



# ARTIFICIAL INTELLIGENCE

## Combining Deep Learning and Artificial Evolution

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Center for Computer Games Research  
Robotics, Evolution and Art Lab (REAL)

# Outline

- Artificial Evolution (AE)
- Advantages/Disadvantages of AE and DL
- Towards combining AE and DL

# Evolve Artificially Intelligent Robots



Natural evolution is the source of astronomical complexity and **creativity**

# Evolve Artificially Intelligent Robots

Goals:

- Understand by building
- Engineering applications



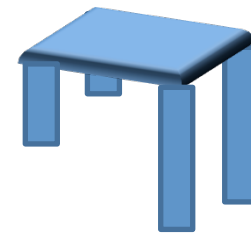
([www.dailymail.co.uk](http://www.dailymail.co.uk))

# Evolutionary Algorithms (EAs)

Encode Problem

genome

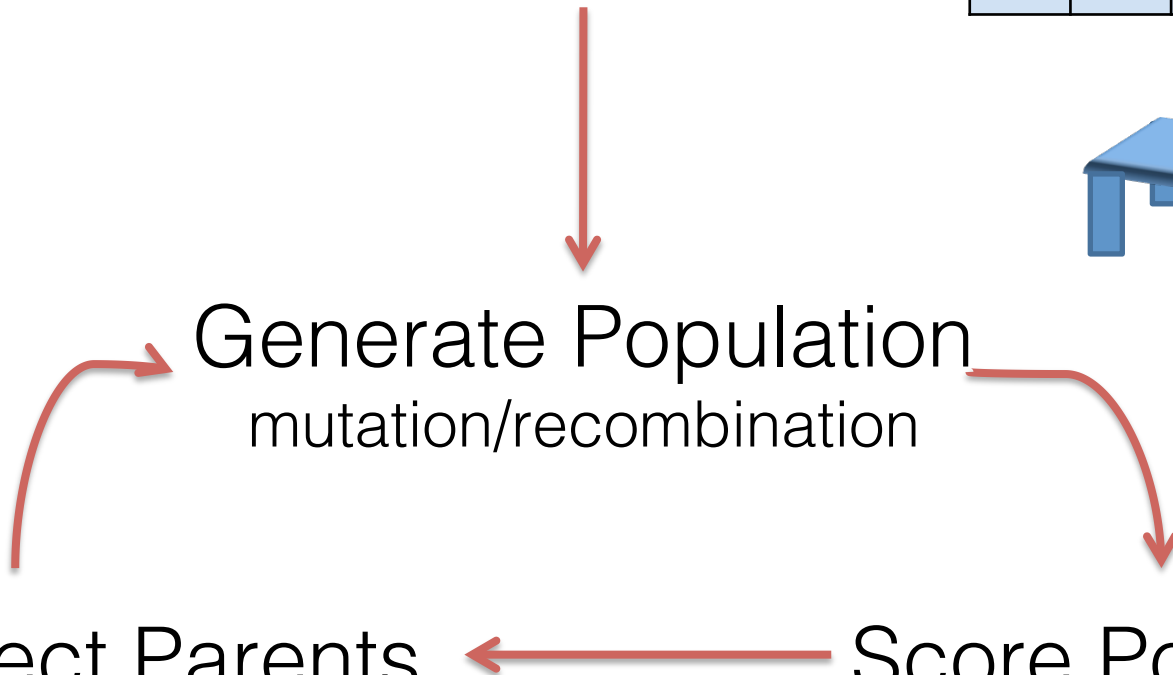
1	2	3	4	w	l
0.4	0.5	1.0	0.8	0.5	0.9



Generate Population  
mutation/recombination

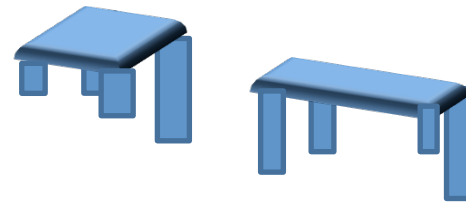
Select Parents

Score Population

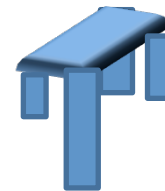


# Evolutionary Algorithms (EAs)

Encode Problem

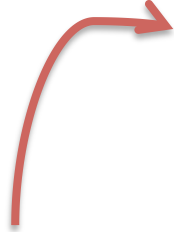


Generate Population  
mutation/recombination



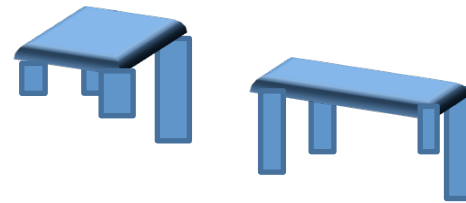
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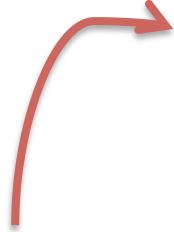
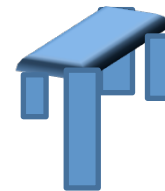


# Evolutionary Algorithms (EAs)

Encode Problem



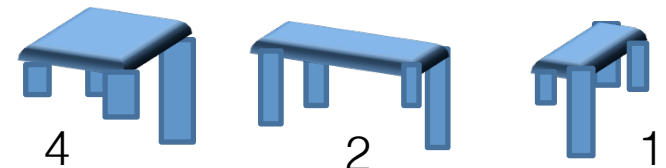
Generate Population  
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Select Parents

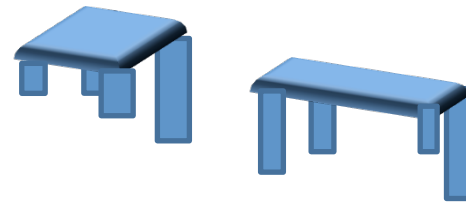


Score Population

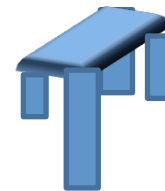


# Evolutionary Algorithms (EAs)

Encode Problem



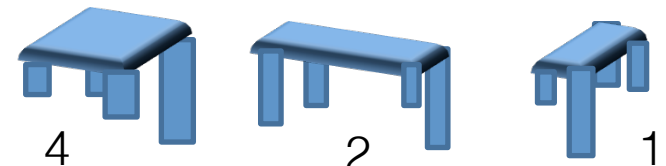
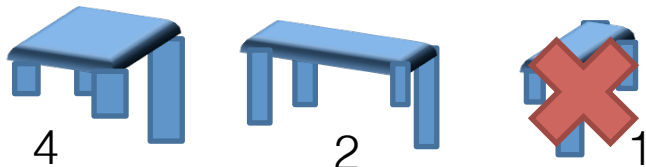
Generate Population  
mutation/recombination



Select Parents



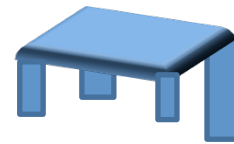
Score Population



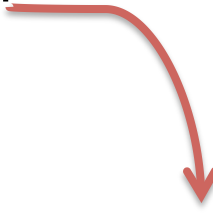
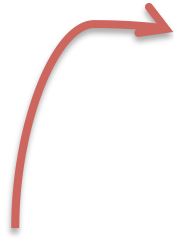


