Neural Networks
in
Artificial Intelligence

Artificial intelligence is the process of using computers to analyze complex information in order to assist with making decisions.

"Is that really you looking at me?"

There are many approaches to artificial intelligence.

The approach we introduce here is the use of artificial neural networks.

There are software tools available which allow people to apply neural networks to solve problems without having to understand what is going on inside the tools.

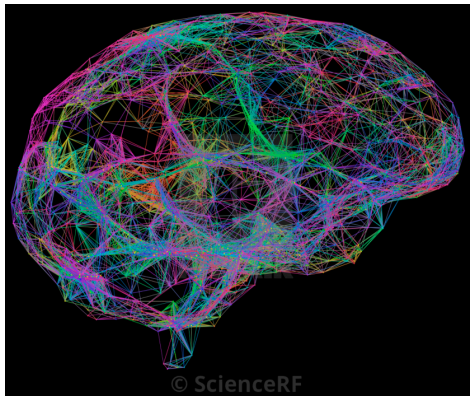
Our purpose is to explain the computational aspects behind simple artificial neural networks.

The goal is an understanding of the basics which underly the software tools.

MATLAB code used here is available at https://github.com/RichardHerz/neural-networks

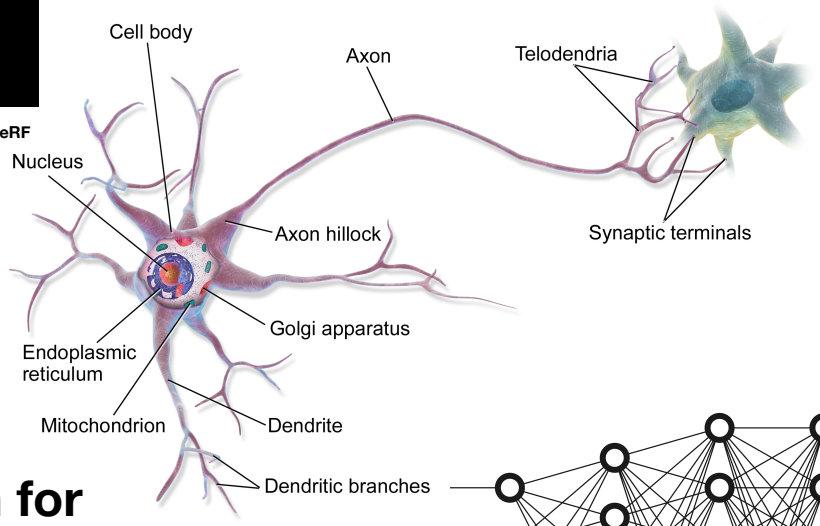
Our brains sense and think using connected networks of cells called neurons

www.braininjuryaustralia.org.au

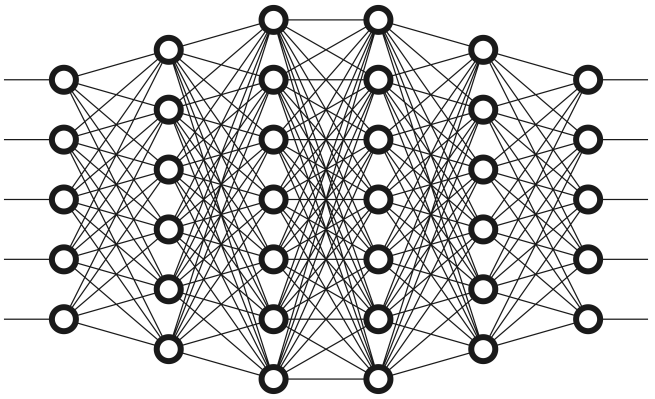


@ScienceRF

Blausen_0657_MultipolarNeuron



These networks are the inspiration for "artificial neural networks" which can be trained to solve complex problems such as object recognition in images and speech recognition



