Neural Networks

Vishal Patel

Spring 2022

Feature Engineering

CUSTOMER ID	PURCHASE DATE
1001	02-12-2015:05:20:39
1001	05-13-2015:12:18:09
1001	12-20-2016:00:15:59
1002	01-19-2014:04:28:54
1003	01-12-2015:09:20:36
1003	05-31-2015:10:10:02
…	…

CUSTOMER ID	x_1	x_2	…	x_j
1001	…	…		…
1002	…	…		…
1003	…	…		…
…	…	…	…	…

1. Number of transactions (Frequency)
2. Days since the last transaction (Recency)
3. Days since the earliest transaction (Tenure)
4. Avg. days between transaction
5. # of transactions during weekends
6. % of transactions during weekends
7. # of transactions by day-part (breakfast, lunch, etc.)
8. % of transactions by day-part
9. Days since last transaction / Avg. days between transactions
10. …

Training Data

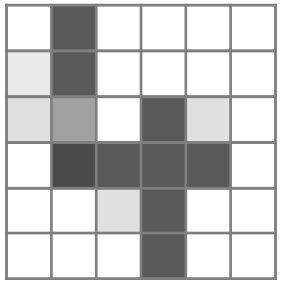
Domain Knowledge

Create Features

Train Models

Feature Engineering?

Training Data

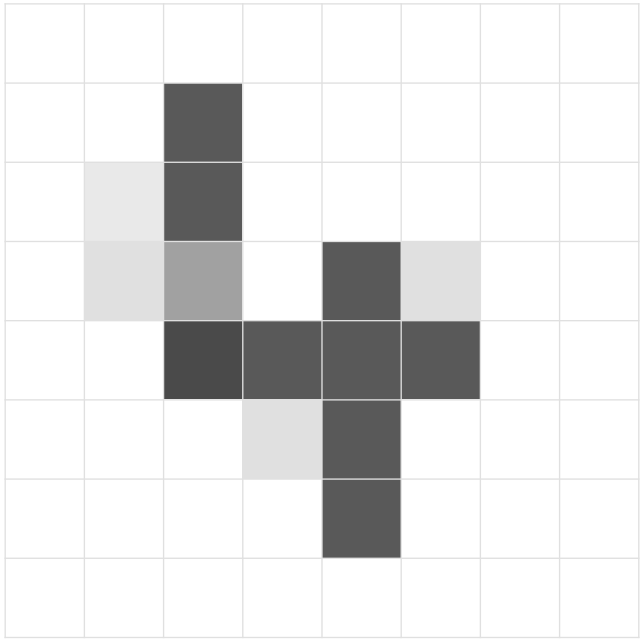


$$\begin{pmatrix} x_{11} & x_{12} & x_{13} & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & x_{1j} \\ x_{21} & x_{22} & x_{23} & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & x_{2j} \\ x_{31} & x_{32} & x_{33} & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & x_{3j} \\ . & . & . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . & . & . \\ x_{n1} & x_{n2} & x_{n3} & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & x_{nj} \end{pmatrix} \qquad \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ . \\ . \\ . \\ y_n \end{pmatrix}$$

