Neural Networks - Deep Learning

Artificial Intelligence @ Allegheny College

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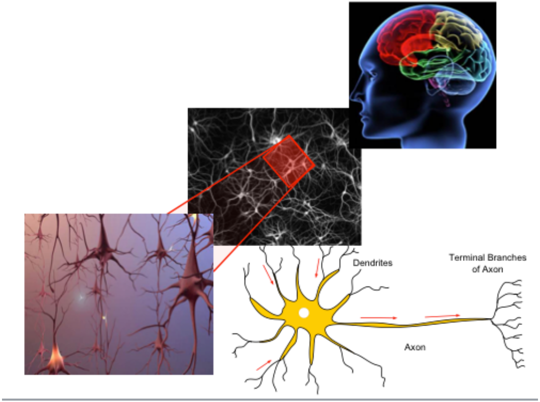
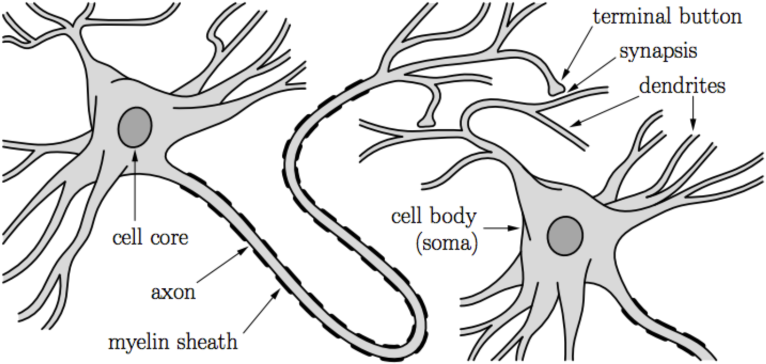
Credit: Google Workshop

Neural Networks



Neural Networks

Structure of a prototypical biological neuron

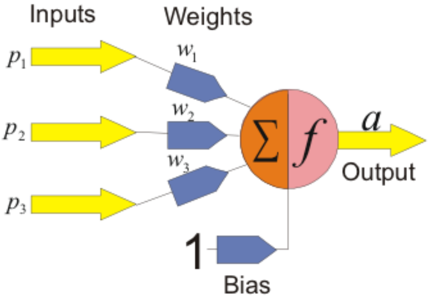


Neural Networks

Neural computing requires a number of **neurons**, to be connected together into a **neural network**.

Neurons are arranged in layers.
Two main **hyperparameters** that control the architecture or topology of the network: 1) the number of layers, and 2) the number of nodes in each hidden layer.

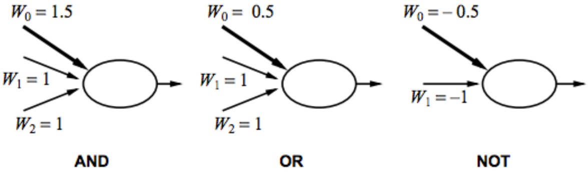
Neural Networks



$$a = f(p_1 w_1 + p_2 w_2 + p_3 w_3 + b) = f\left(\sum p_i w_i + b\right)$$

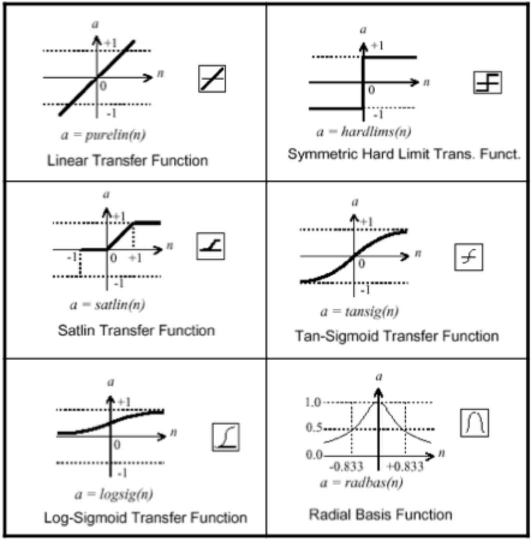
Activation Functions

- The activation function is generally non-linear.
- Linear functions are limited because the output is simply proportional to the input.



