人工智能

The ShanghAI Lectures

上海授课

Today’s schedule

09.00 - 09.05 Introduction

09.05 - 09.55 Artificial evolution and morphogenesis

09.55 Break

10.00 - 10.30 Prof. Josh Bongard
“Morphological Change in Machines Accelerates the Evolution of Robust Behavior”

10.30 - 11.00 Prof. Fumiya Iida, ETH Zurich
“Soft robotics approach toward artificial ontogenetic development”

University of Zurich

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人工智能 上海授课 The ShanghAI Lectures

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

Today from the University of Zurich

17 November 2011

欢迎您参与

“来自上海的人工智能系列讲座”

Lecture 7

Evolution:
Cognition from scratch

17 November 2011

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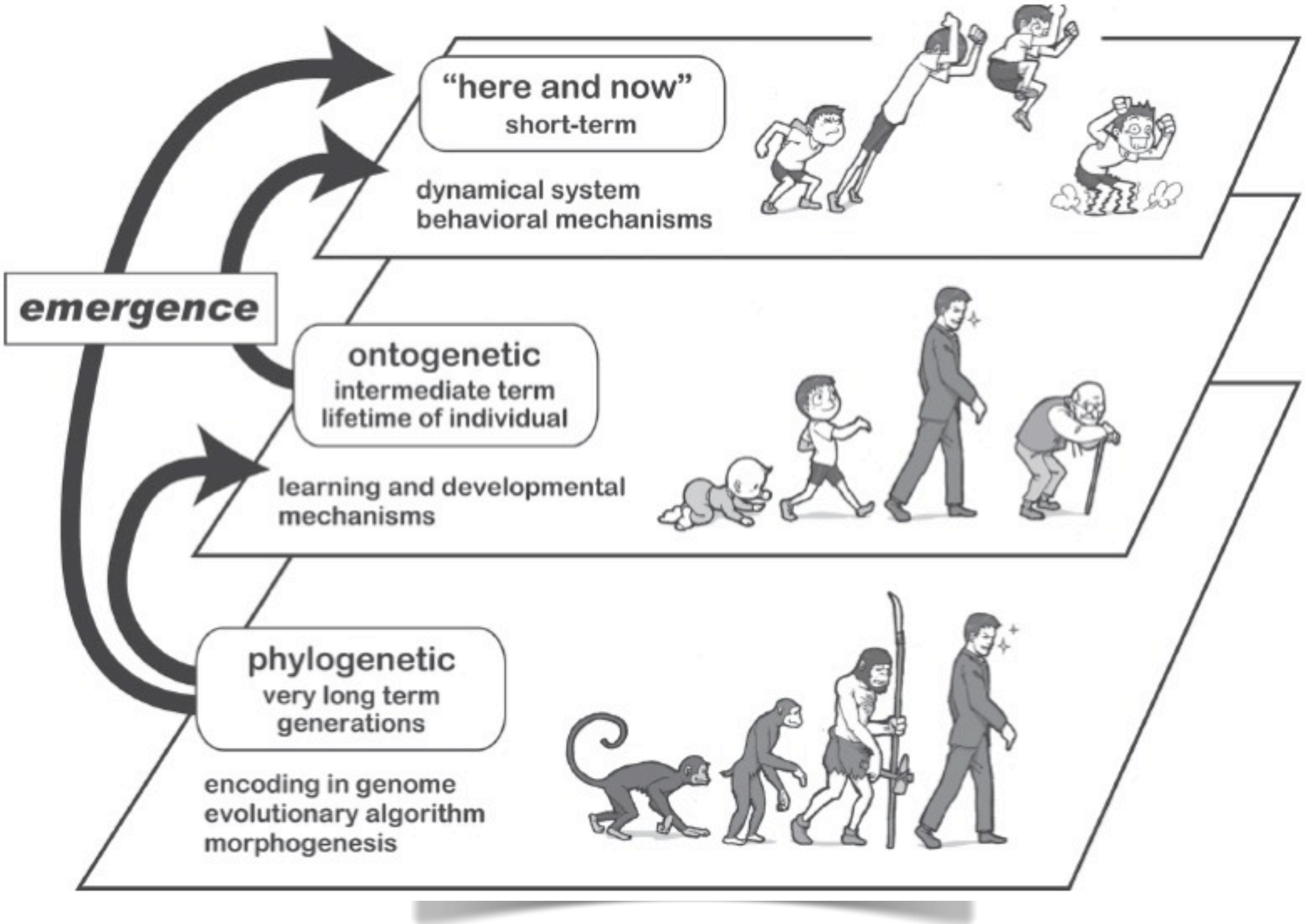
The ShanghAI Lectures 人工智能 上海授课

Today’s topics

- short recap
- artificial evolution: introduction
- co-evolution of morphology and control
- artificial evolution and morphogenesis
- principles for artificial evolution

Time perspectives



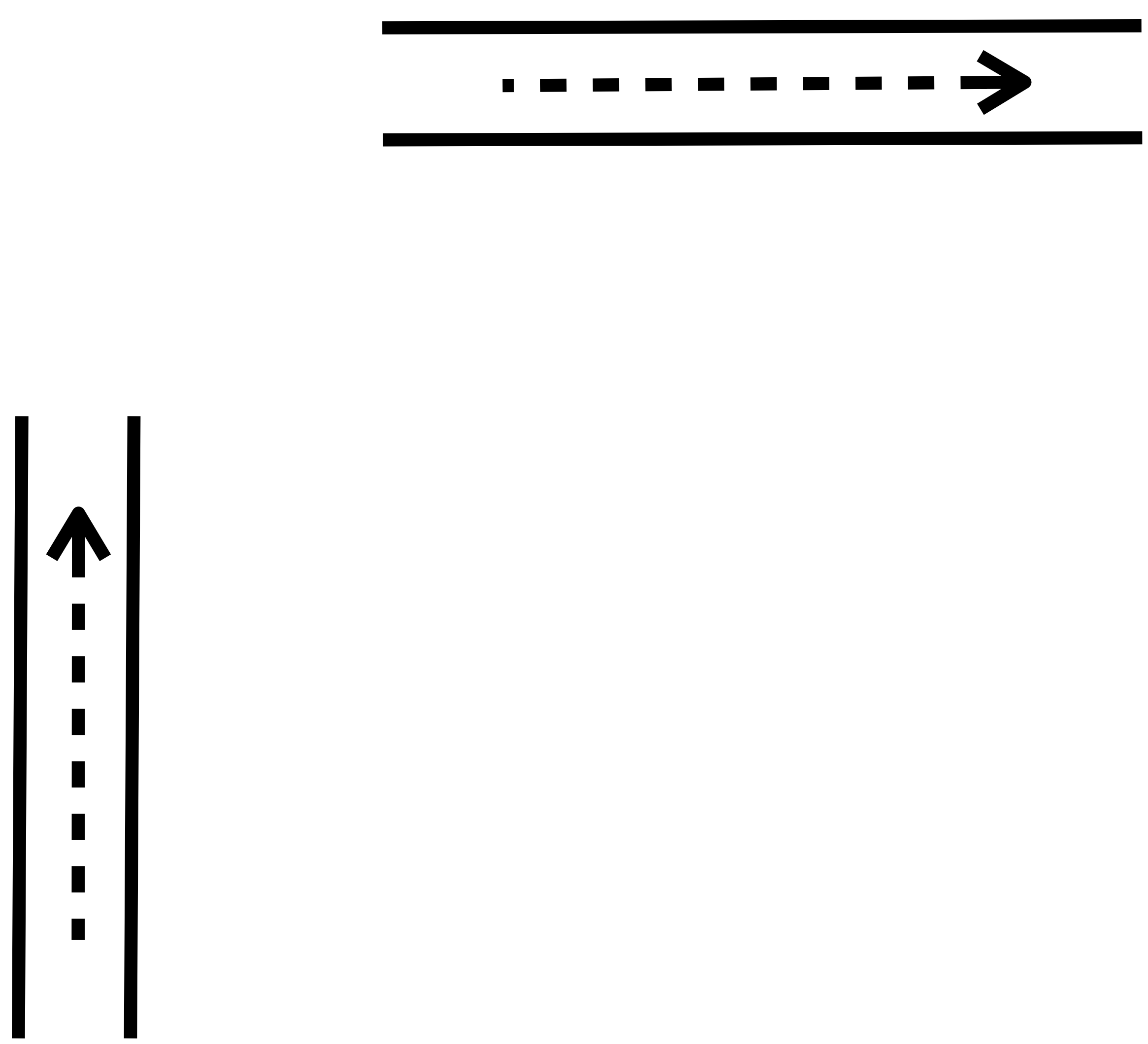
Time perspectives in understanding and design

state-oriented **"hand design"**	"here and now" perspective
learning and development **initial conditions, learning and developmental processes**	"ontogenetic" perspective
evolutionary **evolutionary algorithms, morphogenesis**	"phylogenetic" perspective

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

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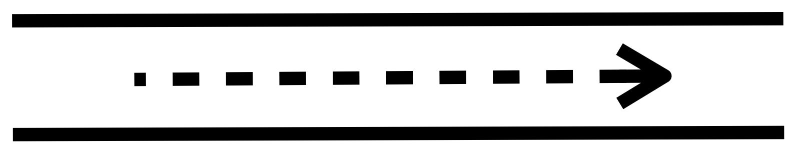
The fluid that enters the system on the left has to be deflected into the horizontal pipe. What is the optimal shape of the connecting piece to minimize turbulence?
Ingo Rechenberg: Technical University of Berlin, in the 1960s.
He found that the optimal shape has a kind of "hunch", rather than being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

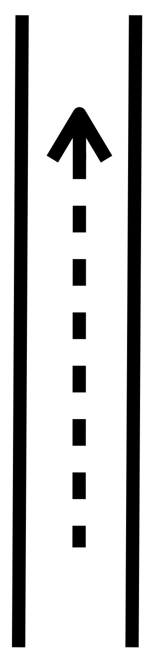
Rechenberg's "fuel pipe problem"



Creative?

—>

Chiba University

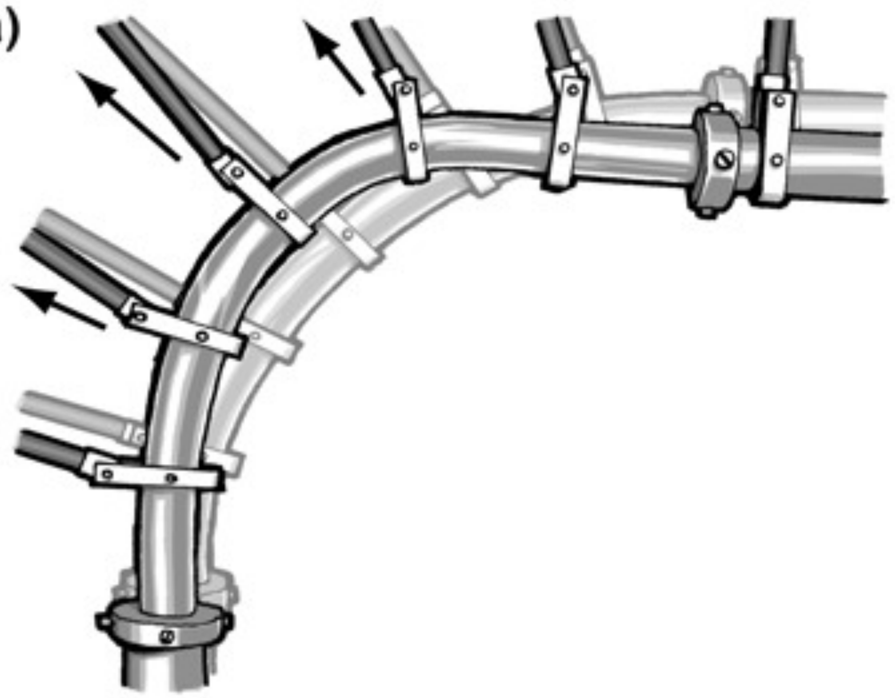


There is the fundamental and very popular question of whether computers or robots can ever be creative. Many engineers that have been dealing with this problem, have not come up with the same solution that GAs have – but still, we don't consider the GA "creative", it's "merely" an algorithm, even though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

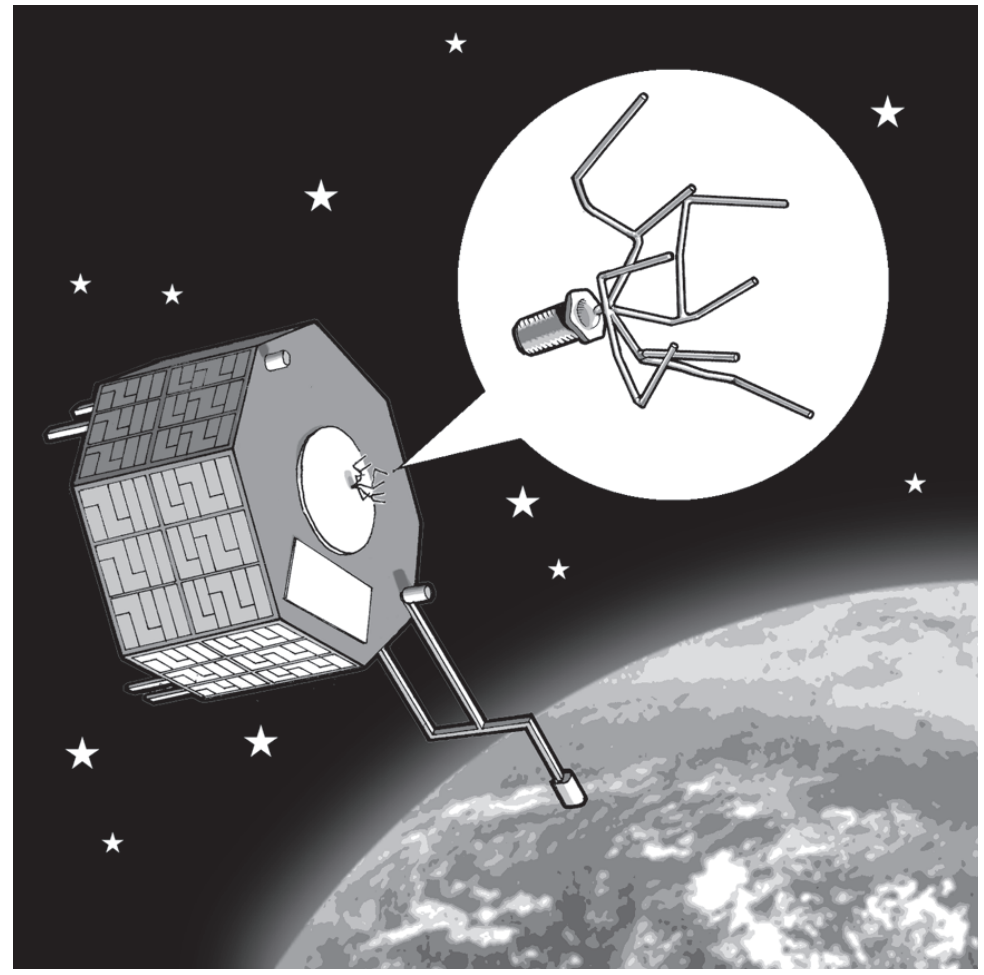
On the anecdotal side there is this scene in the movie iRobot where the human says to the robot: a robot could never have written a symphony like Beethoven, and the robot replies: "Could you?".