$j = 36$

$y_1 = 4$

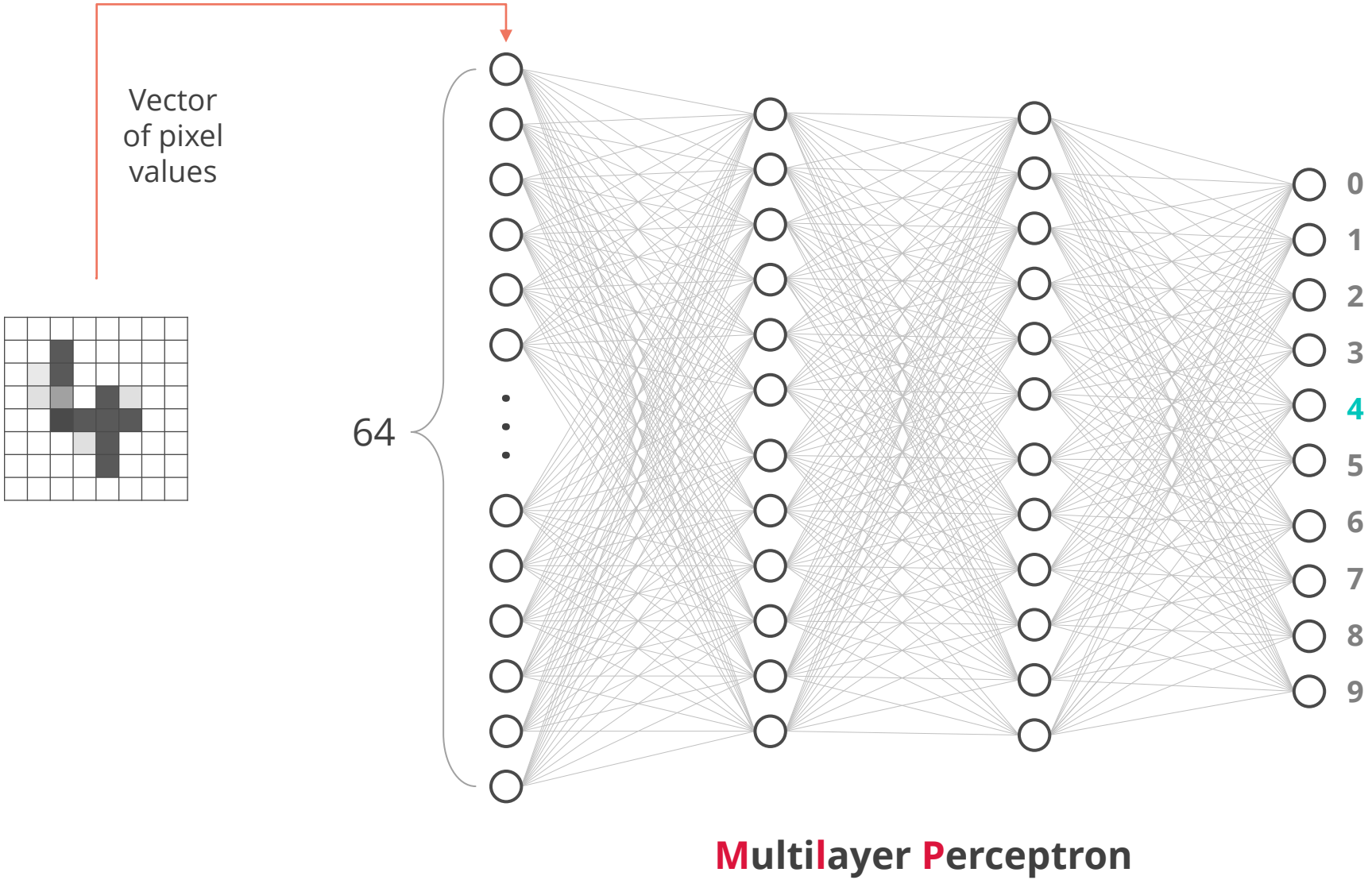
Digit Recognition Program



Input (8x8 grid)

