CIENCIAS DE LA COMPUTACIÓN
UNIVERSIDAD DE CHILE

Neuroevolution

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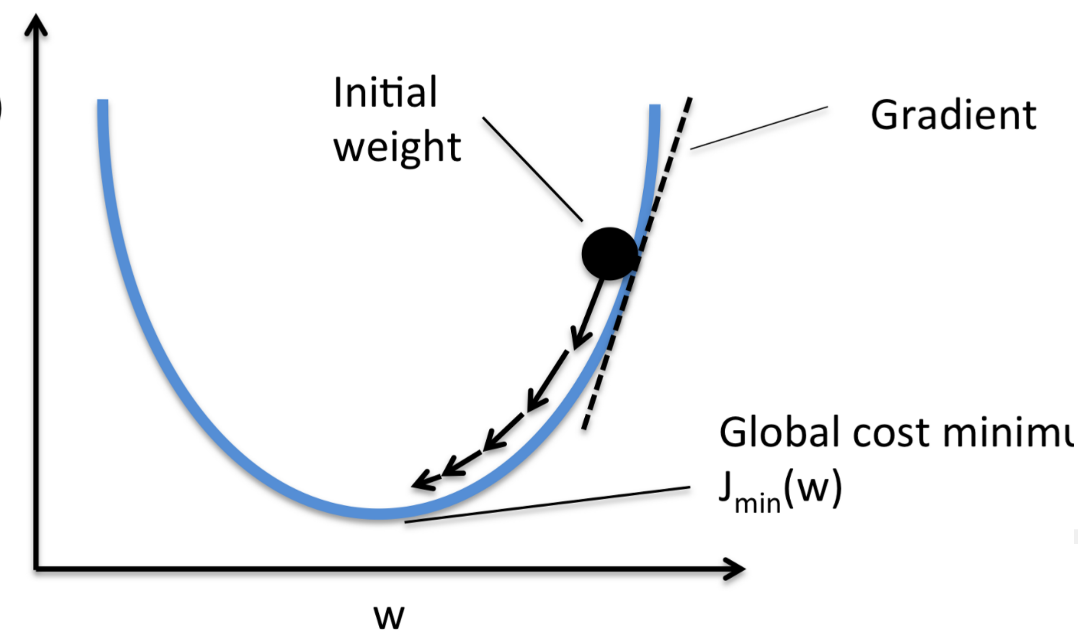
= Neuroevolution

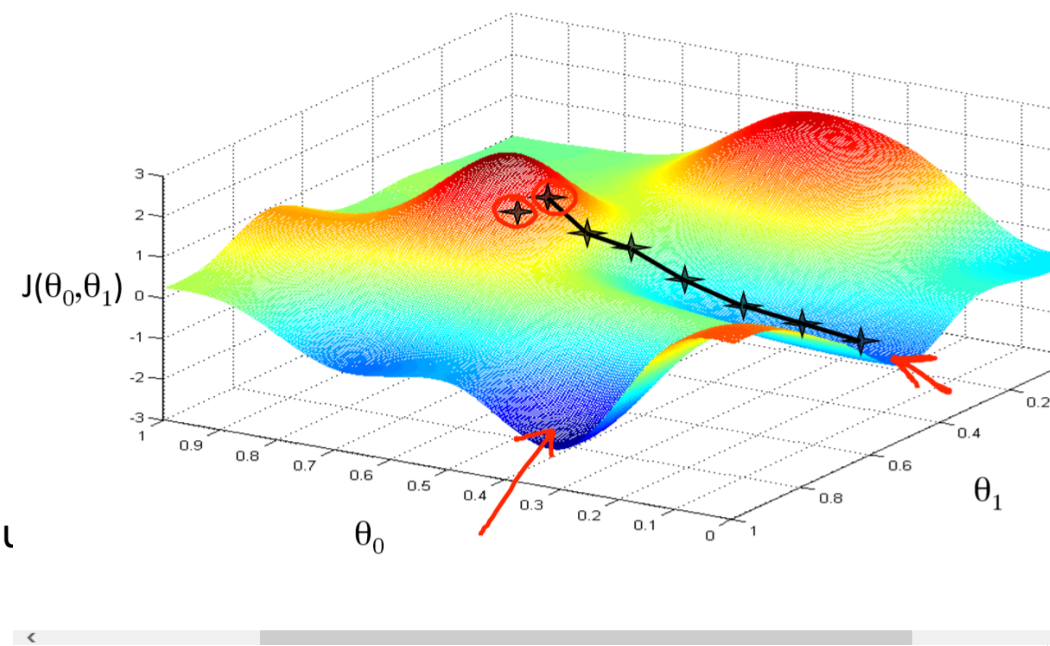
Goal of today

Overview of neuroevolution, a combination of *deep learning* and *genetic algorithm*

Gradient decent

Gradient descent is commonly used to make a neural network "learn"





Gradient descent requires examples

Examples are required to train a neural network

Picture recognition *may require thousands* of pictures

Requiring a large number of training examples may be *problematic*

e.g., video games, self-driving cars

Generalization

How do we get from where we are to *artificial general intelligence?*

How to make the learning process *closer to how human learn*?

https://www.nature.com/articles/s42256-018-0006-z

Neuroevolution

"Neuroevolution is a form of artificial intelligence that *uses evolutionary algorithms* to generate *artificial neural networks*, parameters, topology and rules. It is most commonly applied in artificial life, general game playing and evolutionary robotics."

