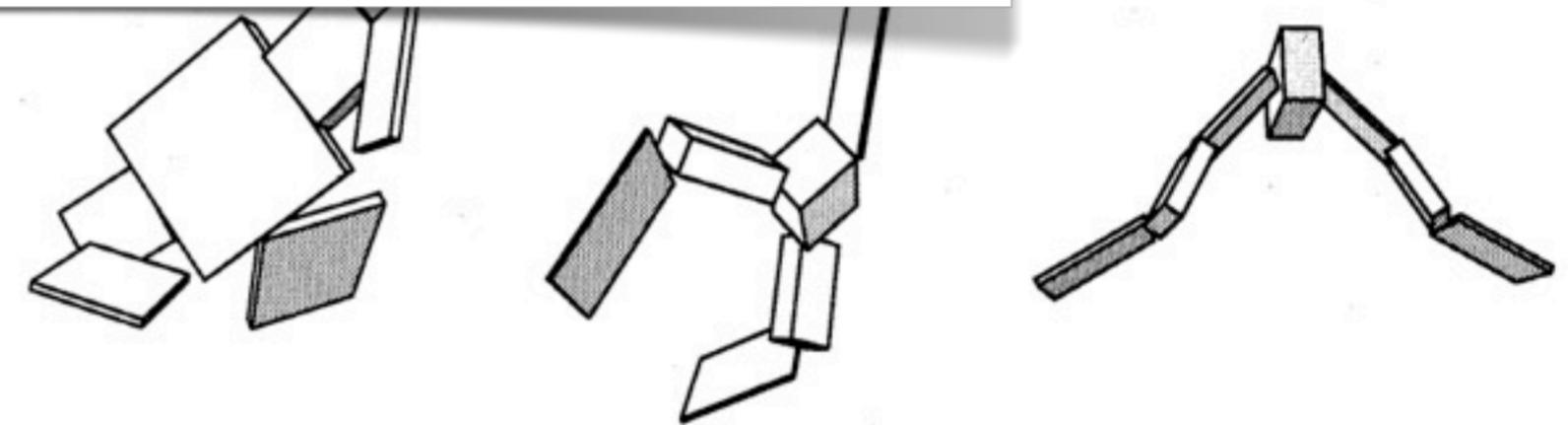


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Evolving morphology and control: Karl Sims's creatures

Please watch: “Karl Sims’s evolved creatures”



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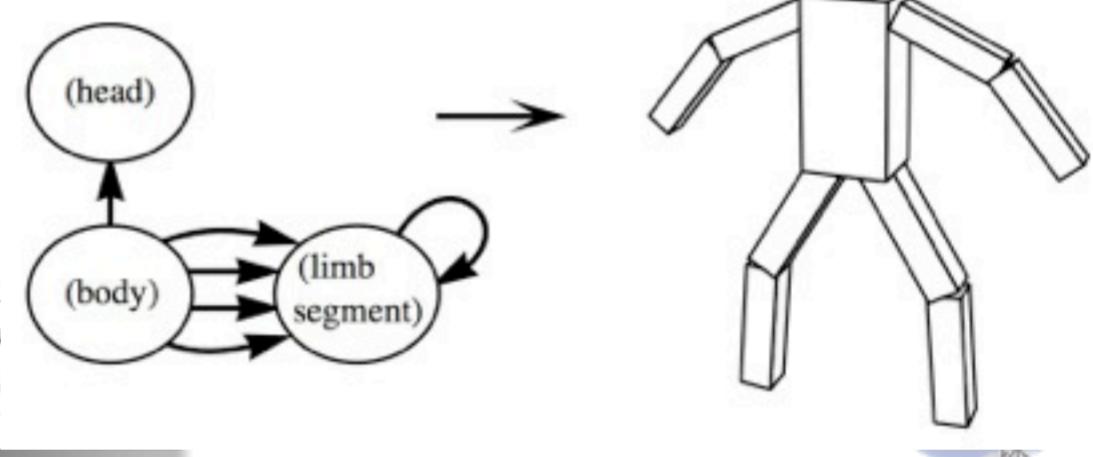
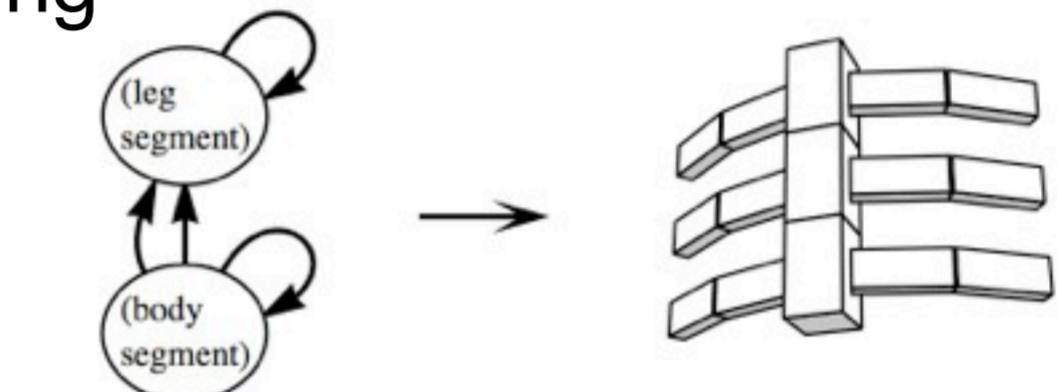
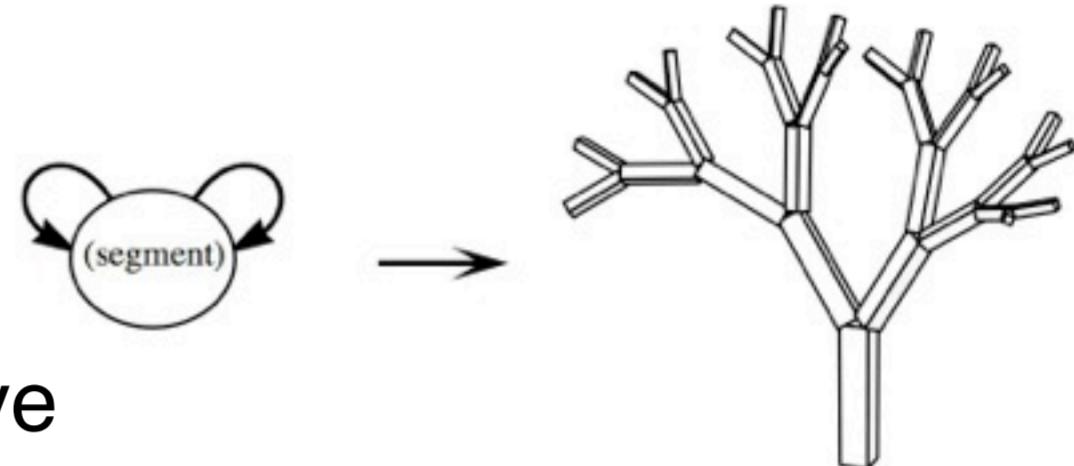
Parameterization of morphology

encoding in
genome
“genotype”

development

embodied
agent
“phenotype”

recursive
encoding



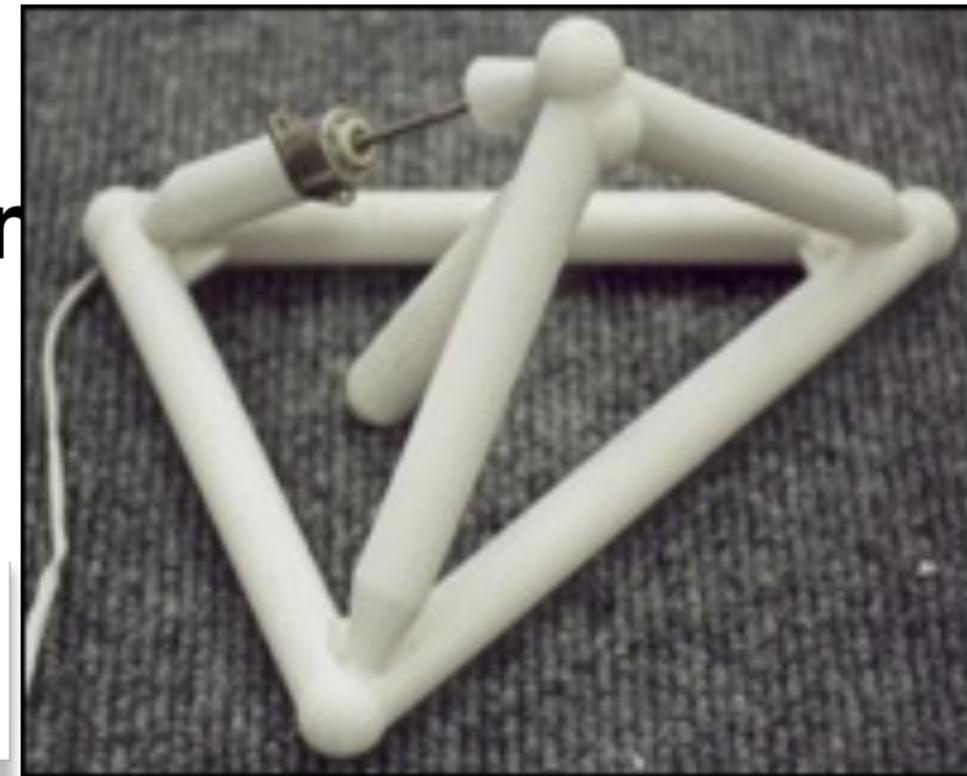
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New version: Golem (Lipson and Pollack)

