This Week's Lab

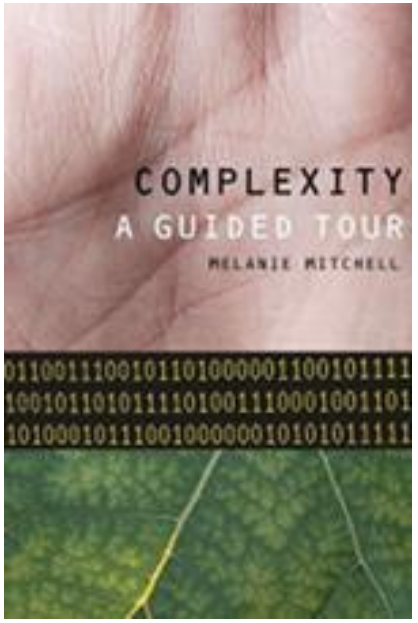
- In preparation for lab tomorrow, download **NetLogo** on your computer:

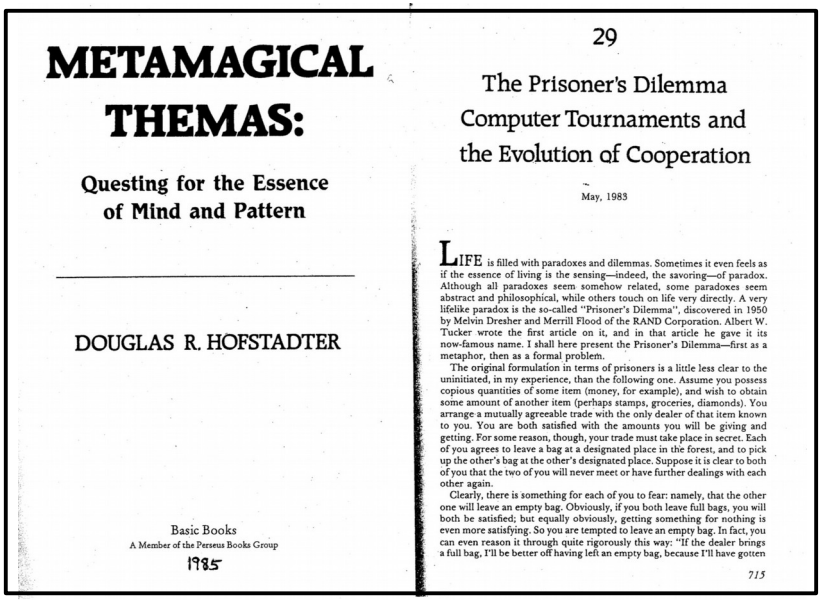
http://ccl.northwestern.edu/netlogo

This Week's Reading

Required:

- Chapter 14 of *Complexity: A Guided Tour*
- “The Prisoner's Dilemma Computer Tournaments and the Evolution of Cooperation”, by Douglas R. Hofstadter





METAMAGICAL THEMAS:

Questing for the Essence of Mind and Pattern

DOUGLAS R. HOFSTADTER

Basic Books
A Member of the Perseus Books Group
1985

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The Prisoner's Dilemma Computer Tournaments and the Evolution of Cooperation

May, 1983

LIFE is filled with paradoxes and dilemmas. Sometimes it even feels as if the essence of living is the sensing—indeed, the savoring—of paradox. Although all paradoxes seem somehow related, some paradoxes seem abstract and philosophical, while others touch on life very directly. A very lifelike paradox is the so-called "Prisoner's Dilemma", discovered in 1950 by Melvin Dresher and Merrill Flood of the RAND Corporation. Albert W. Tucker wrote the first article on it, and in that article he gave it its now-famous name. I shall here present the Prisoner's Dilemma—first as a metaphor, then as a formal problem.

The original formulation in terms of prisoners is a little less clear to the uninitiated, in my experience, than the following one. Assume you possess copious quantities of some item (money, for example), and wish to obtain some amount of another item (perhaps stamps, groceries, diamonds). You arrange a mutually agreeable trade with the only dealer of that item known to you. You are both satisfied with the amounts you will be giving and getting. For some reason, though, your trade must take place in secret. Each of you agrees to leave a bag at a designated place in the forest, and to pick up the other's bag at the other's designated place. Suppose it is clear to both of you that the two of you will never meet or have further dealings with each other again.

Clearly, there is something for each of you to fear: namely, that the other one will leave an empty bag. Obviously, if you both leave full bags, you will both be satisfied; but equally obviously, getting something for nothing is even more satisfying. So you are tempted to leave an empty bag. In fact, you can even reason it through quite rigorously this way: "If the dealer brings a full bag, I'll be better off having left an empty bag, because I'll have gotten

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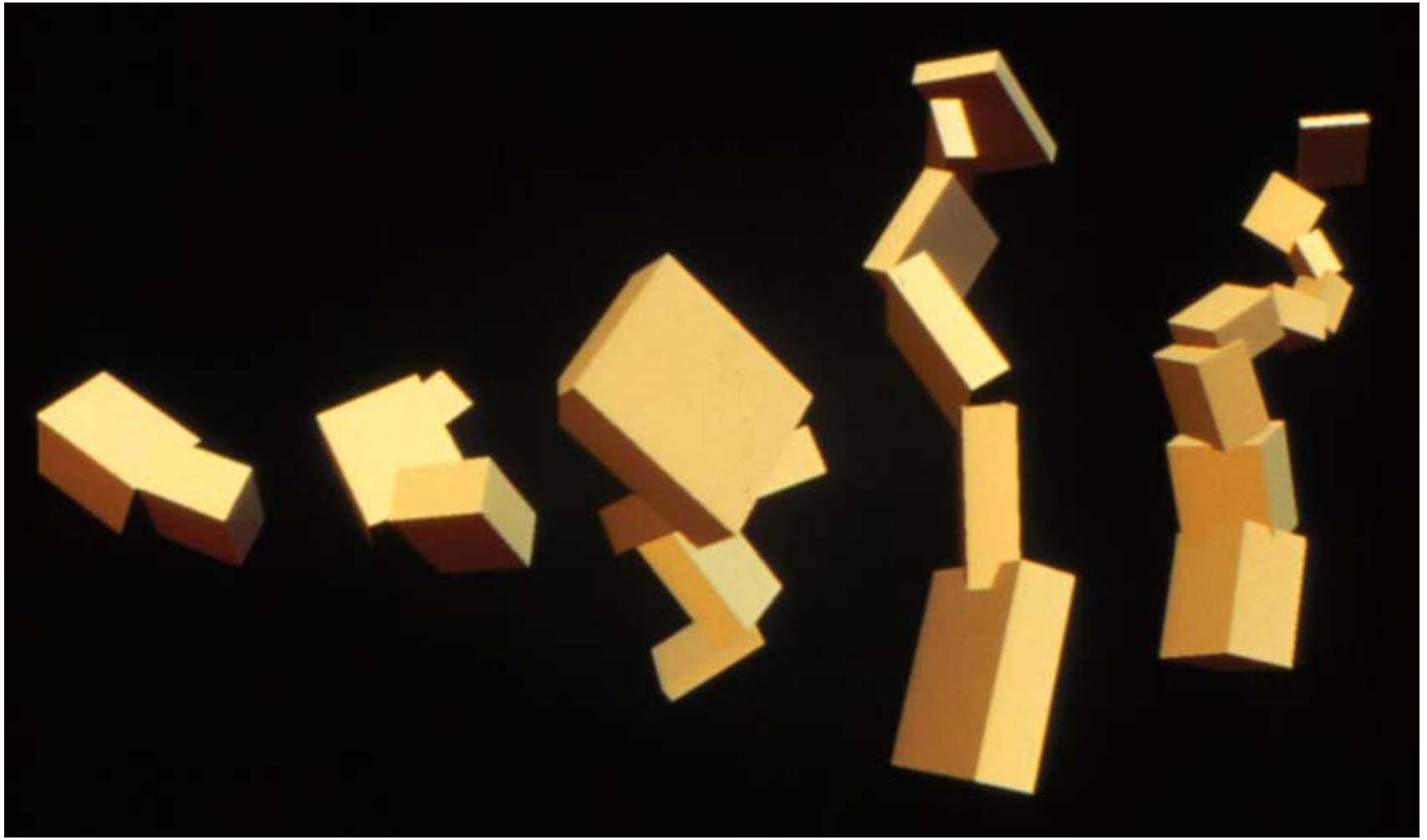
To dive deeper (optional):

