BLG456E
Robotics
Evolutionary Robotics

Lecture Contents:

- Evolutionary Algorithms.
- Evolutionary Robotics:
  - Evolving Controllers.
    - Neural Networks (biological)
    - Neural Networks (artificial)
    - Variants
  - Evolving Morphology.
- Resources.

Lecturer:	Damien Jade Duff
Email:	djduff@itu.edu.tr
Office:	EEBF 2316
Schedule:	http://djduff.net/my-schedule
Coordination:	http://ninova.itu.edu.tr/Ders/4709

Evolved Virtual Creatures

Karl Sims

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Evolutionary Computation

- Essentially “generate and test” with:
  - Generate:
    - Multiple candidate solutions (populations).
    - Variation (mutation, crossover, etc.).
  - Test:
    - Selection.
- Many variations.

(M+N)-EA

Initialise M solutions.
Until End:
    Generate N solutions from M.
        (mutation/crossover/etc)
    Evaluate fitness of $N+M$ solutions.
    Select M solutions.

Evolutionary Robotics

- Evolve:
  - Behaviour.
  - Morphology.

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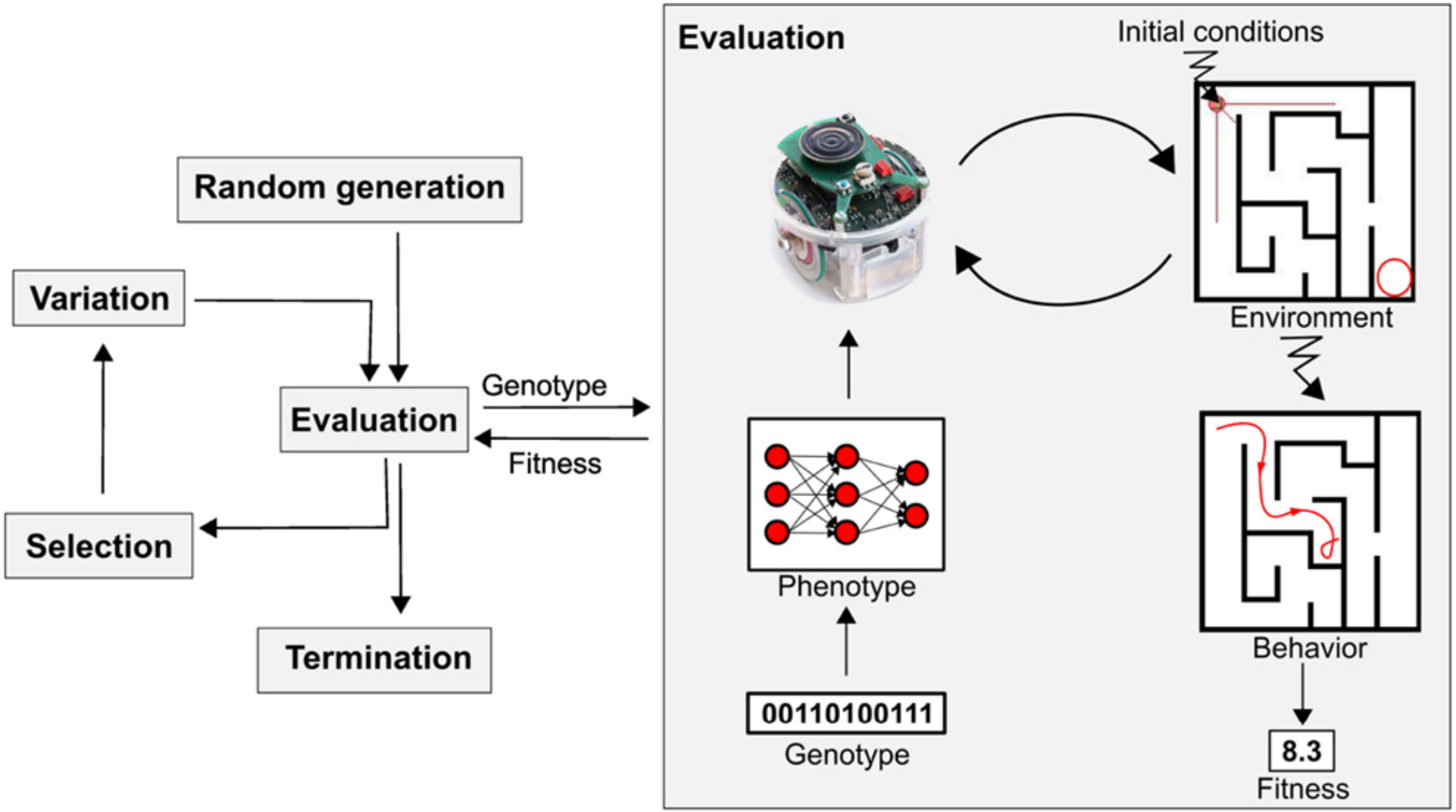
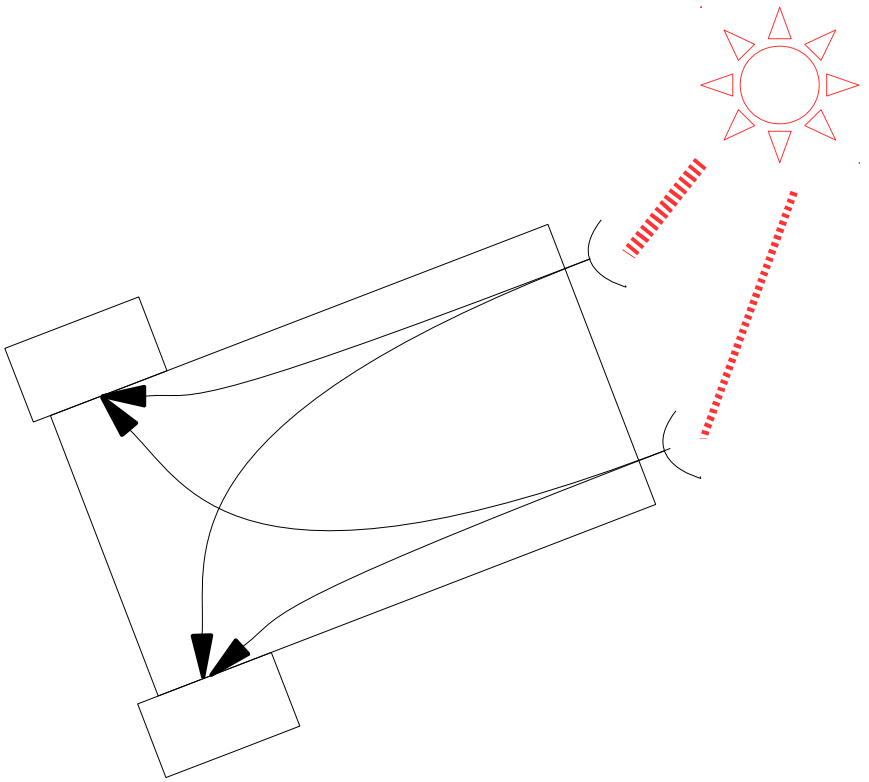
Evolving Controllers



https://www.frontiersin.org/articles/10.3389/frobt.2015.00004/full

Neural Networks

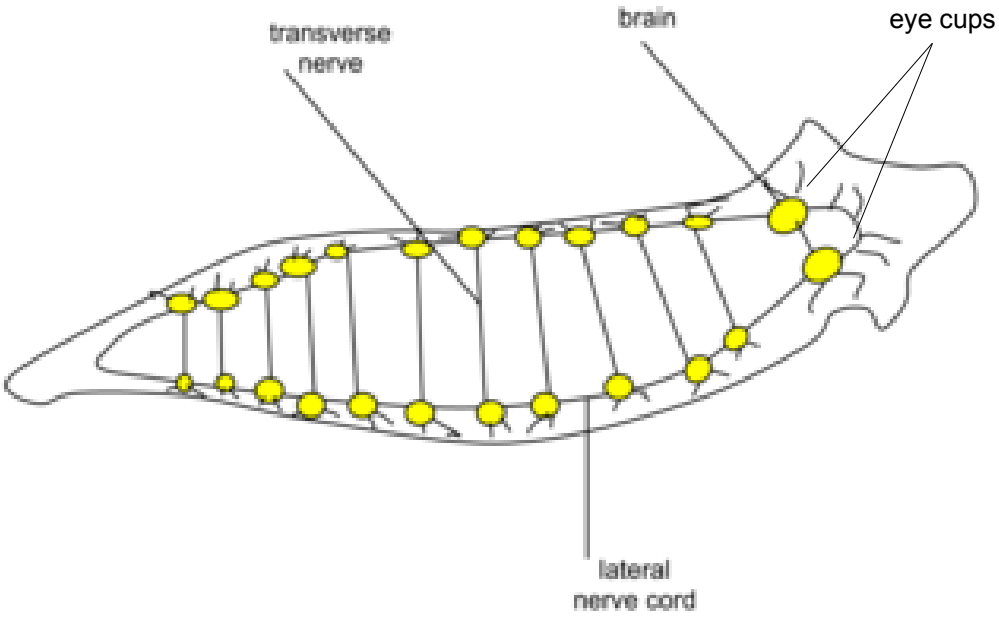
Recall Braitenburg Car:



