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The  
ShanghAI  
Lectures

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# Video clips, demonstrations

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- **Video: Karl Sims' evolved creatures**
- **Video: Josh Bongard's “Block Pusher”**
- **Video: JB Mouret's “Evolution of modularity”**





# 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 - 9:15 Short intro + remaining site presentations (Osaka, Pisa, Madrid, Plymouth)**

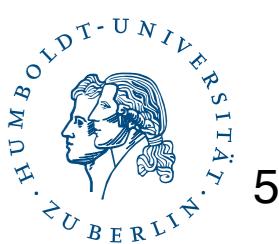
**9:15 - 10:00 Lecture 4:  
Evolution: cognition from scratch (Verena Hafner, HU Berlin)**

**10:00 Discussion and Coffee break**

**10:15 Guest lecture "Challenges and perspectives on morphology changing robots" by Fumiya Iida, Cambridge, UK**

**11:00 Wrap up**

**11:15 End**

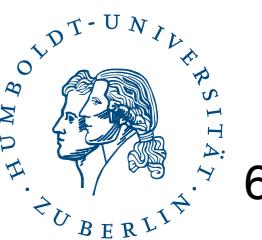


# Lecture 4

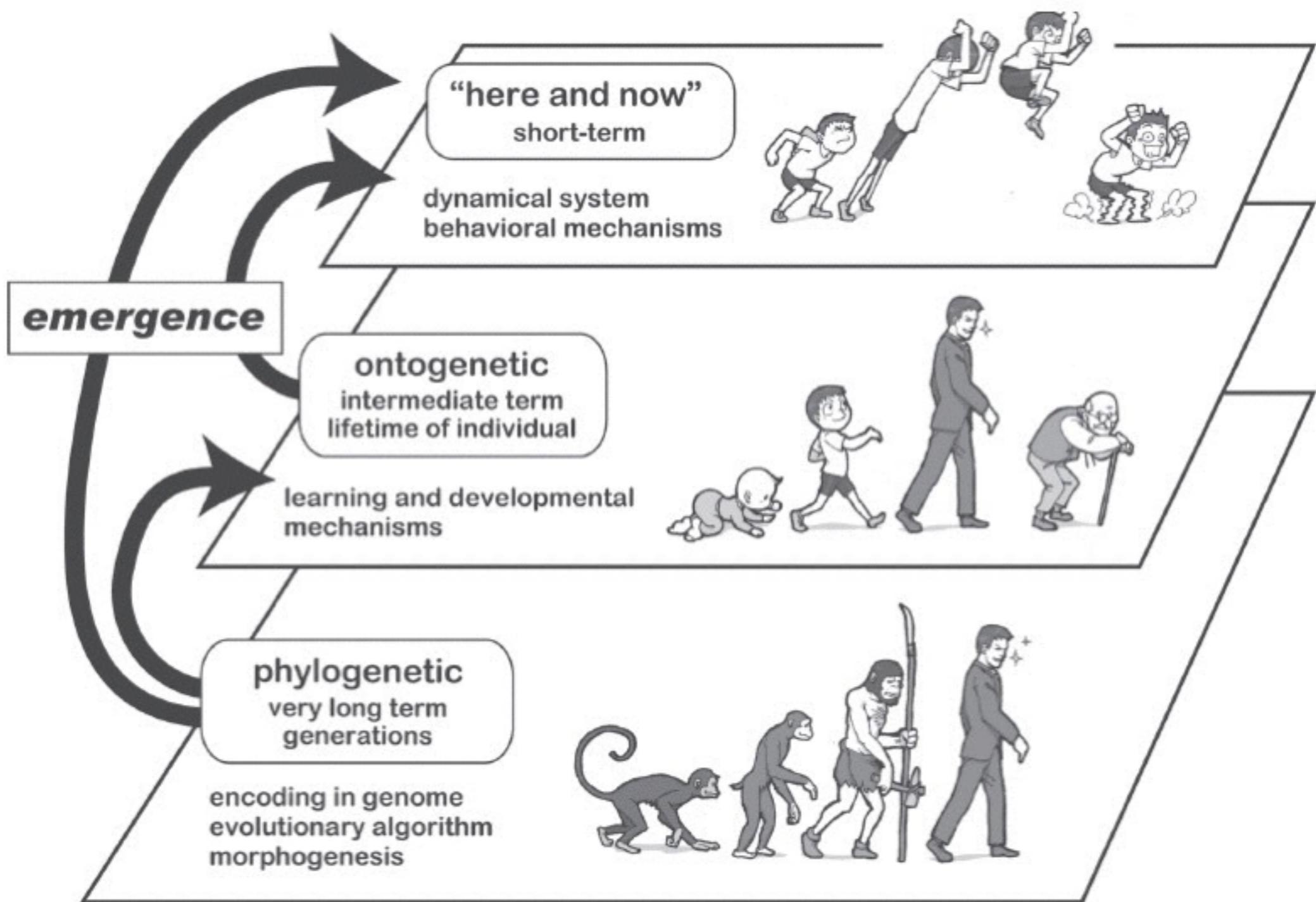
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**Evolution:  
Cognition from scratch**

**5th November 2015**



# Time perspectives



# Time perspectives in understanding and design

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state-oriented

**“hand design”**

learning and development

**initial conditions, learning and developmental processes**

evolutionary

**evolutionary algorithms,  
morphogenesis**

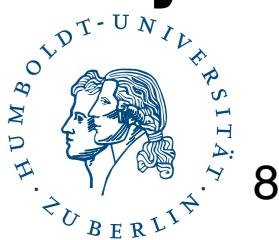
“here and now” perspective

“ontogenetic” perspective

“phylogenetic” perspective

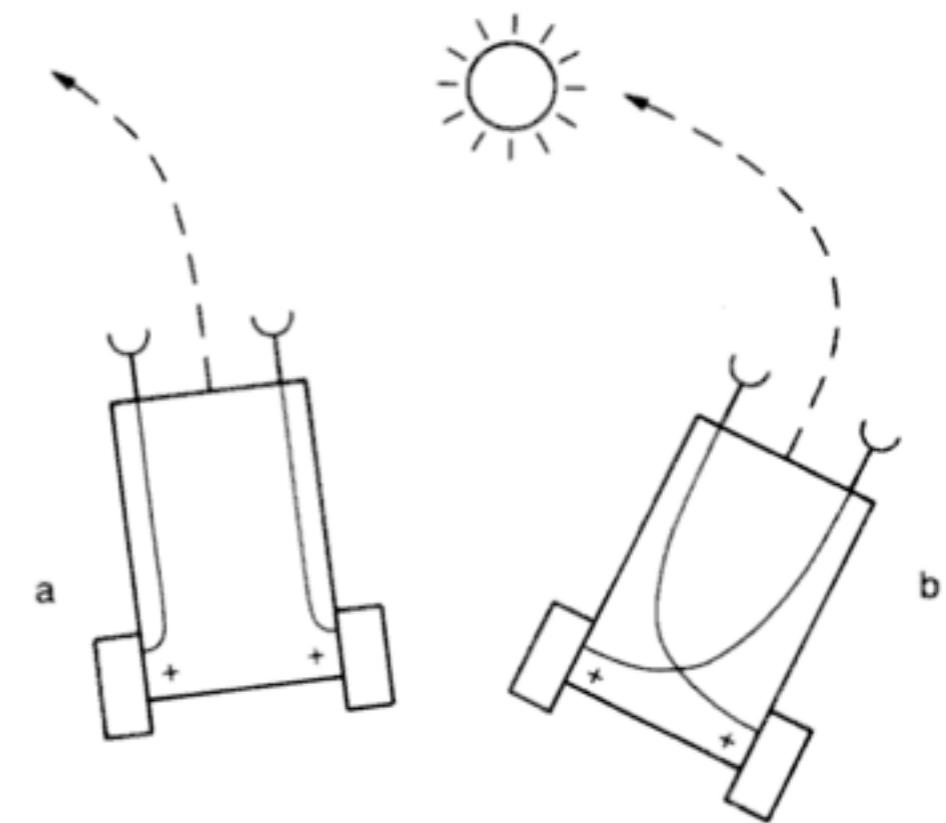
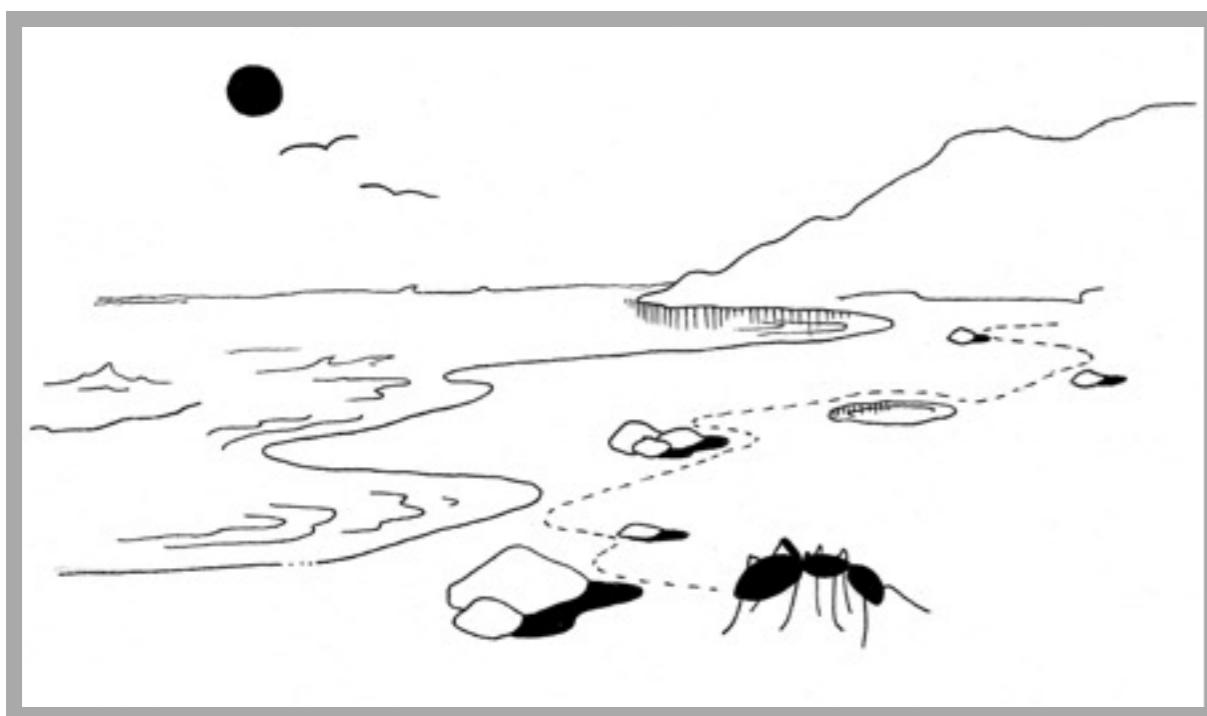
Understanding: **all three perspectives required**

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

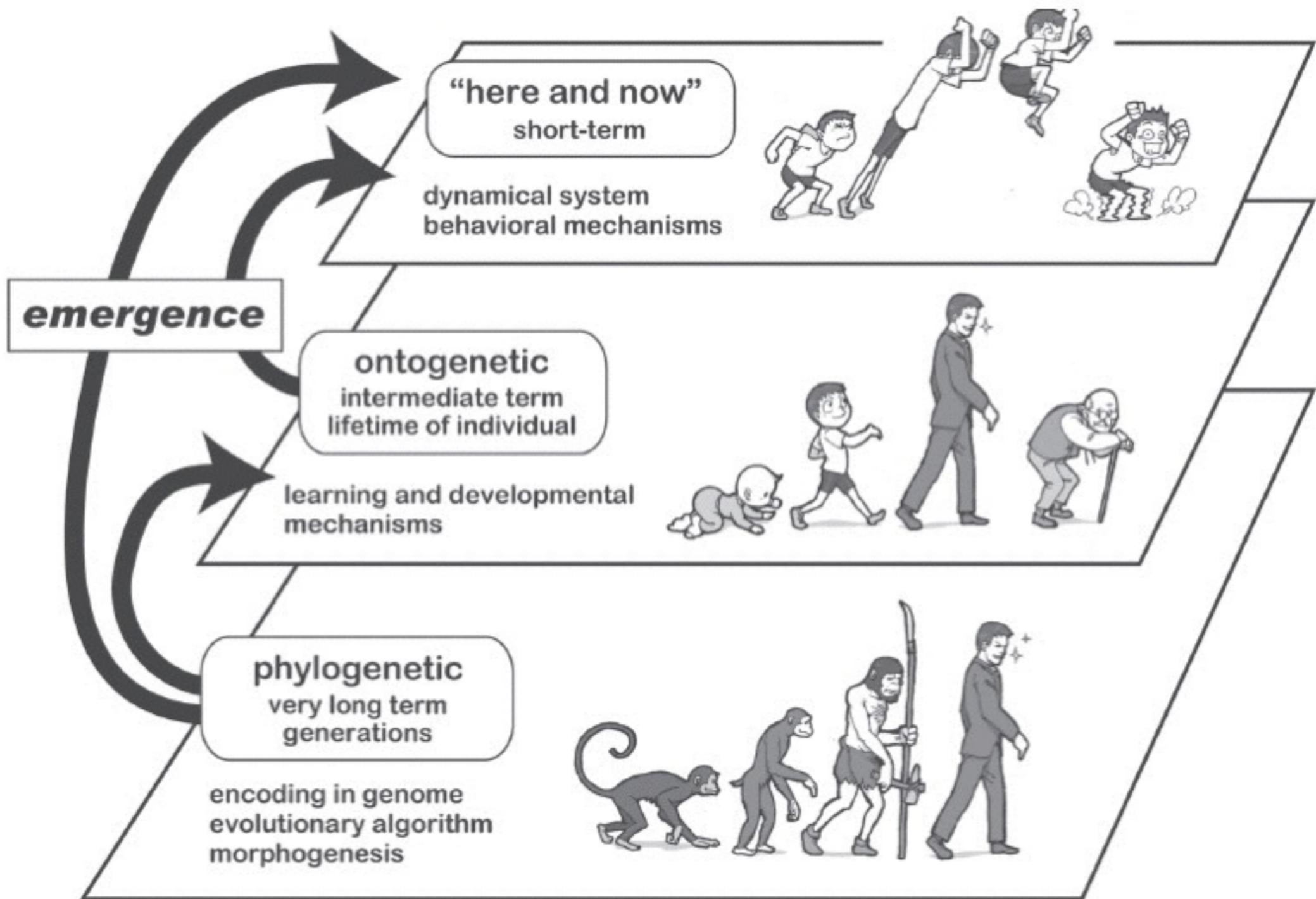


# here&now Perspective

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# Time perspectives



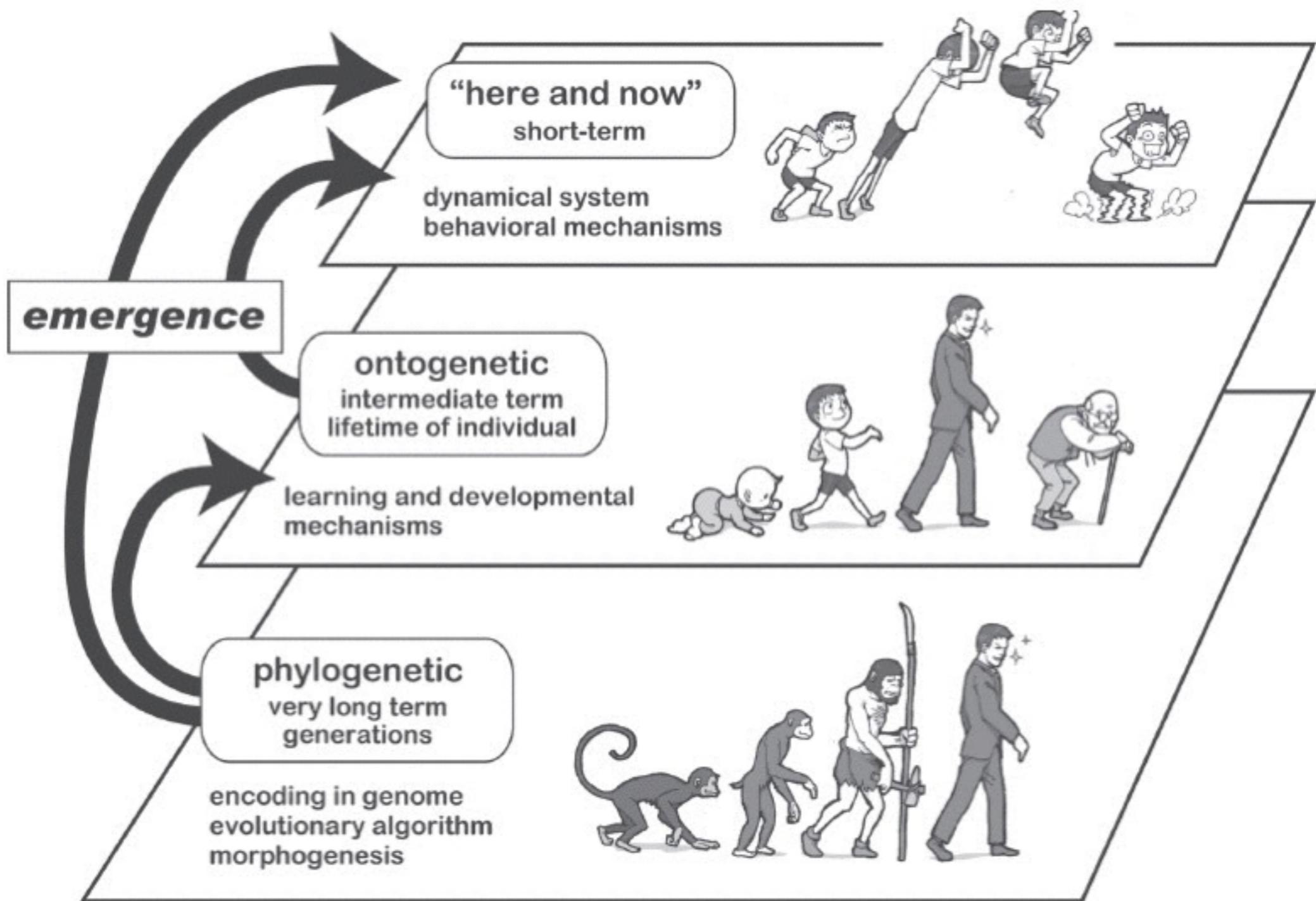
# Ontogenetic Perspective

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**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.*

