



The Importance of Topology Evolution in NeuroEvolution: A Case Study using Cartesian Genetic Programming of Artificial Neural Networks

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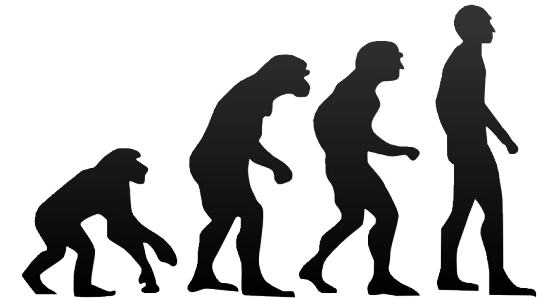
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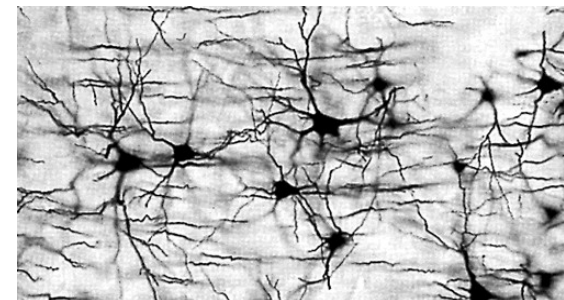


Application of Evolutionary Algorithms towards training Neural Networks

- Key Advantages
 - No restraint on activation functions
 - No restraint on topology
 - Can escape local optima
 - Applicable to reinforcement learning



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Two types of NeuroEvolution

- Weight Evolving - fixed topology
- Topology & Weight Evolving

- 1) Does the choice of topology impact on the effectiveness of weight only NeuroEvolution?
- 2) Is evolving topology beneficial for neuroEvolution?

- **Conventional NeuroEvolution**

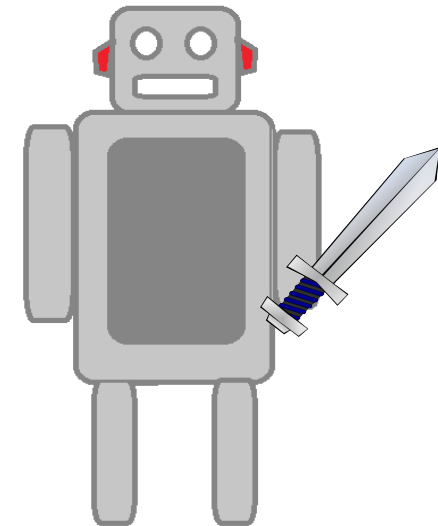
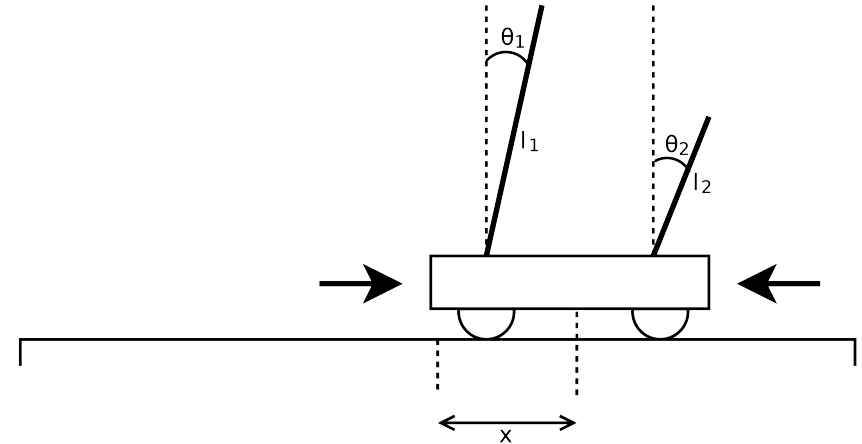
- CNE
- Simplest and oldest (1990's)
- Evolves connection weights
- Fixed user defined topology

- **Cartesian Genetic Programming Artificial Neural Networks**

- CGPANN
- Based on Cartesian Genetic Programming
- Evolves connection weights
- Evolves topology
- Feed-forward & recurrent
- Evolves neuron transfer functions functions



- Double Pole balancing
 - Control task
 - Reinforcement learning
- Monks Problem 1
 - Classification task
 - Supervised learning