Planaria Nervous System:

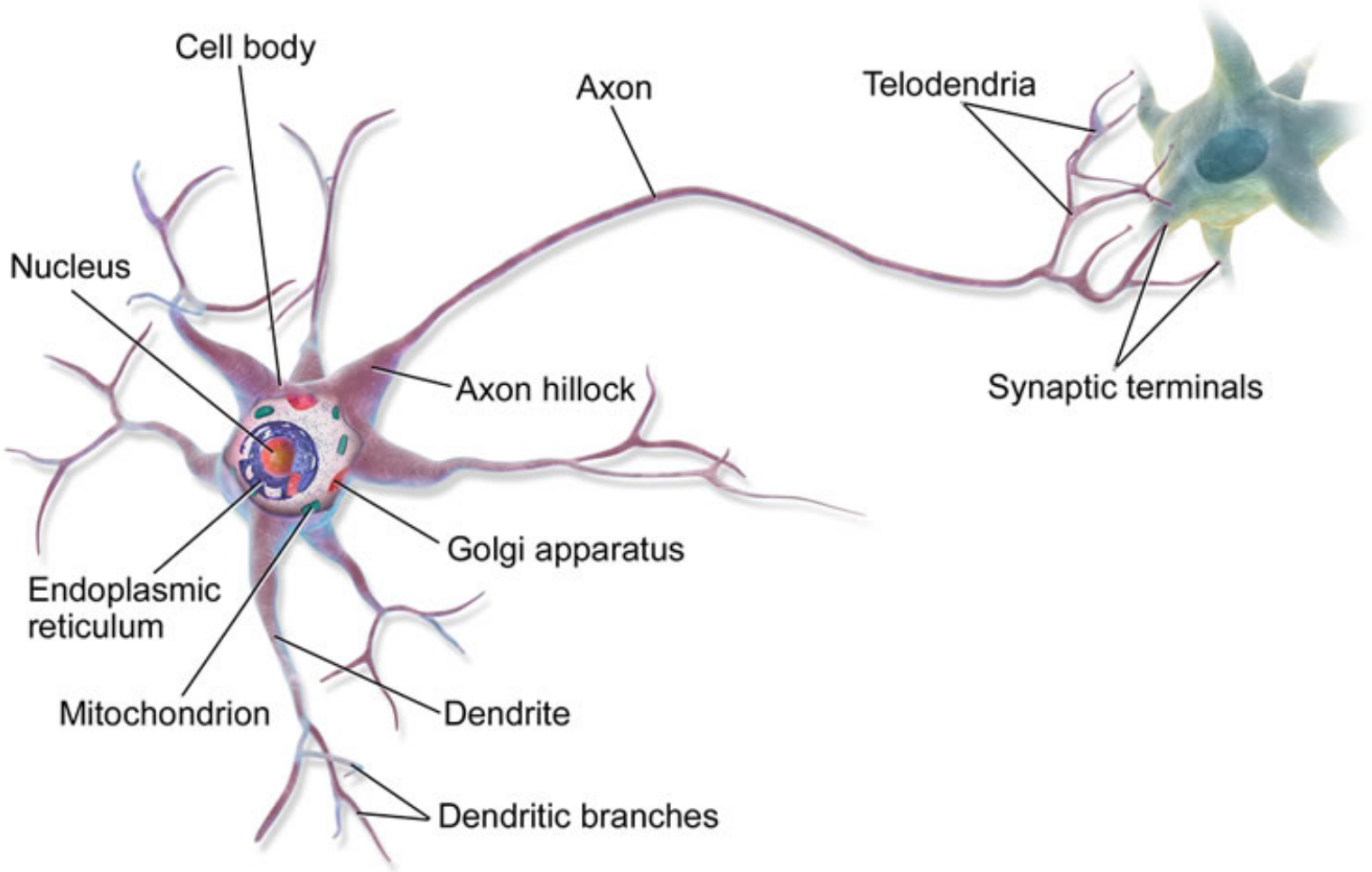
(8000+ neurons)

(phototaxic)



https://en.wikipedia.org/wiki/File:Planaria_nervous.png

A lot is known about the structure of neurons



C. Elegans worm: 282 neurons

Touch receptors

Oxygen receptors

Salt receptors

Etc.

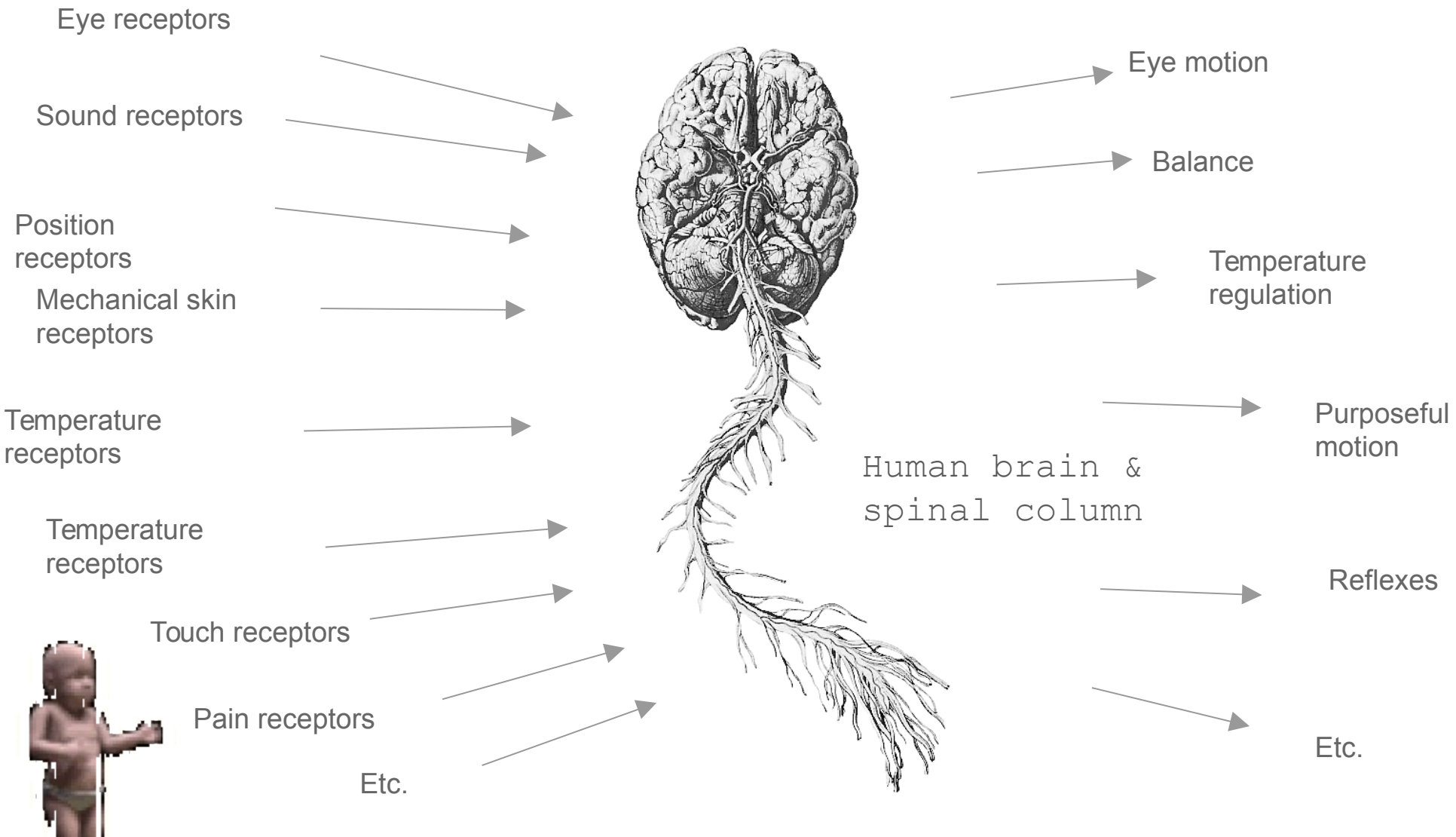
Temperature receptors

Head muscles

Body muscles

Neck muscles

A Network of about 100 billion neurons governs human perception, behaviour and intelligence.