Evolutionary designs

(a)



(b)



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

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

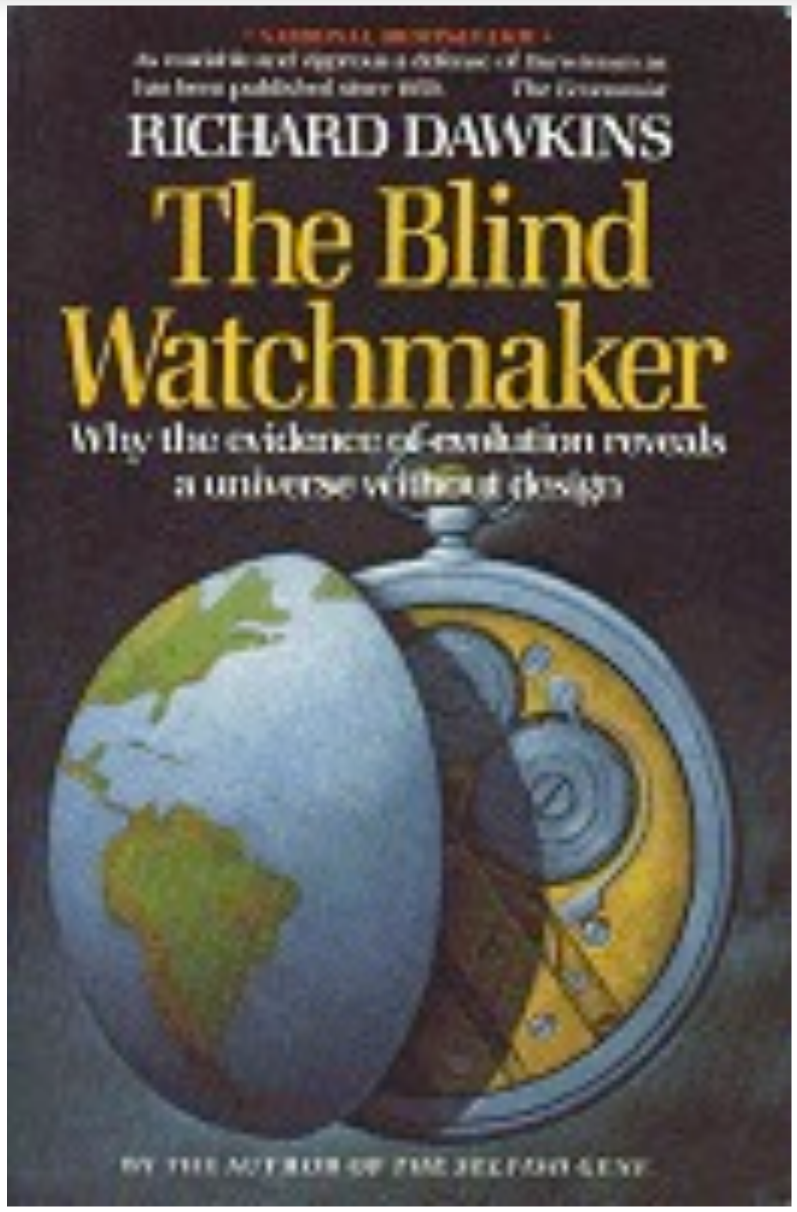
Artificial evolution

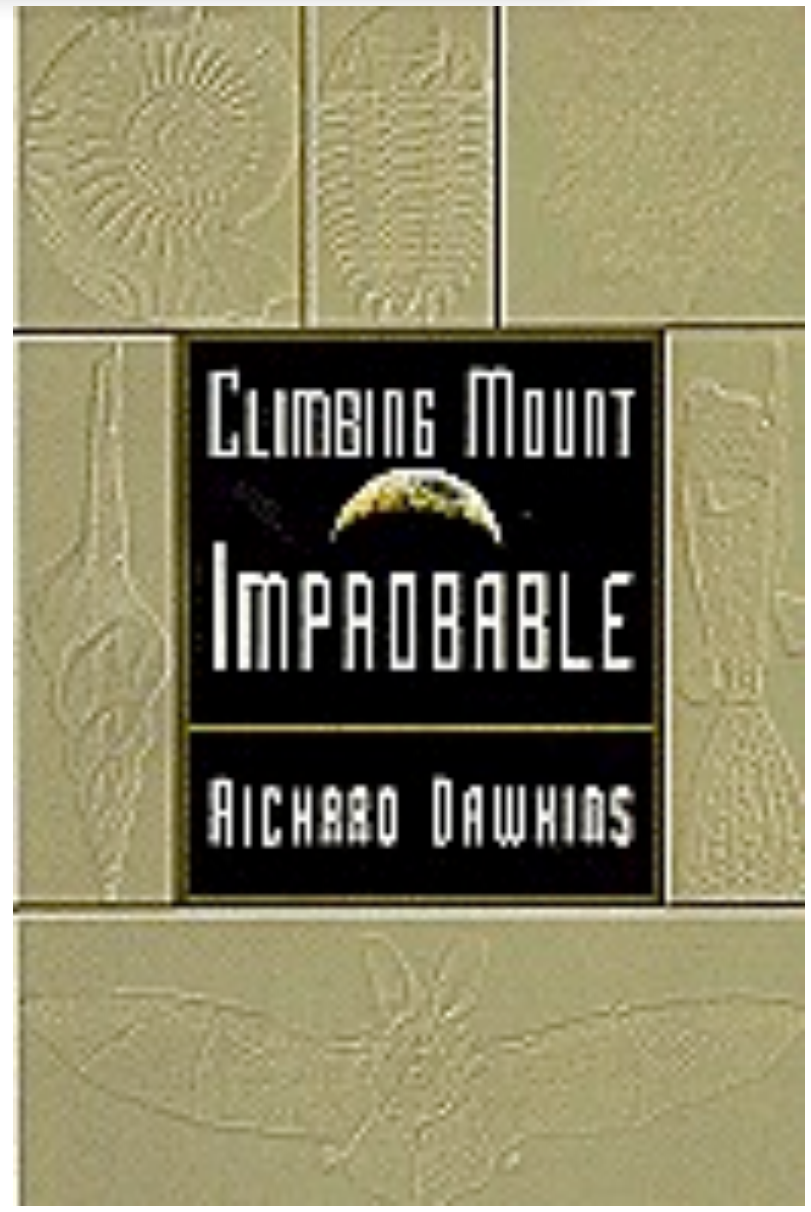
- John Holland: Genetic Algorithm, GA
- Ingo Rechenberg: Evolution Strategy, ES
- John Koza: Genetic Programming, GP

Goal: exploiting evolution for the design of intelligent agents

Cumulative selection

Richard Dawkins (author of "The selfish gene")





Watch out!!

the creationists!?!!!

Richard Dawkins:
very outspoken against creationism

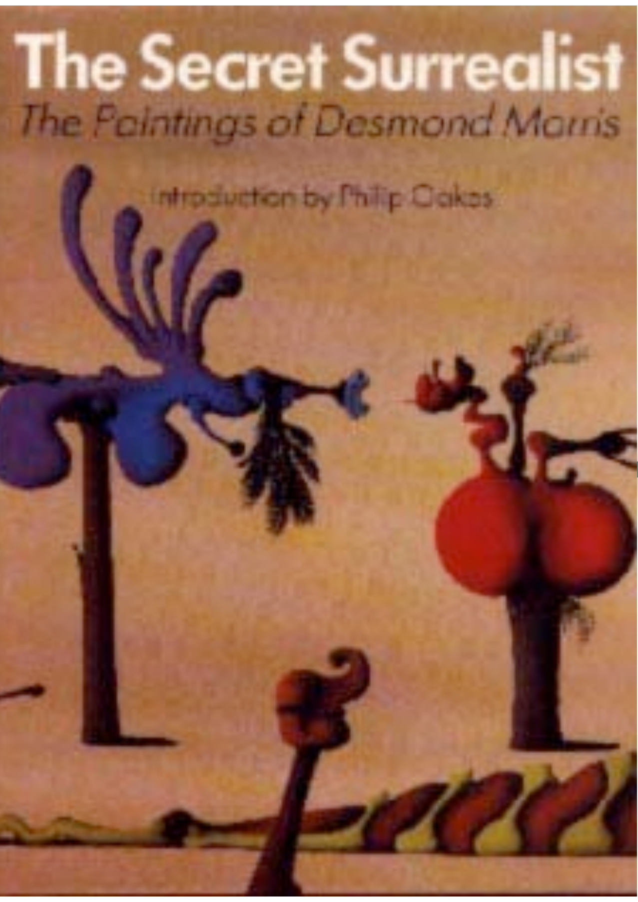
Biomorphs
The power of esthetic selection

- **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)**

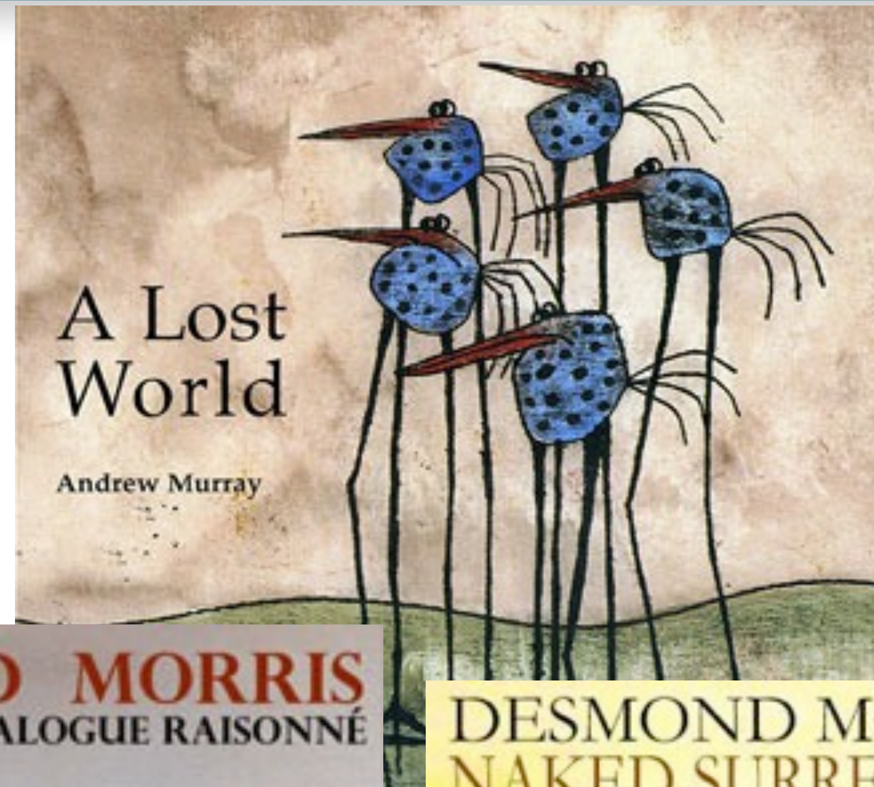
http://suhep.phy.syr.edu/courses/mirror/biomorph/

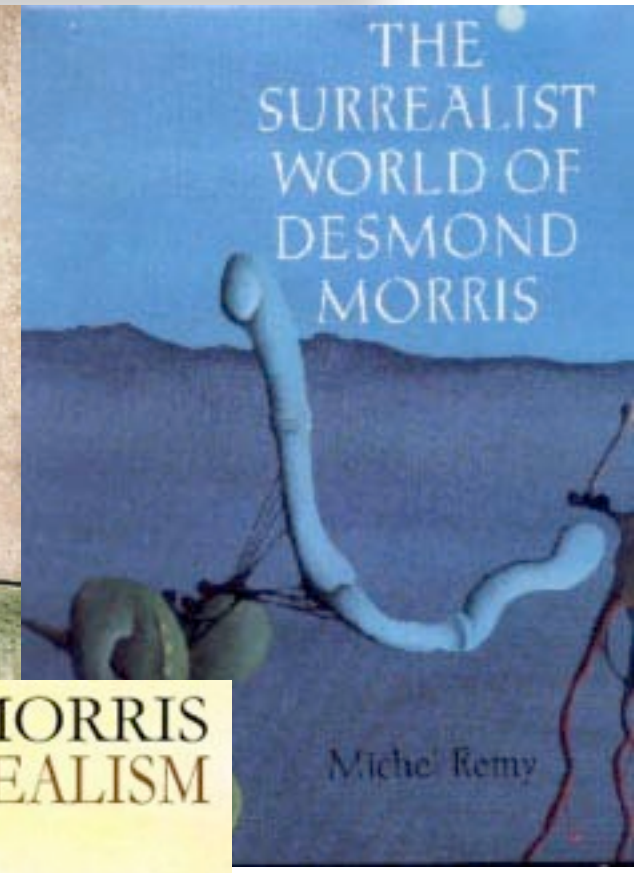
encoding “creature” in genome (string of numbers): **genotype**
expression of “genes”: **phenotype**
esthetic selection designates the process by which a user selects an object that he “likes” and evolution proceeds from there)

