

The AI Lectures from Tokyo

Lecture 6

The Emergence of Intelligence: Artificial Evolution and Morphogenesis

Robots for the elderly ("Roboter für den Lebensabend")

In a high-tech home for the elderly in Japan, machines and sensors are taking over the caring for the senior citizens - a model for Germany?



*Der Spiegel, 49
1 Dec. 2003 p. 212*

DER SPIEGEL

Nr. 43/20,10.03
Deutschland: 3,00 €



Questions from last week

- “redundancy principle”: partial overlap in functionality of different subsystems

Today's topics

- The Kirsh-Brooks debate: Participants from Tokyo (special assignment)
- The “behavior-based” approach: final comments
- The emergence of intelligence: Artificial evolution and morphogenesis
- “The latest from Japan”: Self-assembly and self-repair

The latest
from Japan

Prof. Satoshi Murata
Autonomous Decentralized Control
Tokyo Institute of Technology

self-assembling re-configurable robots



“Behavior-based approach”

beginning of “embodied artificial intelligence”

Rodney Brooks *MIT AI Lab (now: CSAIL - Computer Science and Artificial Intelligence Laboratory)*

“Behavior-based approach”

beginning of “embodied artificial intelligence”

Rodney Brooks *MIT AI Lab (now: CSAIL - Computer Science and Artificial Intelligence Laboratory)*

“live from Boston”

16 December 2003

09.15 - 10.15: Zurich, Munich, Warsaw

16.15 - 17.15: Beijing

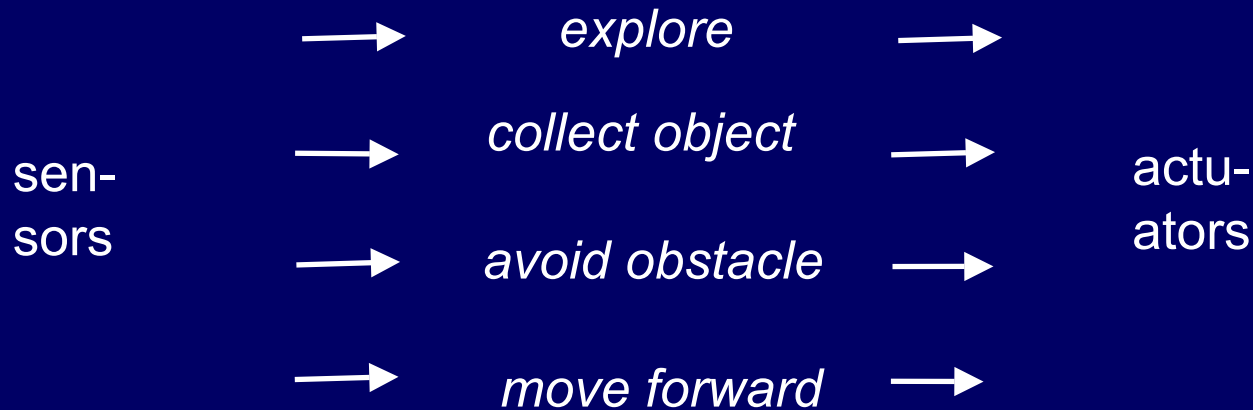
17.15 - 19.15: Tokyo

03.15 - 04.15: Boston

Traditional vs. “behavior-based” decomposition



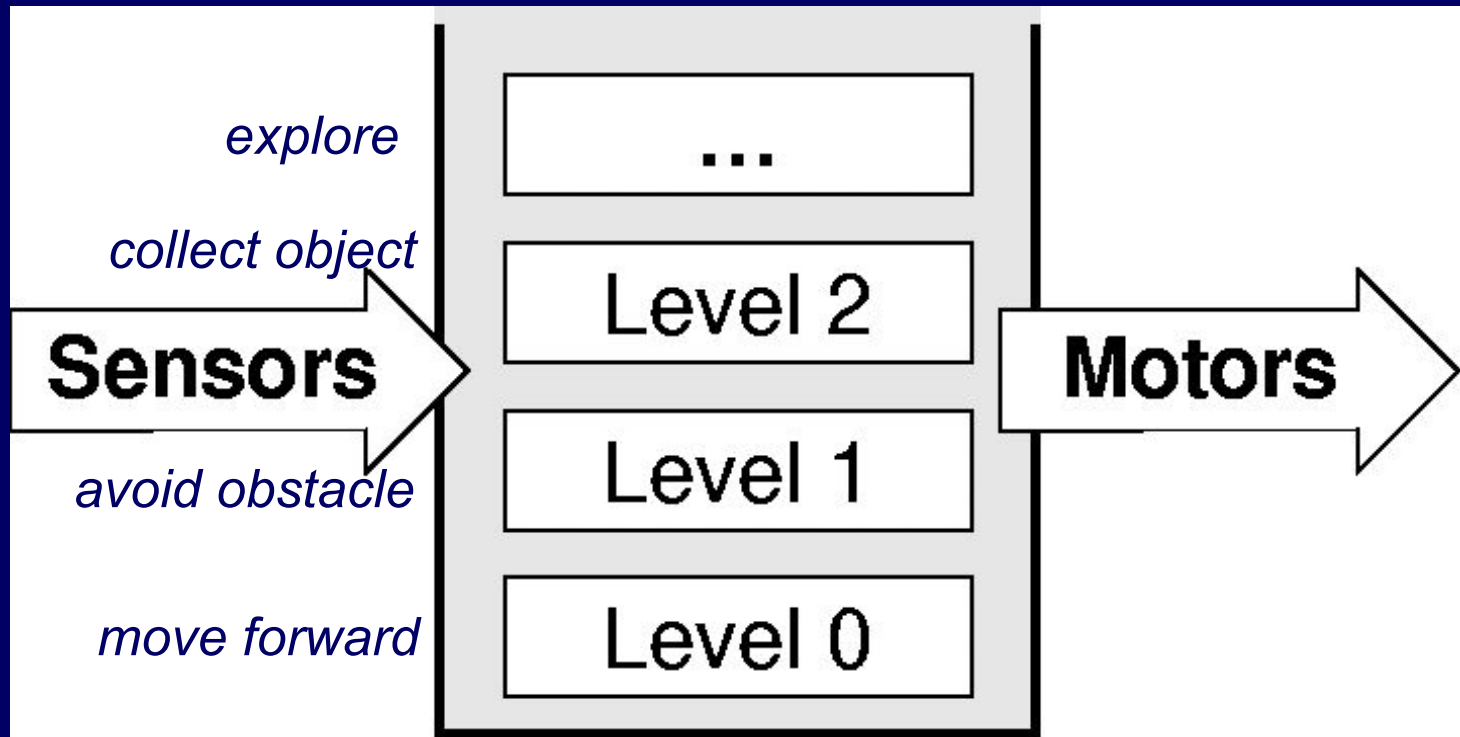
(sense - model - plan - act)
(sense - think - act) *cycle*



“behaviors”

Levels of Competence - “Behaviors”

Tight sensory-motor coupling



augmented finite state machines

suppression and inhibition links between layers

The principle of “parallel, loosely coupled processes”

