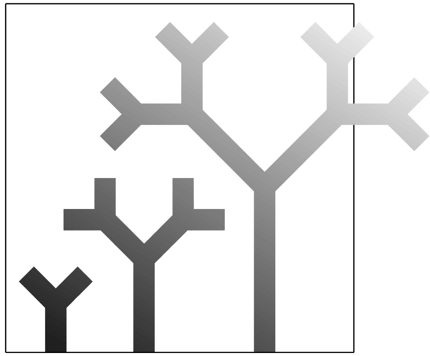
Coevolution of Morphologies and Brains

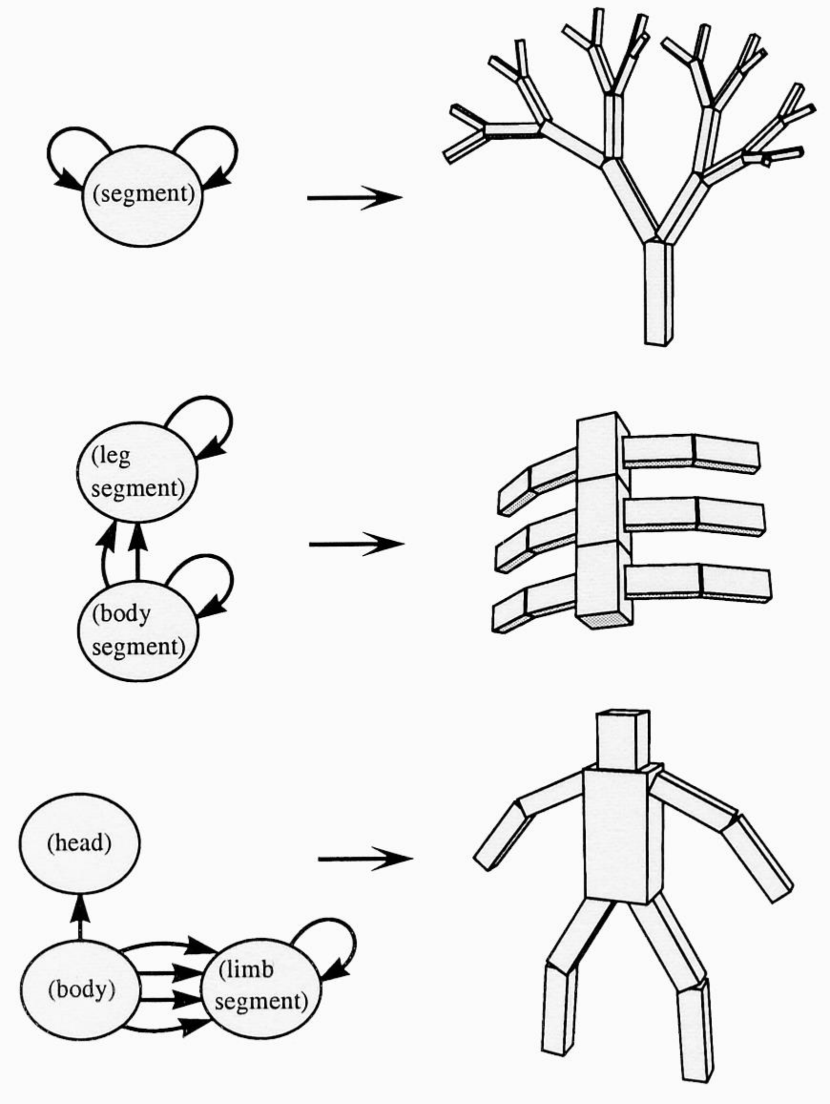


What you will learn in this class

- Encoding and evolution of robotic bodies and brains
- Composition Pattern Producing Networks
- Co-evolved bodies make learning faster and better

Grammar encoding of robotic bodies and brains

[Sims, 1994]



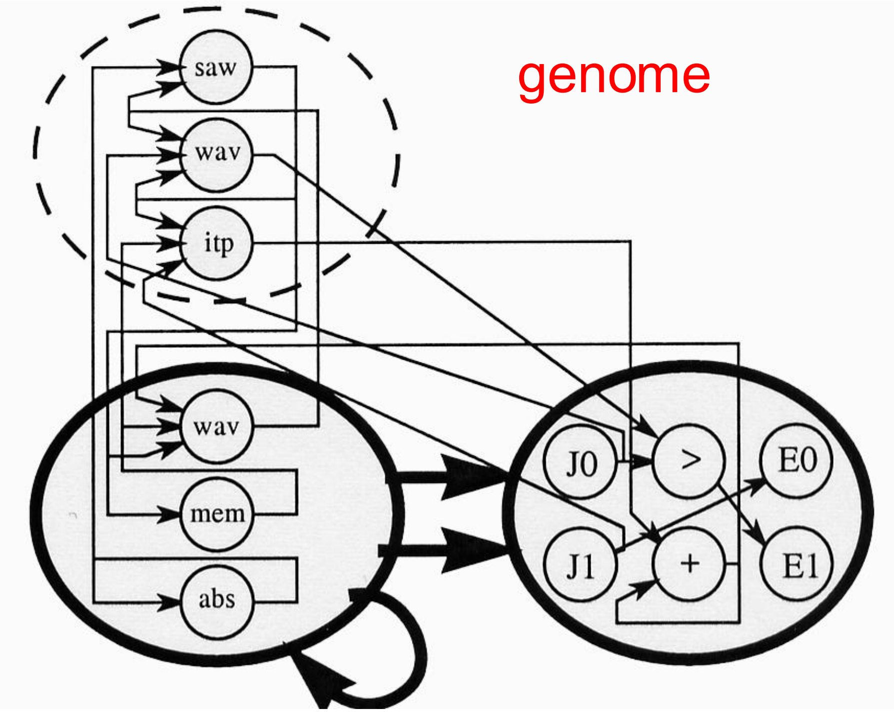
genotype phenotype

Body components:

- dimension
- joint type (rigid, twist, revolute, ...)
- recursive-limit
- connection (position, orientation, scale, reflection)
- terminal
- neural circuit

Neural circuit components:

- sensors: rotation, contact, light
- neurons: sum, memory, oscillator, max, etc.
- effectors: push, pull


genome
saw
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E0
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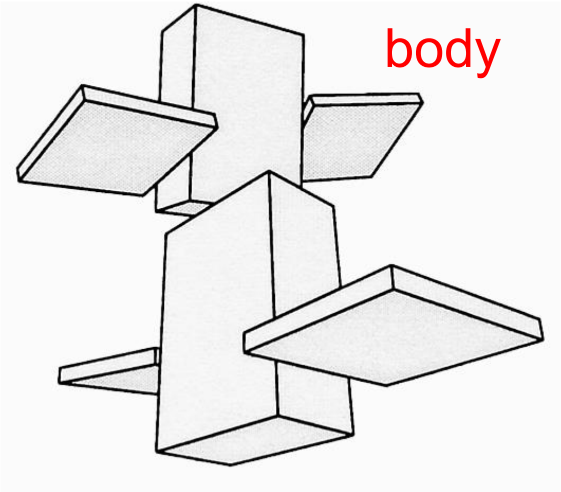
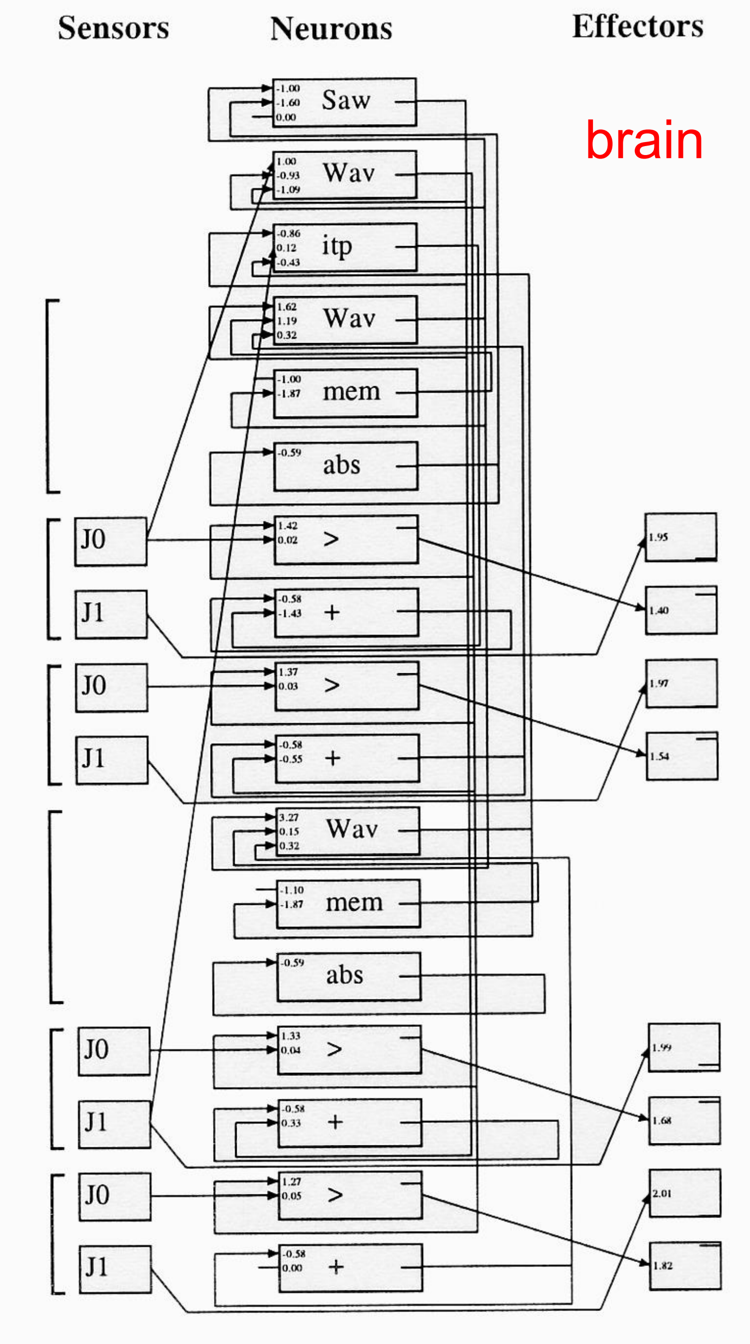