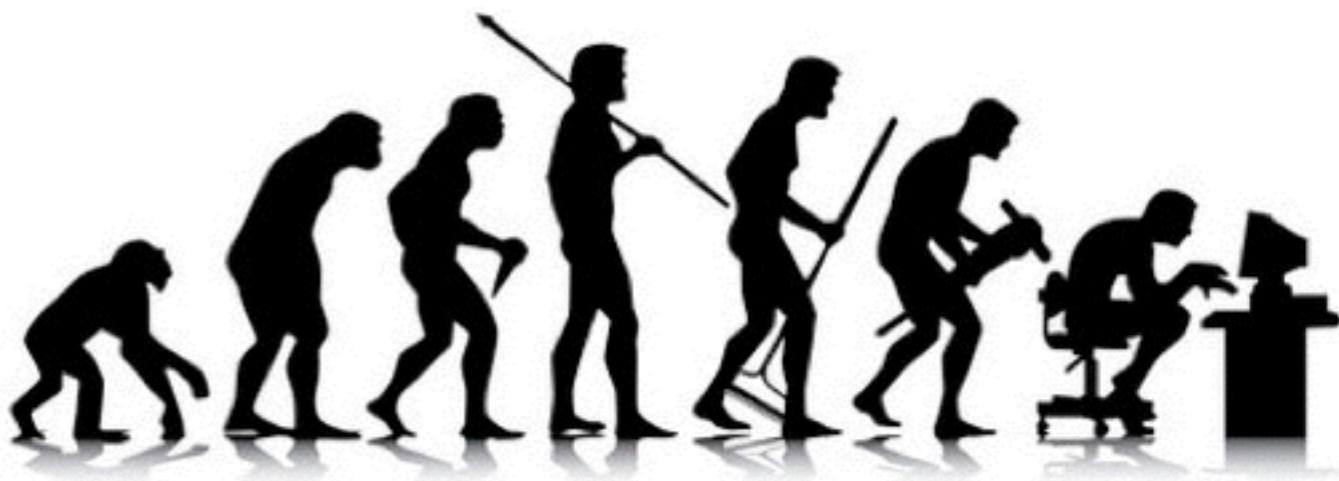
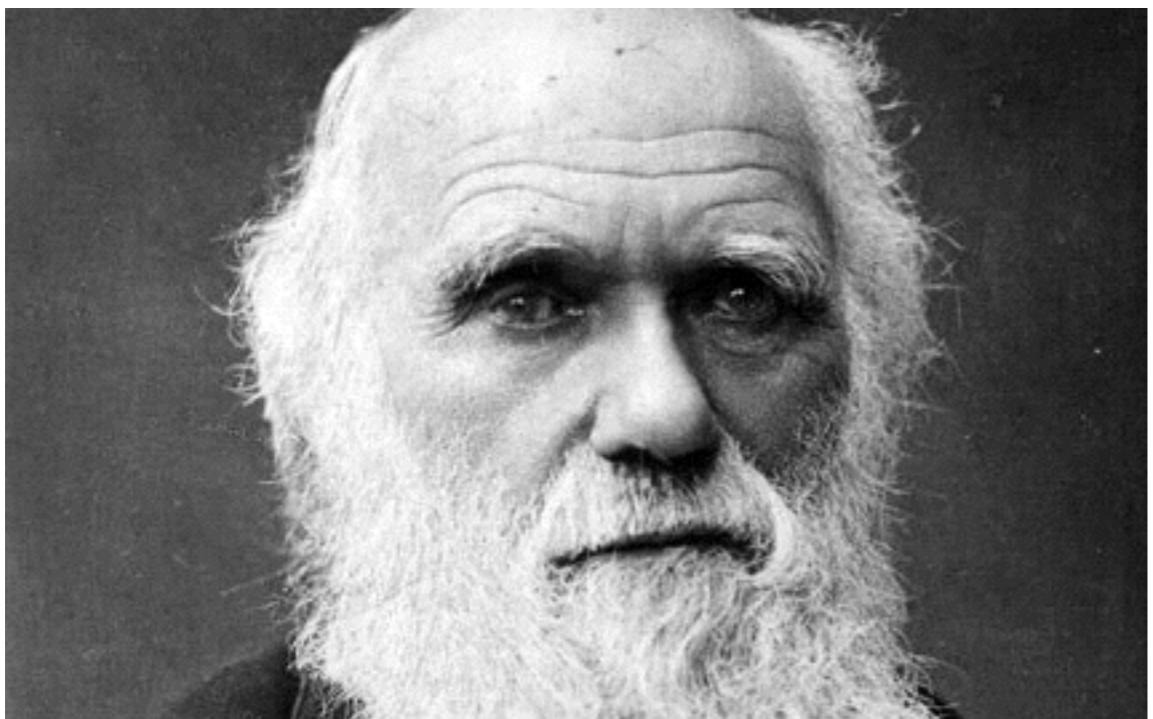
# Time perspectives



# Phylogenetic Perspective

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## Evolution

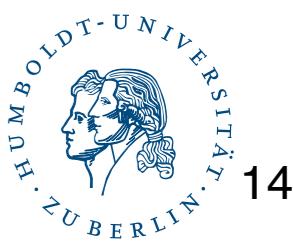


Charles Darwin

# Artificial evolution

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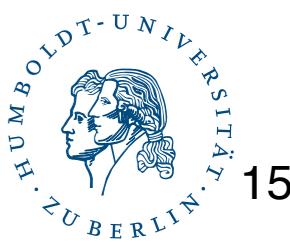
- John Holland
- Ingo Rechenberg
- John Koza



# 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://bionik.tu-berlin.de/>



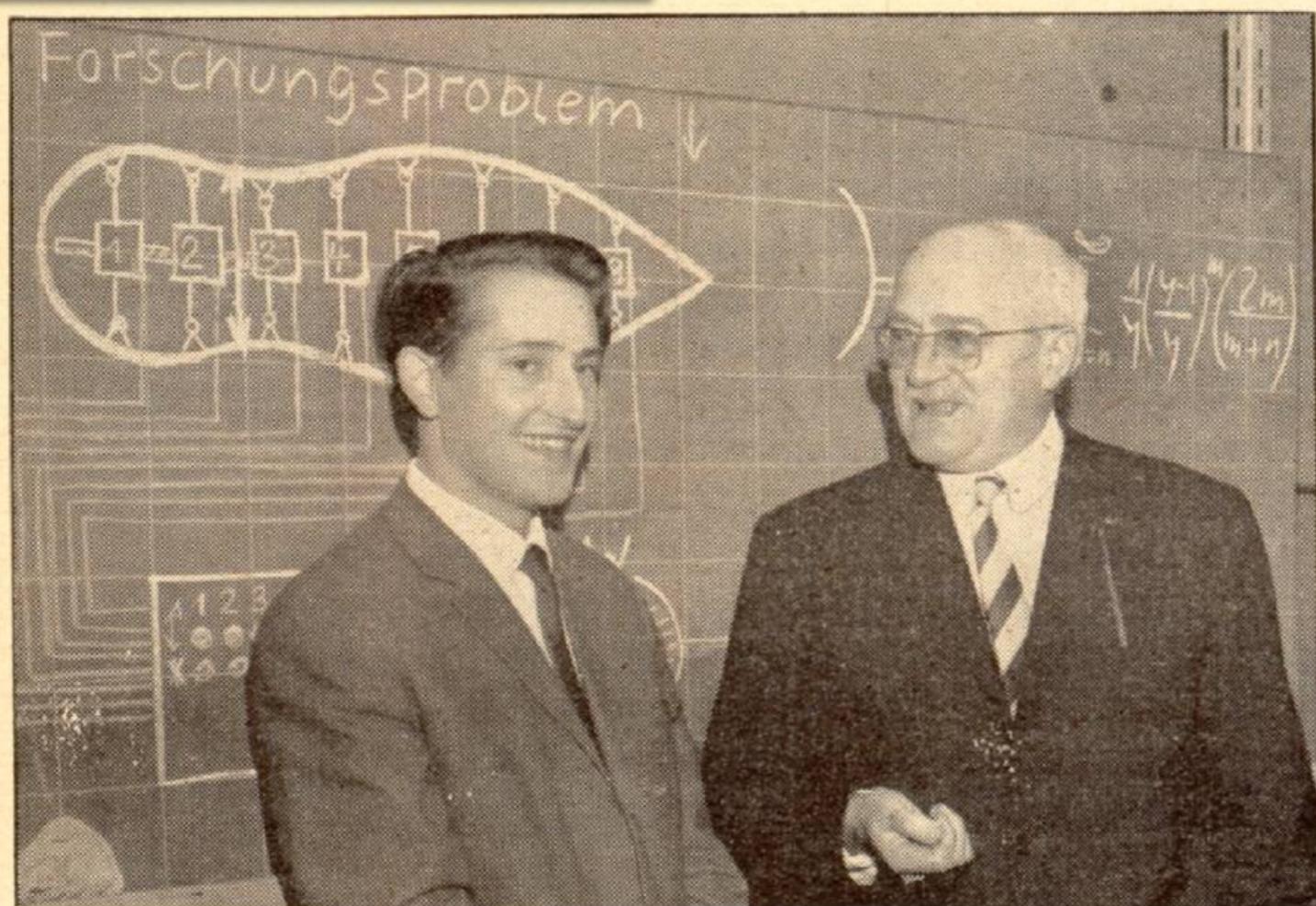
# FORSCHUNG

## AERODYNAMIK

### Zickzack nach Darwin

Der Eingebung und oftmals auch glücklichem Zufall verdanken Generationen von Flugzeugtechnikern zukunftsweisende Lösungen. Aber ein Student der Technischen Universität in West-Berlin möchte den Fortschritt kalkulabel machen: Er fand für das Roulette-Spiel der Flugzeugingenieure ein System.

Zahllose aufwendige Versuchsreihen in mietshausgroßen Windkanälen, deren Bau Millionen Dollar kostet und in denen Mammut-Flügelräder leichte Brise ebenso wie heulenden Orkan oder mehrfach schallschnelle Luftströme erzeugen können, sind bei den großen Flugzeugfirmen nötig, um für ein neues



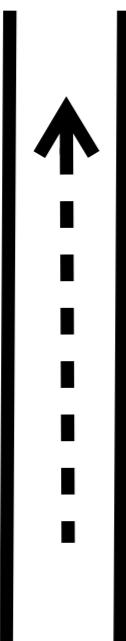
Student Rechenberg, Lehrer Wille\*: Roulette in der Hochschule

**DER SPIEGEL**

18. November 1964

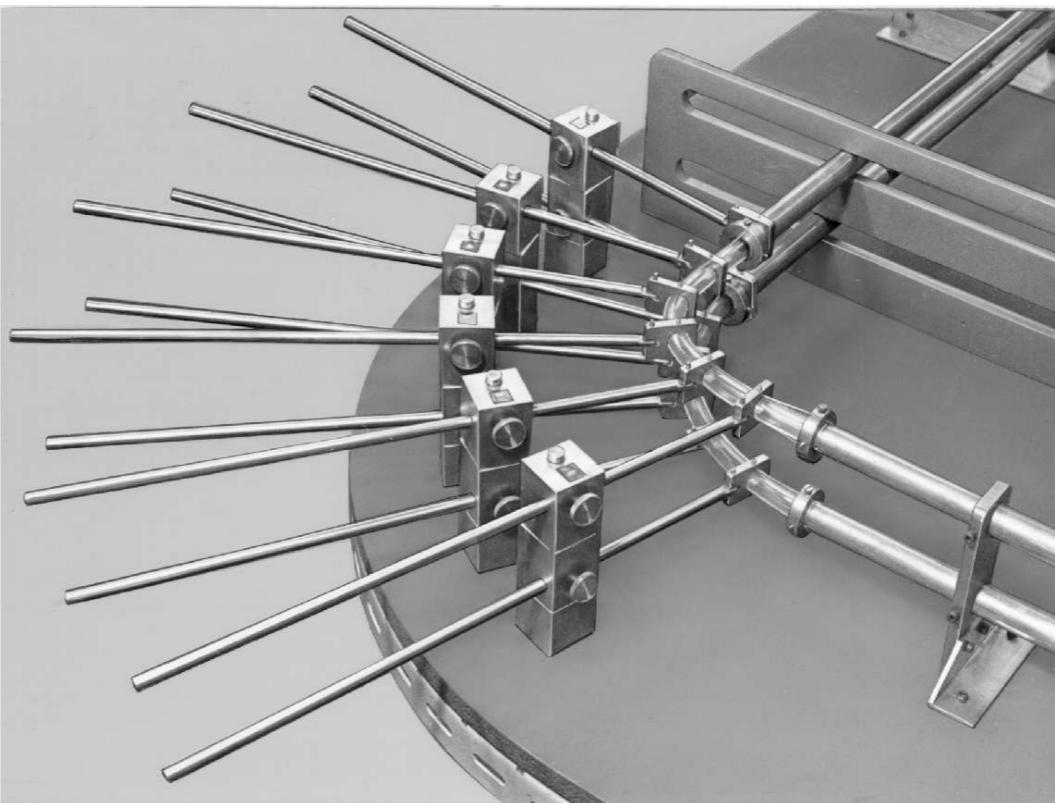
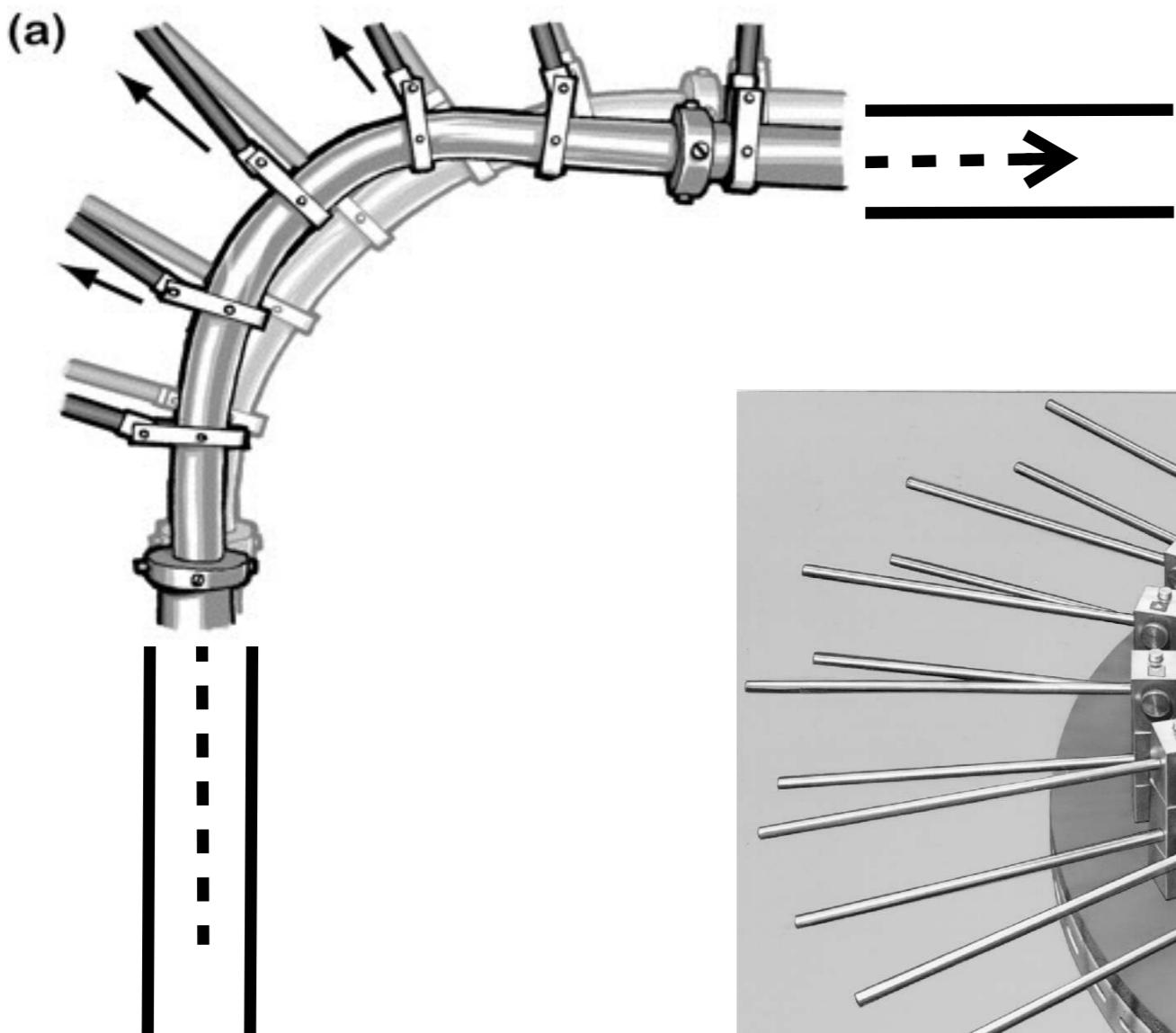
# Rechenberg's “fuel pipe problem”