# Evolutionary Algorithms (EAs)

Encode Problem



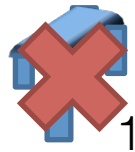
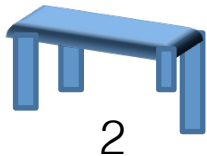
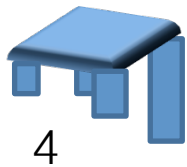
Generate Population  
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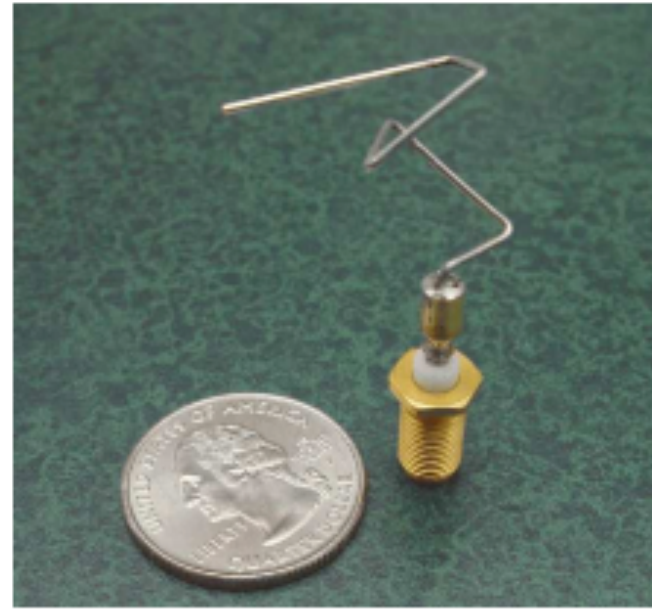
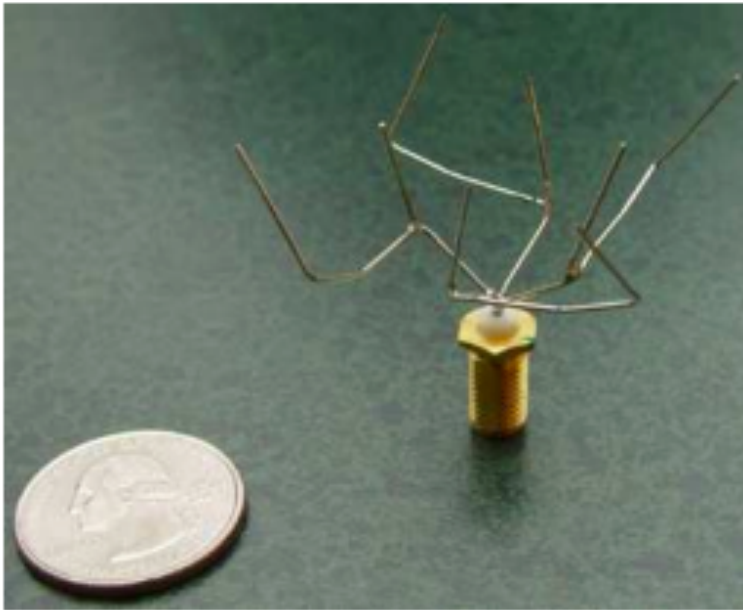
Select Parents



Score Population

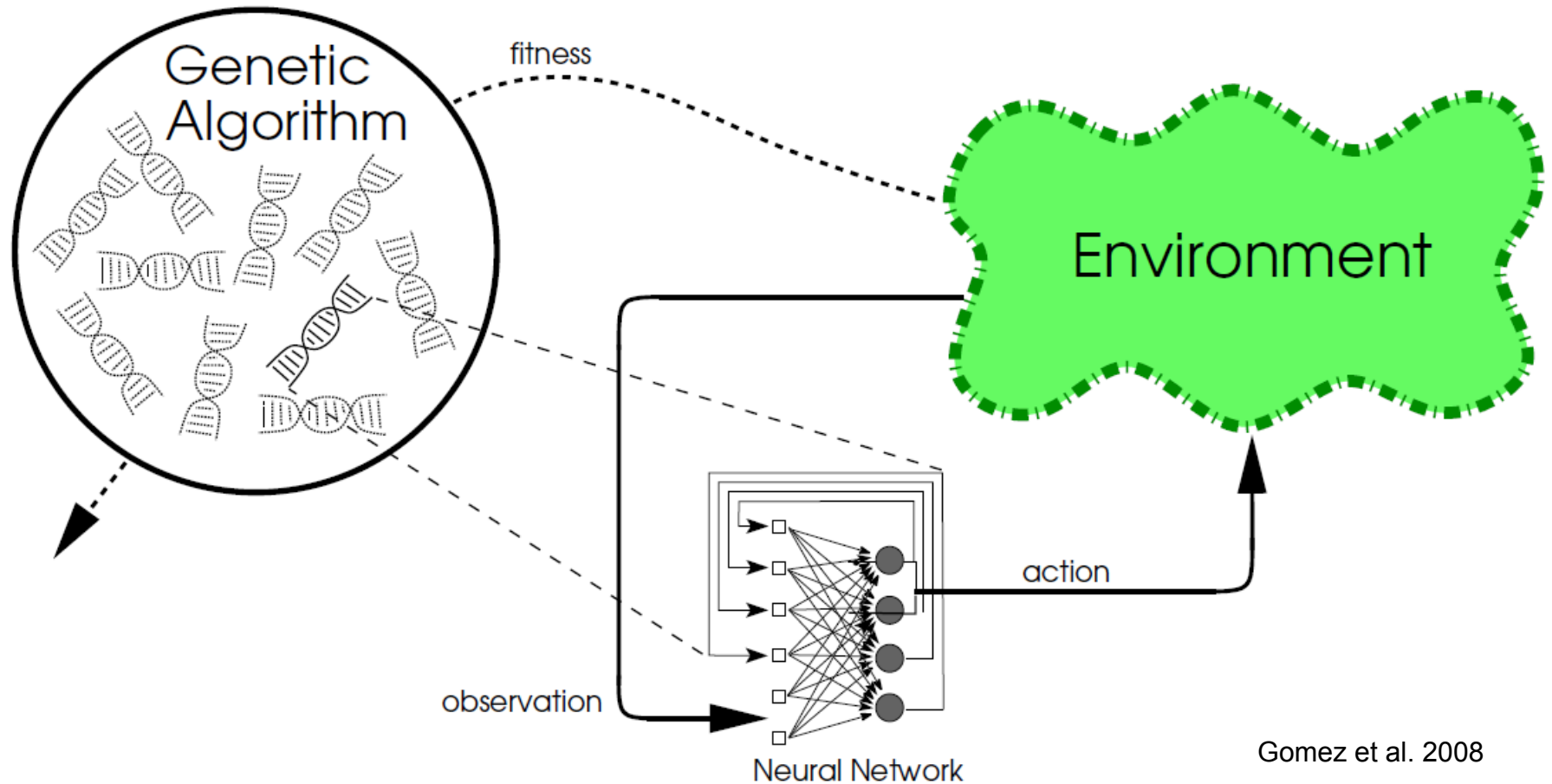


# Artificial Evolution Examples



NASA Evolvable Systems Group

# Neuroevolution: Evolving Artificial Brains

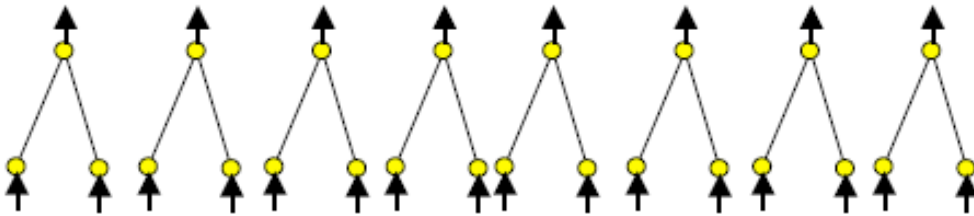


Gomez et al. 2008

**NE can be applied to supervised but also reinforcement learning tasks**

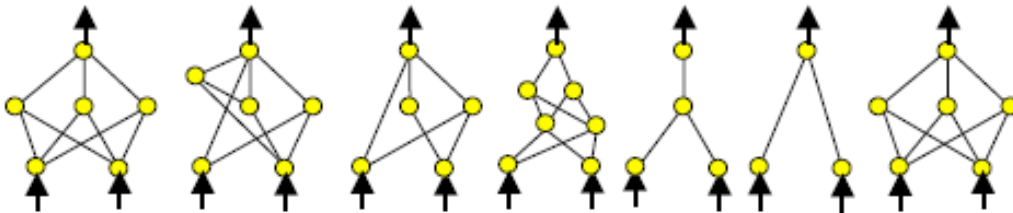
# Evolving Topologies

Minimal Starting Networks



Generations pass...