neural_network_shutterstock_all_is_magic.jpg

Neural Network

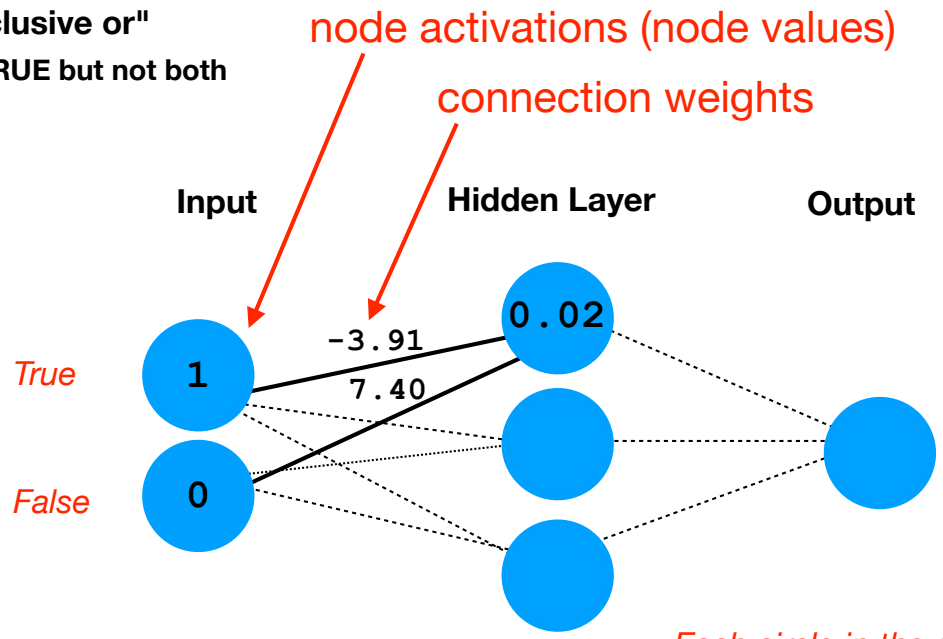
1

Simulates XOR logic - "exclusive or"

Output is TRUE when one input is TRUE but not both

2 inputs, 1 output,
1 hidden layer
with 3 neurons &
9 synapses

A simple example



2

Each circle in the diagram represents a node or "neuron."
Each line represents a connection or "synapse."
The value in a neuron is its "activation."
Each synapse has a connection "weight."

3

EXAMPLE for input of 1
0

node value = sigmaFunc(sum of (connection weight * node activation))

a math function

* is multiply

where sigmaFunc(x) = exp(x) / (1 + exp(x)) >> converts all input x values into range 0 to 1

exp(x) is exponential of x

INPUT > HIDDEN LAYER

sigmaFunc((-3.91 * 1) + (7.40 * 0)) = 0.02 = hidden node 1 activation

4

Every node - neuron - has a connection - synapse - to every neuron in nearest-neighbor layers of neurons in this basic type of neural network.

The values are held in memory locations and the CPU executes the math - there are no physical, hardware neurons and synapses.

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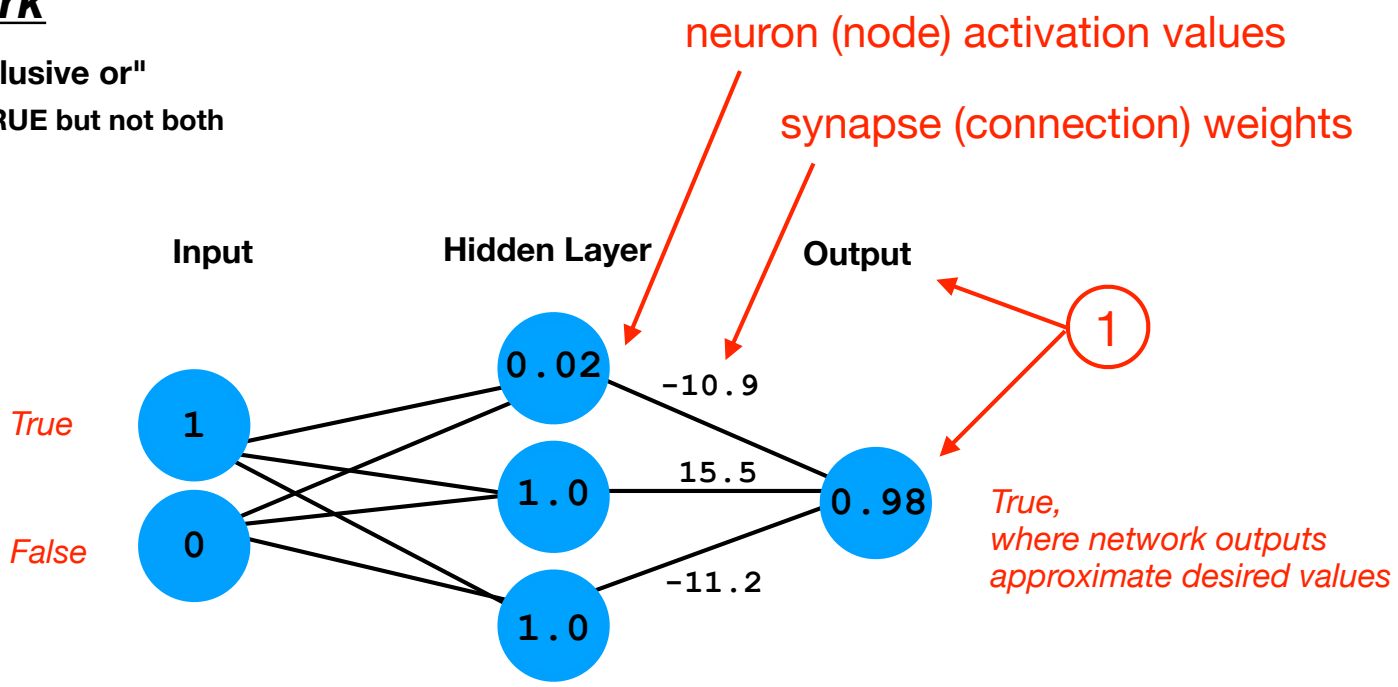


