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)

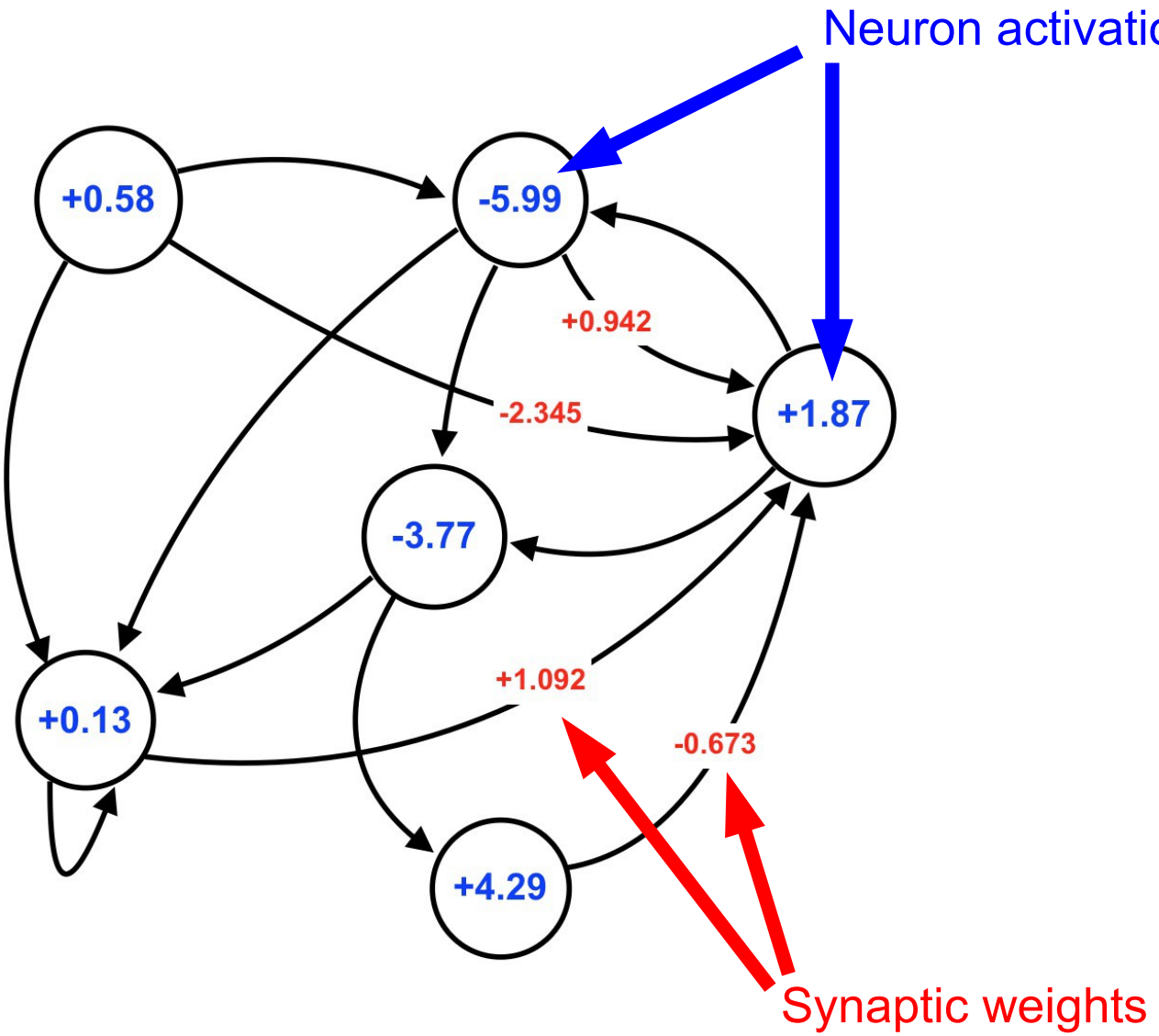
Genotype → Phenotype Mappings

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

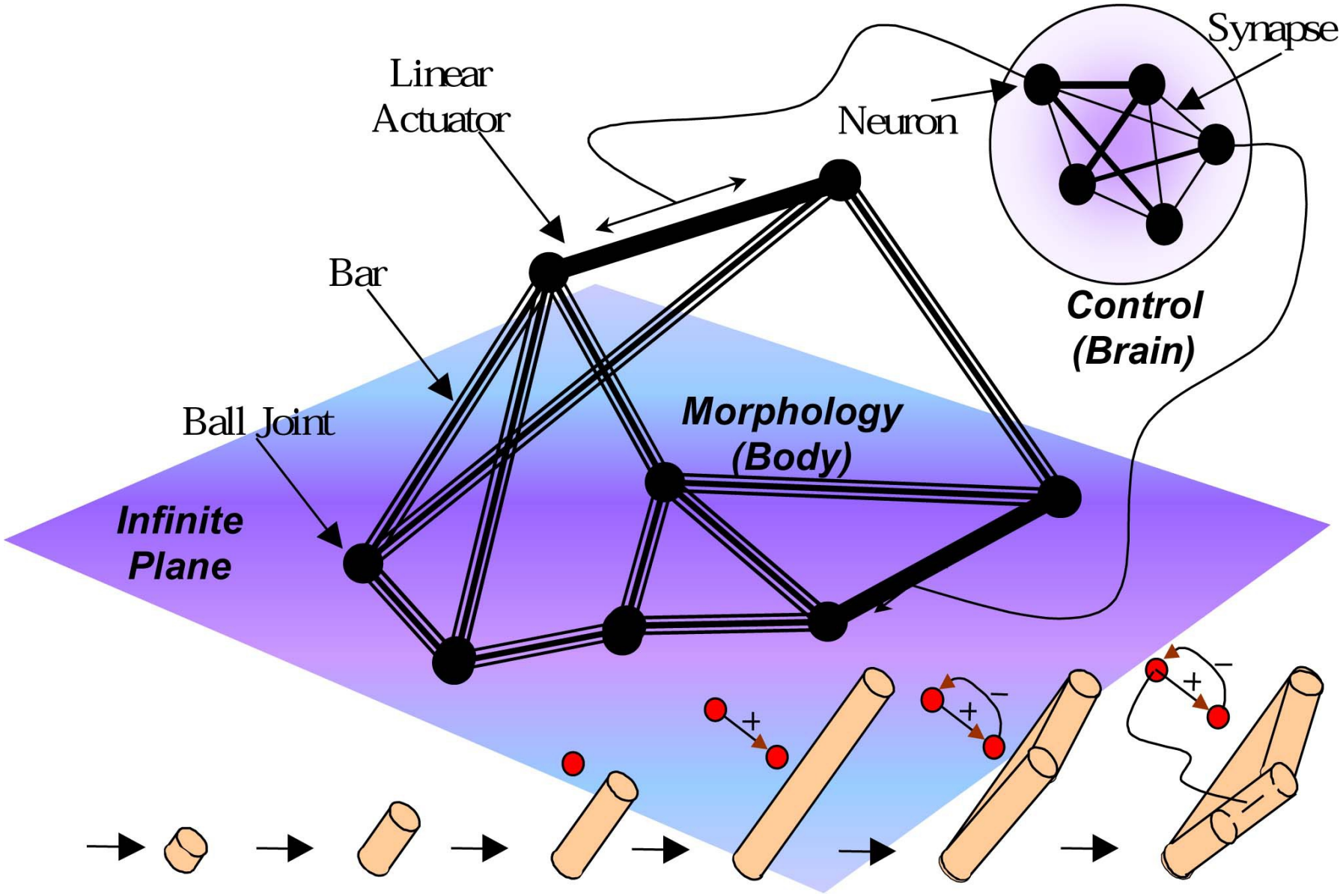
The Golem Project

- Hod Lipson & Jordan Pollack, “Automatic design and manufacture of robotic lifeforms”, *Nature*, vol. 406, pp. 974-978, 2000.
- Virtual creatures are evolved in a simulated 3-D world
- Fitness: net distance traveled in a fixed time period
- Body
  - **bars** connected by movable joints
  - **linear actuators** to expand/shrink bar lengths
  - **no sensors** of any kind
- Brain
  - network of **artificial neurons** with arbitrary connectivity
  - neurons control linear actuators

An Artificial Neural Network “Brain”