— Wikipedia

"The evolution of neural networks is called neuroevolution"
— Hannah Le

Idea of Neuroevolution

Supervised learning algorithms require correct input-output pairs

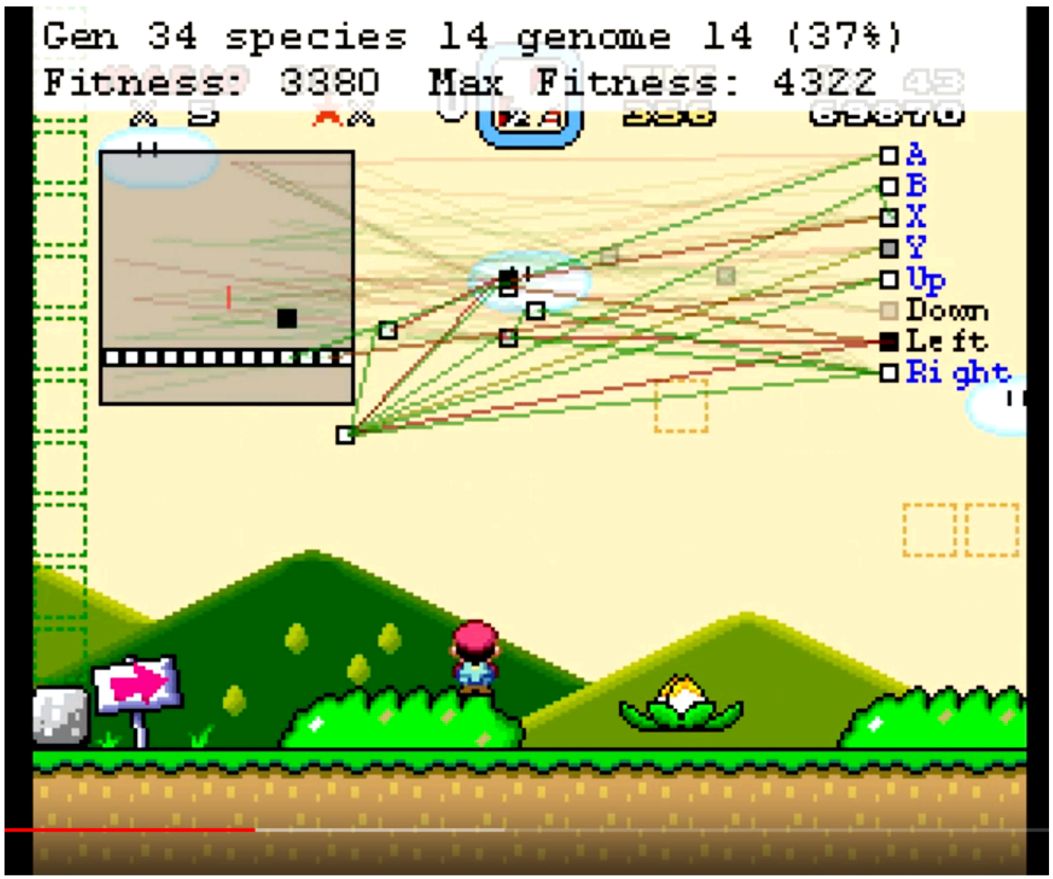
Neuroevolution only *requires a measure of a network's performance*

A major inspiration for the investigation of neuroevolution is the *evolution of brains* in nature