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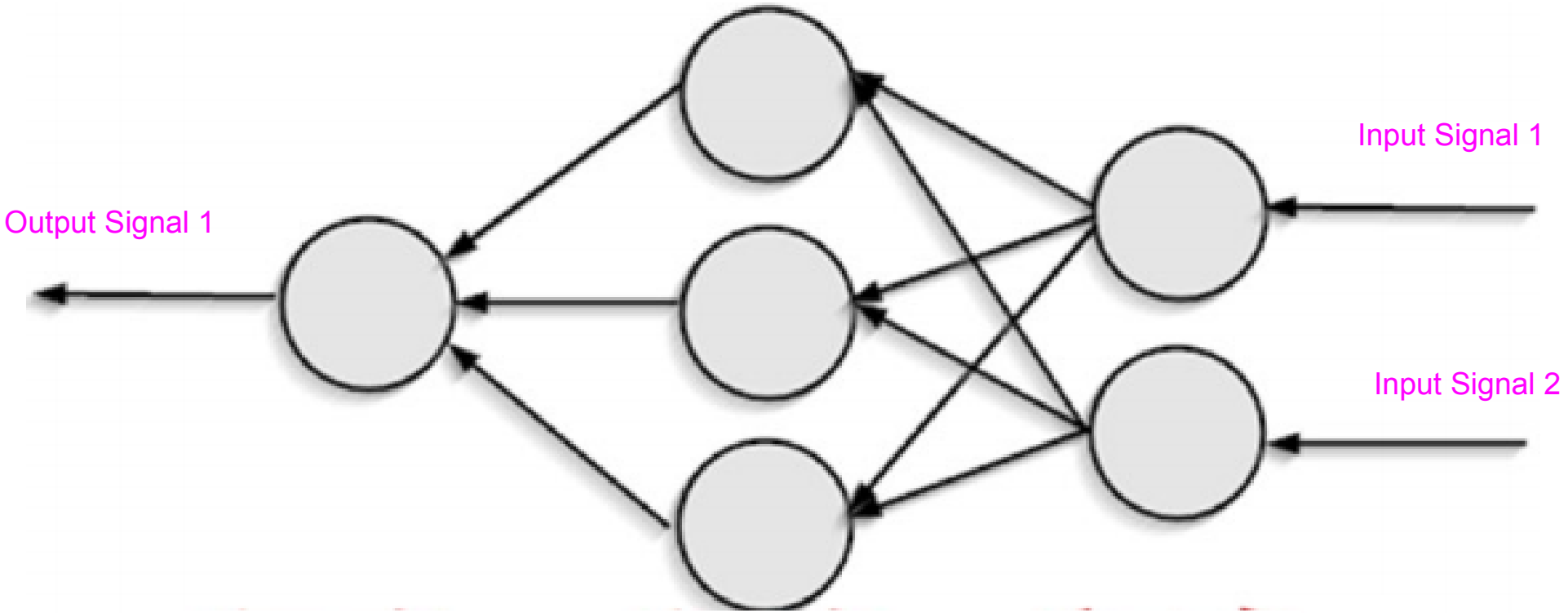
Artificial Neural Networks:
Many Types - All Approximations

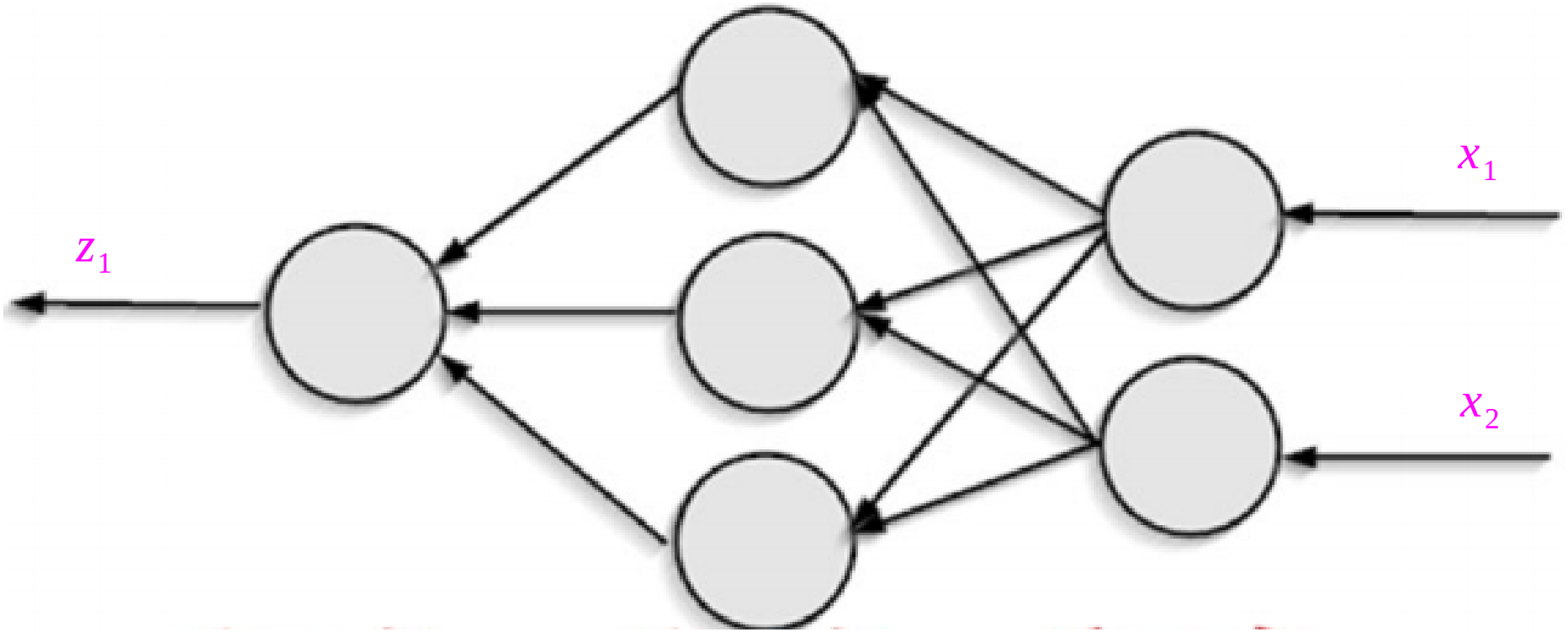
- Perceptron.
- Feedforward neural network.
- Recurrent neural network.
- Self-ordering map.
- Spiking neural network.
- ….

Basic structure of a feedforward neural network

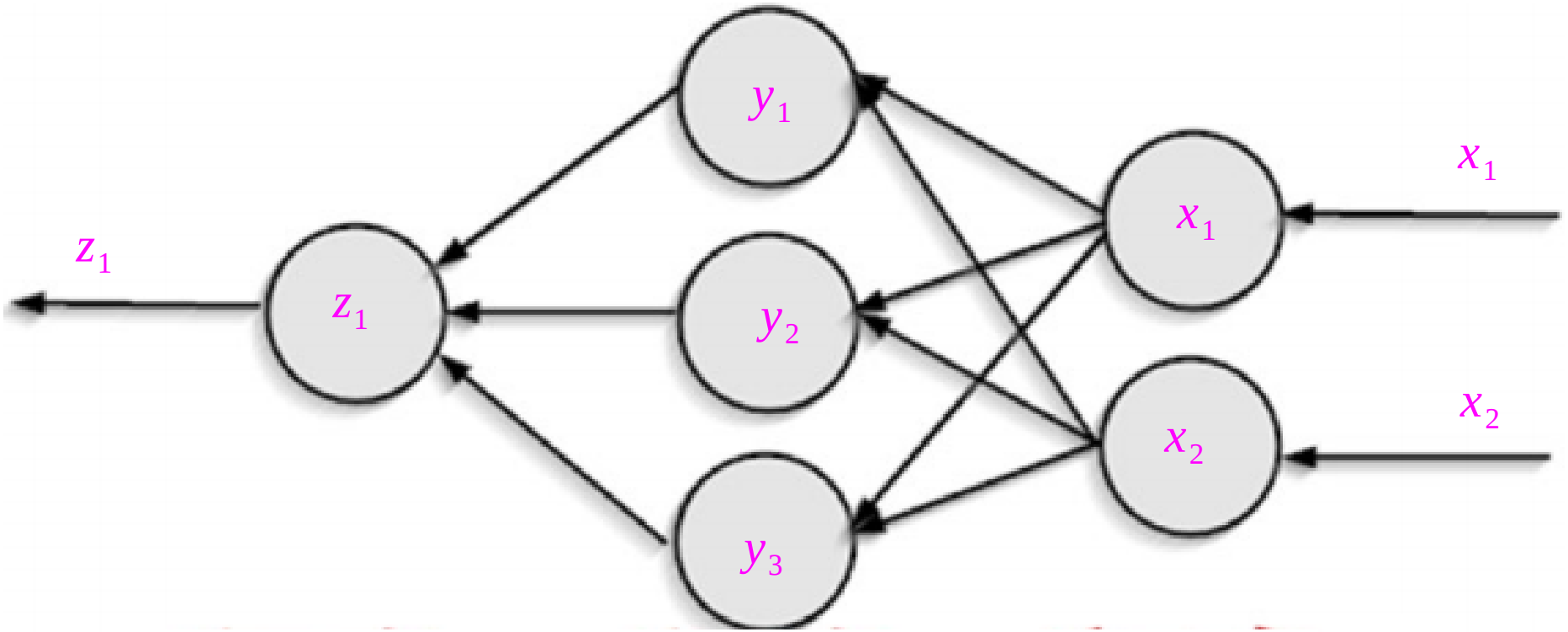
Information is encoded in connection strength.