2 HIDDEN LAYER > OUTPUT

sigmaFunc((-10.9 * 0.020) + (15.5 * 1.0) + (-11.2 * 1.0)) = 0.98 = output node

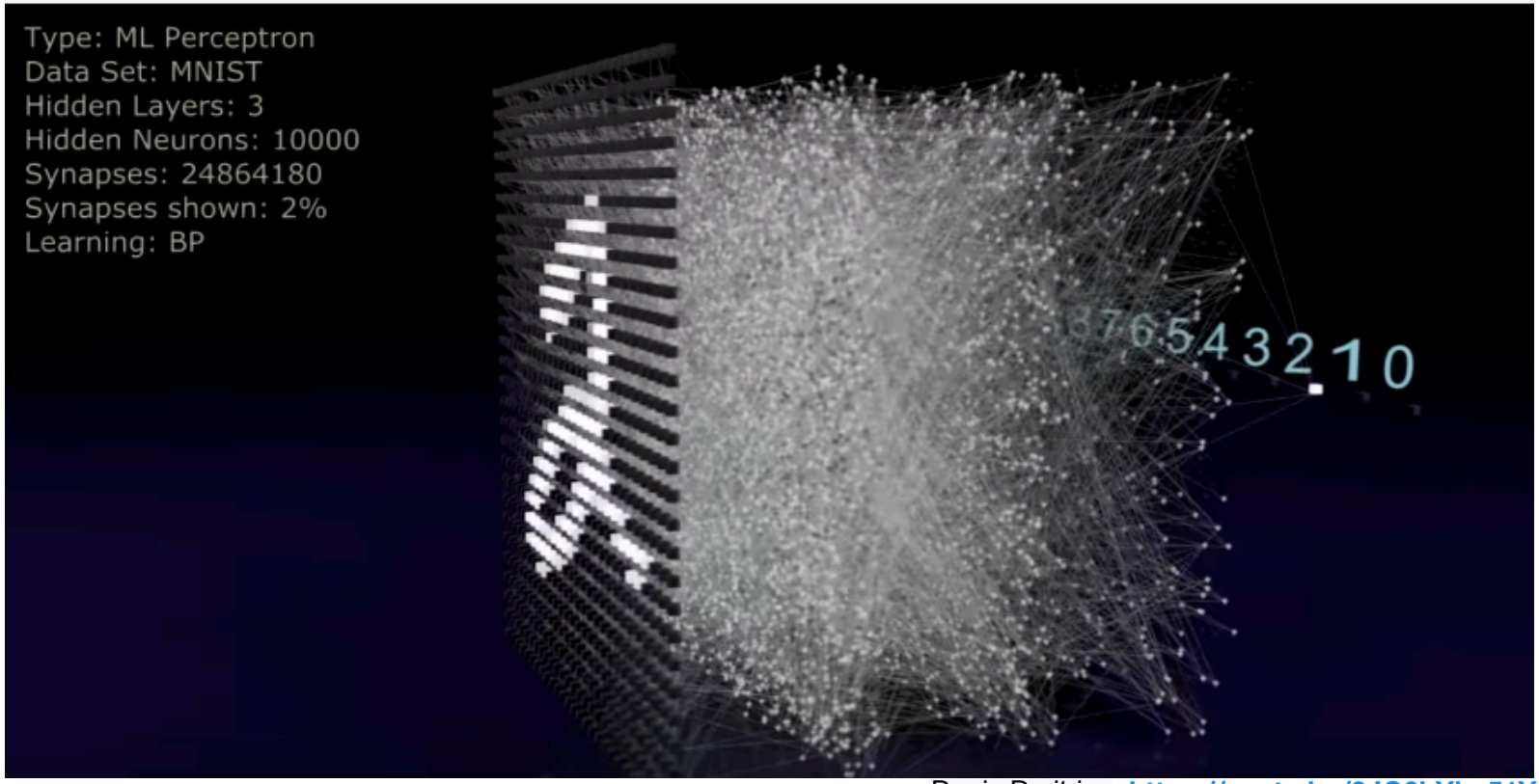
The MATLAB code to solve for the output remains the same as that below, regardless of the size of the network:

```
for i = 2 : numHiddenLayers + 2
    a{i} = sigmaFunc( W{i-1} * a{i-1} );
end
```