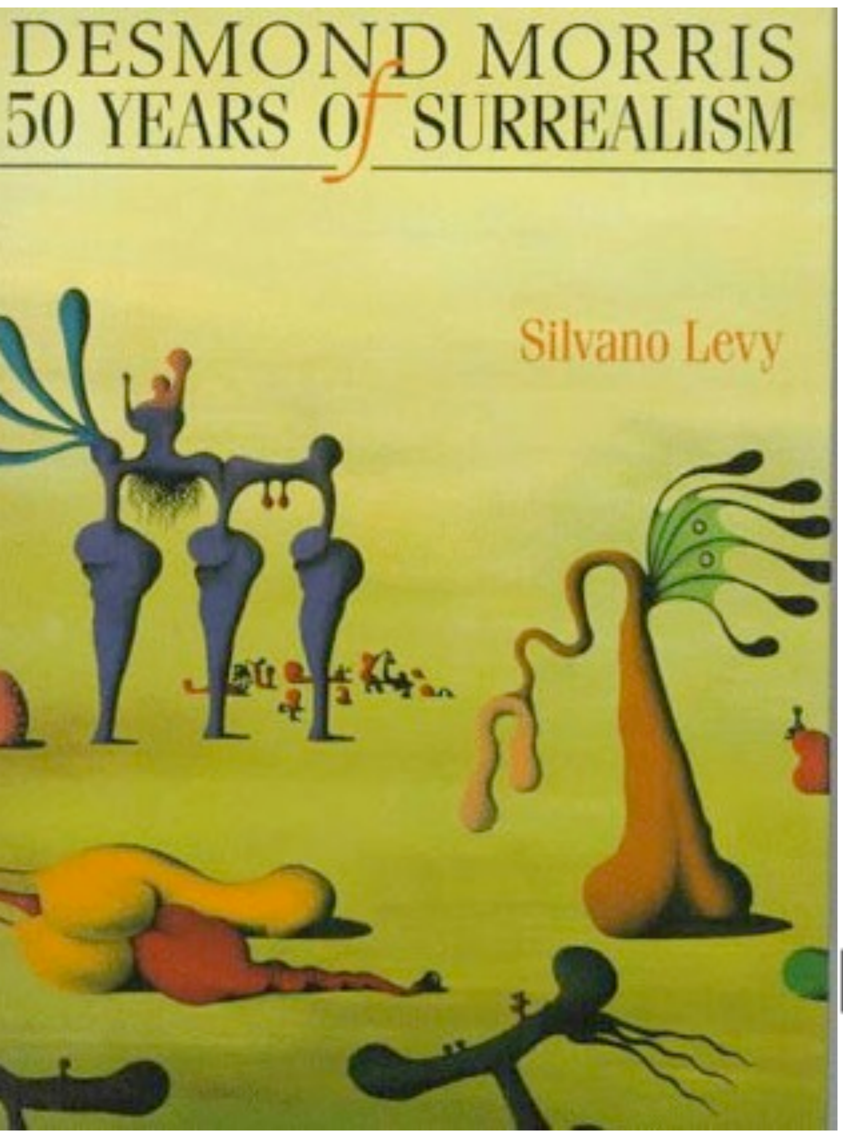
Biomorphs: by surrealist painter Desmond Morris

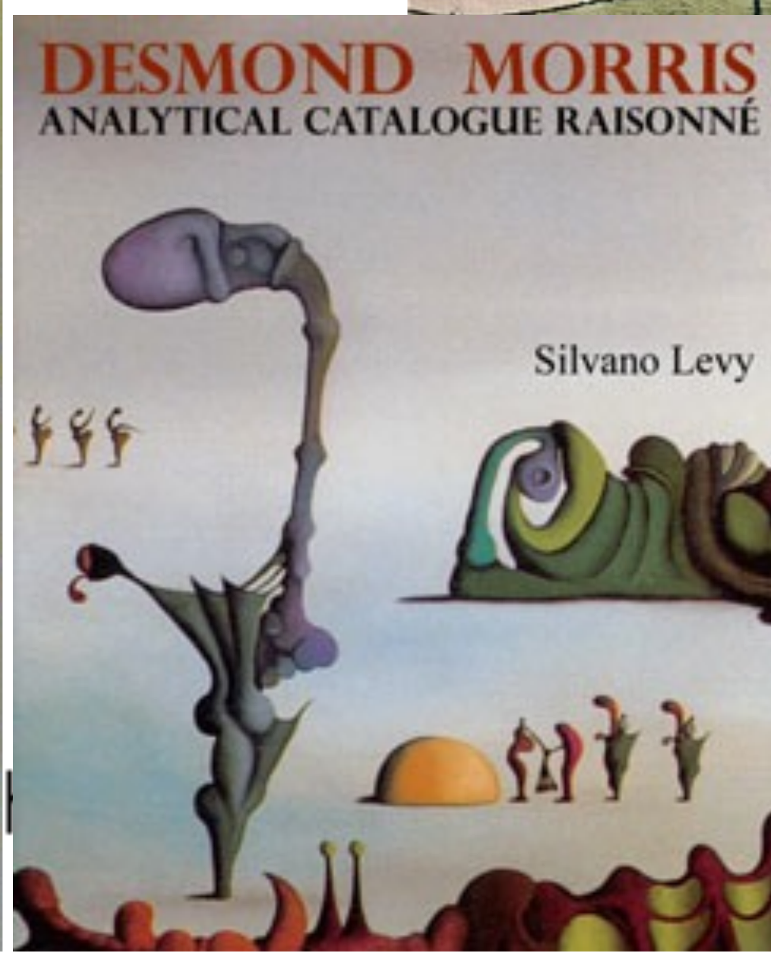


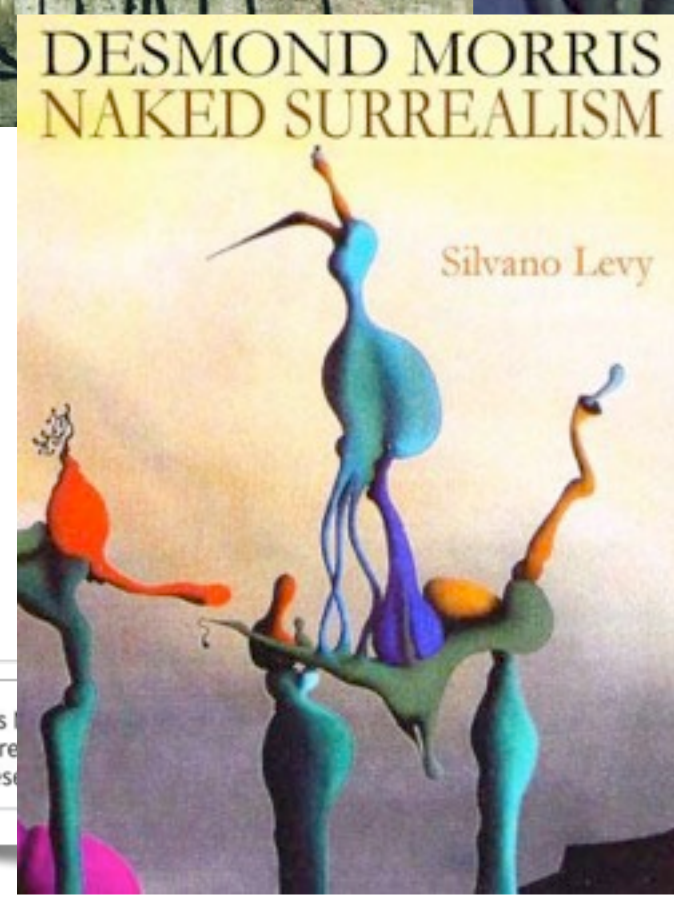
exhibitions:
1948 - 2008







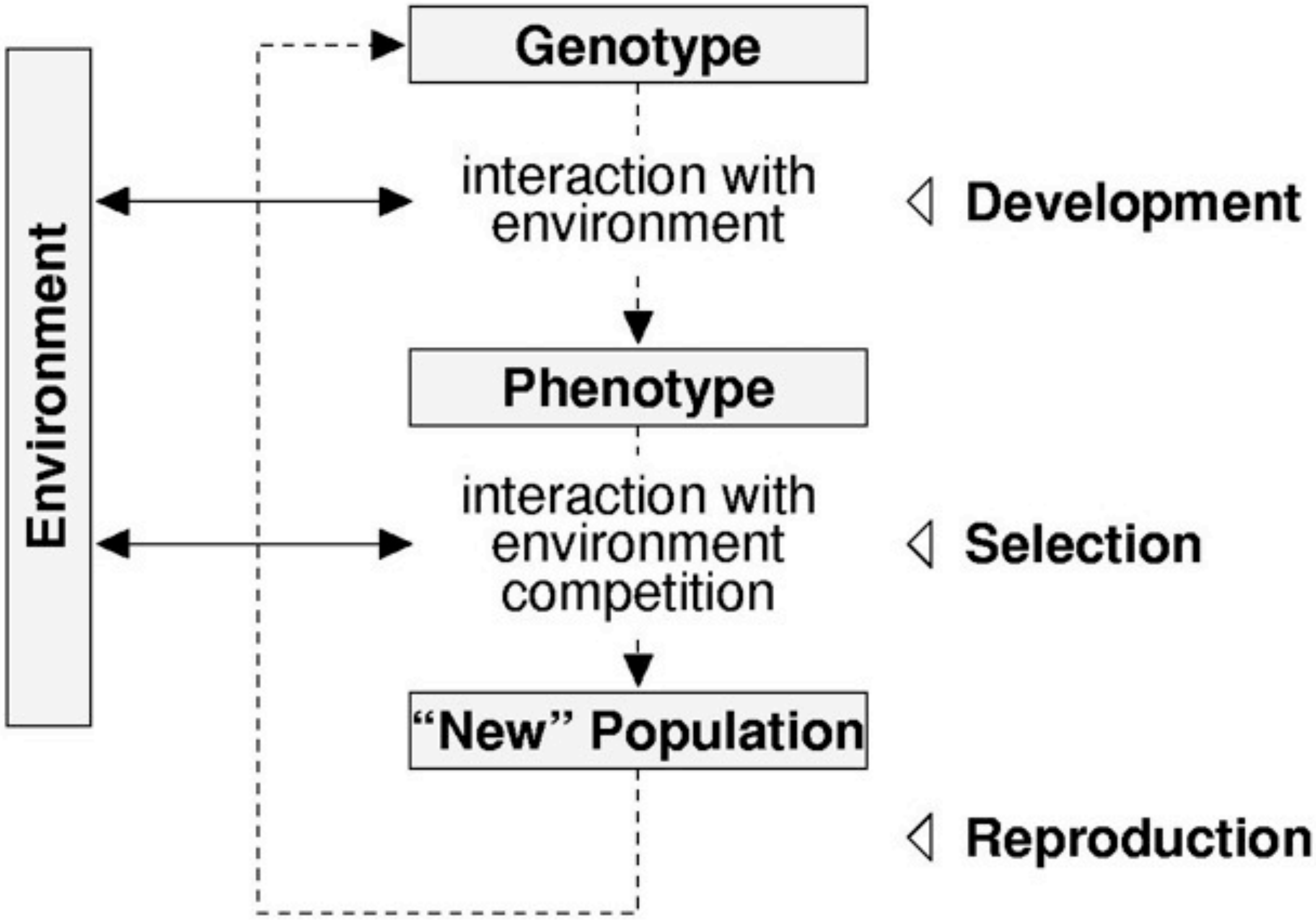




Biomorphs
Encoding in genome

- “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 evolu-tionary scheme"