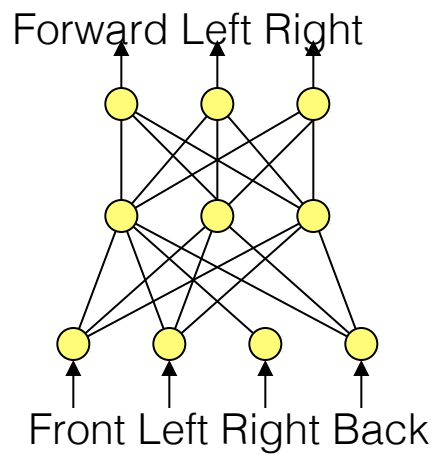
Population of Diverse Topologies



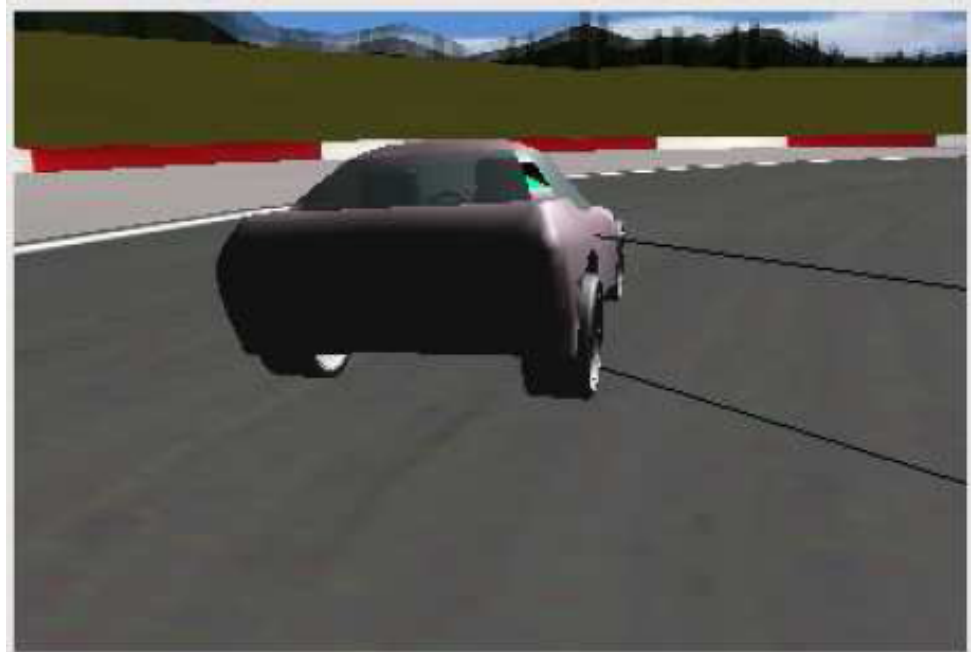
- E.g. Neuroevolution of Augmenting Topologies (NEAT; Stanley 2002)
- Networks and behavior get more complex

# Car Racing Example

Outputs (effectors/controls)



Inputs (Sensors)

