

Genome Representations We've Seen

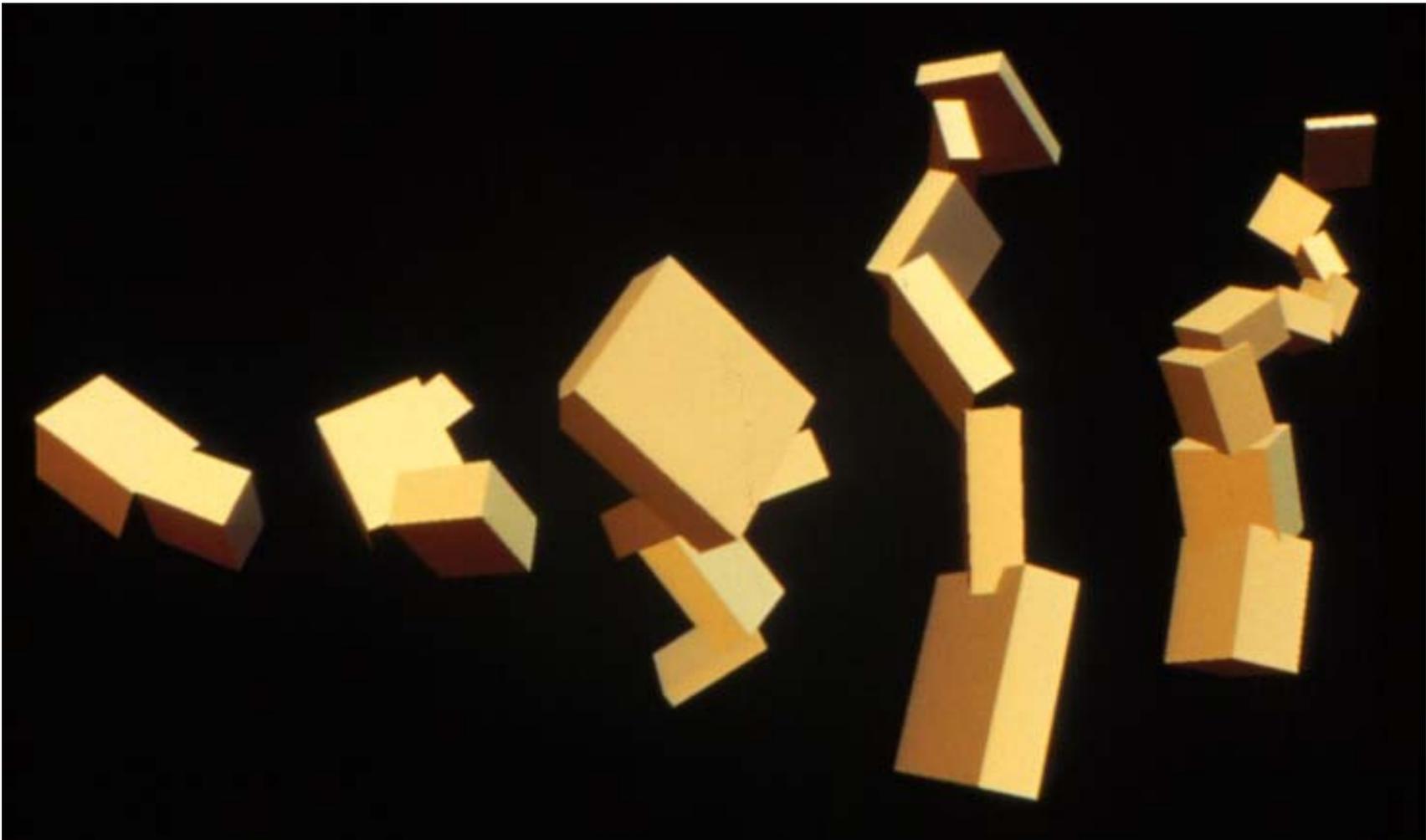
- Binary strings (evolving a string of all 1's)
- Letter strings (evolving an English phrase)
- Strings of action symbols (evolving a robot strategy)

Genotype → Phenotype Mappings

- Trivial for binary strings and letter strings
- More complex for robot strategies
- No interaction between “body” and “brain”

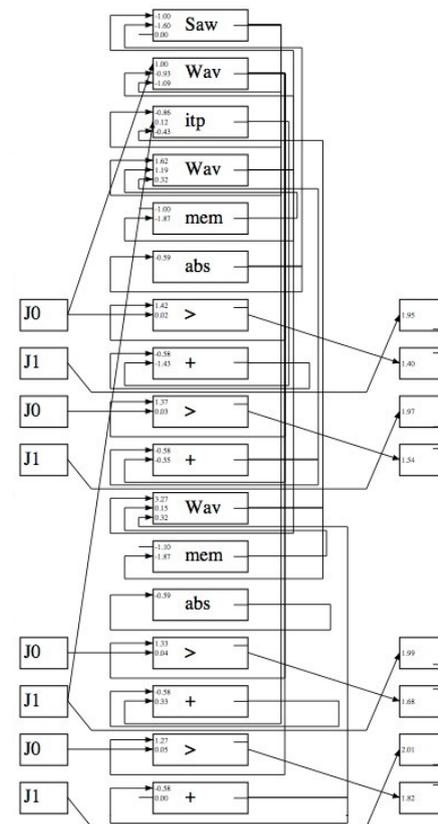
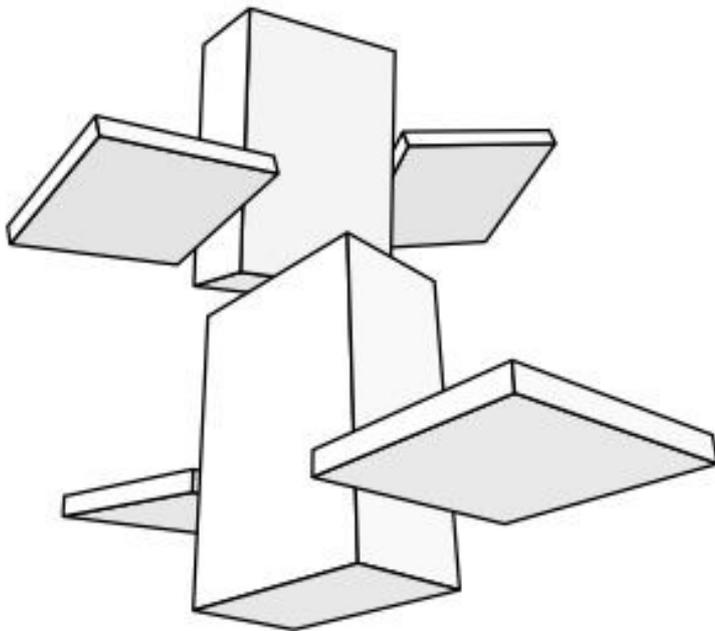
Evolving Virtual Creatures