Examples of neuroevolution

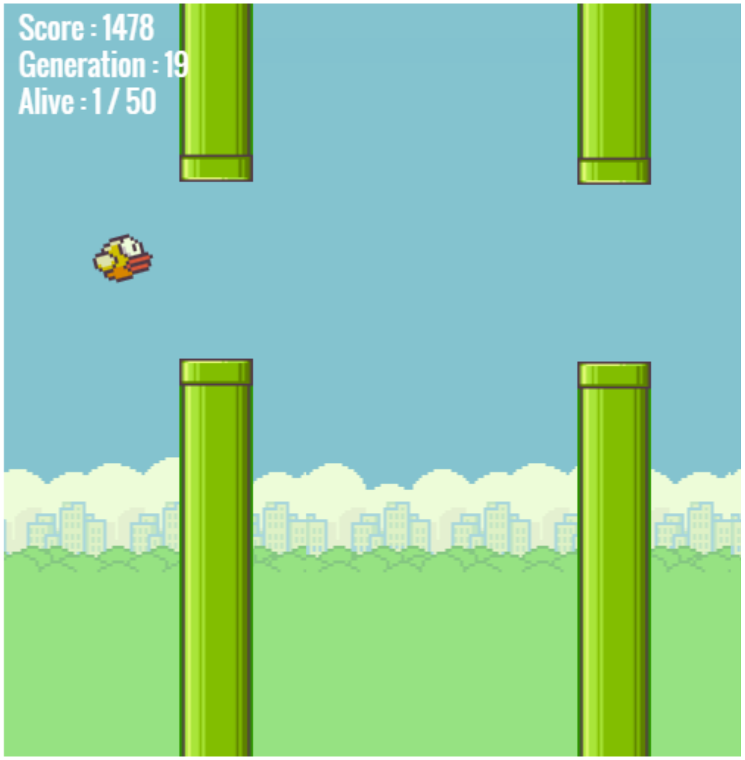
MarIO

https://www.youtube.com/watch?v=qv6UVOQ0F44



Flappy Bird

https://github.com/xviniette/FlappyLearning



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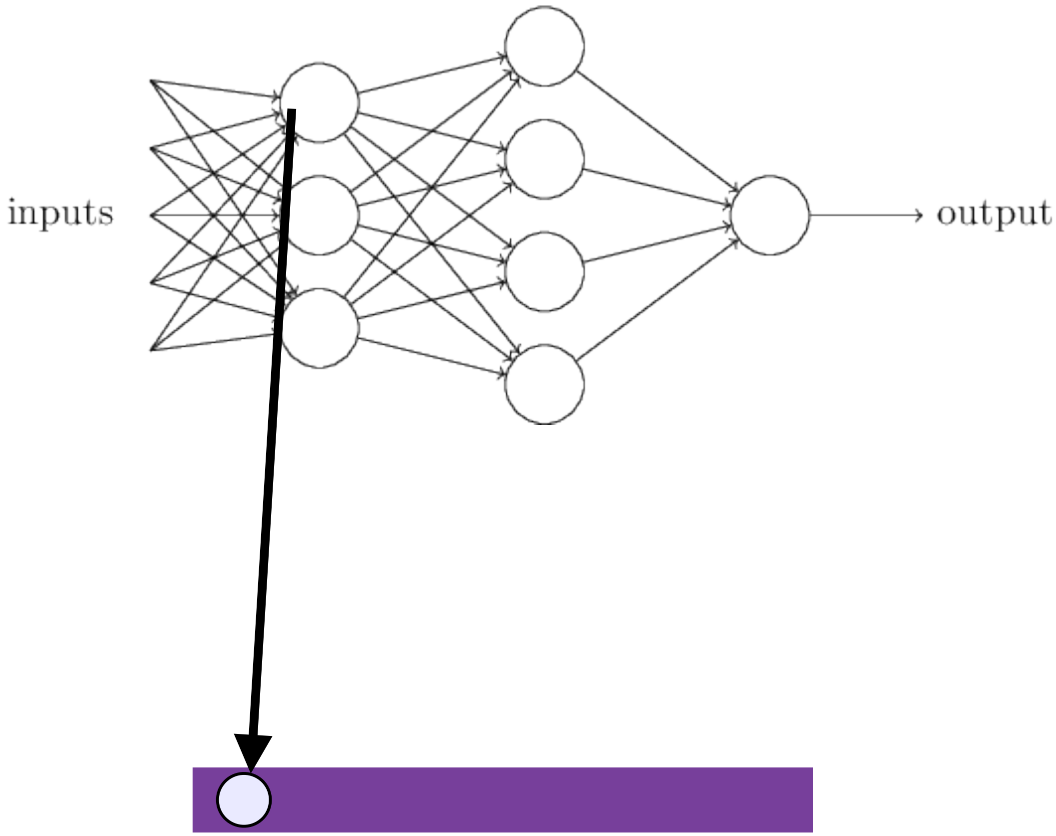
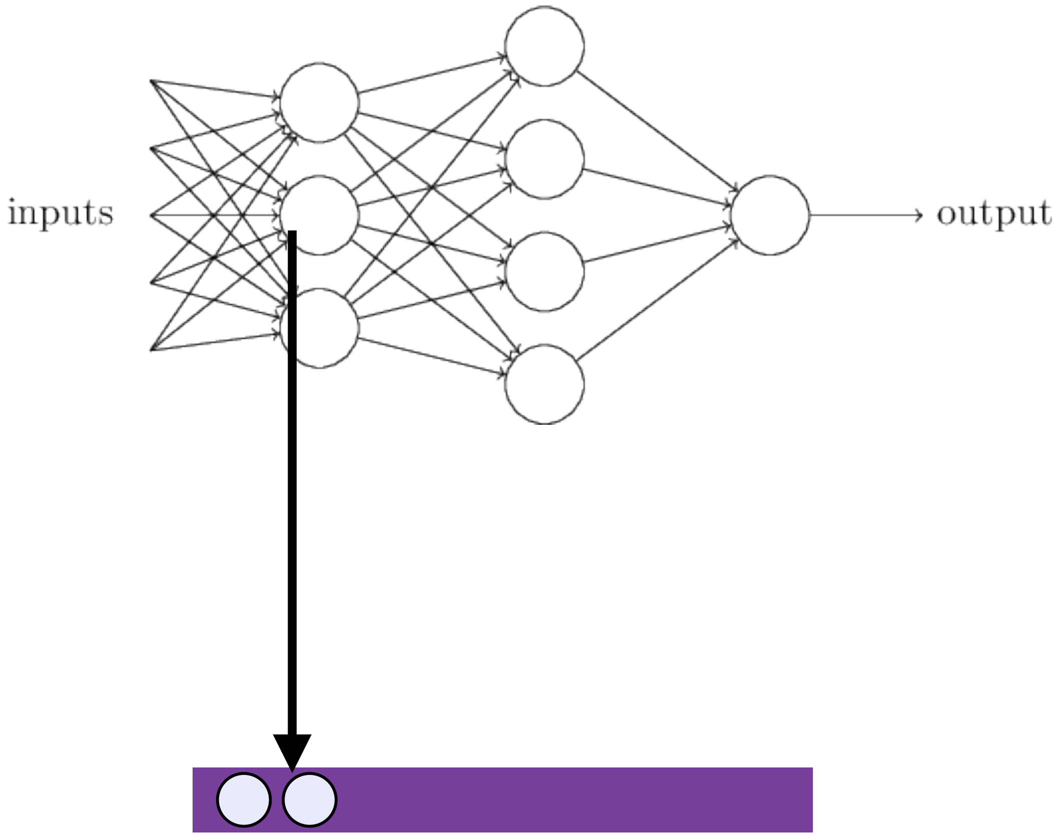
A simple algorithm for neuroevolution

Simple Algorithm

Use Genetic Algorithm to *search for the weights and bias* of each neuron

The fitness function to optimize could be based on the error function (e.g., MSE loss)


