

CS 229 - Machine Learning (<https://stanford.edu/%7Eshervine/teaching/cs-229.html>)

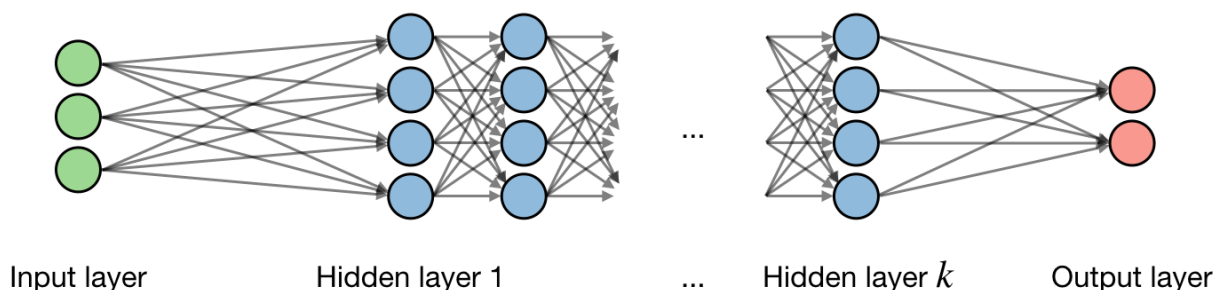
# Deep Learning cheatsheet

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## Neural Networks

Neural networks are a class of models that are build with layers. Commonly used types of neural networks include convolutional and recurrent neural networks.

**Architecture** — The vocabulary around neural networks architectures is described in the figure below:



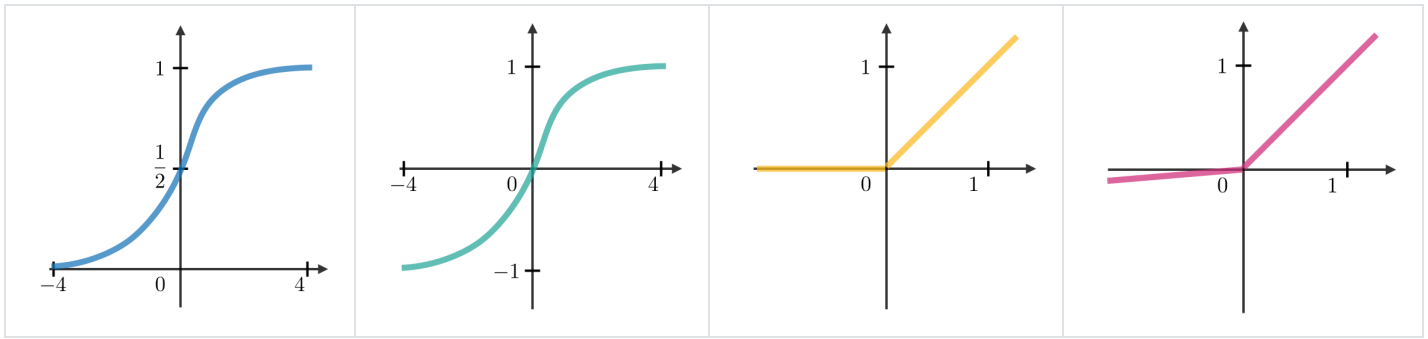
By noting  $i$  the  $i^{th}$  layer of the network and  $j$  the  $j^{th}$  hidden unit of the layer, we have:

$$z_j^{[i]} = w_j^{[i]T} x + b_j^{[i]}$$

where we note  $w$ ,  $b$ ,  $z$  the weight, bias and output respectively.

**Activation function** — Activation functions are used at the end of a hidden unit to introduce non-linear complexities to the model. Here are the most common ones:

Sigmoid	Tanh	ReLU	Leaky ReLU
$g(z) = \frac{1}{1 + e^{-z}}$	$g(z) = \frac{e^z - e^{-z}}{e^z + e^{-z}}$	$g(z) = \max(0, z)$	$g(z) = \max(\epsilon z, z)$ with $\epsilon \ll 1$



**Cross-entropy loss** — In the context of neural networks, the cross-entropy loss  $L(z, y)$  is commonly used and is defined as follows:

$$L(z, y) = -[y \log(z) + (1 - y) \log(1 - z)]$$

**Learning rate** — The learning rate, often noted  $\alpha$  or sometimes  $\eta$ , indicates at which pace the weights get updated. This can be fixed or adaptively changed. The current most popular method is called Adam, which is a method that adapts the learning rate.

**Backpropagation** — Backpropagation is a method to update the weights in the neural network by taking into account the actual output and the desired output. The derivative with respect to weight  $w$  is computed using chain rule and is of the following form:

$$\frac{\partial L(z, y)}{\partial w} = \frac{\partial L(z, y)}{\partial a} \times \frac{\partial a}{\partial z} \times \frac{\partial z}{\partial w}$$

As a result, the weight is updated as follows:

$$w \leftarrow w - \alpha \frac{\partial L(z, y)}{\partial w}$$

**Updating weights** — In a neural network, weights are updated as follows:

- Step 1: Take a batch of training data.
- Step 2: Perform forward propagation to obtain the corresponding loss.
- Step 3: Backpropagate the loss to get the gradients.
- Step 4: Use the gradients to update the weights of the network.