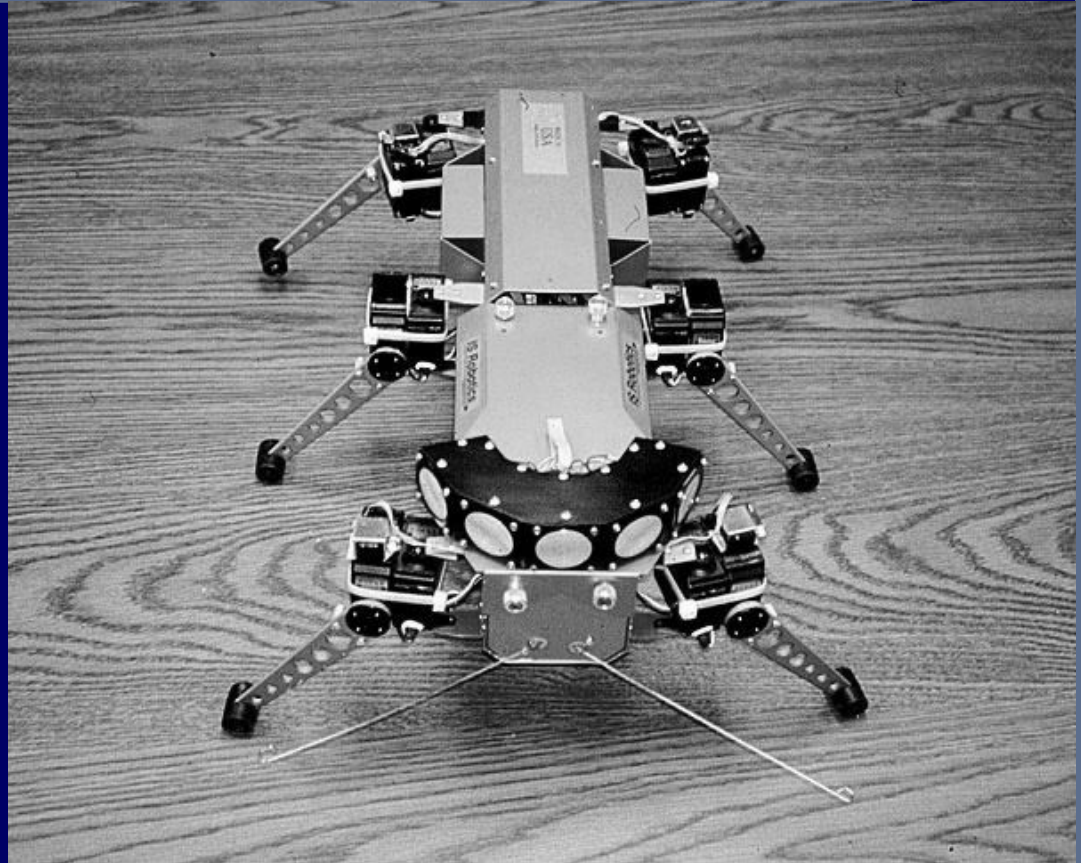
Intelligent behavior:

- emergent from agent-environment interaction
- based on large number of parallel, loosely coupled processes
- asynchronous
- coupled through agent's sensory-motor system and environment

Ghengis: insect-level intelligence

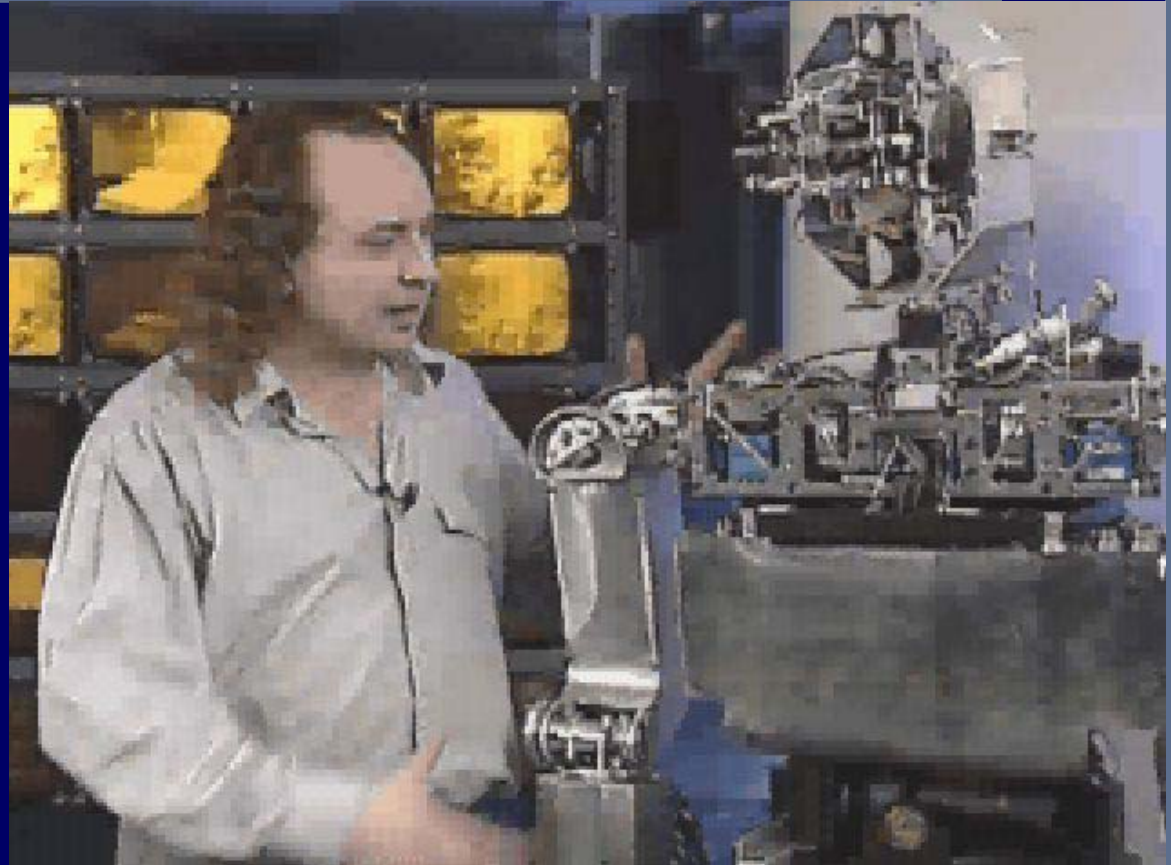
*six-legged robot to
mimic insect walking*