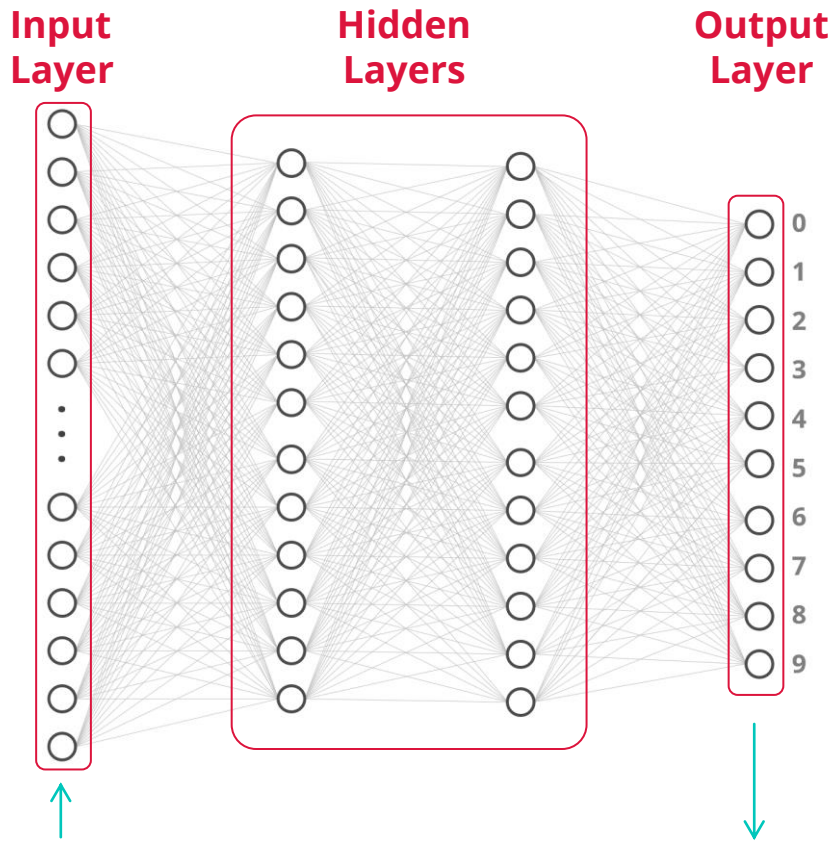
Output

Neural Network

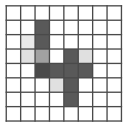


Multilayer Perceptron

Terminology



Activation values for the input layer



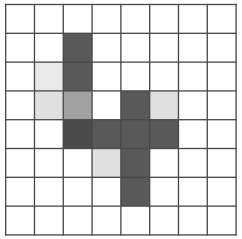
Probability that a given input is that number