The Golem Project

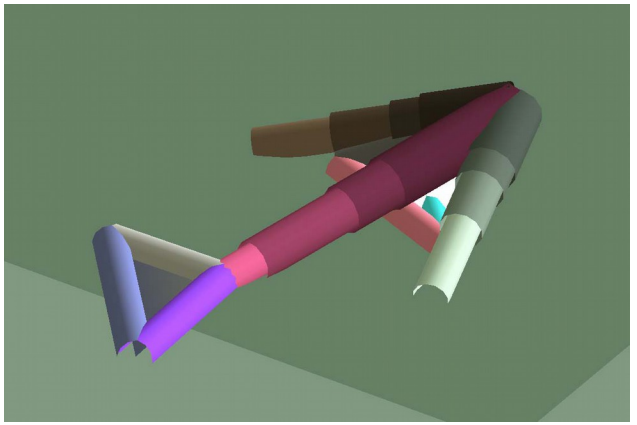
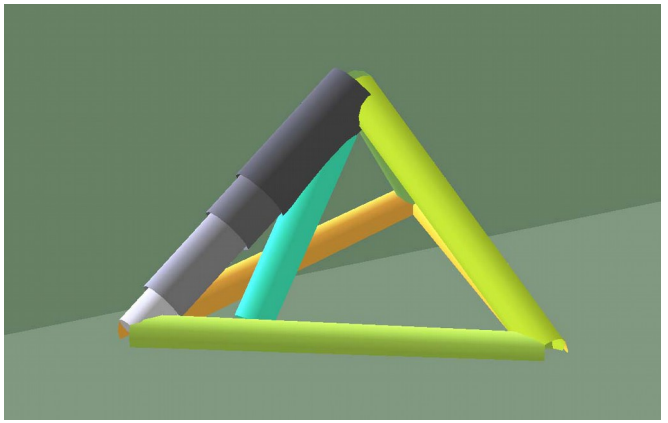
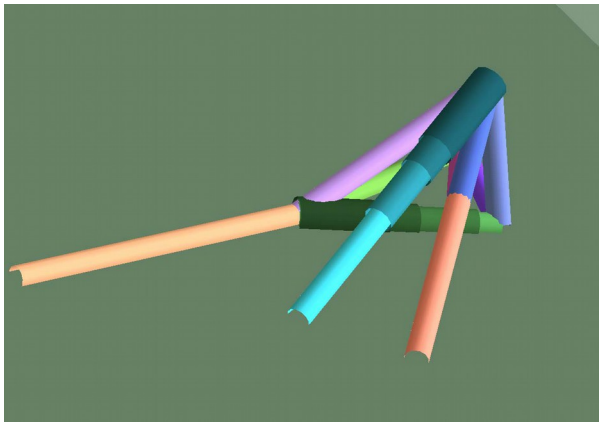


The Golem Project

- Genome encodes information about **body and brain**
- Population size 200
- Fitness-proportionate selection
- No crossover
- Mutation (at least one is applied):
  - Change bar-length or synaptic-weight (10%)
  - Remove/add a bar, or remove/add a neuron (1%)
  - Split vertex and add bar, or split bar and add vertex (3%)
  - Attach/detach neuron to bar (3%)
- Mutated genome replaces a genome chosen at random

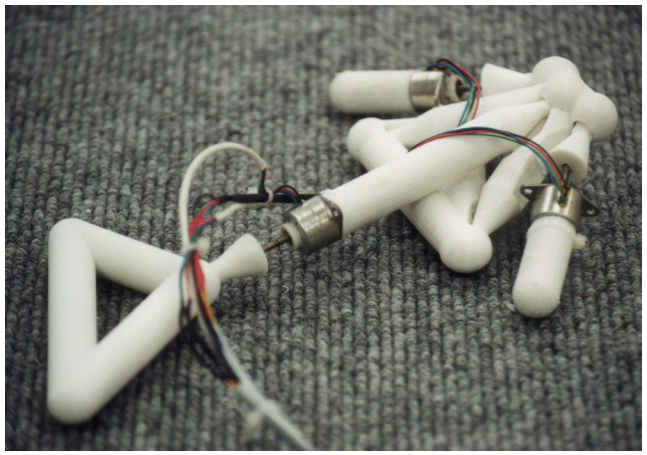
The Golem Project

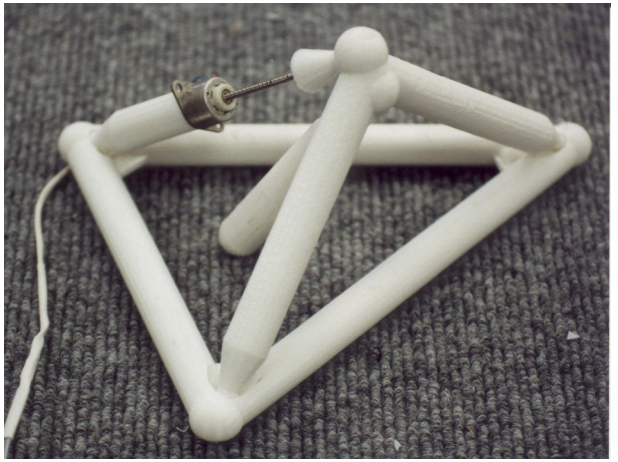
- **Evolution**
  - 200 creatures evolved for 300-600 generations
  - a subset of the fittest evolved creatures are chosen
- **Solidification**
  - wire-frame body design is converted to a solid-body design with ball joints and space for linear motors