*subsumption architecture
well suited*



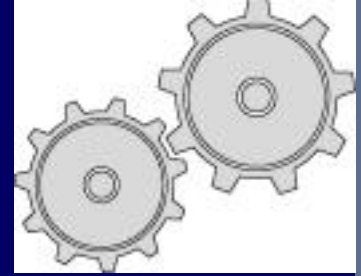
Cog

humanoid robot

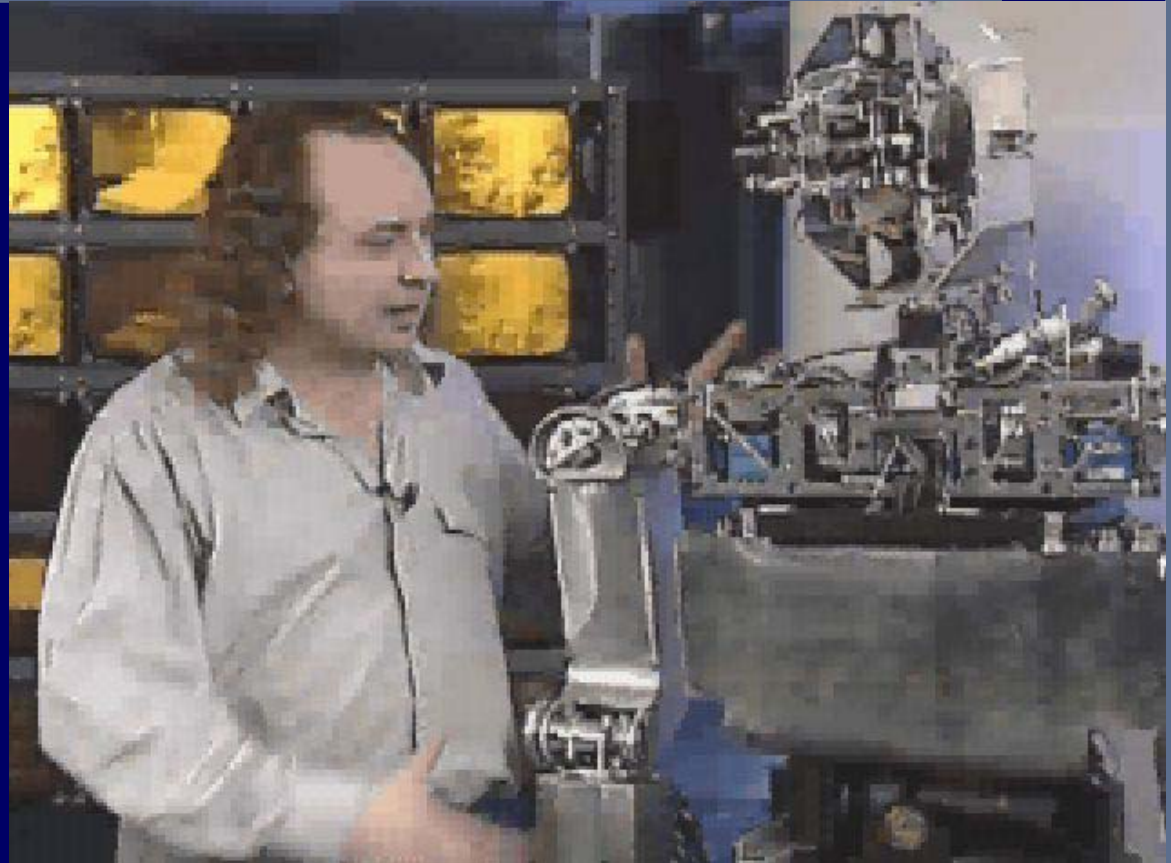


Cog

Cognition and Cog Wheels



humanoid robot



Scaling issue

insect level --> human-level ??

Debate:

David Kirsh: “Today the earwig, tomorrow man?”
(1991)

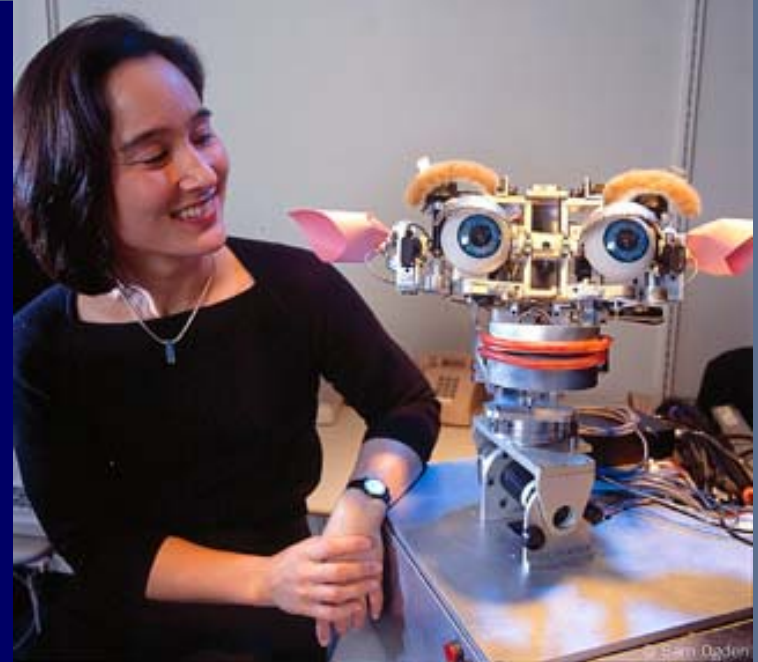
Rodney Brooks: “From earwigs to humans.”
(1997)

--> Tokyo students

Special assignment: Tokyo

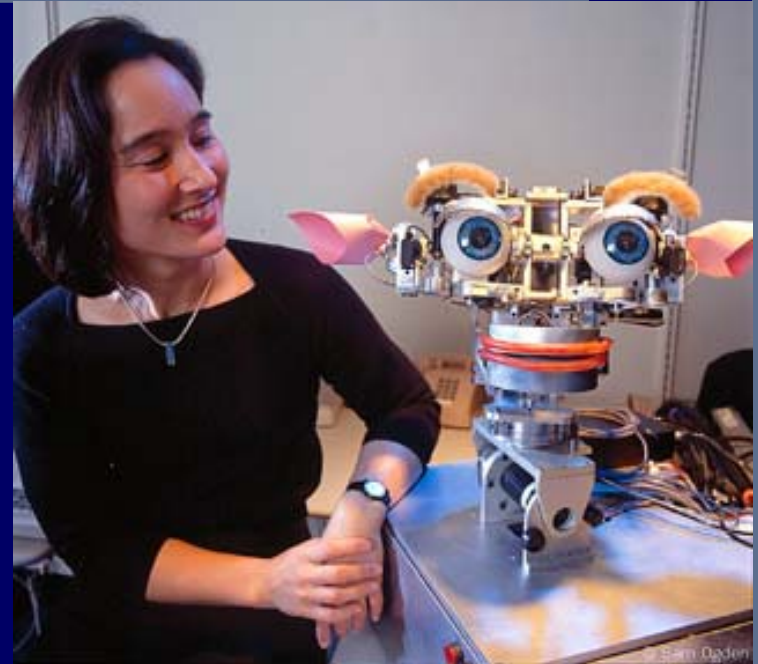
5min statement on the debate between David Kirsh and Rodney Brooks on earwigs and humans (scalability of the behavior-based approach to robotics).

Kismet - the social interaction robot *Kismet*



*Cynthia Breazeal, MIT Media Lab
(previously MIT AI Lab)*

Kismet - the social interaction robot *Kismet*



*Cynthia Breazeal, MIT Media Lab
(previously MIT AI Lab)*

comments from Munich?

The Emergence of Intelligence

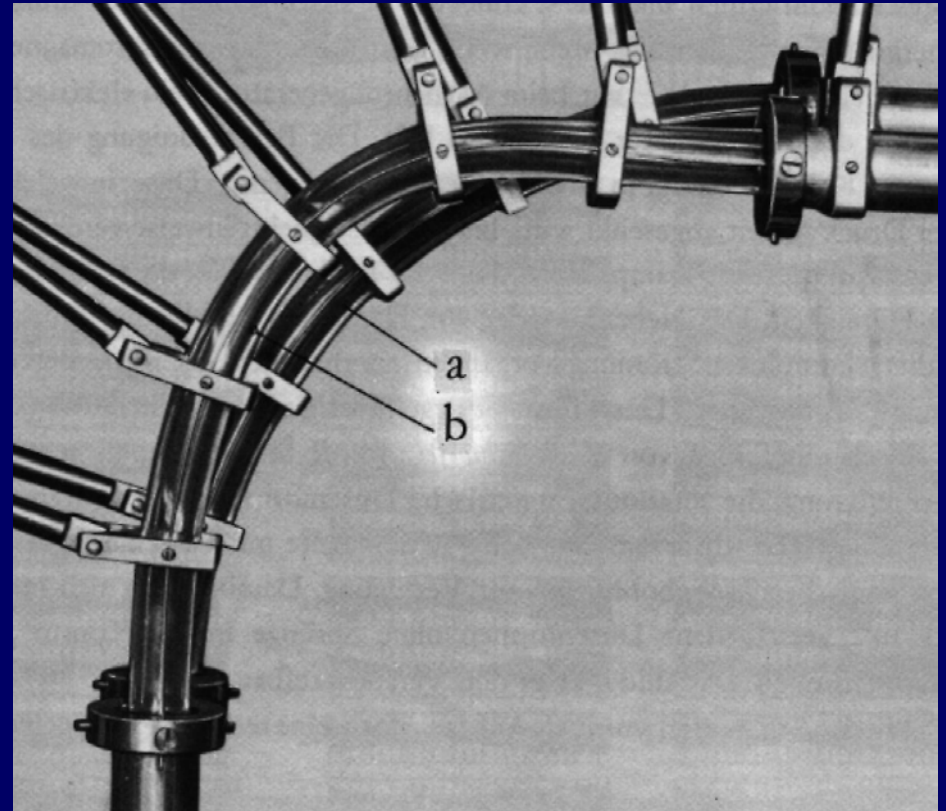
Artificial Evolution and Morphogenesis

Artificial Evolution

Rechenberg's "fuel pipe problem"