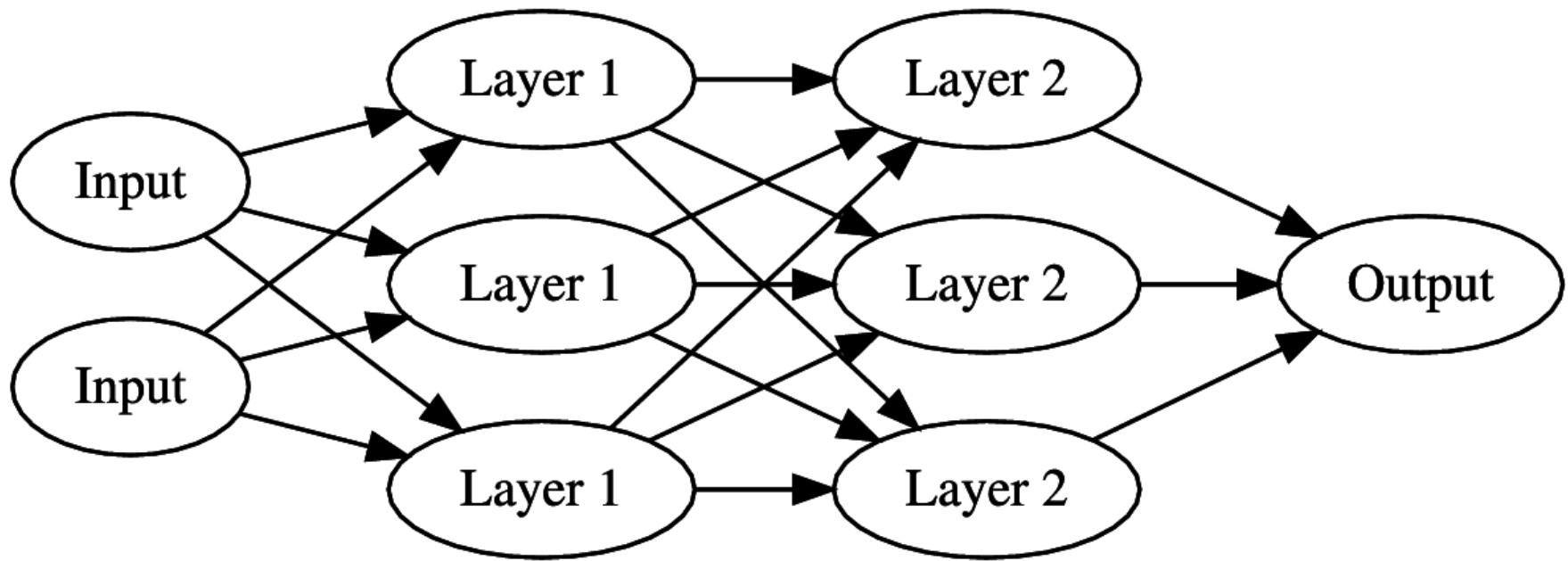


Does the choice of topology impact on the effectiveness of weight only NeuroEvolution?

- Using Conventional NeuroEvolution
- Sweep a range of topologies
 - Number of hidden layers (0->19)
 - Number of neurons per hidden layer (1->20)
 - That's 400 separate topologies!
- Compare the fitnesses achieved for each topology
 - After 5000 generations (Avg 50)