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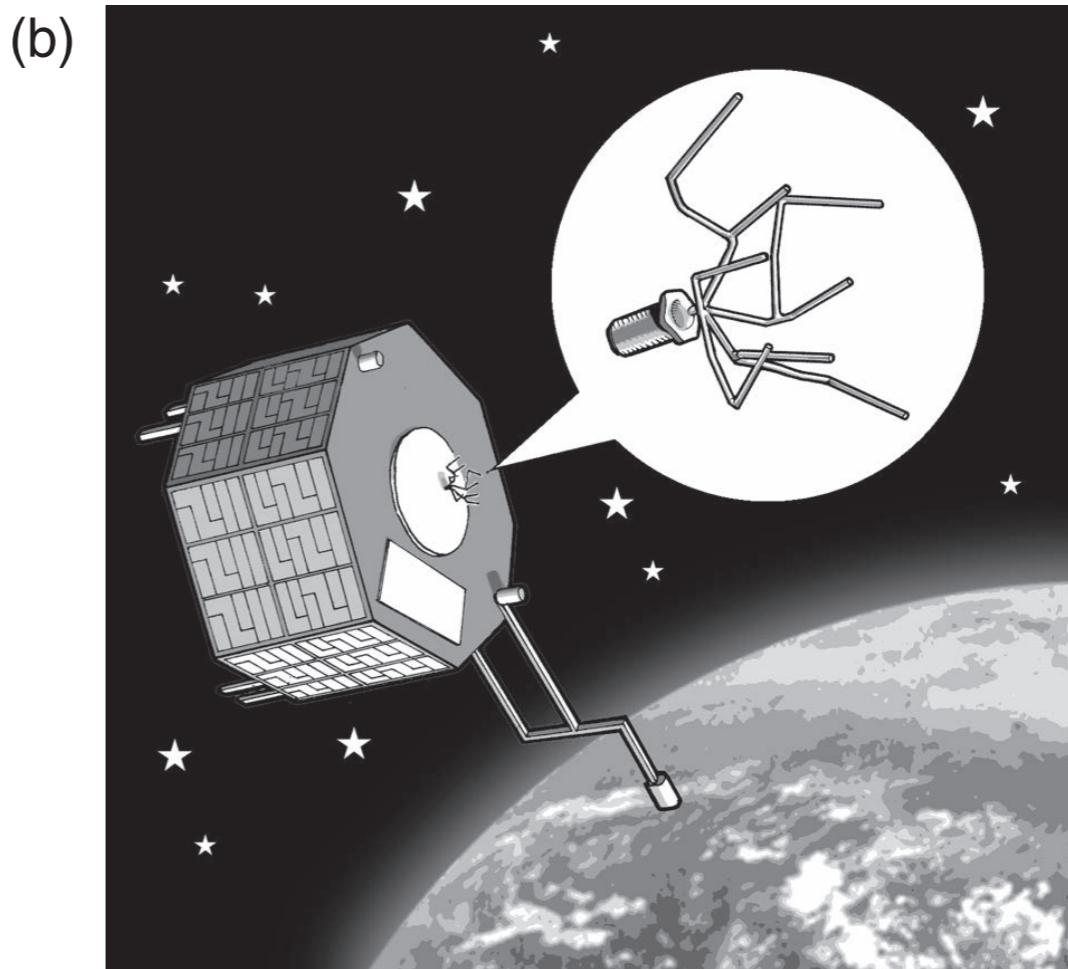
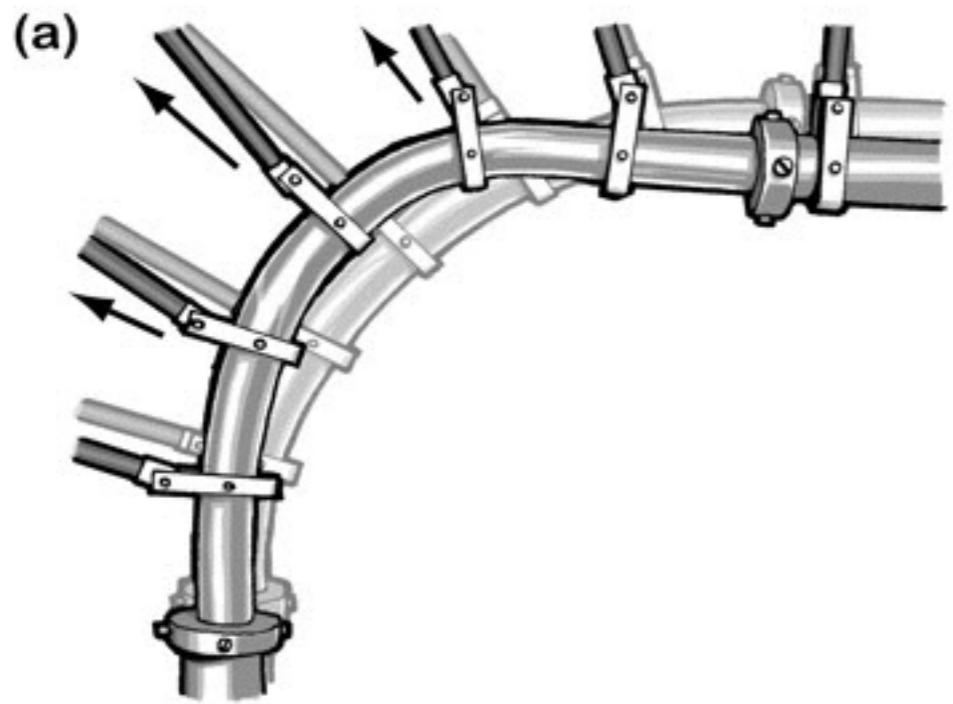
# Rechenberg's “fuel pipe problem”

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1965

# Evolutionary designs



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

# Creativity: Connecting corners of square

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x

x

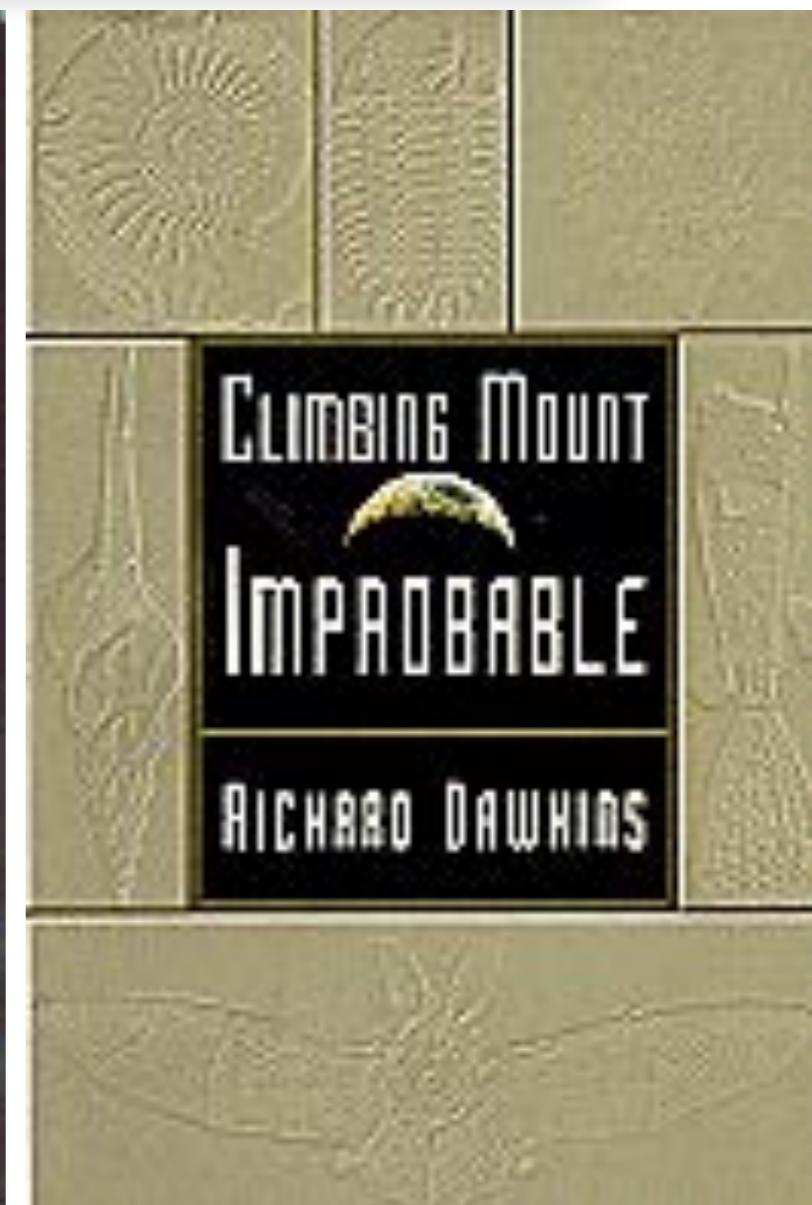
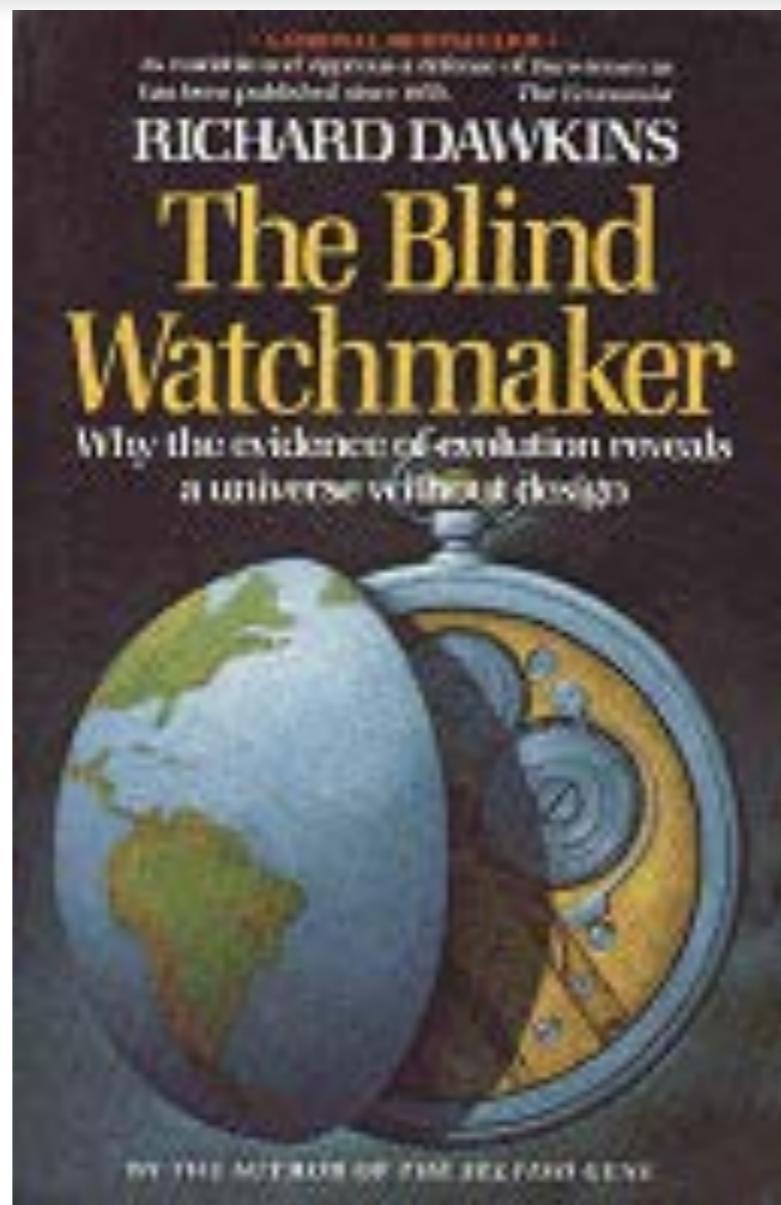
**connect four corners  
of square with three  
straight lines, ending up  
in the starting corner**

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?

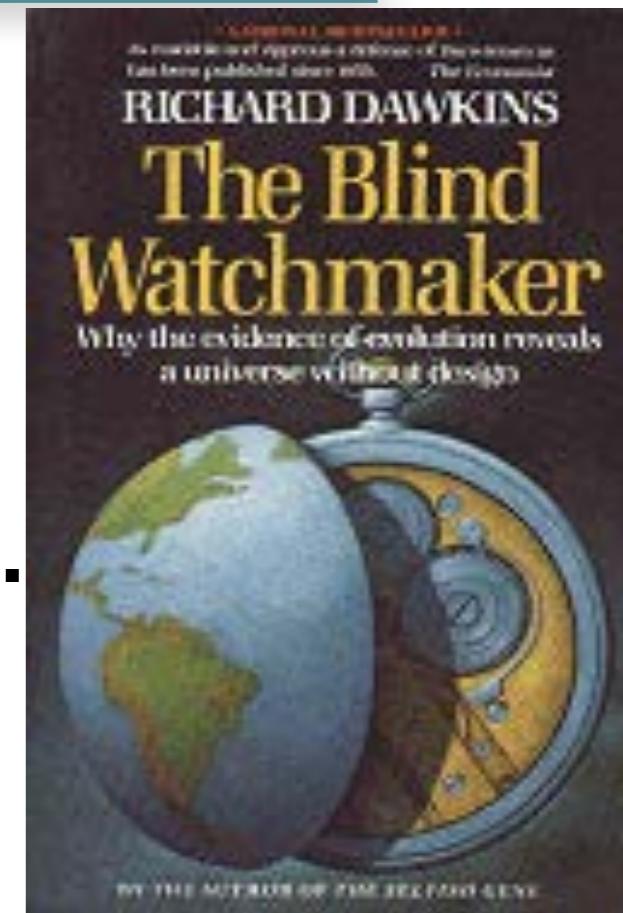
Polonius: By the mass, and 'tis like a camel, indeed.

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

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

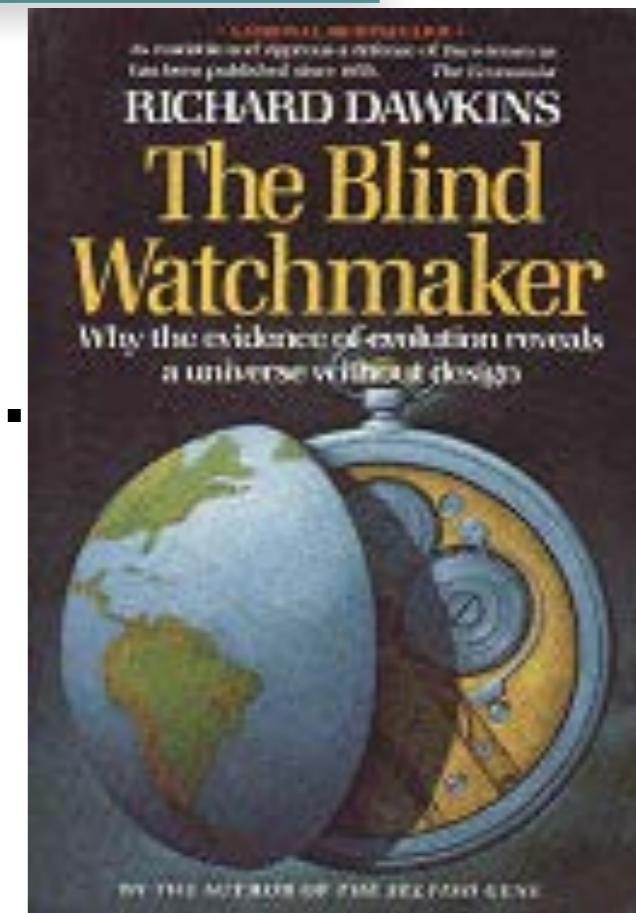
Polonius: By the mass, and 'tis like a camel, indeed.