inputs
output


inputs
output

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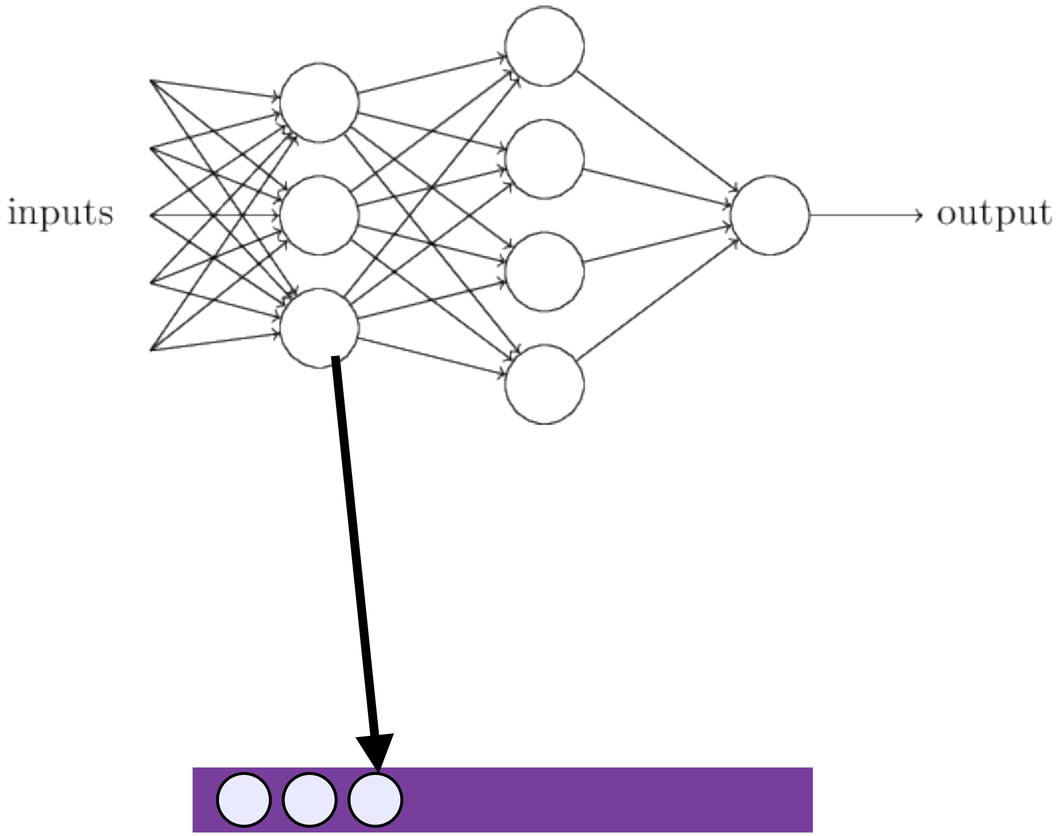
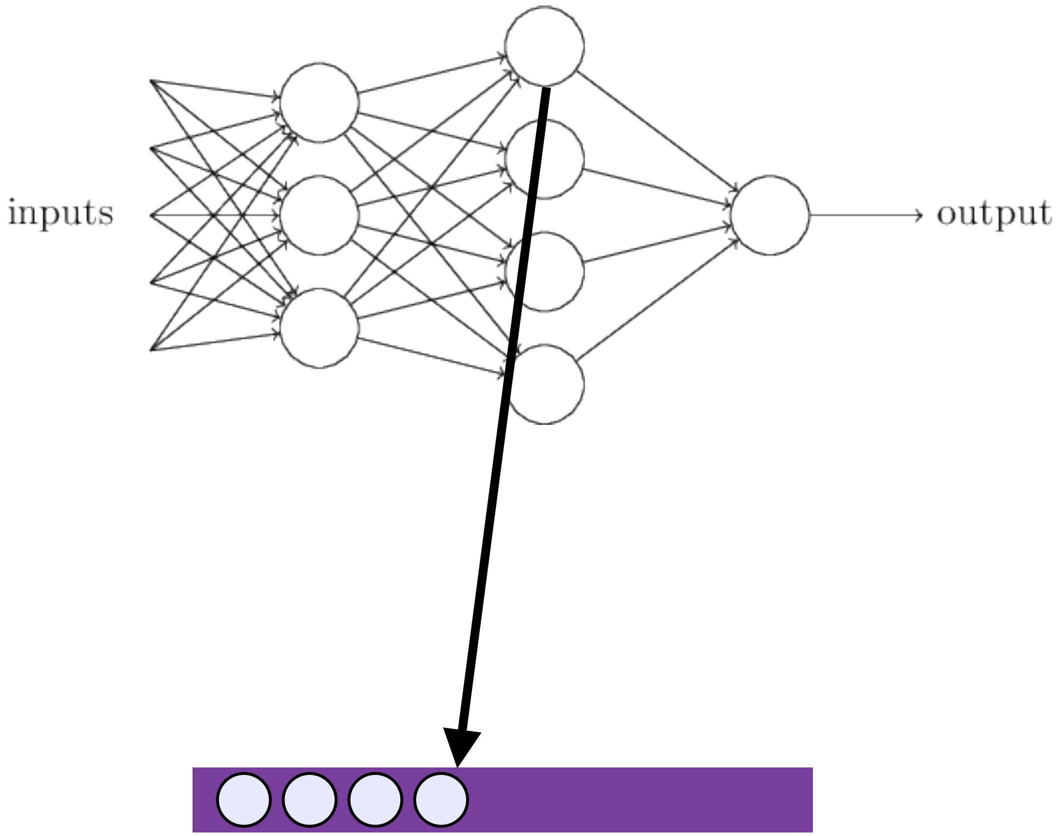
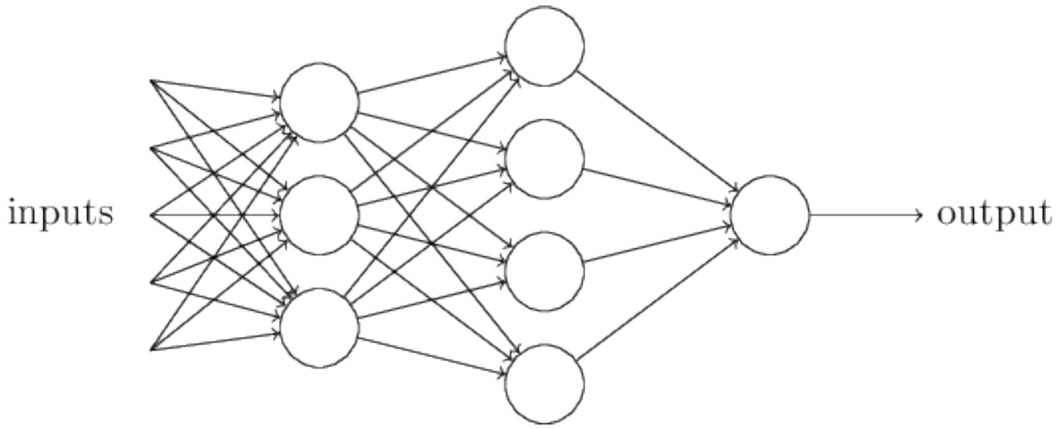
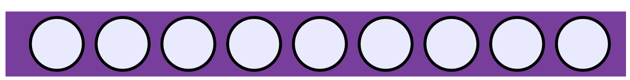
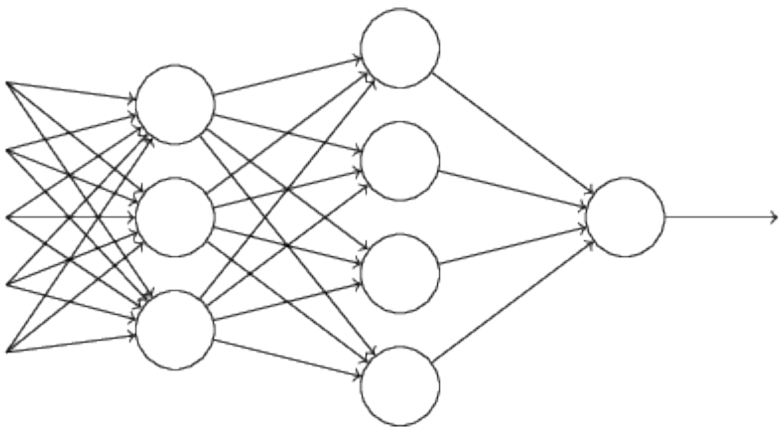
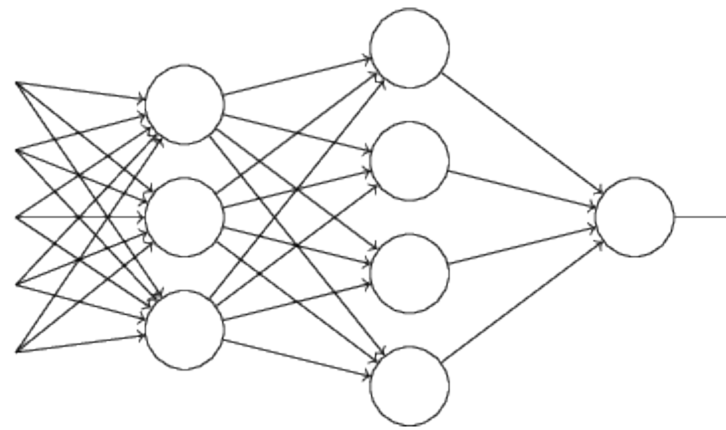