McCulloch and Pitts: every Boolean function can be implemented

Activation Functions

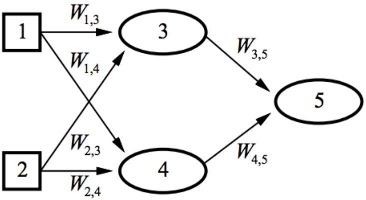


Network structures

Two phases in each iteration:

1. Calculating the predicted output $\mathbf{y}$, known as feed-forward
2. Updating the weights and biases, known as backpropagation

Feed-forward example



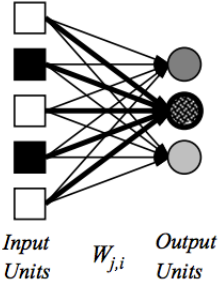
Feed-forward network = a parameterized family of nonlinear functions:

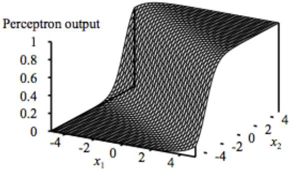
$$
\begin{aligned}
a_5 &= g(W_{3,5} \cdot a_3 + W_{4,5} \cdot a_4) \\
&= g(W_{3,5} \cdot g(W_{1,3} \cdot a_1 + W_{2,3} \cdot a_2) + W_{4,5} \cdot g(W_{1,4} \cdot a_1 + W_{2,4} \cdot a_2))
\end{aligned}
$$

Feed-forward networks:

- Single-layer perceptrons
- Multi-layer perceptrons

Single-layer Perceptrons

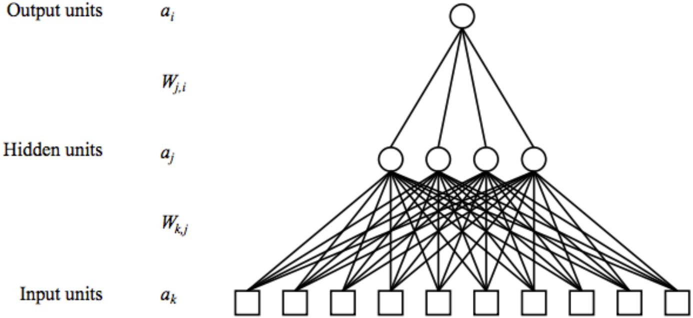




Output units all operate separately – no shared weights.

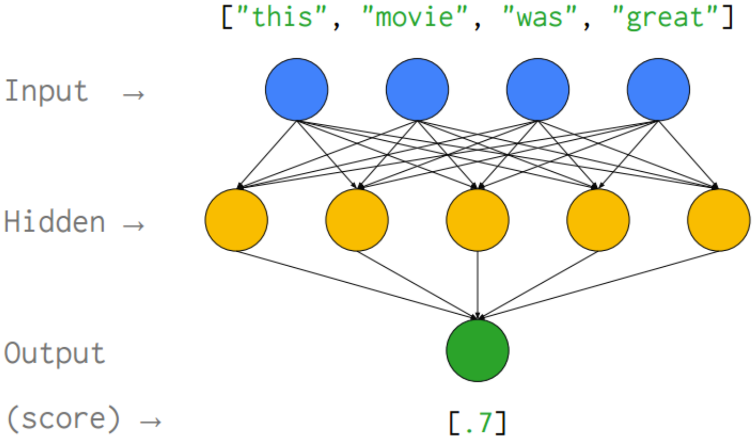
Adjusting weights moves the location, orientation, and steepness of cliff.