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

```

from string import letters
from random import choice, random

target = list("METHINKS IT IS LIKE A WEASEL")
charset = letters + ' '
parent = [choice(charset) for _ in range(len(target))]
minmuterate = .09
C = range(100)

perfectfitness = float(len(target))

def fitness(trial):
    'Sum of matching chars by position'
    return sum(t==h for t,h in zip(trial, target))

def muterate():
    'Less mutation the closer the fit of the parent'
    return 1 - ((perfectfitness - fitness(parent)) / perfectfitness * (1 - minmuterate))

def mutate(parent, rate):
    return [(ch if random() <= rate else choice(charset)) for ch in parent]

def que():
    '(from the favourite saying of Manuel in Fawlty Towers)'
    print ("#%-4i, fitness: %4.1f%%, '%s'" %
          (iterations, fitness(parent)*100./perfectfitness, ''.join(parent)))

def mate(a, b):
    place = 0
    if choice(xrange(10)) < 7:
        place = choice(xrange(len(target)))
    else:
        return a, b

    return a, b, a[:place] + b[place:], b[:place] + a[place:]

iterations = 0
center = len(C)/2
while parent != target:
    rate = muterate()
    iterations += 1
    if iterations % 100 == 0: que()
    copies = [mutate(parent, rate) for _ in C] + [parent]
    parent1 = max(copies[:center], key=fitness)
    parent2 = max(copies[center:], key=fitness)
    parent = max(mate(parent1, parent2), key=fitness)
que()

```

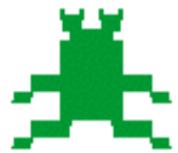
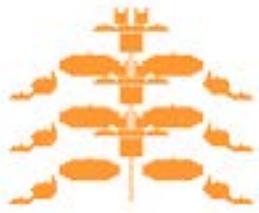
[http://rosettacode.org/wiki/Evolutionary\\_algorithm#Python](http://rosettacode.org/wiki/Evolutionary_algorithm#Python)



# Biomorphs

## The power of esthetic selection

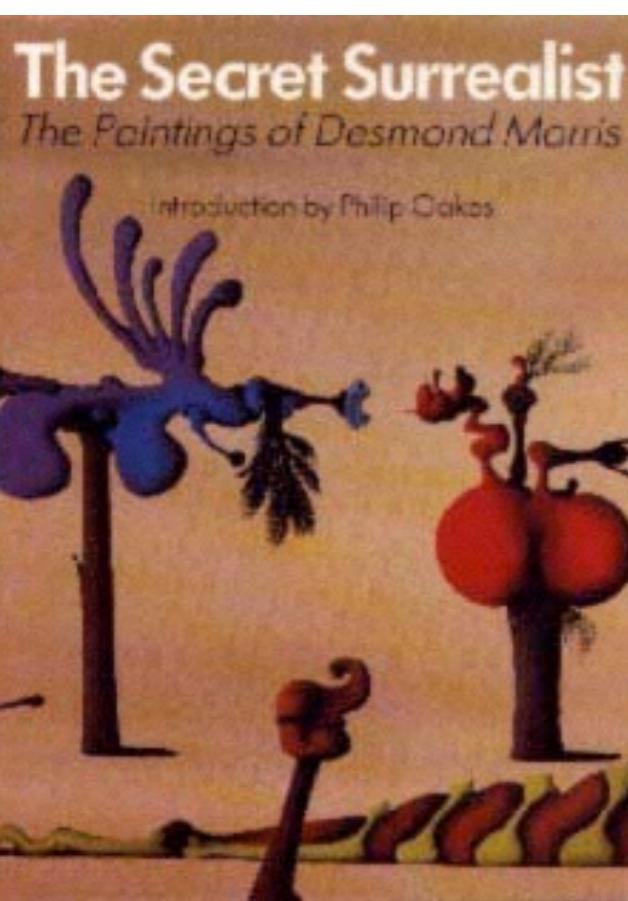
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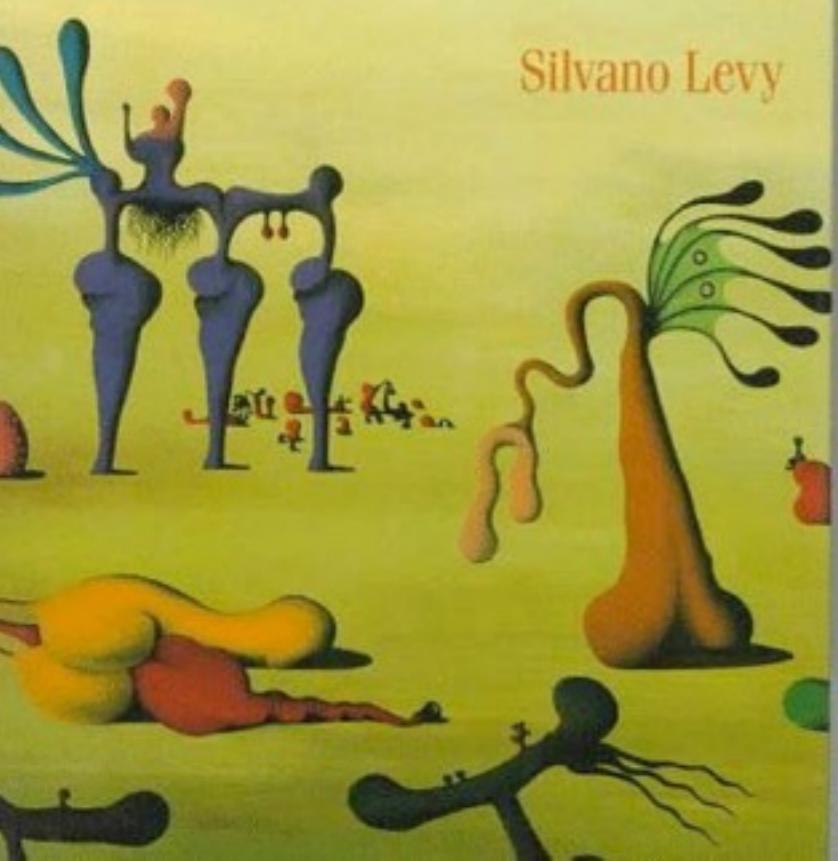
- encoding “creature” in genome (string of numbers)
- expression of “genes” (graphical appearance):
- selection of individuals for “reproduction” (based on “fitness” – esthetic appeal)  
“reproduction” (with mutation)

<http://www.well.com/~hernan/ biomorphs/>

<http://www.emergentmind.com/ biomorphs>

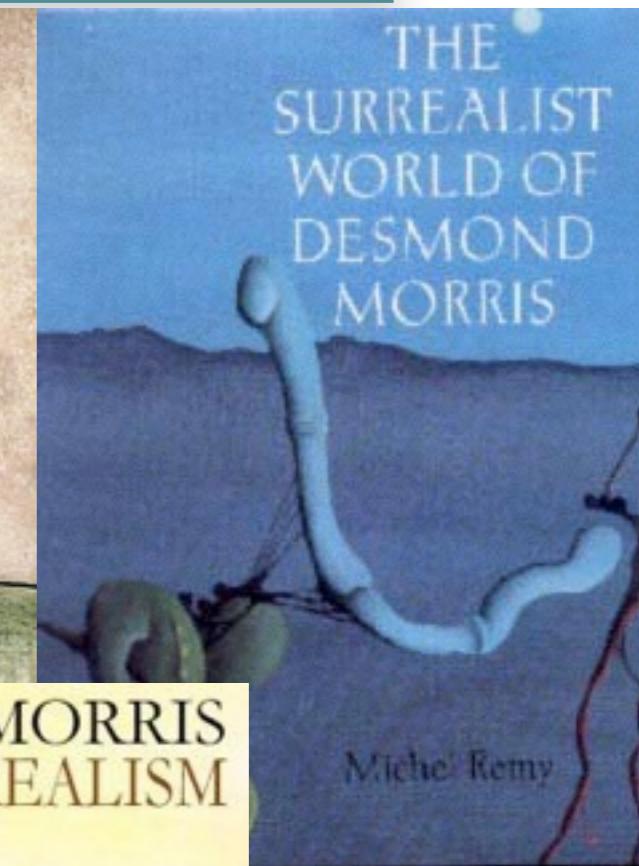
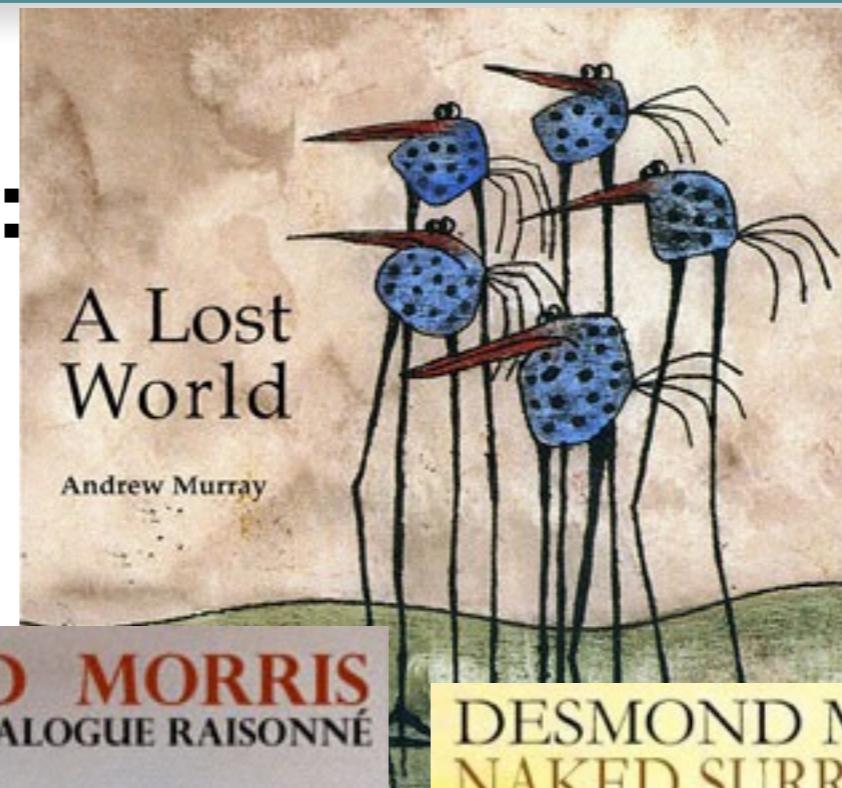