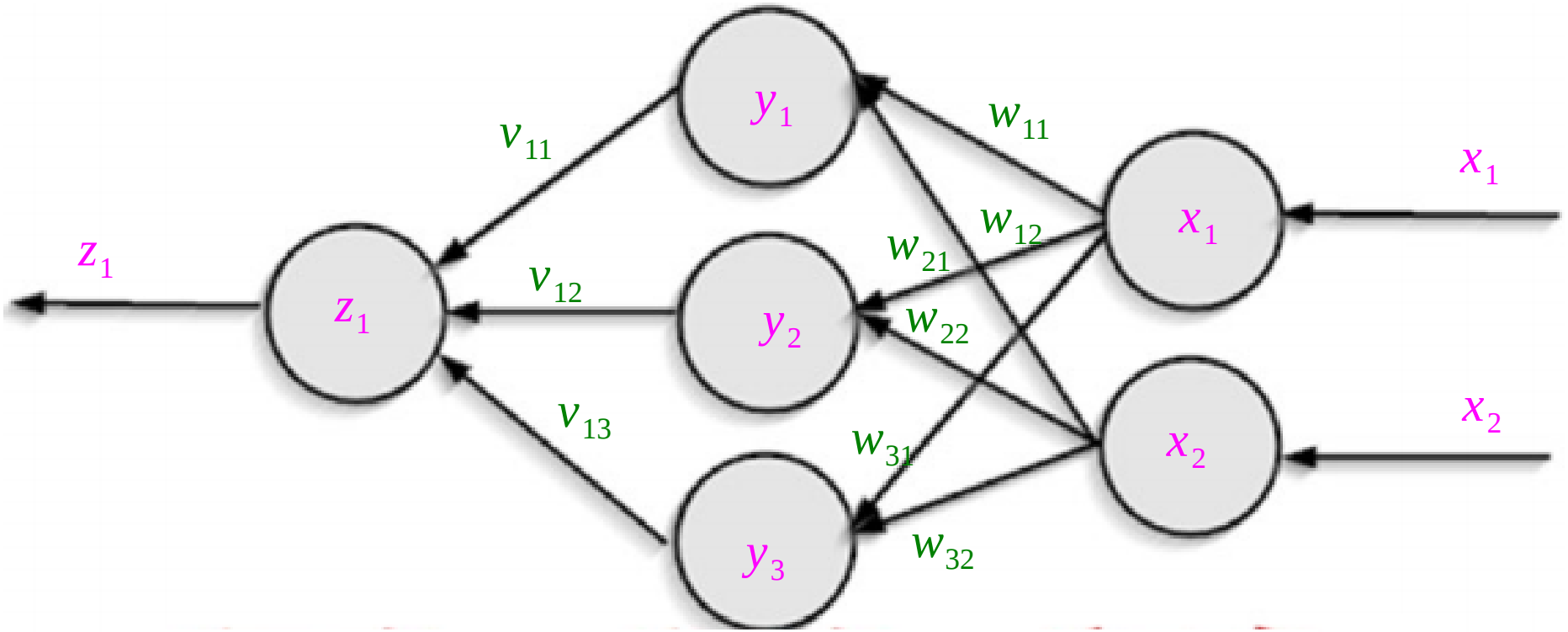
Feedforward neural networks create mappings from input numbers to output numbers (functions)



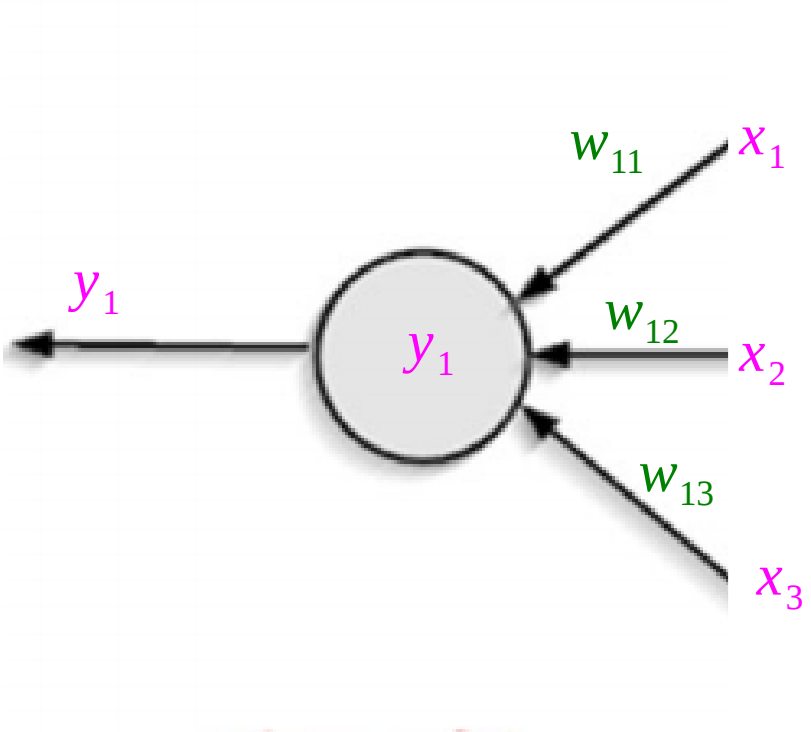
They work by propagating the numbers through the network



The numbers propagate based on the strength ("weight") of connections between neurons.



Each neuron is a simple function from input to output

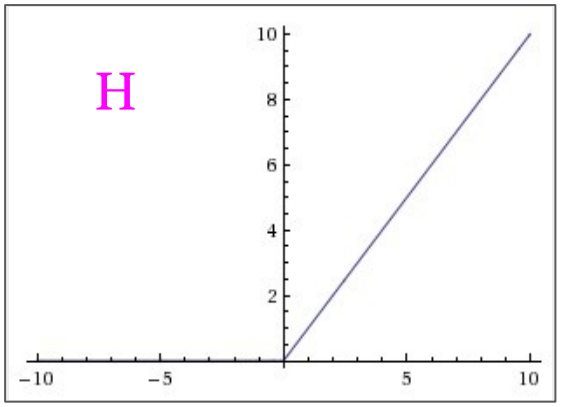


$$y_1 = max(0, w_{11} x_1 + w_{12} x_2 + w_{13} x_3)$$

This mapping is in two parts:

- Weighted summing of inputs.
- Activation function.