representation of morphology in genome

- **robot: bars, actuators, neurons**
- **bars: length, diameter, stiffness, joint type**
- **actuators: type, range**
- **neurons: thresholds, synaptic strength (recursive encoding)**



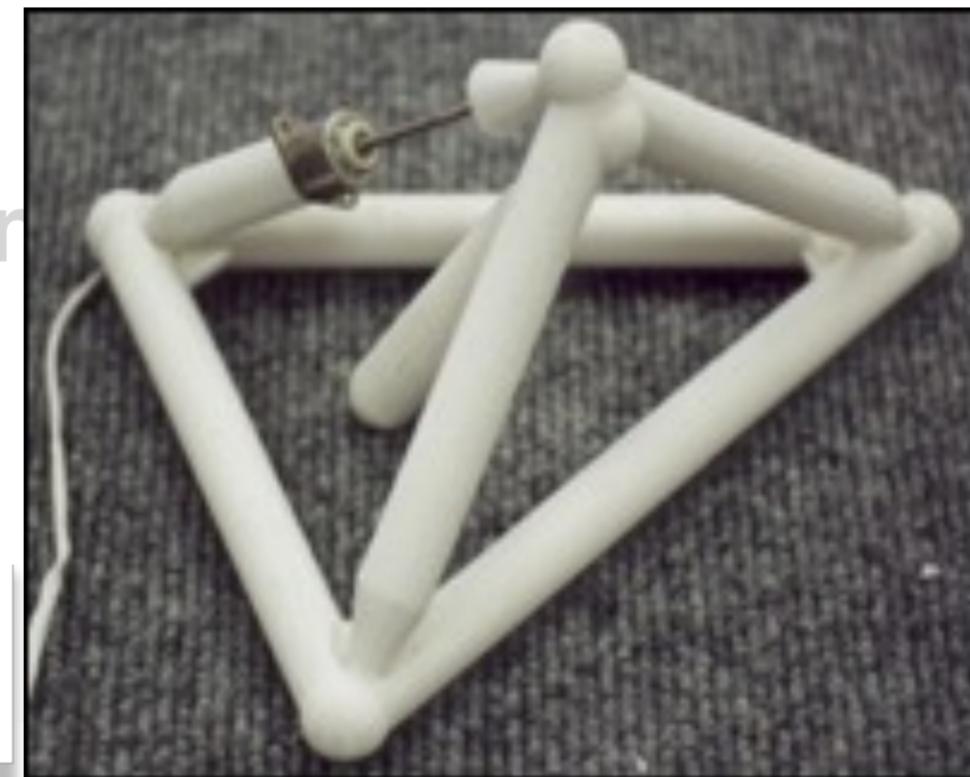
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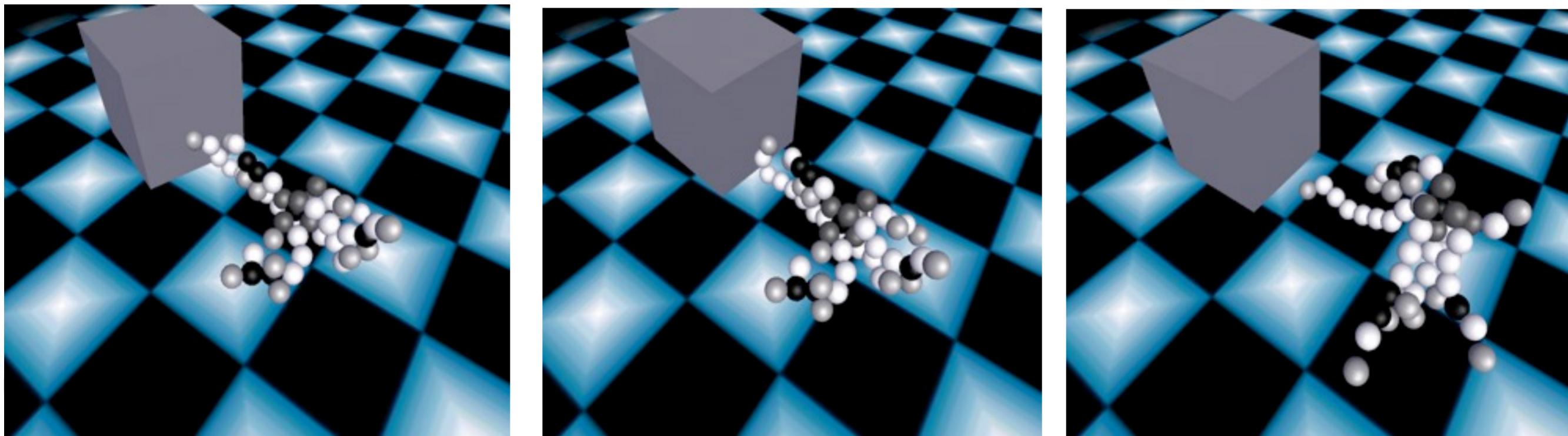
Golem as the first self-evolving joint type machine in history!

- actuators: type, range
- neurons: thresholds, synaptic strength
(recursive encoding)