DESMOND MORRIS  
50 YEARS OF SURREALISM

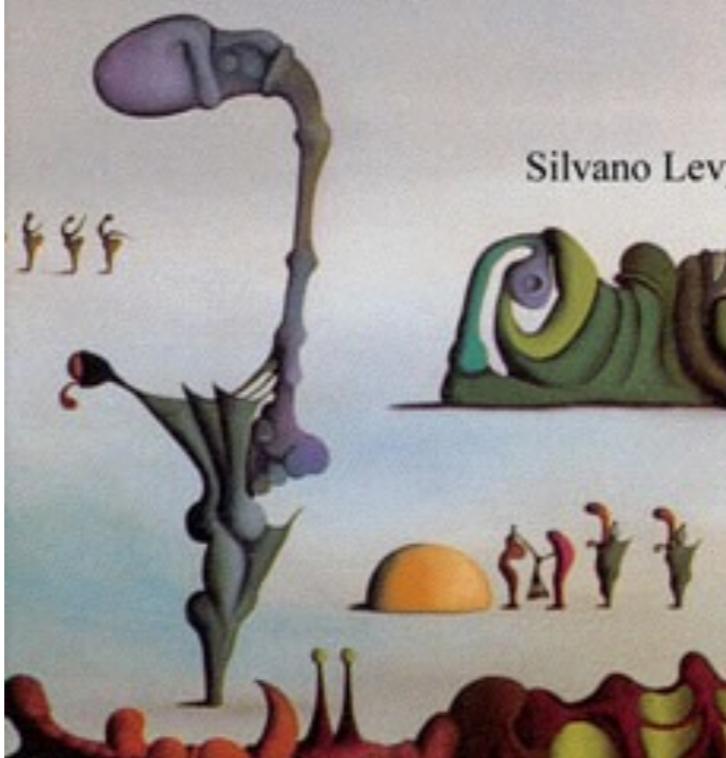


# Biomorphs: by surrealist painter Desmond Morris

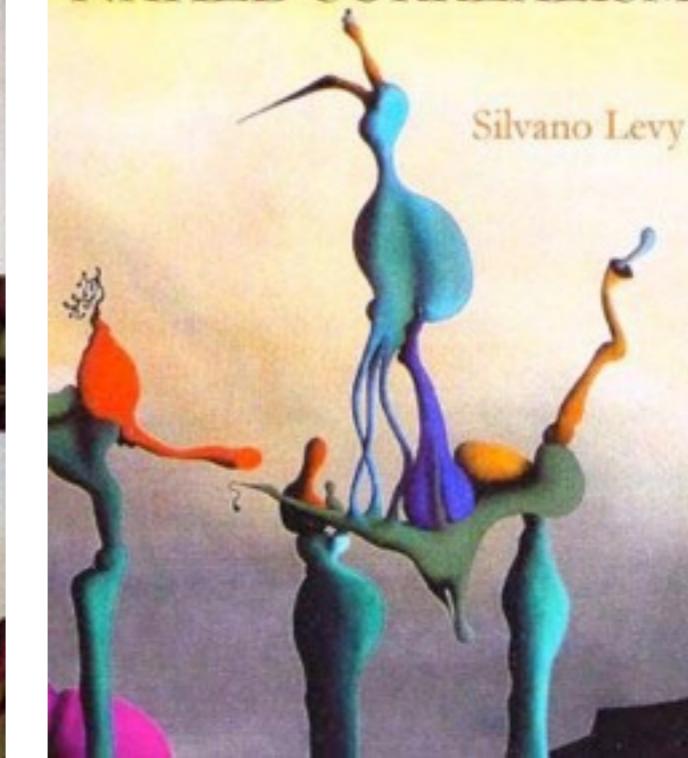
exhibitions:  
1948 - 2008



DESMOND MORRIS  
ANALYTICAL CATALOGUE RAISONNÉ

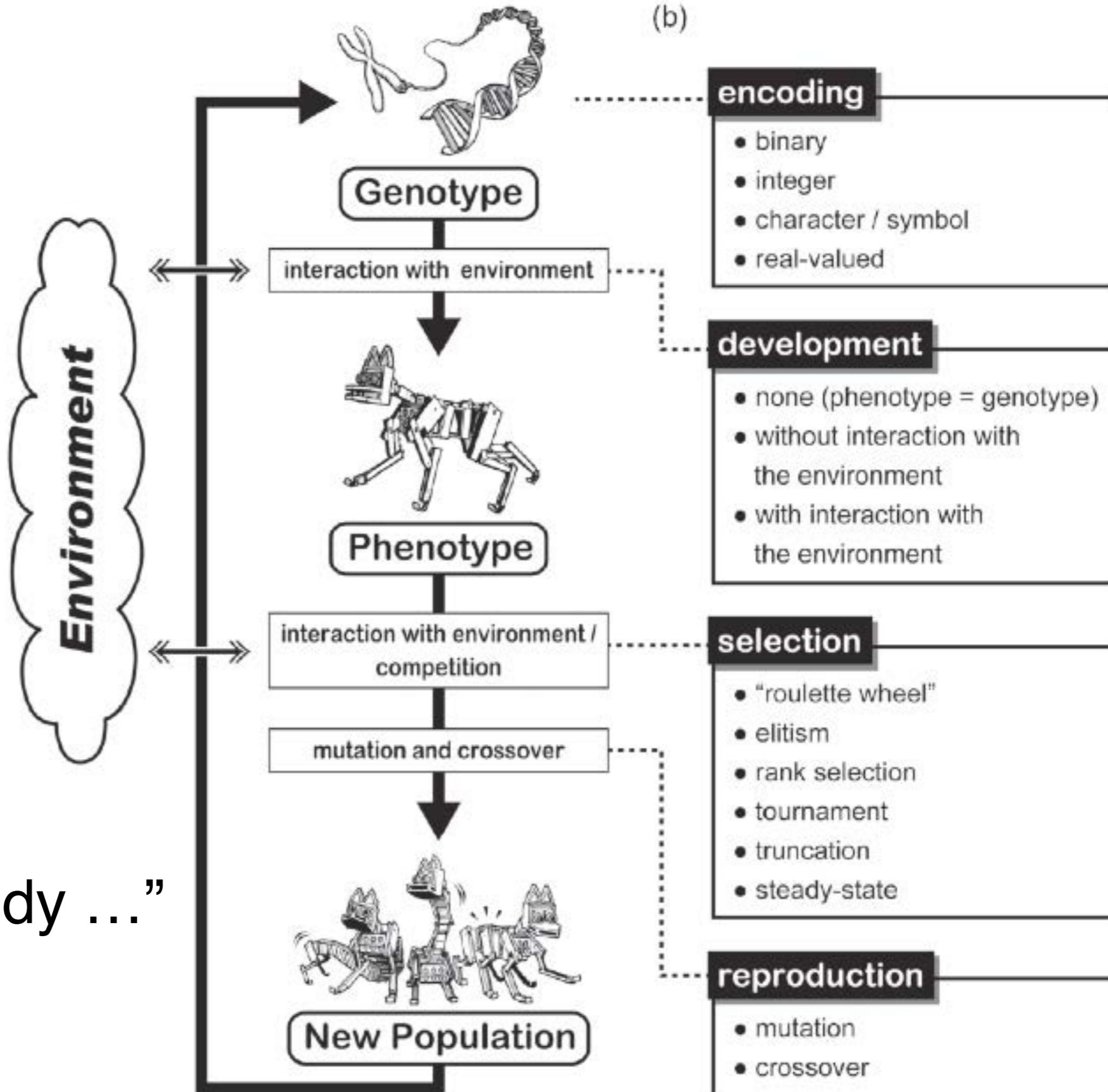


DESMOND MORRIS  
NAKED SURREALISM

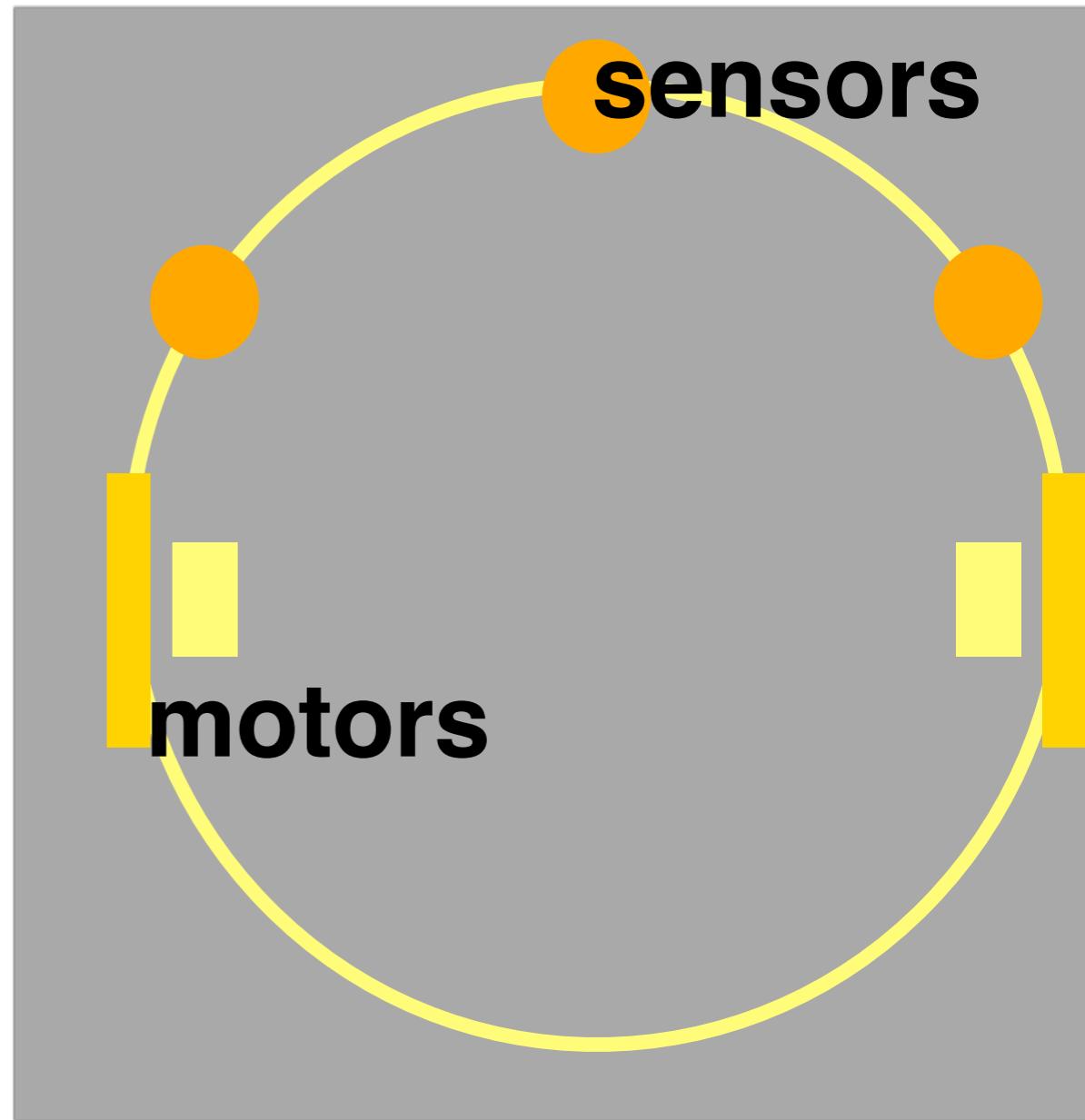


# Basic cycle for artificial evolution

from  
“How the body ...”



# Evolving a neural controller



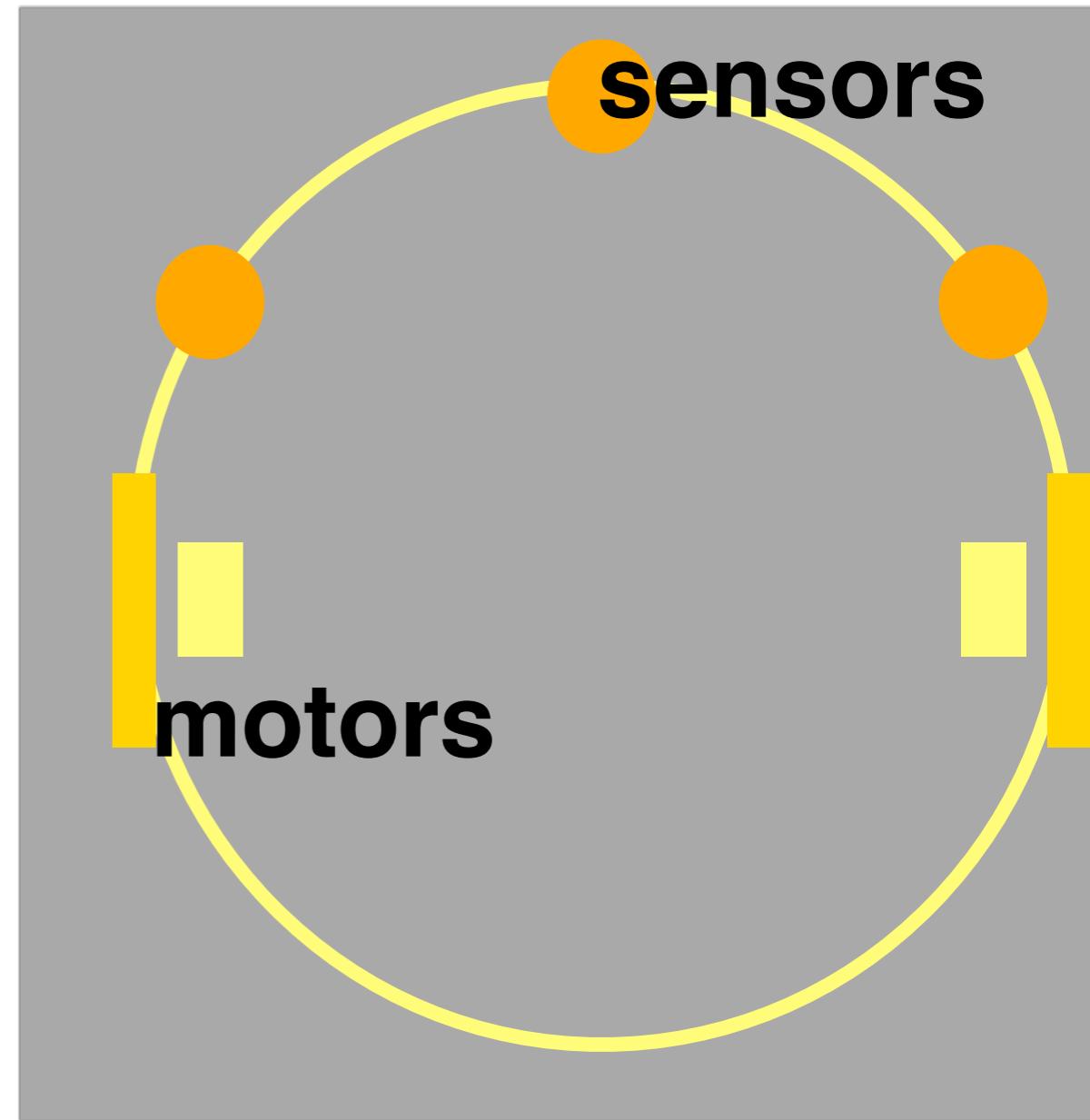
# Evolving a neural controller

What do we need to specify?

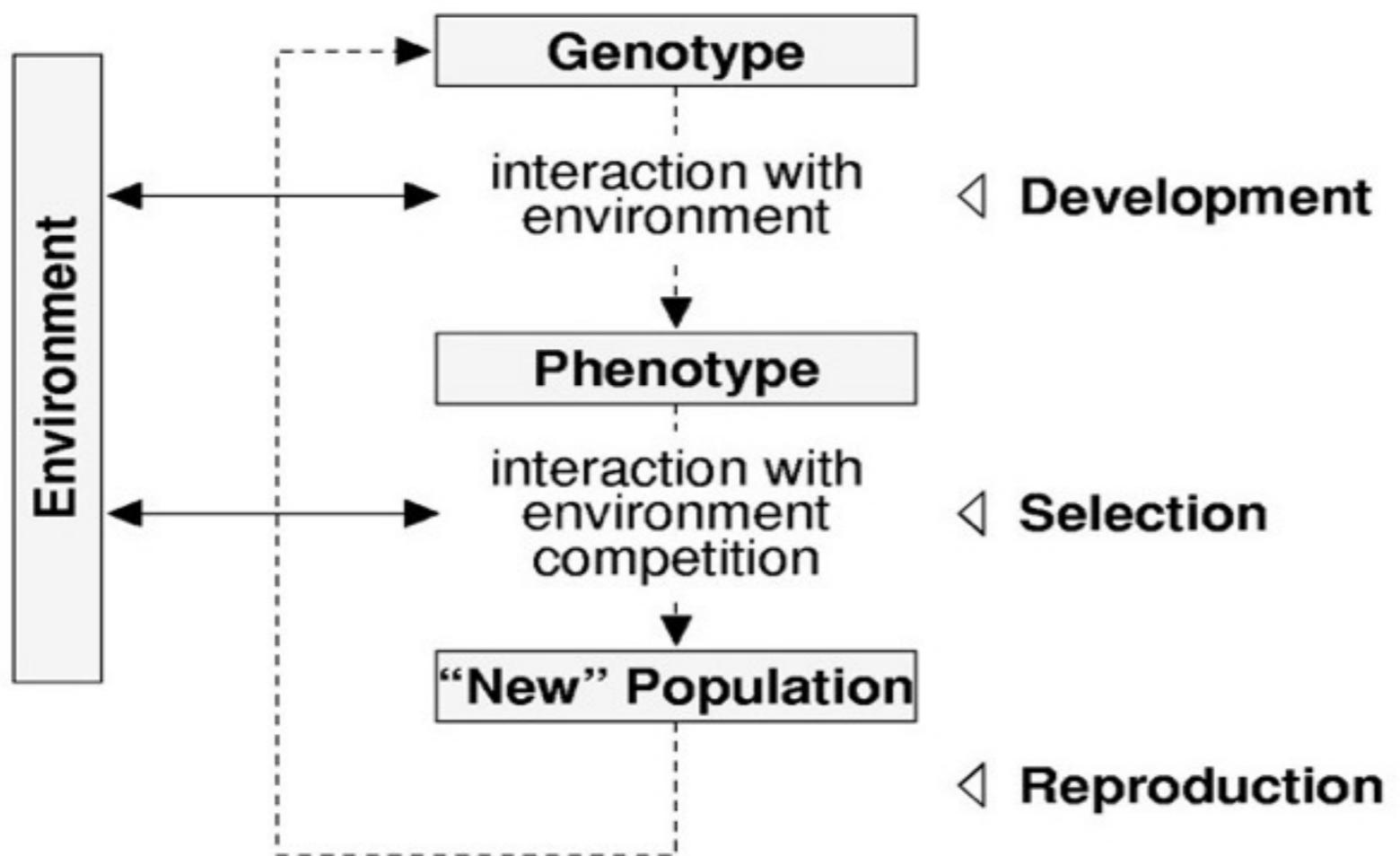
given: 2 motors, 3 sensors

(encoding in genome?)

behaviour, fitness?



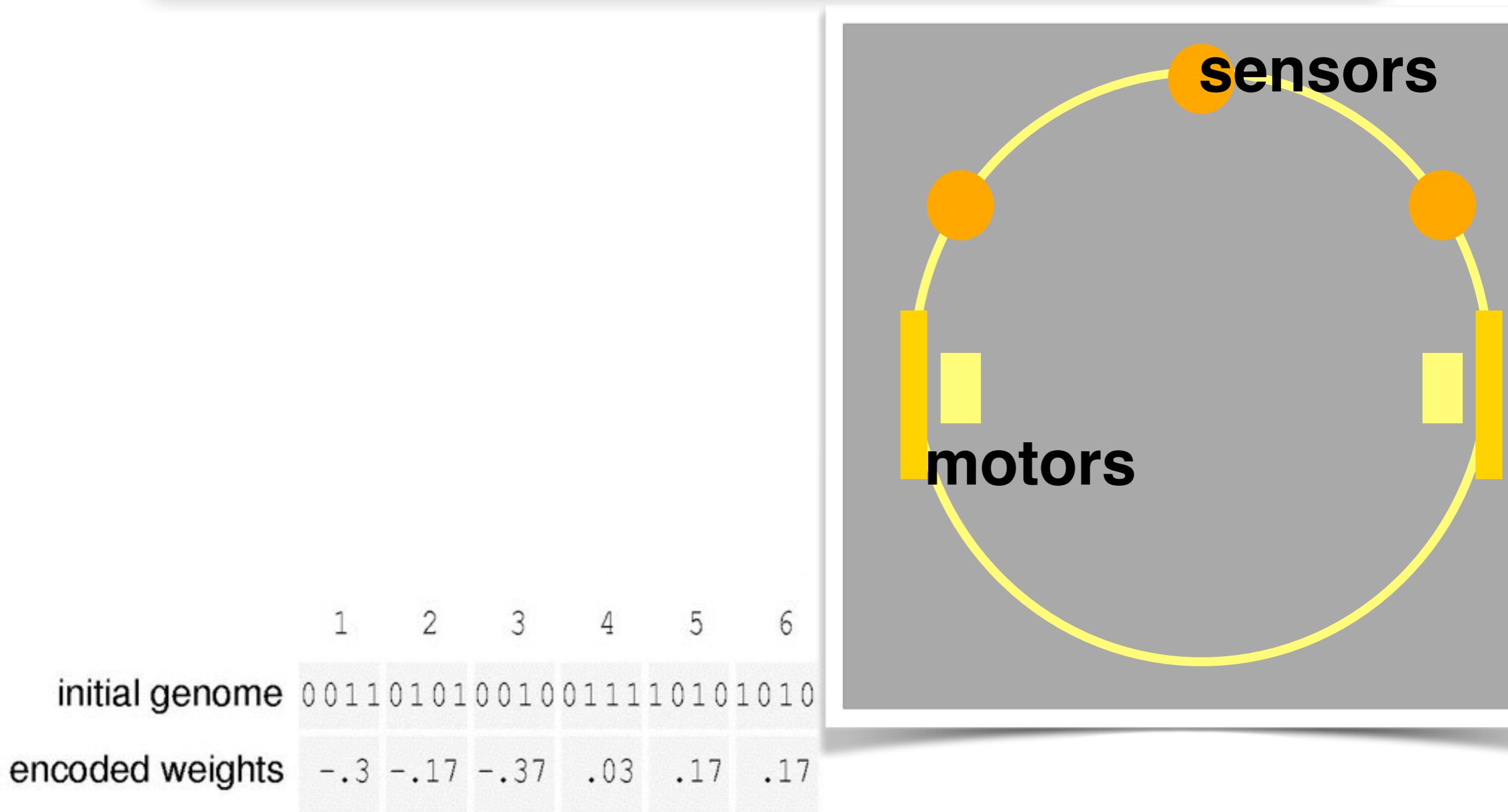
# TASK: think of an evolutionary process for this little robot



