WOW - RESEARCHERS TAUGHT A COMPUTER TO BEAT THE WORLD'S BEST HUMANS AT YET ANOTHER TASK. DOES OUR SPECIES HAVE ANYTHING LEFT TO BE PROUD OF?

WELL, IT SOUNDS LIKE WE'RE PRETTY AWESOME AT TEACHING.

HUH? WHAT GOOD IS THAT?
Neural Networks

David Kauchak
Alexandra Papoutsaki
Zilong Ye
CS51A
Spring 2022
Neural Networks

Neural Networks try to mimic the structure and function of our nervous system

*People like biologically motivated approaches*
Our Nervous System

- Dendrites
- Axon
- Synapses
- Neuron
Our nervous system: the computer science view

The human brain is a large collection of interconnected neurons

A NEURON is a brain cell

- They collect, process, and disseminate electrical signals
- They are connected via synapses
- They fire depending on the conditions of the neighboring neurons
Our nervous system

The human brain

- contains ~$10^{11}$ (100 billion) neurons
- each neuron is connected to ~$10^{4}$ (10,000) other neurons
- Neurons can fire as fast as $10^{-3}$ seconds

How does this compare to a computer?
Man vs. Machine

$10^{11}$ neurons
$10^{11}$ neurons
$10^{14}$ synapses
$10^{-3}$ “cycle” time

$10^{10}$ transistors
$10^{11}$ bits of ram/memory
$10^{13}$ bits on disk
$10^{-9}$ cycle time
Brains are still pretty fast

Who is this?
Brains are still pretty fast

If you follow basketball, you’d be able to identify this person in under a second!

Given a neuron firing time of $10^{-3}$ s, how many neurons in sequence could fire in this time?

- A few hundred, maybe a thousand

What are possible explanations?

- either neurons are performing some very complicated computations
- brain is taking advantage of the massive parallelization (remember, neurons are connected $\sim$10,000 other neurons)
Artificial Neural Networks

Node (Neuron)

Edge (synapses)

our approximation
$W$ is the strength of signal sent between A and B.

If A fires and $w$ is \textbf{positive}, then A \textbf{stimulates} B.

If A \textit{fires} and $w$ is \textbf{negative}, then A \textbf{inhibits} B.
A given neuron has many, many connecting, input neurons.

If a neuron is stimulated enough, then it also fires.

How much stimulation is required is determined by its threshold.
A Single Neuron/Perceptron

Each input contributes: $x_i \times w_i$

threshold function

$in = \sum_{i} w_i x_i$
Possible threshold functions

hard threshold

\[ g(x) = \begin{cases} 
1 & \text{if } x \geq \text{threshold} \\
0 & \text{otherwise}
\end{cases} \]

sigmoid

\[ g(x) = \frac{1}{1 + e^{-ax}} \]
A Single Neuron/Perceptron

Threshold of 1
A Single Neuron/Perceptron

Threshold of 1

1*1 + 1*-1 + 0*1 + 1*0.5 = 0.5

?
A Single Neuron/Perceptron

Weighted sum is 0.5, which is not larger than the threshold.
A Single Neuron/Perceptron

Threshold of 1
A Single Neuron/Perceptron

Threshold of 1

\[ 1 \times 1 + 0 \times -1 + 0 \times 1 + 1 \times 0.5 = 1.5 \]
A Single Neuron/Perceptron

Weighted sum is 1.5, which is larger than the threshold
Neural network

inputs

Individual perceptrons/neurons
Neural network

some inputs are provided/entered
Neural network

Each perceptron computes and calculates an answer.
Neural network

inputs

those answers become inputs for the next level
Neural network

Finally get the answer after all levels compute.
Neural networks

Different kinds/characteristics of networks

How are these different?
Neural networks

Feed forward networks

inputs

hidden units/layer
Neural networks

Recurrent network

Output is fed back to input

Can support memory!