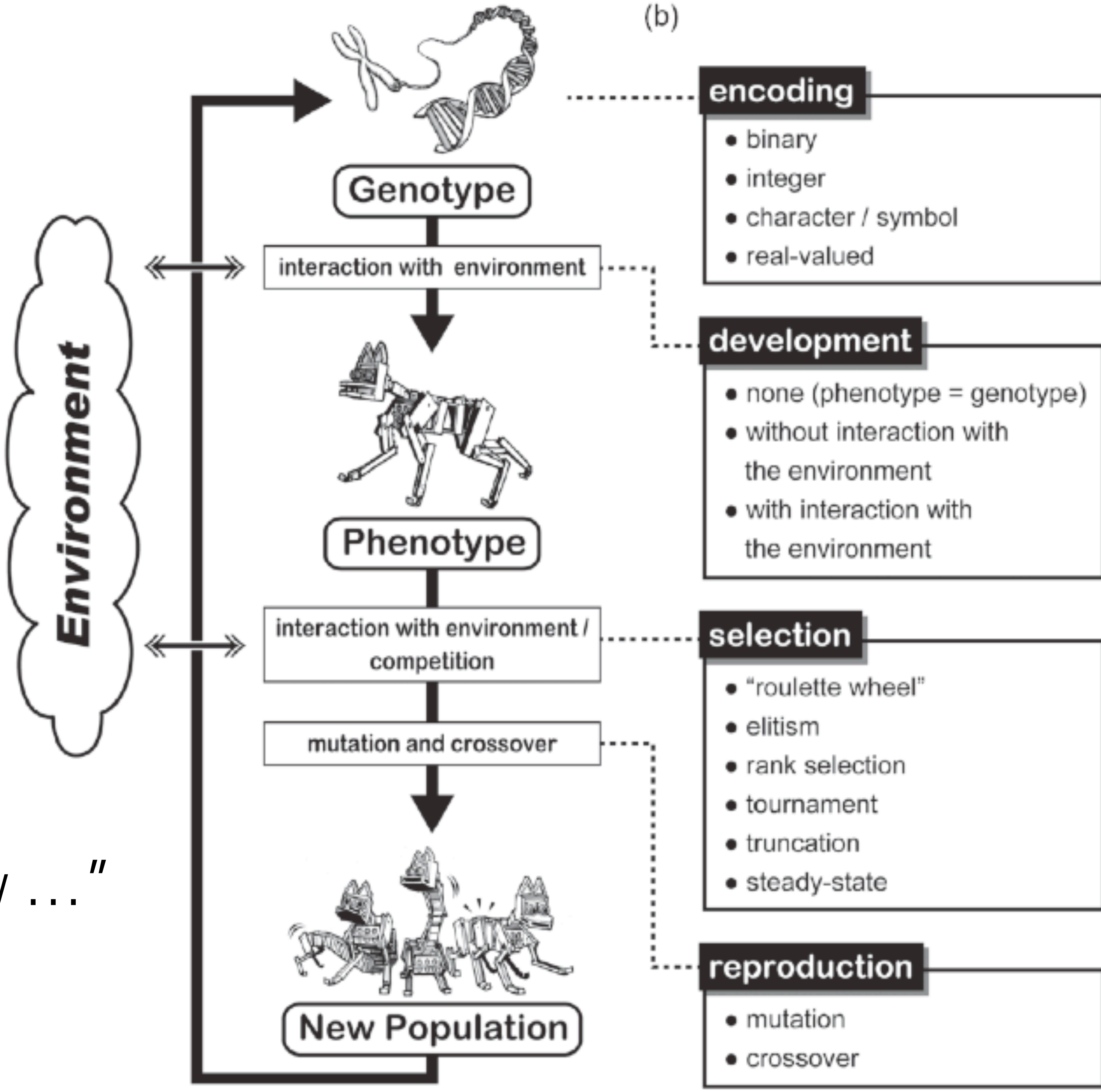
encoding	development	selection	reproduction
• binary • many-character • real-valued	• no development (phenotype = genotype) • development with and without interaction with the environment	• "roulette wheel" • elitism • rank selection • tournament • truncation • steady-state	• mutation • crossover

Most of the approaches from the literature on artificial evolution can be mapped onto this scheme. Often, GAs don't make a clear distinction between genotype and phenotype, but in biological systems it is very clear.

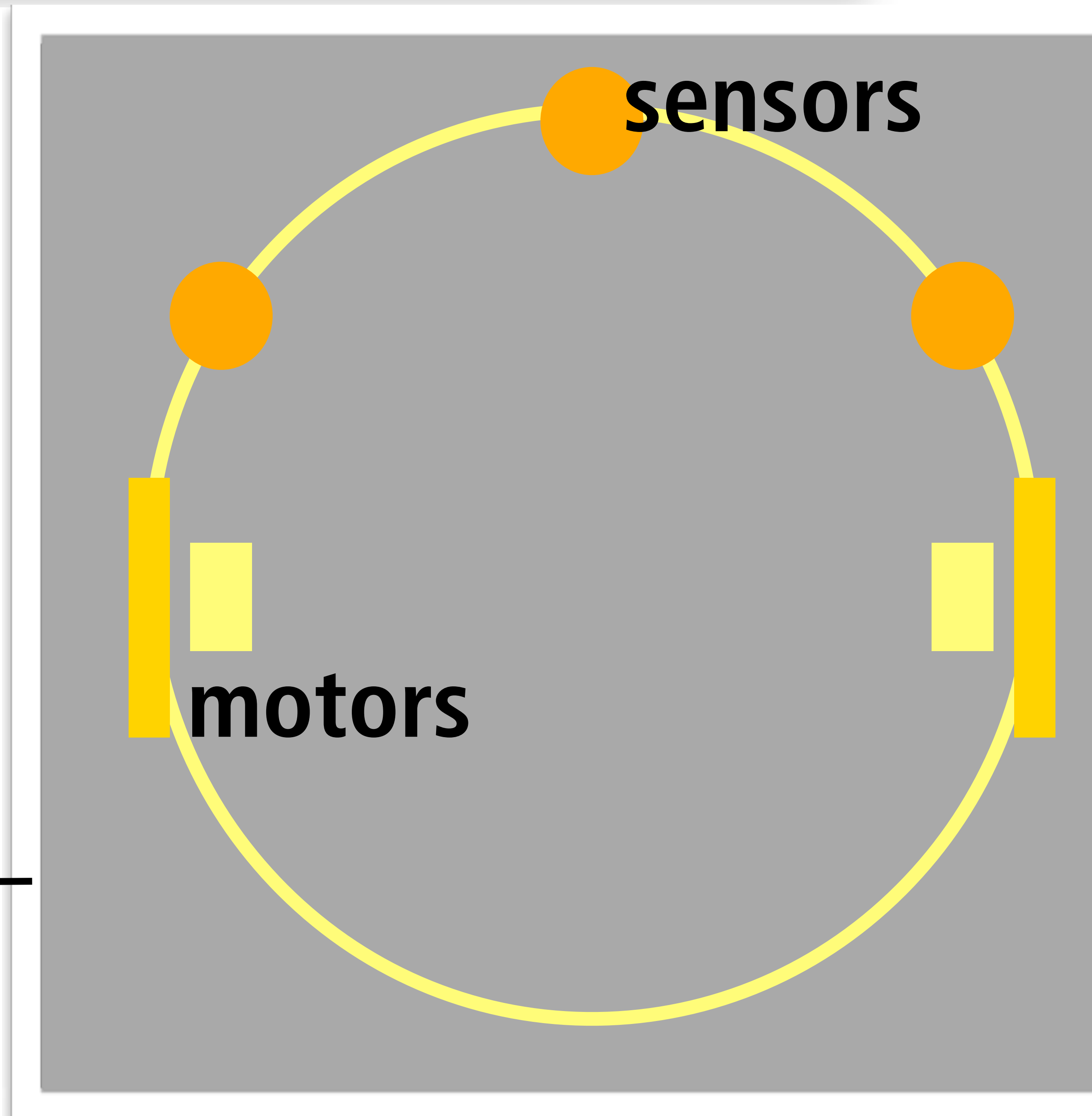
Basic cycle for artificial evolution

from
"How the body …"