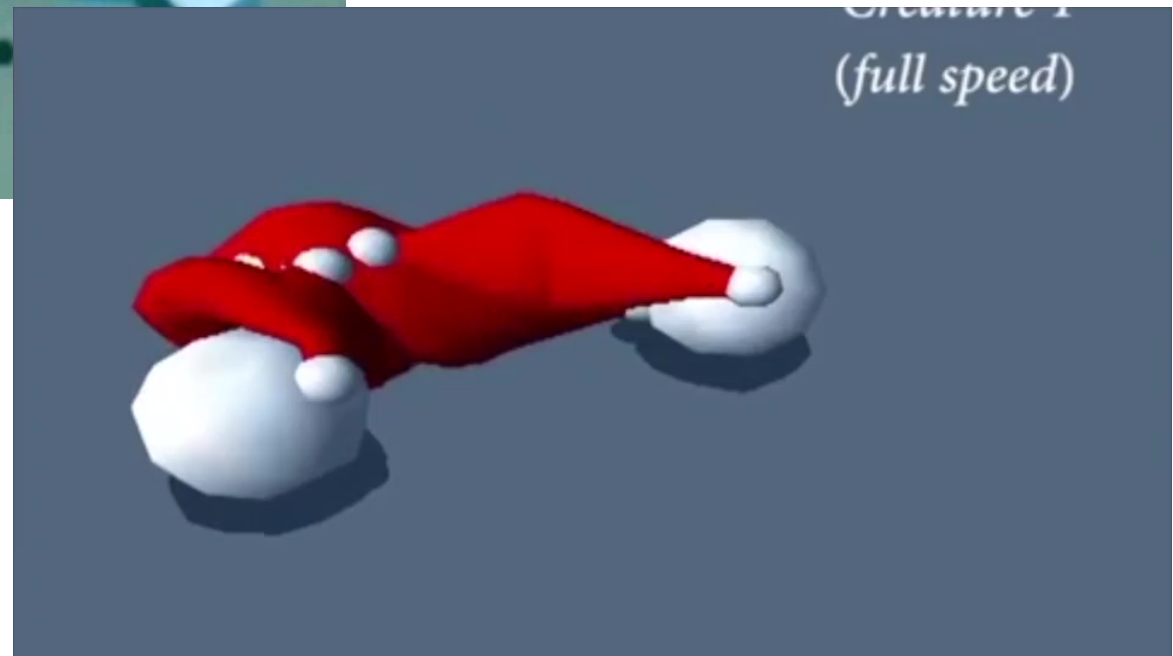




# Artificial Evolution of Bodies and Brains



Sims 1994



Lessin and Risi, ECAL 2015

# Petalz Social Facebook Game



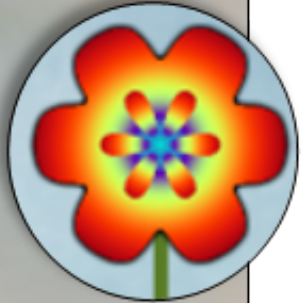


# New Game Mechanic Based on Artificial Evolution



# Planting the Offspring





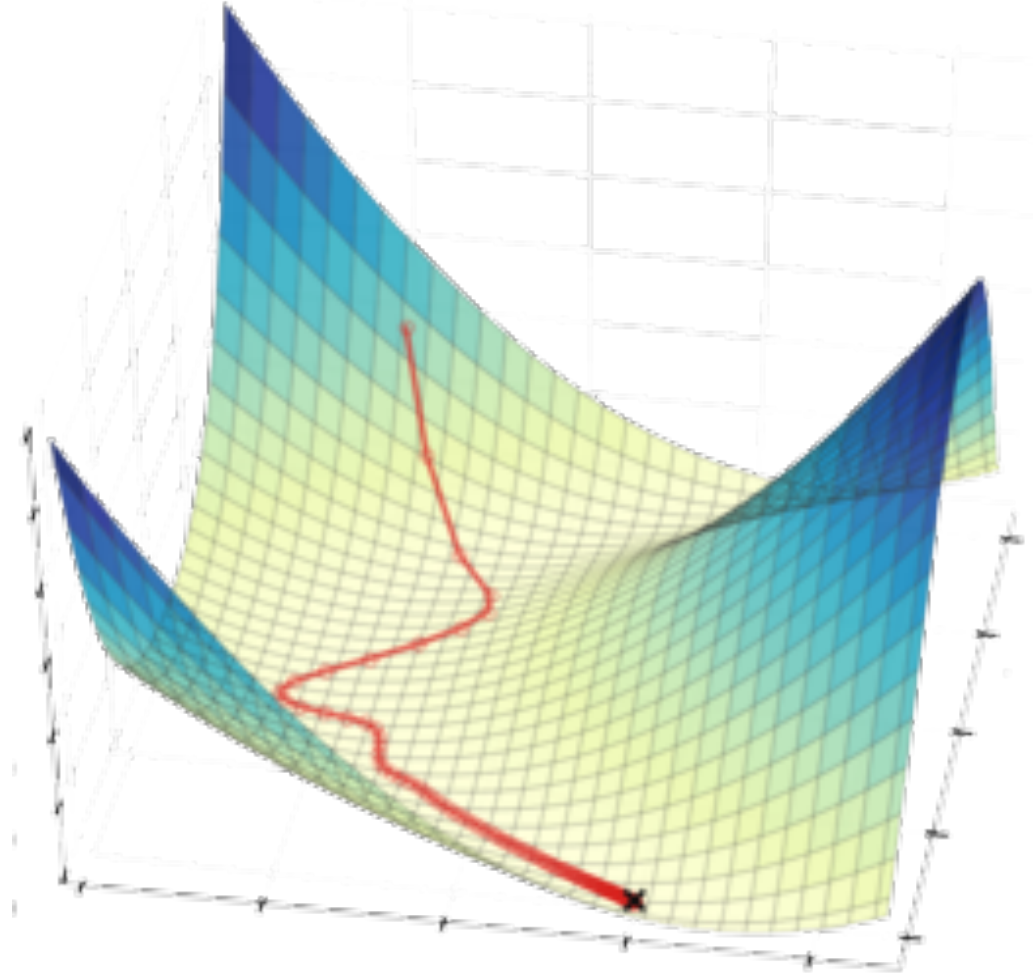
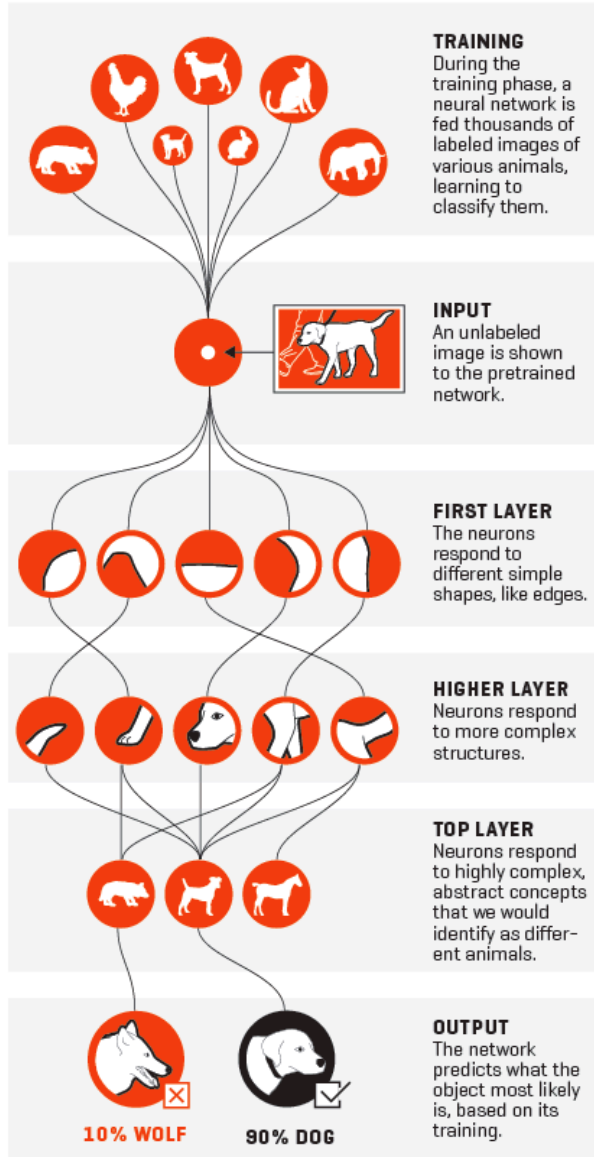
# Motivation