Layers and Nodes per Layer

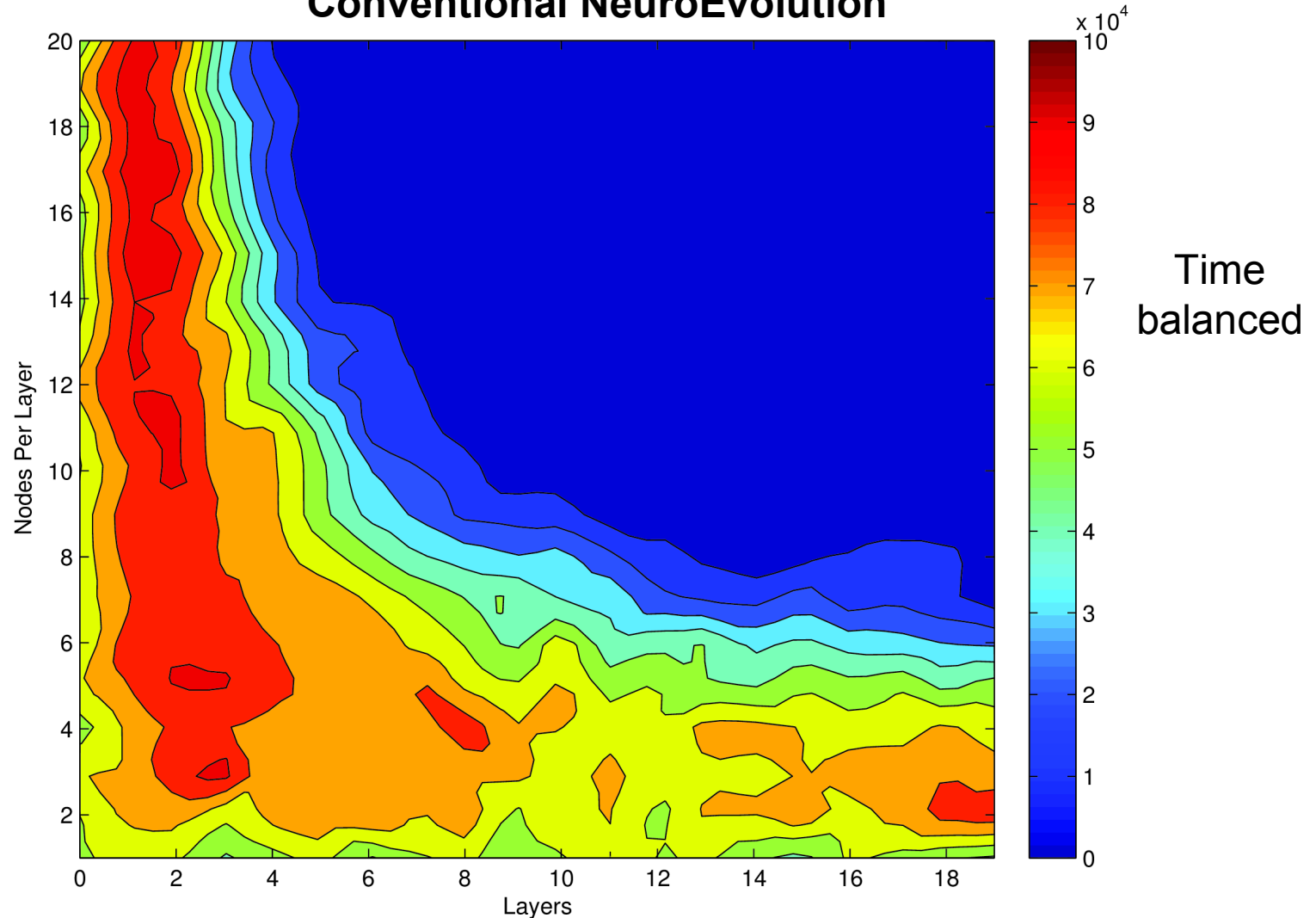


2 x hidden layers
3 x nodes per layer
Fully Connected between layers



Experiment 1 - Double Pole

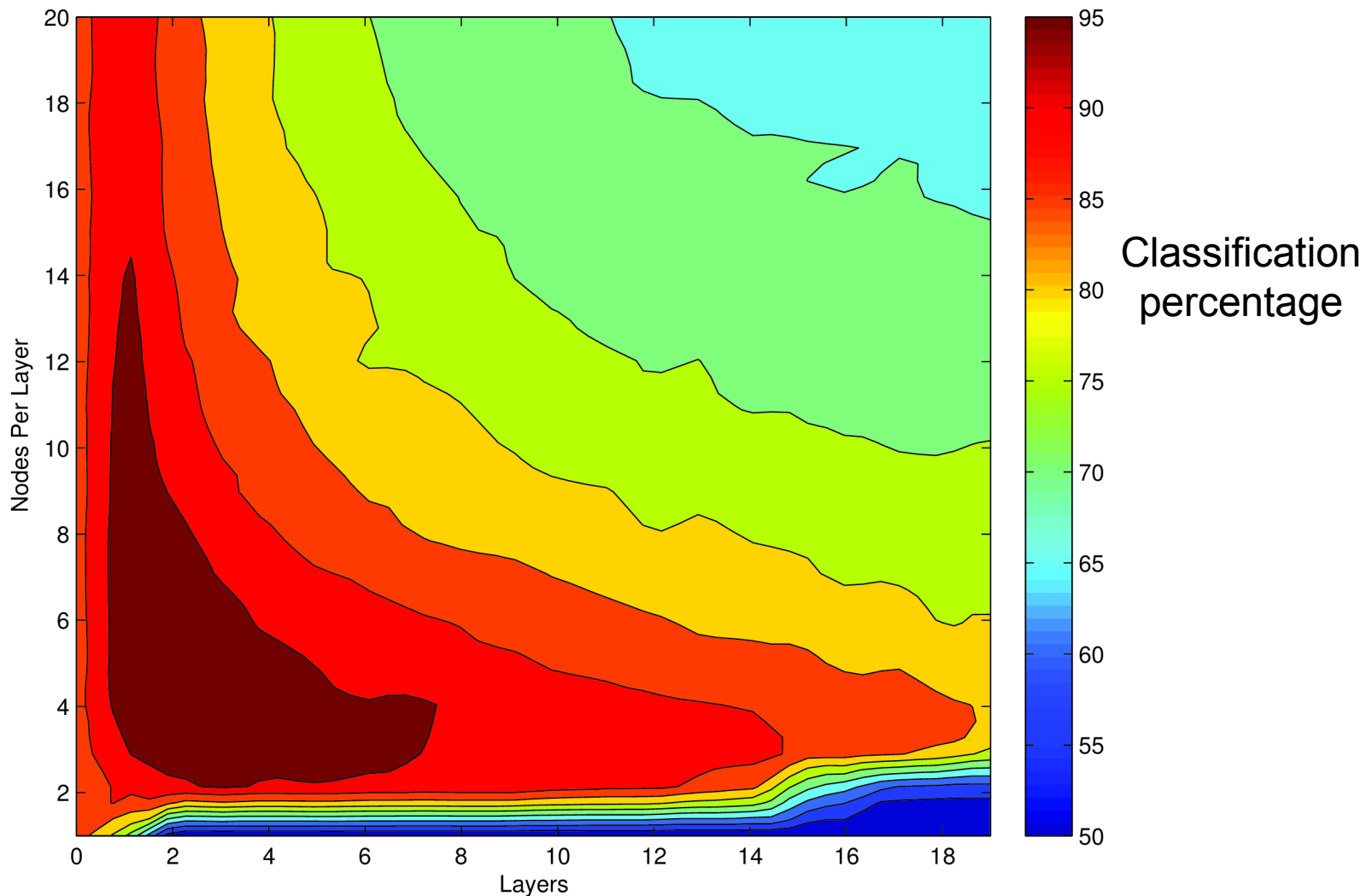
Conventional NeuroEvolution





Experiment 1 - Monks Problem

Conventional NeuroEvolution