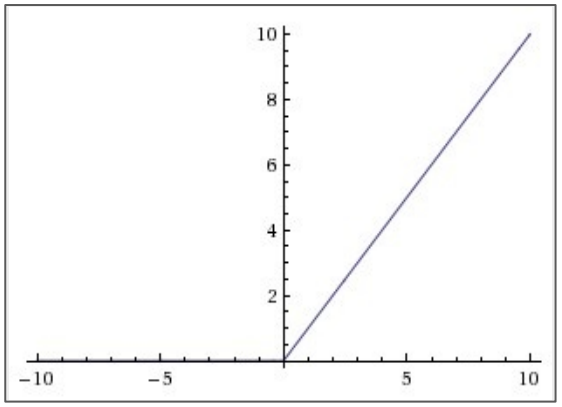
ReLU activation:



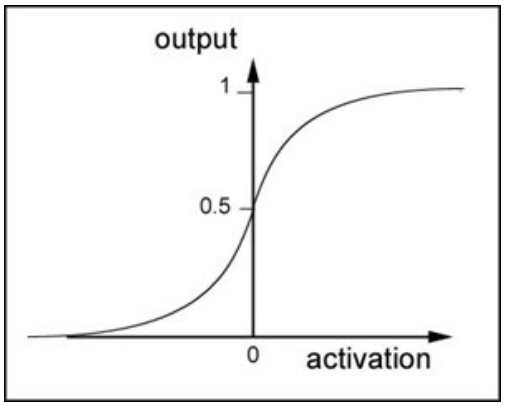
H(x) = max(x,0)

Other activation functions

ReLU activation:



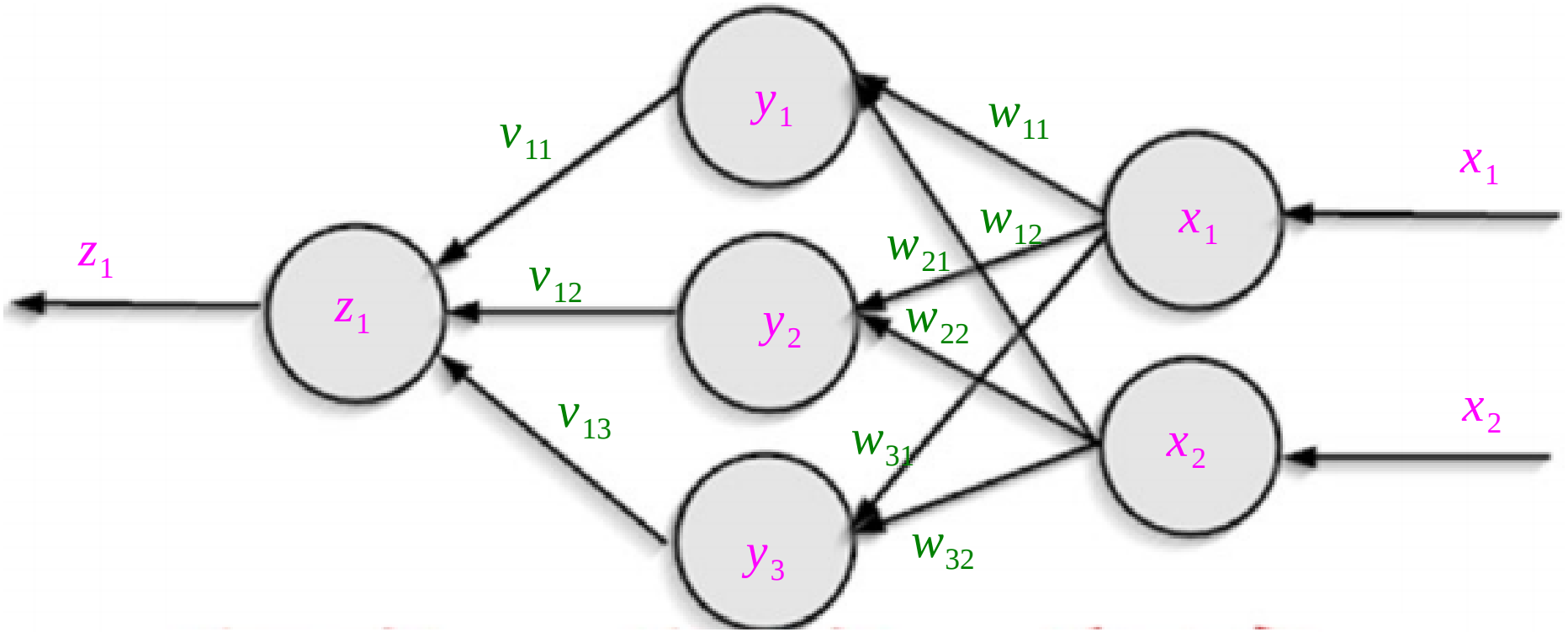
Sigmoid activation:



Others

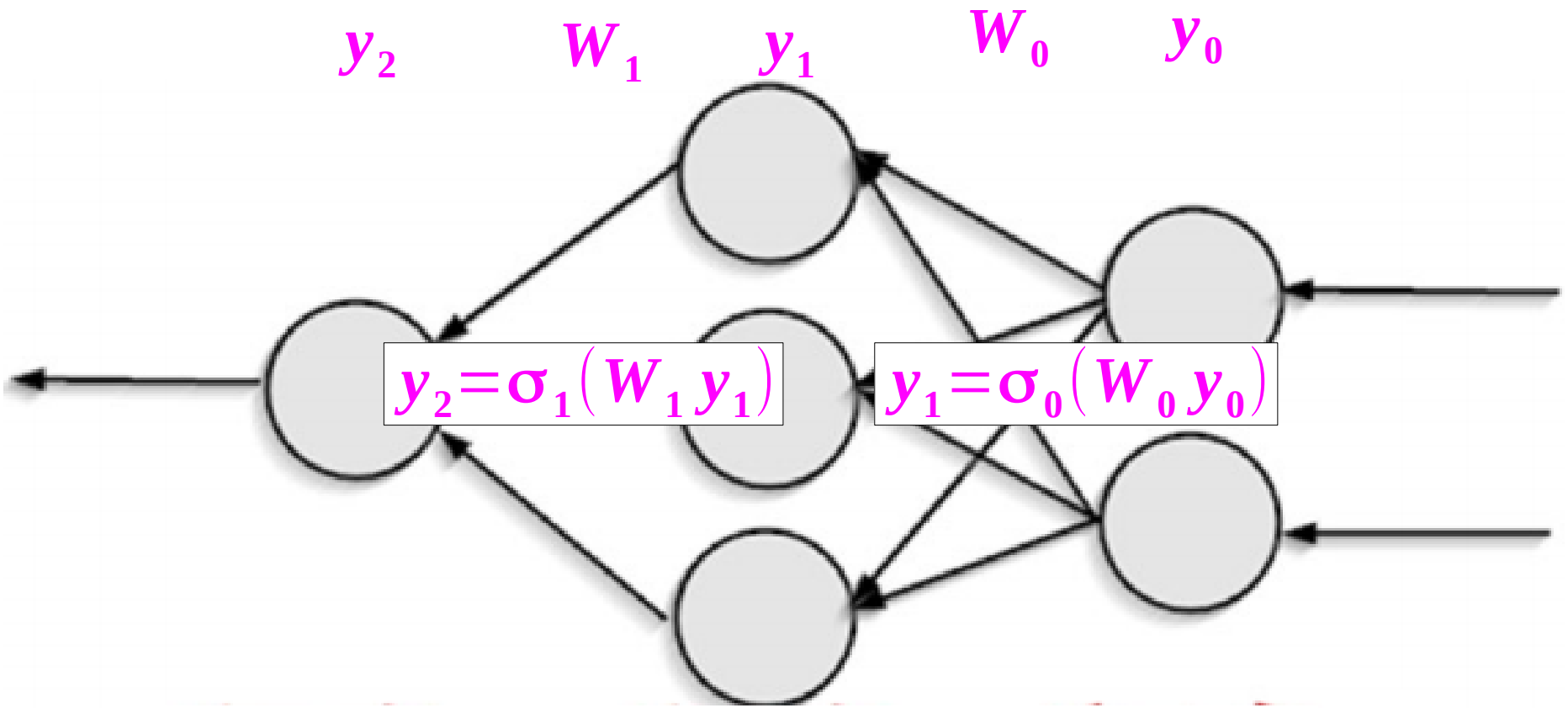
- Leaky ReLU.
- Tanh.
- Step function.
- ….

Changing the weights changes the function: The network can **learn.**



Implementation detail:

We usually store weights as matrices and activations as vectors.