Multi-layer Perceptrons

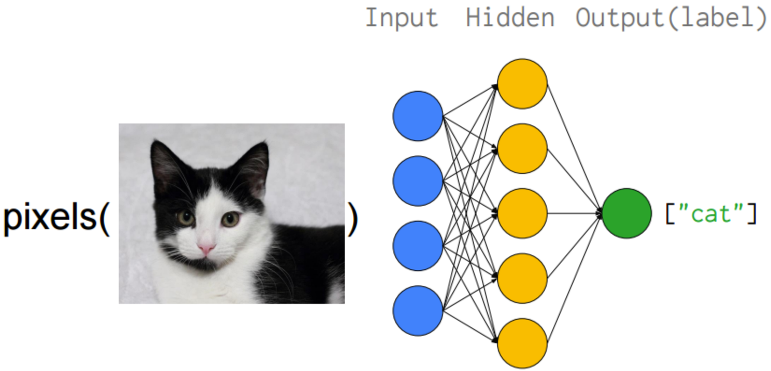


- Layers are usually fully connected.
- Numbers of hidden units typically chosen by hand.

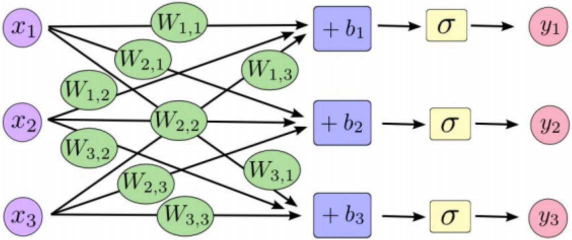
Neural Networks



Neural Networks



Neural Networks: A fully connected NN layer



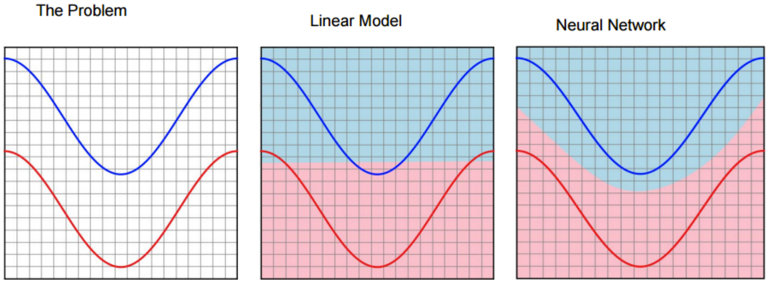
$$
\begin{aligned}
y_1 &= \sigma\left(W_{1,1}x_1 + W_{1,2}x_2 + W_{1,3}x_3 + b_1 \right)\\
y_2 &= \sigma\left(W_{2,1}x_1 + W_{2,2}x_2 + W_{2,3}x_3 + b_2 \right)\\
y_3 &= \sigma\left(W_{3,1}x_1 + W_{3,2}x_2 + W_{3,3}x_3 + b_3 \right)
\end{aligned}
$$

Implementation as Matrix Multiplication

$$
\begin{aligned}
y_1 &= \sigma(W_{1,1}x_1 + W_{1,2}x_2 + W_{1,3}x_3 + b_1) \\
y_2 &= \sigma(W_{2,1}x_1 + W_{2,2}x_2 + W_{2,3}x_3 + b_2) \\
y_3 &= \sigma(W_{3,1}x_1 + W_{3,2}x_2 + W_{3,3}x_3 + b_3)
\end{aligned}
$$

$$
\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \sigma\left(\begin{bmatrix} W_{1,1} & W_{1,2} & W_{1,3} \\ W_{2,1} & W_{2,2} & W_{2,3} \\ W_{3,1} & W_{3,2} & W_{3,3} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}\right)
$$

Non-Linear Data Distributions



Deep Learning

- Most current machine learning works well because of human-designed representations and input features.
- Machine learning becomes just optimizing weights to best make a final prediction.

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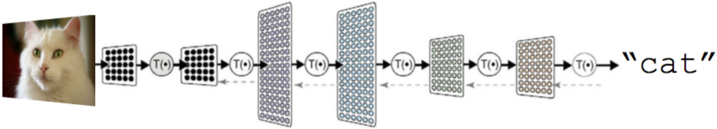
- Machine learning becomes just optimizing weights to best make a final prediction.
- **Deep learning** algorithms attempt to learn multiple levels of representation of increasing complexity/abstraction.