- Chapter 17 of *The Computational Beauty of Nature*
- “The Evolution of Strategies in the Iterated Prisoner's Dilemma”, by Robert Axelrod

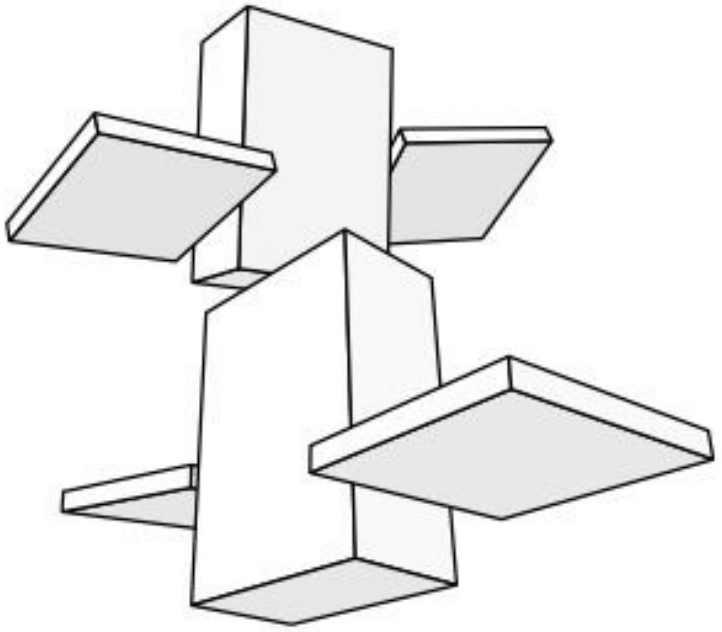
Evolving Virtual Creatures

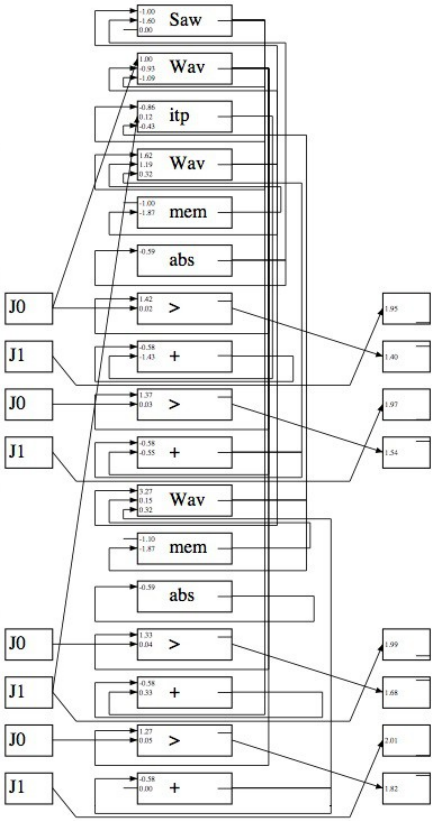
- Karl Sims, “Evolving virtual creatures”, *Proceedings of the SIGGRAPH '94 Conference*, pp. 15-22, 1994



Evolving Virtual Creatures

- Virtual creatures move around in a **3-D simulated world**
- Creatures' **bodies** are rectangular blocks connected by movable joints, with **sensors** for light and proprioception
- Creatures' **brains** are complex neural networks

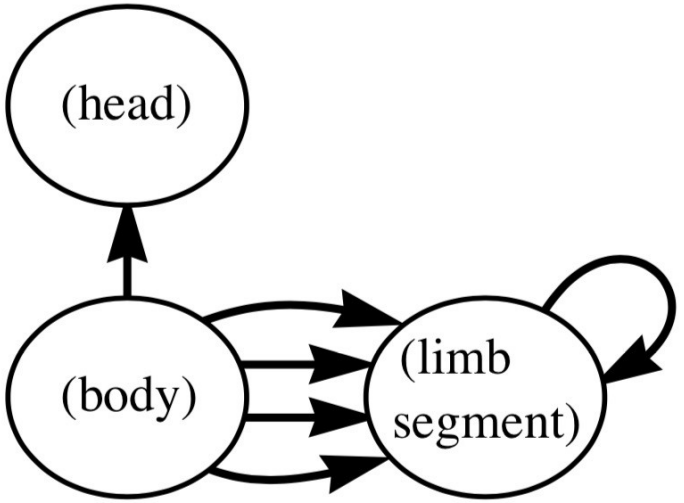




Evolving Virtual Creatures

- A **genome** is a set of nodes and links that encode a creature's body structure and brain structure