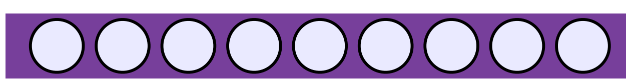

inputs
output

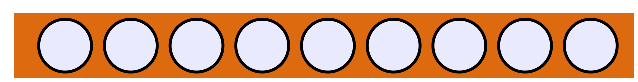

inputs
output

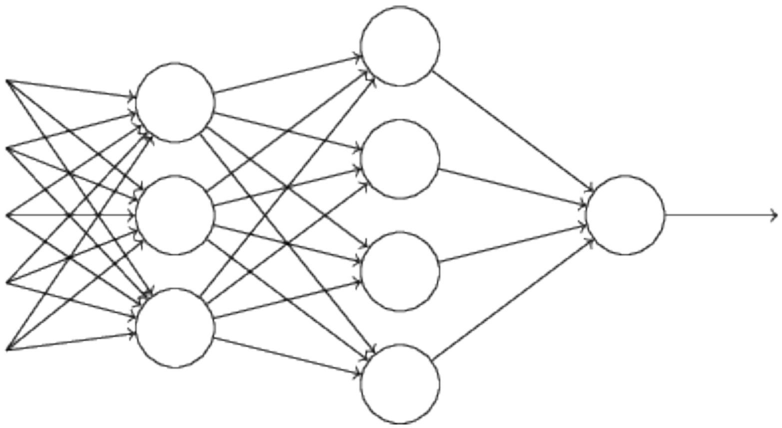


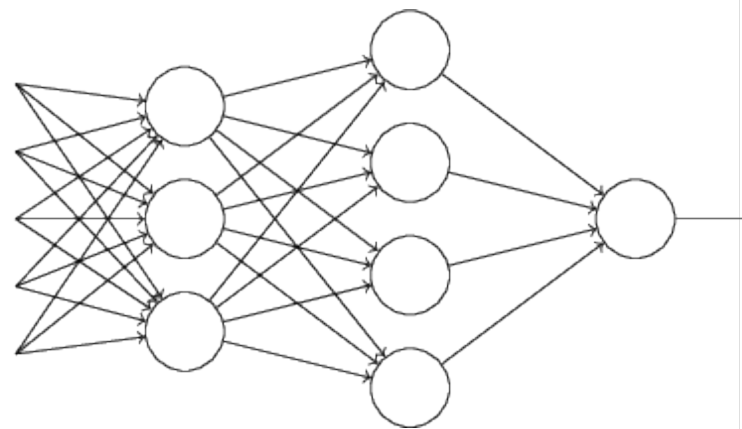


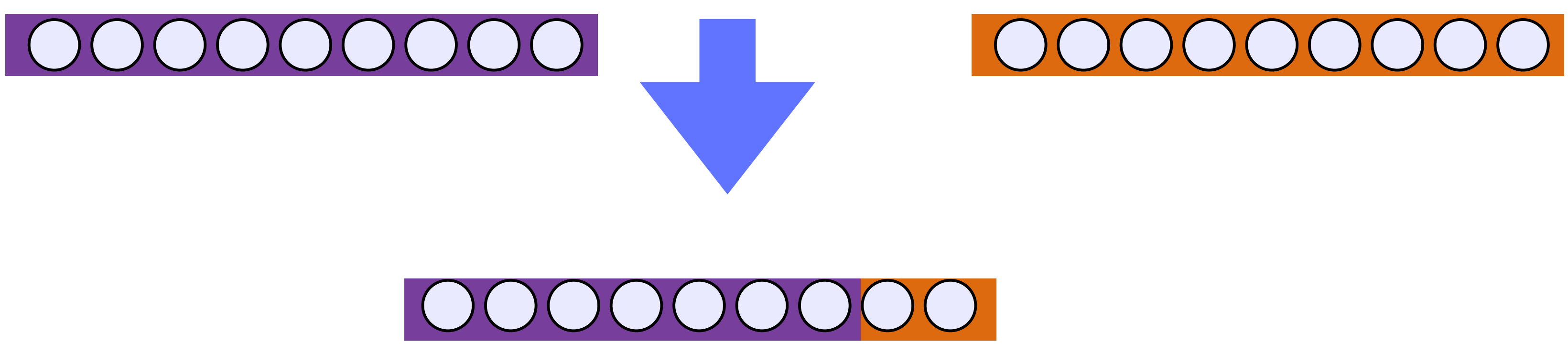


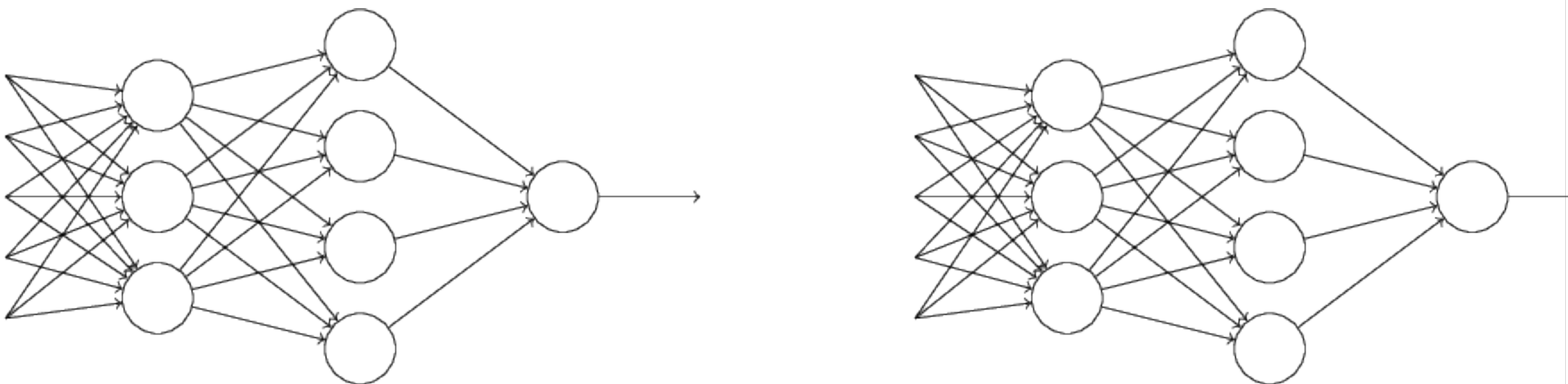




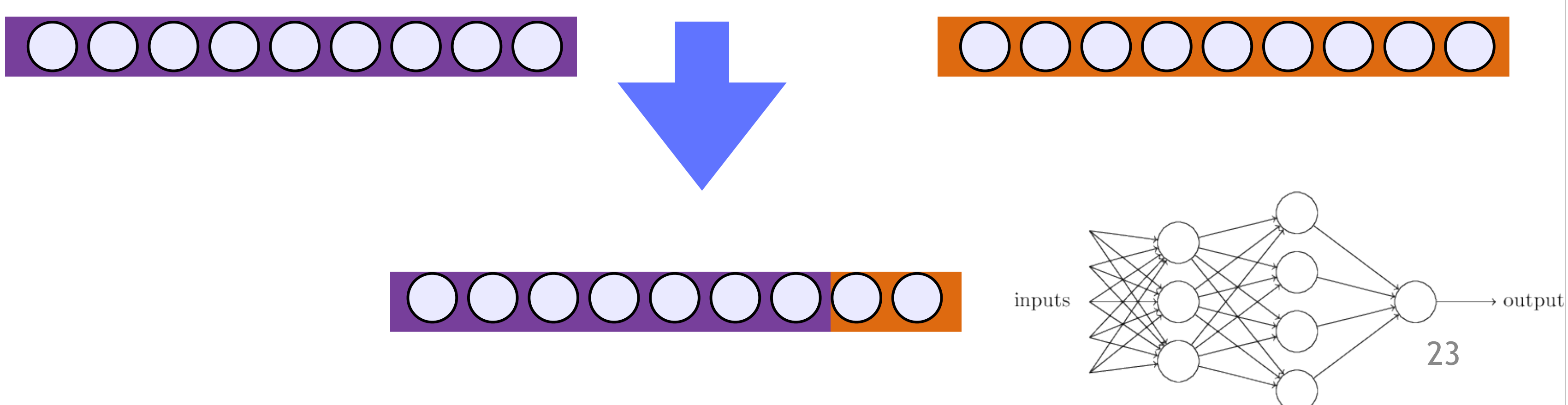








New neural network
With a better accuracy



Genetic operations

Applying genetic algorithm to find weights and bias of a neural network involves *particular genetic operations*

The cross-over operations *must consider the neuron* as a whole

ie. Crossover *should not divide the genetic information obtained from a neuron*

Cross-over happens only at a limit of a neuron

Because of the *competing convention* we will later see

Variant of crossover

We have originally presented GA with two genetic operations

In fact, we can run GA *with more operations*

You can also have an additional *second cross-over operations* that crosscut only at the limit of a layer

Cross-over happens at the *junction* of a layer

Genetically modified neural network

Neuroevolution is convenient when training data is either missing, insufficient, or unusable (eg bad quality, imbalanced)

The small algorithm we have just seen is *effective in many situations*

- Iris or seed data set
- AI for a simple game (e.g., Flappy bird)

What about network architecture?

This simple algorithm finds weights and bias while maintaining *a fixed network structure*

Structure of the network and some of its parameters can also be *discovered*

The idea of searching for a network architecture is to look for *simple and minimal networks*

Actually, fully-connected forward networks are pretty far away from what nature has brought us

NEAT — NeuroEvolution of Augmenting Topologies

Kenneth O. Stanley and Risto Miikkulainen. 2002.