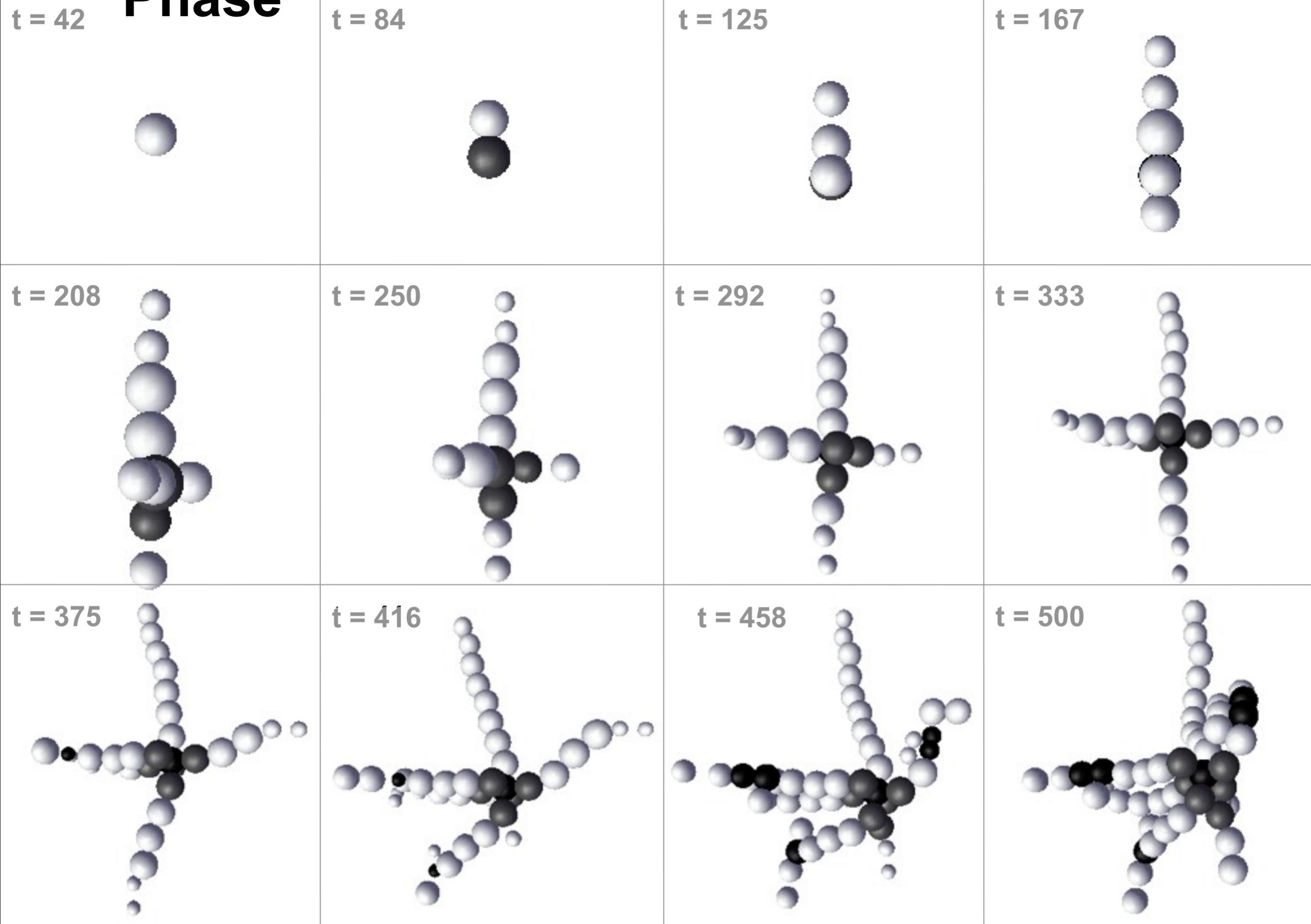


Genetic Regulatory Networks (GRNs): Bongard’s “block

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



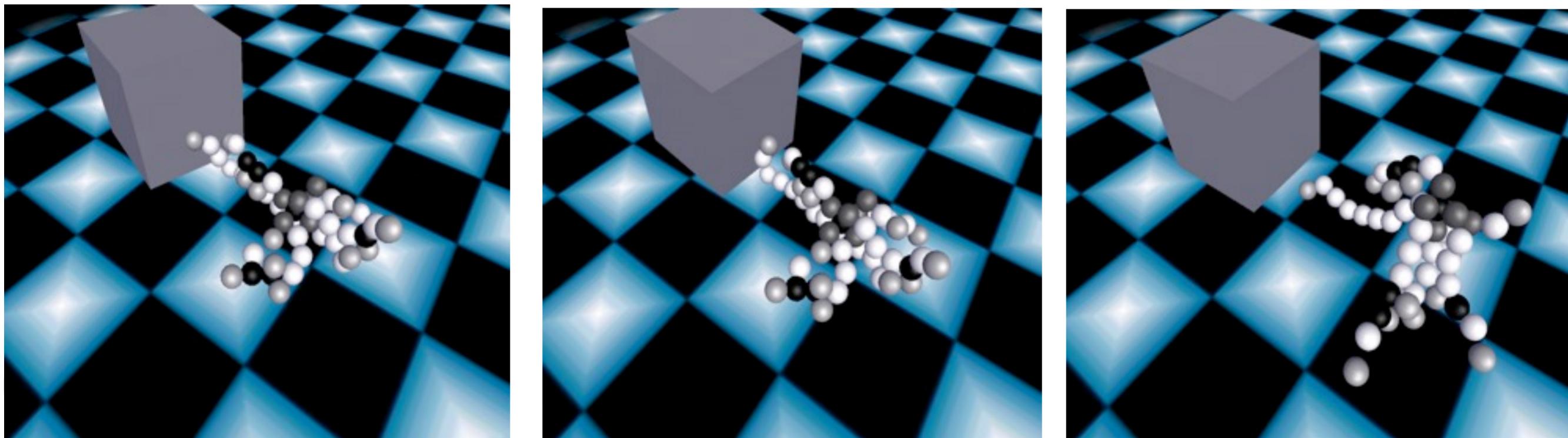
The Growth Phase



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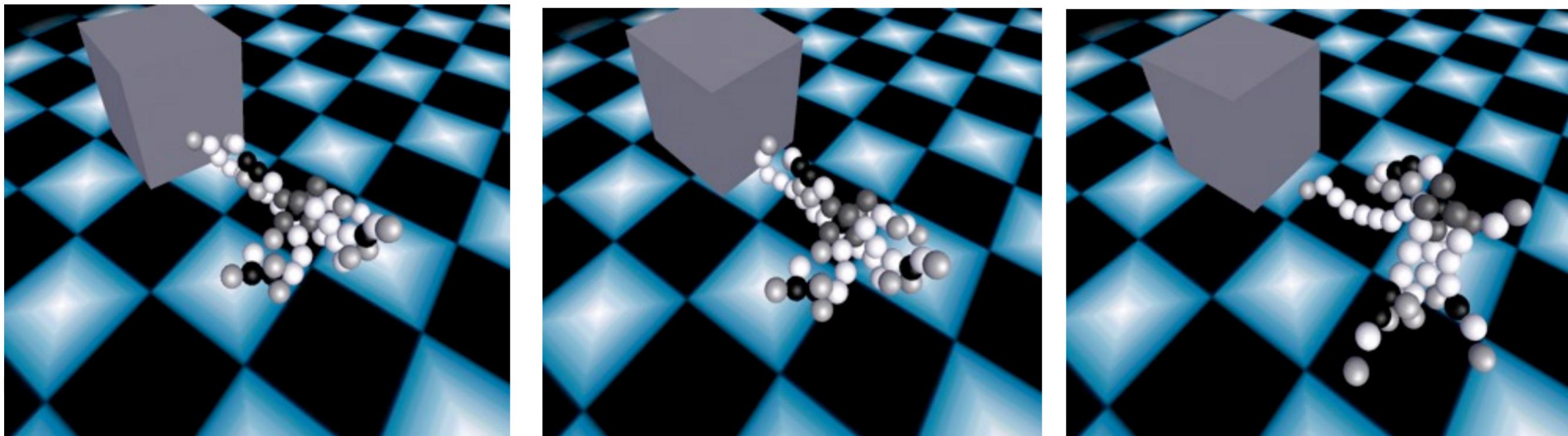
Evolution of a “block pusher” (“Artificial Ontogeny”)