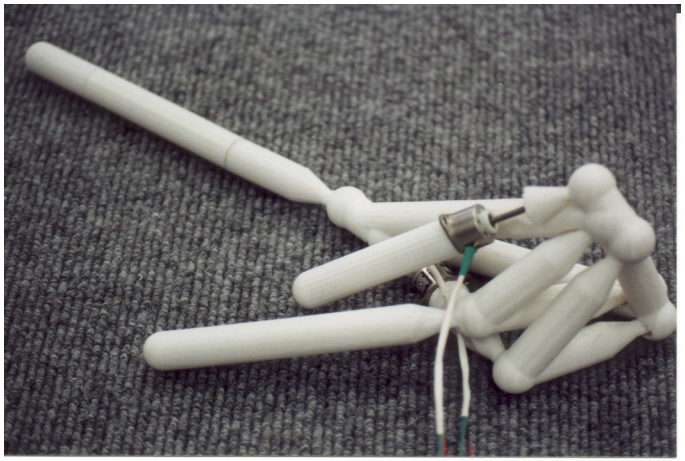




The Golem Project

- **Materialization**
  - solid design is fabricated by rapid prototyping technology (3-D printer)
  - entire pre-assembled machine printed as a single unit
  - ball joints are printed already inside the socket
  - linear motors are snapped into place (by humans)

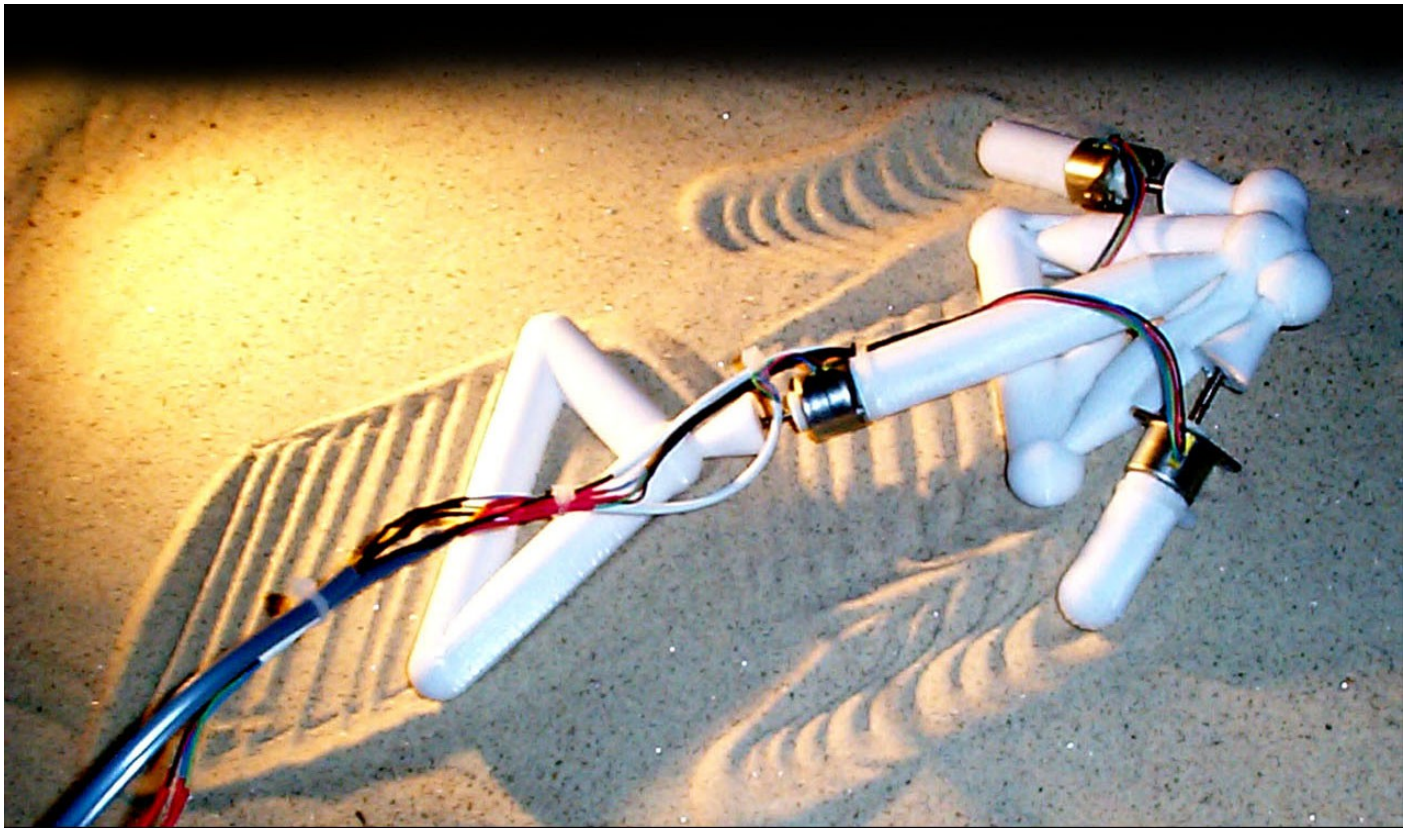






The Golem Project

- **Testing**
  - neural network brain is downloaded into a microcontroller on the robot
  - neural network sends control signals to the motors



Videos

http://www.demo.cs.brandeis.edu/golem/