Deep Learning

- Each neuron implements a relatively simple mathematical function.
- $y = g(\overline{w} \cdot \overline{x} + b)$

Deep Learning

- Each neuron implements a relatively simple mathematical function.
- $y = g(\overline{w} \cdot \overline{x} + b)$
- The composition of $10^6 - 10^9$ such functions is powerful.



Deep Learning

Book: http://www.deeplearningbook.org/

Chapter 5

"A core idea in deep learning is that we assume that the data was generated by the composition of factors or features, potentially at multiple levels in a hierarchy."

Deep Learning

Results get better (to a degree) with:

- more data
- bigger models
- more computation

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Better algorithms, new insights and improved methods help, too!

TensorFlow

- Open source Machine Learning library
- Especially useful for **Deep Learning**
- For research **and** production
- **Apache 2.0** license
- tensorflow.org

TensorFlow

- *Epoch*: a training iteration (one pass through the dataset).
- *Batch*: Portion of the dataset (number of samples after dataset has been divided).
- *Regularization*: a set of techniques that helps learning models to converge (`http://www.godeep.ml/regularization-using-tensorflow/`).

TensorFlow

A multidimensional array.

TensorFlow

A graph of operations.

- Operates over **tensors**: n-dimensional arrays

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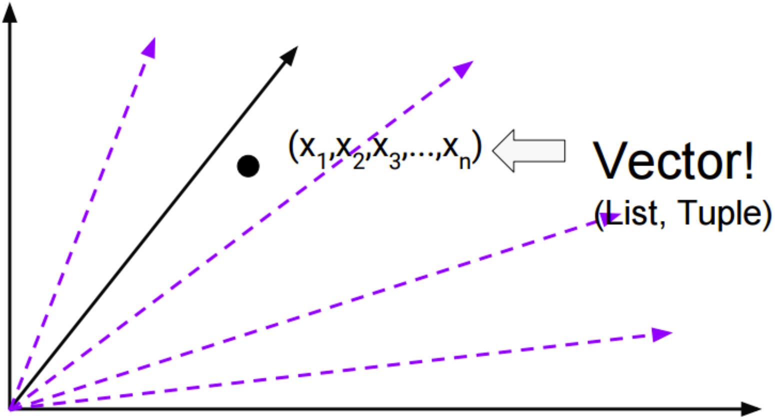
A graph of operations.

- Operates over **tensors**: n-dimensional arrays
- Using a **flow graph**: data flow computation framework

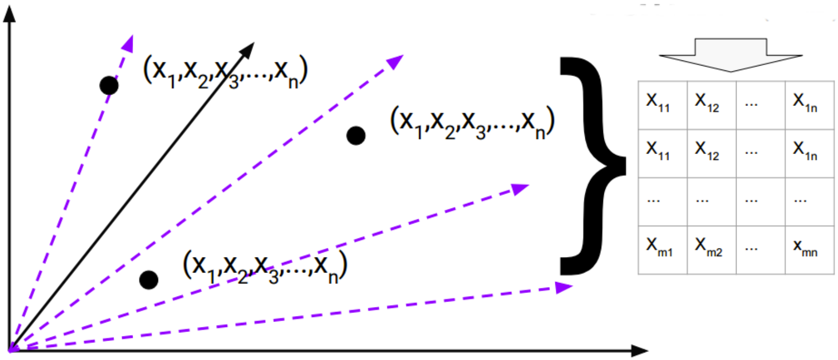
TensorFlow

- 5.7 $\leftarrow$ Scalar
- Number, Float, etc.