- Topology does influence the effectiveness of weight only NeuroEvolution.
- And as subtitle topologies are often not known in advance of training, this is a disadvantage.
 - And one shared with other non topology optimising training methods.

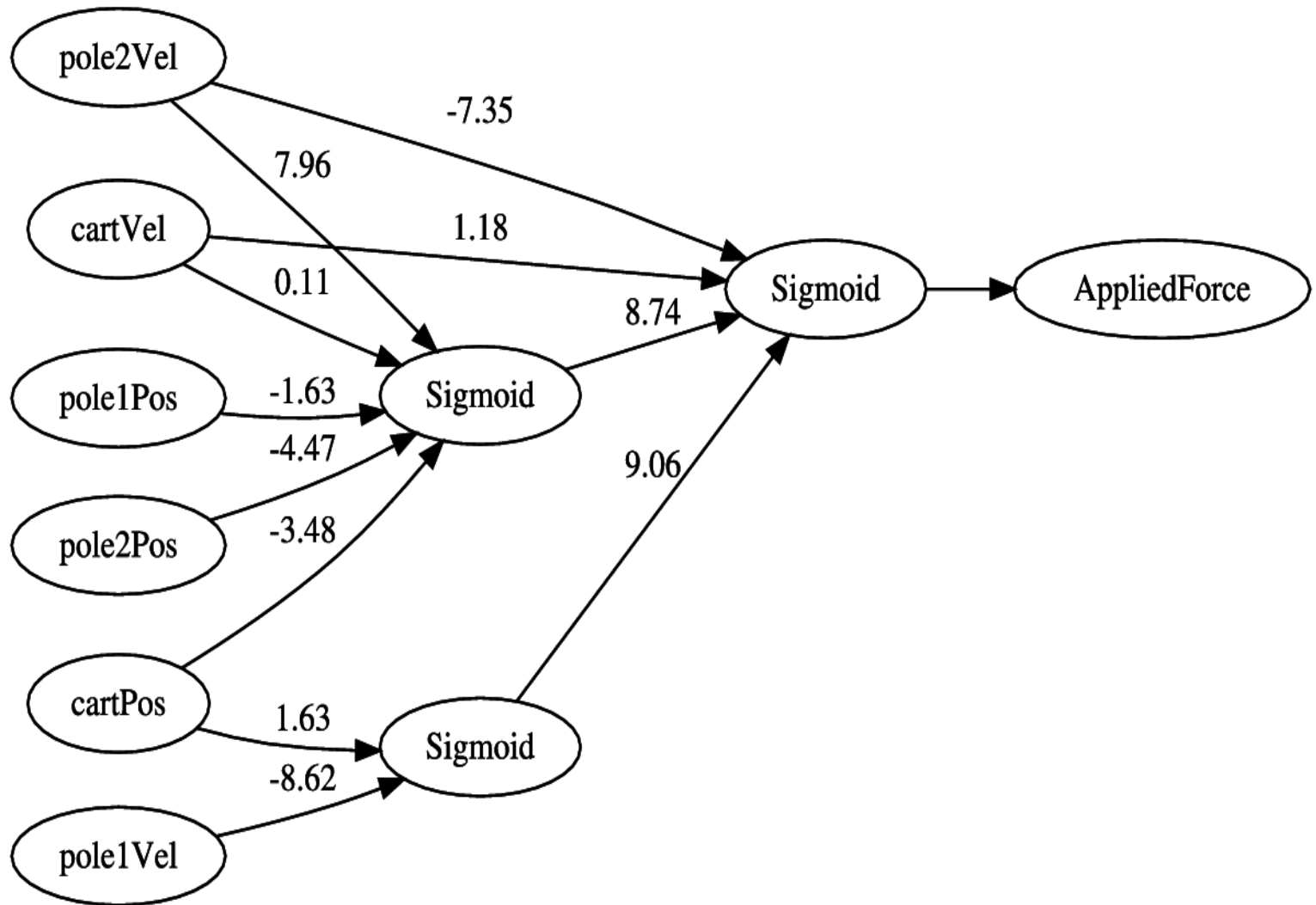
Is evolving topology beneficial for neuroEvolution?