Evolving neural networks through augmenting topologies

Evolutionary Computation archive

Volume 10 Issue 2, Summer 2002

Pages 99-127

http://dx.doi.org/10.1162/106365602320169811

Essence of NEAT

Genetic algorithm that *produces neural networks*

NEAT varies the *structure of the network*, producing complex solutions over time

NEAT needs its overall population of networks to be *diverse*

The reproduction phase should produces *a novel individual*

NEAT groups *similar individuals into species*

Direct competition for survival happens *only within a species*

Essence of NEAT

Species compete with each other for reproduction rights

Mating only happens within species (unless interspecies matin is explicitly allowed)

Because NEAT uses species, it *takes longer* for the whole population to become uniform

Limitation of gradient-based approaches

Neuroevolution can learn things that classical neural networks *cannot learn*

activation functions, hyperparameter, architectures

Encoding

Genome (Genotype)

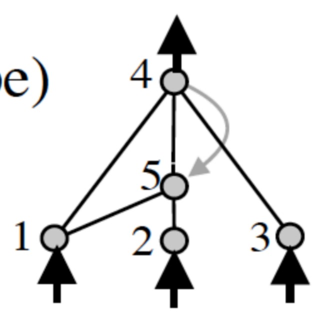
Node Genes

Node 1 Sensor	Node 2 Sensor	Node 3 Sensor	Node 4 Output	Node 5 Hidden

Connect. Genes

In 1	In 2	In 3	In 2	In 5	In 1	In 4
Out 4	Out 4	Out 4	Out 5	Out 4	Out 5	Out 5
Weight 0.7	Weight-0.5	Weight 0.5	Weight 0.2	Weight 0.4	Weight 0.6	Weight 0.6
Enabled	**DISABLED**	Enabled	Enabled	Enabled	Enabled	Enabled
Innov 1	Innov 2	Innov 3	Innov 4	Innov 5	Innov 6	Innov 11

Network (Phenotype)



Genome (Genotype)

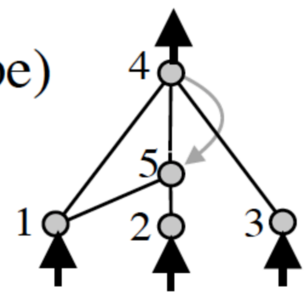
Node Genes

Node 1 Sensor	Node 2 Sensor	Node 3 Sensor	Node 4 Output	Node 5 Hidden

Connect. Genes

In 1 Out 4 Weight 0.7 Enabled Innov 1	In 2 Out 4 Weight-0.5 **DISABLED** Innov 2	In 3 Out 4 Weight 0.5 Enabled Innov 3	In 2 Out 5 Weight 0.2 Enabled Innov 4	In 5 Out 4 Weight 0.4 Enabled Innov 5	In 1 Out 5 Weight 0.6 Enabled Innov 6	In 4 Out 5 Weight 0.6 Enabled Innov 11