TensorFlow



TensorFlow



(x1,x2,x3,...,xn)
(x1,x2,x3,...,xn)
(x1,x2,x3,...,xn)
X11 X12 ... X1n
X11 X12 ... X1n
... ...
Xm1 Xm2 ... xmn

TensorFlow

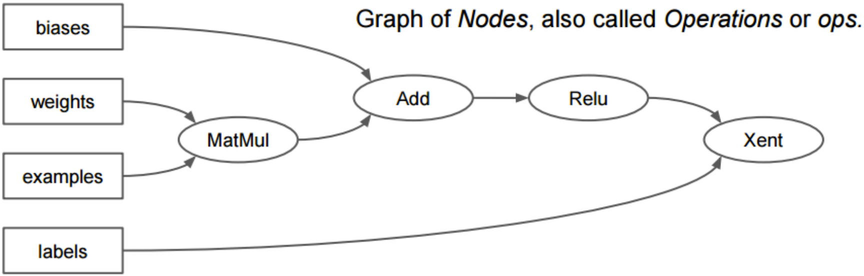
- Tensors have a **Shape** that is described with a vector

TensorFlow

- Tensors have a **Shape** that is described with a vector
- $[1000, 256, 256, 3]$
- 10000 Images
- Each Image has 256 Rows
- Each Row has 256 Pixels
- Each Pixel has 3 values (RGB)

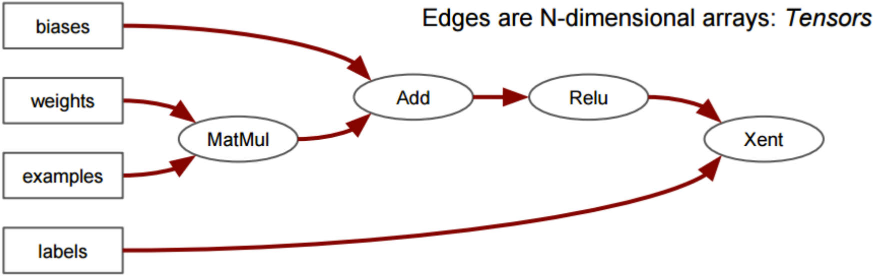
TensorFlow

Com



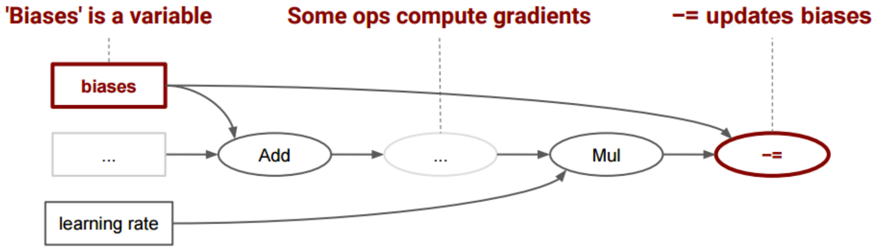
TensorFlow

Com



TensorFlow

Computation is a dataflow graph with state



Core TensorFlow data structures and concepts

- **Graph**: A TensorFlow computation, represented as a dataflow graph:
  - collection of ops that may be executed together as a group.

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- **Graph**: A TensorFlow computation, represented as a dataflow graph:
  - collection of ops that may be executed together as a group.
- **Operation**: a graph node that performs computation on tensors
- **Tensor**: a handle to one of the outputs of an Operation:
  - provides a means of computing the value in a TensorFlow Session.

TensorFlow

- **Constants**

TensorFlow

- **Constants**
- **Placeholders**: must be fed with data on execution.

TensorFlow

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TensorFlow

- **Constants**
- **Placeholders**: must be fed with data on execution.
- **Variables**: a modifiable tensor that lives in TensorFlow's graph of interacting operations.
- **Session**: encapsulates the environment in which Operation objects are executed, and Tensor objects are evaluated.

TensorFlow

Category	*Examples*
Element-wise math ops	**Add**, Sub, **Mul**, Div, Exp, Log, Greater, Less...
Matrix ops	**Concat**, Slice, **Split**, Constant, Rank, **Shape...**
Matrix ops	**MatMul**, MatrixInverse, MatrixDeterminant...
Stateful ops	**Variable**, Assign, AssignAdd...
NN building blocks	**SoftMax**, Sigmoid, **ReLU**, **Convolution2D...**
Checkpointing ops	Save, Restore
Queue & synch ops	Enqueue, Dequeue, MutexAcquire...
Control flow ops	Merge, Switch, Enter, Leave...

TensorFlow

`https://playground.tensorflow.org`