- Compare:
 - Only evolving weights of fixed random topologies
 - Only evolving topologies with fixed random weights
 - Evolving both weights and topologies

- Achieved using CGPANN
 - Can evolve only connection weights
 - Can evolve only network topology
 - Can evolve both connection weights and topology

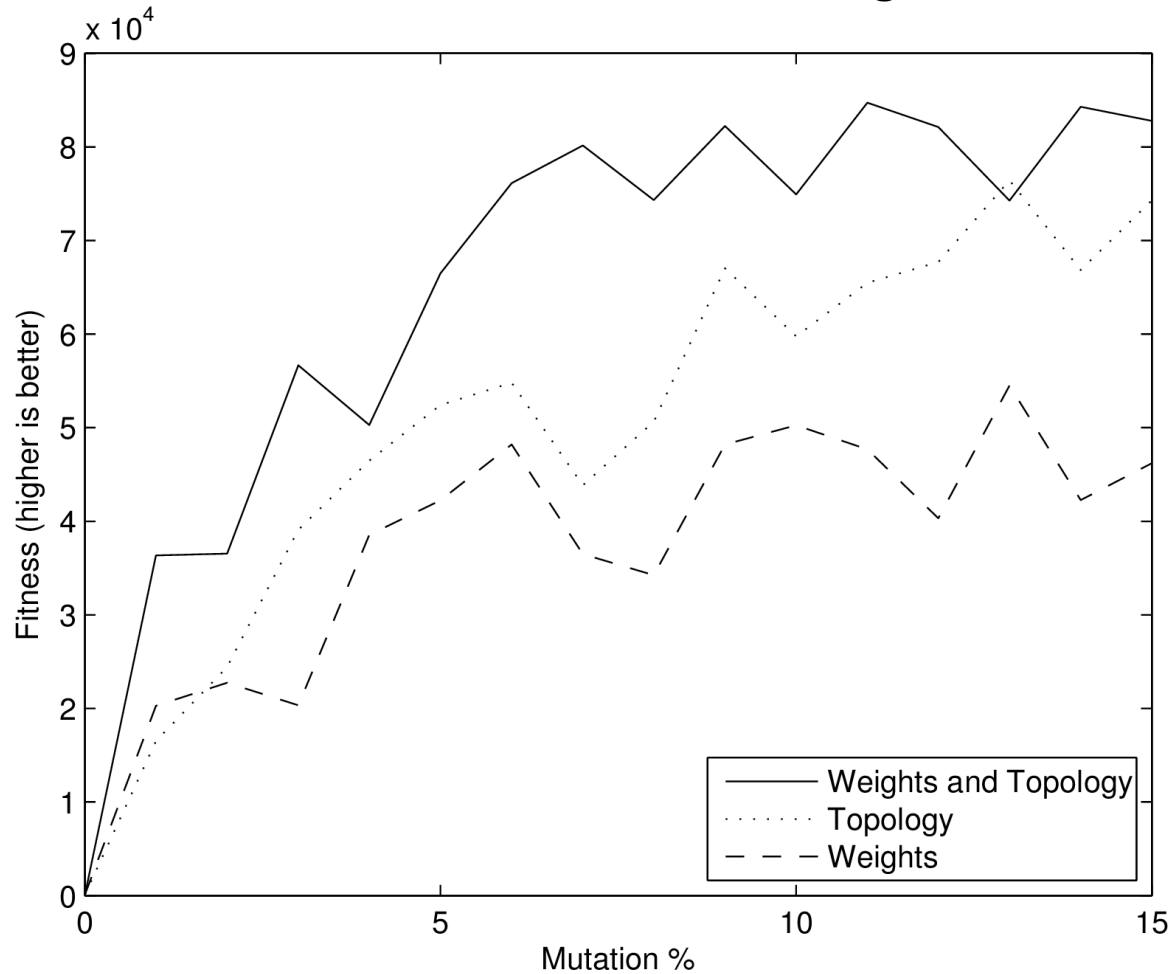


Network created using CGPANN



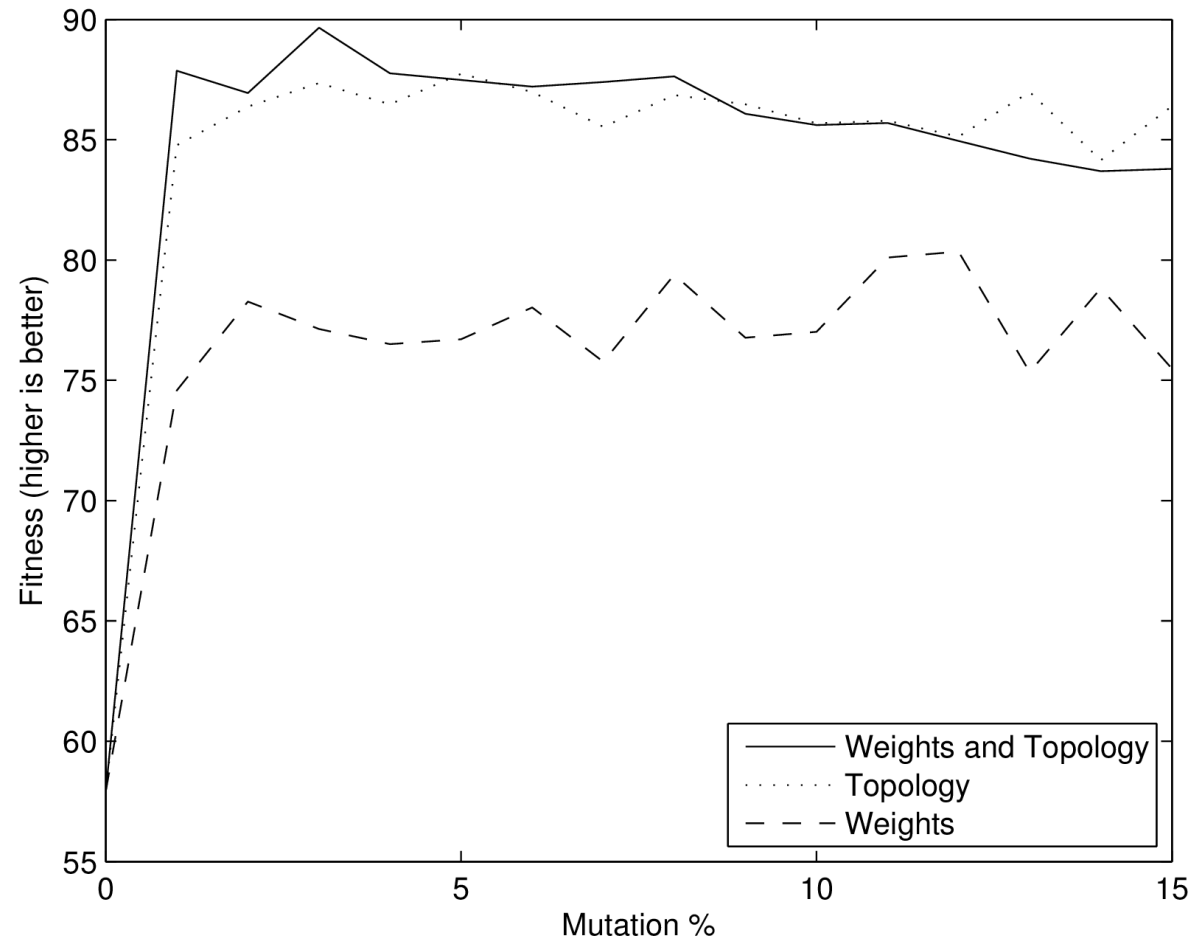
Experiment 2 – Double Pole

Double Pole Balancing



Experiment 2 – Monks Problem

Monks Problem



Method 1	Method 2	Best	Statistically Significant
Weights & Topology	Weights alone	Weights & Topology	Yes
Weights & Topology	Topology alone	Weights & Topology	No
Topology alone	Weights alone	Topology alone	Yes

- Evolving weights & topology is statistically significantly better than evolving weights alone.
- Evolving topology alone is statically significantly better than evolving weights alone! - surprising!