University

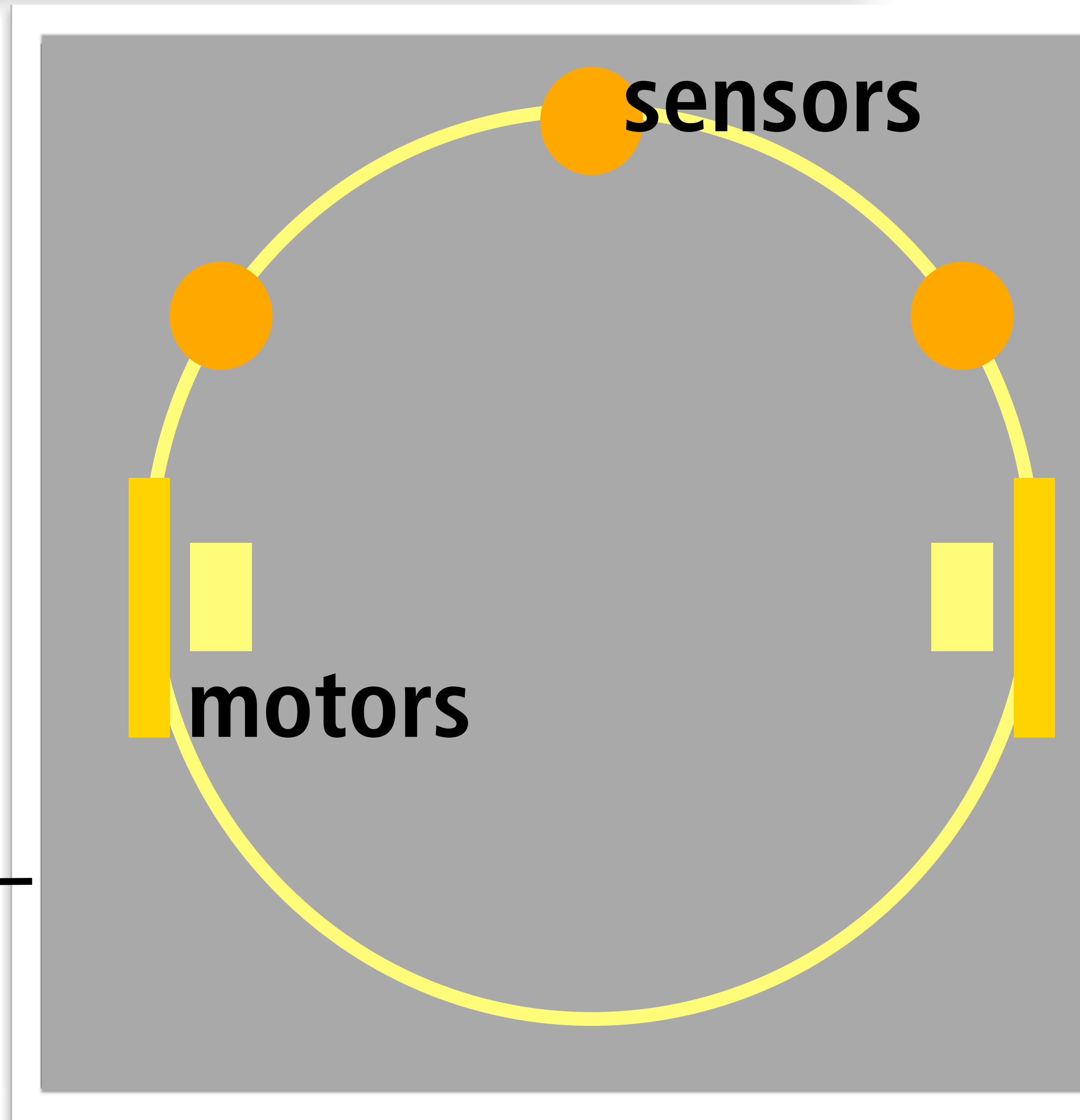


Evolving a neural controller



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

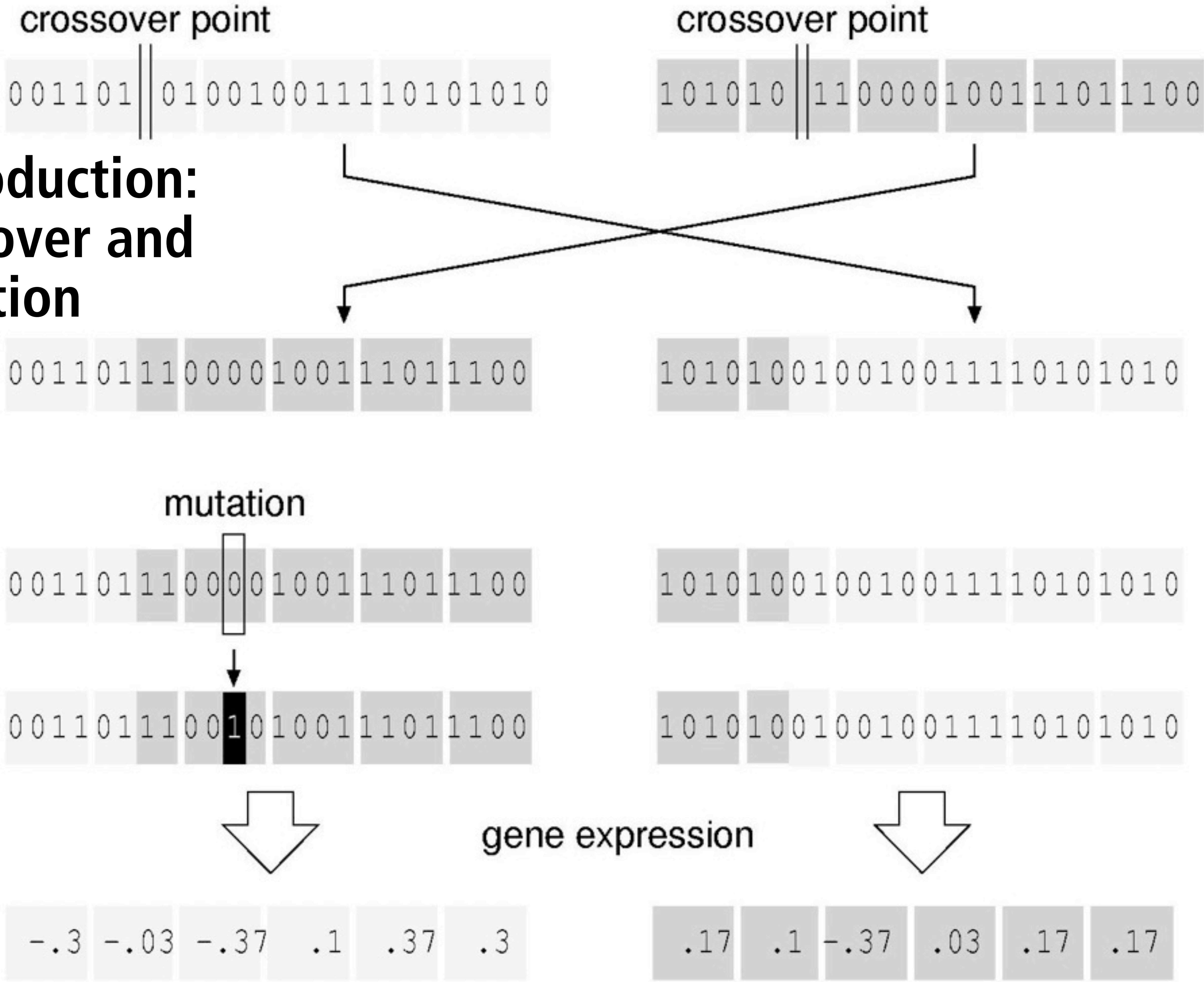
Fitness function and selection

suggestions? —> Algiers

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



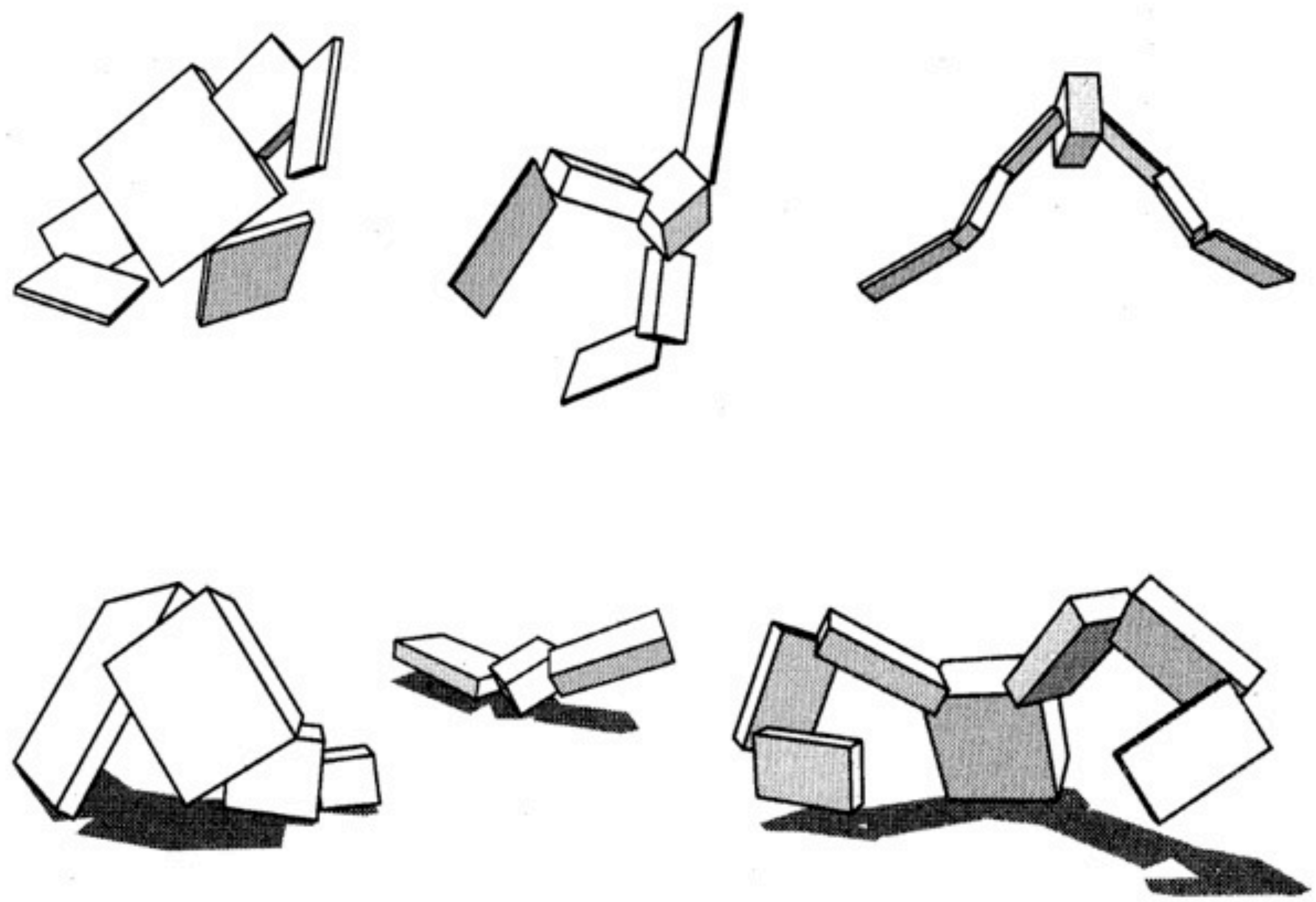
Choice of mutation rate: too large —> random search (we lose the effect of cumulative selected); too small: organism will evolve too slowly. In the evolution strategy by Rechenberg, the mutation rate itself is under evolutionary control.

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



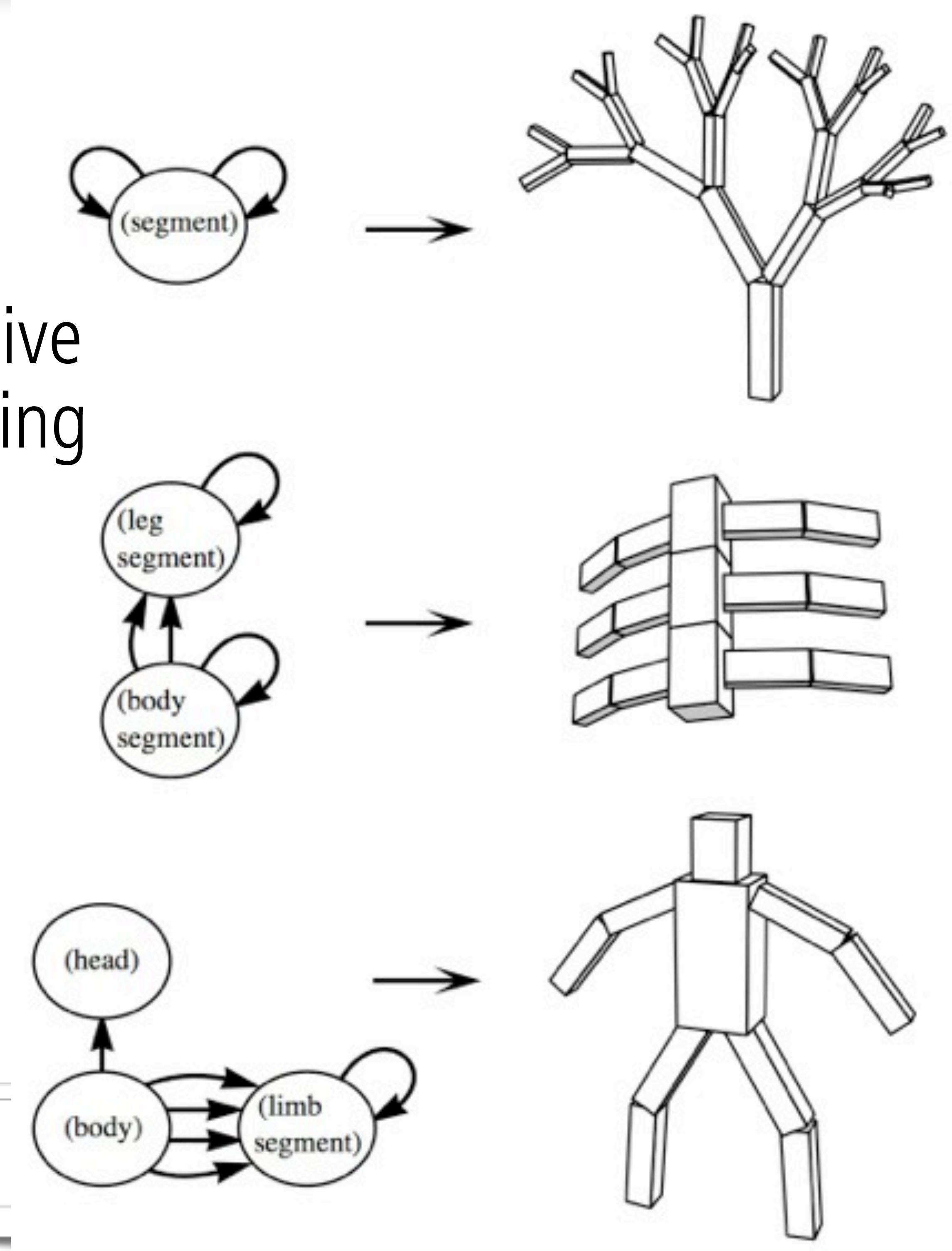
Parameterization of morphology

encoding in genome “genotype”

development

embodied agent “phenotype”

recursive encoding



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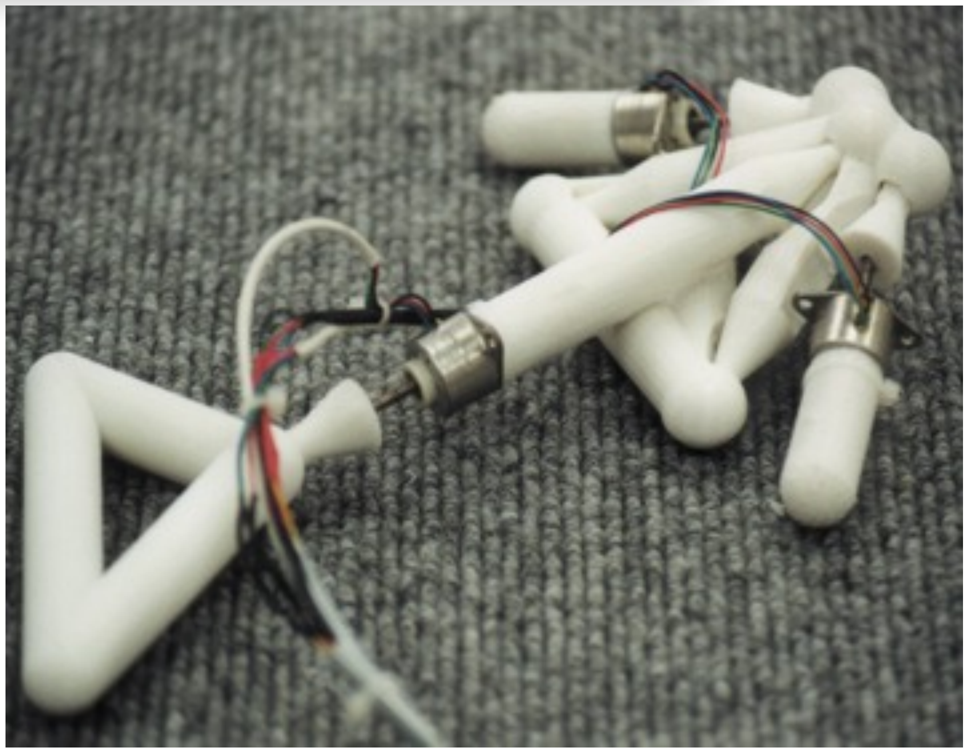
The genotype is a graph structure (rather than merely a bit string) which needs to be transformed into the phenotype (on the far right). The interpretation is straightforward. Parameters that can be varied by evolution include the length, width, and hight of the segments, the joint types, the number of recursions, etc. Embedded into the segments are neural networks that are also under evolutionary control.

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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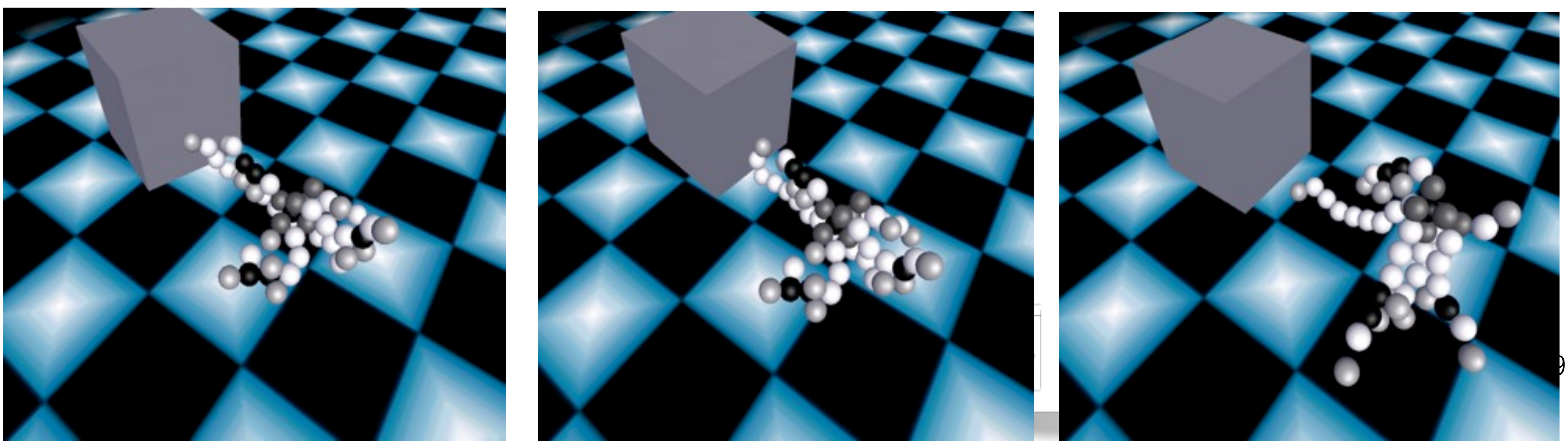
Hod Lipson and Jordan Polluck added a 3D printer to the end of the evolutionary algorithm, but in essence, it is the same approach as the one of Karl Sims: everything happens in the simulation and the physical instantiation at the end does not feed back onto the evolutionary process. Actuators need to be mounted manually. The “creatures” don’t have any sensors. The claim of some of the newspapers that this demonstrates self-replicating machines is grossly over-stated.