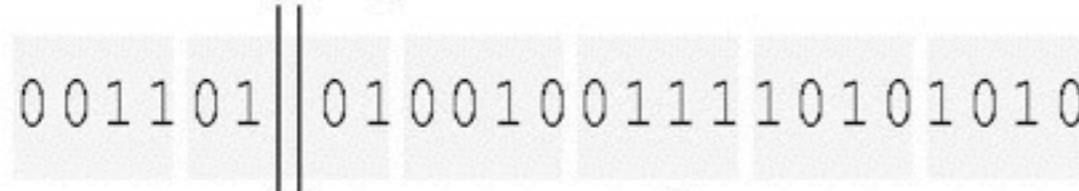
encoding	development	selection	reproduction
<ul style="list-style-type: none"><li>• binary</li><li>• many-character</li><li>• real-valued</li></ul>	<ul style="list-style-type: none"><li>• no development (phenotype = genotype)</li><li>• development with and without interaction with the environment</li></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>

# Encoding in genome

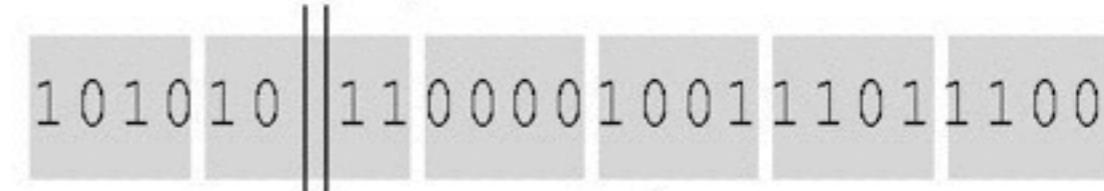
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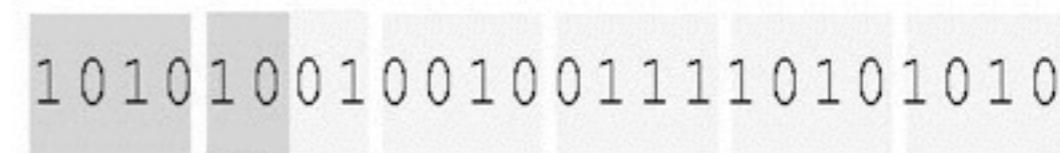
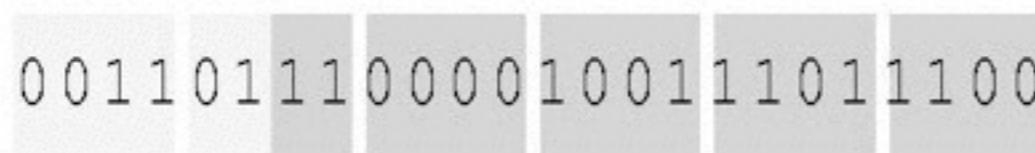
crossover point



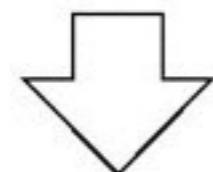
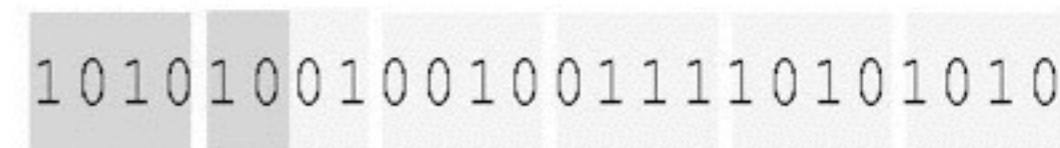
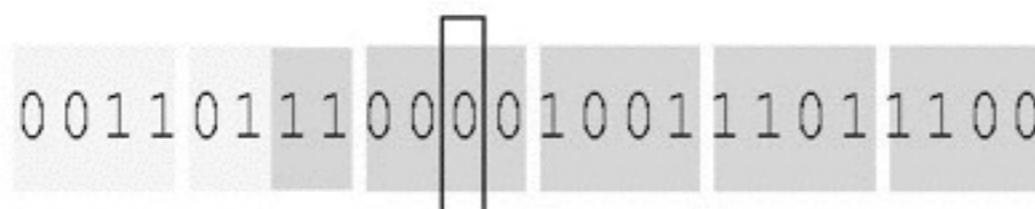
crossover point



## Reproduction: crossover and mutation



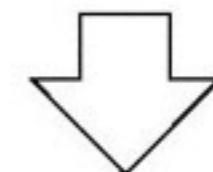
mutation



gene expression

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

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



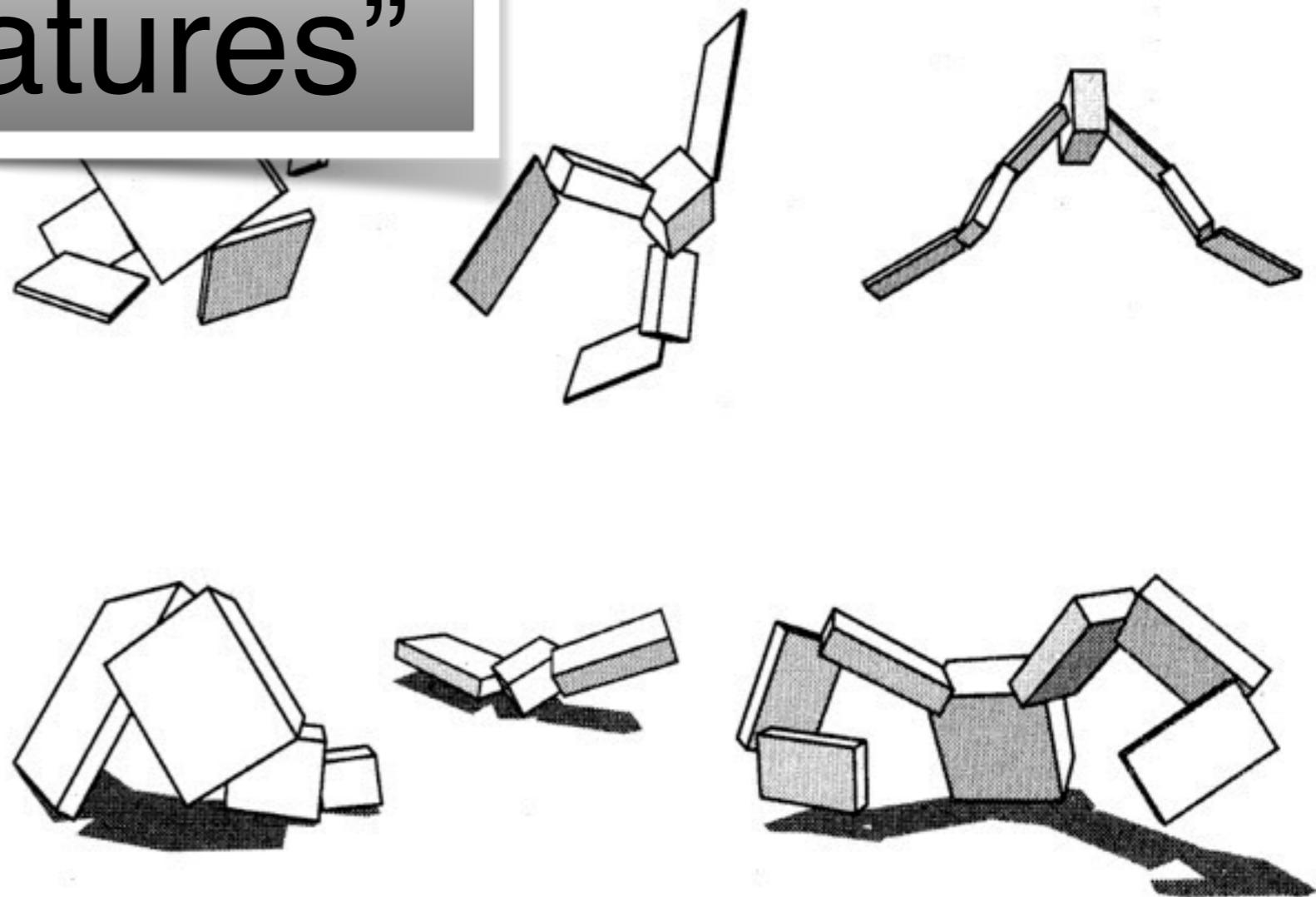
# Approaches to evolutionary robotics

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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

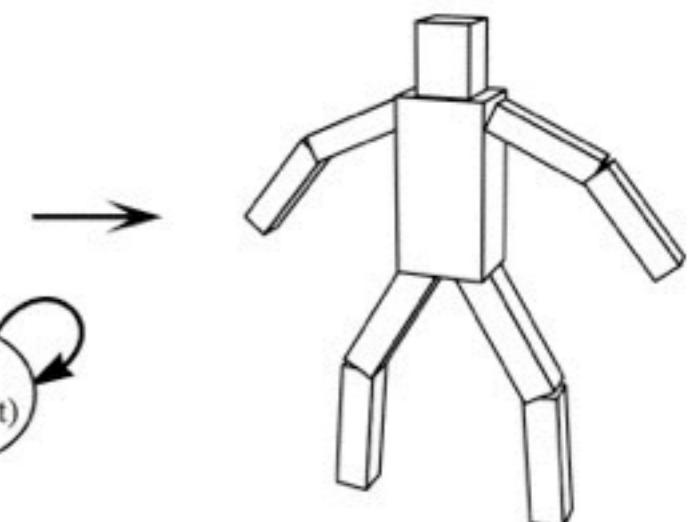
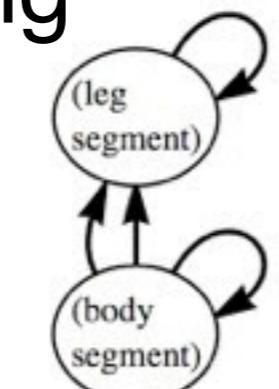
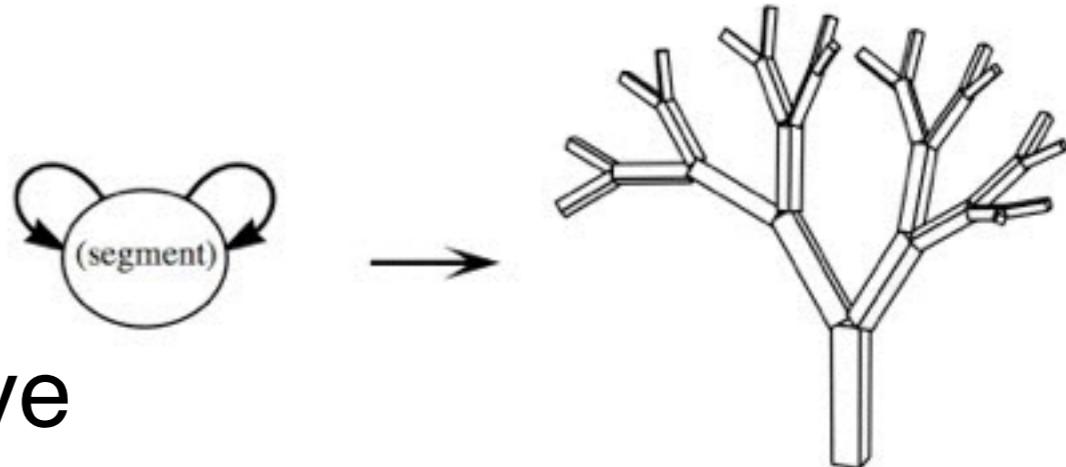
encoding in  
genome  
“genotype”

development



embodied  
agent  
“phenotype”

recursive  
encoding



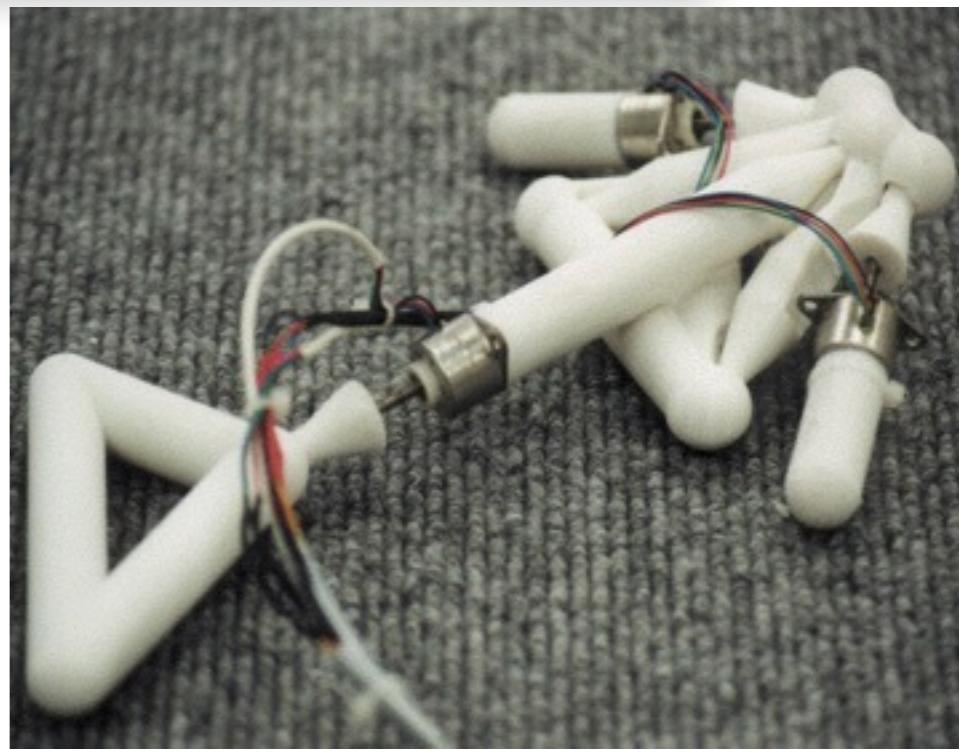
# Golem project

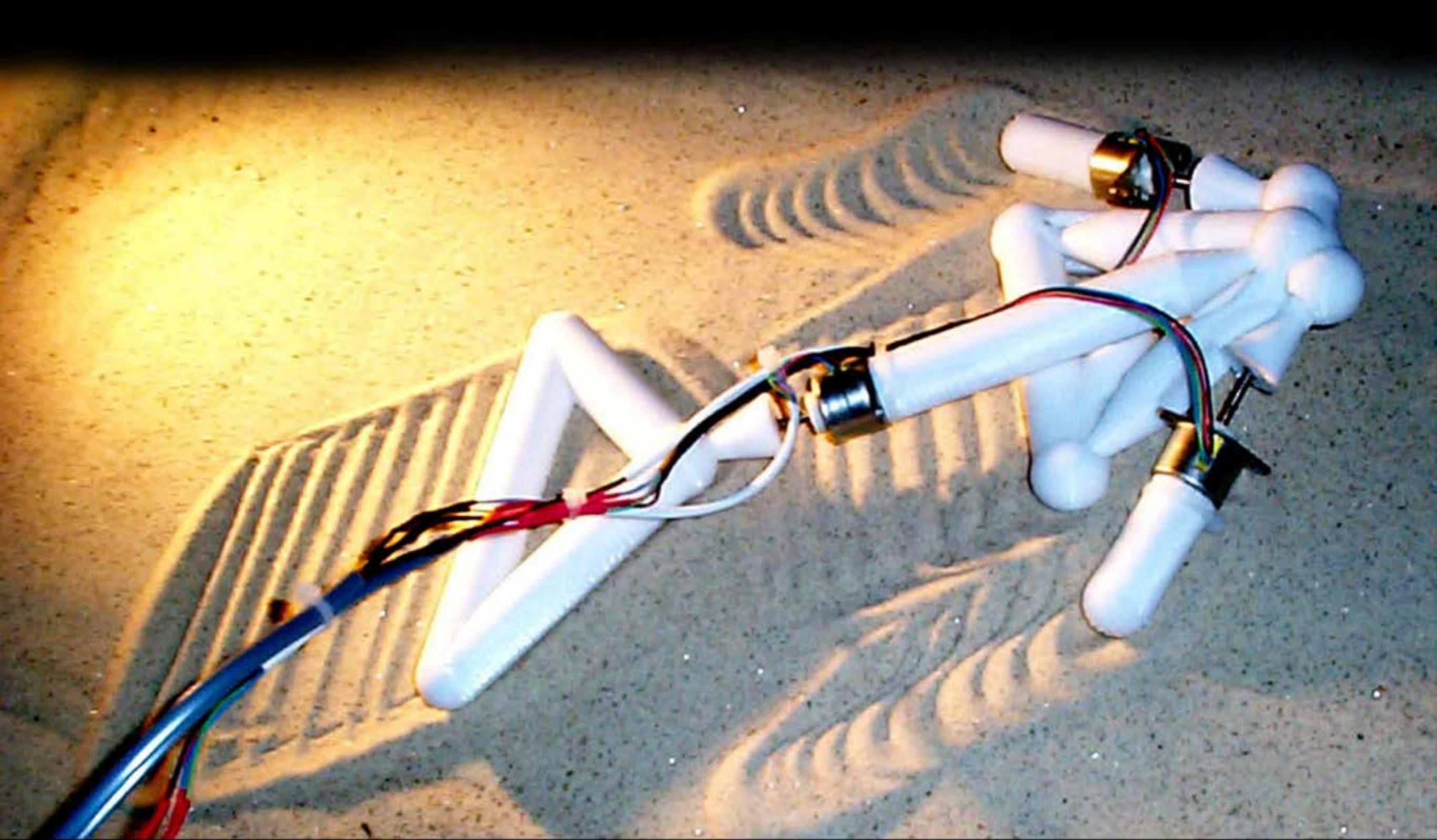
(Lipson and Pollack)

representation of morphology  
in genome

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

(recursive encoding)