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



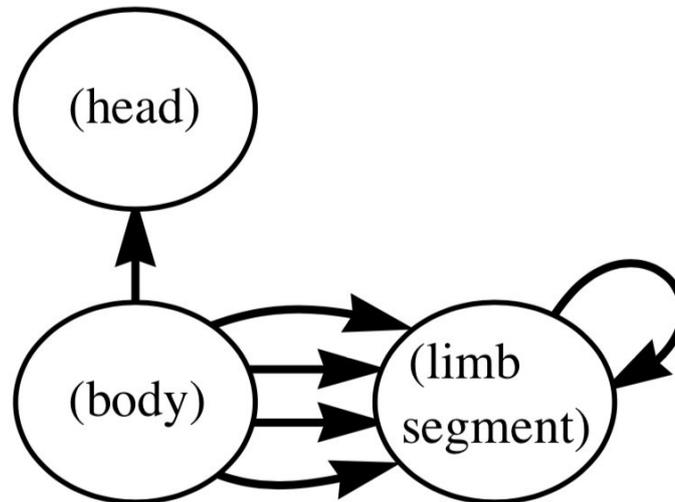
Evolving Virtual Creatures

- 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

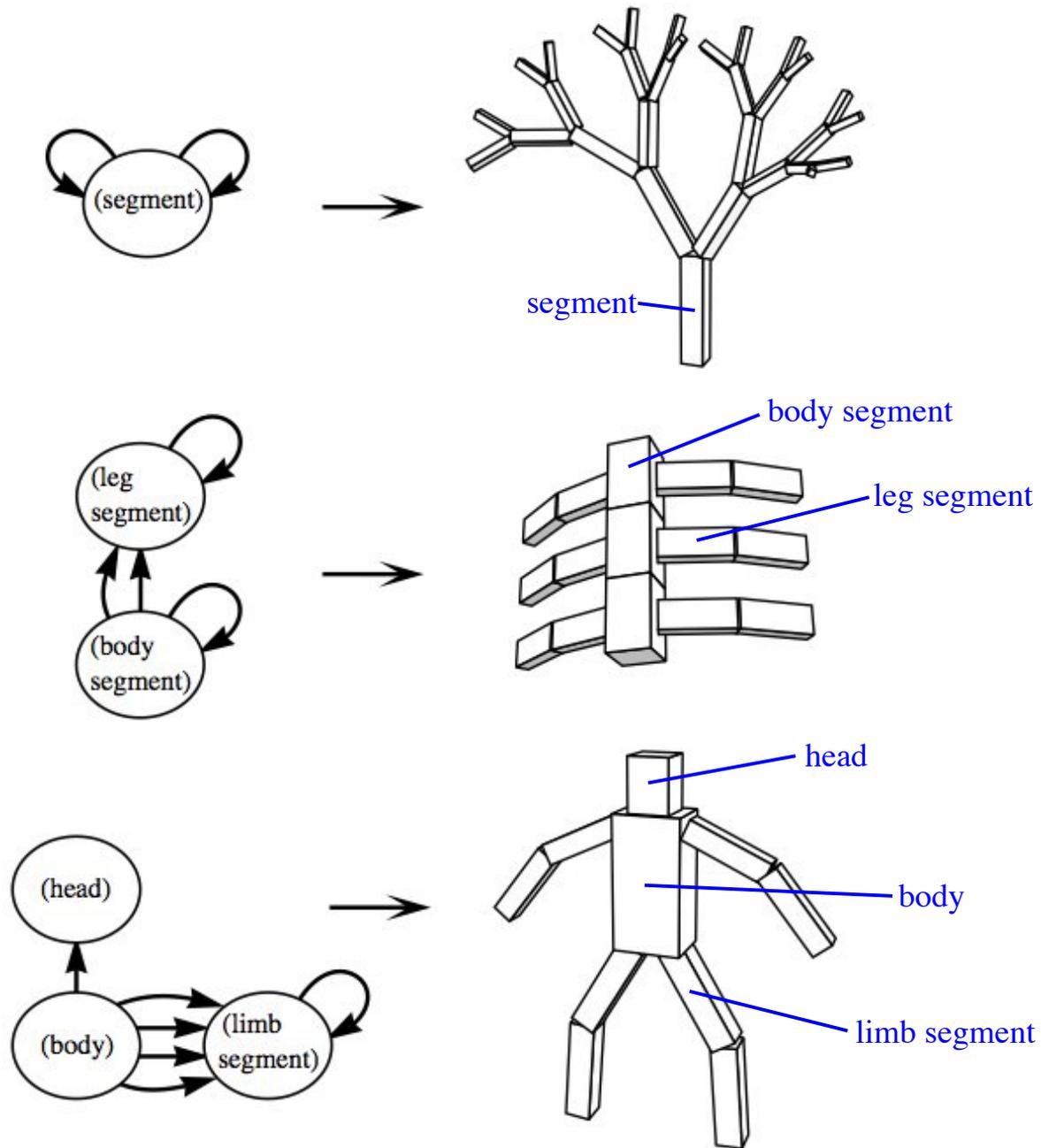
- A **genome** is a set of nodes and links that encode a creature's body structure and brain structure
- Complex **genotype** → **phenotype** mapping