Evolutionary  
Algorithm

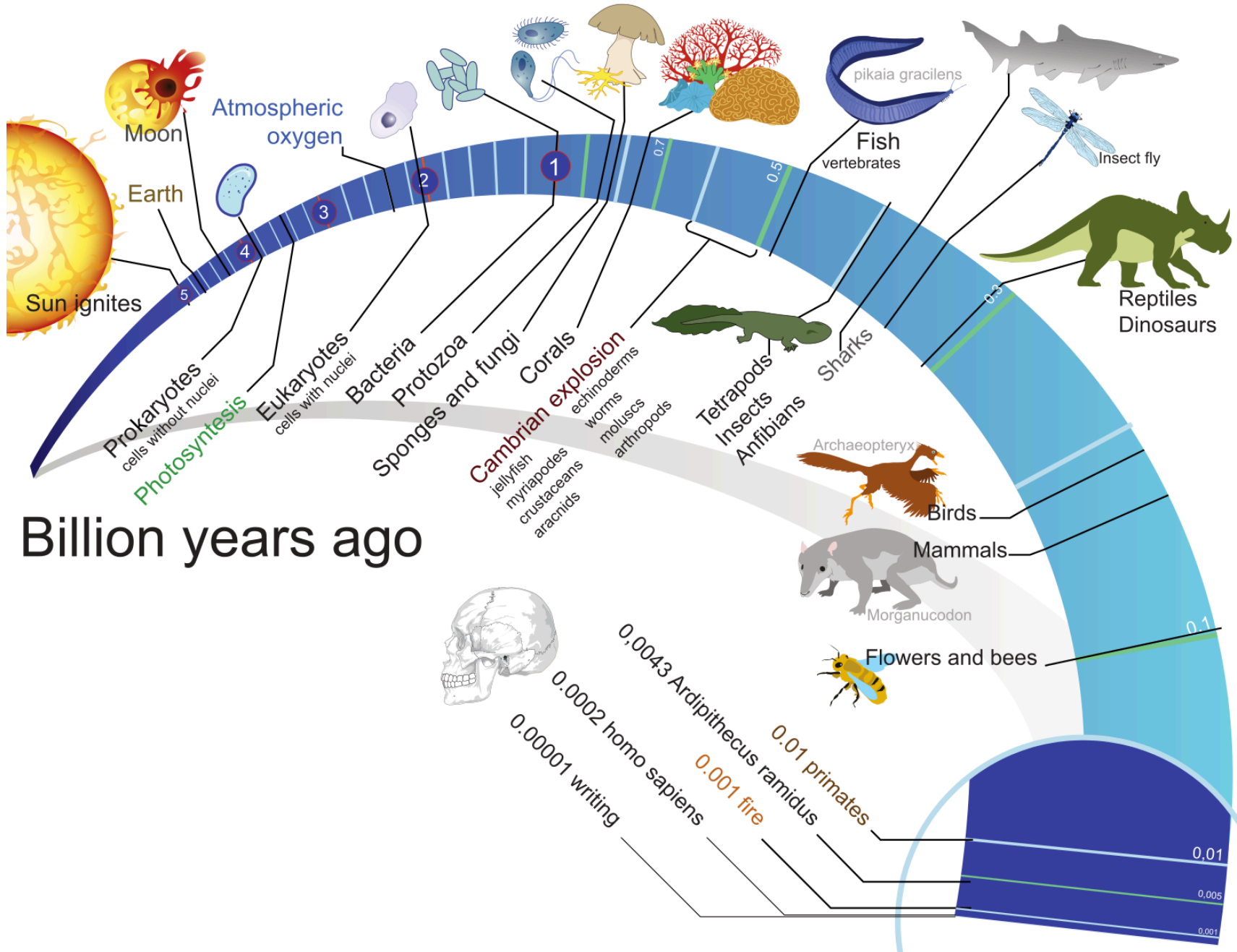
Deep Neural  
Net

# Deep Neural Networks

## HOW NEURAL NETWORKS RECOGNIZE A DOG IN A PHOTO



# Evolution



# Motivation

Evolutionary  
Algorithm

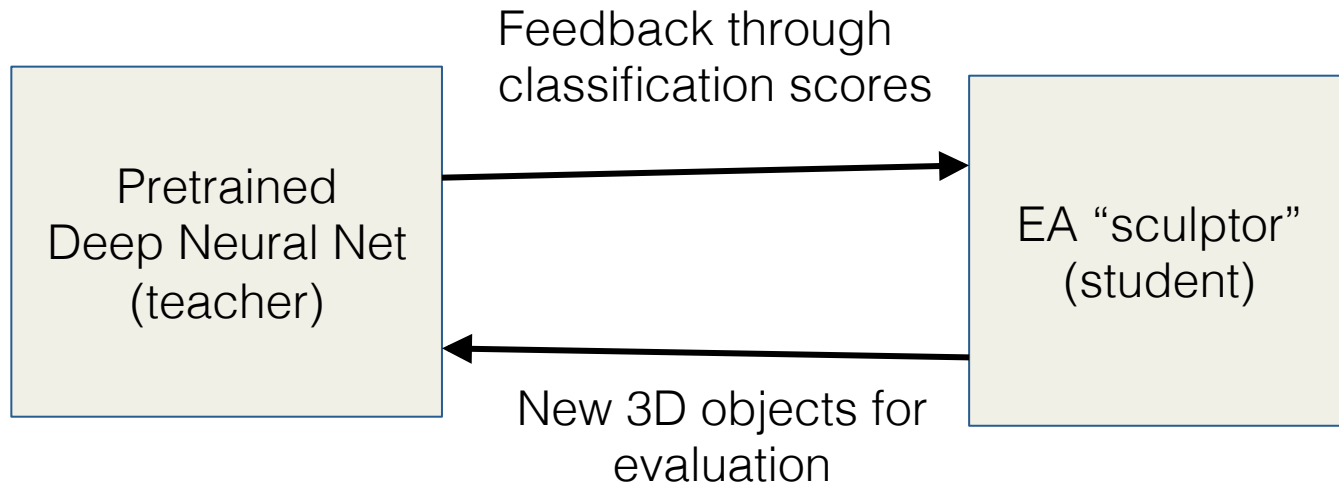


Deep Neural  
Net

Slower  
Less Constrained  
Divergent Search

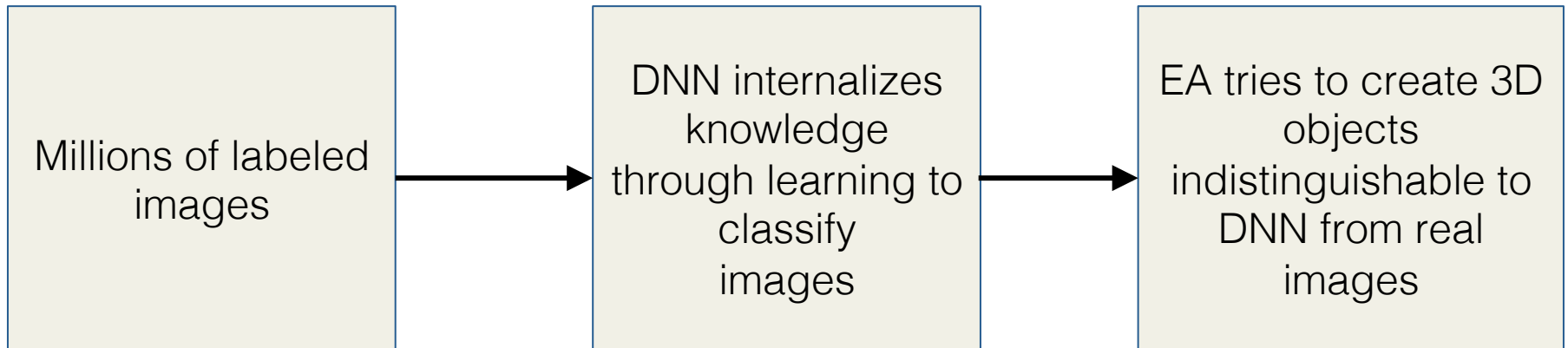
Faster  
More Constrained  
Single-minded Search