**Dropout** — Dropout is a technique meant at preventing overfitting the training data by dropping out units in a neural network. In practice, neurons are either dropped with probability  $p$  or kept with probability  $1 - p$ .

## Convolutional Neural Networks

**Hyperparameters** — In a convolutional neural networks, we fix the following hyperparameters (stride, padding, width, height).

Stride	Padding	Dimensions of filter
Purpose	Purpose	height, width, depth
Image	Image	Image

**Types of layer** — In a convolutional neural networks, we can encounter the following types of layer:

Convolutional layer	Pooling	ReLU	Fully Connected	Softmax
Uses filter to convolve	Purpose	Purpose	Converts to 1-dimensional vector	Purpose
Image	Image	Image	Image	Image

**Convolutional layer requirement** — By noting  $W$  the input volume size,  $F$  the size of the convolutional layer neurons,  $P$  the amount of zero padding, then the number of neurons  $N$  that fit in a given volume is such that:

$$N = \frac{W - F + 2P}{S} + 1$$

**Batch normalization** — It is a step of hyperparameter  $\gamma, \beta$  that normalizes the batch  $\{x_i\}$ . By noting  $\mu_B, \sigma_B^2$  the mean and variance of that we want to correct to the batch, it is done as follows:

$$x_i \leftarrow \gamma \frac{x_i - \mu_B}{\sqrt{\sigma_B^2 + \epsilon}} + \beta$$

It is usually done after a fully connected/convolutional layer and before a non-linearity layer and aims at allowing higher learning rates and reducing the strong dependence on initialization.

## Recurrent Neural Networks

**Types of gates** — Here are the different types of gates that we encounter in a typical recurrent neural network:

Forget gate	Input gate	Gate	Output gate
Write to cell or not?	Erase a cell or not?	How much to reveal cell?	How much to write to cell?

**LSTM** — A long short-term memory (LSTM) network is a type of RNN model that avoids the vanishing gradient problem by adding 'forget' gates.

## Reinforcement Learning and Control

The goal of reinforcement learning is for an agent to learn how to evolve in an environment.

### Definitions

**Markov decision processes** — A Markov decision process (MDP) is a 5-tuple

$(\mathcal{S}, \mathcal{A}, \{P_{sa}\}, \gamma, R)$  where:

- $\mathcal{S}$  is the set of states
- $\mathcal{A}$  is the set of actions
- $\{P_{sa}\}$  are the state transition probabilities for  $s \in \mathcal{S}$  and  $a \in \mathcal{A}$
- $\gamma \in [0, 1[$  is the discount factor
- $R : \mathcal{S} \times \mathcal{A} \longrightarrow \mathbb{R}$  or  $R : \mathcal{S} \longrightarrow \mathbb{R}$  is the reward function that the algorithm wants to maximize

**Policy** — A policy  $\pi$  is a function  $\pi : \mathcal{S} \longrightarrow \mathcal{A}$  that maps states to actions.

*Remark: we say that we execute a given policy  $\pi$  if given a state  $a$  we take the action  $a = \pi(s)$ .*

**Value function** — For a given policy  $\pi$  and a given state  $s$ , we define the value function  $V^\pi$  as follows:

$$V^\pi(s) = E \left[ R(s_0) + \gamma R(s_1) + \gamma^2 R(s_2) + \dots \mid s_0 = s, \pi \right]$$

**Bellman equation** — The optimal Bellman equations characterizes the value function  $V^{\pi^*}$  of the optimal policy  $\pi^*$ :

$$V^{\pi^*}(s) = R(s) + \max_{a \in \mathcal{A}} \gamma \sum_{s' \in \mathcal{S}} P_{sa}(s') V^{\pi^*}(s')$$

*Remark: we note that the optimal policy  $\pi^*$  for a given state  $s$  is such that:*

$$\pi^*(s) = \operatorname{argmax}_{a \in \mathcal{A}} \sum_{s' \in \mathcal{S}} P_{sa}(s') V^*(s')$$

**Value iteration algorithm** — The value iteration algorithm is in two steps:

1) We initialize the value:

$$V_0(s) = 0$$

2) We iterate the value based on the values before:

$$V_{i+1}(s) = R(s) + \max_{a \in \mathcal{A}} \left[ \sum_{s' \in \mathcal{S}} \gamma P_{sa}(s') V_i(s') \right]$$

**Maximum likelihood estimate** — The maximum likelihood estimates for the state transition probabilities are as follows:

$$P_{sa}(s') = \frac{\text{\#times took action } a \text{ in state } s \text{ and got to } s'}{\text{\#times took action } a \text{ in state } s}$$

**Q-learning** — Q-learning is a model-free estimation of  $Q$ , which is done as follows:

$$Q(s, a) \leftarrow Q(s, a) + \alpha \left[ R(s, a, s') + \gamma \max_{a'} Q(s', a') - Q(s, a) \right]$$



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