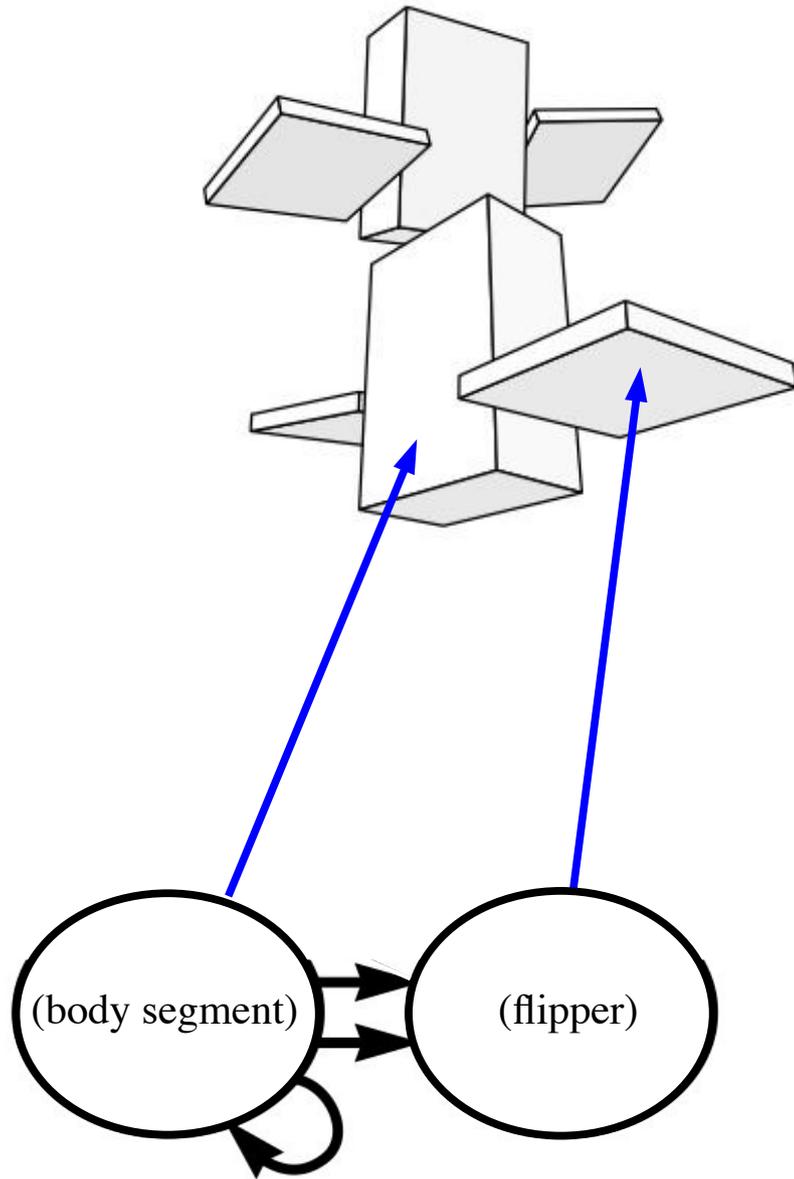
Evolving Virtual Creatures

- 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

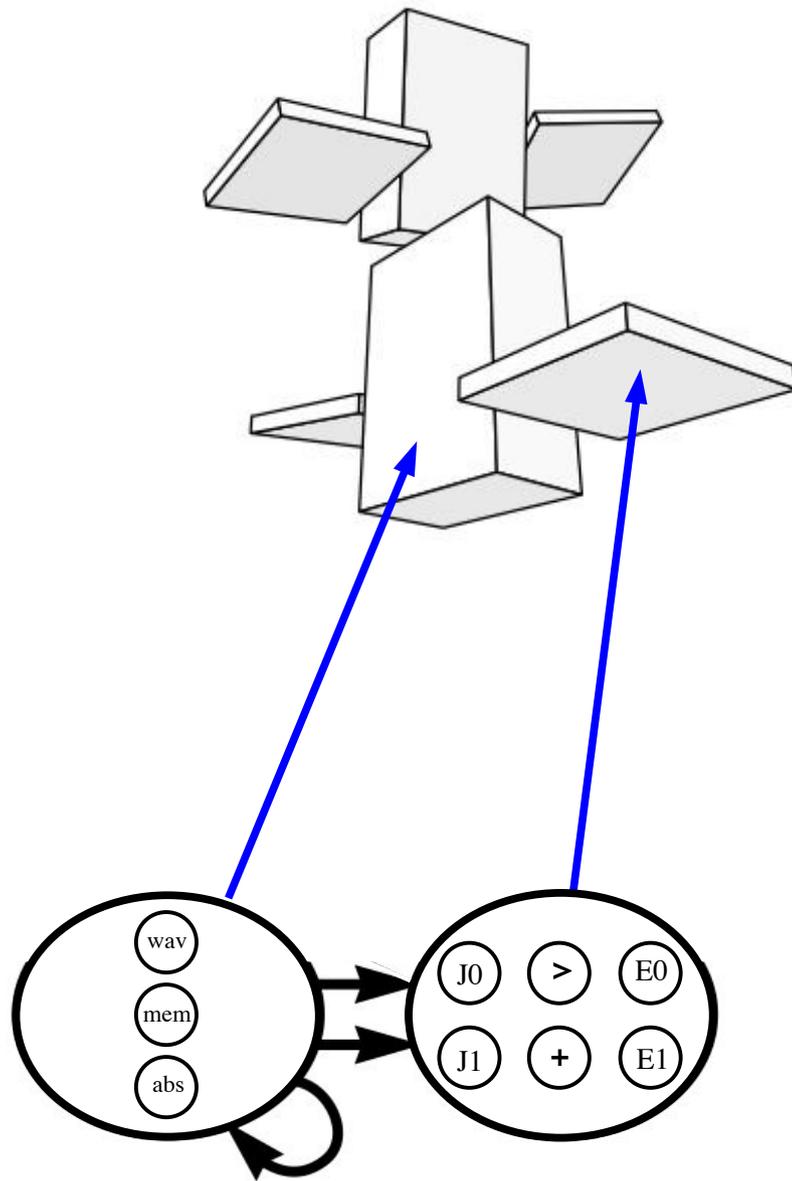
Genetic Encoding of Body Structure



Genetic Encoding of Brain Structure



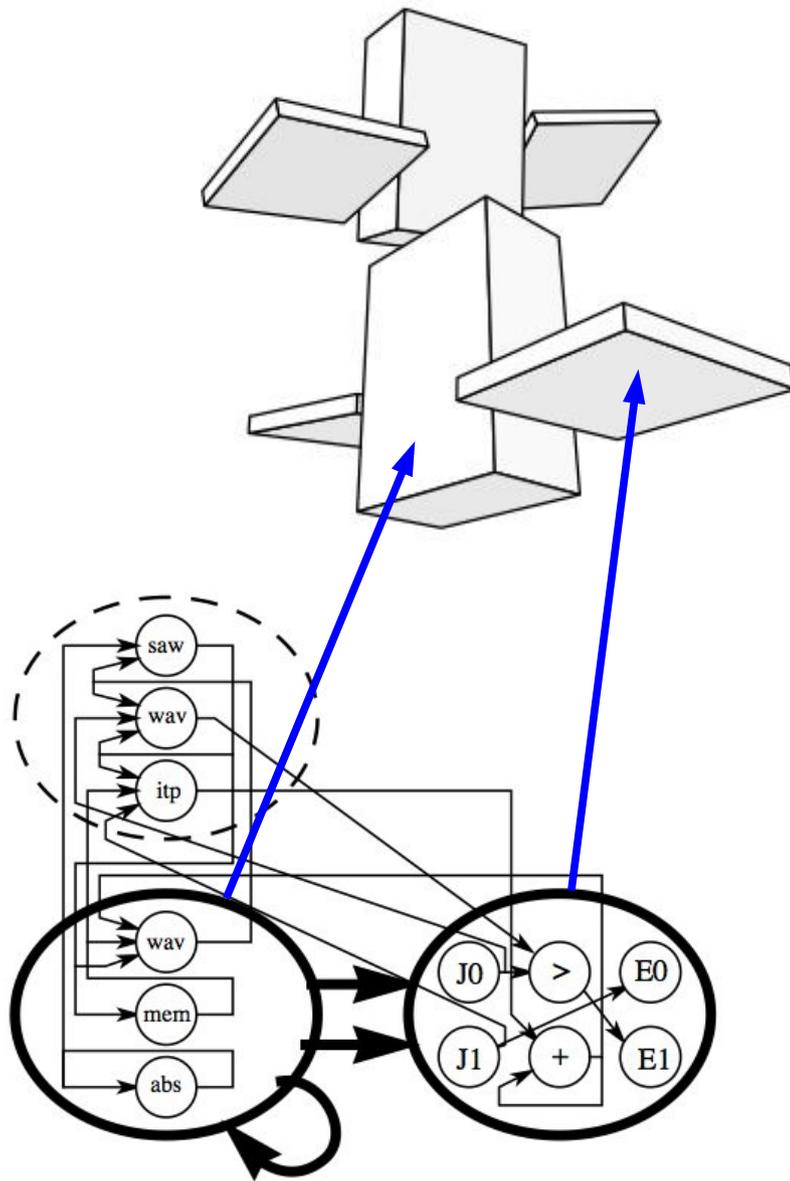