body


Sensors
Neurons
Effectors
brain
Saw
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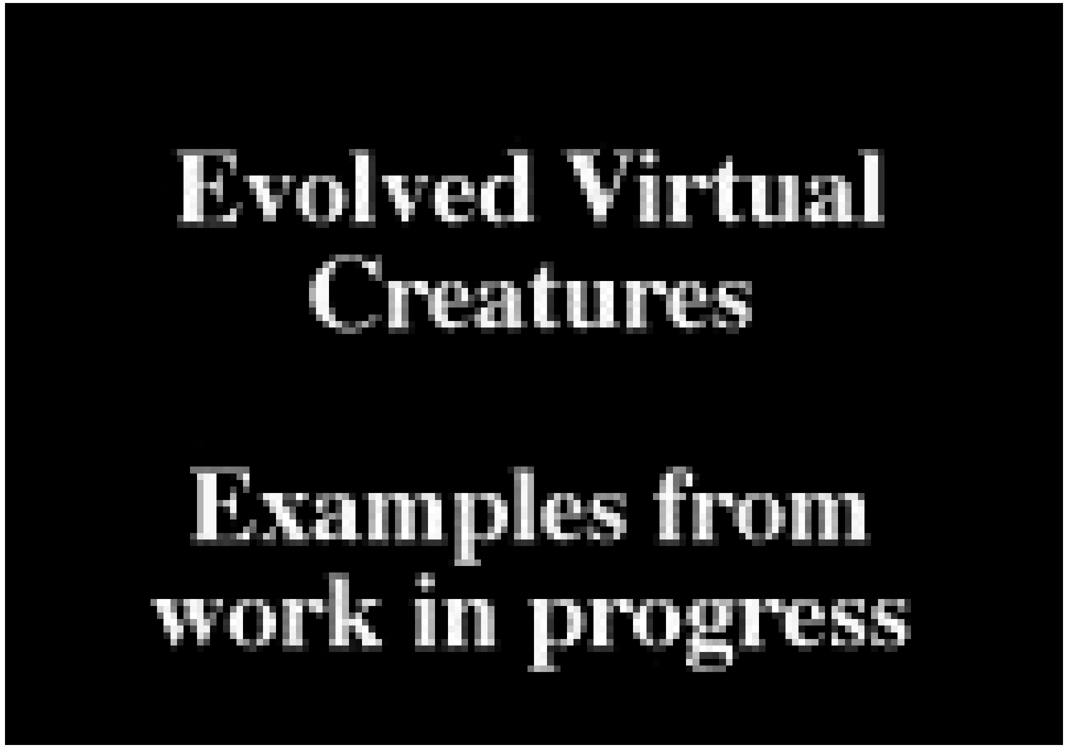
[Sims, 1994]

Co-evolved robotic bodies and brains

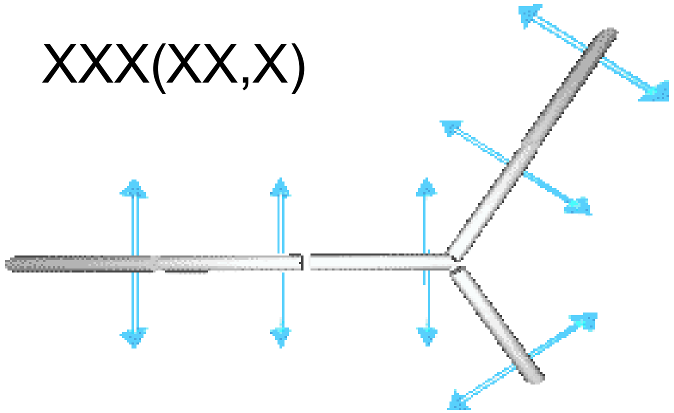


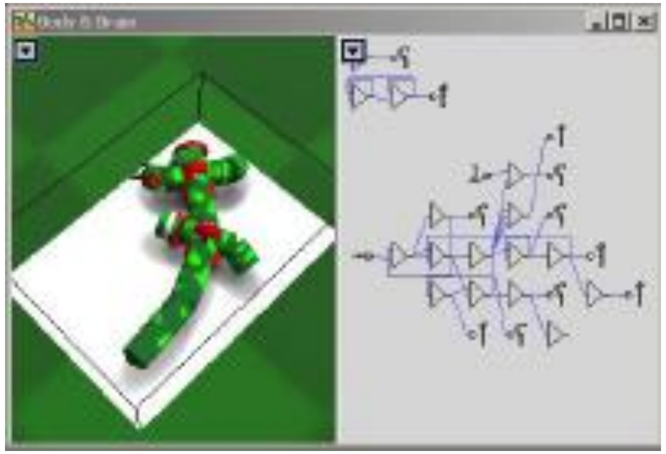
Sims, *1994*

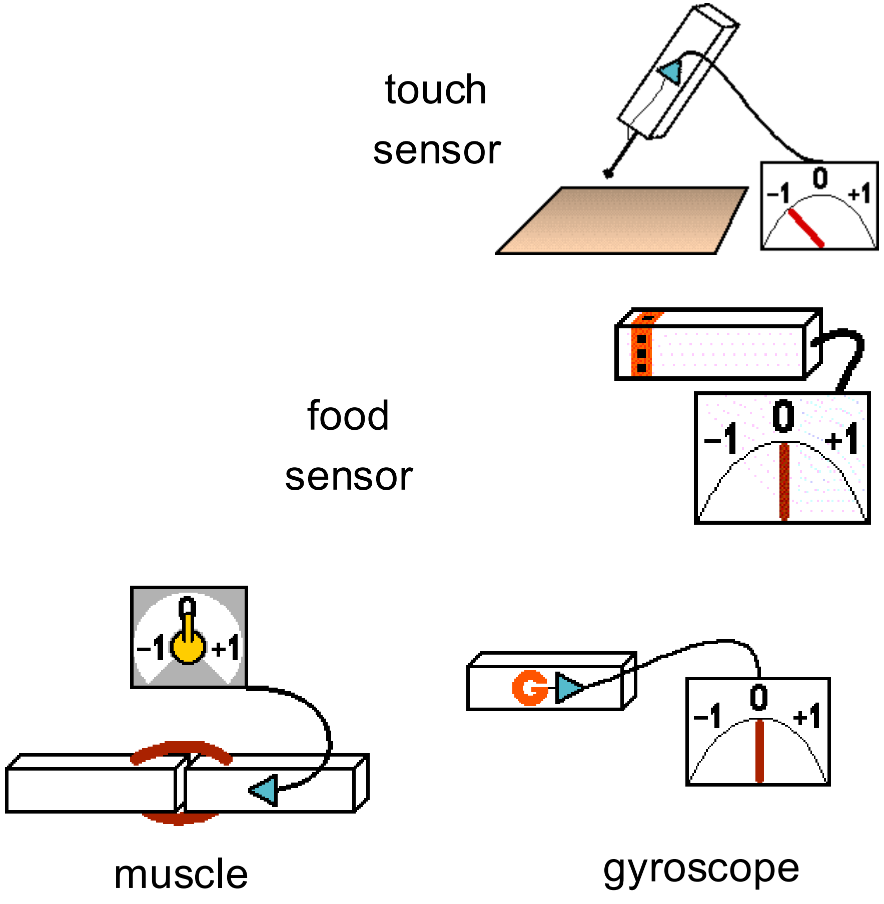
Framstick [Komosinski & Ulatowski, 1999]

Body parts are joined sticks. Sticks can host sensors and neurons. Joints are actuated by muscles.