- Complex **genotype** → **phenotype** mapping



Evolving Virtual Creatures

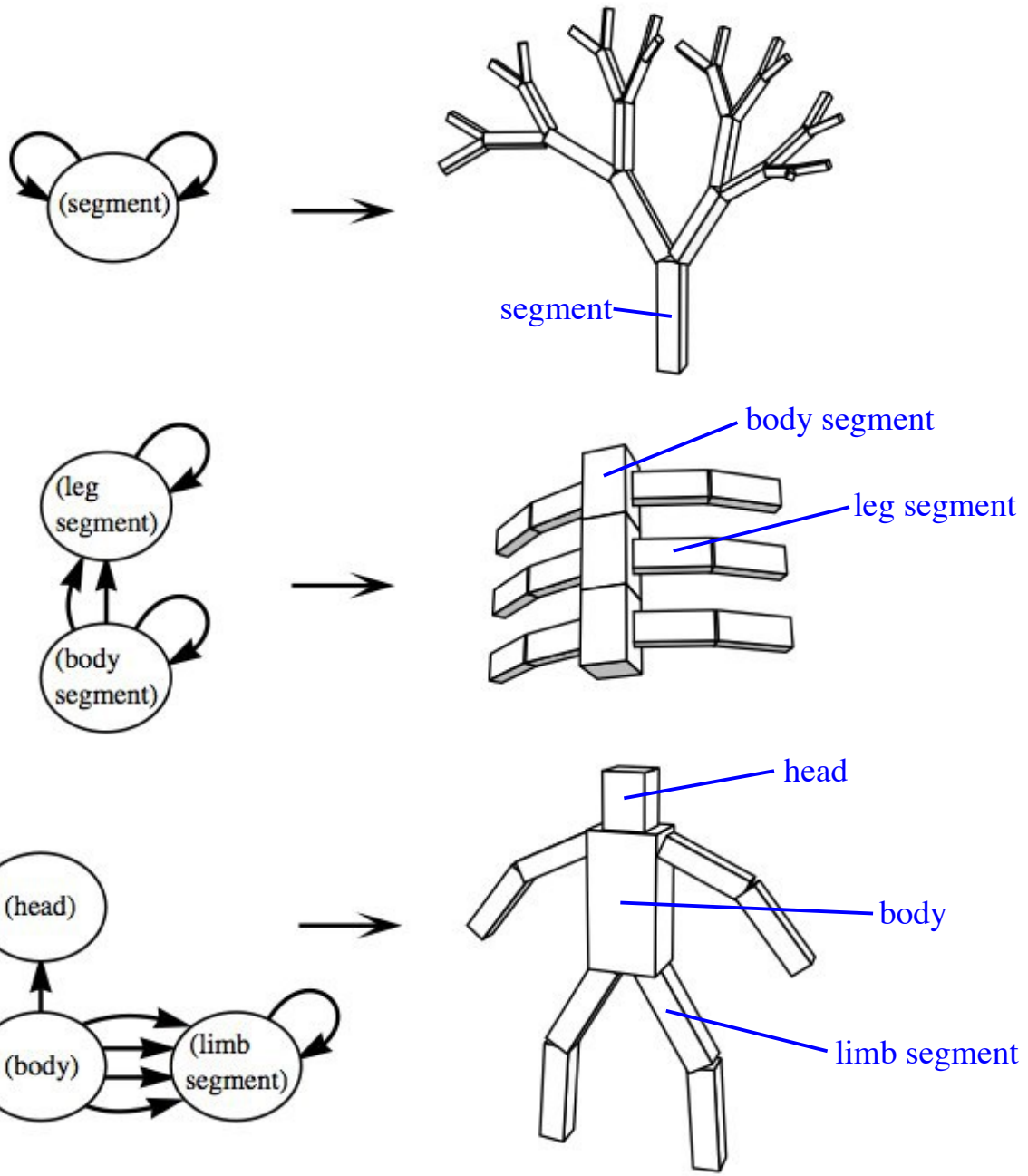
- A **genome** is a set of nodes and links that encode a creature's body structure and brain structure

- Complex **genotype** → **phenotype** mapping

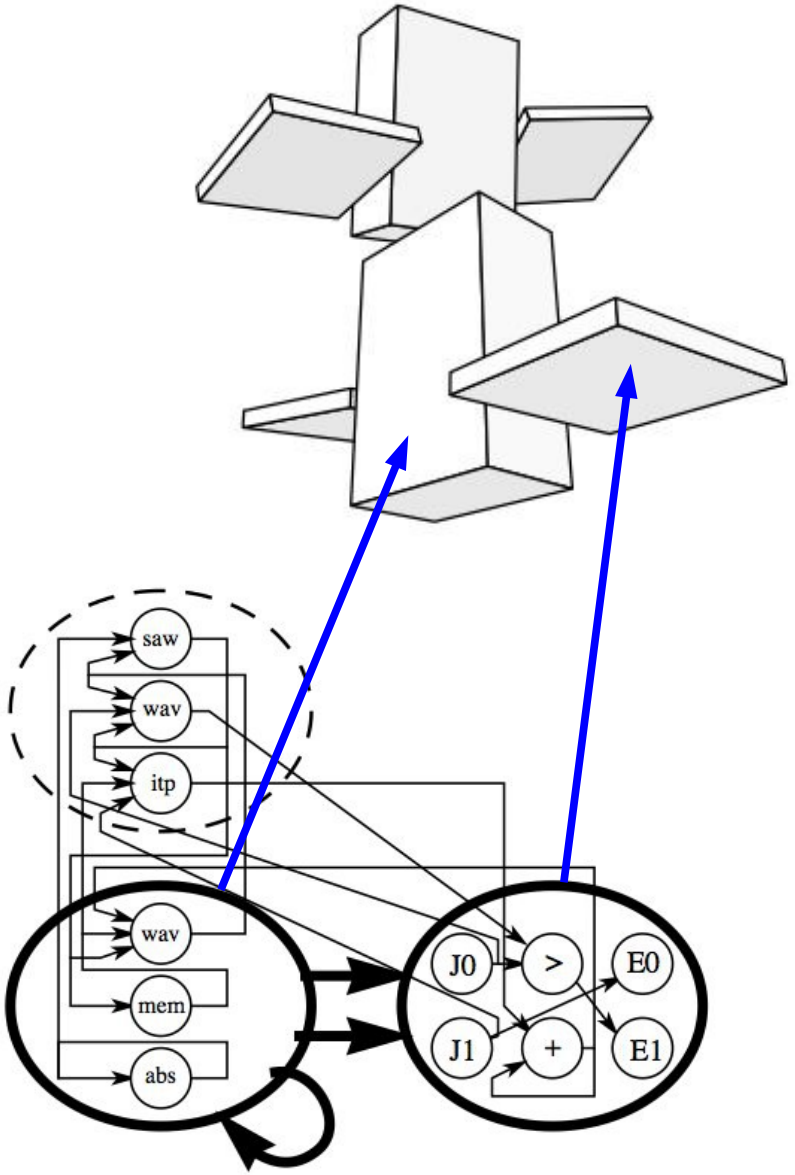
- Brains and bodies **co-evolve** together
  - Body structure evolves
  - Brain structure evolves (neural network topology)
  - Brain parameters evolve (neural network weights)

- Fitness: how well a creature can **swim**, **walk**, **jump**, **follow** a light source, or **compete** for control of a block