Genetic Encoding of Brain Structure



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

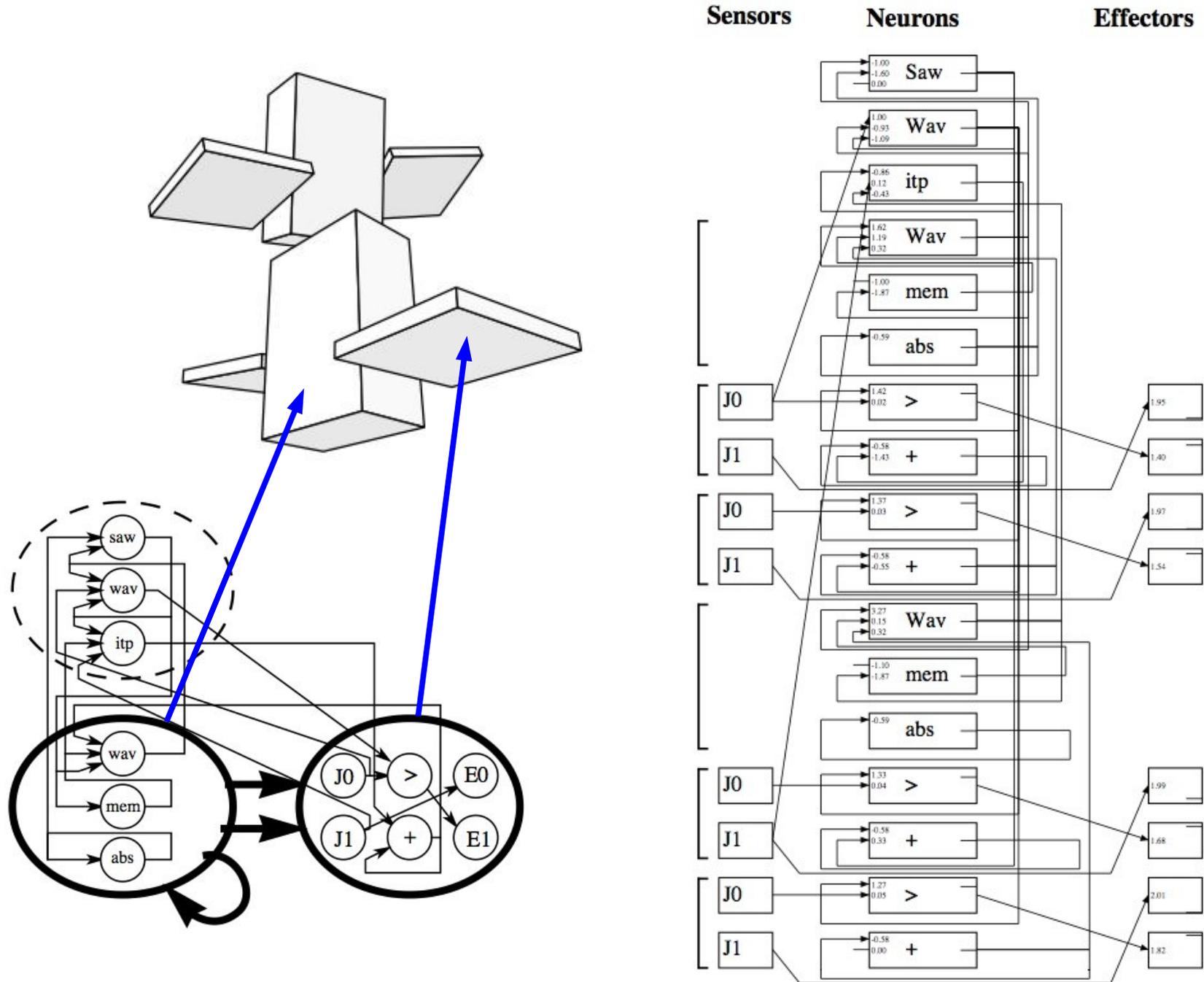
Genetic Encoding of Brain Structure



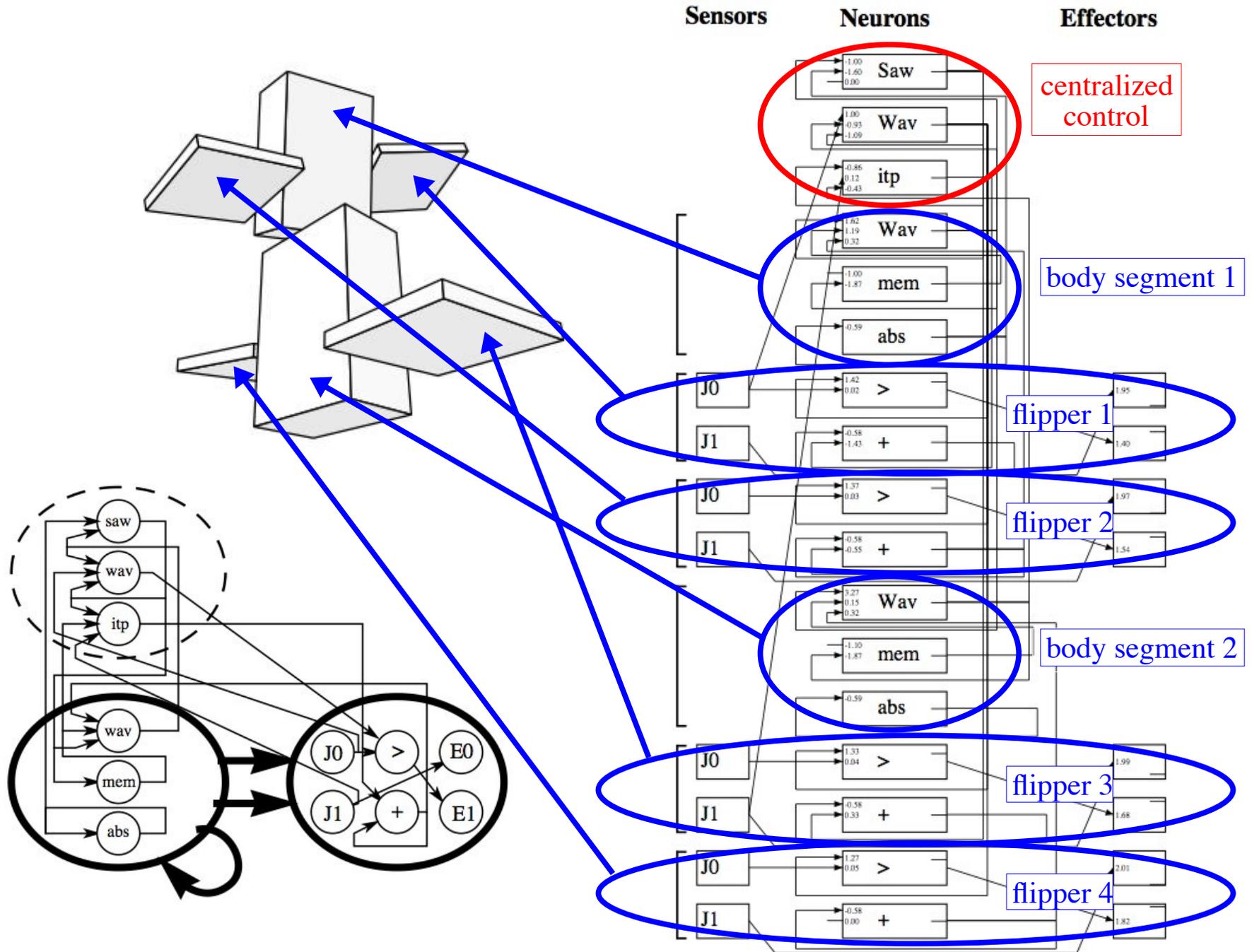
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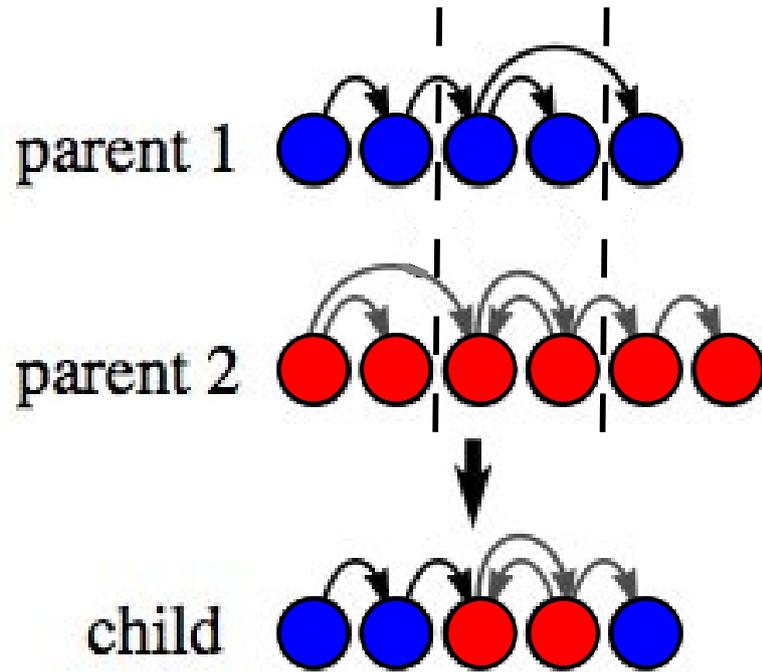