3 ***W*** *is a MATLAB cell array whose elements are the matrices of synapse weights for each layer;* ***a*** *is a cell array whose elements are the vectors of neuron activation values. Each set of* ***W*** *and* ***a*** *are matrix-multiplied to obtain the neuron activation values for the next layer in the series of neuron layers.*

4 *Matrix multiplication is well suited to being accelerated in hardware Graphical Processing Units, since graphic transformations also involve matrix multiplication.*

A neural network for a 28 x 28 “touch screen” that identifies handwritten numerals 0-9



Denis Dmitriev https://youtu.be/3JQ3hYko51Y

This network was trained with a set of known inputs and outputs that is much smaller than all the possible ways in which numbers can be drawn. The power of a trained network is to be able to give correct outputs for inputs for which the network wasn’t trained. That’s the main purpose of neural networks!

A neural network represents a large number of coupled equations which, when given a set of input values, can produce a set of desired output values.

The more neurons and synapses - the more equations - and the greater complexity of inputs and outputs which can be "fit" by the system of equations. Note the significant increase in complexity going from the XOR example (9 synapse weights) to the 2 x 2 “touch screen” (11,300) to the 28 x 28 touch screen in the figure above (24.9 million) to Open AI’s GPT-3 (175 billion)!

A neural network might be thought of as a general function which can fit anything given enough terms…

In a sense, neural networks are math functions which can "fit" any desired input and output data given enough adjustable parameters, which are the "synapse" connection weights and, thus, enough neurons.

Using a neural network is somewhat similar to using a polynomial function to fit a series of data points (empirical fit) vs. using a functional form that represents the underlying physics (theoretical fit).

In a neural network, the functional form is fixed by the network structure. The values of the constants in the function are the connection weights, whose values are determined during training.

For the XOR network above, this is the Matlab code which computes the output a{3} given the input a{1}

```
for i = 2:3
    a{i} = sigmaFunc( W{i-1}*a{i-1} );
end
```

Matrix W{i-1} and vector a{i-1} are elements of the cell arrays W and a. They are matrix multiplied. The Matlab code is very compact. We can see the form of this network's function by looking at the expanded equation, which shows the individual terms. The output $a\{3\}$ is a function of the inputs $a\{1\}$:

$$a^{\{3\}} = f(a^{\{1\}}) = \sigma\left(W_1^{\{2\}}a_1^{\{2\}} + W_2^{\{2\}}a_2^{\{2\}} + W_3^{\{2\}}a_3^{\{2\}}\right)$$

$$= \sigma\left(W_1^{\{2\}}\sigma\left(W_{1,1}^{\{1\}}a_1^{\{1\}} + W_{1,2}^{\{1\}}a_2^{\{1\}}\right) + W_2^{\{2\}}\sigma\left(W_{2,1}^{\{1\}}a_1^{\{1\}} + W_{2,2}^{\{1\}}a_2^{\{1\}}\right) + W_3^{\{2\}}\sigma\left(W_{3,1}^{\{1\}}a_1^{\{1\}} + W_{3,2}^{\{1\}}a_2^{\{1\}}\right)\right)$$

where, for more compact notation, the superscript {n} of cell arrays a and W denotes a matrix in cell array element n, and the subscripts are the indices within that matrix. The hidden layer activations are $a\{2\}$. The nonlinear activation function for this network, which constrains activation values between 0 and 1, is

$$\sigma(x) = \frac{e^x}{1 + e^x}$$

For a larger neural network of this type, there are more terms but the functional form remains unchanged. With the continued development of computers, larger networks can be computed more rapidly.