Network (Phenotype)



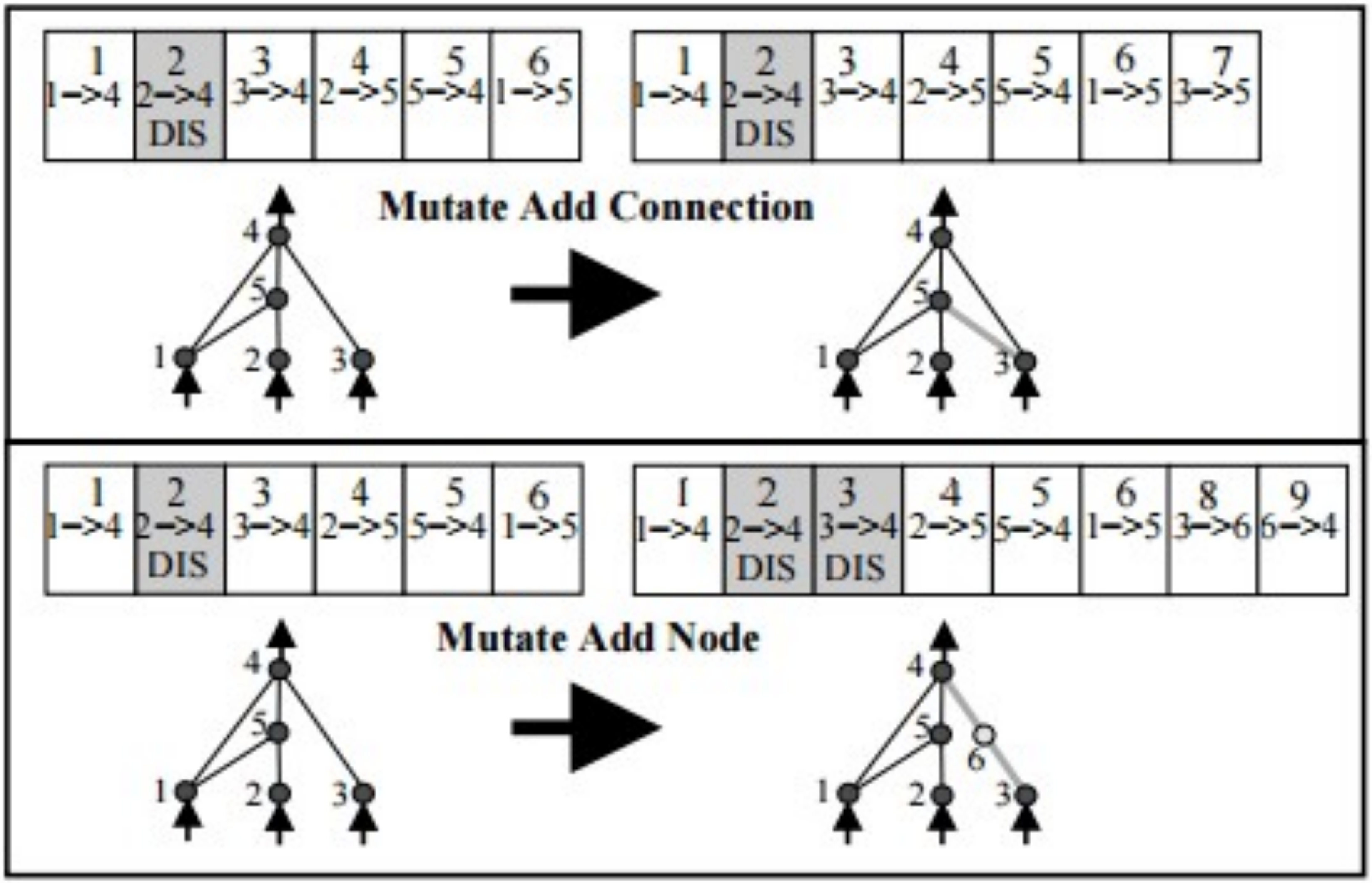
Inputs and outputs nodes are not encoded

Hidden nodes can be added or removed

A connection may be enabled or not, and has an innovation number

Individuals do not necessarily have the same size

Mutation


1 1->4
2 2->4 DIS
3 3->4
4 2->5
5 5->4
6 1->5
1 1->4
2 2->4 DIS
3 3->4
4 2->5
5 5->4
6 1->5
7 3->5
Mutate Add Connection
1 1->4
2 2->4 DIS
3 3->4
4 2->5
5 5->4
6 1->5
1 1->4
2 2->4 DIS
3 3->4 DIS
4 2->5
5 5->4
6 1->5
8 3->6
9 6->4
Mutate Add Node

Mutation

If a new node is added:

1 - it is placed between two connected nodes

2 - the previous connection is disabled (but still present in the genome)

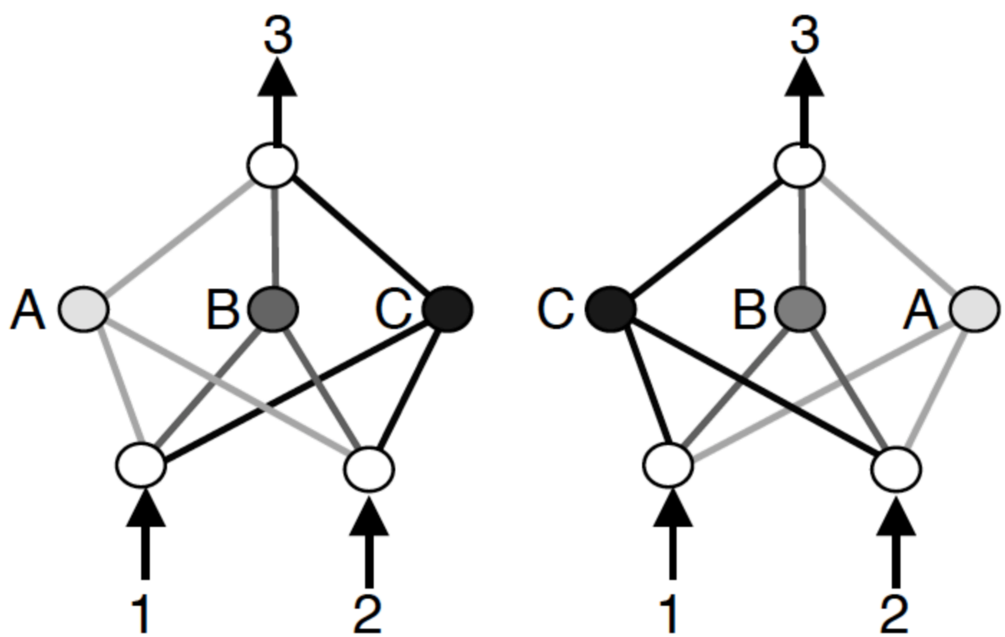
Competing Convention Problem

In ordinary evolution algorithms it can happen that two individuals encode very *similar behavior*, but with very *different genotype*