Genetic Encoding of Brain Structure



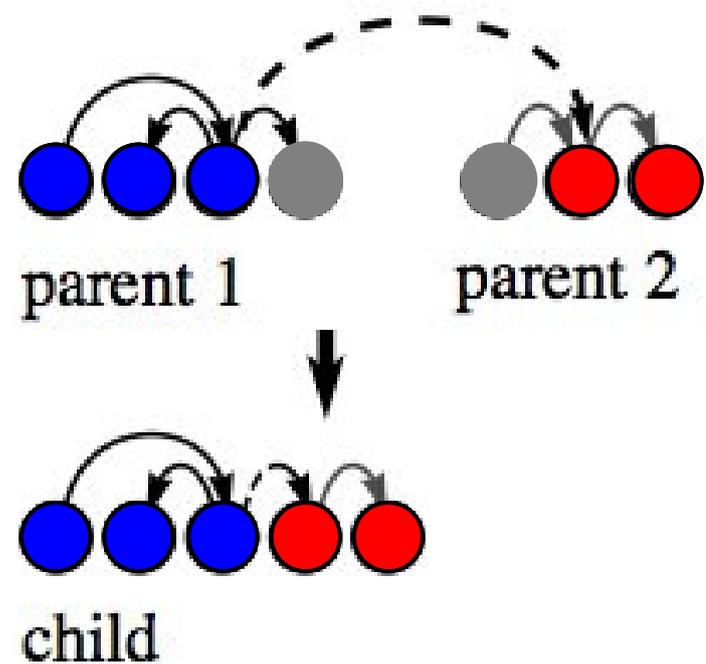
Genetic Encoding of Brain Structure



Genetic Recombination



Crossover



Grafting

The Genetic Algorithm

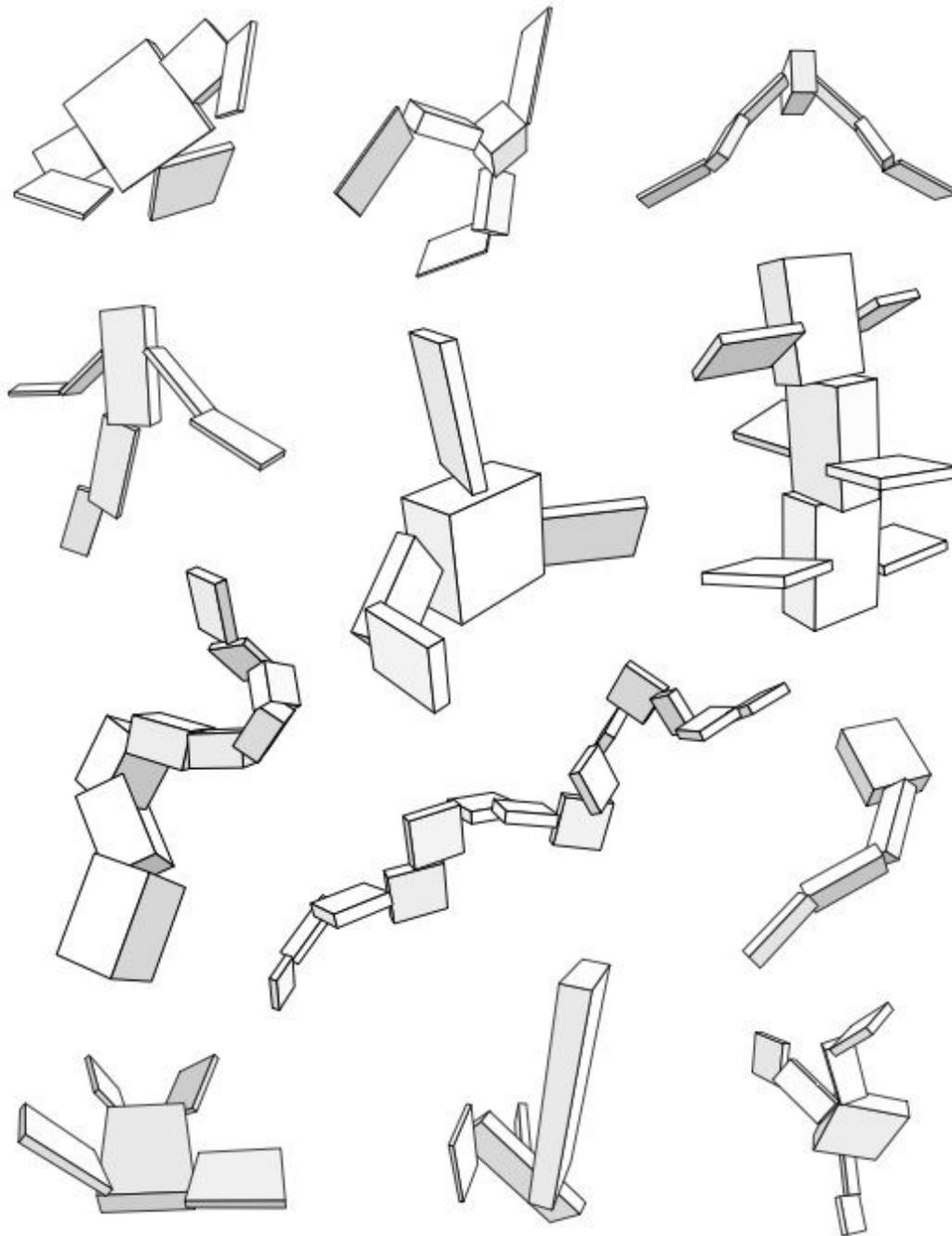
- Population size: 300 genomes
- Evolved for 100 generations
- Fitness evaluation:

genetic description → creature → 3-D simulation

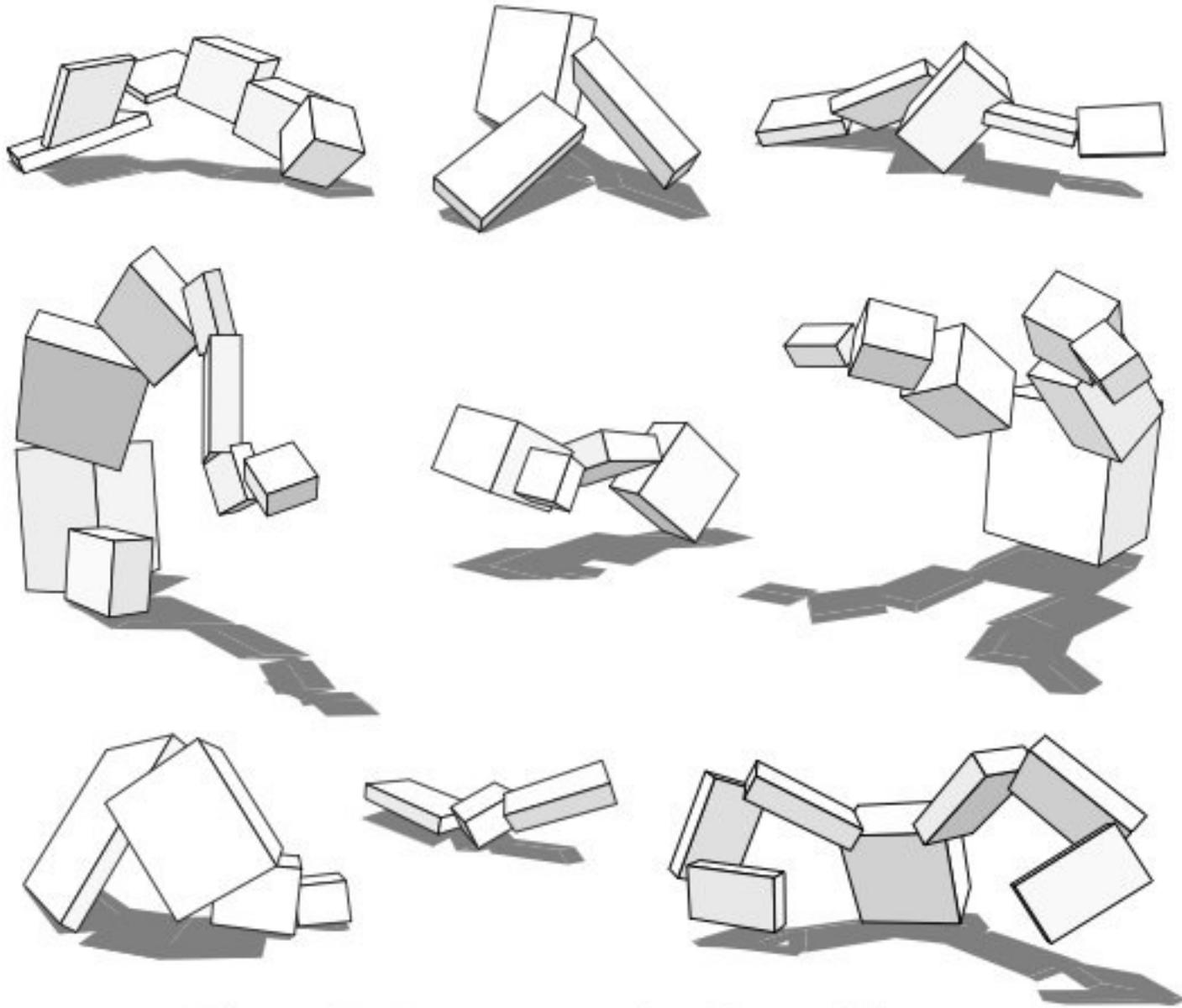
fitness = distance creature walks / swims / jumps / etc.
in a fixed amount of simulation time