# Creative Generation of 3D Objects through Deep Learning and Evolution

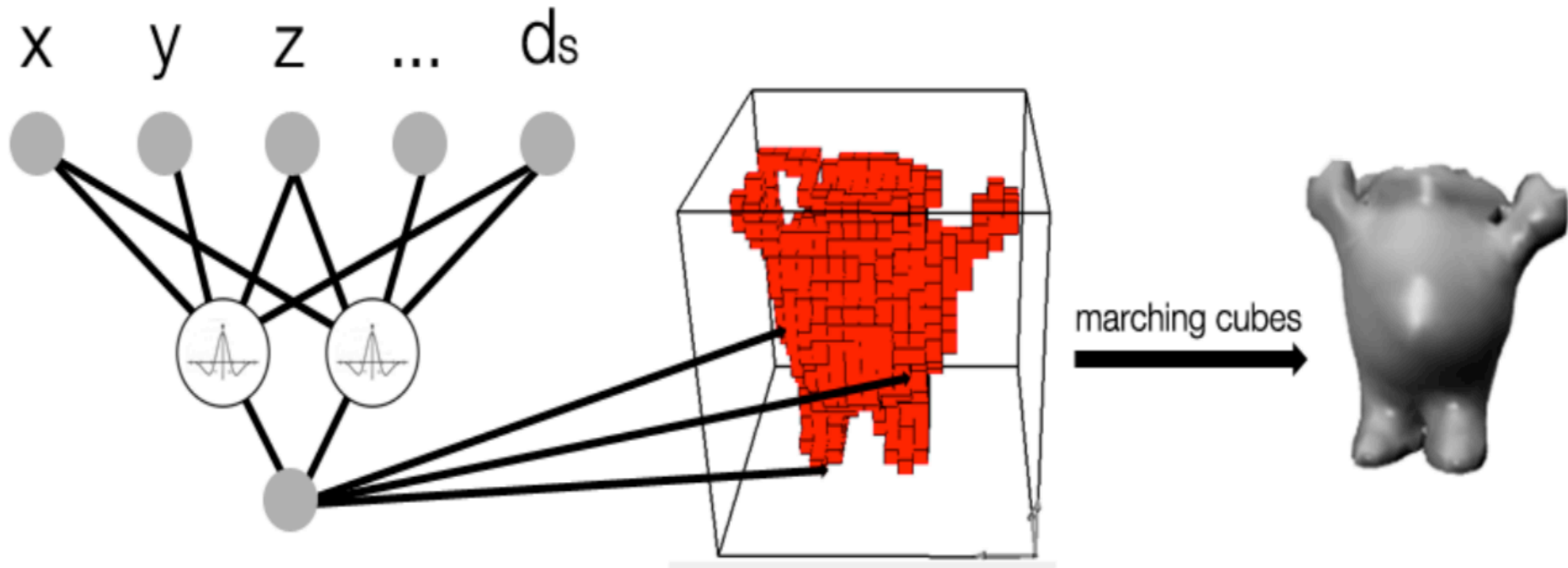




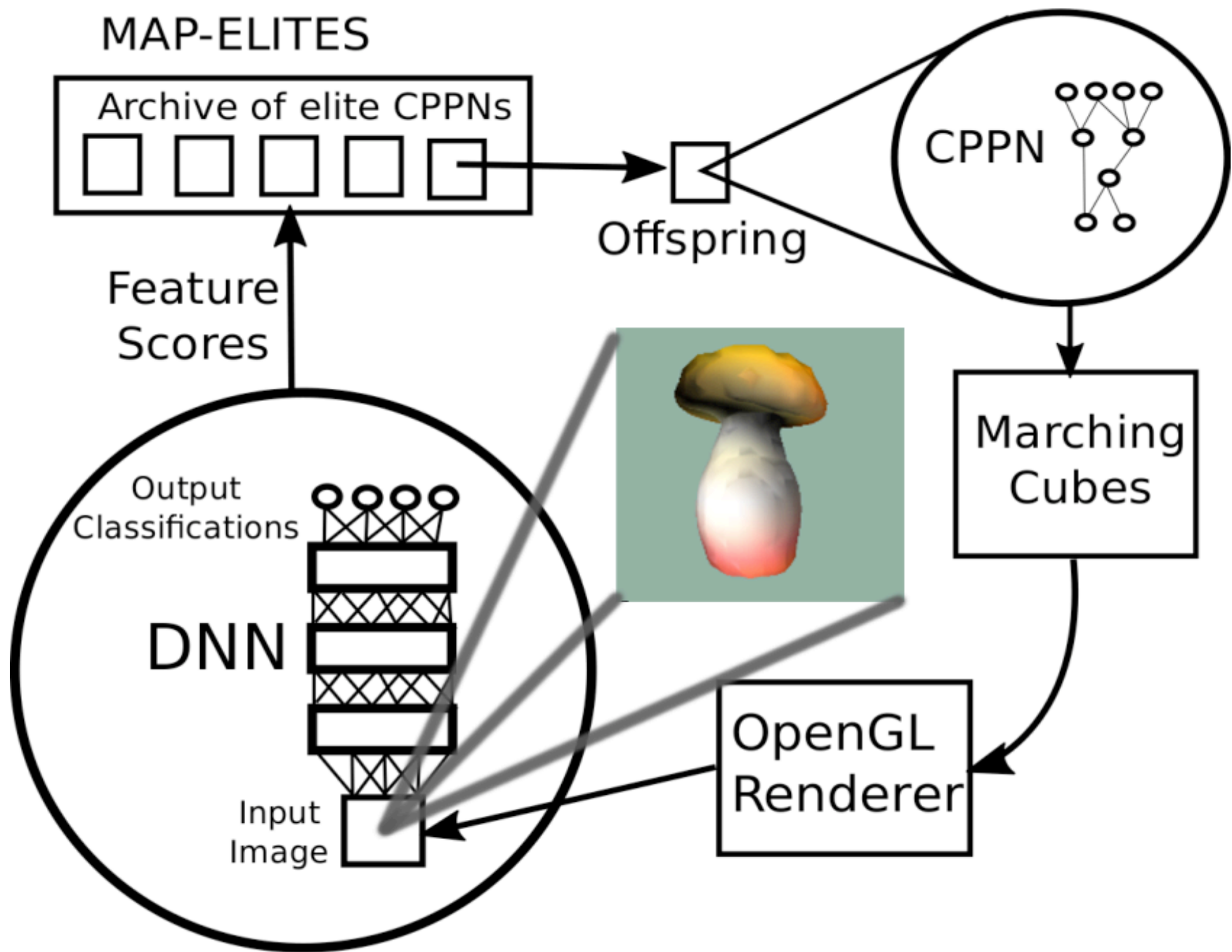
# What is actually going on?



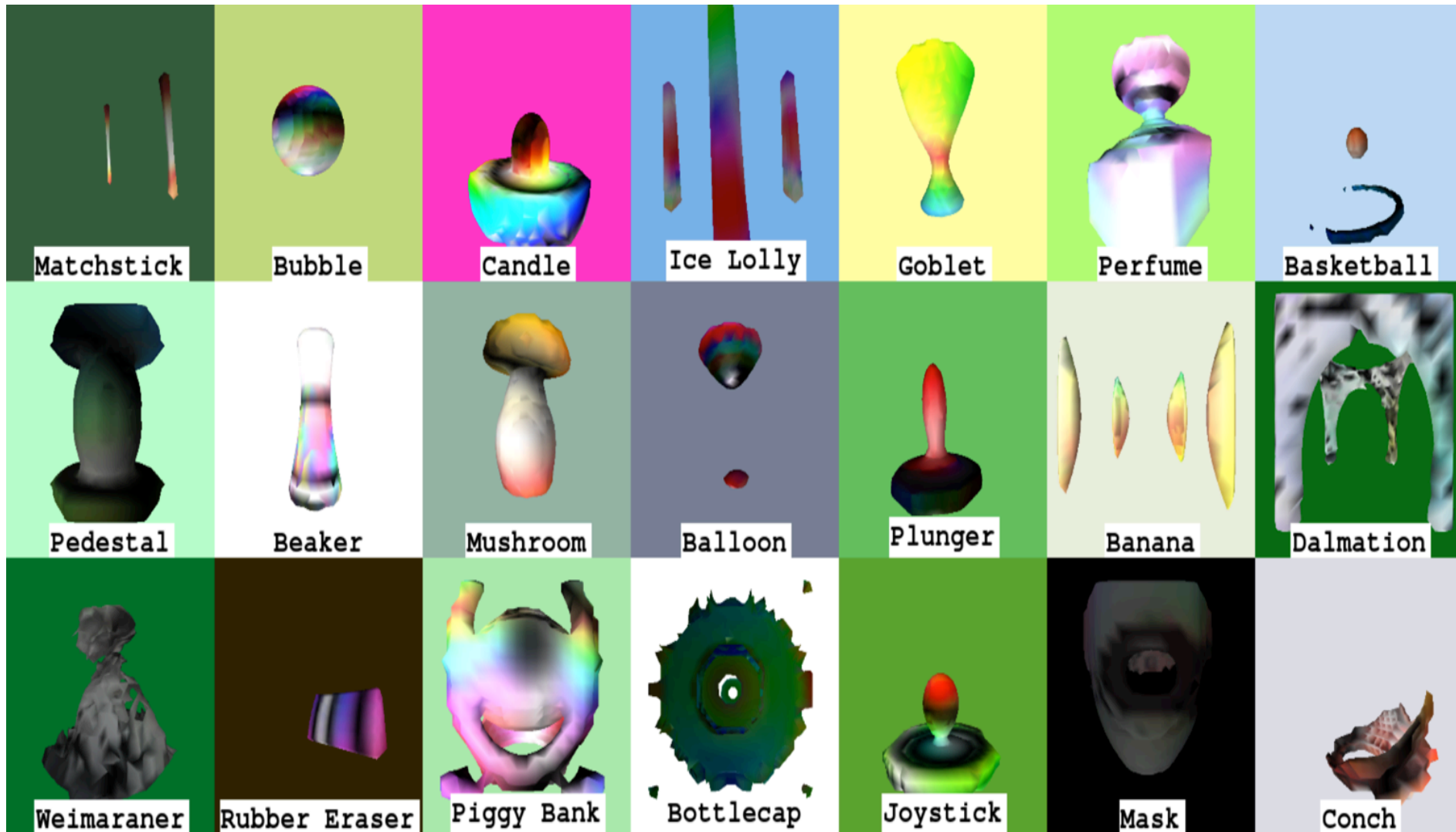
# Background: Endless Forms Genetic Encoding