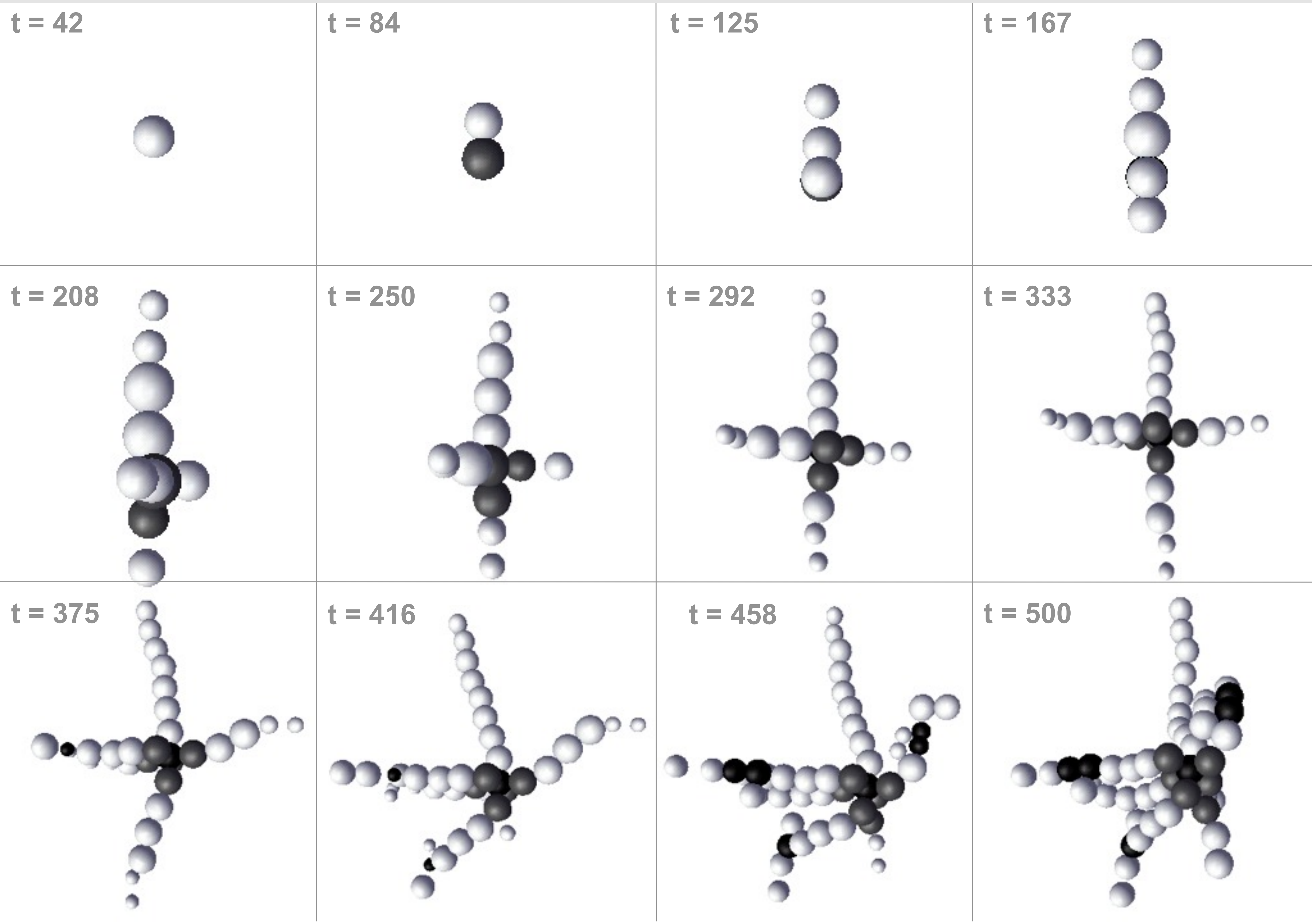
Genetic Regulatory Networks (GRNs): Bongard's "block pushers"

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



Fitness function: push a large block as far as possible.

The Growth Phase

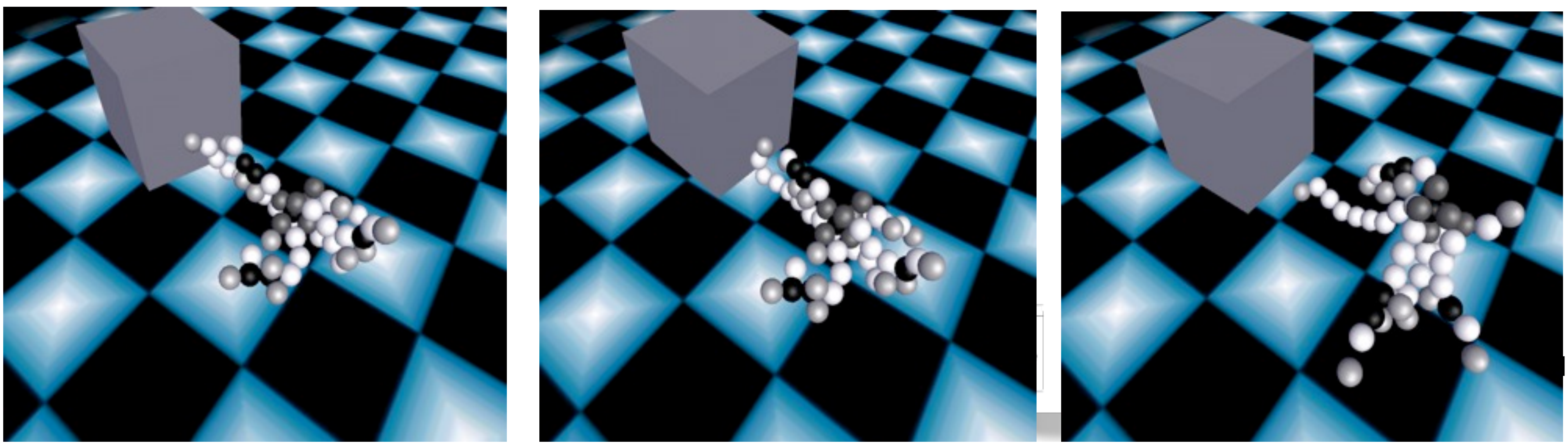


The process of ontogenetic development from a single cell to an “adult” organism.

Evolution of a "block pusher" ("Artificial Ontogeny")

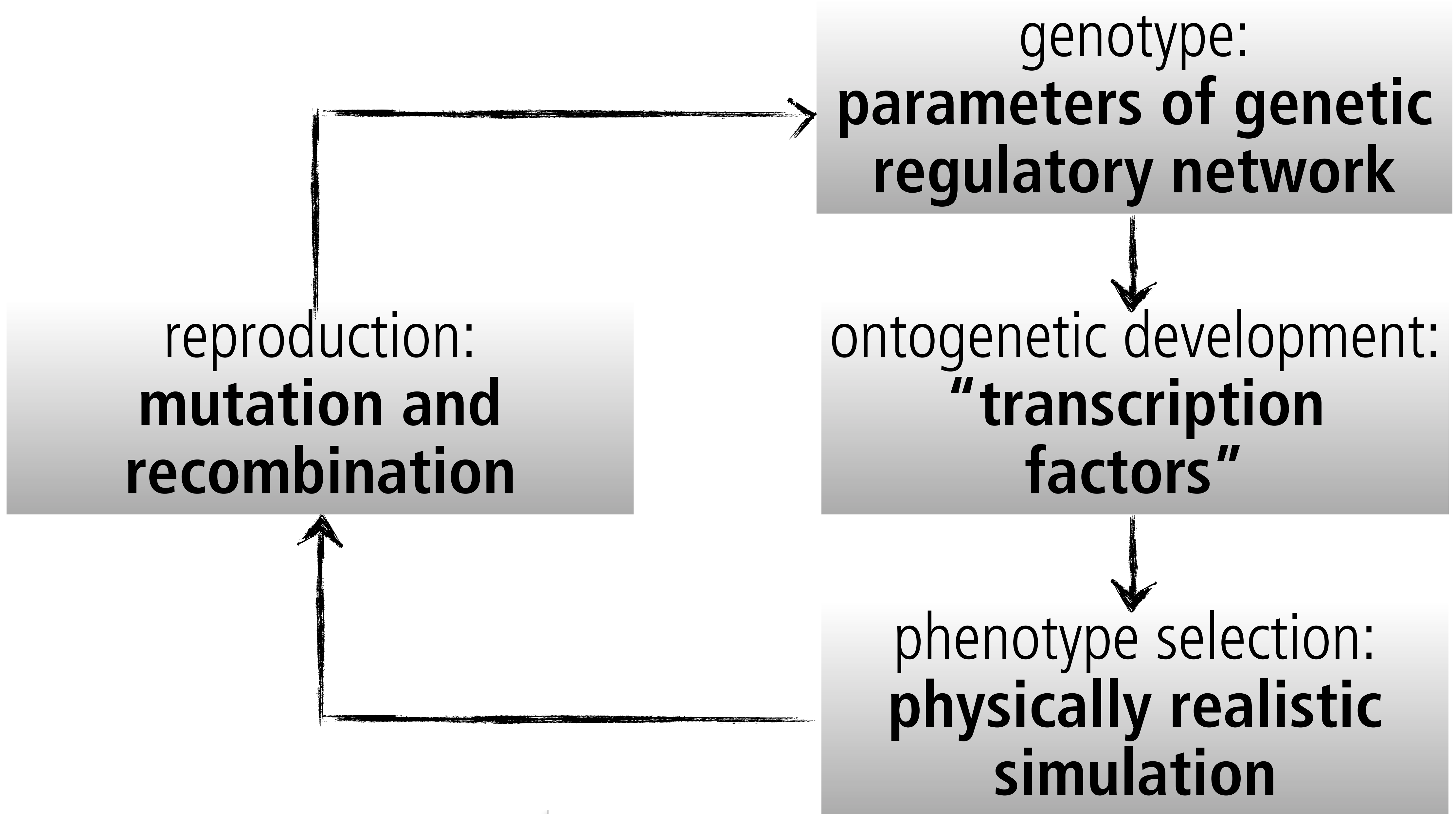
- **development (morphogenesis) embedded**
-

Video "Evolution of block pushers"



A nice demonstration of the "creativity" of evolutionary systems. The behavior of the block pushers is entirely emergent: they are only told *what* they should do, but not how – the how is discovered by evolution. Again, emergence is a matter of degree, not a binary concept.

Bongard's evolutionary scheme



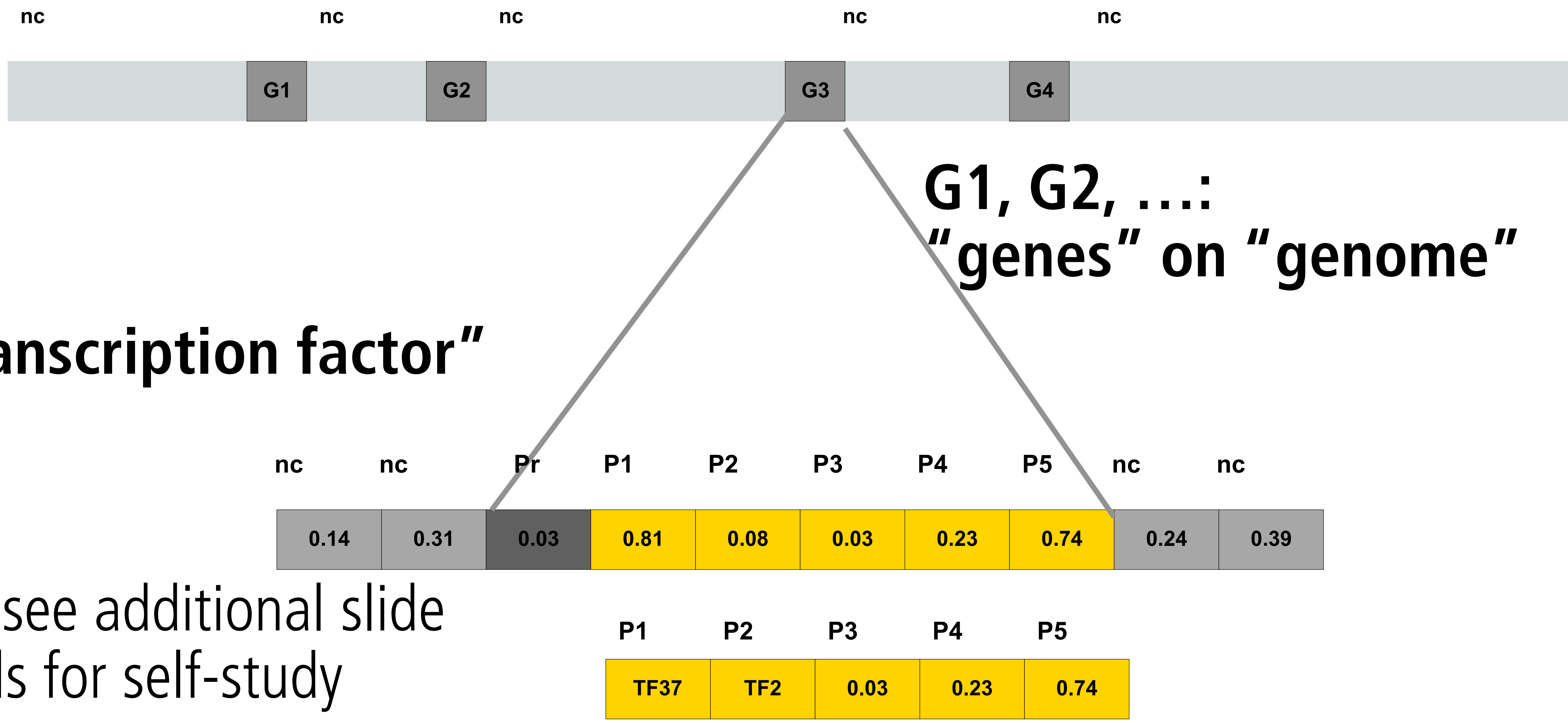
In this case, evolution manipulates the parameters of the genetic regulatory network, rather then the parameters of the structure of the organism (as is the case in Karl Sims's creatures).