XXX(XX,X)

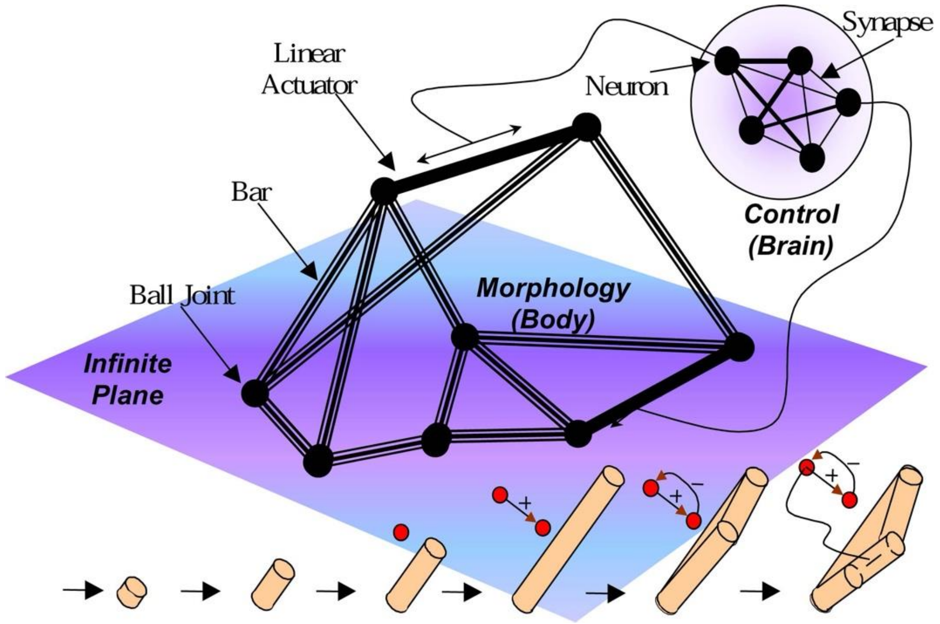


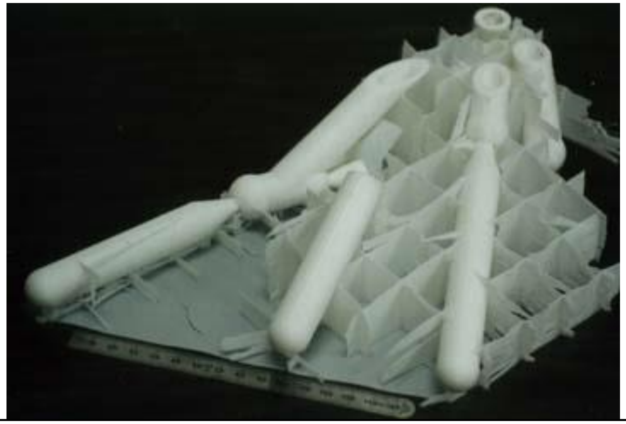


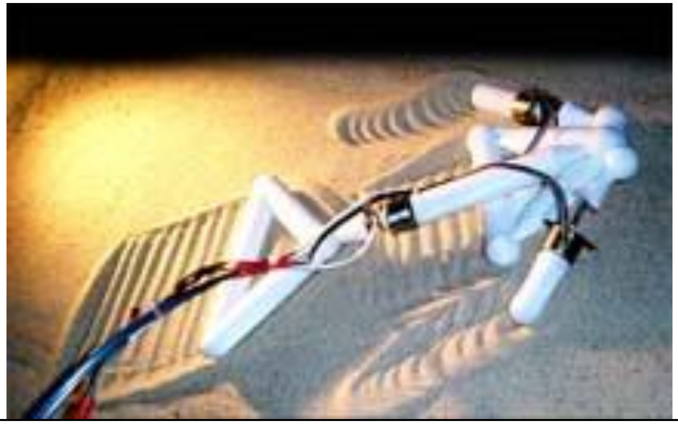


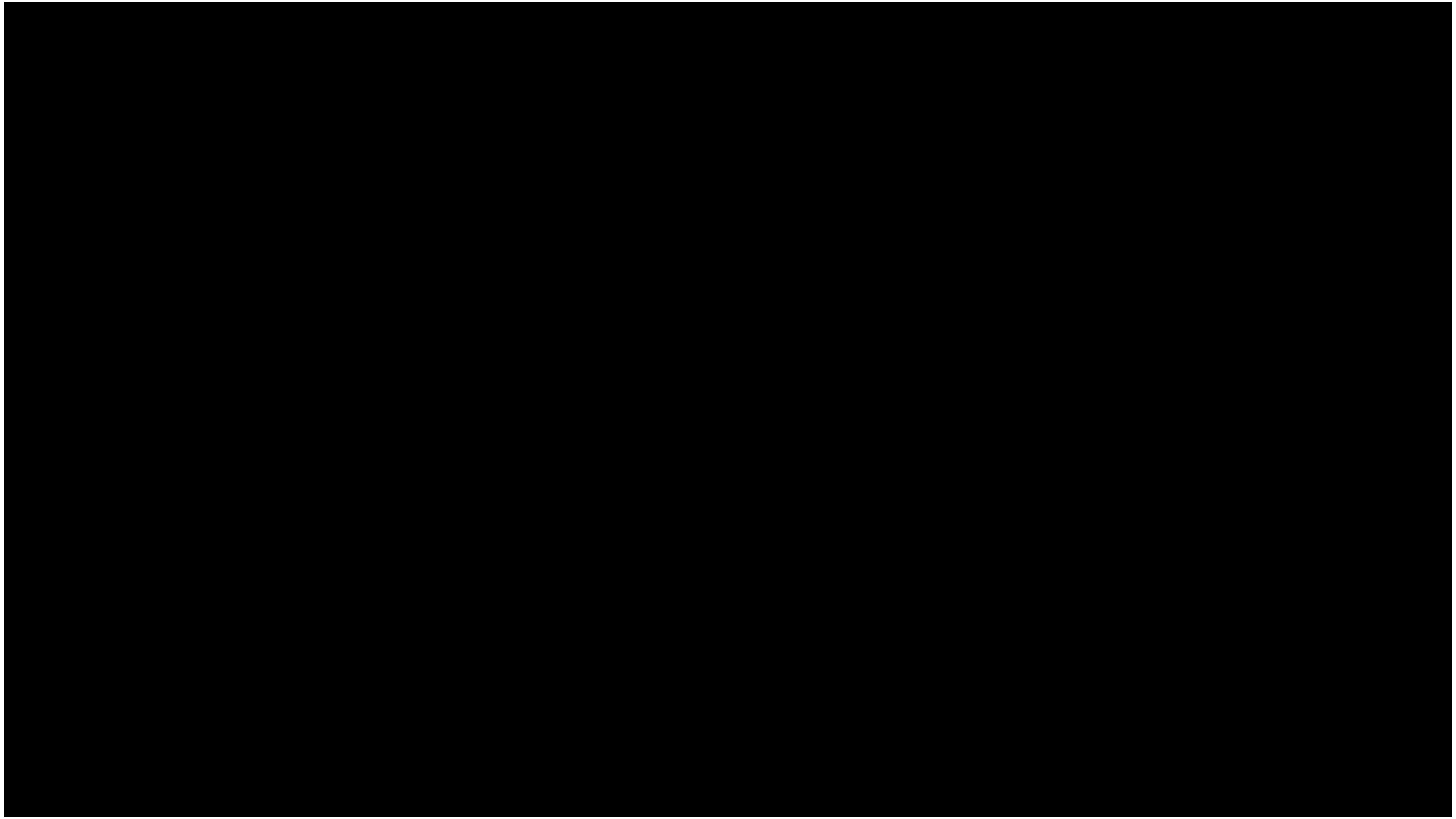
www.frams.alife.pl

The Golem project (Lipson & Pollack, 2000)