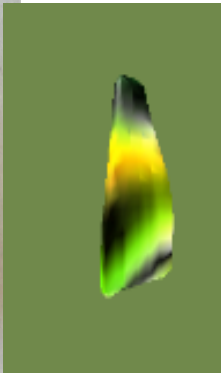
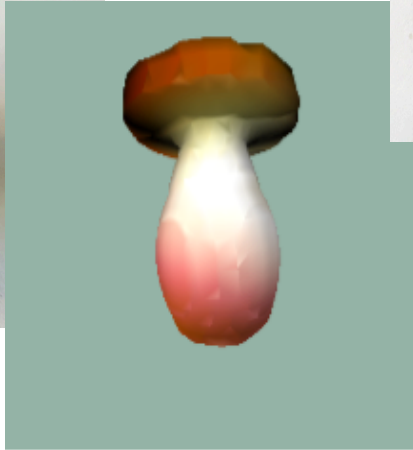


(Clune and Lipson 2011)



# Gallery

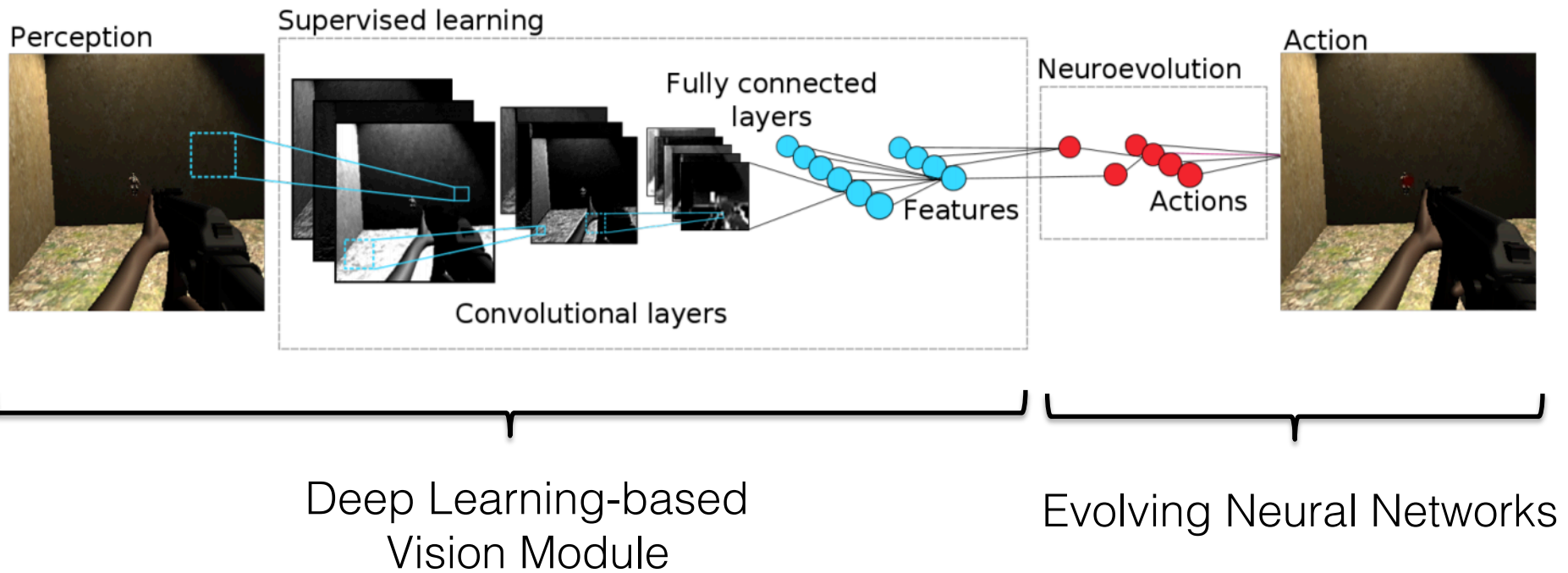




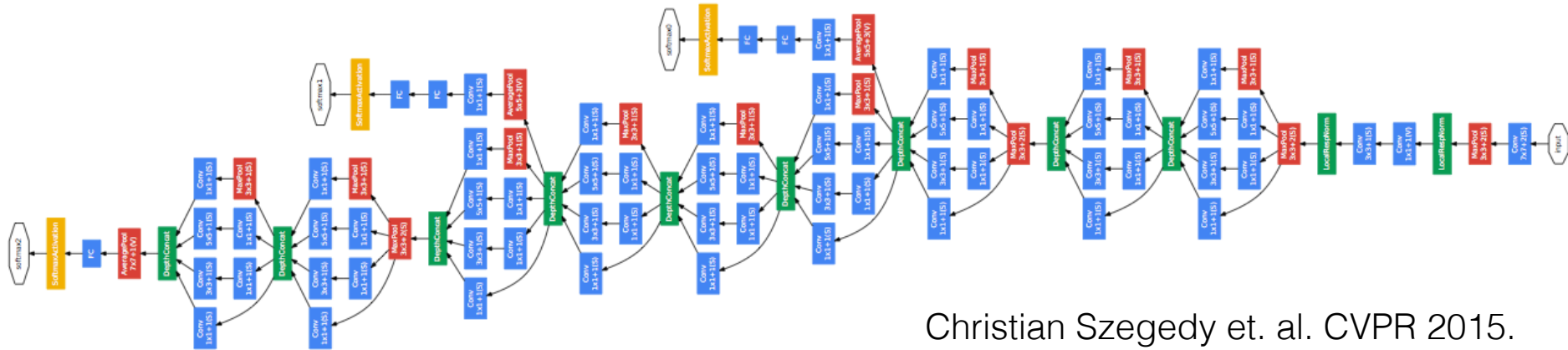
# General Video Game Playing



# Jumpstarting Artificial Evolution

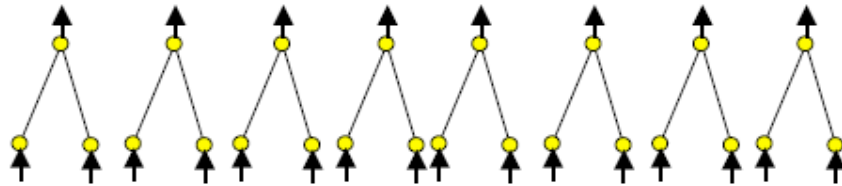


# Evolving Neural Architectures



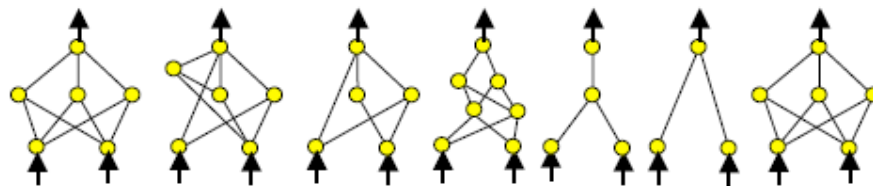
Christian Szegedy et. al. CVPR 2015.

## Minimal Starting Networks



Generations pass...