$$N(\theta, o_o)=o_2=a_1(W_1 a_0(W_0 o_0))$$
$$\theta=\{W_0, W_1\}$$

y_i output of layer $i-1$ /input to layer i

W_i weights of layer i

σ_i activation function for layer i

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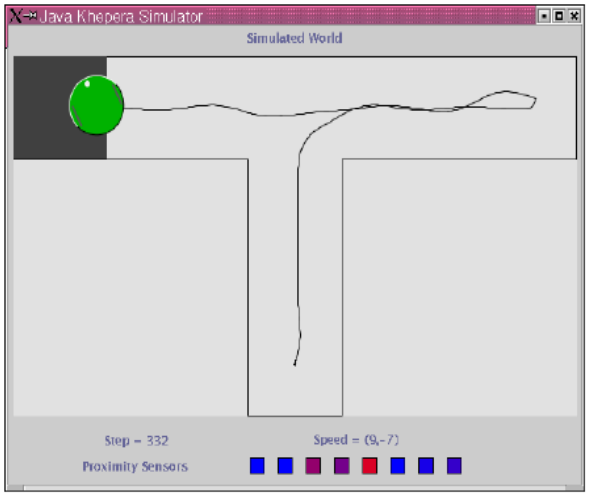
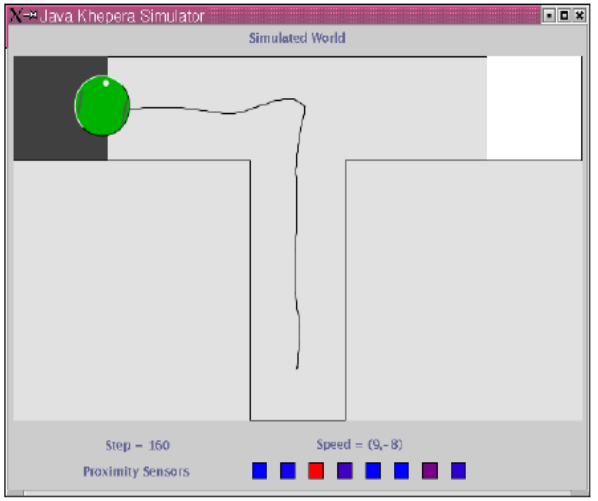
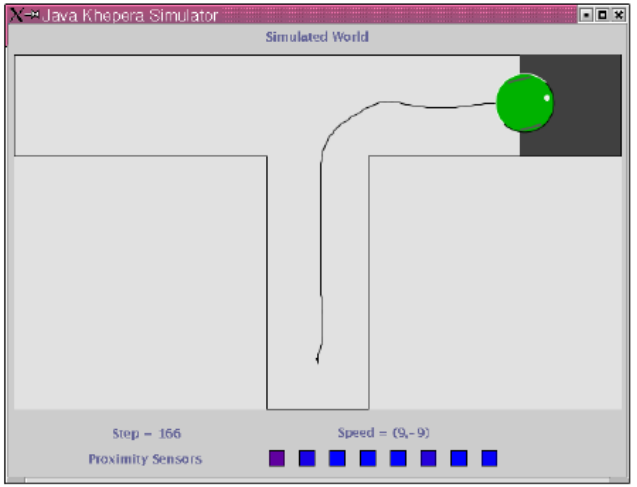
Evolving neural networks

- Evolve weights of network.
  - Fitness calculated as “success” over multiple episodes. E.g.
    - Hitting wall: -100
    - Reaching target: +100
  - Successful networks selected & bred.



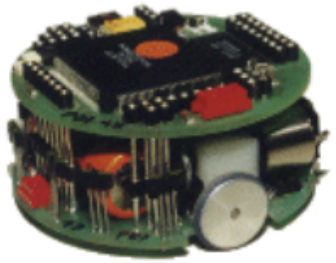




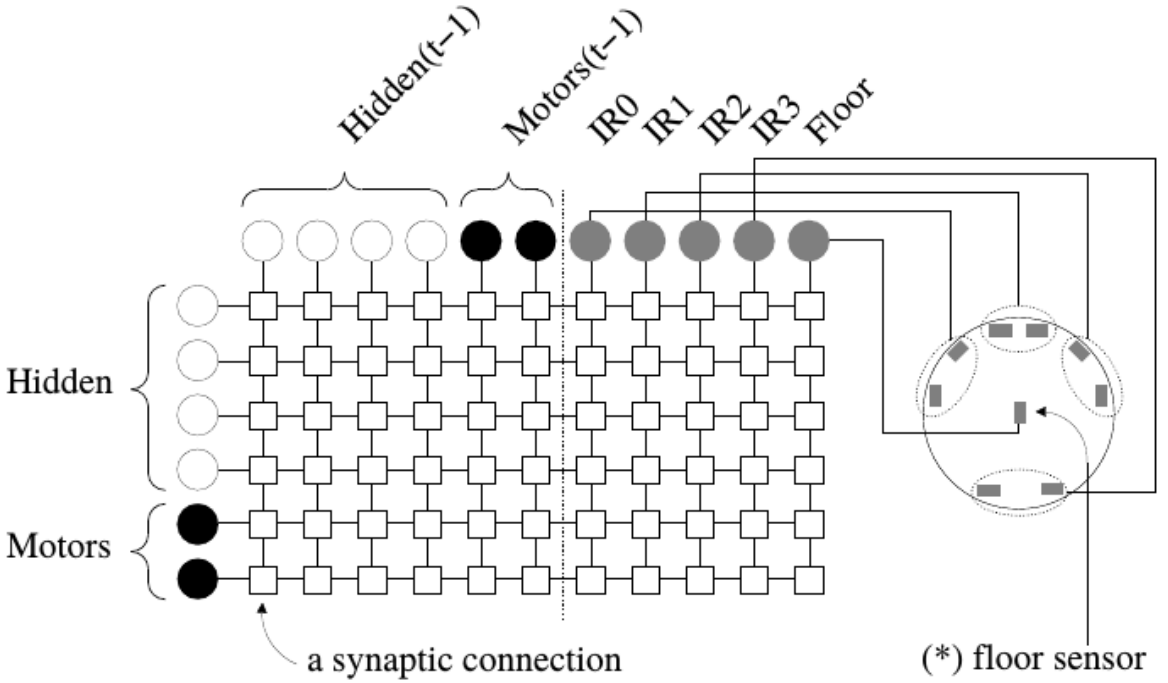
http://link.springer.com/chapter/10.1007/3-540-36605-9_54

Evolving neural networks

- Evolve weights of network.
  - Example neural structure:



(a) Khepera Robot.

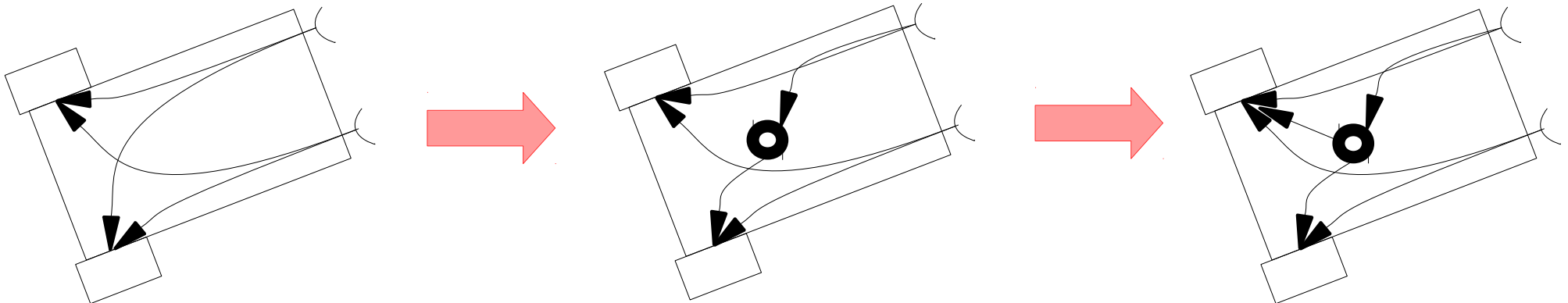


(b) Neural Network Architecture.

http://link.springer.com/chapter/10.1007/3-540-36605-9_54

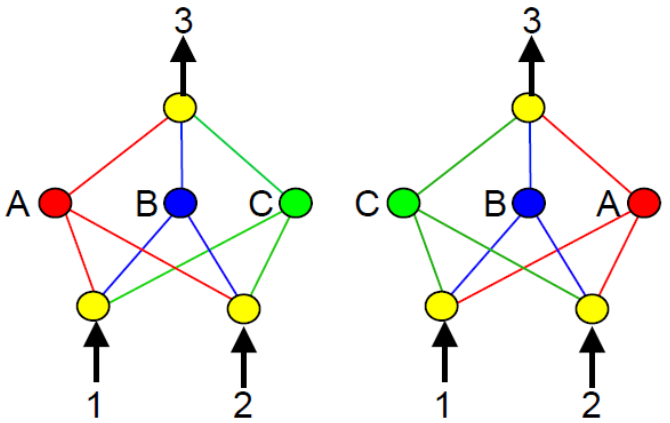
Evolving structure of neural network

- Basic approach: new “genetic operators”.
  - Mutation:
    - add new connection.
    - adds intervening neuron.
    - Etc.
- Keep complexity low:
  - Fitness penalty for extra neurons/connections.