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



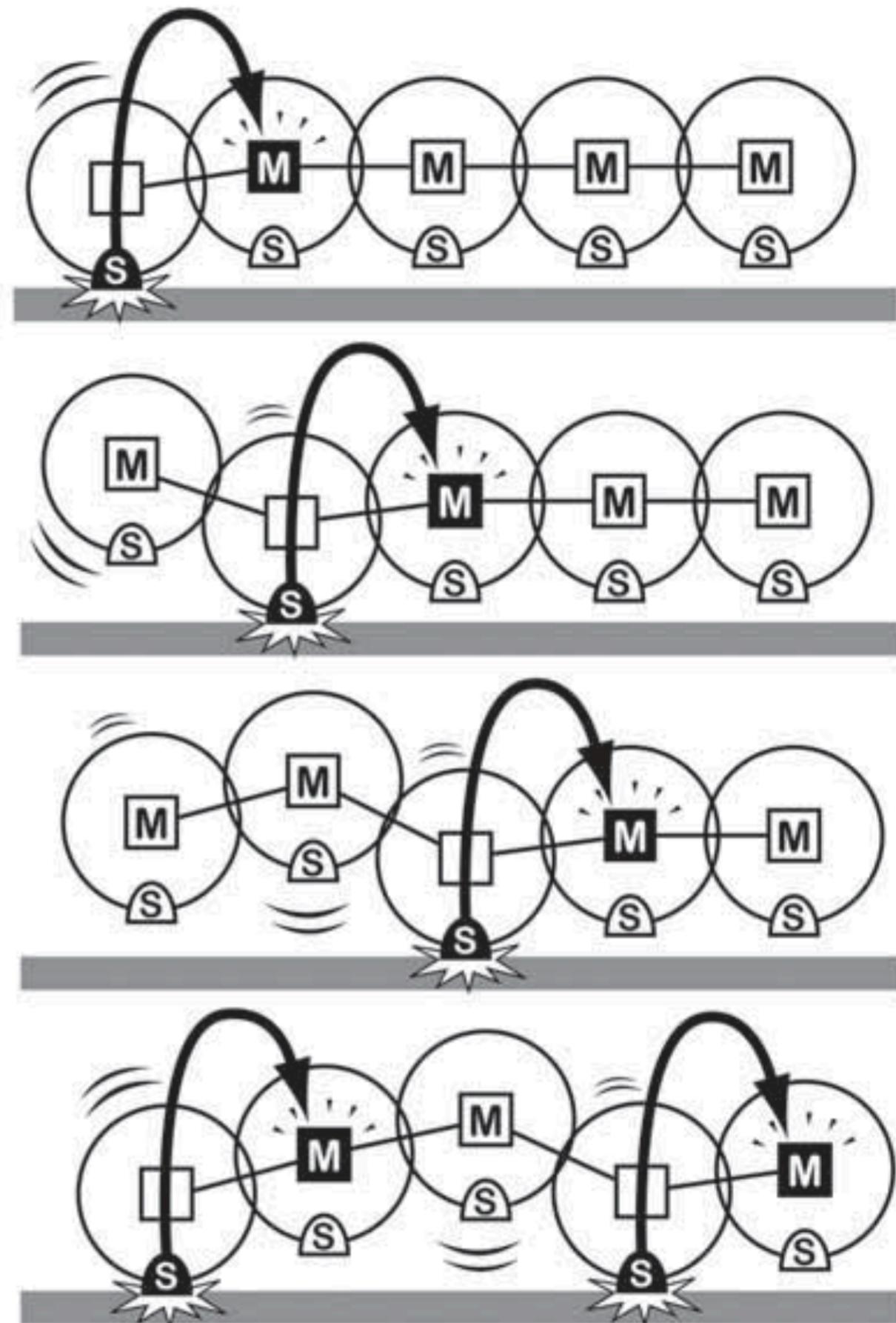
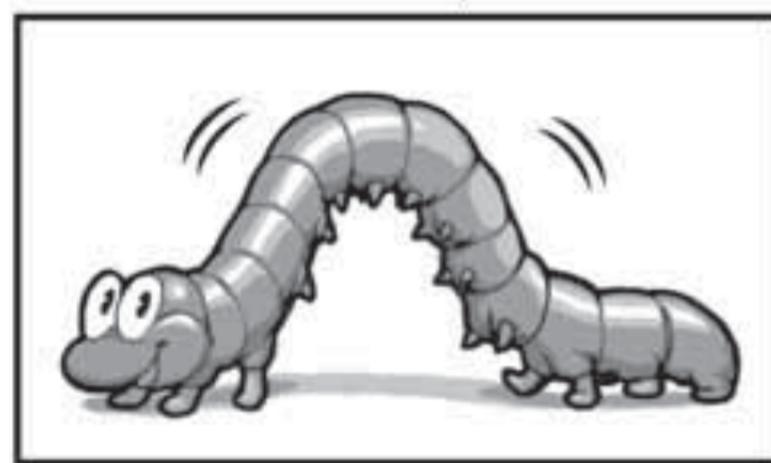
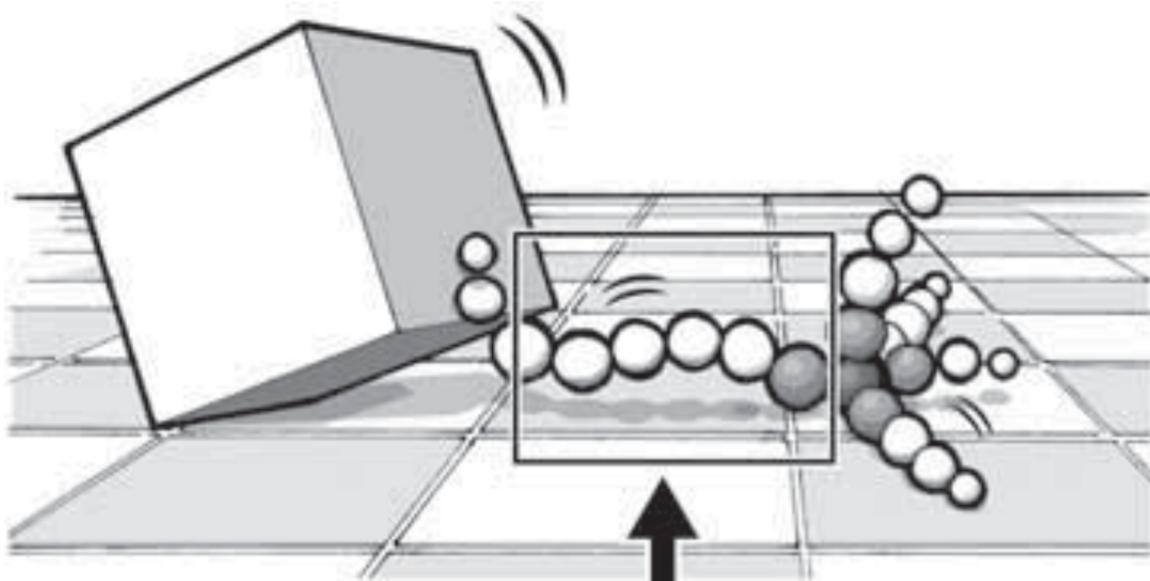
Evolution of a “block pusher” (“Artificial Ontogeny”)

- development (morphogenesis) embedded
- Video “Evolution of block pushers”
- testing of phenotypes in physically realistic simulation



Inchword method of locomotion

S: sensor , M: motor



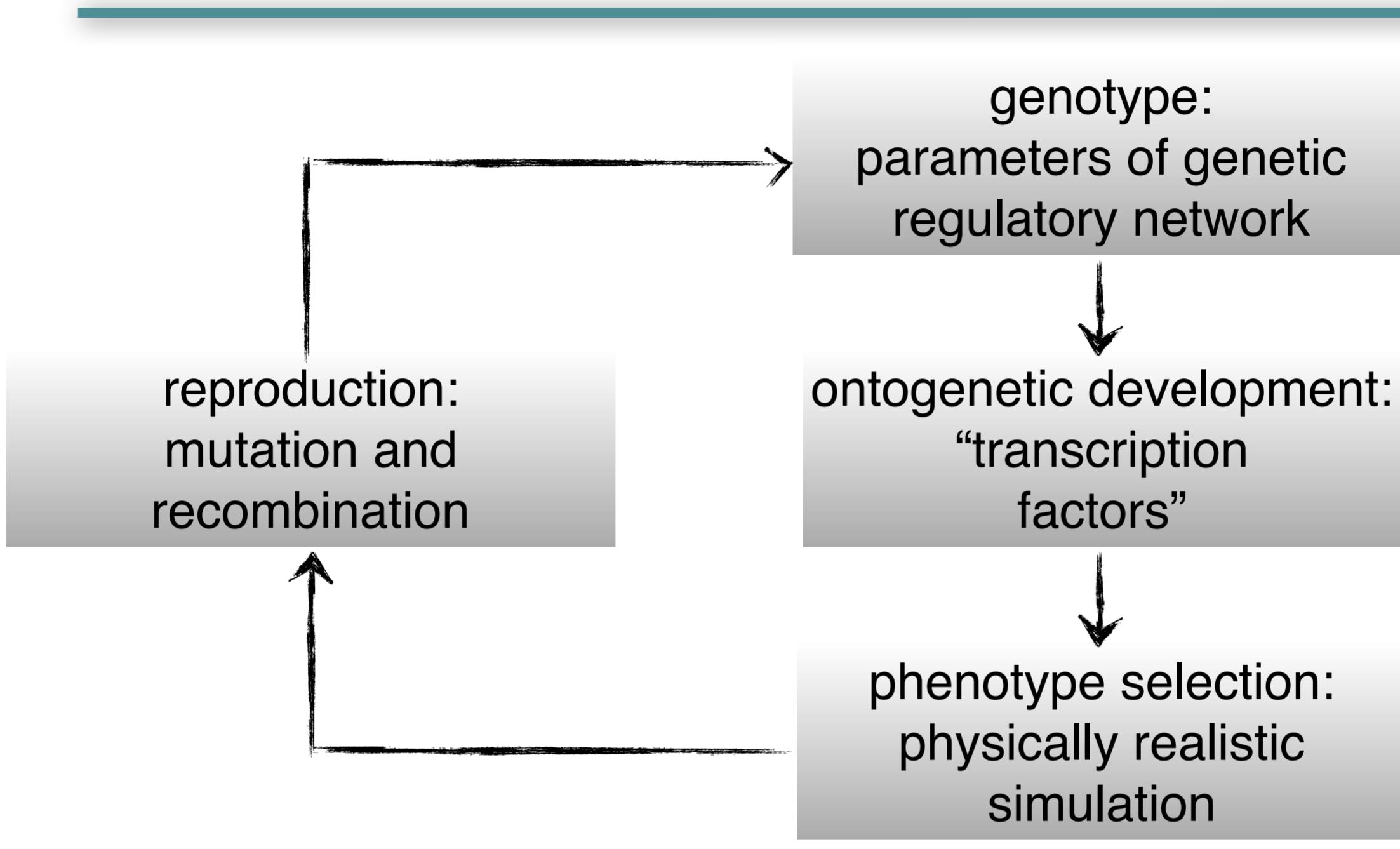
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robotics+