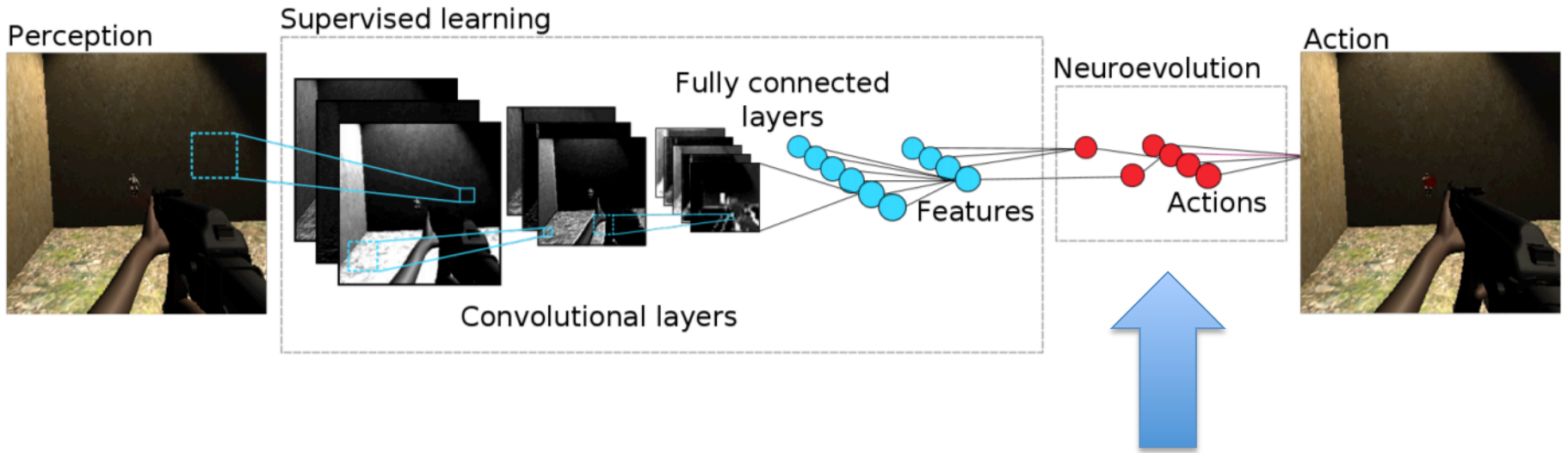
## Population of Diverse Topologies



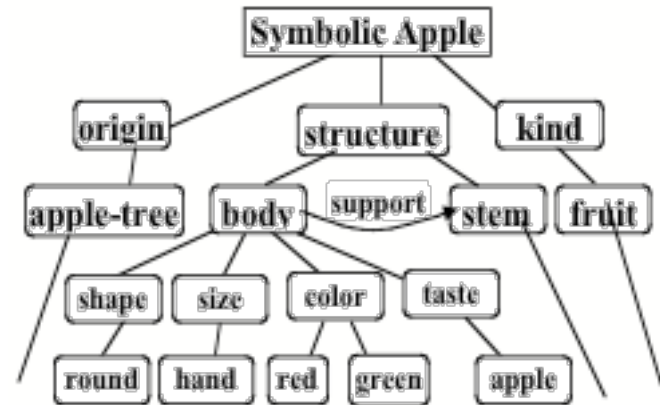
- E.g. Neuroevolution of Augmenting Topologies (NEAT; Stanley 2002)
- Networks and behavior get more complex
- Evolving Deep Neural Network Topologies might now be possible



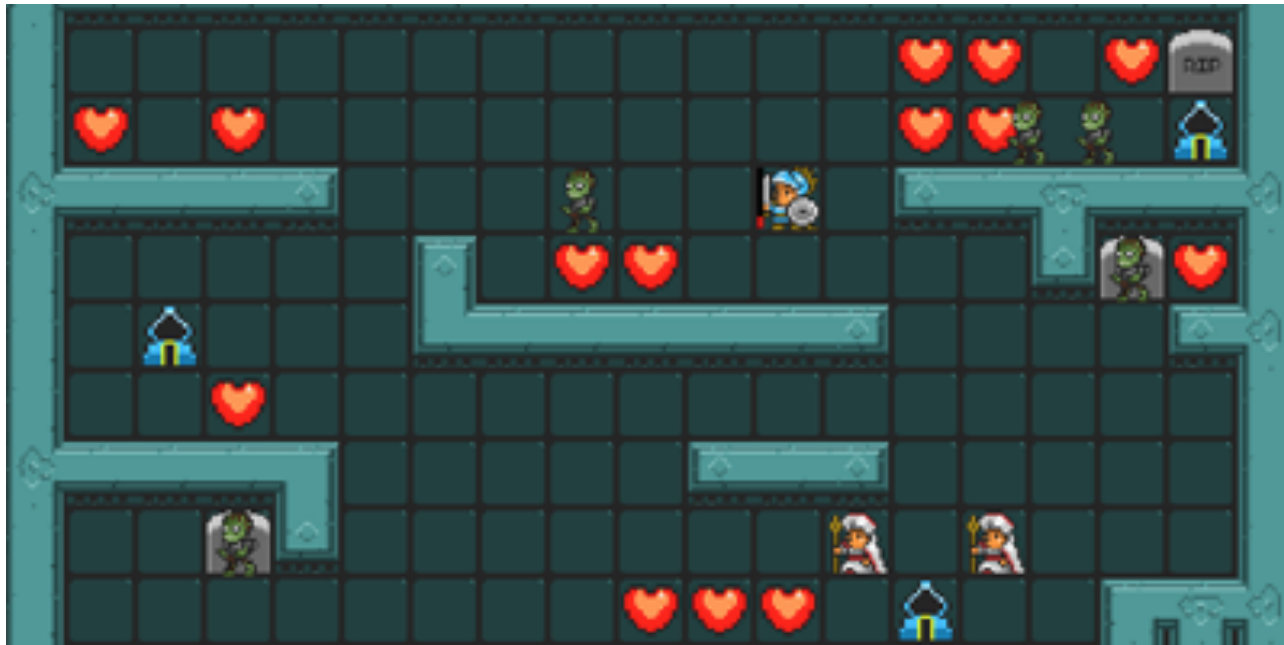
# Evolution as Interface Between Sub-symbolic and Symbolic AI



Symbolic AI (planning, etc.)



# General Video Game AI Competition: Learning Track 2017



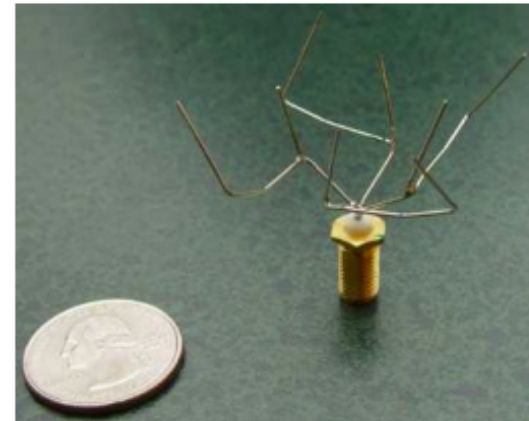
<http://www.gvgai.net/>

# Evolutionary Algorithm



# Deep Neural Net

- Away from pure optimization tasks
- Towards more creative AI  
(interesting instead of perfect solutions)
- Could facilitate collaborations between humans and machines



# Thank you for your attention! Questions?

## ARTIFICIAL INTELLIGENCE

### Additional Information

- My homepage: [www.sebastianrisi.com](http://www.sebastianrisi.com)
- Email: [sebr@itu.dk](mailto:sebr@itu.dk)
- Twitter: [@risi1979](https://twitter.com/risi1979)

# Backup Slides

# Results - Mutational Neighborhood



# Minecraft meets Artificial Evolution



<https://www.youtube.com/watch?v=6LHYHwQGdus>