Statistically significant: U-test $p < 0.05$ & effect size > 0.64 (medium)



1) Does the choice of topology impact on the effectiveness of weight only NeuroEvolution?

Yes - Massively!

2) Is evolving topology beneficial for neuroEvolution?

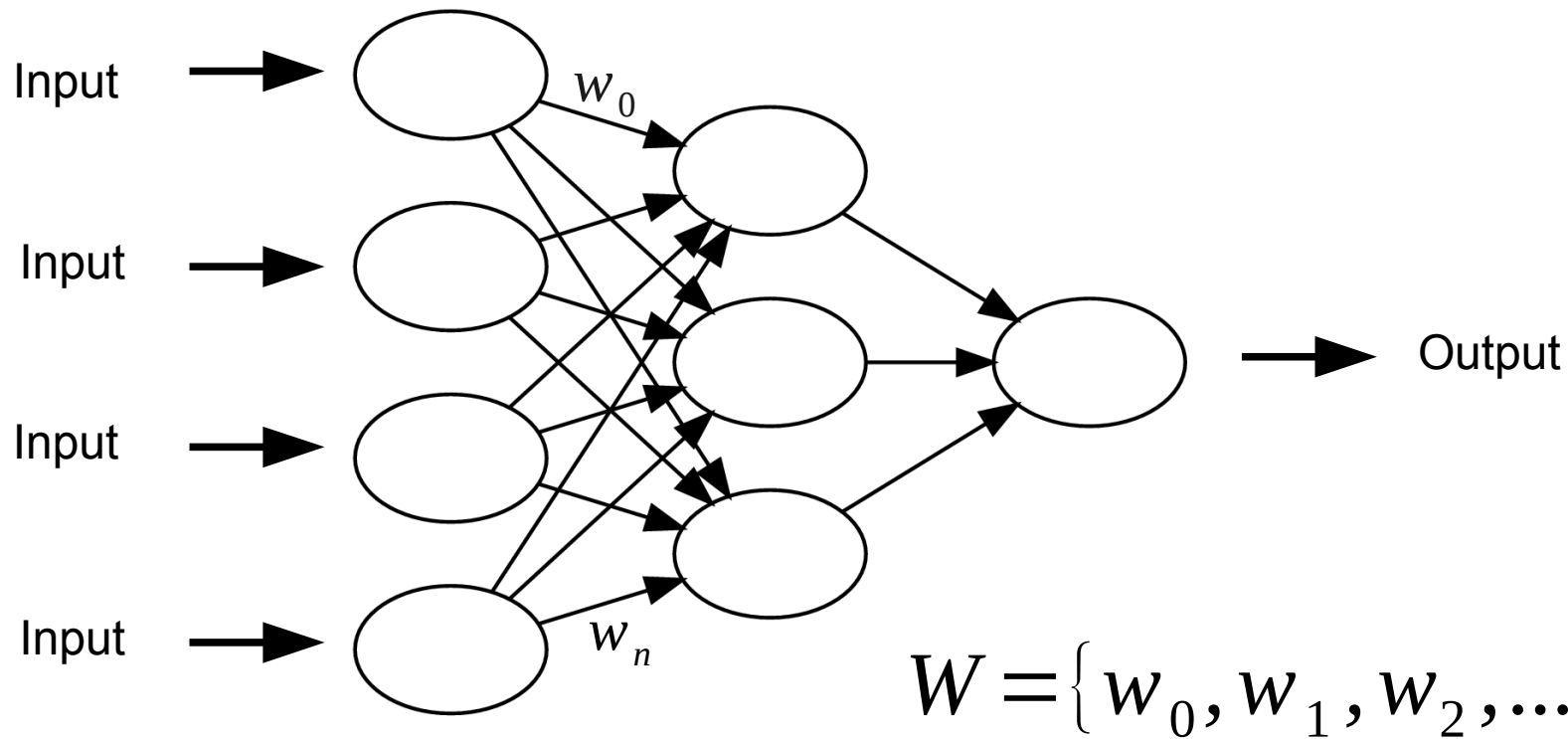
Yes – possibly even more so than weights!



Questions?