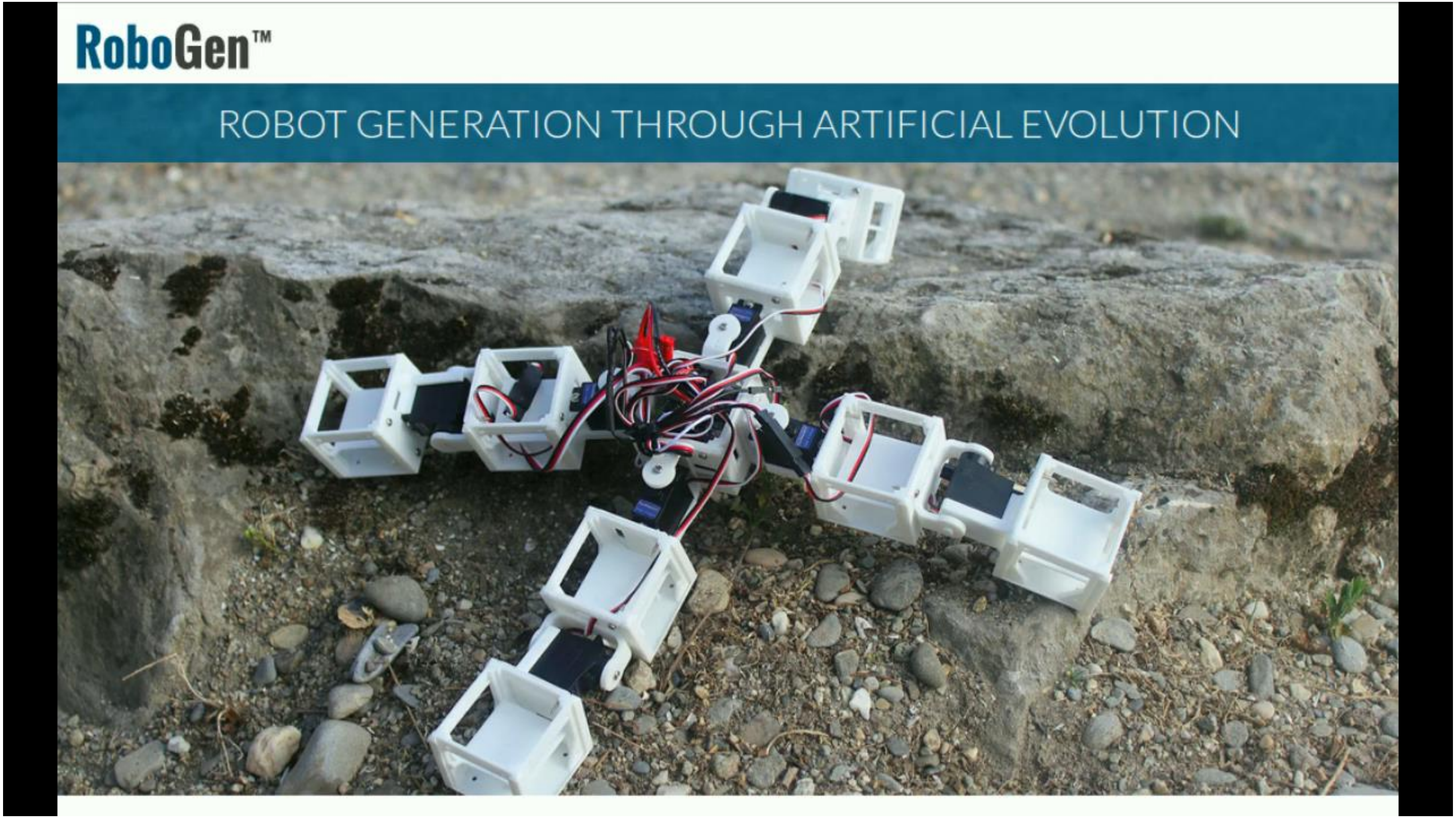






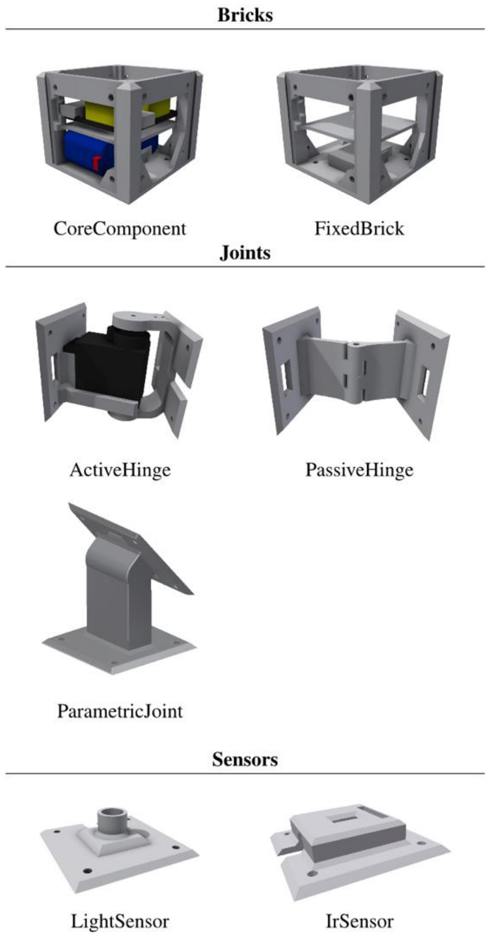


http://www.demo.cs.brandeis.edu/golem/

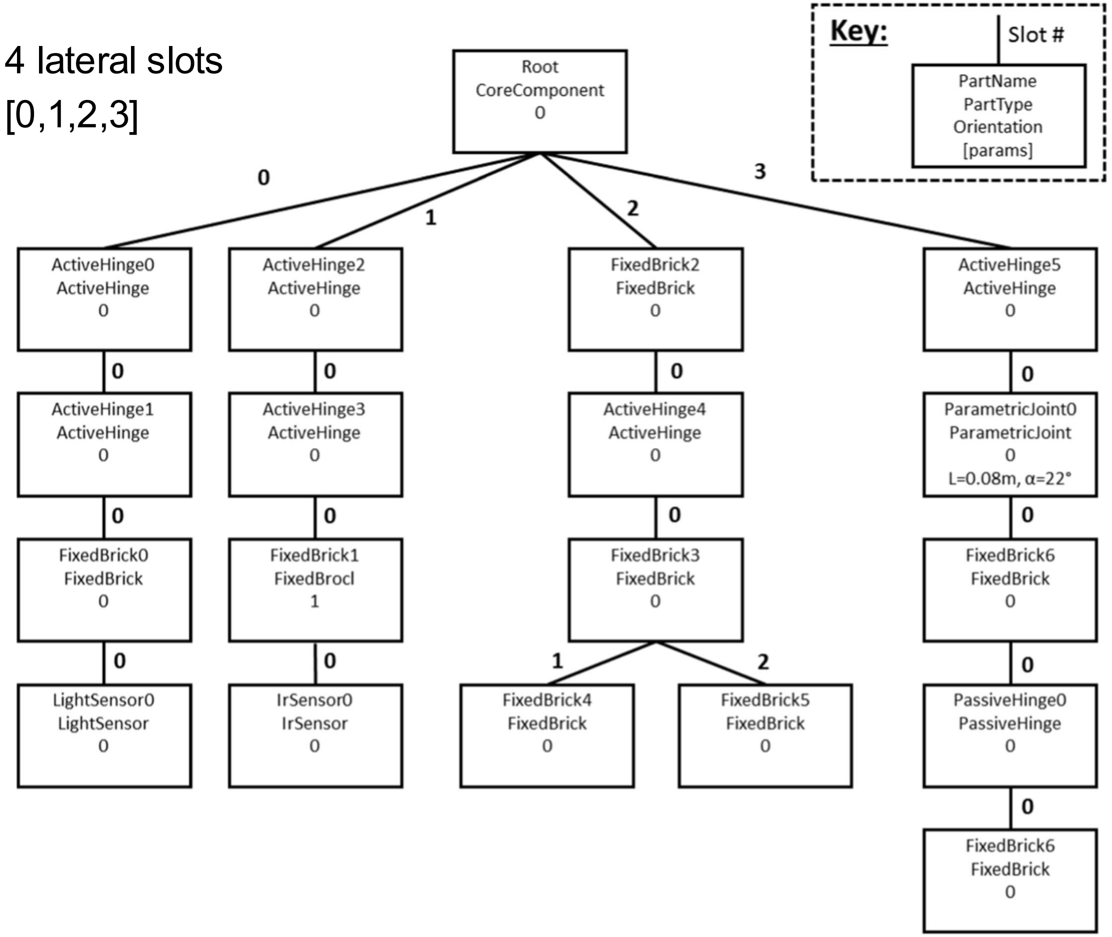


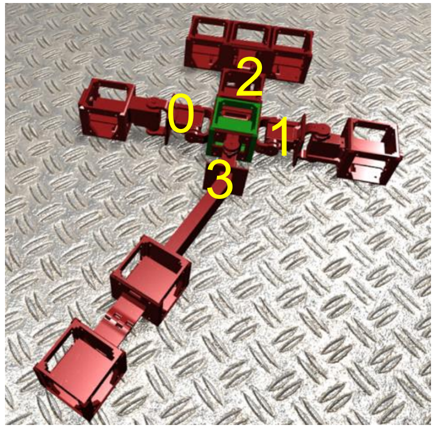
Auerbach, Concordel, Kornatowski, Floreano (2018) *IEEE Transactions on Learning Technologies*

Robogen: Morphology Encoding and Mutations



4 lateral slots
[0,1,2,3]