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

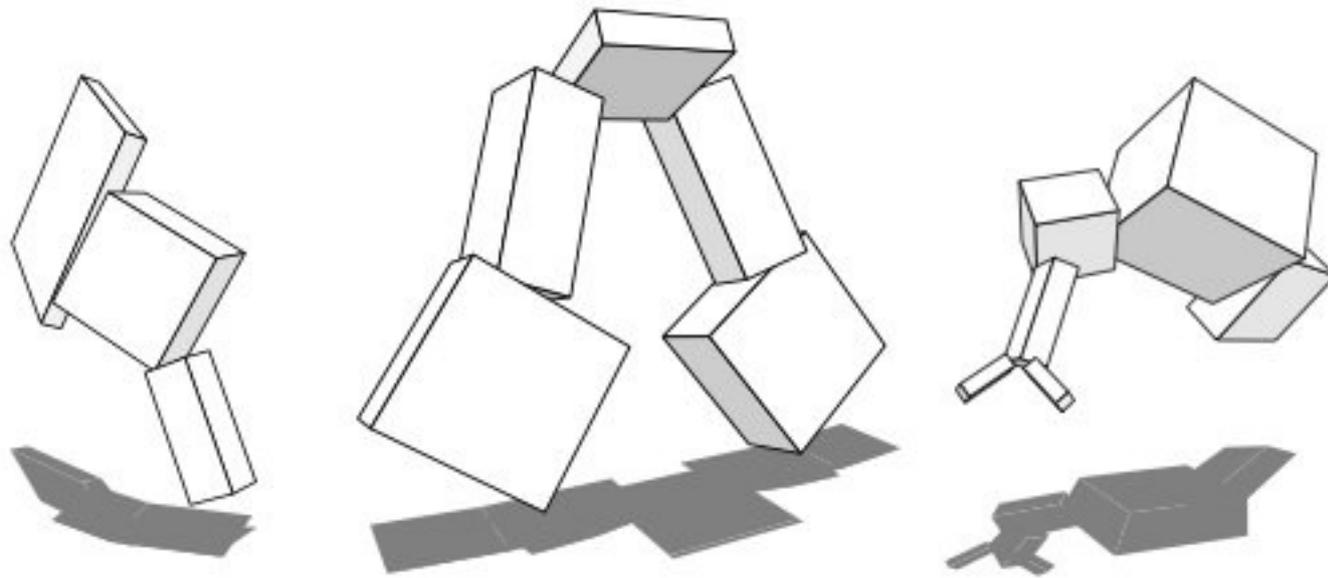
Results: Swimmers



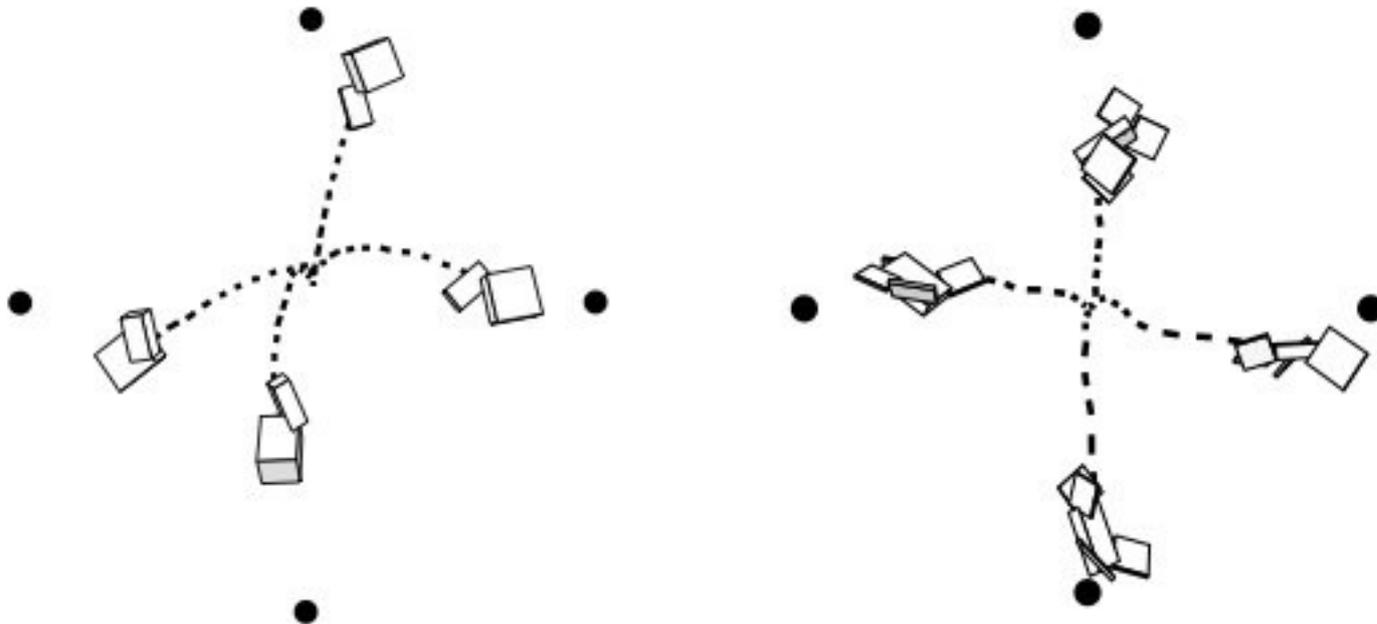
Results: Walkers



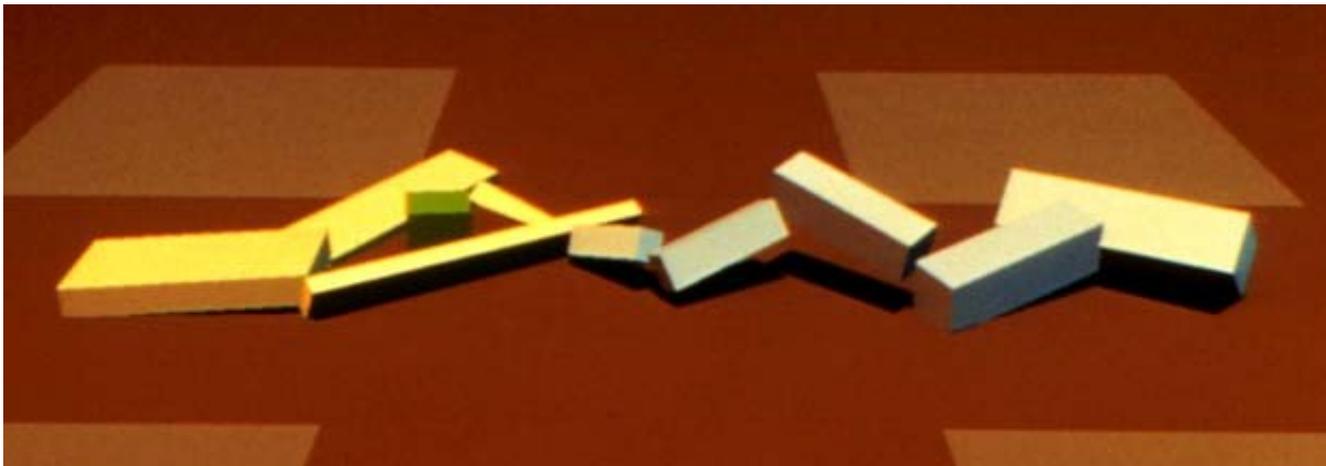
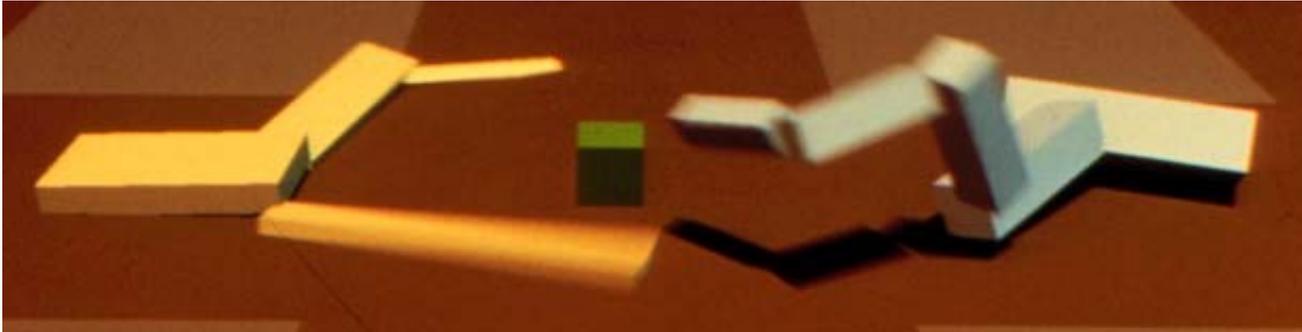