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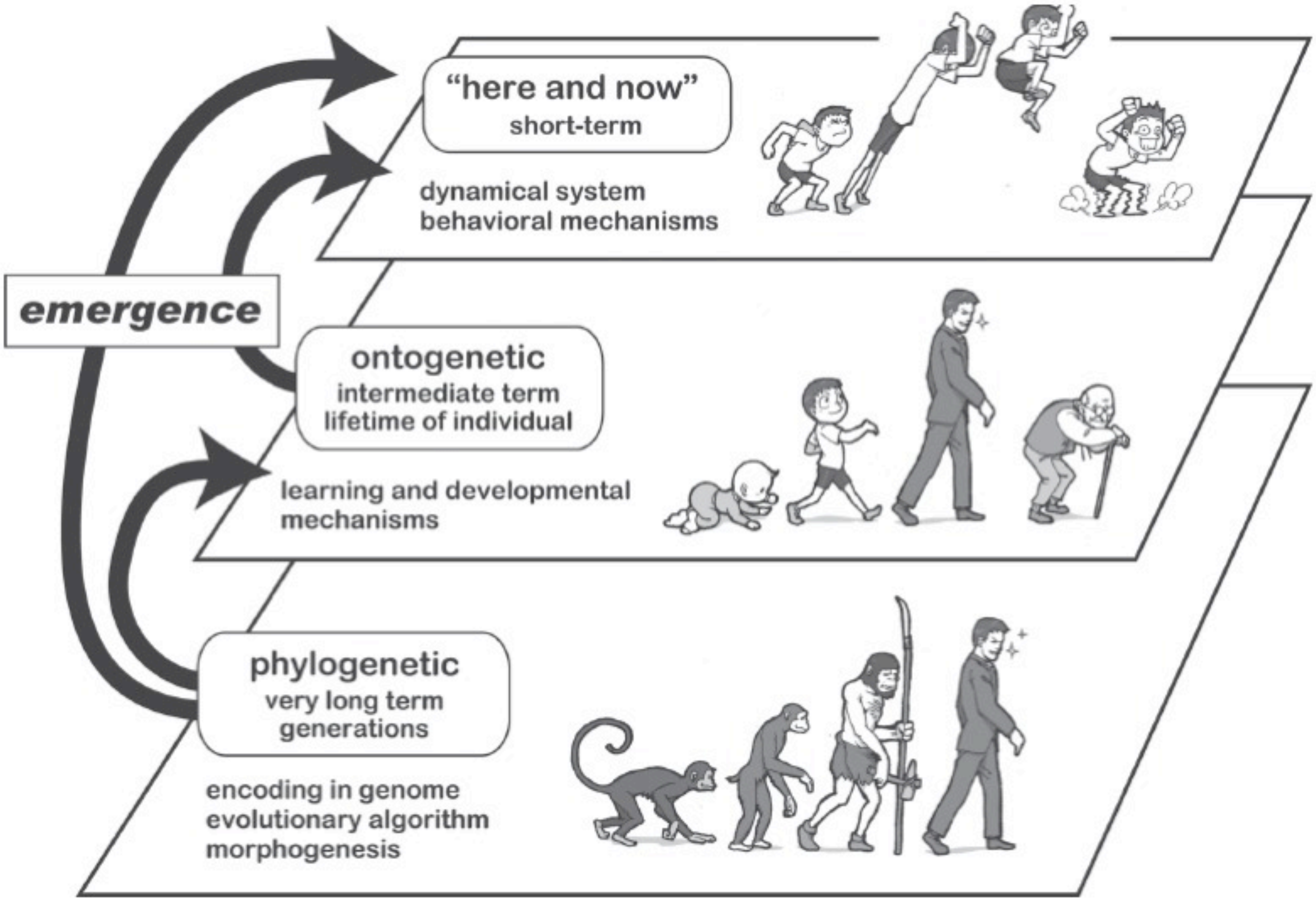
What is evolved in this case are the parameters of the genetic regulatory network, rather than the structure of the organism. The GRNs characterize (enable, constrain) the developmental process.

Time scales tightly intertwined



In the block pusher example, the "here and now" behavior, i.e. what the robot actually does in reaction to the environment, emerges from an evolutionary process (the outer left arrow).

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

(see “How the body …” for explanations).

Assignments for next week

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

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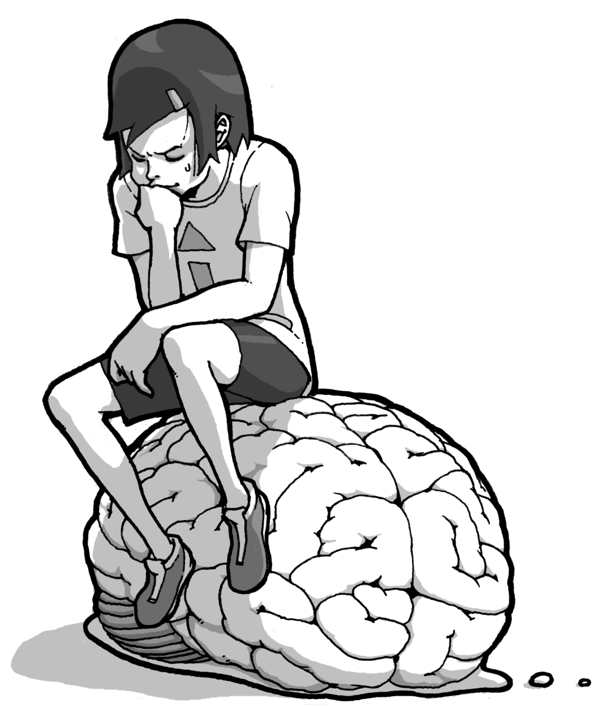
End of lecture 7

Thank you for your attention!

stay tuned for guest lectures

on artificial evolution, and on “soft robotics”



Lecture 7: Guest speaker

from Burlington, Vermont, U.S.

(recipient: Presidential Early Career Award for Science and Technology, 2011)

Prof. Josh Bongard, University of Vermont
“Morphological Change in Machines Accelerates the Evolution of Robust Behavior”

10.00h Zurich/CET — 4.00am US Eastern Time!! thank you,

Lecture 7: Guest speaker

from UZH Zurich, Switzerland

Prof. Fumiya Iida, ETH Zurich, "Soft robotics approach toward artificial ontogenetic devolopment"

10.30h Zurich (CET) time

End of lecture 7

Thank you for your attention!

stay tuned for lecture 8

“Collective intelligence: Cognition from interaction”

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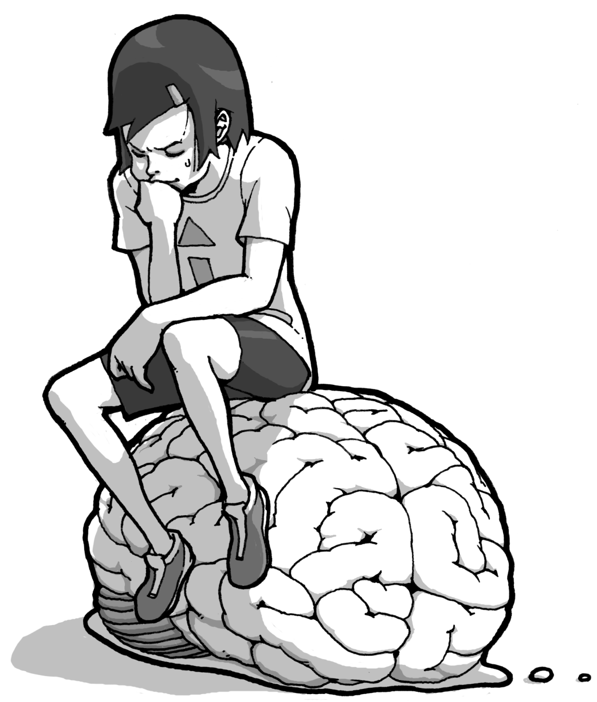

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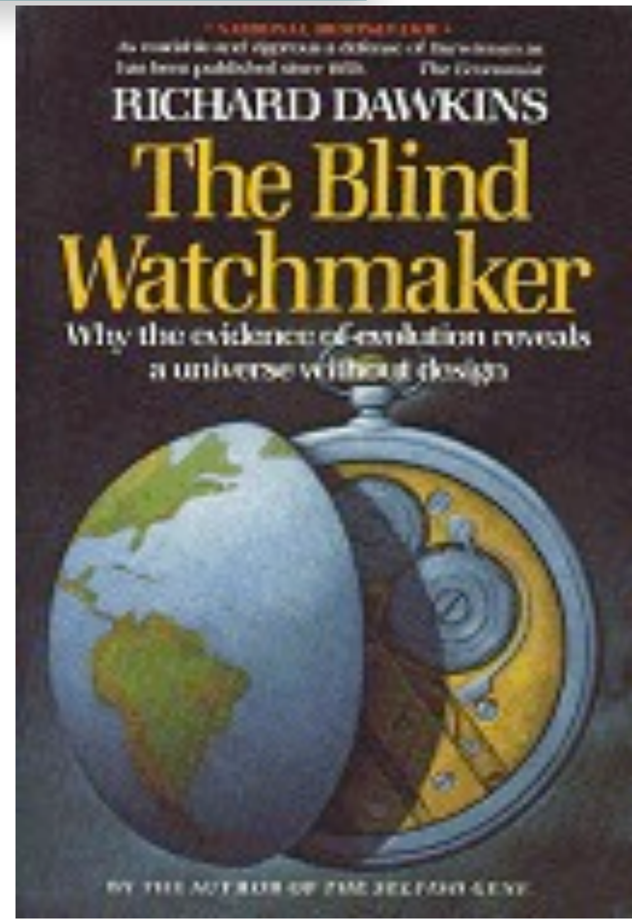
Additional slide materials for self-study

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?**

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

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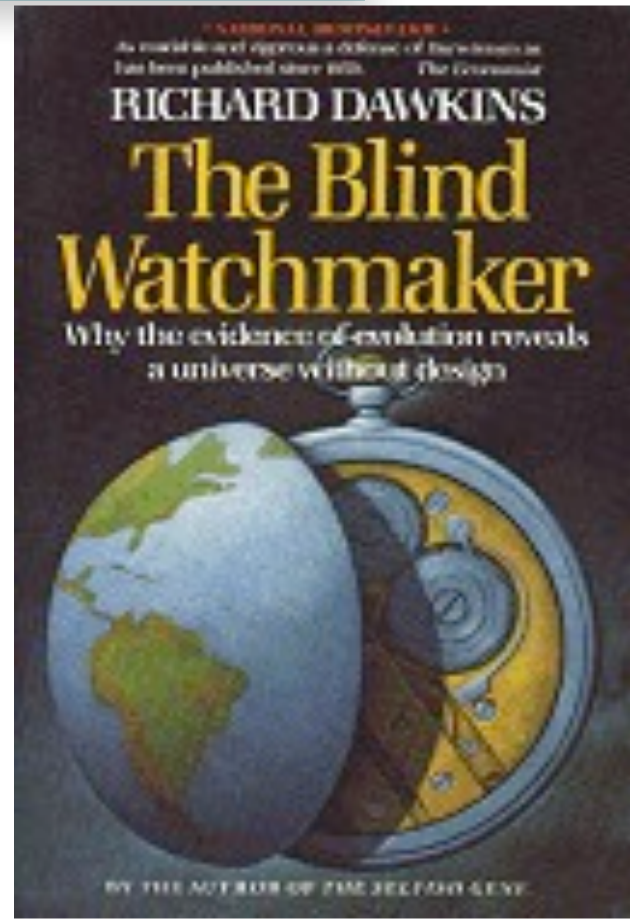
Hamlet: **Or like a whale?**

Polonius: **Very 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’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

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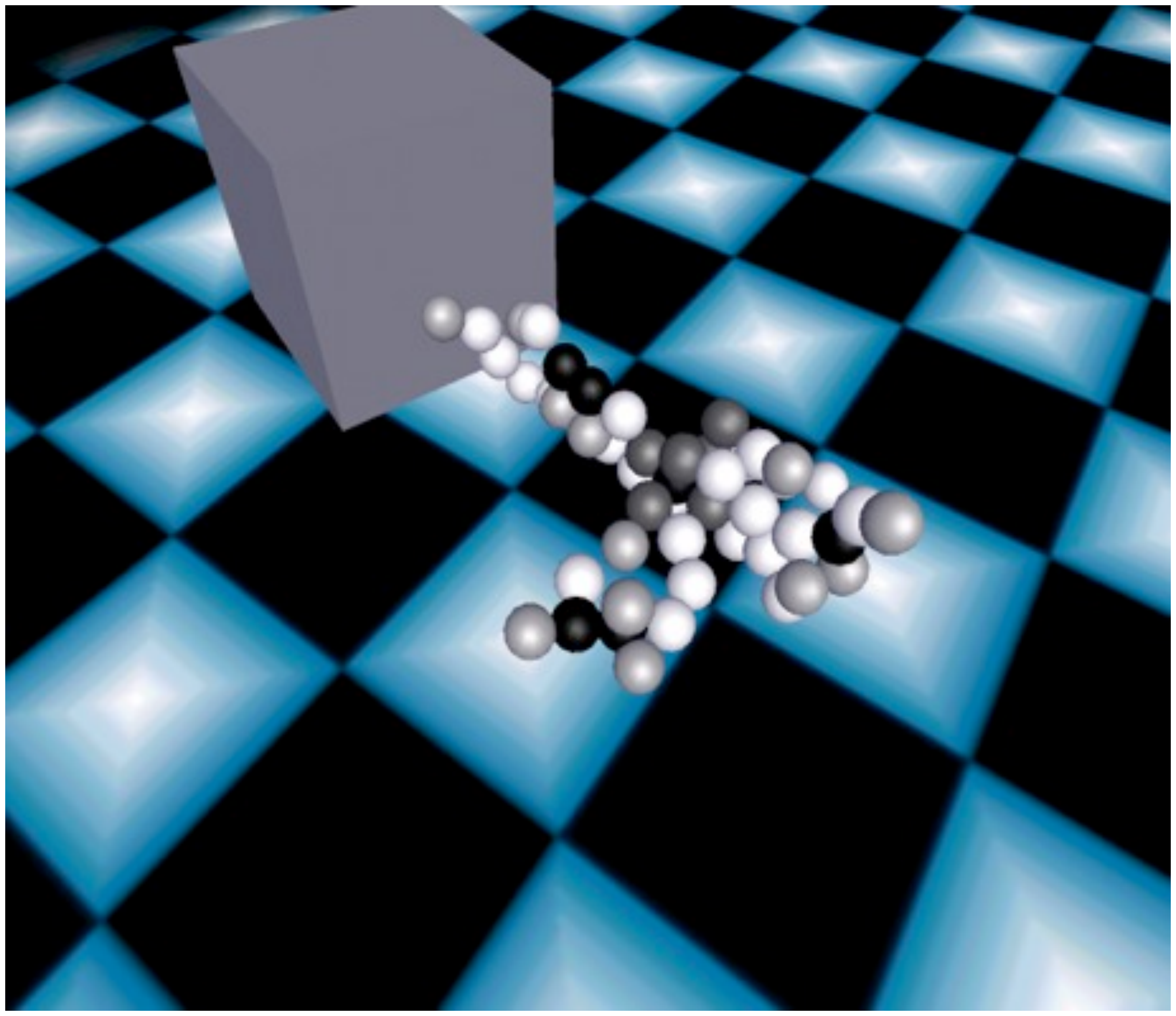
try one of the applets on the net