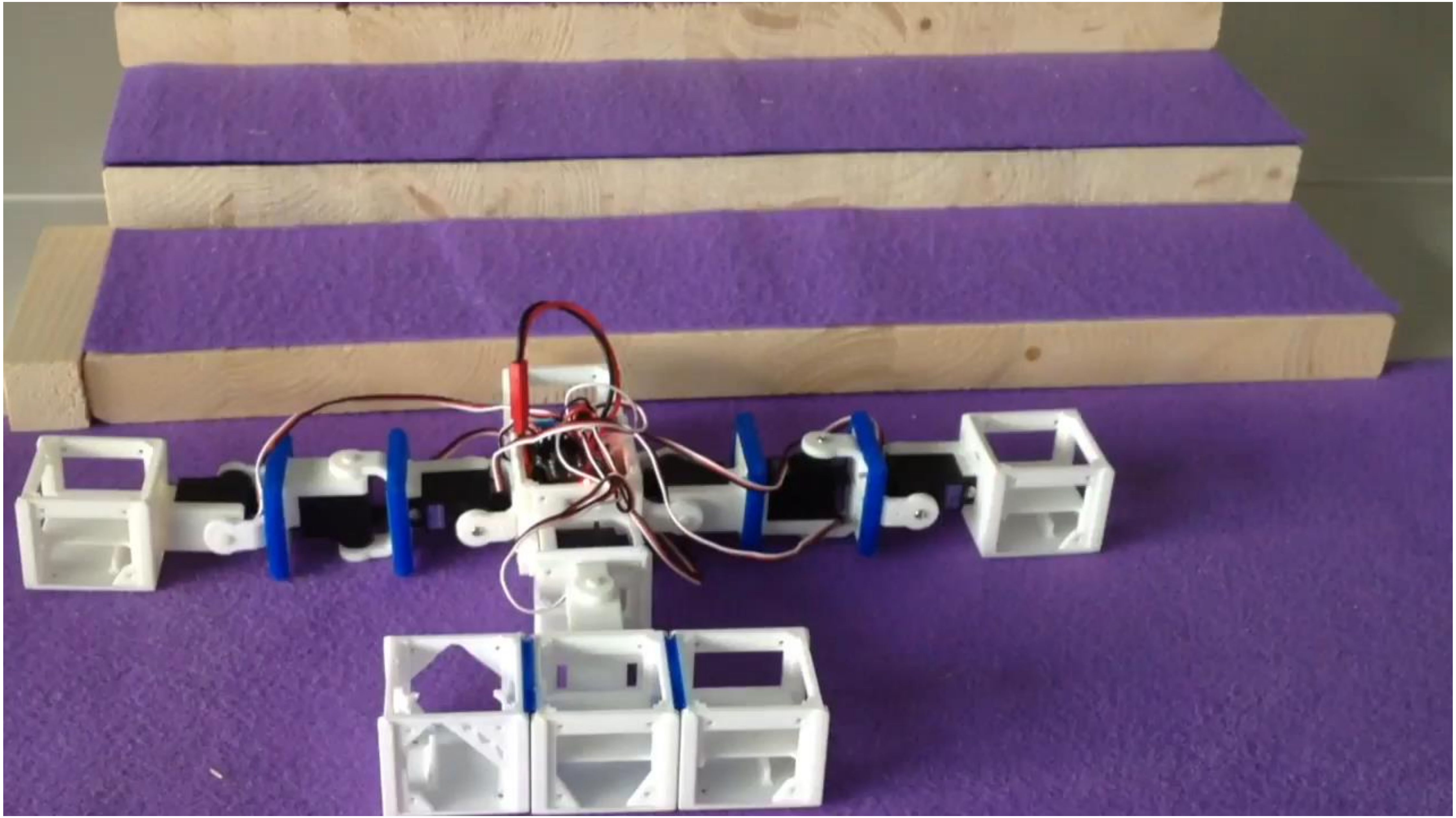
Mutation Operator	Description
NodeInsert	Insert a random node at a random location in the body representation tree.
NodeRemove	Remove a random node from the body tree representation.
SubtreeDuplicate	Duplicate a randomly chosen subtree and insert it at a random location on the body tree.
SubtreeSwap	Swap two randomly chosen subtrees of the body tree representation.
SubtreeRemove	Remove a randomly chosen subtree from the body tree representation. Unlike *NodeRemove* which attempts to remove a node and propagate its children upwards, *SubtreeRemove* removes a node and all of its descendants.
MutateParam	Mutate a randomly chosen parameter of a randomly chosen node. For the purpose of this operator a node's orientation relative to its parent is also consider to be a parameter.

The probability of applying each operator is user-configurable.