Evolving structure of neural network

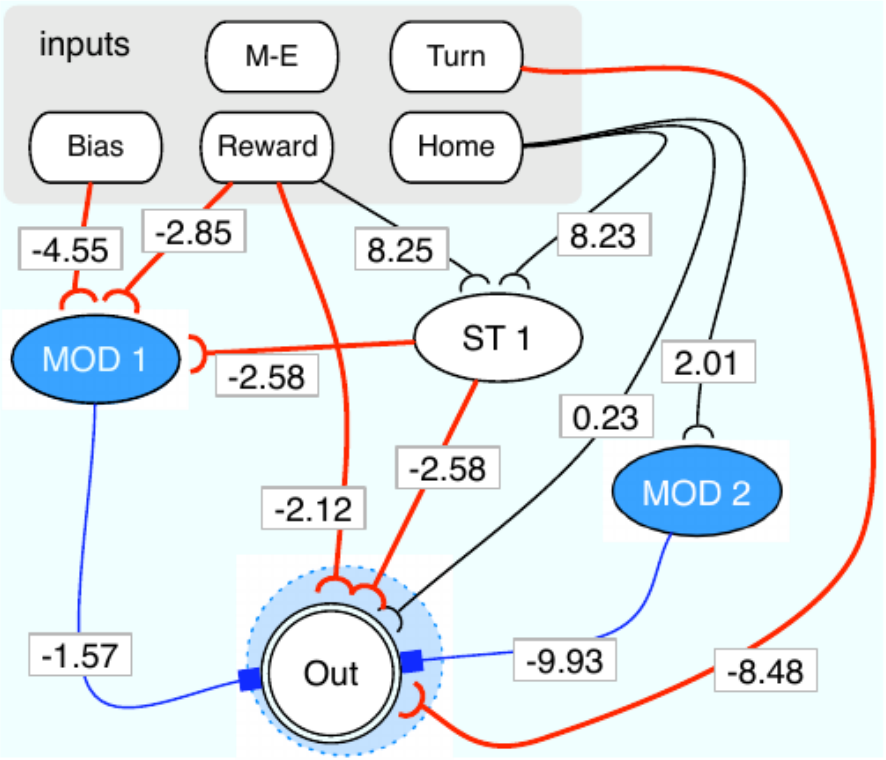
- Basic approach: new “genetic operators”.
  - Crossover???
    - Allow junk DNA.
    - “Competing conventions”.
      - Solution: keep track of innovation history
        - (like GIT!)



[A,B,C]
X[C,B,A]

Crossovers: [A,B,A] [C,B,C]
(both are missing information)

Evolving to Learn I: *neuromodulation*



A learnt neuromodulating controller

- So far: evolving a brain….
  - but brains are evolved to learn
- *Neuromodulation*:
  - Neurons affect each other's weights.

http://infoscience.epfl.ch/record/121548

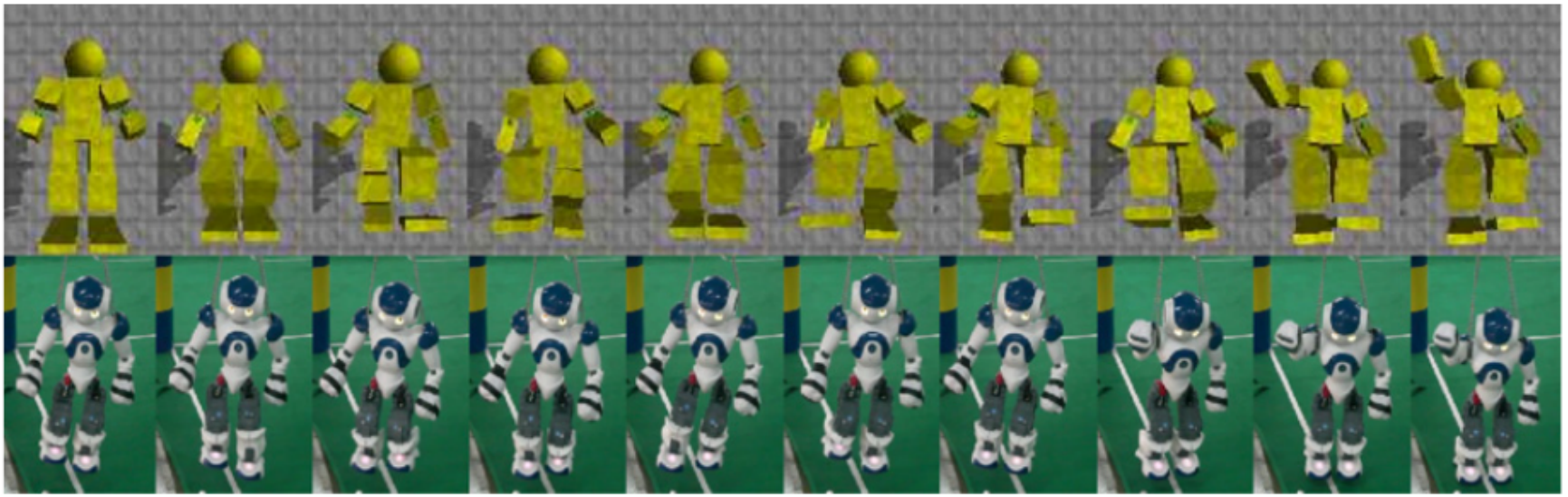
Evolving to Learn II: *Embryogenic*

- Neurons change during episodes:
  - Developmental growth.
- Interaction: environment/genotype.

- Approaches:
  - grammatical (evolve rules for generating structure)
  - cell chemistry (evolve signalling/chemical factors etc.)

The reality gap: Solutions

- Add noise to simulator.
- Evolve adaptive learners.
- Co-evolve controller & simulator.
  - In simulation: Fix simulation: Evolve controller.