Genetic Encoding of Body Structure

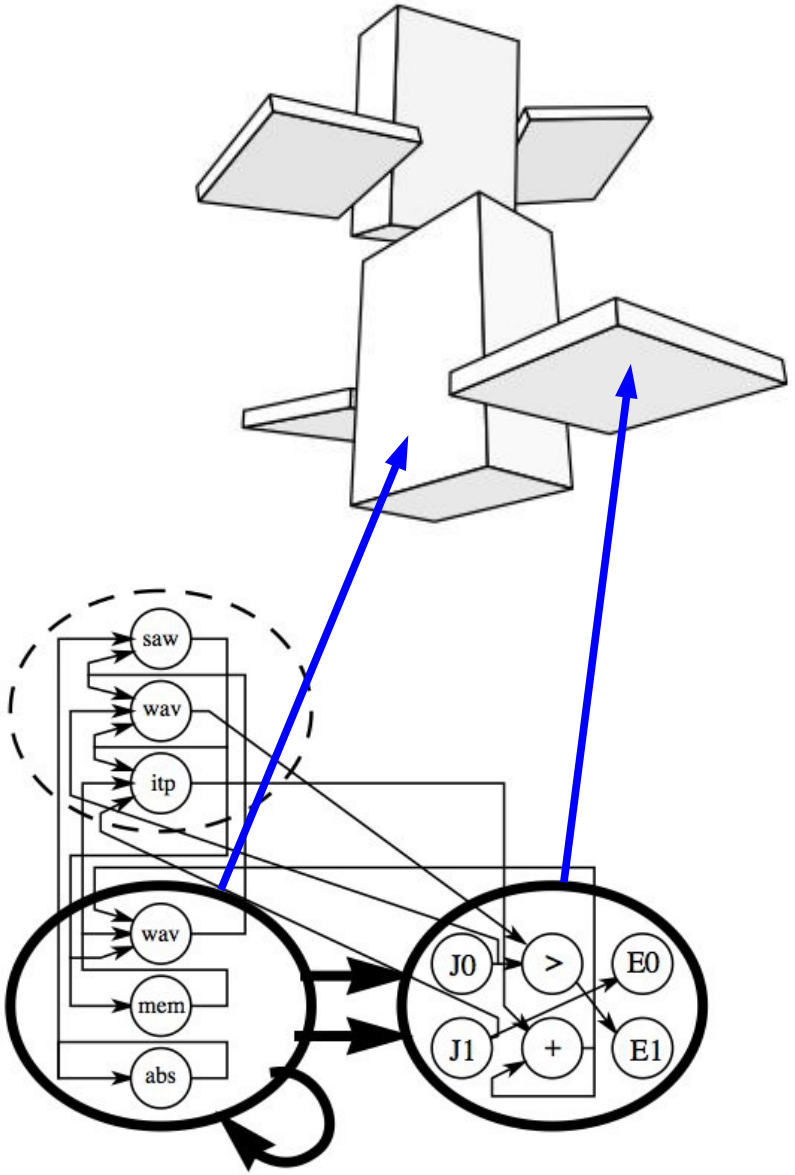


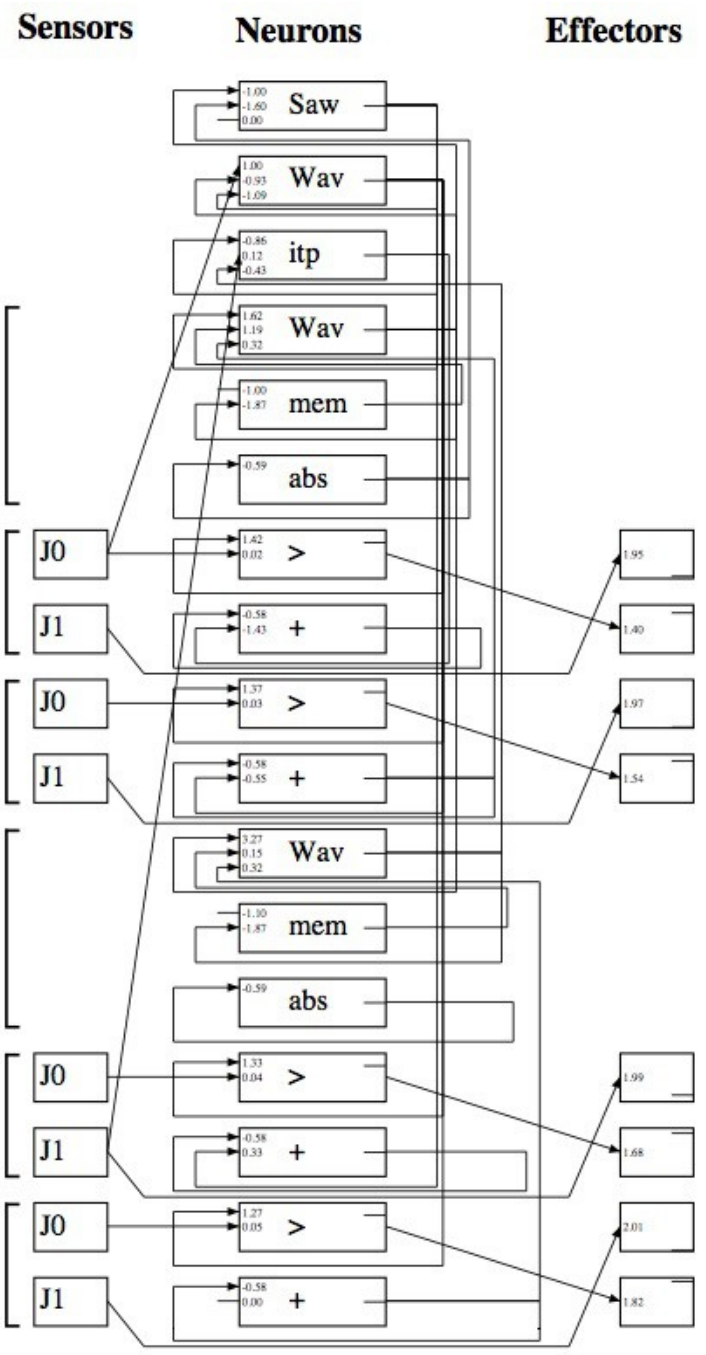
Genetic Encoding of Brain Structure



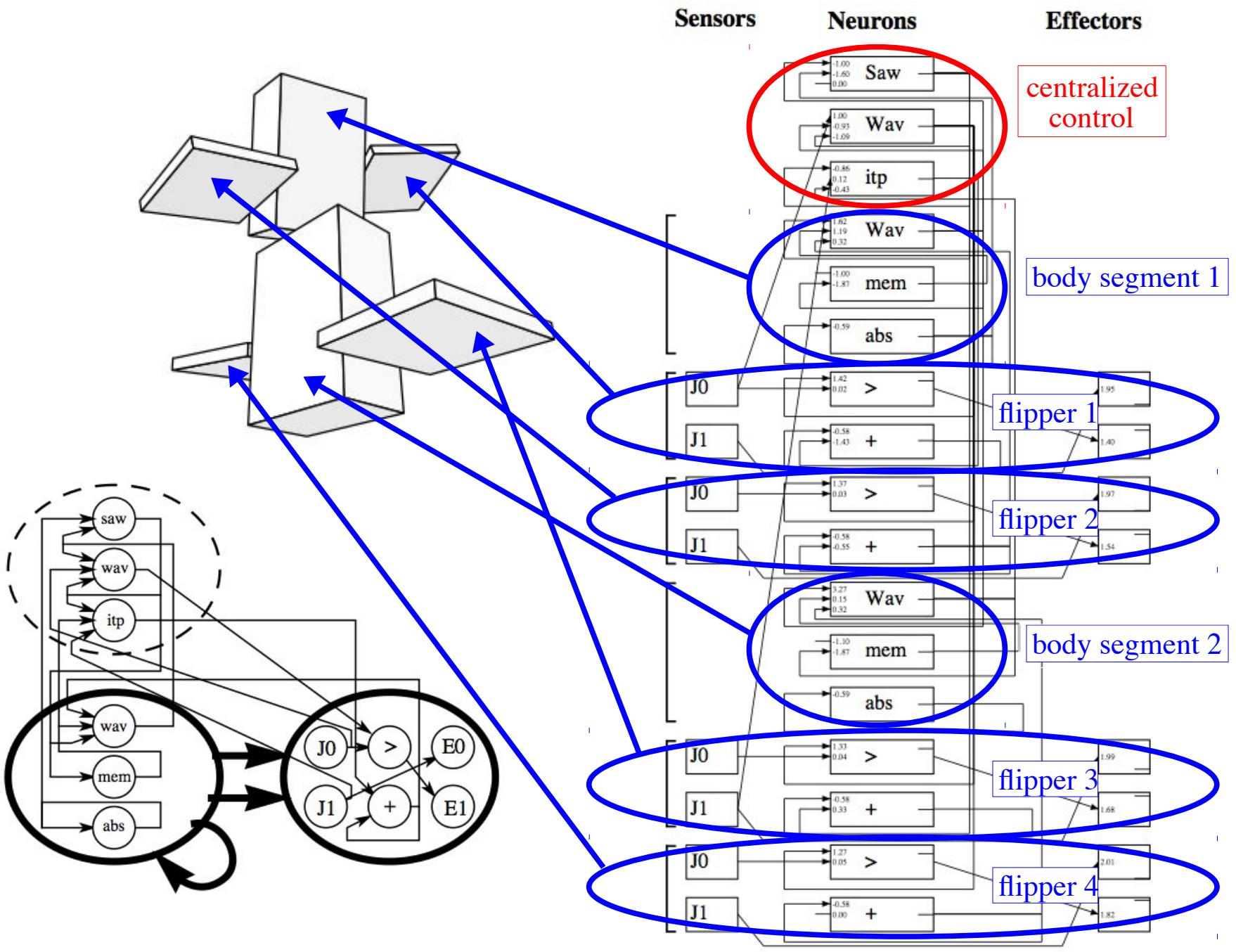
23 different neuron types:
sum, product, divide, sum-threshold, greater-than, less-than, sign-of, min, max, abs, if, interpolate, sin, cos, atan, log, expt, sigmoid, integrate, differentiate, smooth, memory, oscillate-wave, oscillate-saw