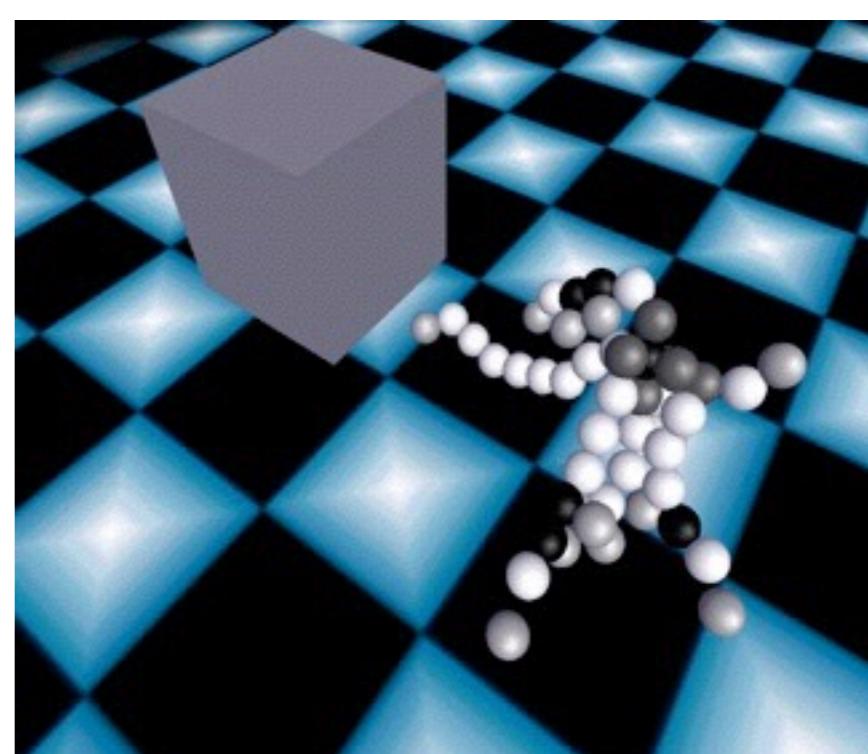
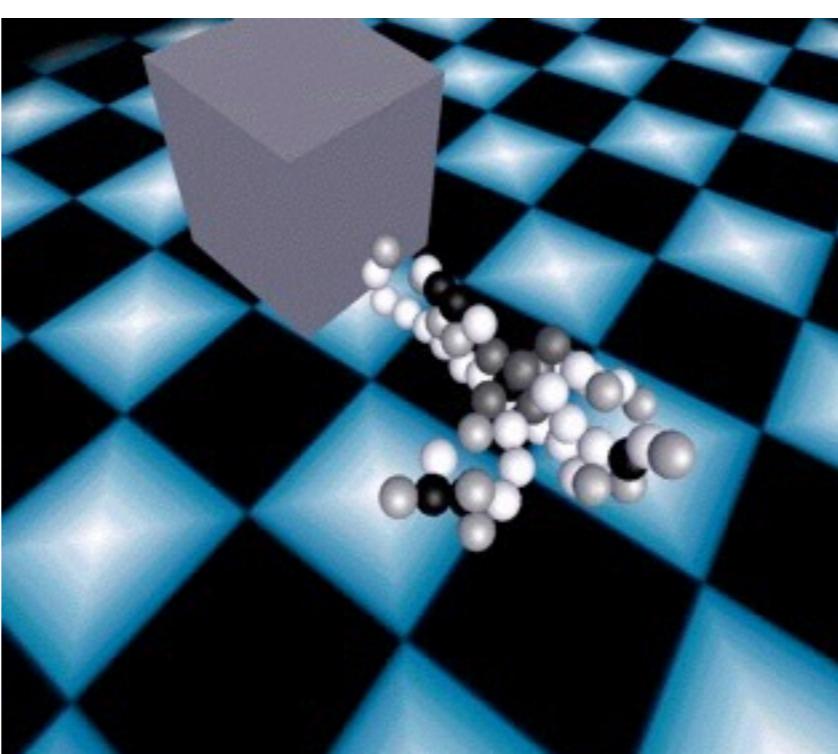
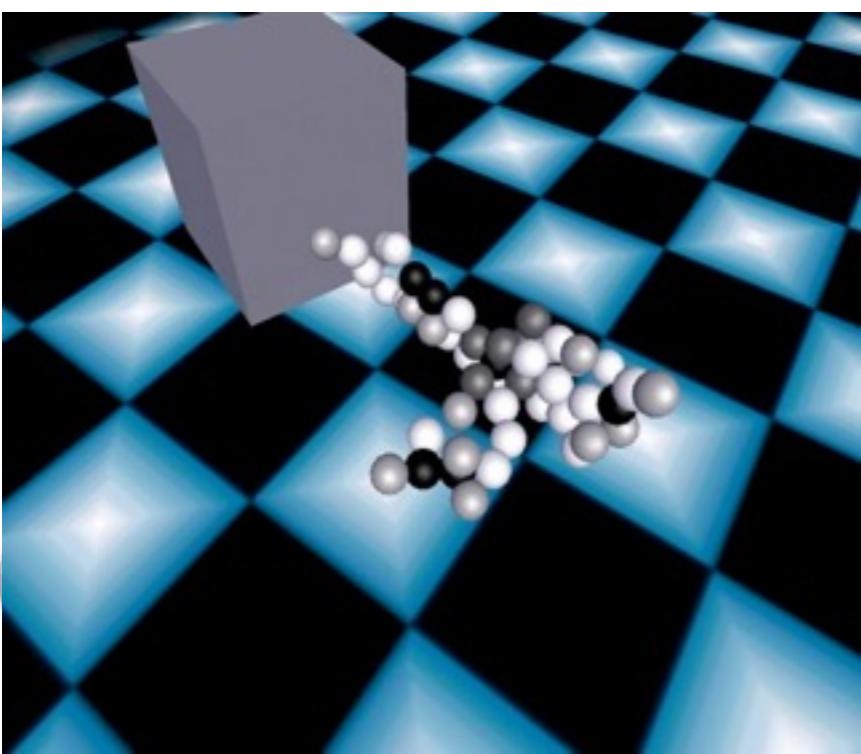




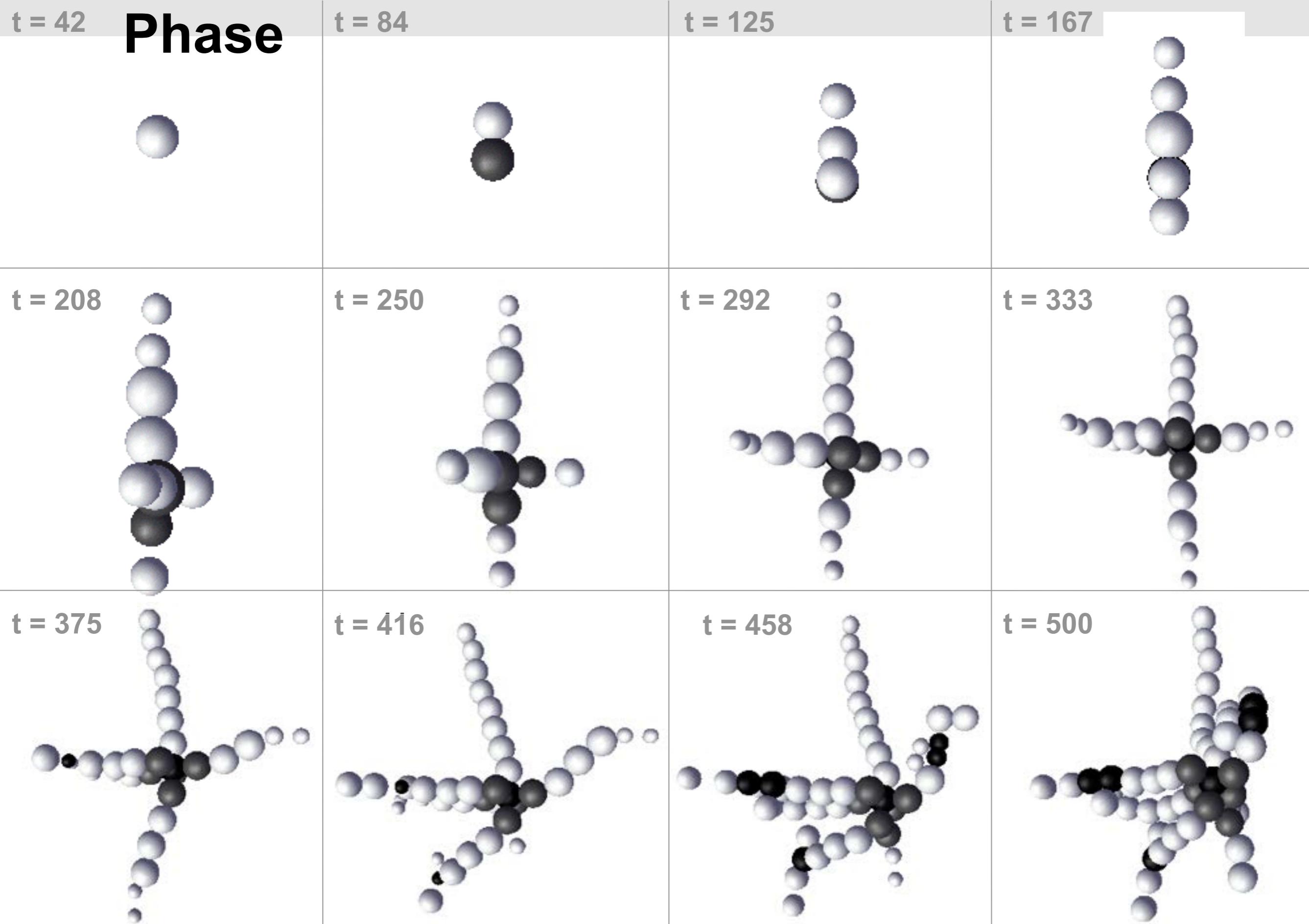
# Genetic Regulatory Networks (GRNs): Bongard's “block pushers”

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



# The Growth Phase

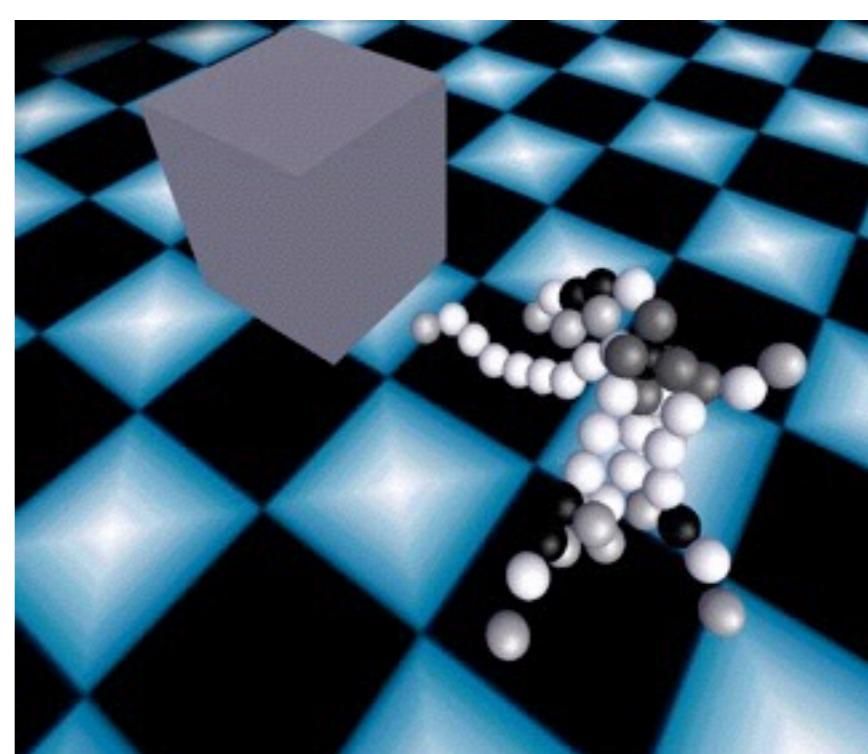
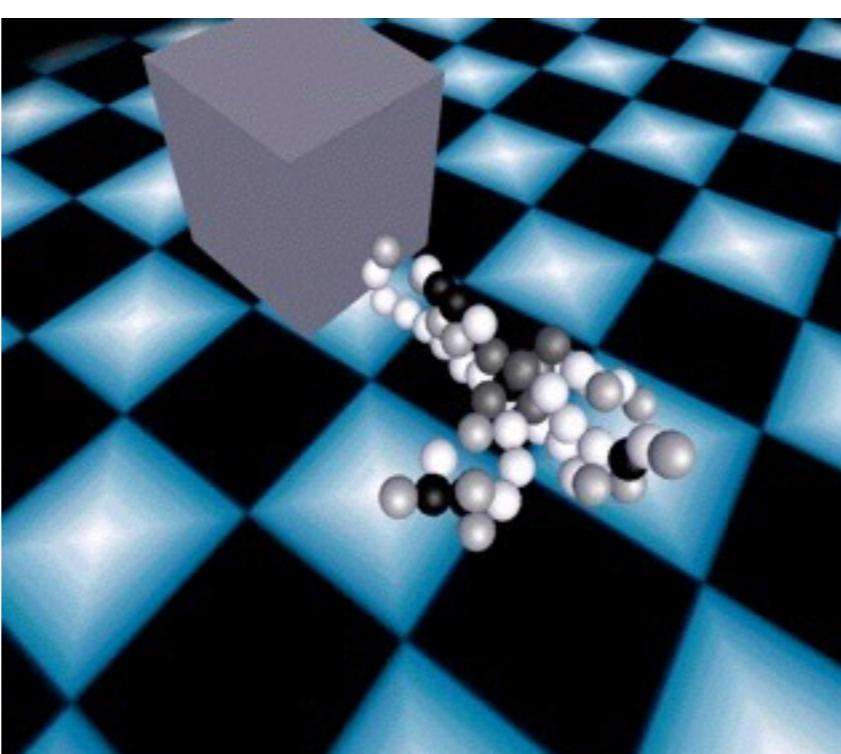
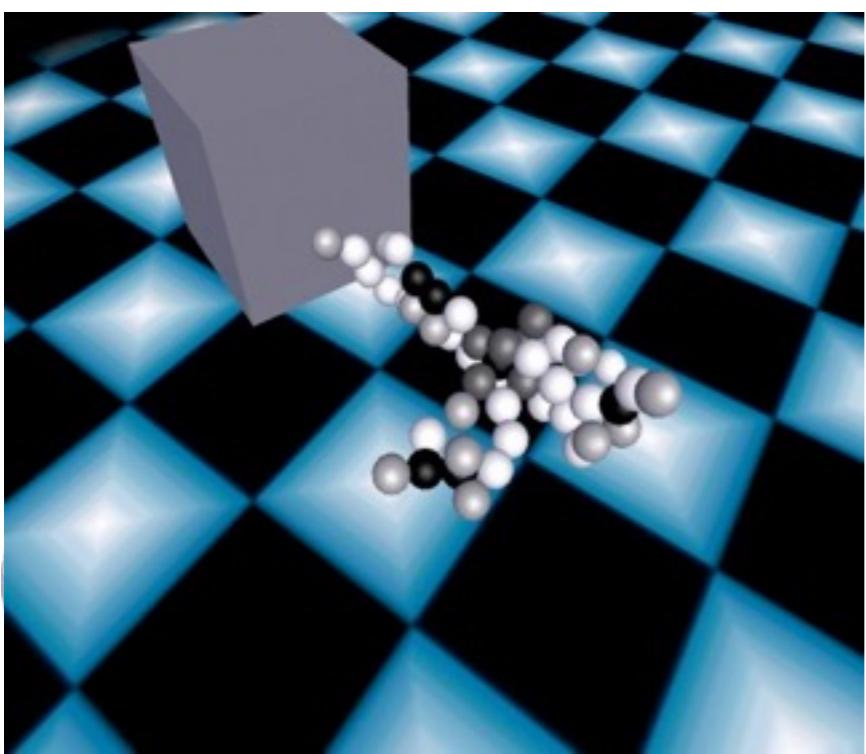