Artificial Evolution

Rechenberg's "fuel pipe problem"

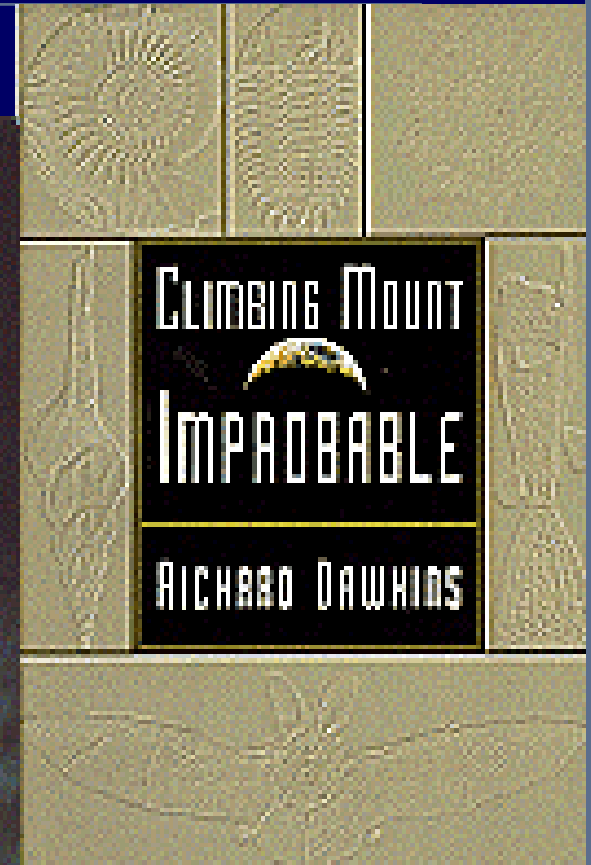
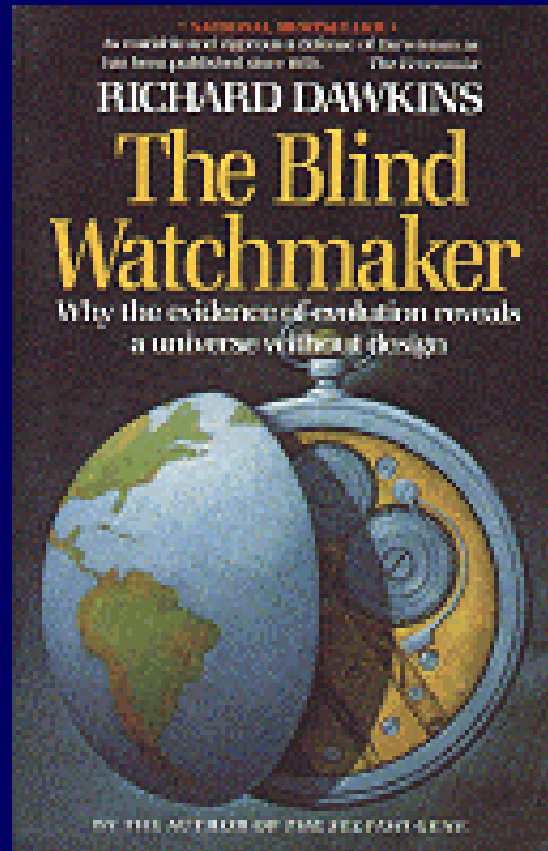


Artificial Evolution

- John Holland (“genetic algorithms”, GAs)
- Ingo Rechenberg (“evolution strategy”, ES)
- John Koza (“evolutionary programming”, GP)

Cumulative Selection

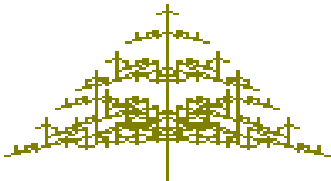
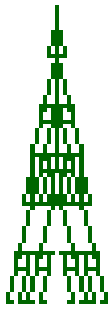
Richard Dawkins



Munich: a brief comment?

The Biomorphs: The power of aesthetic selection

comment / demonstration by participants from Beijing?



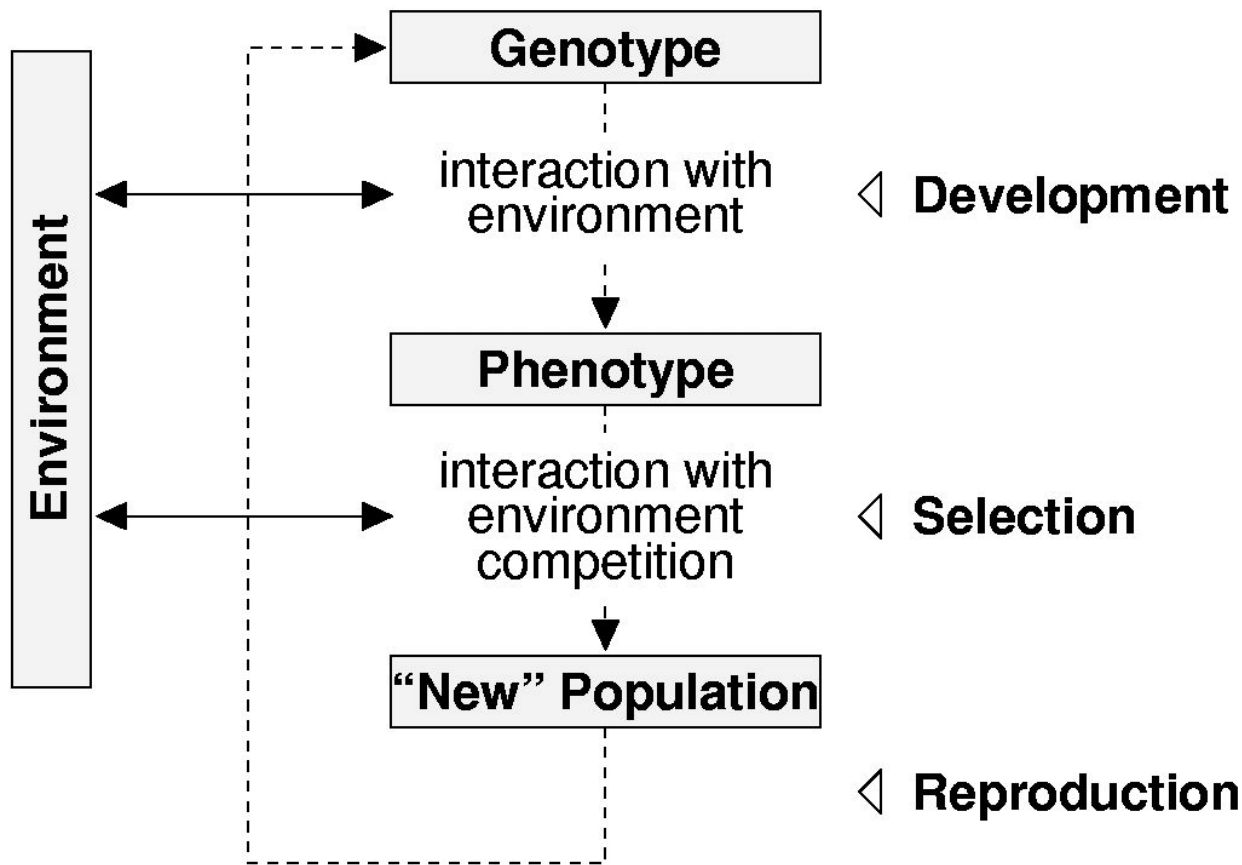
The Biomorphs: Encoding in the genome

- genes 1-8 control the overall shape of the biomorph,
- gene 9 the depth of recursion,
- genes 10-12 the colour of the biomorph,
- gene 13 the number of segmentations,
- gene 14 the size of the separation of the segments,
- gene 15 the shape used to draw the biomorph (line, oval, rectangle, etc).