Genetic Encoding of Brain Structure

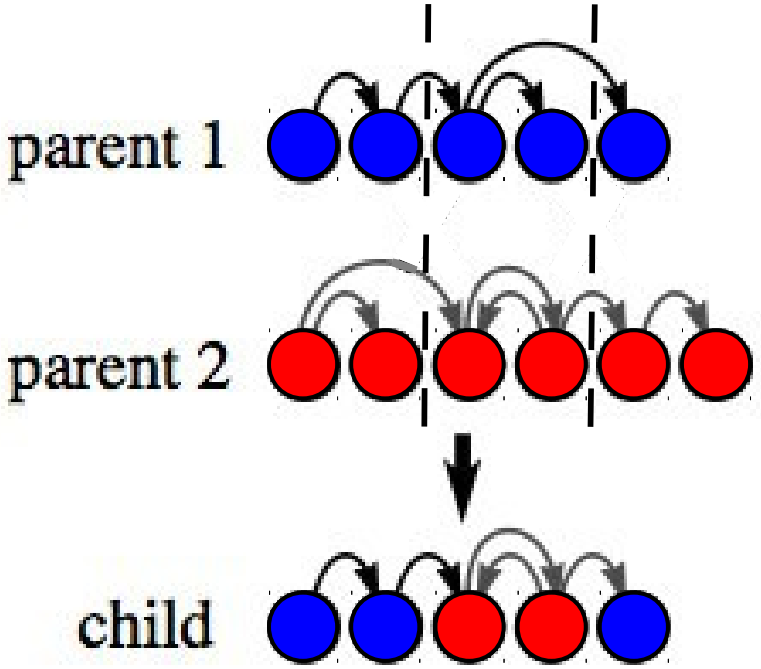




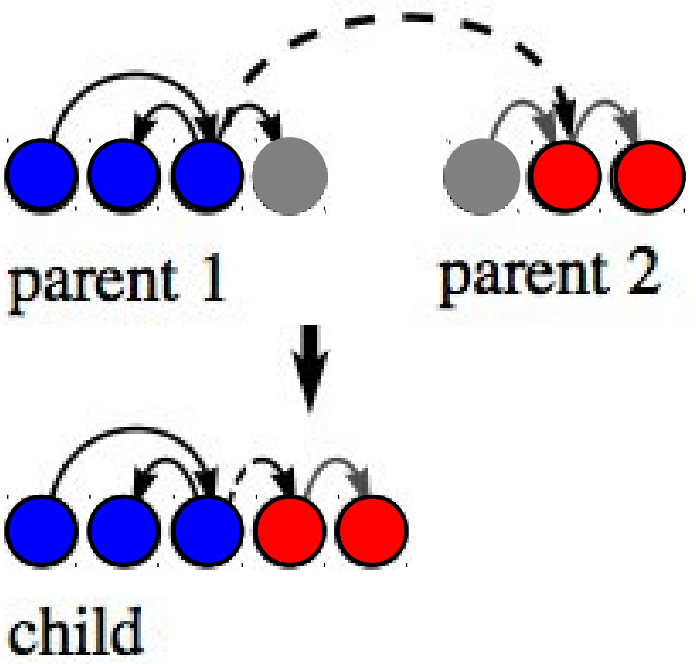
Genetic Encoding of Brain Structure



Genetic Recombination



Crossover



Grafting

The Genetic Algorithm

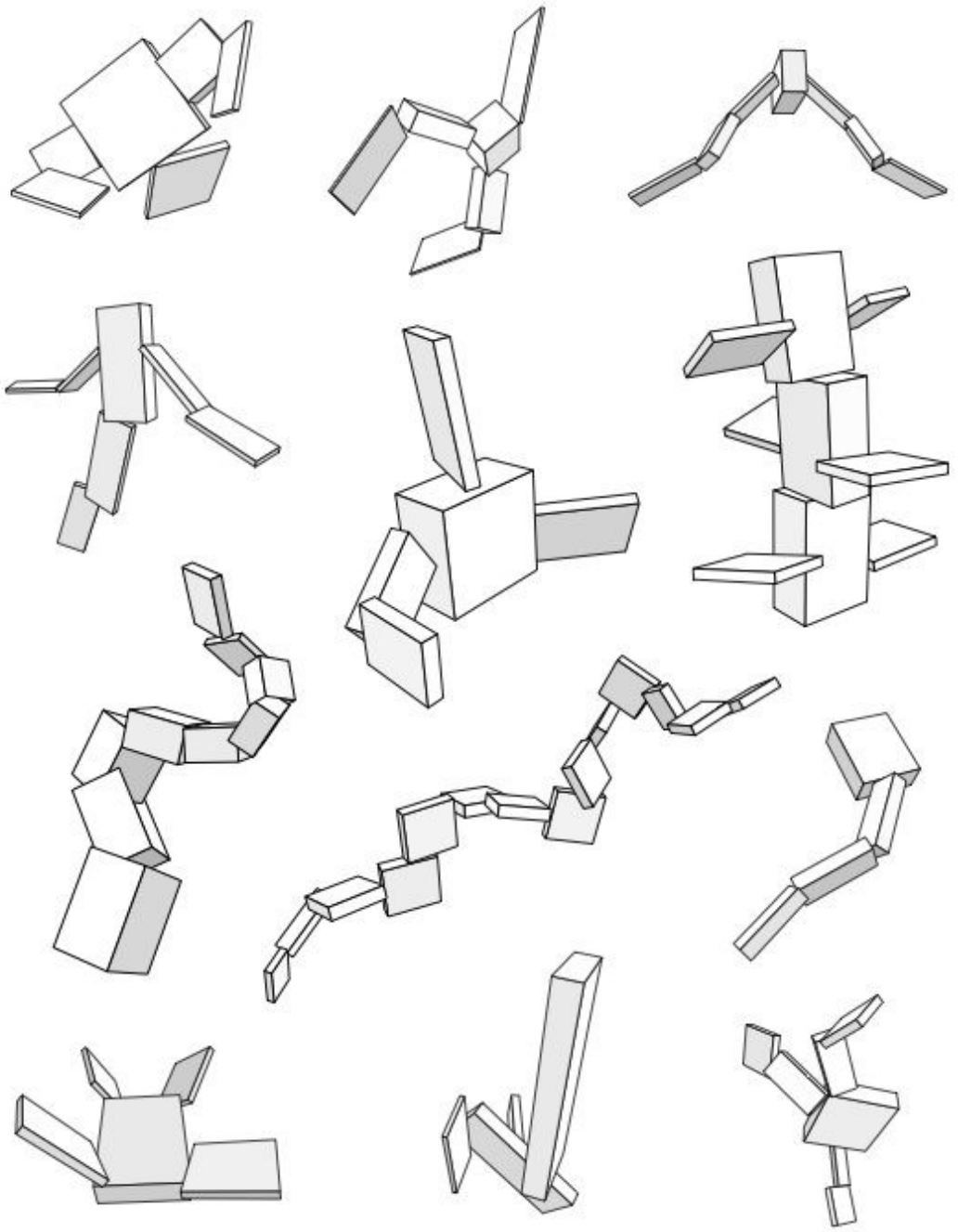