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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



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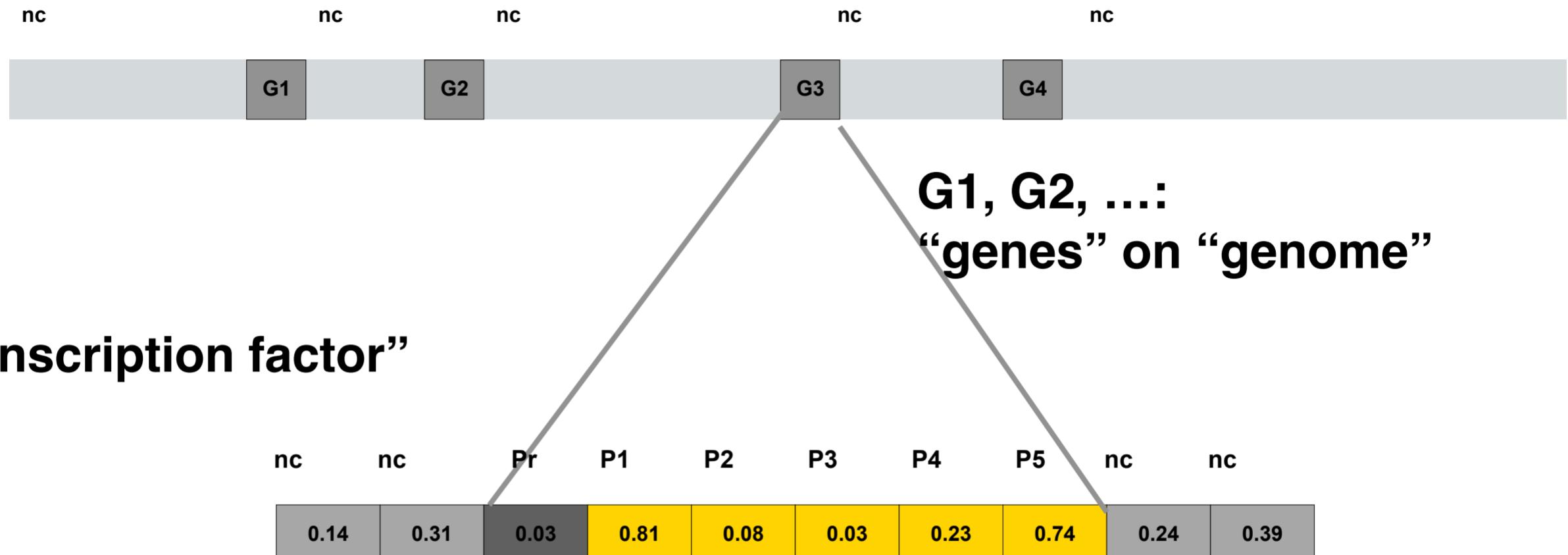
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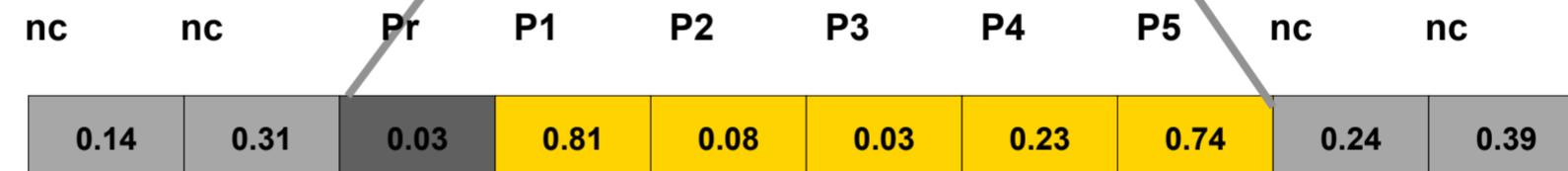
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Representation of “gene”

nc: “non-coding region”



TF: “transcription factor”

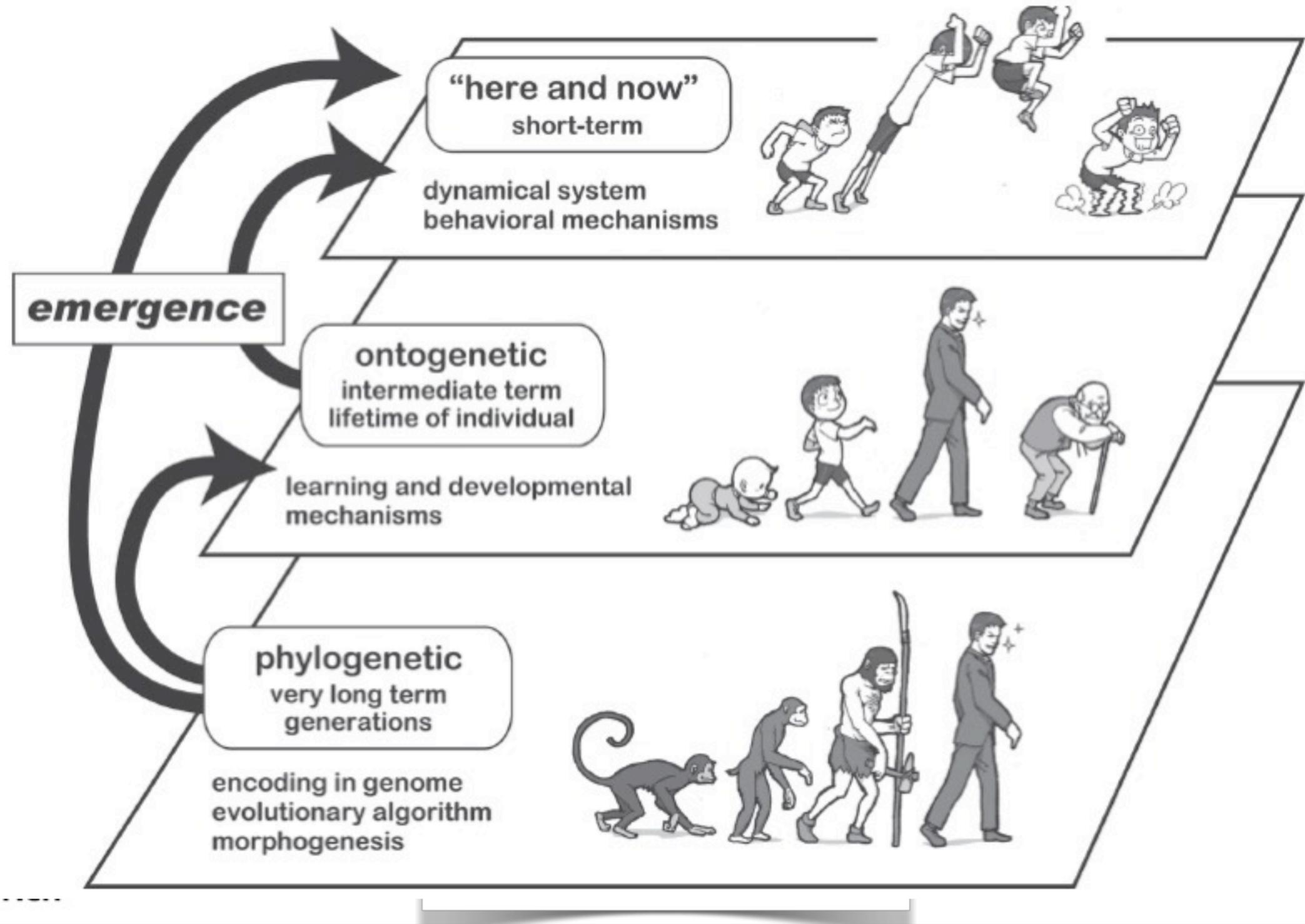


Details: see additional slide materials for self-study

P1	P2	P3	P4	P5
TF37	TF2	0.03	0.23	0.74

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



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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