Morphs: the “blind watchmaker” applet

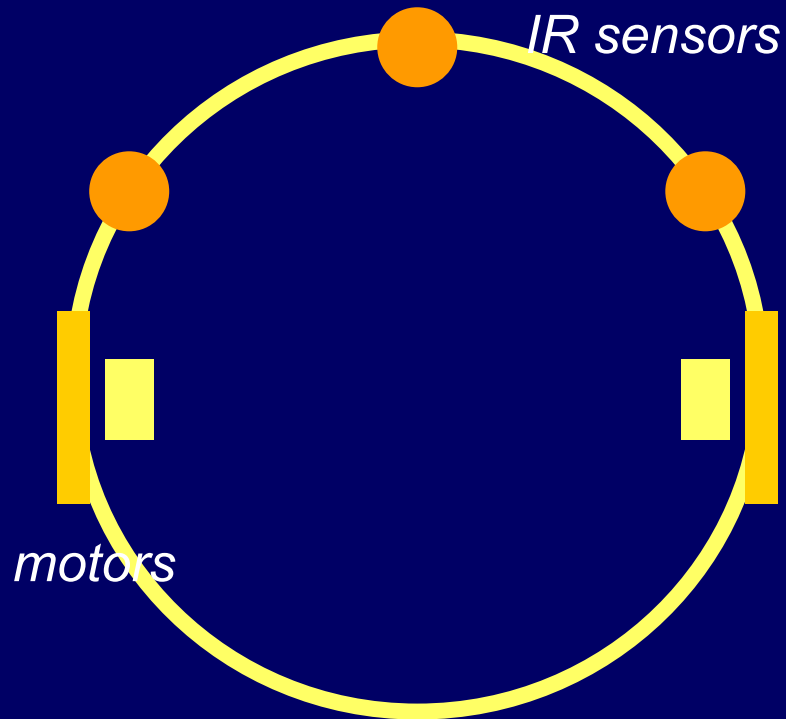
<http://suhep.phy.syr.edu/courses/mirror/biomorph/>

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

Evolving a Neural Controller for an agent



how to proceed?
--> Warsaw

Encoding in genome

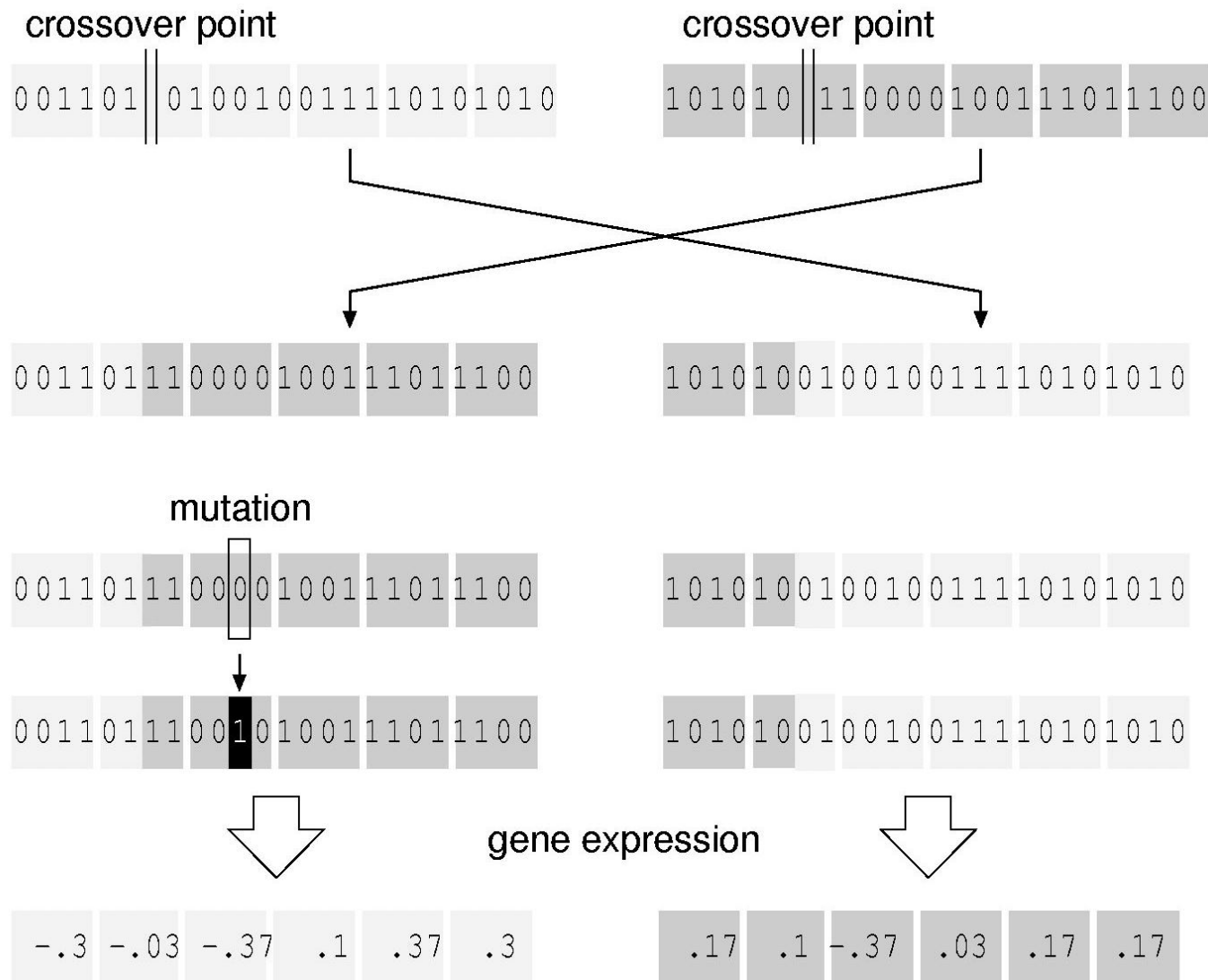
	1	2	3	4	5	6	1	2	3	4	5	6
initial genome	0011	0101	0010	0011	1010	1010	1010	1011	0000	1001	1101	1100
encoded weights	-.3	-.17	-.37	.03	.17	.17	.17	.23	-.5	.1	.37	.3