# Evolution of a “block pusher” (“Artificial Ontogeny”)

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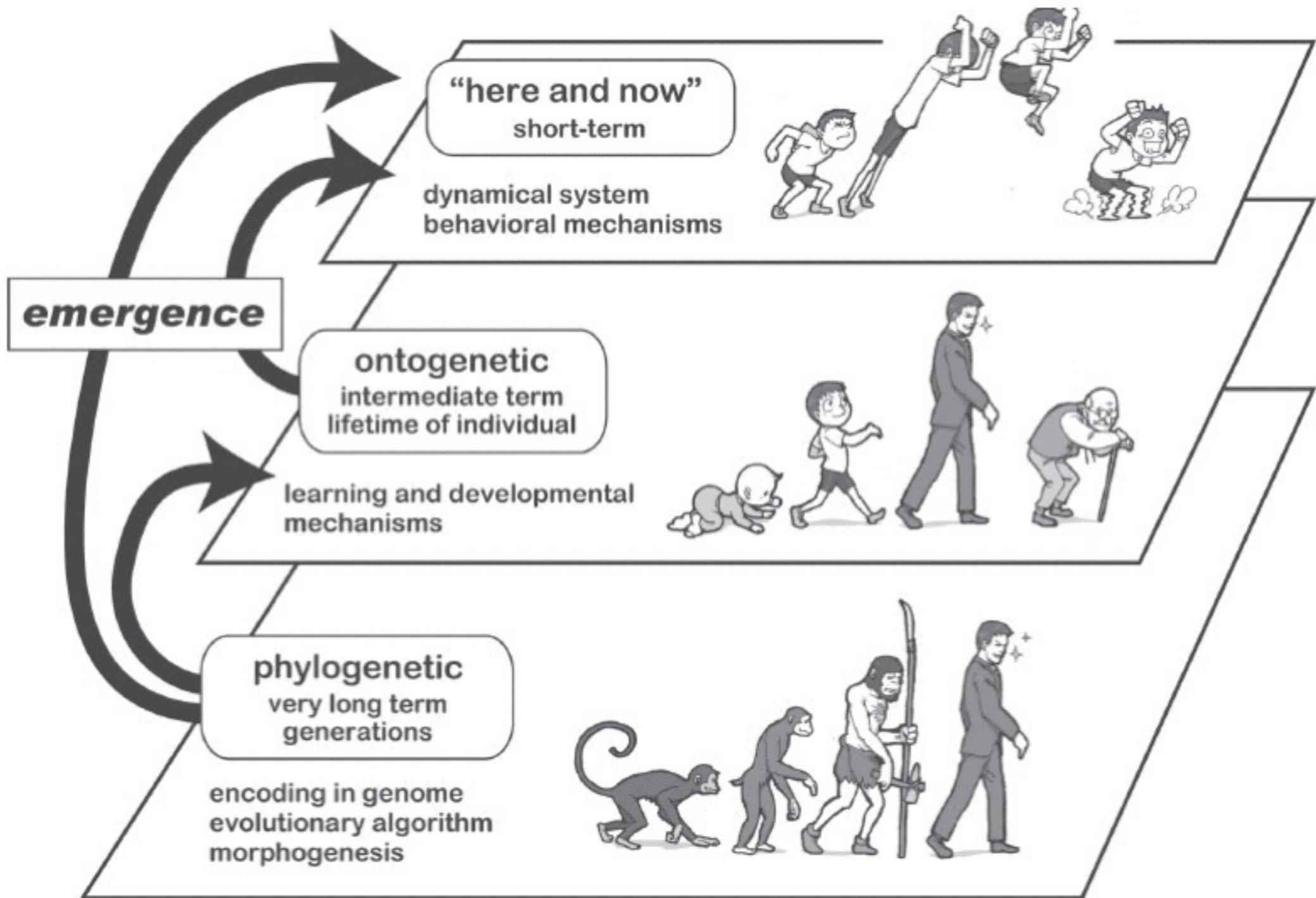
- Video “Evolution of block pushers”

<http://www.youtube.com/watch?v=JzXWQDfOOGM>



- 
- **The Evolution of Locomotion**
  - **The Evolution of Size**
  - **The Evolution of Repeated Structure**

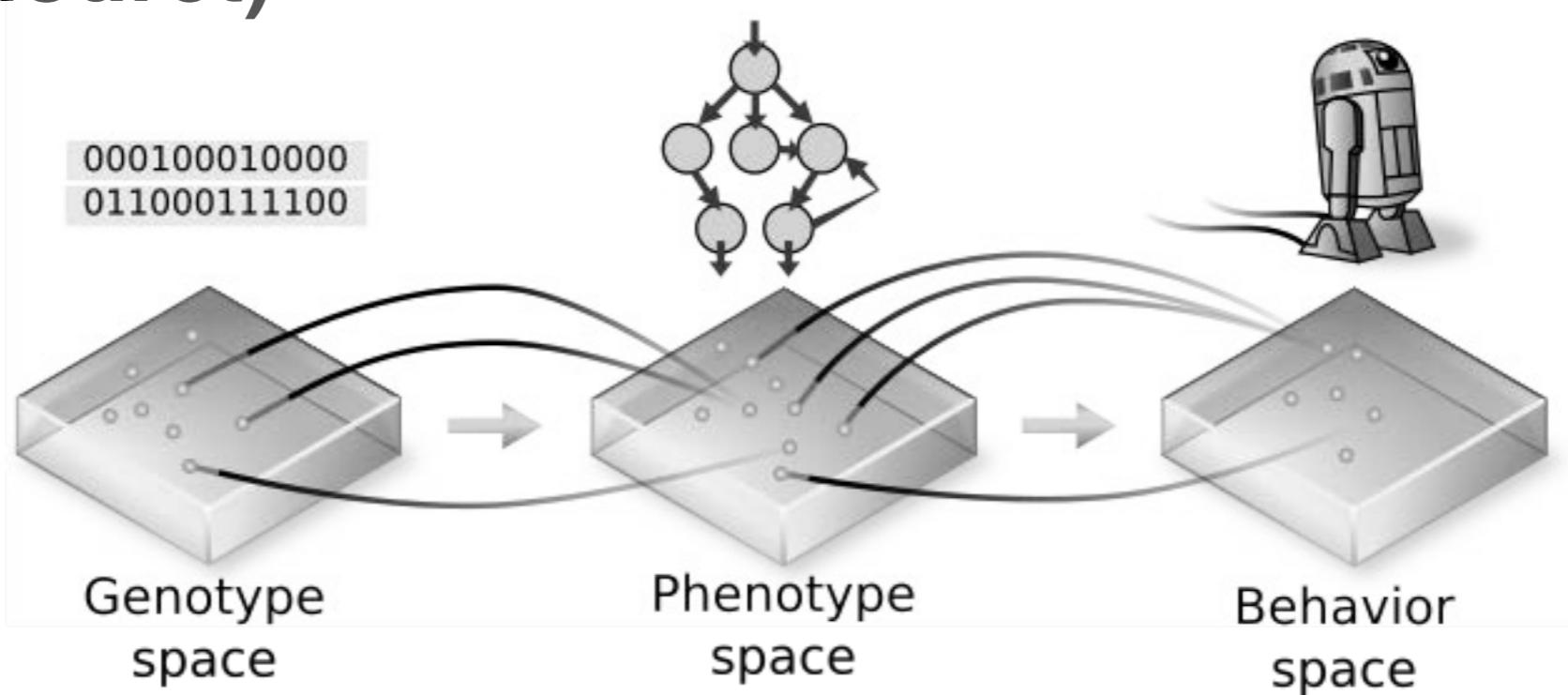
# Time scales tightly intertwined



# Evolutionary Robotics

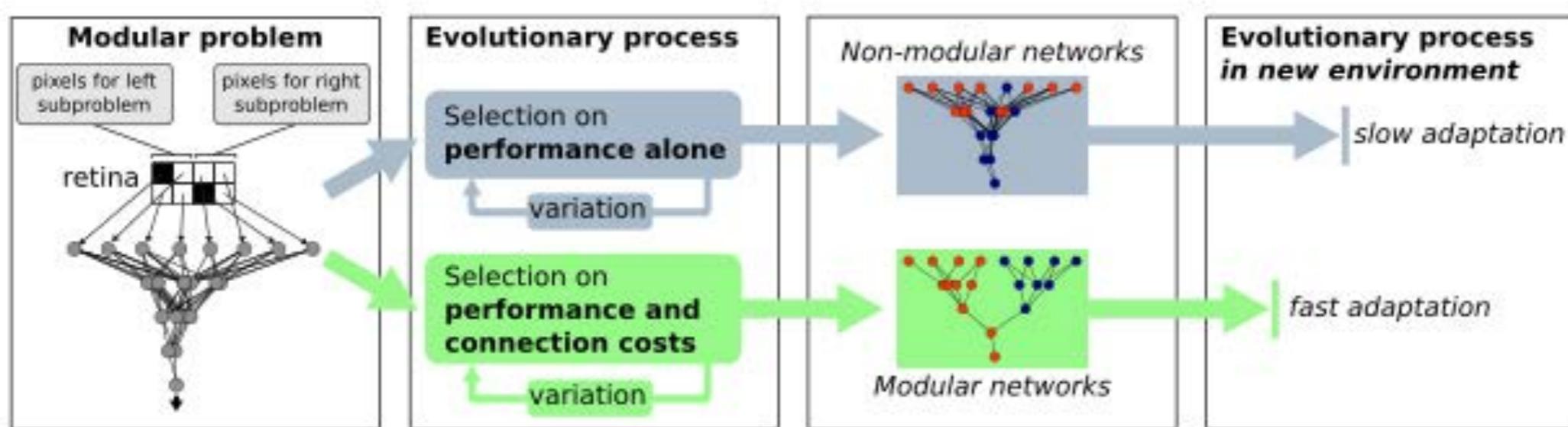
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- Multi-Objective optimisation (Jean-Baptiste Mouret)



[https://www.youtube.com/watch?v=Trj0\\_AIZfNo](https://www.youtube.com/watch?v=Trj0_AIZfNo)

# evolution of modularity



- Clune, Jeff and Mouret, Jean-Baptiste and Lipson, Hod (2013). The evolutionary origins of modularity. Proceedings of the Royal Society B. Vol 280 Pages 20122863

# evolution of modularity

<https://www.youtube.com/watch?v=Rgq7Jzsw8vw>

# Assignments for next week

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

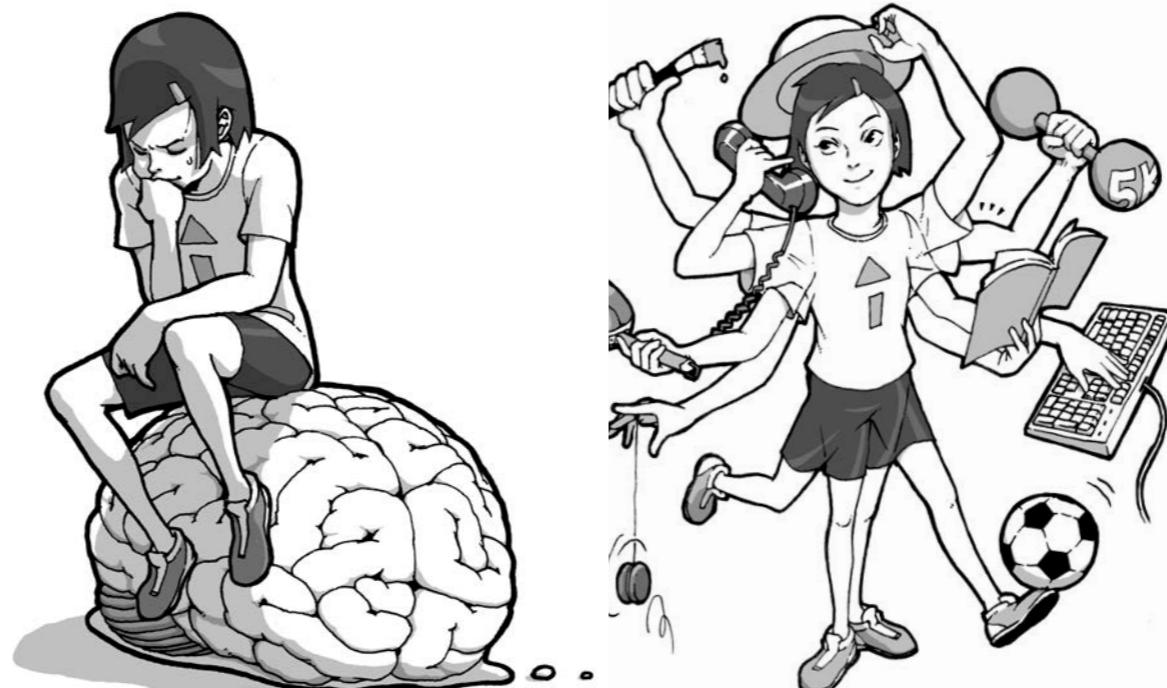


# End of lecture 4

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**Thank you for your attention!**

**stay tuned for the guest lecture**



# Lecture 4: Guest speaker

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**Guest lecture "Challenges and perspectives on morphology changing robots" by Fumiya Iida, Cambridge University**

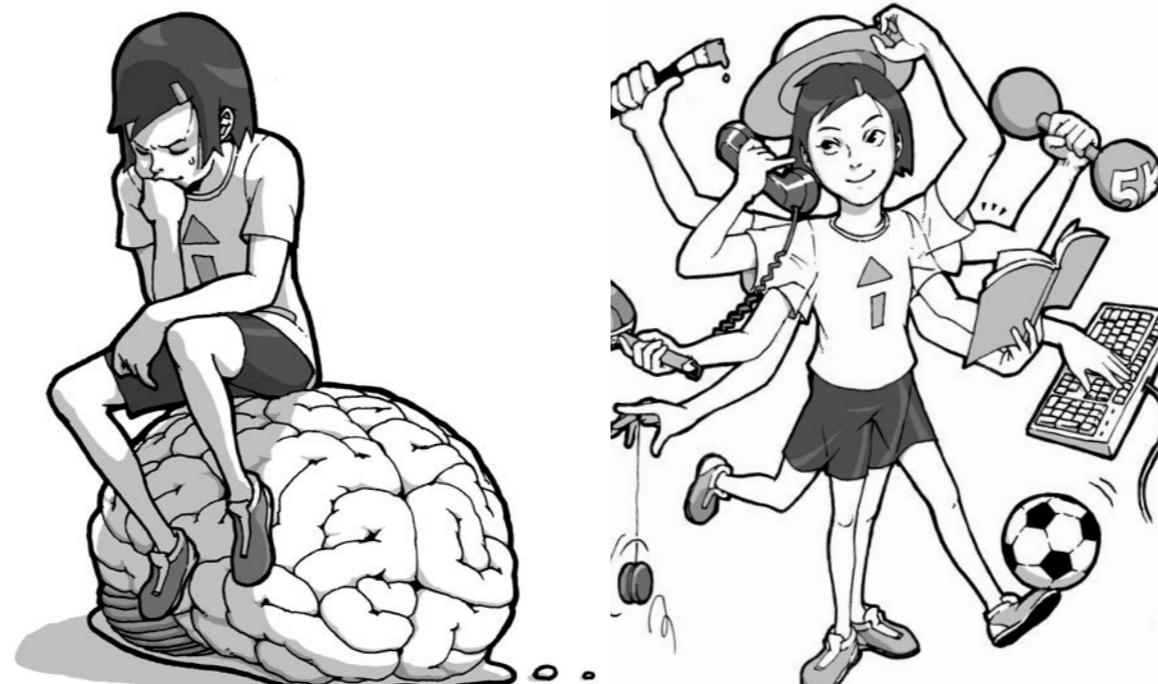
# End of lecture 4

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**Thank you for your attention!**

**stay tuned for lecture 5**

**“developmental robotics”**



# Thank you.

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

Local organisers:

- Andreas Goroncy
- Damien Drix