How?
History of Neural Networks

McCulloch and Pitts (1943) – introduced model of artificial neurons and suggested they could learn

Hebb (1949) – Simple updating rule for learning

Rosenblatt (1962) – the \textit{perceptron} model

Minsky and Papert (1969) – wrote \textit{Perceptrons}

Bryson and Ho (1969, but largely ignored until 1980s--Rosenblatt) – invented back-propagation learning for multilayer networks
Training the perceptron

First wave in neural networks in the 1960’s

Single neuron

Trainable: its threshold and input weights can be modified

If the neuron doesn’t give the desired output, then it has made a mistake

Input weights and threshold can be changed according to a learning algorithm
Examples - Logical operators

**AND** – if all inputs are 1, return 1, otherwise return 0

**OR** – if at least one input is 1, return 1, otherwise return 0

**NOT** – return the opposite of the input

**XOR** – if exactly one input is 1, then return 1, otherwise return 0
AND

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_1 \text{ and } x_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
AND

Input $x_1$  $W_1 = ?$

Input $x_2$  $W_2 = ?$

$T = ?$

Output $y$

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_1$ and $x_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Inputs are either 0 or 1

\[ T = 2 \]

Input \( x_1 \) \( W_1 = 1 \)

Input \( x_2 \) \( W_2 = 1 \)

\[ x_1 \quad x_2 \quad x_1 \text{ and } x_2 \]
\[ 0 \quad 0 \quad 0 \]
\[ 0 \quad 1 \quad 0 \]
\[ 1 \quad 0 \quad 0 \]
\[ 1 \quad 1 \quad 1 \]

Output \[ y \] is 1 only if all inputs are 1

Output is 1 only if all inputs are 1
AND

Input $x_1$  \( W_1 = ? \)

Input $x_2$  \( W_2 = ? \)

Input $x_3$  \( W_3 = ? \)

Input $x_4$  \( W_4 = ? \)

$T = ?$  \( \rightarrow \) Output $y$
Inputs are either 0 or 1

Output is 1 only if all inputs are 1

\[ W_1 = 1 \]
\[ W_2 = 1 \]
\[ W_3 = 1 \]
\[ W_4 = 1 \]
OR

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_1 \text{ or } x_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
OR

\[ T = ? \]

Input \( x_1 \)

\[ W_1 = ? \]

Input \( x_2 \)

\[ W_2 = ? \]

Output \( y \)

<table>
<thead>
<tr>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( x_1 \text{ or } x_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
OR

Inputs are either 0 or 1

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_1 \text{ or } x_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Output is 1 if at least 1 input is 1.
OR

Input $x_1$ \( W_1 = ? \)

Input $x_2$ \( W_2 = ? \)

Input $x_3$ \( W_3 = ? \)

Input $x_4$ \( W_4 = ? \)

$T = ?$ \rightarrow Output $y$
Inputs are either 0 or 1

Input $x_1$ with $W_1 = 1$
Input $x_2$ with $W_2 = 1$
Input $x_3$ with $W_3 = 1$
Input $x_4$ with $W_4 = 1$

Output $y$ with $T = 1$

Output is 1 if at least 1 input is 1
NOT

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>not $x_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Input $x_1$ → $W_1 = ?$ → $T = ?$ → Output $y$

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>not $x_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Input is either 0 or 1

If input is 1, output is 0.
If input is 0, output is 1.
How about...

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Input $x_1$ $w_1 = ?$
Input $x_2$ $w_2 = ?$
Input $x_3$ $w_3 = ?$

Output $y$ $T = ?$
Training neural networks

Learn the individual weights between nodes

Learn individual node parameters (e.g., threshold)
Positive or negative?

NEGATIVE
Positive or negative?

NEGATIVE
Positive or negative?

POSITIVE
Positive or negative?

NEGATIVE
Positive or negative?

POSITIVE
Positive or negative?

POSITIVE
Positive or negative?

NEGATIVE
Positive or negative?

POSITIVE
A method to the madness

blue = positive

yellow triangles = positive

all others negative

How did you figure this out (or some of it)?
Training neural networks

1. start with some initial weights and thresholds
2. show examples repeatedly to NN
3. update weights/thresholds by comparing NN output to actual output