http://www.sciencedirect.com/science/article/pii/S092188900900058X

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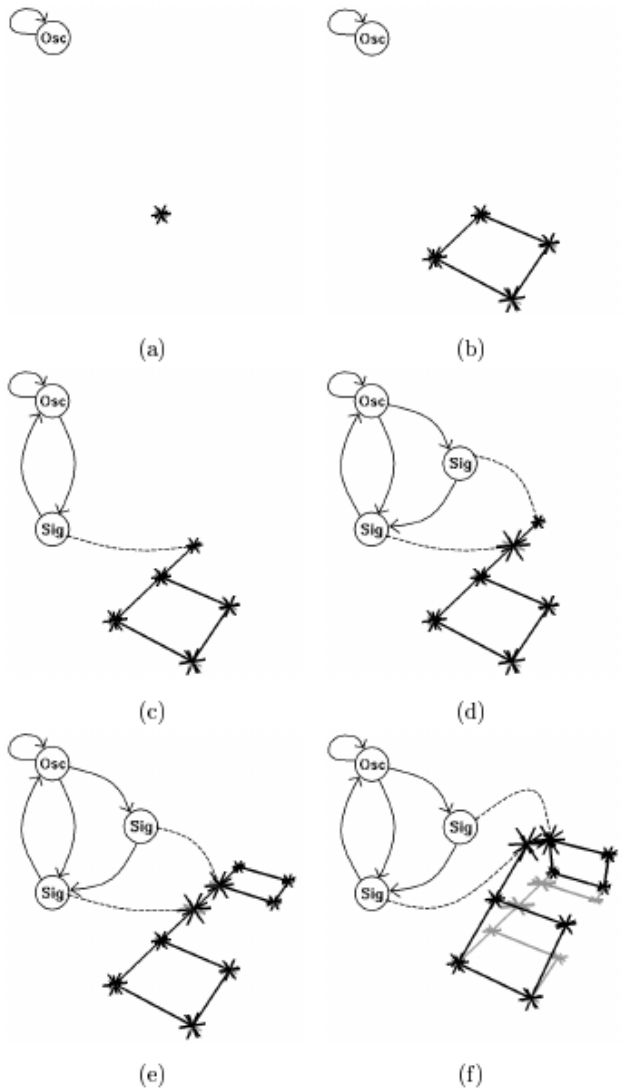
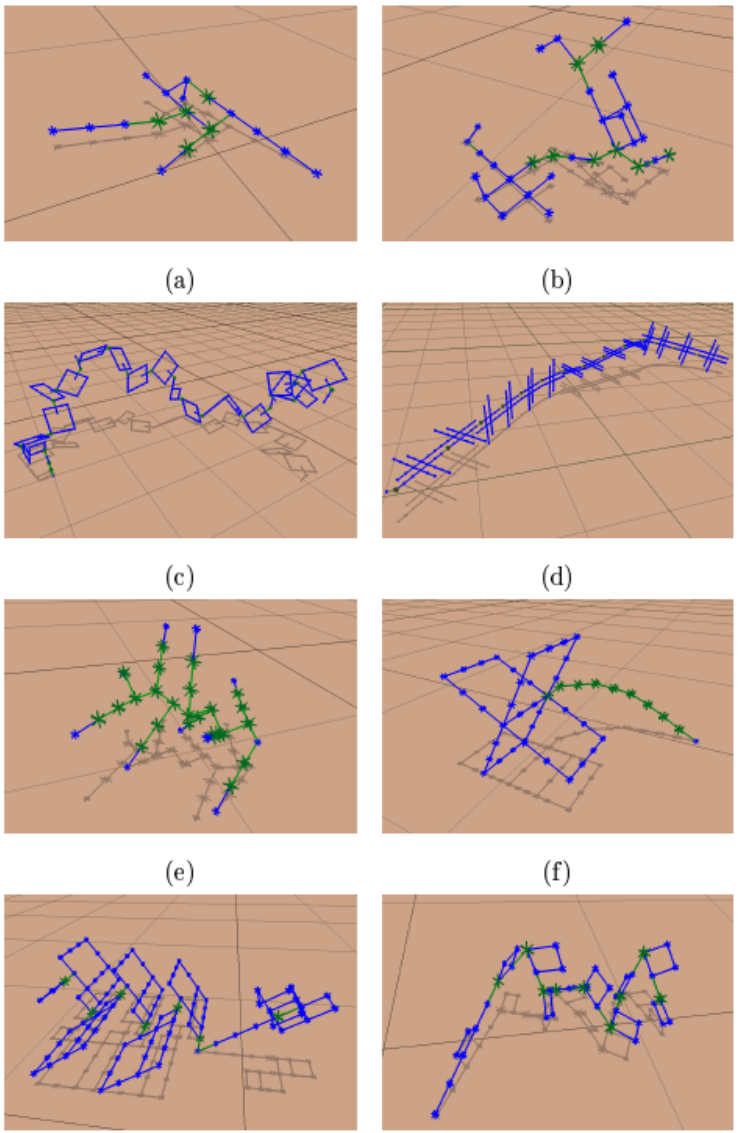
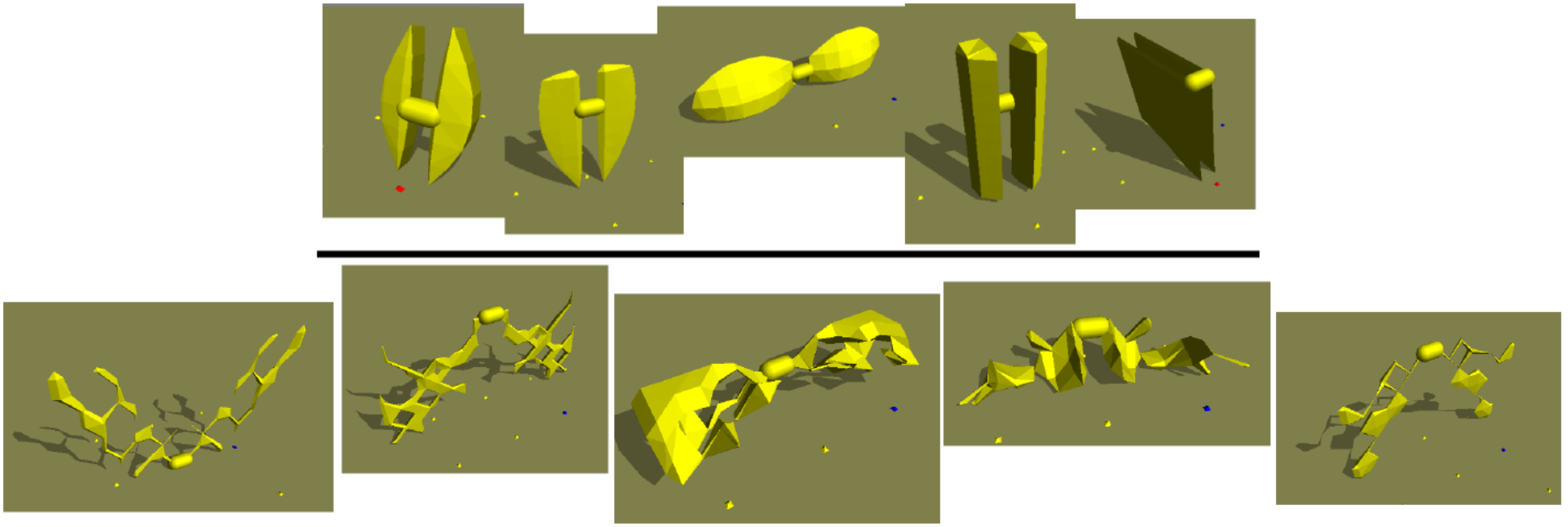
Evolving morphologies 1: Grammars for Bodies & Neural Networks





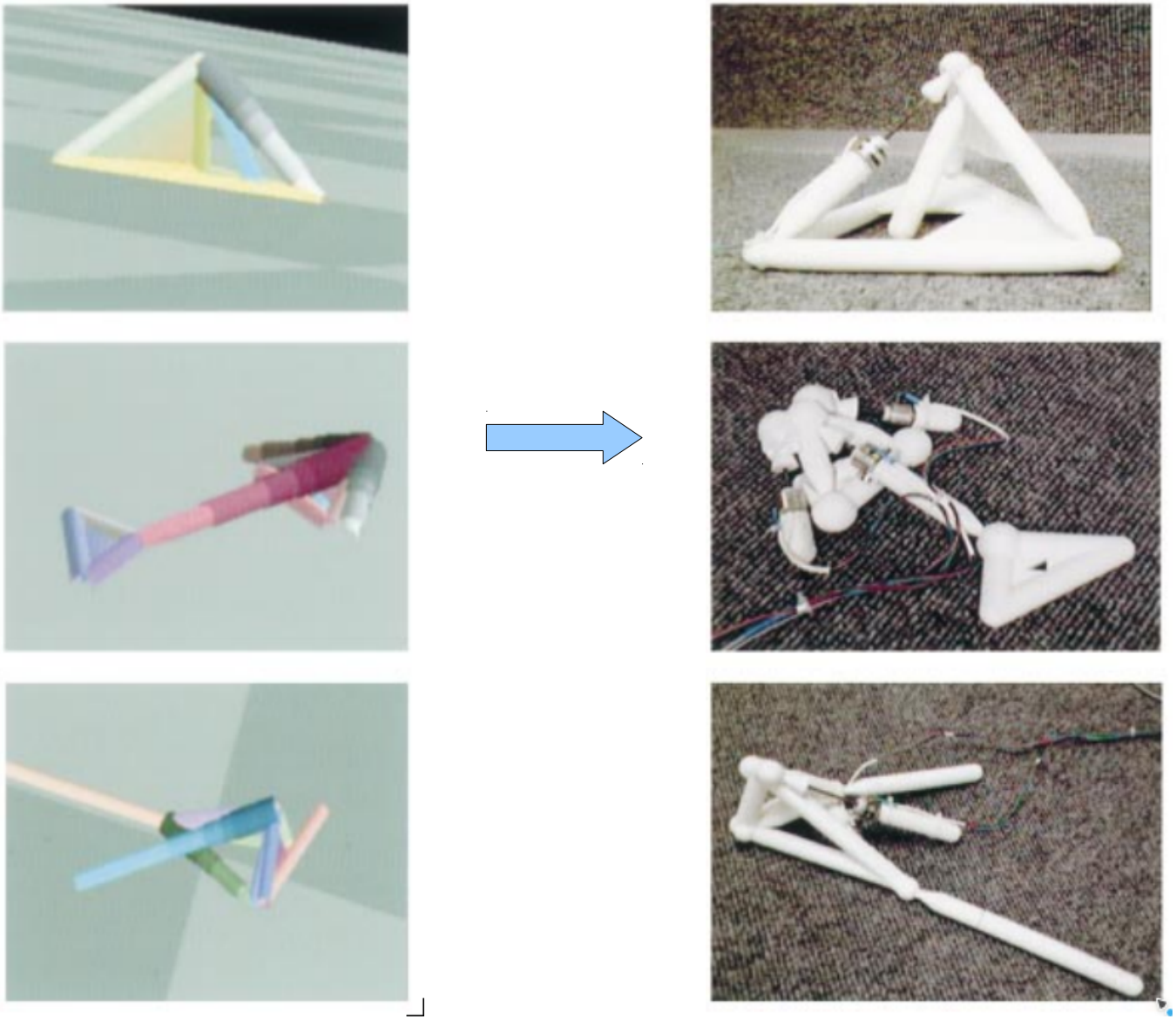
Evolving morphologies 2: Simulating development



- Evolving to walk.
- Evolve:
  - Body shape function.
  - Simple oscillating controllers (6 parameters).

https://dl.acm.org/citation.cfm?id=2330238

Evolving morphologies 3: Towards physical robots



https://www.nature.com/articles/35023115

Other resources

- https://www.youtube.com/watch?v=qv6UVOQ0F44
- http://divit.library.itu.edu.tr/record=b2448449*tur
- http://www.scholarpedia.org/article/Evolutionary_Robotics
- http://www.cs.uvm.edu/~jbongard/teaching.html