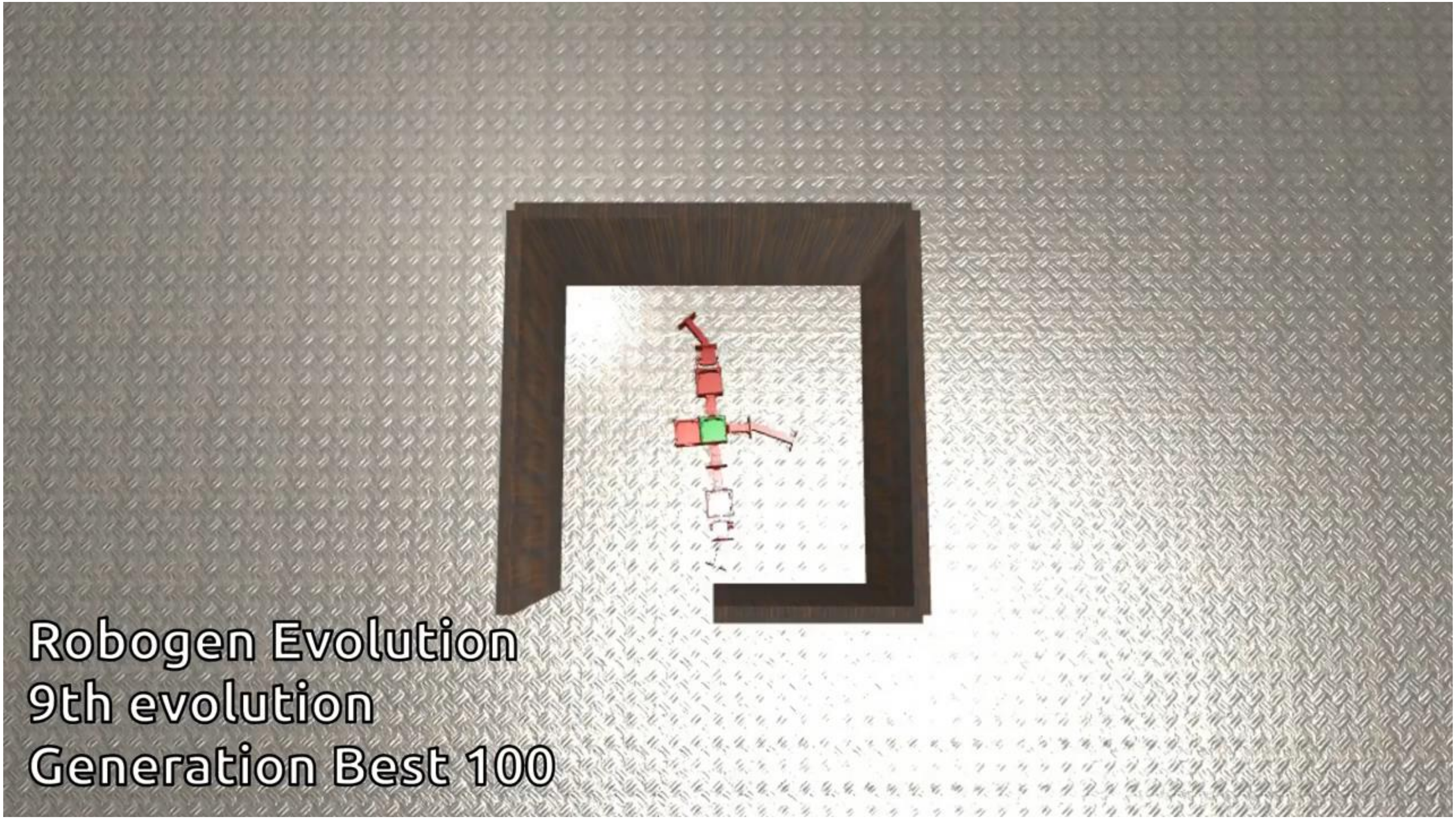
www.robogen.org

EPFL Evolutionary Robotics class, 2018

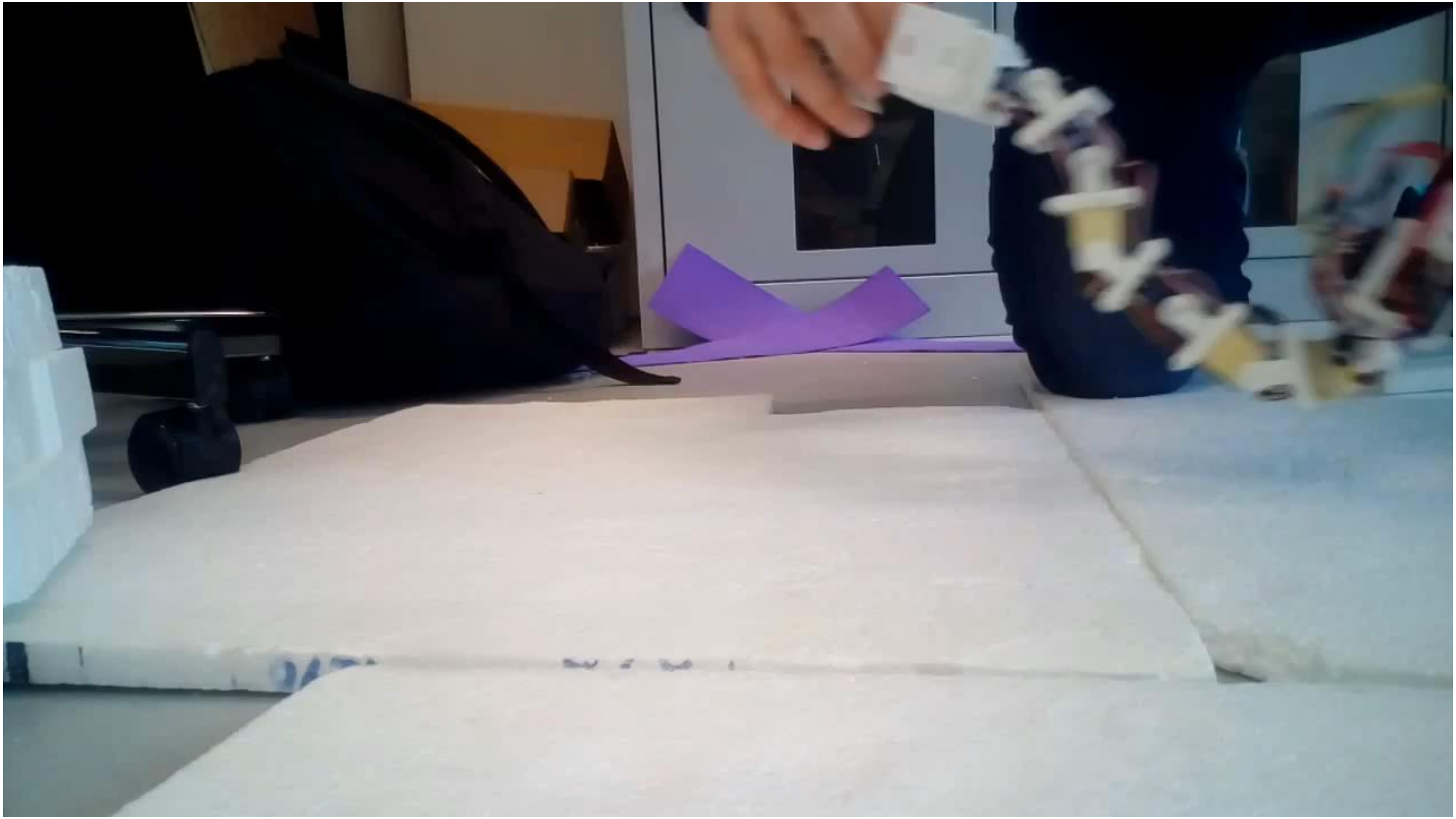
Robot evolved by students: the climber



Robot evolved by students: the jailbreaker



Robot evolved by students: the jumper



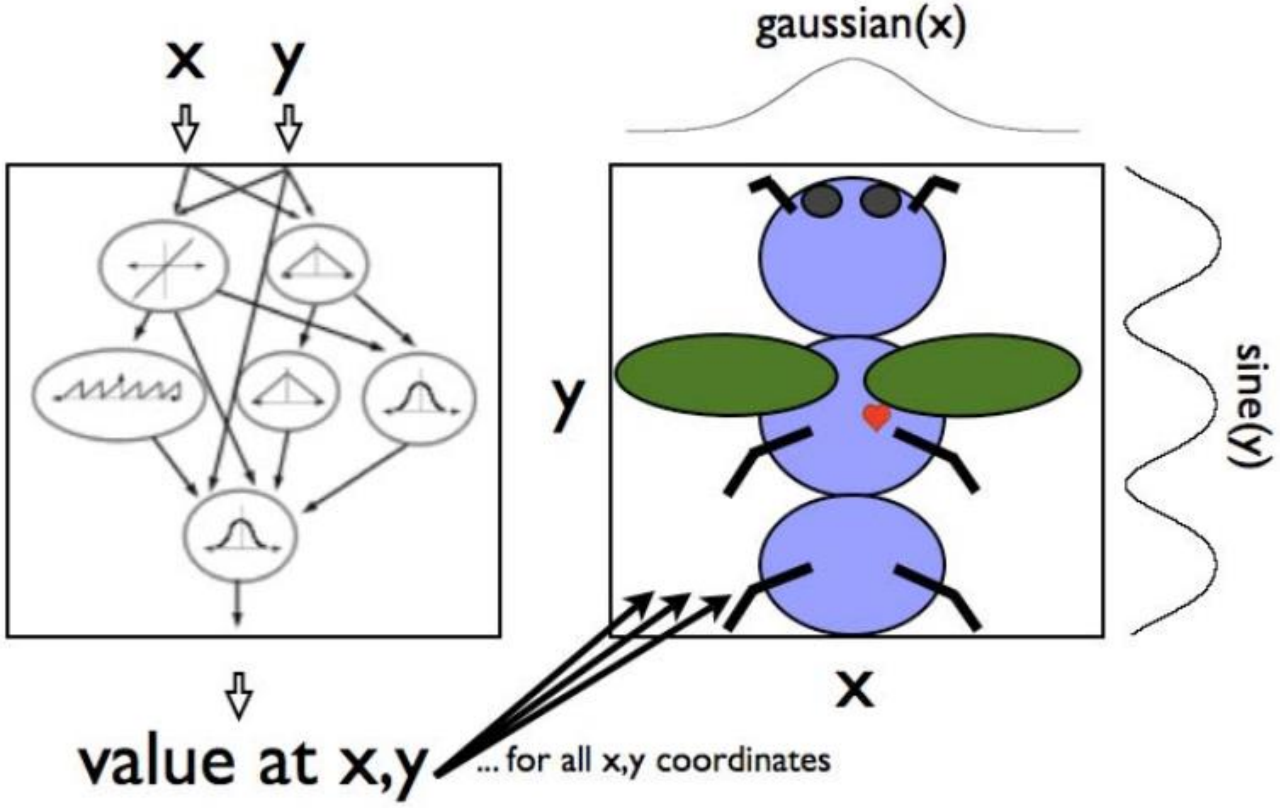
The Robot Baby Project

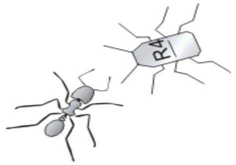
A. E. Eiben, University of Amsterdam

https://www.youtube.com/watch?v=fJlx_2WO7BQ

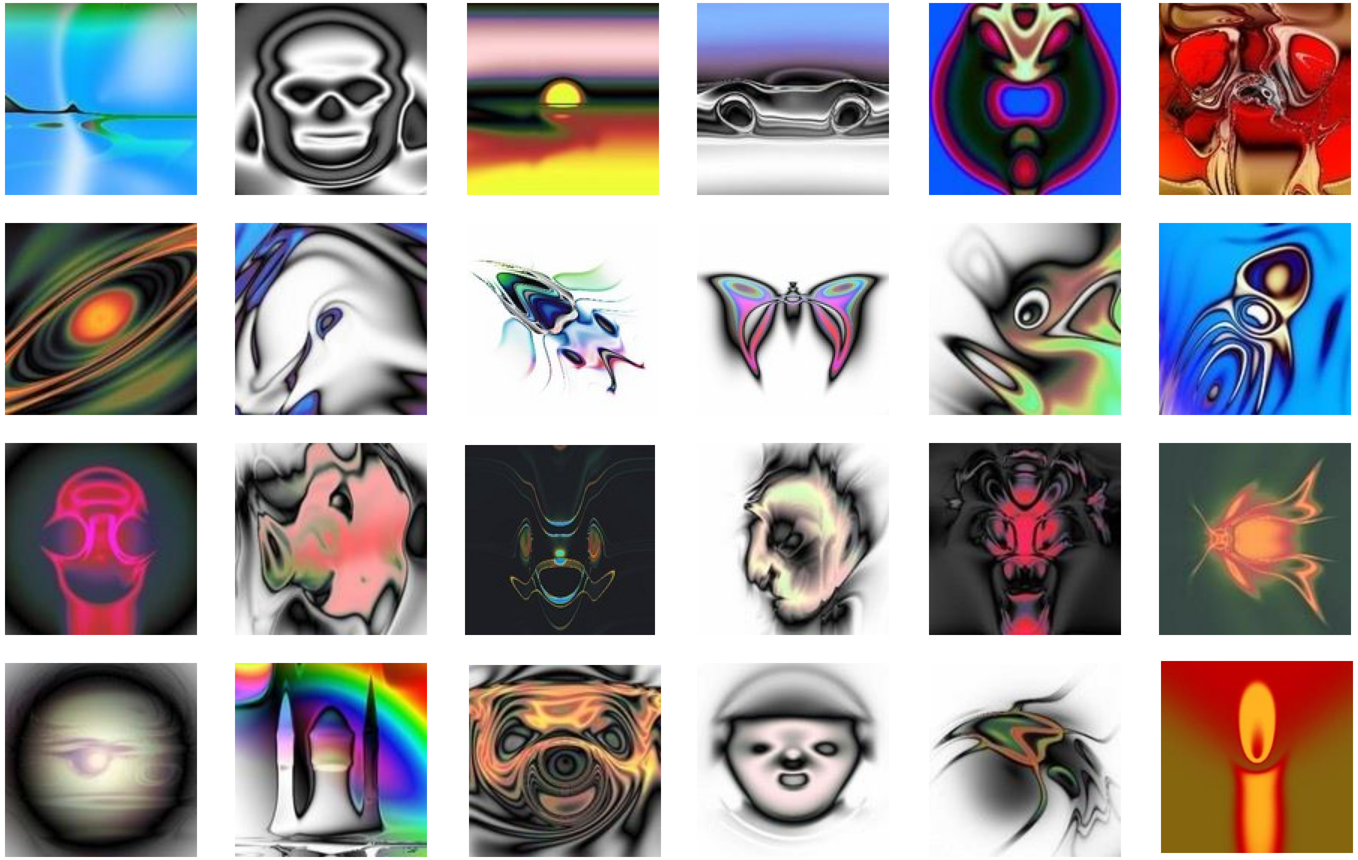
Compositional Pattern Producing Networks (CPPNs)

- CPPNs were devised by Stanley [2007] as an abstraction of development.
- A CPPN is a neural network that generates object properties as a function of position
- CPPN neurons can have a variety of activation functions suitable for geometric descriptions.
- CPPN produce symmetry, repetition, and repetition with variations, as observed in biological development