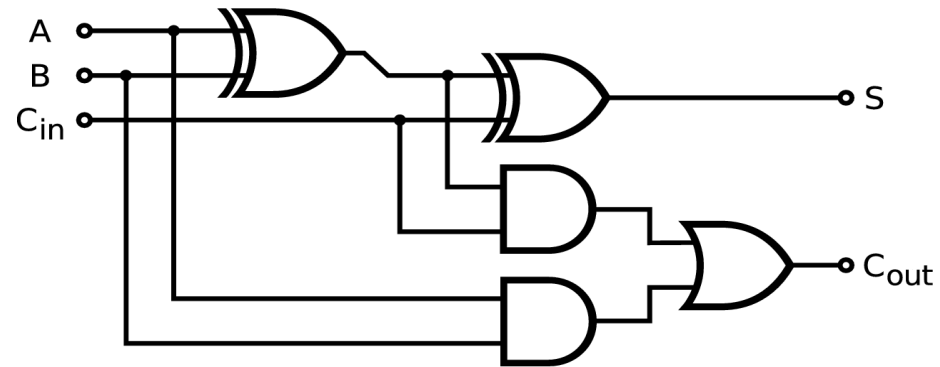
- Simplest and oldest (1990's)
- Only Evolves Connection Weights





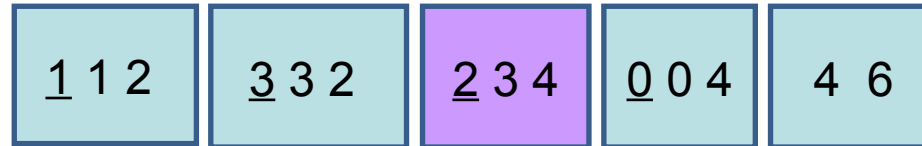
Key Point

- Form of genetic programming
- Uses generic cyclic or acyclic graph structure
- Suited to any data type: ints, floats, images, videos ...
- Can use any node function: XOR, sigmoidal, $\sin(x)$...
- Inbuilt neutrality enabling neutral genetic drift
- Typically uses a (1+4)-ES
- Mutation only (no crossover)
- Not just for circuits

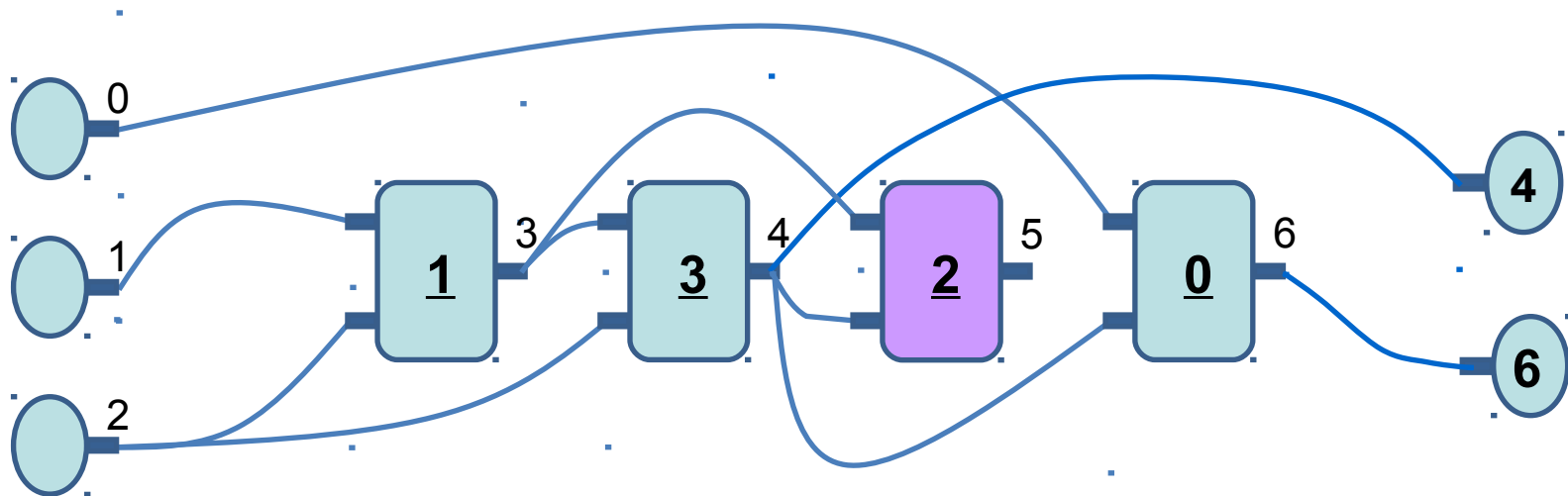


Cartesian Genetic Programming

Genotype



Phenotype



- Based on Cartesian Genetic Programming (CGP)
 - With the addition of connection weight genes
- Features
 - Evolves connection weights
 - Evolves the number of neurons
 - Evolves the topology
 - Evolves the arity of each neuron