- Population size: 300 genomes
- Evolved for 100 generations
- Fitness evaluation:

genetic description → creature → 3-D simulation

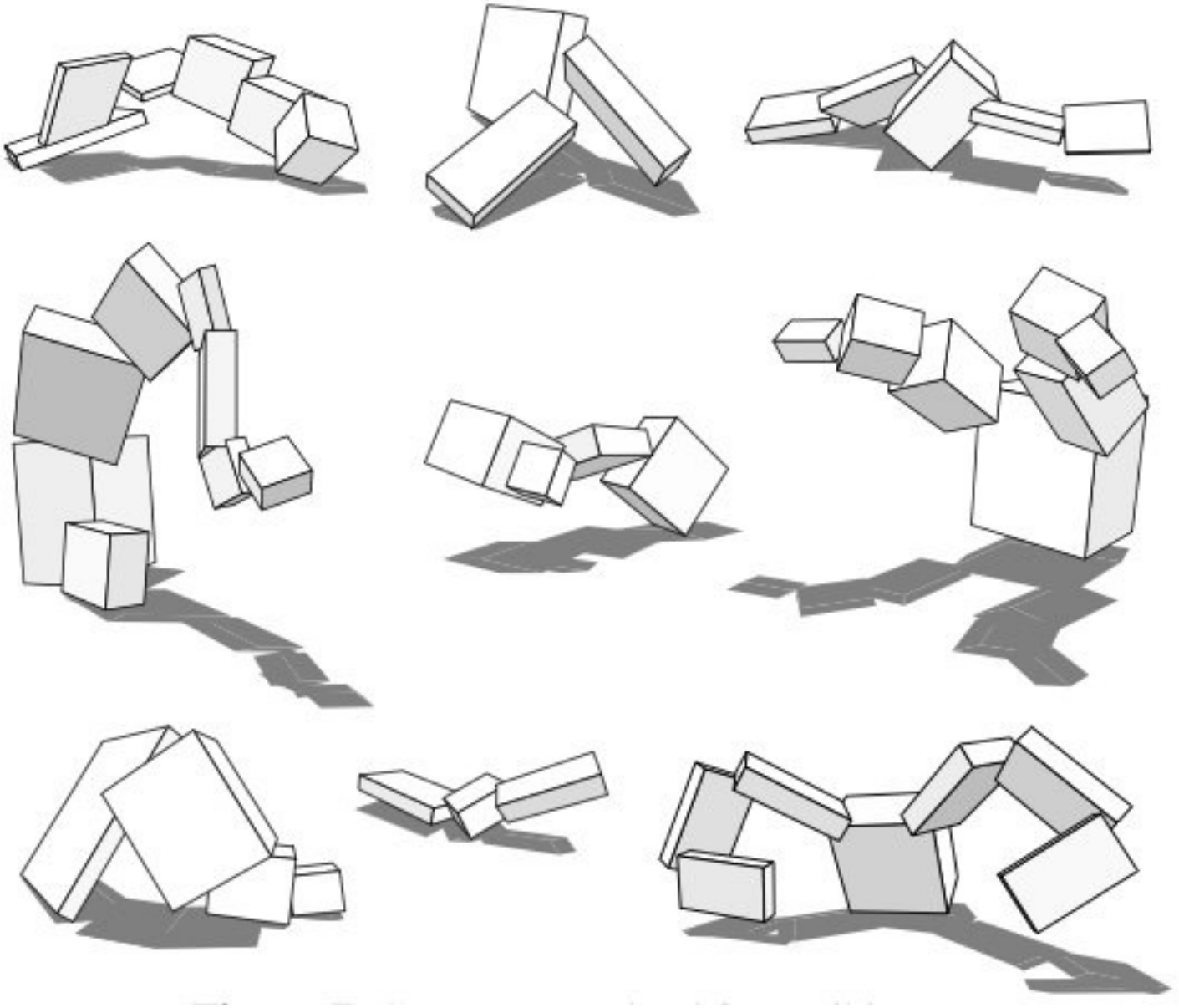
fitness = distance creature walks / swims / jumps / etc.
in a fixed amount of simulation time