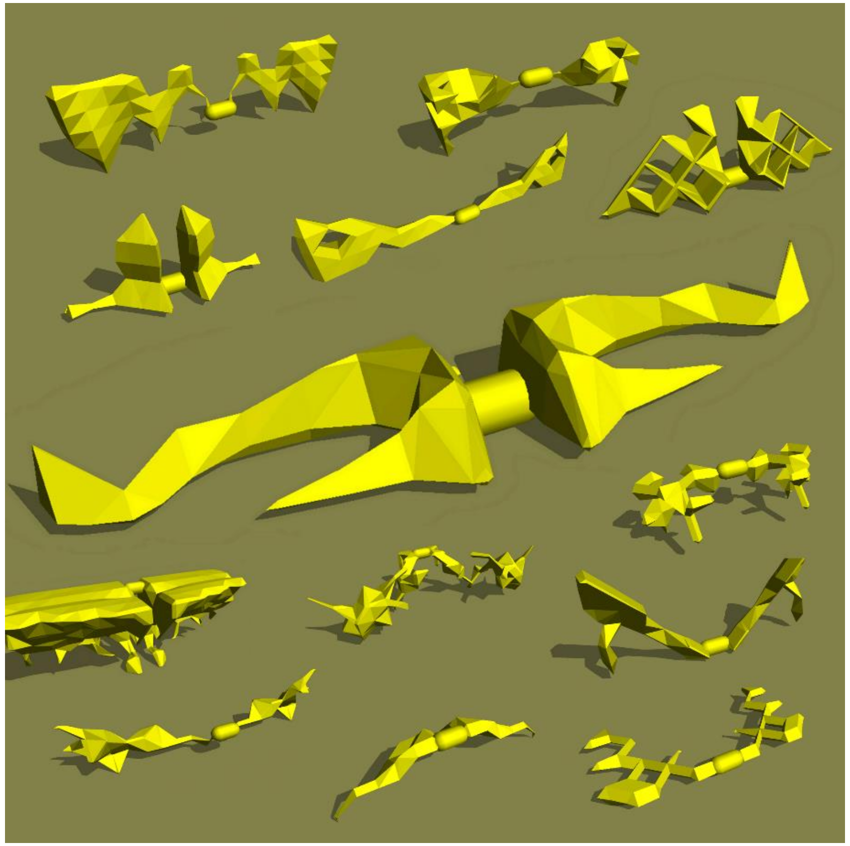
2-Dimensional images



Picbreeder.org

[Secretan et al., 2007]

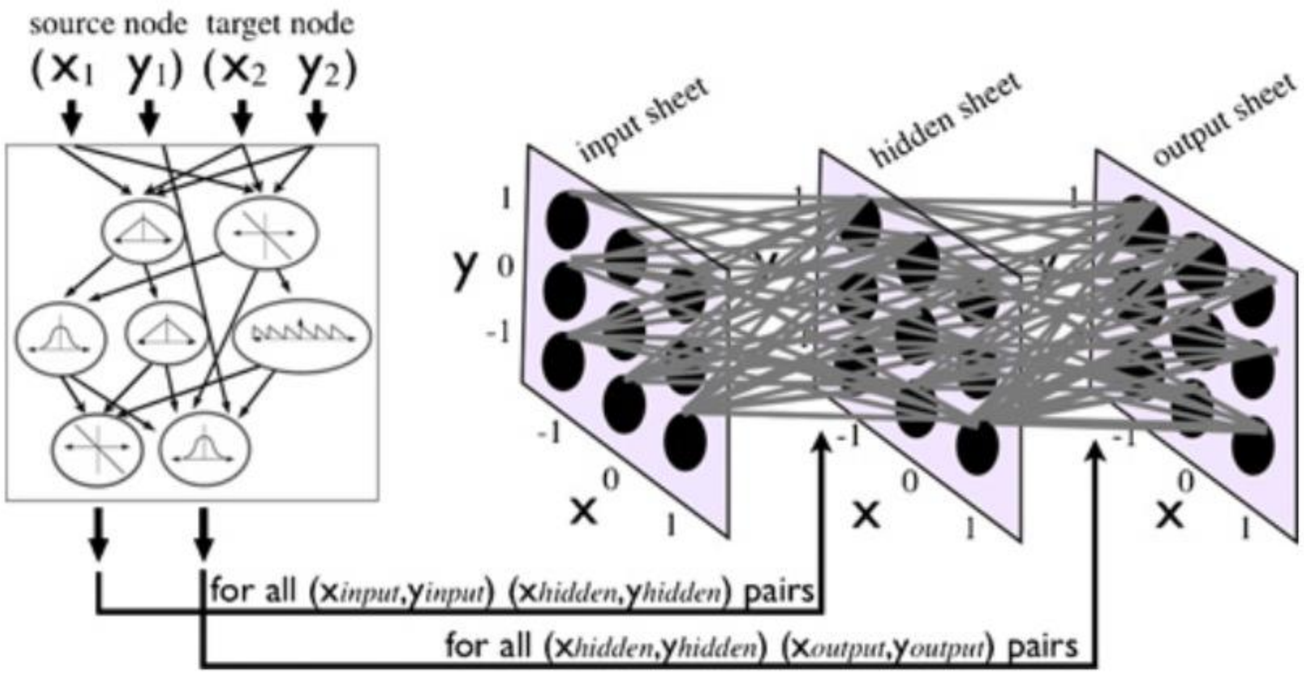
3-Dimensional objects



Robot morphologies

[Auerbach and Bongard, 2014]

Co-design of neural controllers and robotic bodies by CPPNs

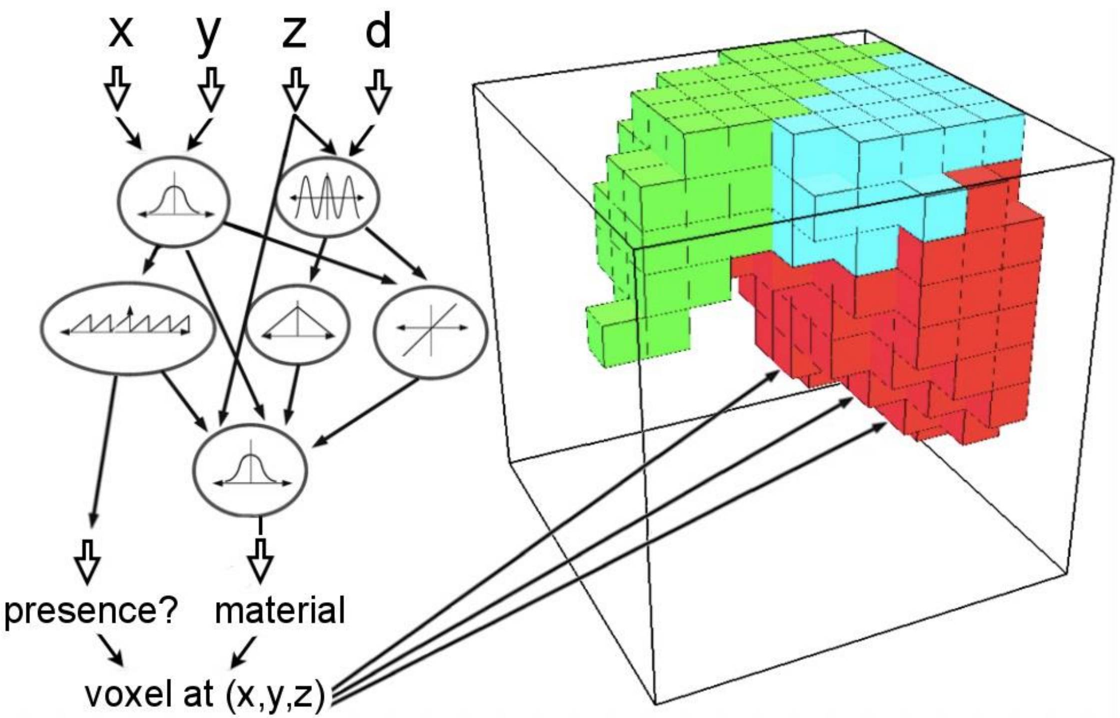


CPPNs can “paint” weights of neural network connections [Stanley et al., 2009], up to several million connections

CPPNs can be used to paint both the robot morphology and the weights of the neural controllers [Clune et al., 2013].