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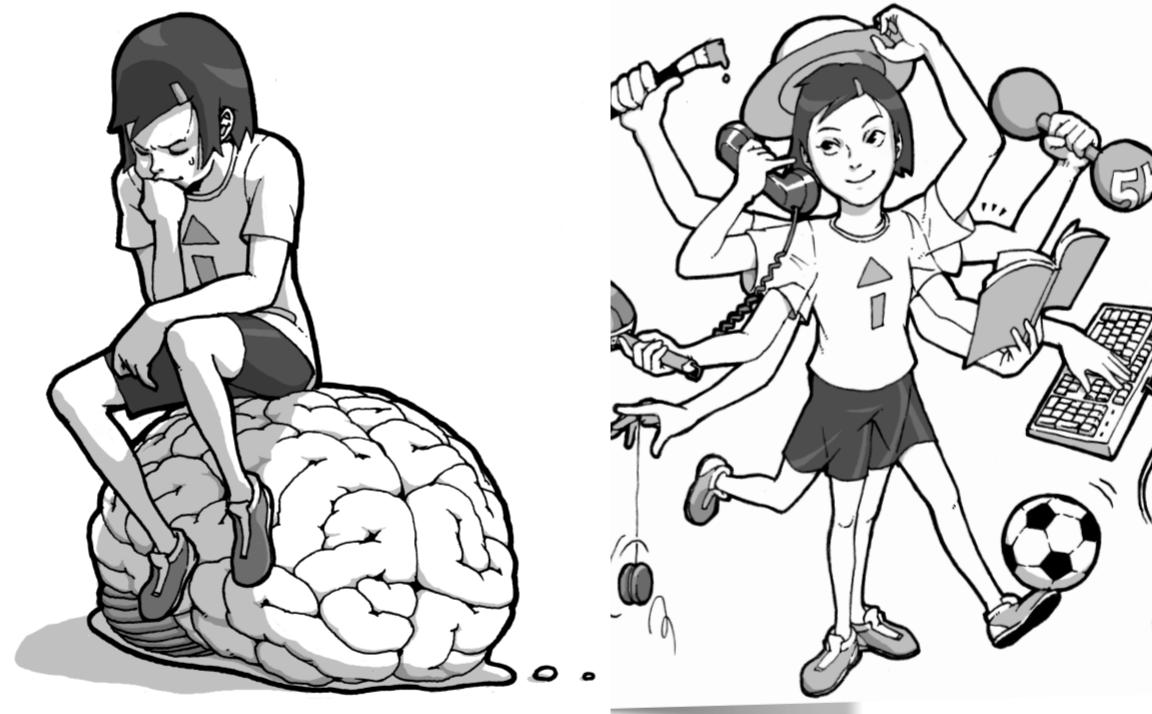
Please read the principles in chapter six of “How the body ...”

Assignments for next week

- **Read chapter 6 of “How the body ...”**
- **Additional slide materials for self-study**
- **Watch the Karl Sims video**
- **Assignment: “brain in a vact” - volunteers?**

End of lecture 7

Thank you for your attention!



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Additional slide materials for self-study



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Cumulative Selection: Example by Richard Dawkins

Monkey typing Shakespeare

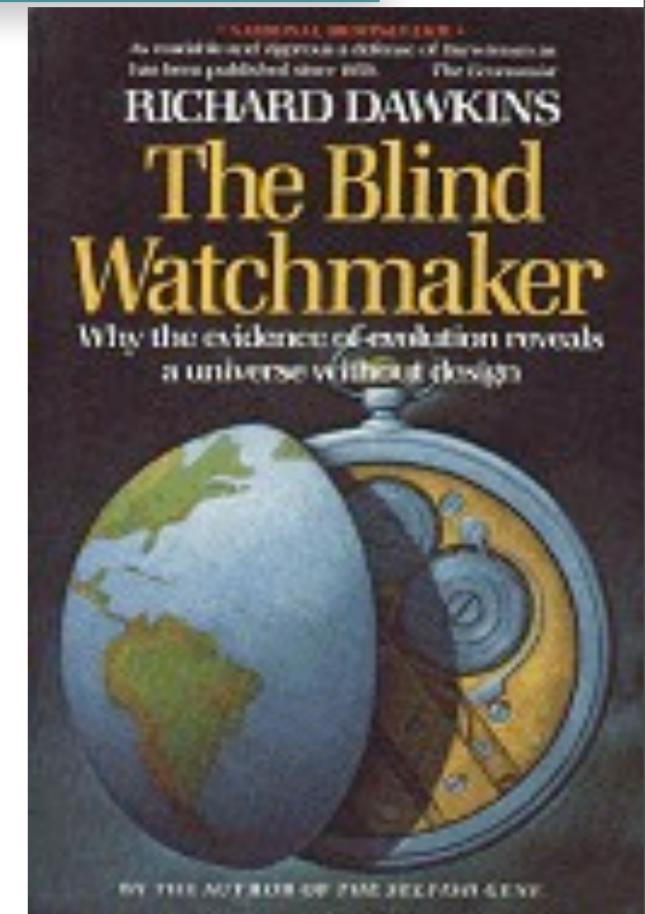
Hamlet: Do you see yonder cloud that's almost in shape of a camel?

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?



Imagine a monkey sitting in front of a keyboard 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?

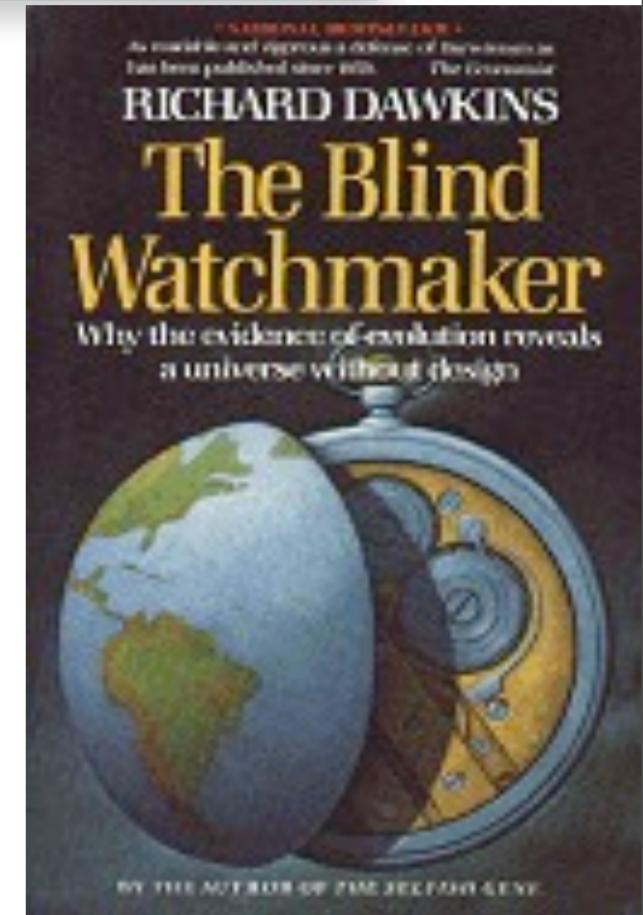
Polonius: By the mass, and 'tis like a camel, indeed.

Hamlet: Methinks it is like a weasel.

Polonius: It is backed like a weasel.

Hamlet: Or like a whale?

How many possible arrangements?