- Virtual 3-D world simulates effects of gravity, friction, viscosity

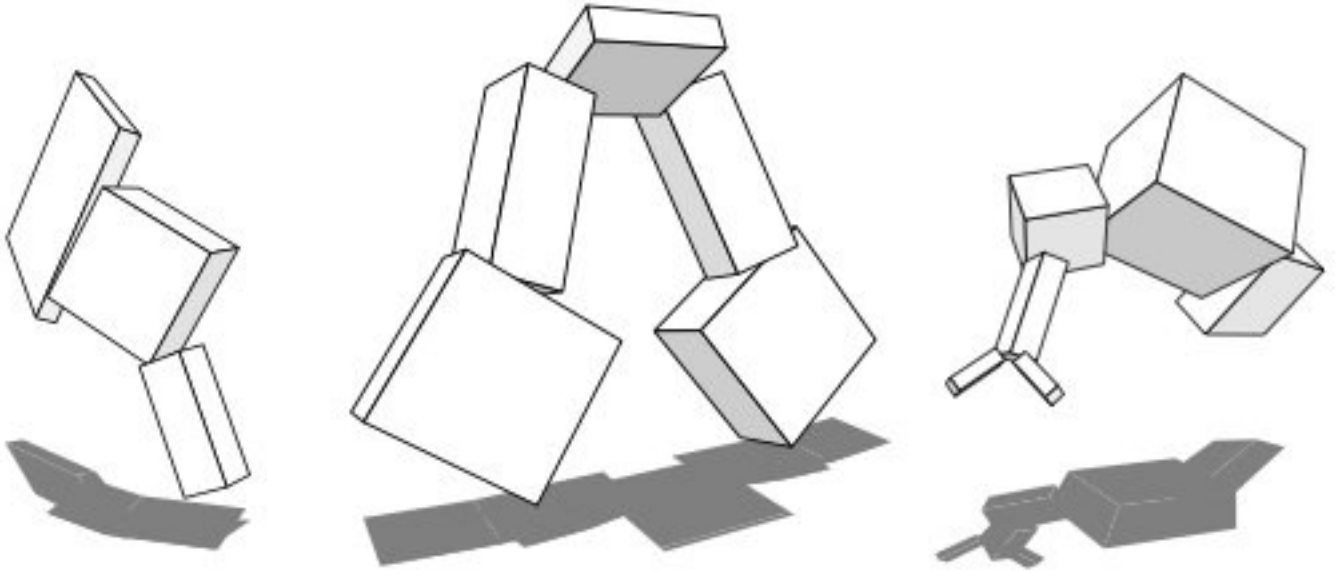
Results: Swimmers



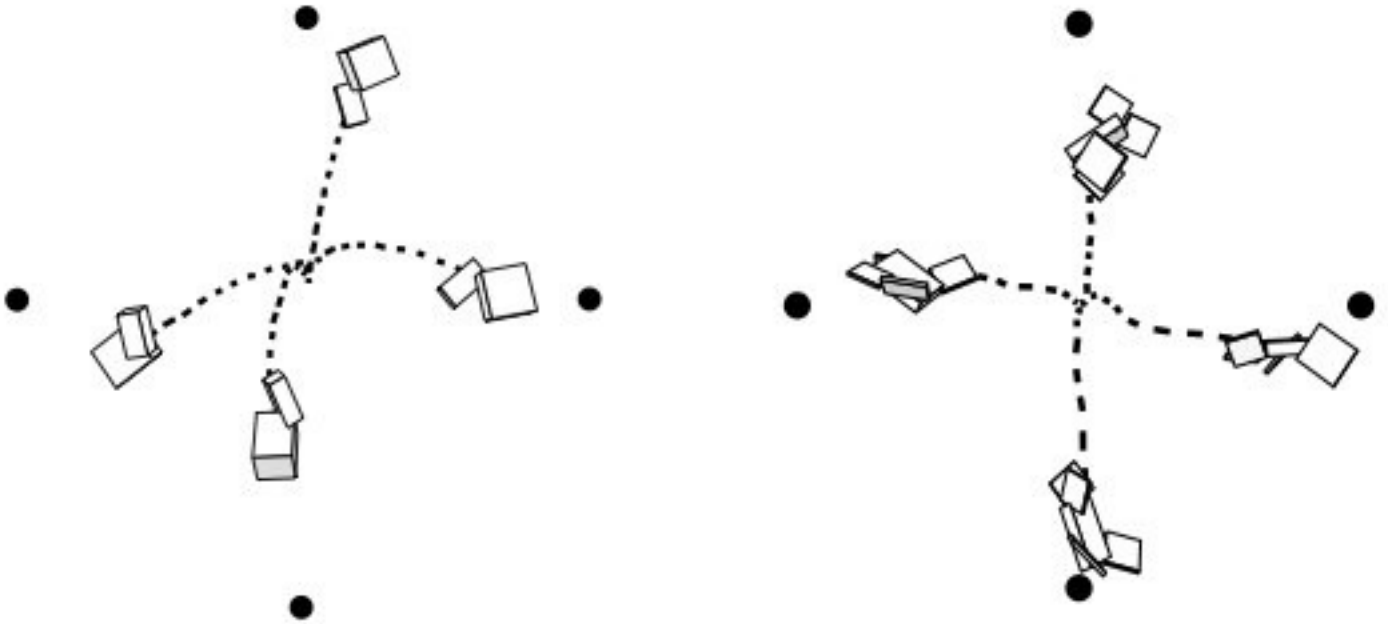
Results: Walkers



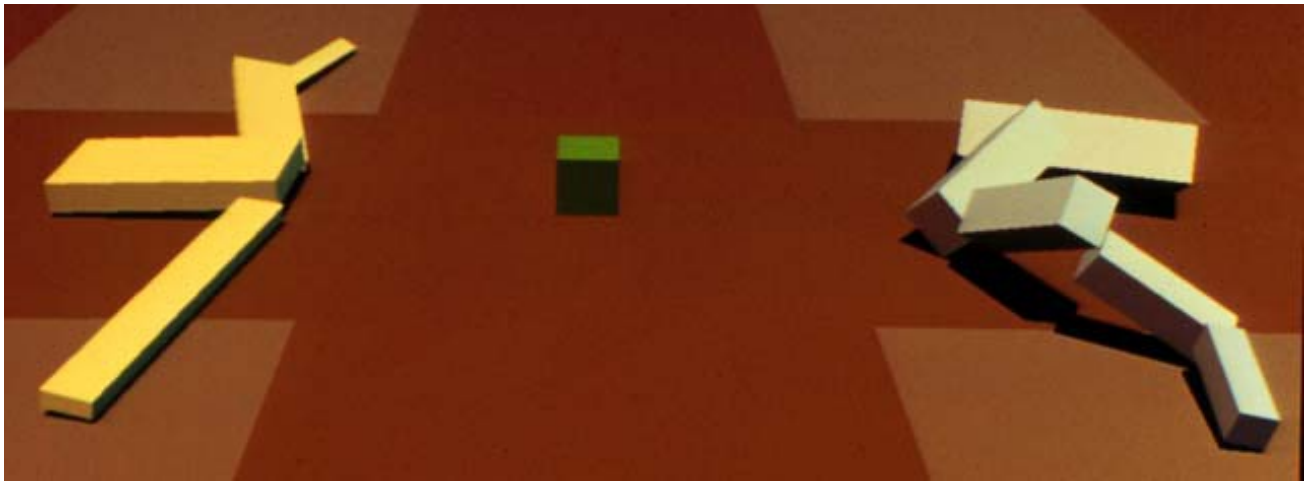
Results: Jumpers

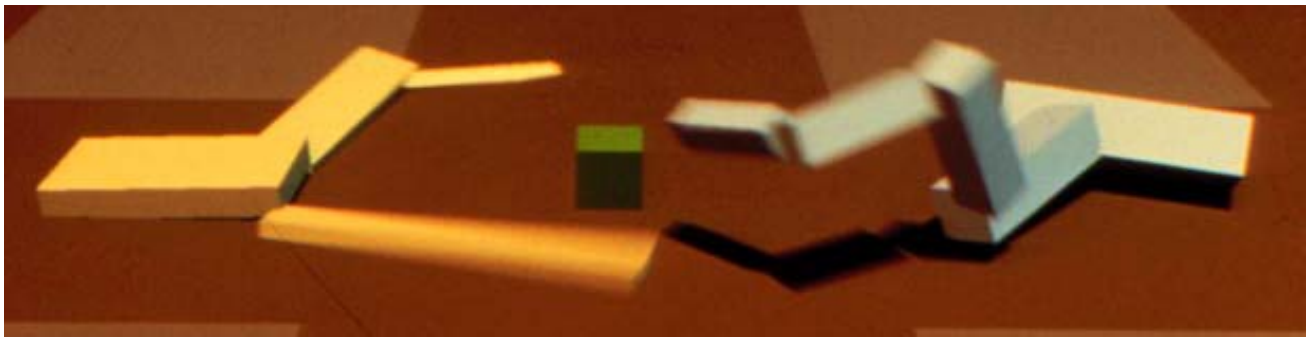