Fitness function and selection

Fitness function and selection

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

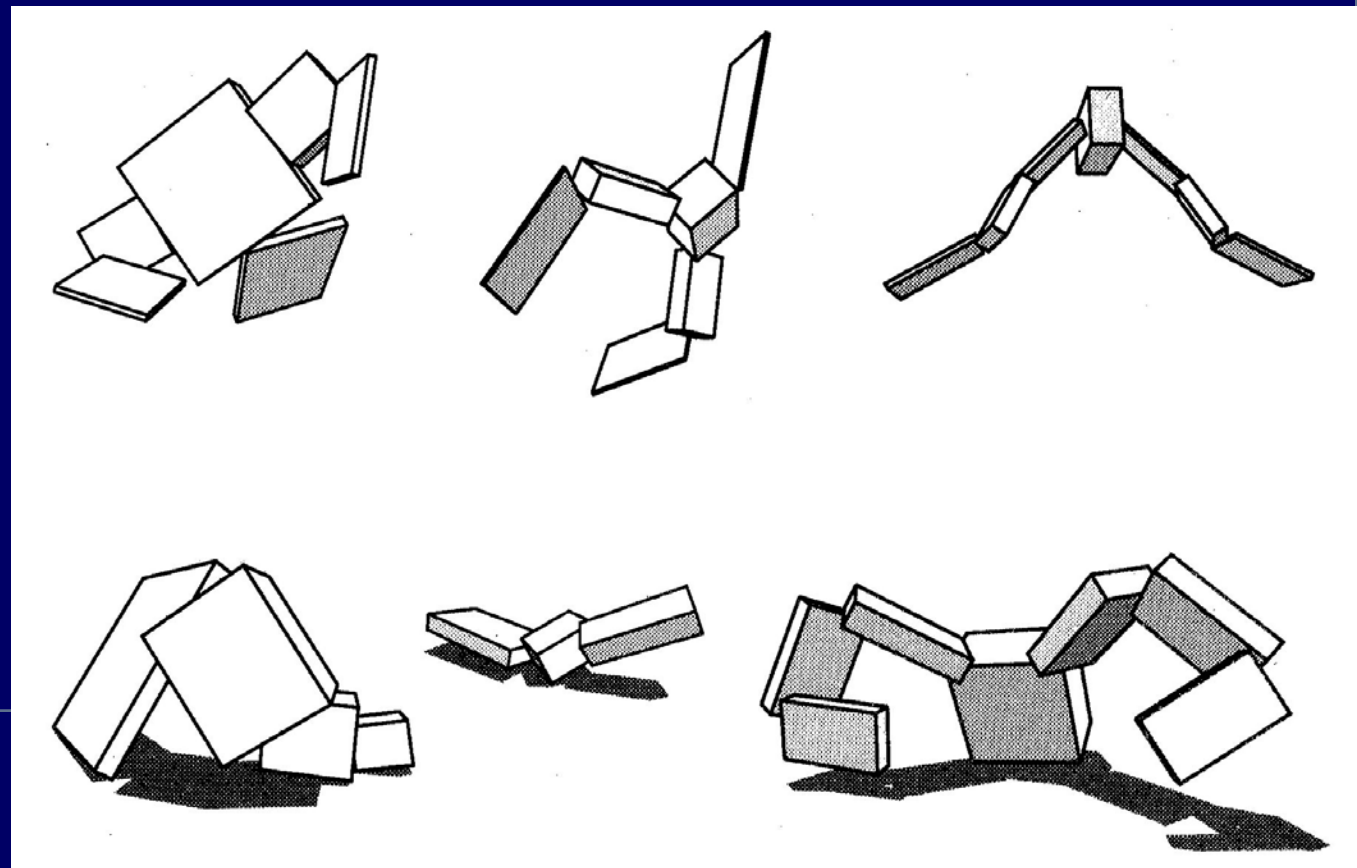
Reproduction: Crossover and mutation “development”



Evolving control and morphology **Video**

Karl Sims's Creatures

Karl Sims



Karl Sims's Creatures: Parameterization of morphology

*encoding in
genome
(genotype)*

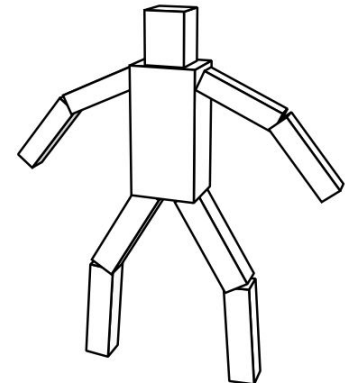
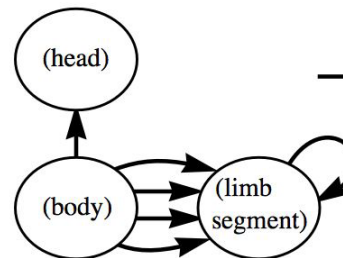
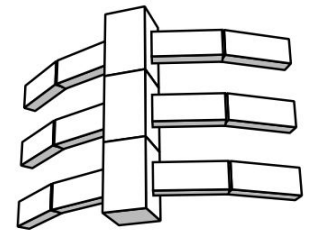
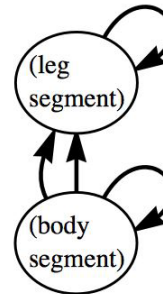
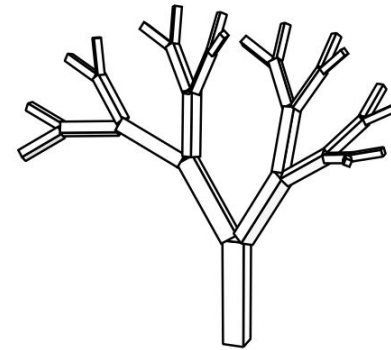
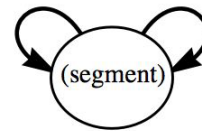


development



*“embodied
agent”
(phenotype)*

(recursive encoding)



Karl Sims' Creatures: Parameterization of morphology

*encoding in
genome
(genotype)*

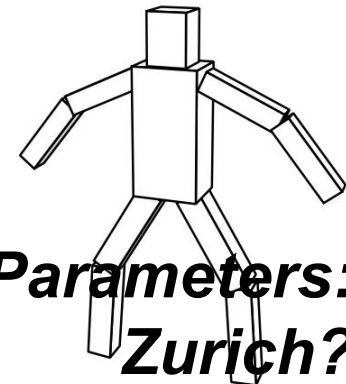
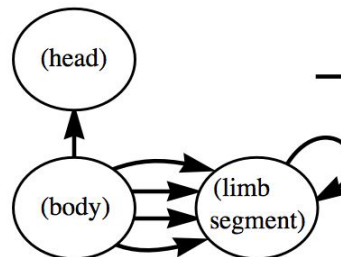
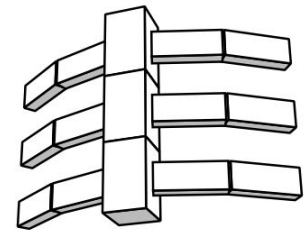
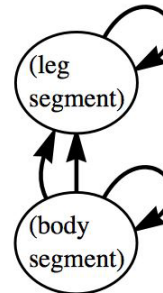
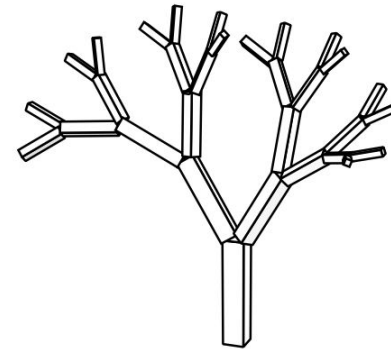
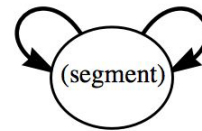


development



*“embodied
agent”
(phenotype)*

(recursive encoding)



**Parameters:
Zurich?**

New version: the „Golem“ project

Parameterization of morphology

(Hod Lipson and Jordan Pollack)

Representation of morphology in genome

- robot: bars, actuators, neurons
- bar: length, diameter, stiffness, joint-type
- neurons: threshold, synaptic strengths
- actuator: type, range

(recursive encoding)



*limitations:
Zurich?*

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(Hod Lipson and Jordan Pollack)