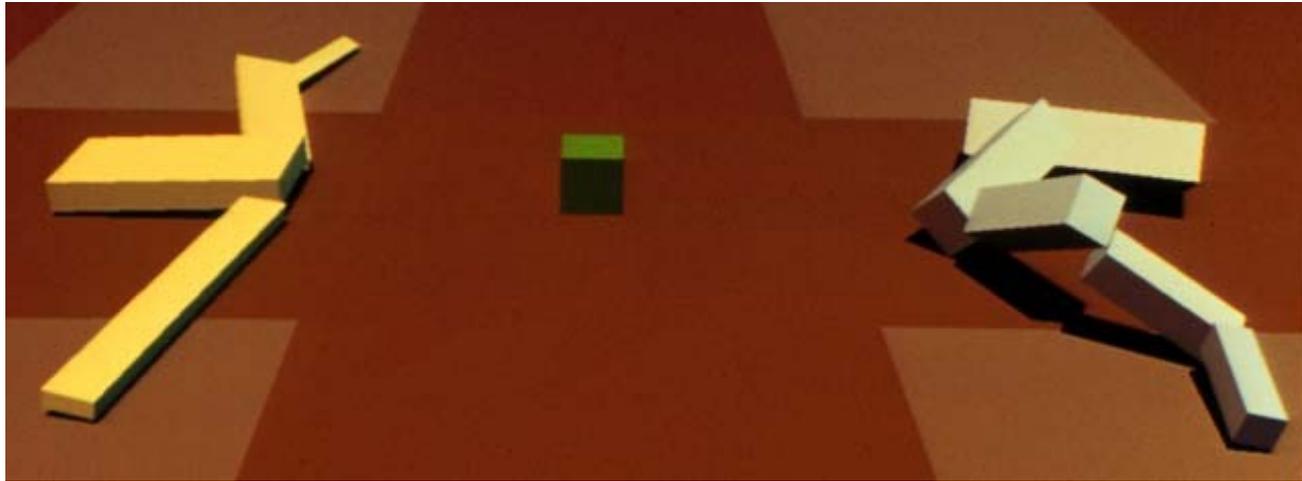
Results: Jumpers



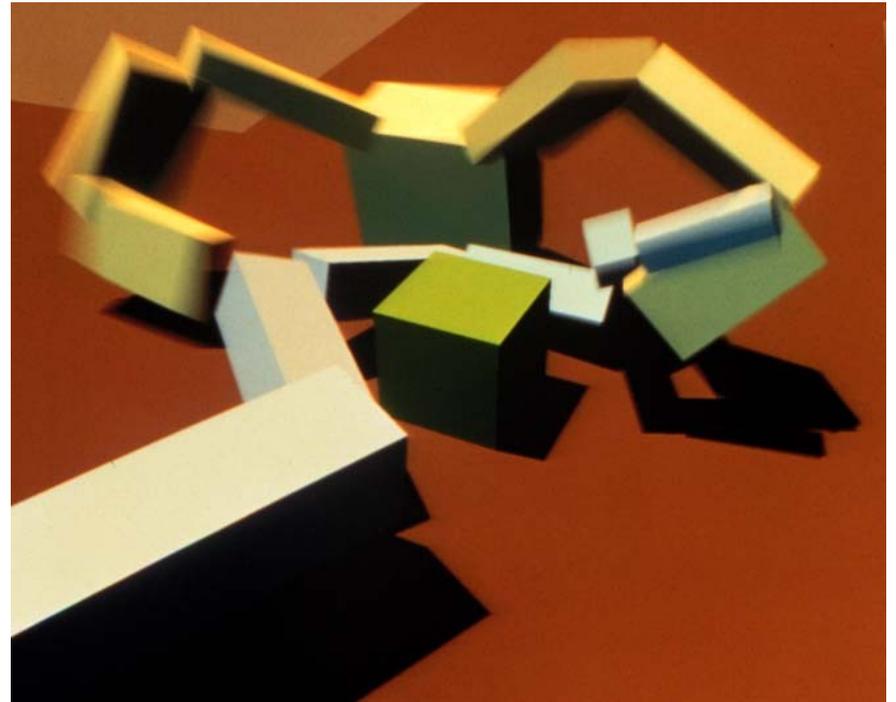
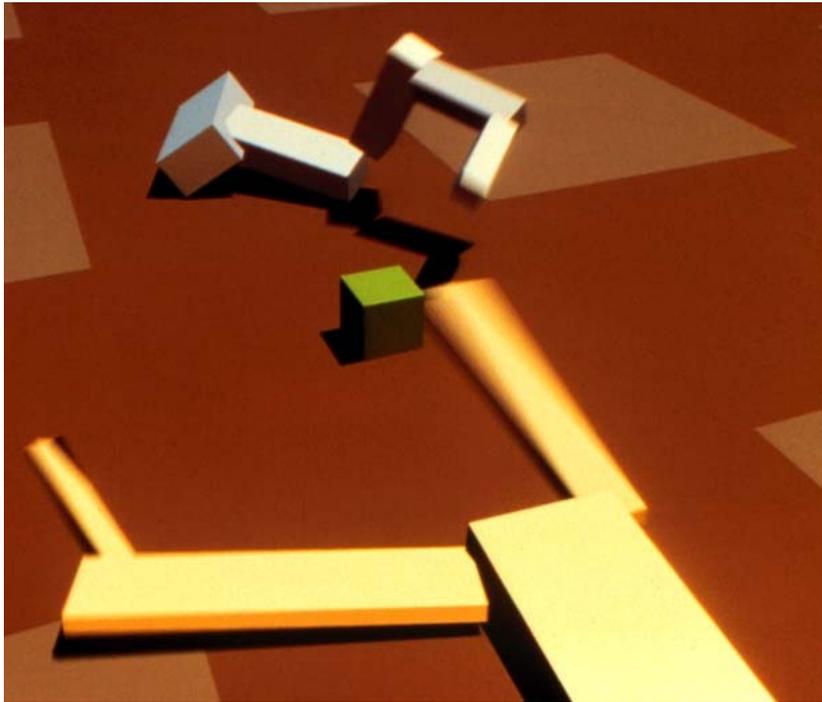
Results: Light Followers



Results: Competitors



Results: Competitors





Video

<https://vimeo.com/235275454>