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’s 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 DTJB SWIRZREZLMQVOP	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



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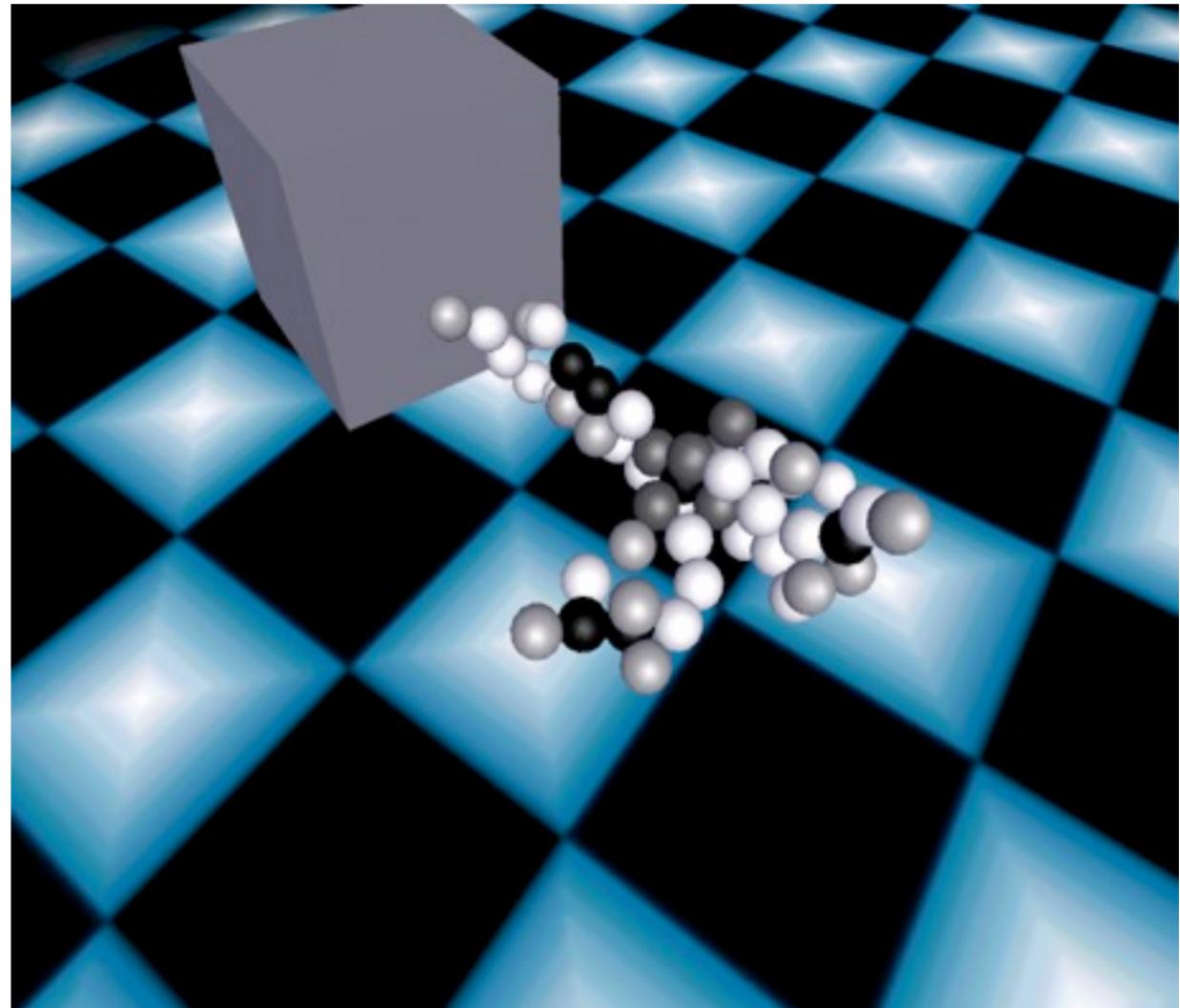


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try one of the applets on the net

Additional materials on Bongard's GRNs



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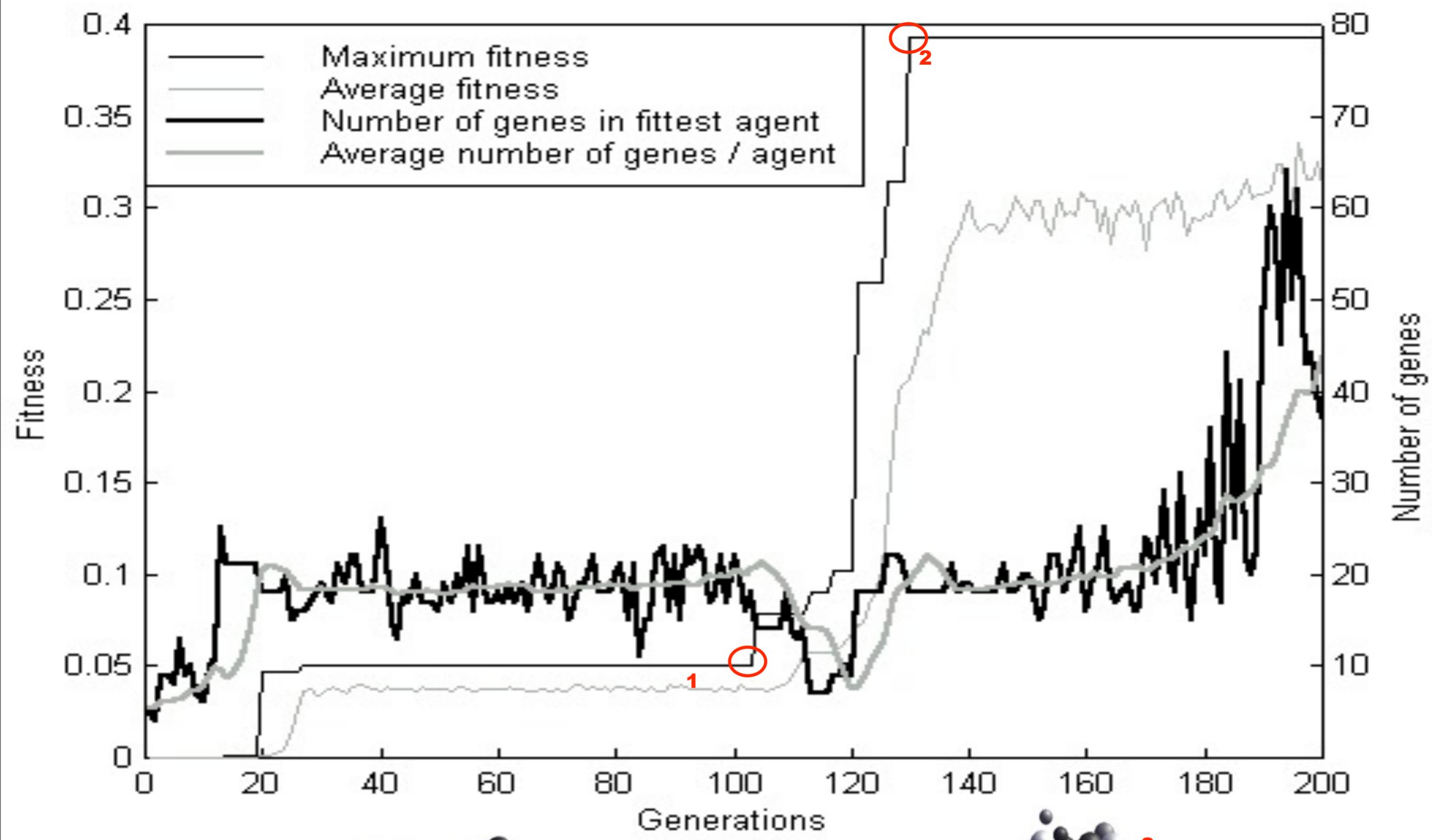
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Observations on Bongard’s “block pushers”