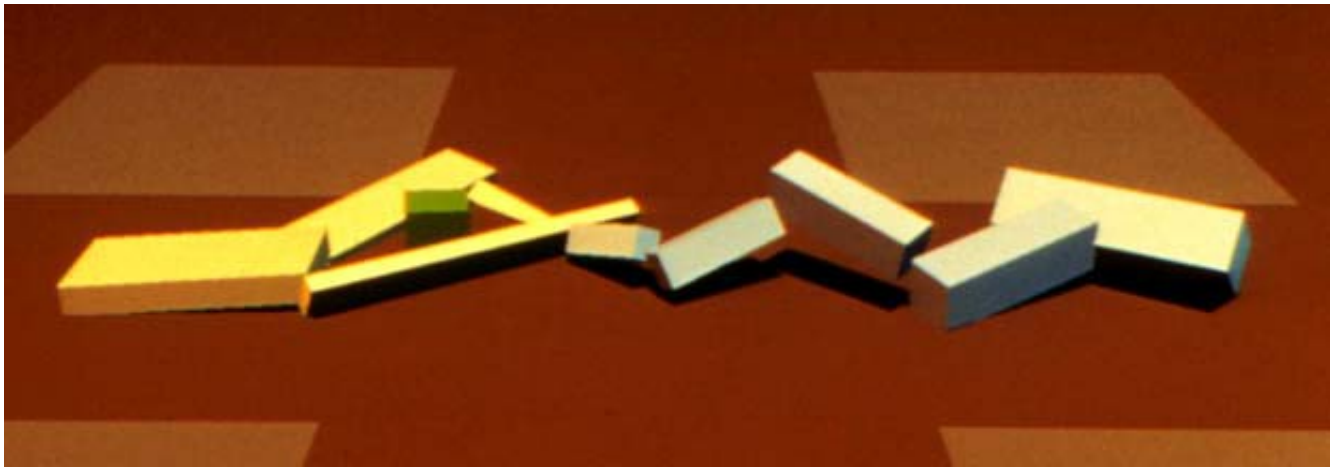
Results: Light Followers



Results: Competitors







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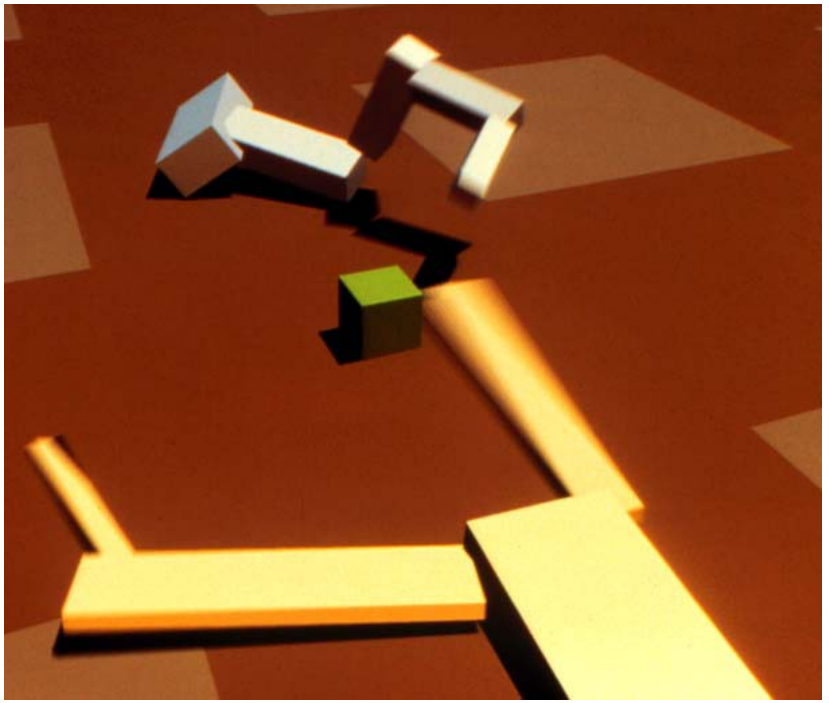

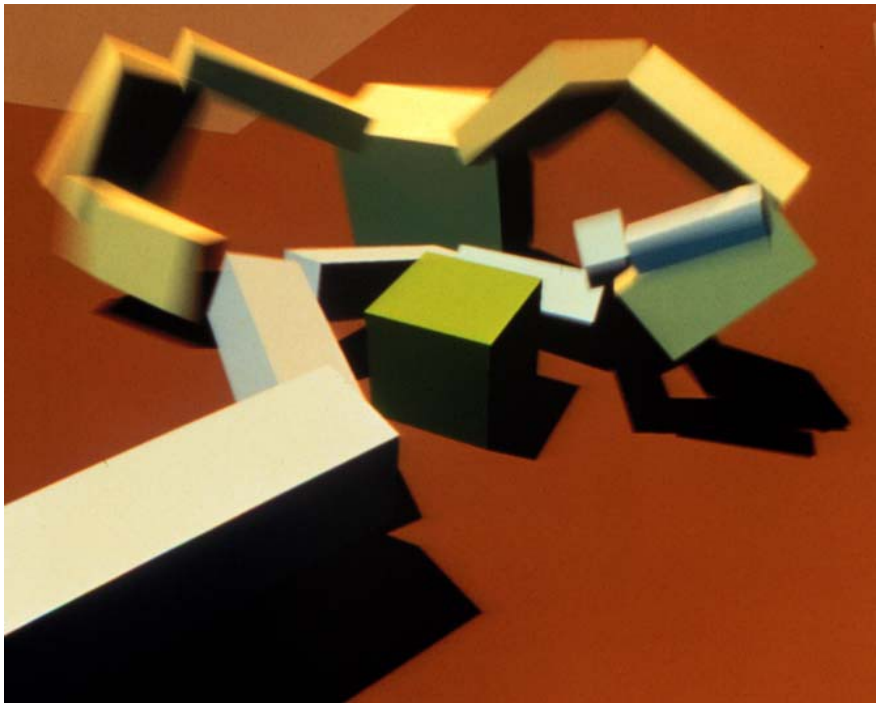

https://vimeo.com/235275454