Representation of morphology in genome

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Implications

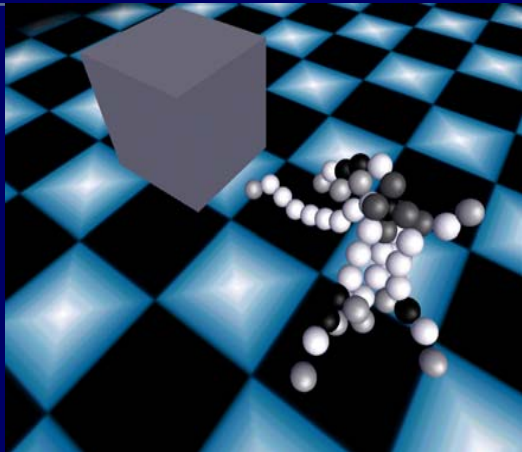
- strong designer bias
- complex structures (like muscles) not possible



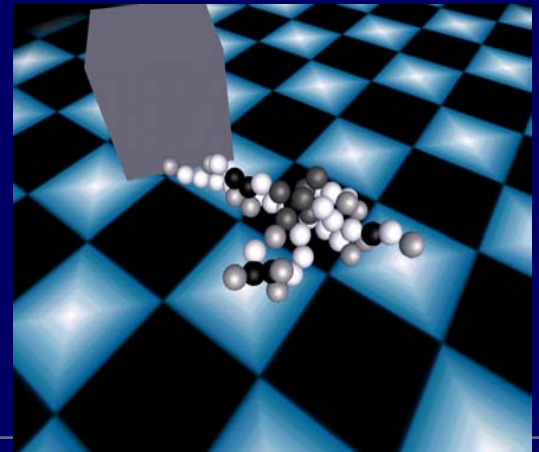
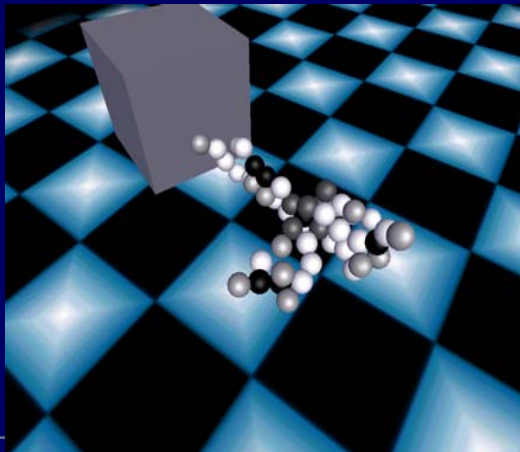
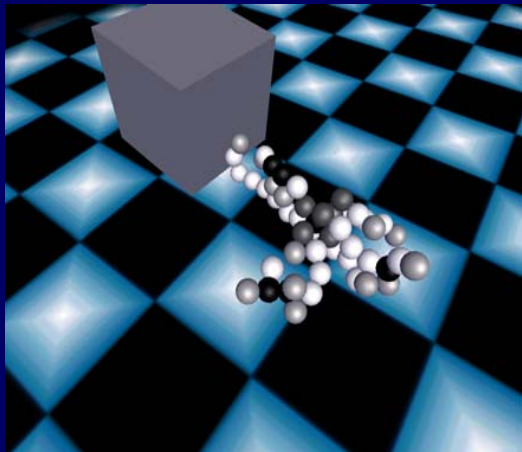
Genetic Regulatory Networks

Josh Bongard's "Block Pushers"

Evolution of a “Block Pusher”

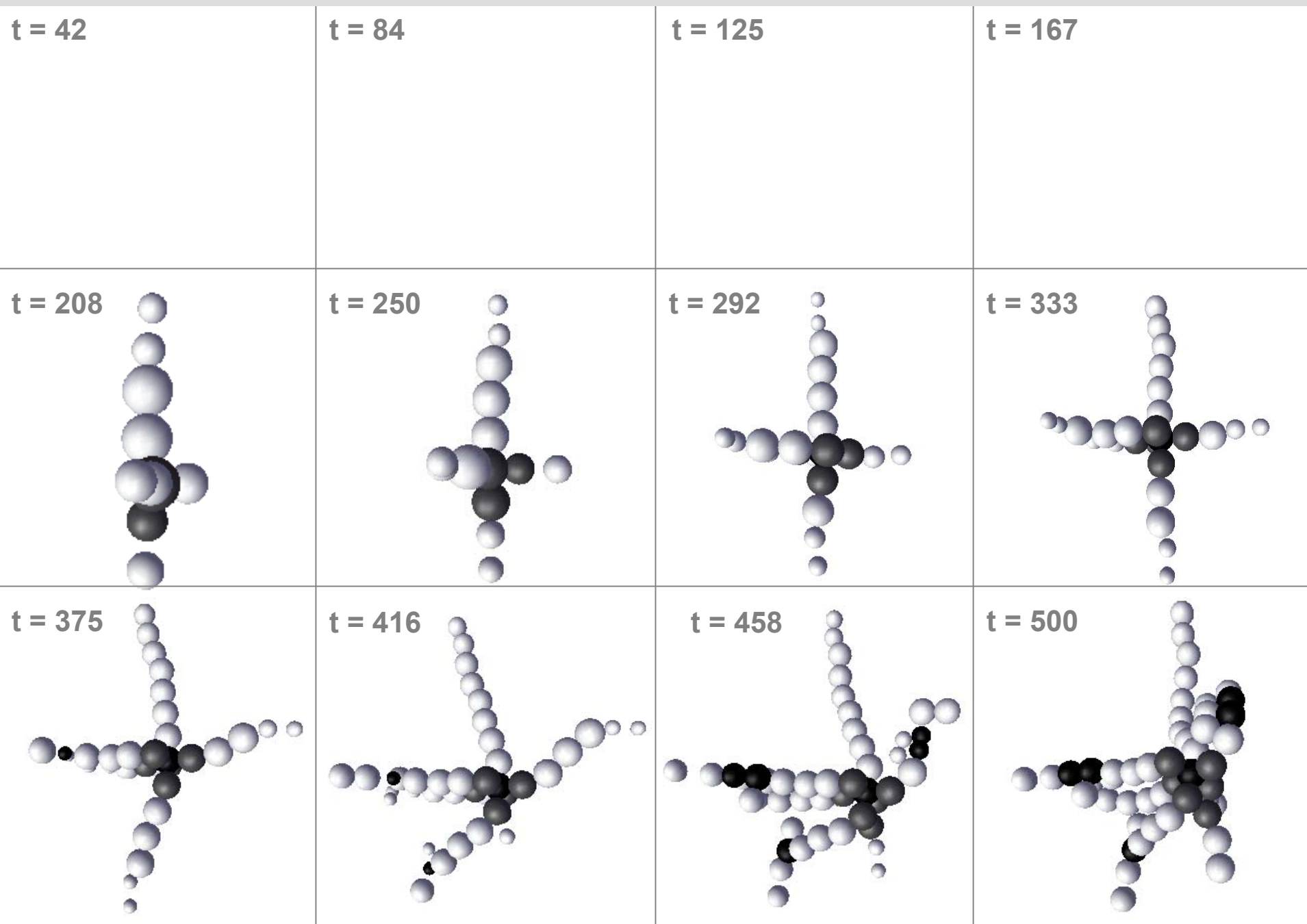


- morphogenesis (genetic regulatory networks) embedded into evolutionary algorithm
- testing of phenotype in physically realistic simulation