Additional materials on Bongard's GRNs



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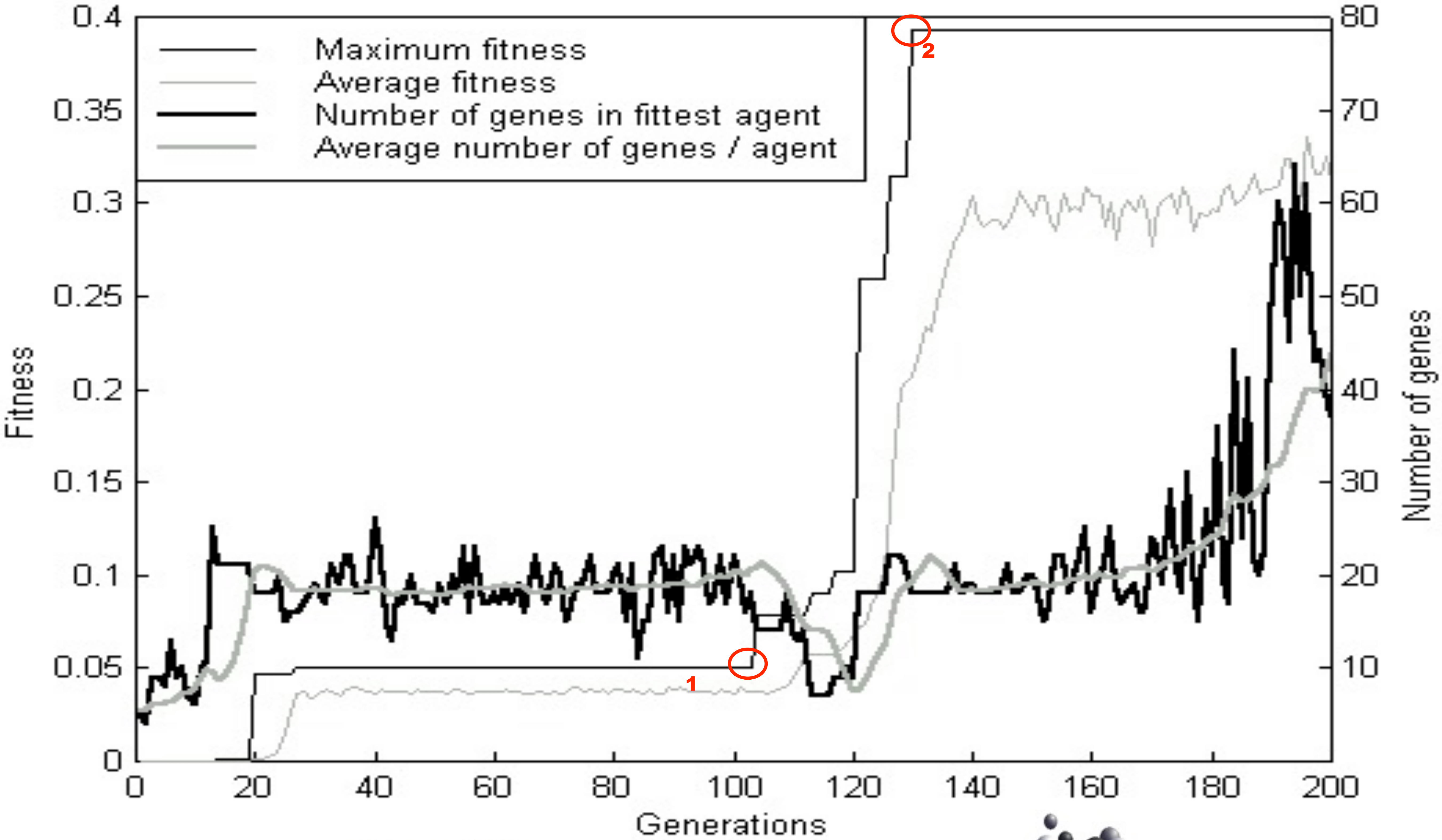
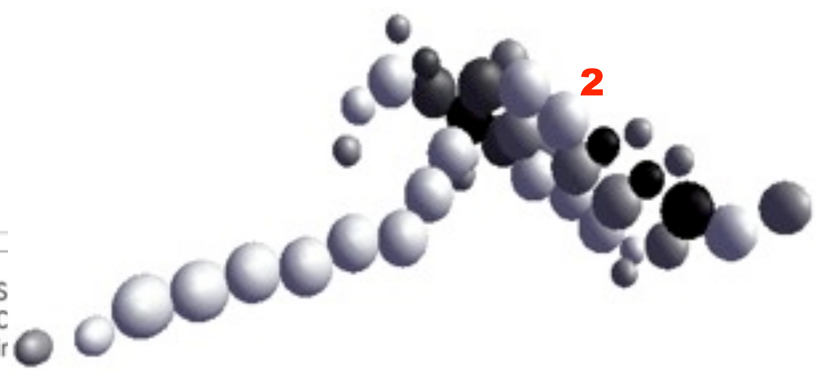
Observations on Bongard's "block pushers"

- 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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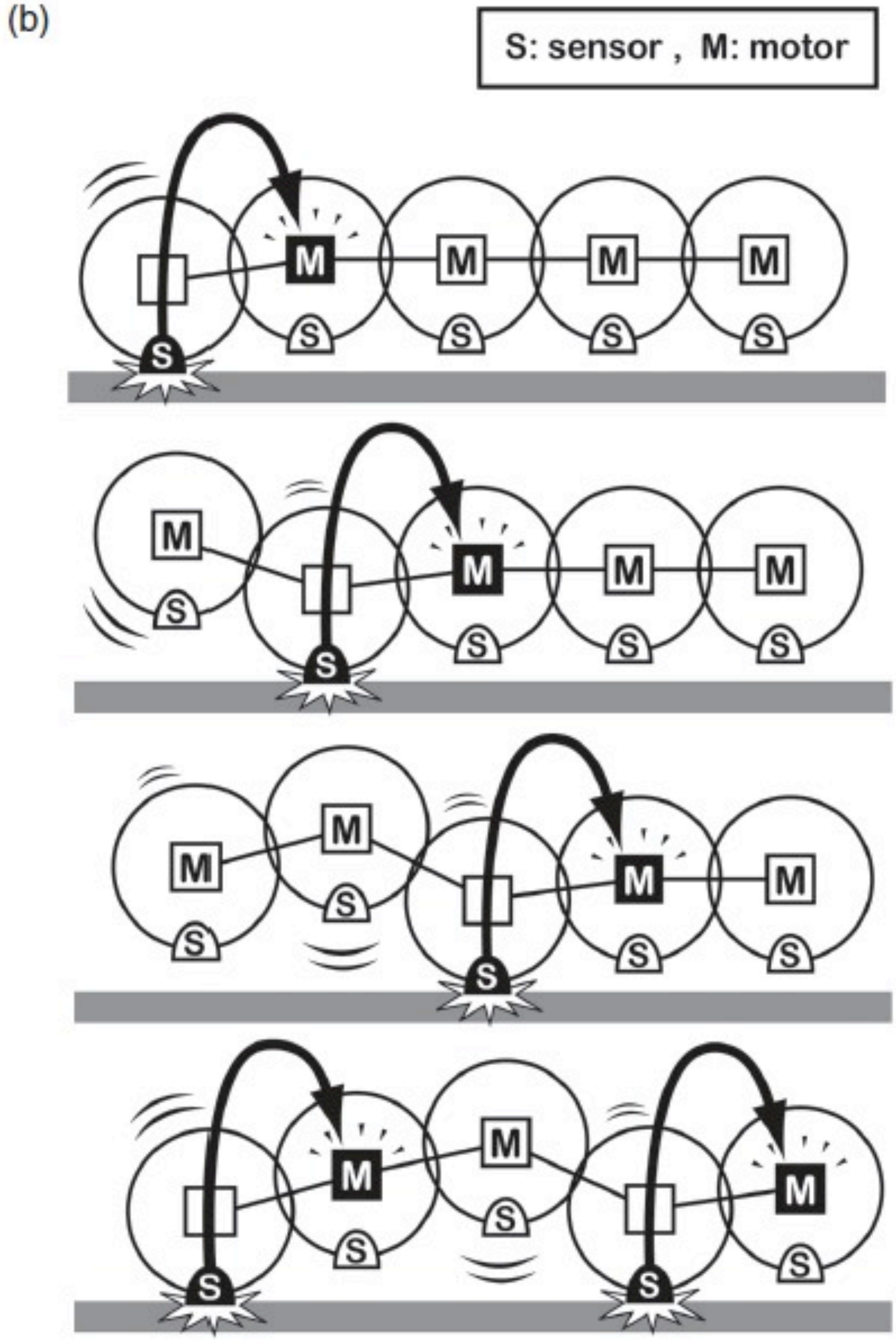
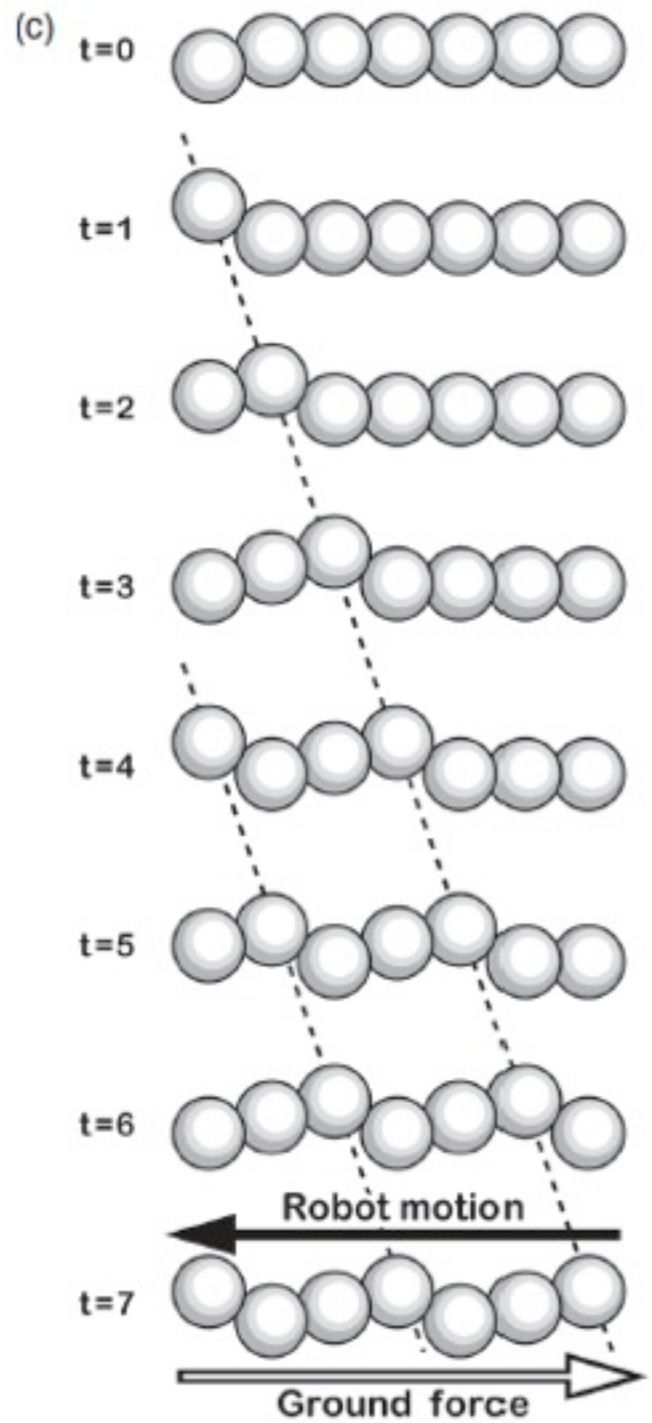
relation between fitness and number of genes. If you look at the fat gray line, i.e. the average number of genes/agent, it increases initially; the maximum fitness jumps at generation 20 and stays the same until about generation 120. Slightly before this jump, the average number of genes/agent decreases and later slowly increases again. So, there is no direct correlation between number of genes and fitness (because of the connectivity of the GRNs.).

Emergence of locomotion through local reflexes





from "How the body …"

Try to figure out how, through these local reflexes, the agent starts moving forward, for details, please consult "How the body …"

Representation of "gene"

nc: "non-coding region"

nc	G1	nc	G2	nc	G3	nc	G4	nc

G1, G2, ...: "genes" on "genome"

TF: "transcription factor"

nc	nc	Pr	P1	P2	P3	P4	P5	nc	nc
0.14	0.31	0.03	0.81	0.08	0.03	0.23	0.74	0.24	0.39

P1	P2	P3	P4	P5
TF37	TF2	0.03	0.23	0.74

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