This is called *competing conventions*

If these individual are subject to crossover, their children are likely to be *worse* than their either parent

Competing Convention Problem



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

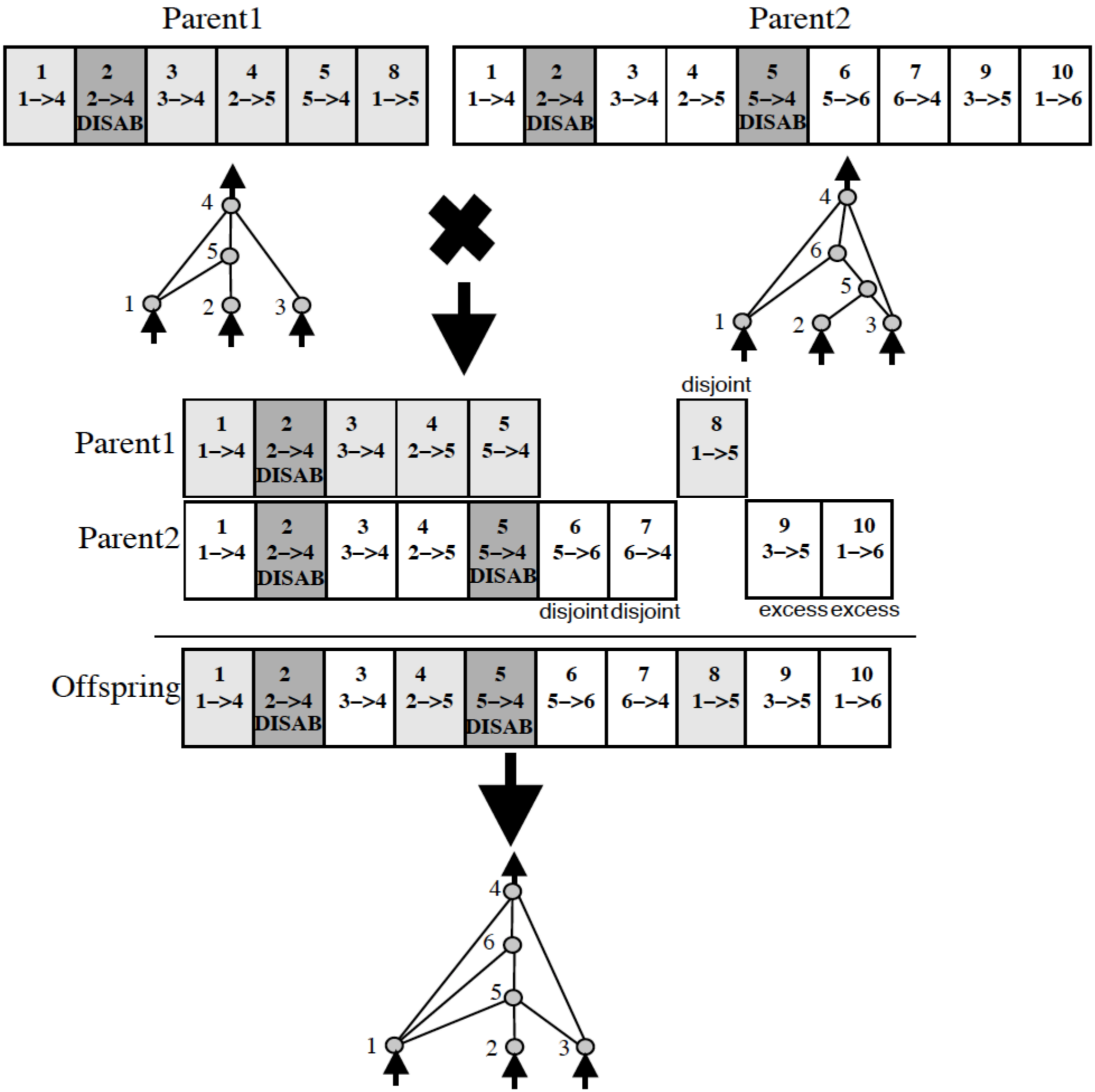
Crossovers: [A,B,A] [C,B,C]
(both are missing information)

Competing Convention Problem

NEAT solves this by *keeping historical markings* of new structural elements

When a new structural element is created (via structural mutation, such as adding a new node or gene), it receives an *innovation number*

When two individuals are crossed over, their genotypes are *aligned* in such a way that the corresponding innovation numbers match and only the different elements are exchanged


Parent1
1 1->4
2 2->4 DISAB
3 3->4
4 2->5
5 5->4
8 1->5
Parent2
1 1->4
2 2->4 DISAB
3 3->4
4 2->5
5 5->4 DISAB
6 5->6
7 6->4
9 3->5
10 1->6
disjoint
disjoint
disjoint
excess
excess
Offspring
1 1->4
2 2->4 DISAB
3 3->4
4 2->5
5 5->4 DISAB
6 5->6
7 6->4
8 1->5
9 3->5
10 1->6

Speciation

Most new evolutions *are not good ones*

A new connection or node degrades the performance of the individual

How can we protect new networks from being eliminated?

NEAT suggests *speciation*

Speciation

Splits up the *population into several species*

Based on the *similarity of topology and connections*

Individuals in a population only have to *compete* within other individuals *within that species*

Allow for a *new network to be created and optimized* without being quickly eliminated

Explore the idea of *explicit fitness sharing*: the whole population has a fitness

Speciation

Speciation *project innovations in the population*

When a network diverges far enough from other networks in the population, NEAT identifies it and put it in its own species

Using innovation numbers NEAT *computes the distance between two genomes*

Minimal structure

NEAT favors *minimal networks to be evolved*

Mutations is about adding a node, adding a connection, or changing a weight

… and not removing structural elements

What have we seen?

Overview of what Neuroevolution is

Two algorithms: simple and NEAT

We want more!

Many improvements were proposed HyperNEAT, ESHyperNEAT, CoDeepNEAT

Indirect coding using rules mimicking cell divisions dcc

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