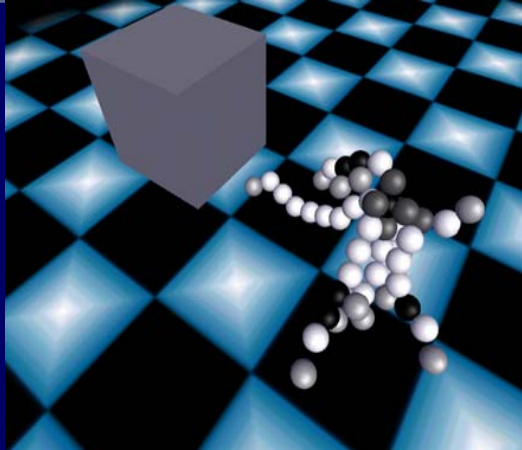
Design and programming: Josh Bongard

The Growth Phase

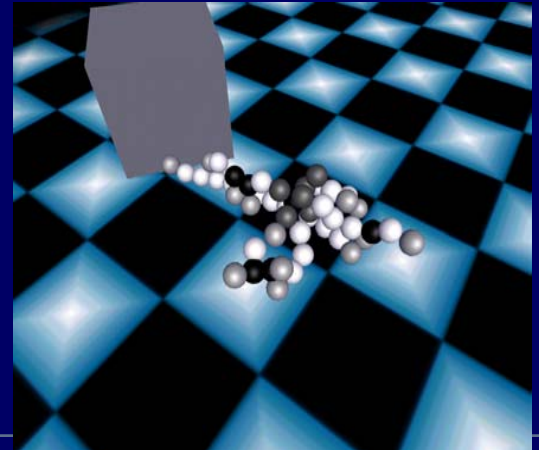
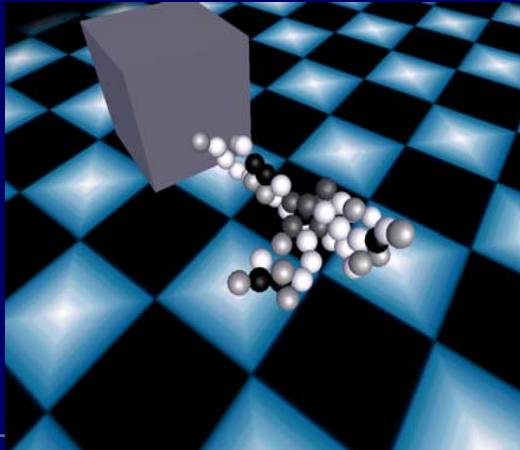
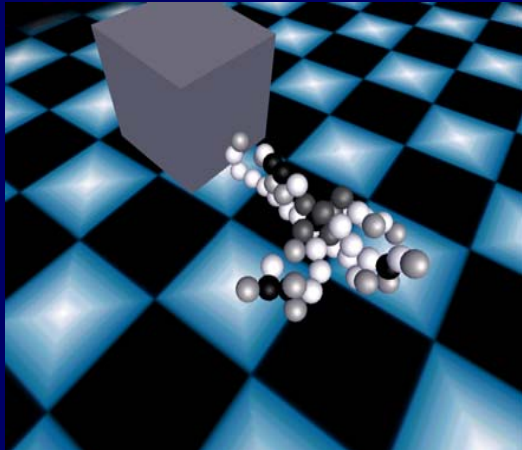


Evolution of a “Block Pusher” **Video**

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

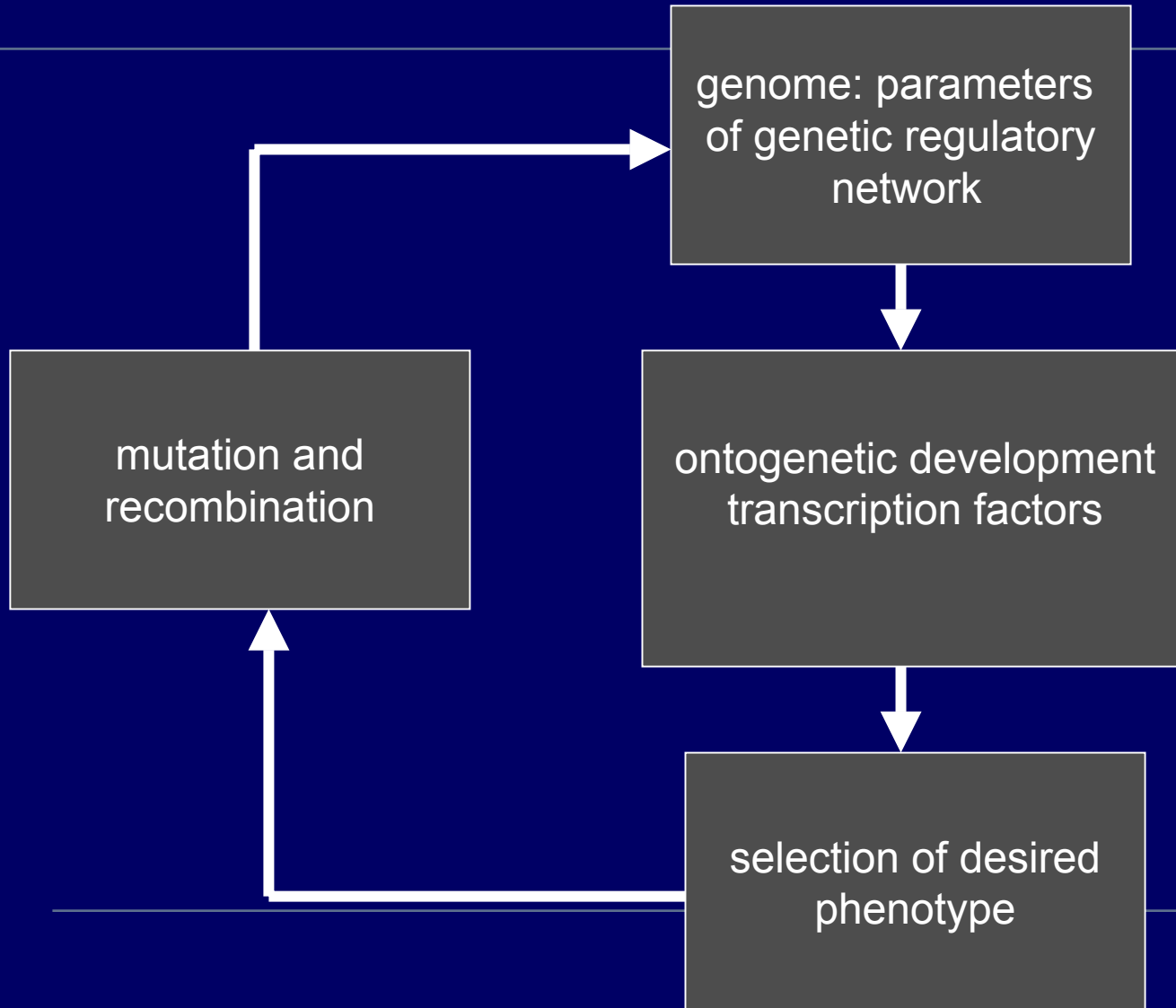


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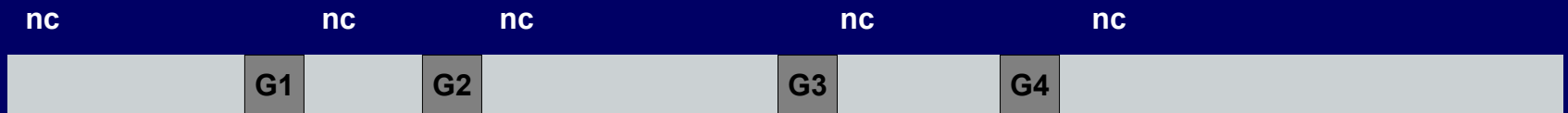


Design and programming: Josh Bongard

Artificial Evolutionary Systems



Ontogenetic growth – genetic regulatory network



TFs: transcription factors

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

Assignments

- Read chapter 8 of “Understanding Intelligence”
- Exercise 5
- Beijing:
Special Assignment: “Artificial Evolution as a tool for Automated Design”

Next:

The Latest from Japan

NOW: The latest
from Japan

Prof. Satoshi Murata
Autonomous Decentralized Control
Tokyo Institute of Technology

self-assembling re-configurable robots



Thank you for your kind attention!

CU all next week in the

**GLOBAL VIRTUAL LECTURE
HALL**