- **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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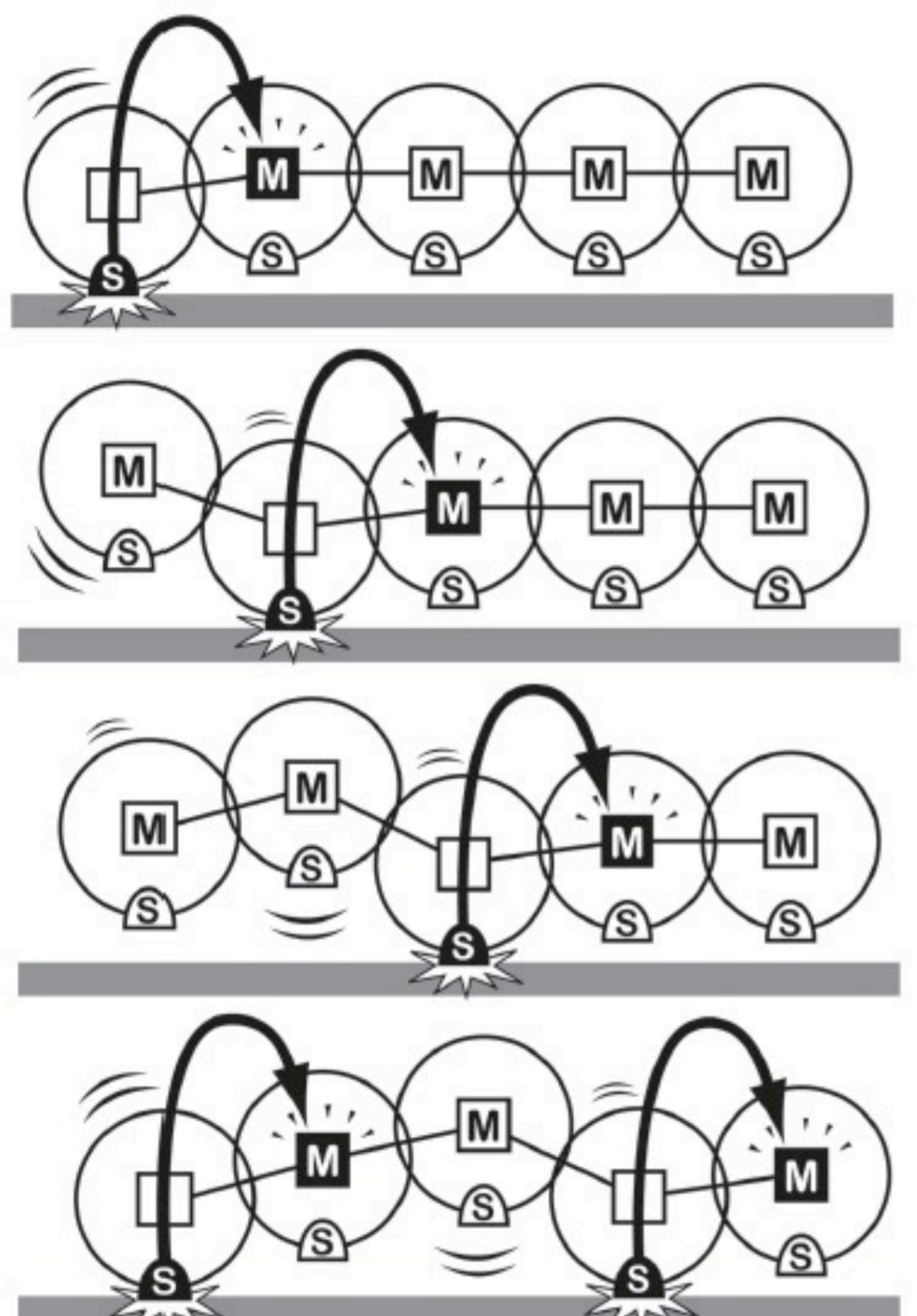


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(b)

S: sensor , M: motor

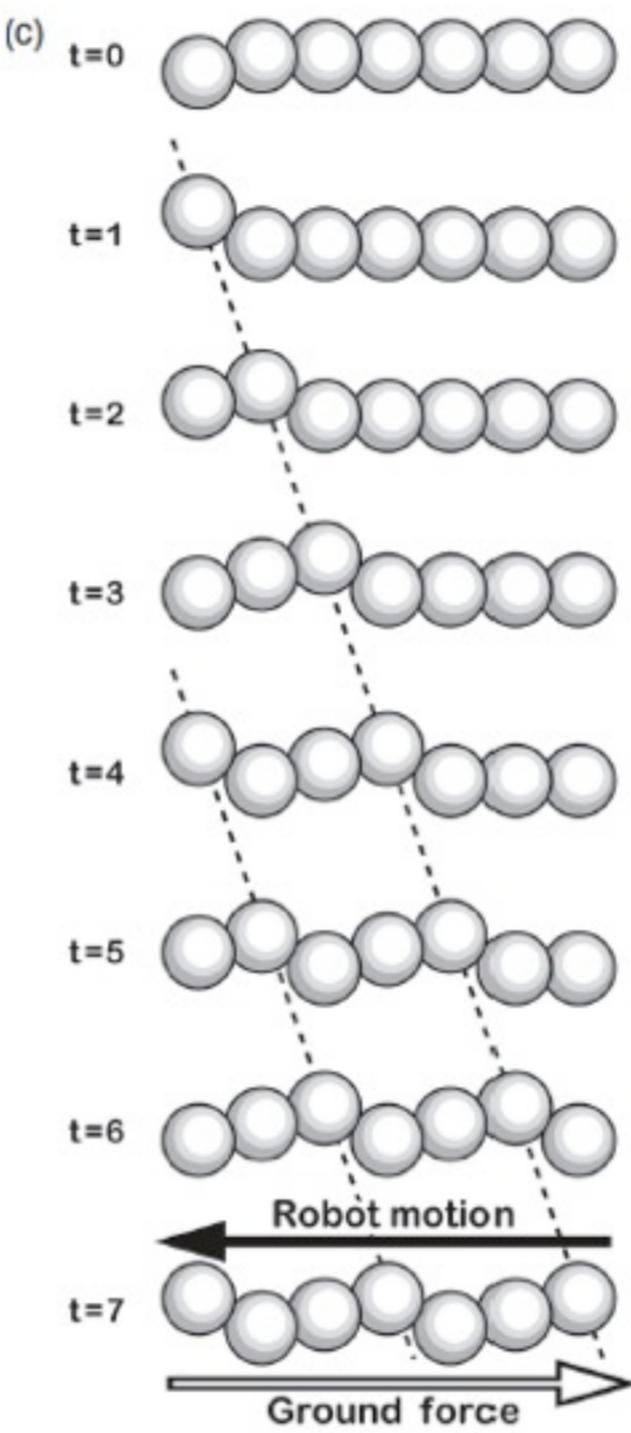


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Emergence of locomotion through local reflexes

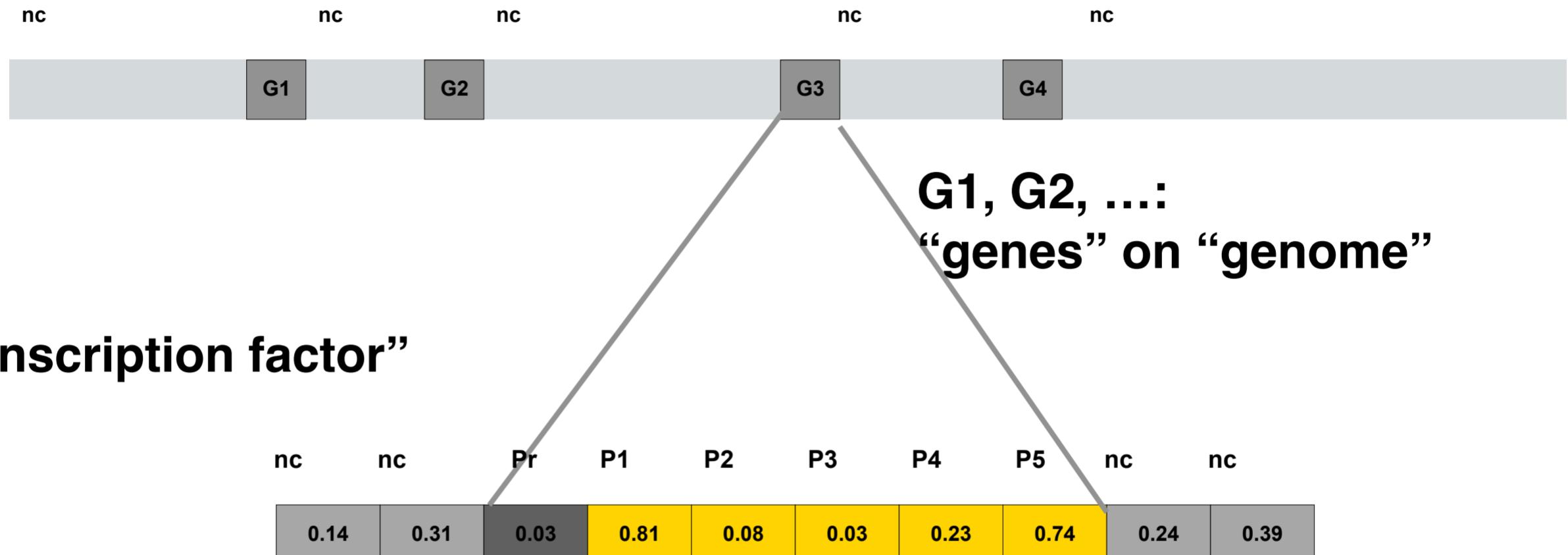


from “How the
body ...”

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Representation of “gene”

nc: “non-coding region”



TF: “transcription factor”

P1	P2	P3	P4	P5
TF37	TF2	0.03	0.23	0.74

Details: see additional slide materials for self-study

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**



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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



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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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