Encoding of soft-bodied robots

Cheney, MacCurdy, Clune, Lipson, 2013

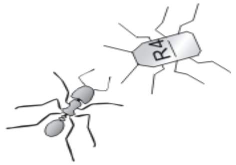


Green voxels undergo periodic volumetric actuations of 20%

Red voxels behave similarly to green ones, but with counter-phase actuation

Light blue voxels are soft and passive, having no intrinsic actuation

Dark blue voxels are also passive, but are stiffer



Evolution of soft-bodied robots

Cheney, MacCurdy, Clune, Lipson, 2013

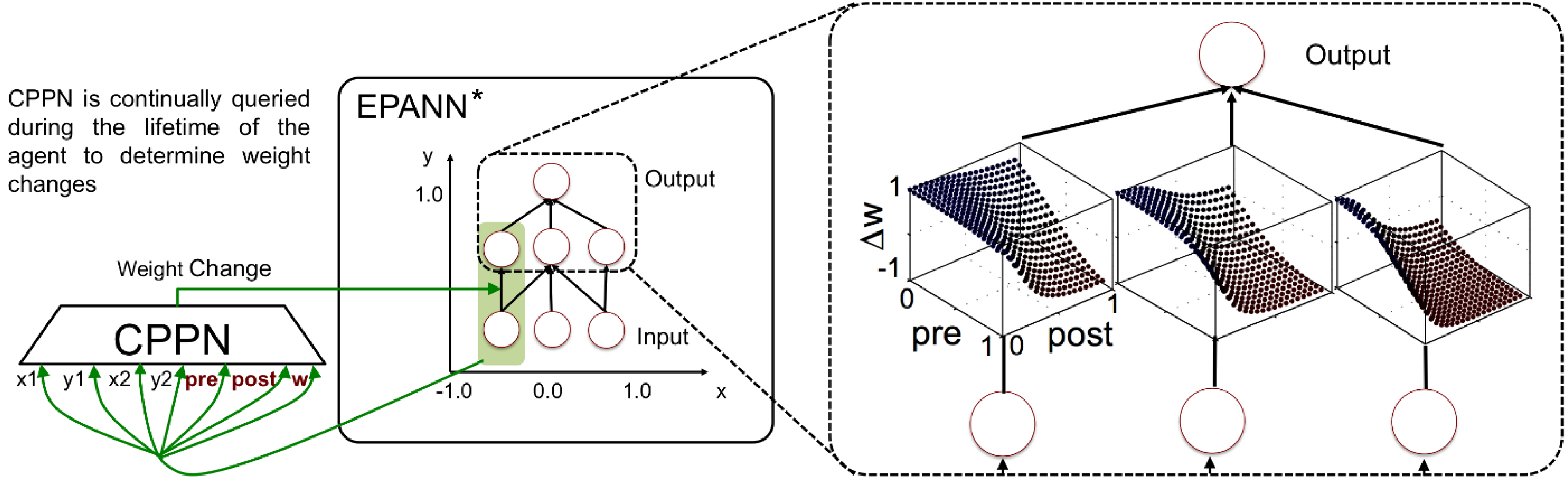
Ever wonder what it would be like
to see evolution happening
right before your eyes?

http://jeffclune.com/videos.html

Using CPPNs as learning rules

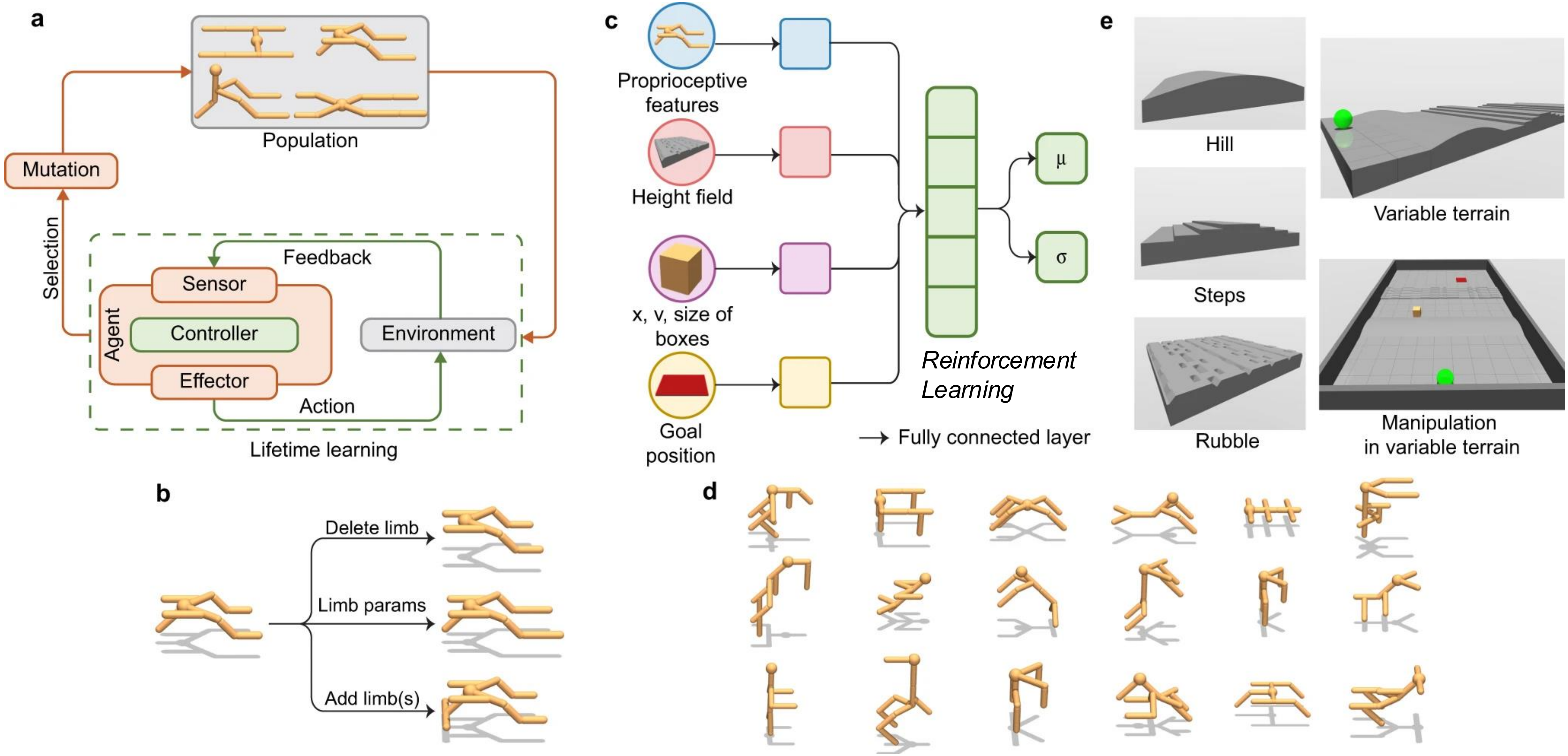
Risi and Stanley, 2010, 2014

- Genetically encode and evolve the weights of the CPNN
- Use CPNN to compute weight updates of the neural controller at each time step of the robot lifetime
- Use robot's performance to compute fitness of the CPNN for selection



*Evolutionary Plastic Artificial Neural Network

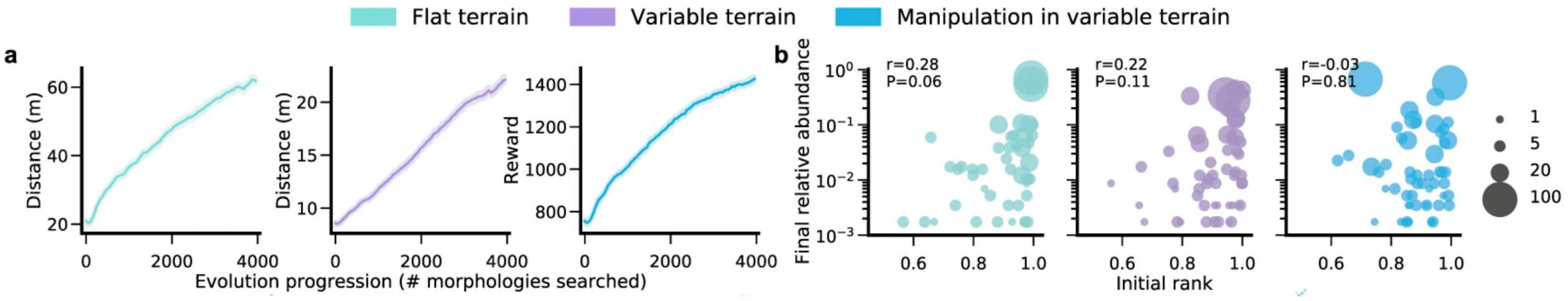
Morphological evolution of learning robots

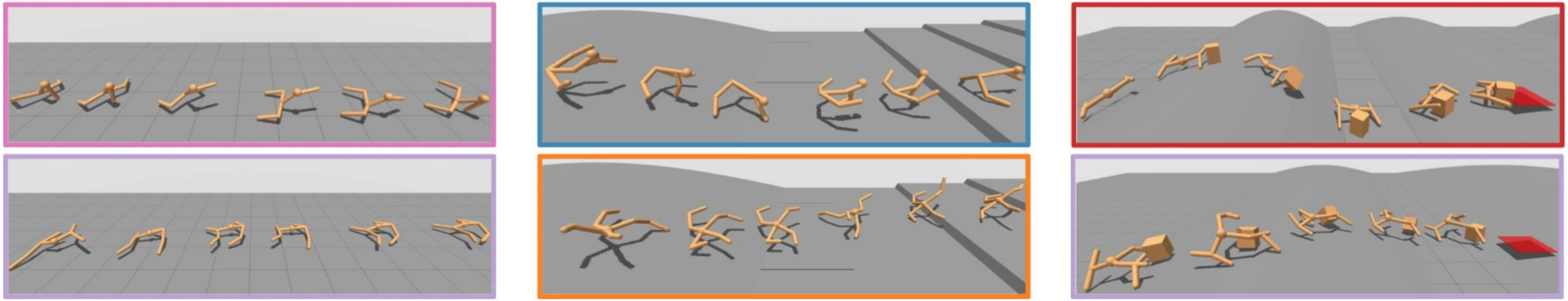


Gupta A, Savarese S, Ganguli S, Fei-Fei L (2021) Embodied Intelligence via Learning and Evolution. *Nature Communications* 12(1), 5721

Local tournament selection preserves diversity

Population spread across 100’s of CPU, each simulating 4 individuals and reproducing the best one





Better bodies learn faster and better