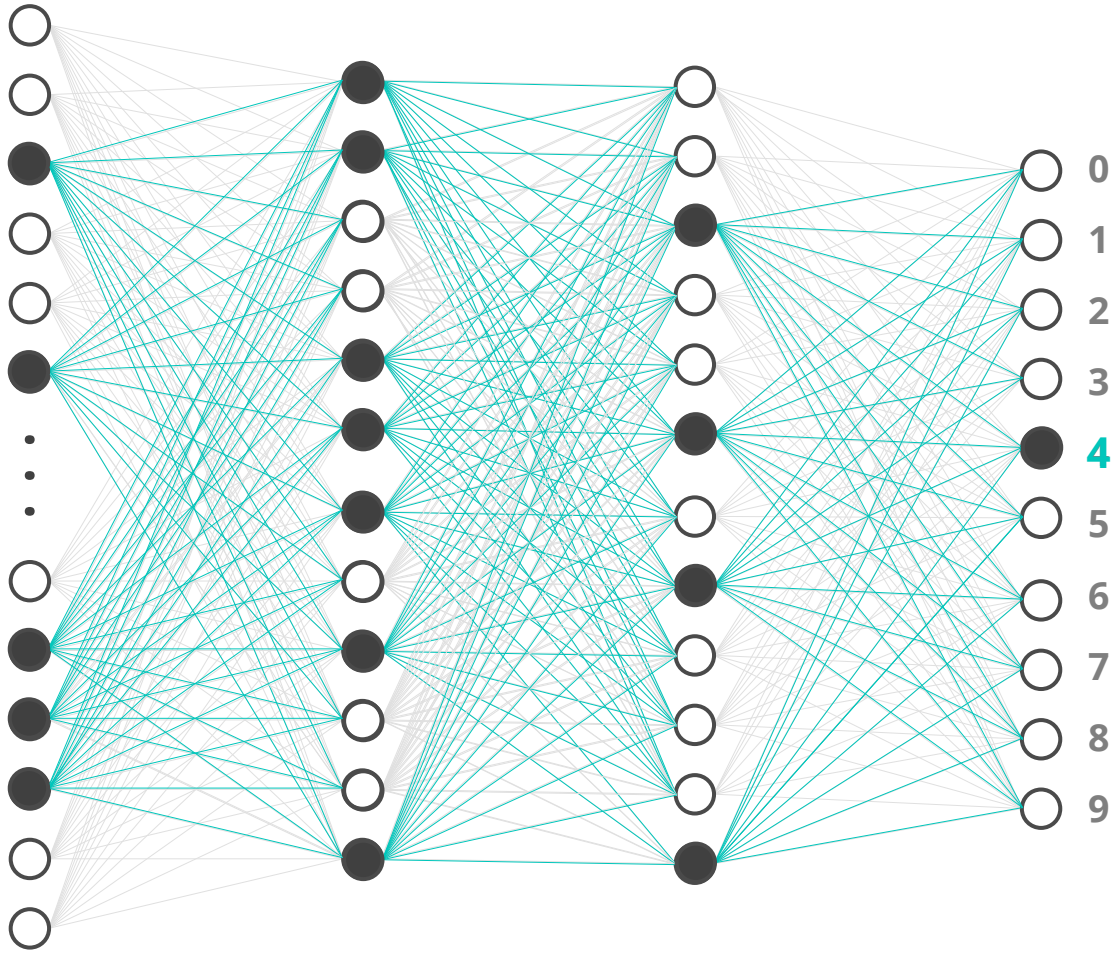
Neuron

Activation Value

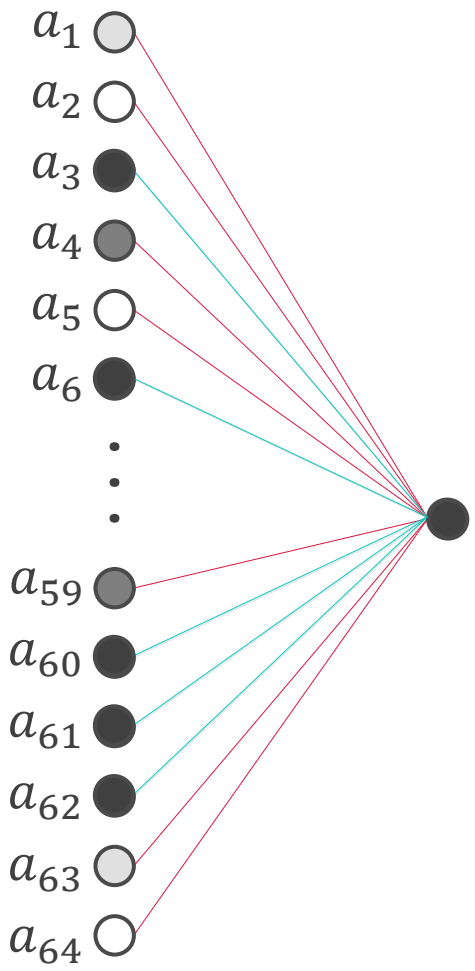
0.0 — 1.0

The Layers



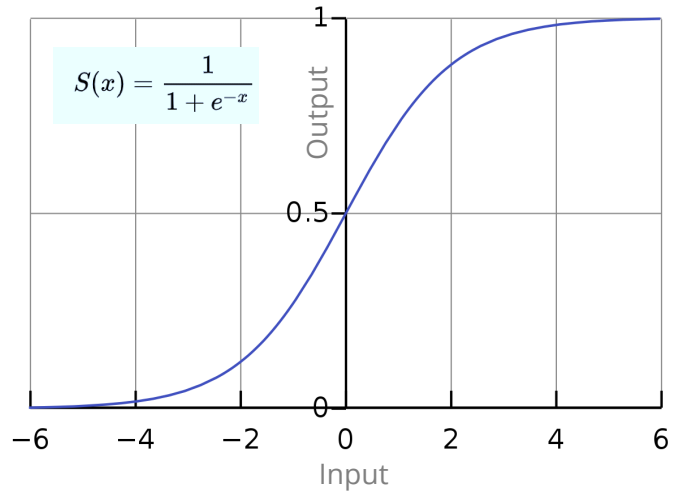


Activation Function



$$w_1 = -0.17$$
$$w_2 = -2.09$$
$$w_3 = +3.25$$
$$w_4 = -0.05$$
$$w_5 = -2.99$$
$$w_6 = +1.11$$

Sigmoid function



The logistic curve

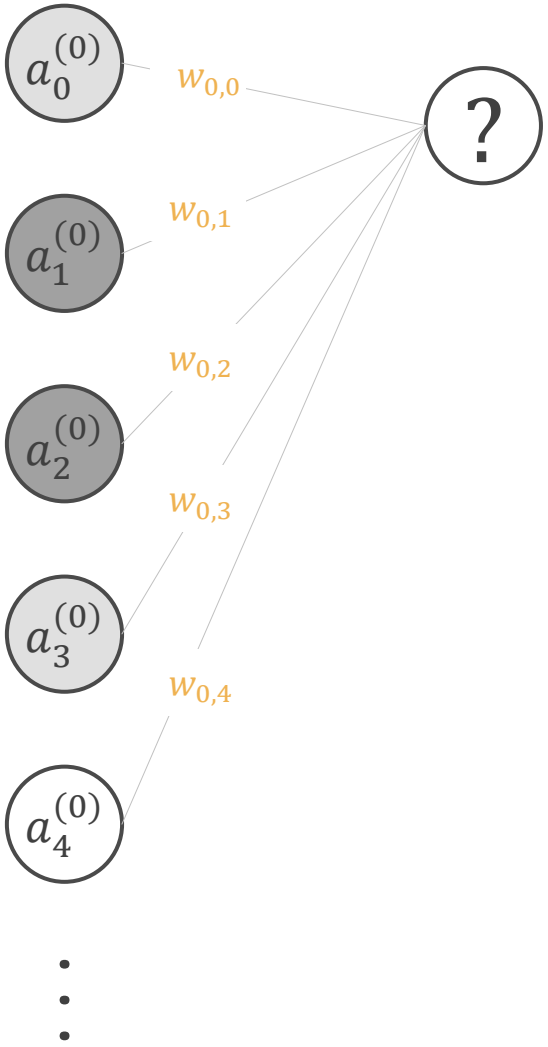
Activation value of a neuron:

$$\sigma(w_1 a_1 + w_2 a_2 + w_3 a_3 + \cdots + w_n a_n + bias)$$

Sigmoid function

Note: A generalized sigmoid function, called softmax, us used for the output layer.

Activation Function



$$a_0^{(1)} = \sigma\left(w_{0,0}a_0^{(0)} + w_{0,1}a_1^{(0)} + \cdots + w_{0,n}a_n^{(0)} + b_0 \right)$$

$$\sigma\left(\begin{bmatrix} w_{0,0} & w_{0,1} & \cdots & w_{0,n} \\ w_{1,0} & w_{1,1} & \cdots & w_{1,n} \\ \cdots & \cdots & \cdots & \cdots \\ w_{k,0} & w_{k,1} & \cdots & w_{k,n} \end{bmatrix} \begin{bmatrix} a_0^{(0)} \\ a_1^{(0)} \\ \cdots \\ a_n^{(0)} \end{bmatrix} + \begin{bmatrix} b_0 \\ b_1 \\ \cdots \\ b_n \end{bmatrix} \right)$$

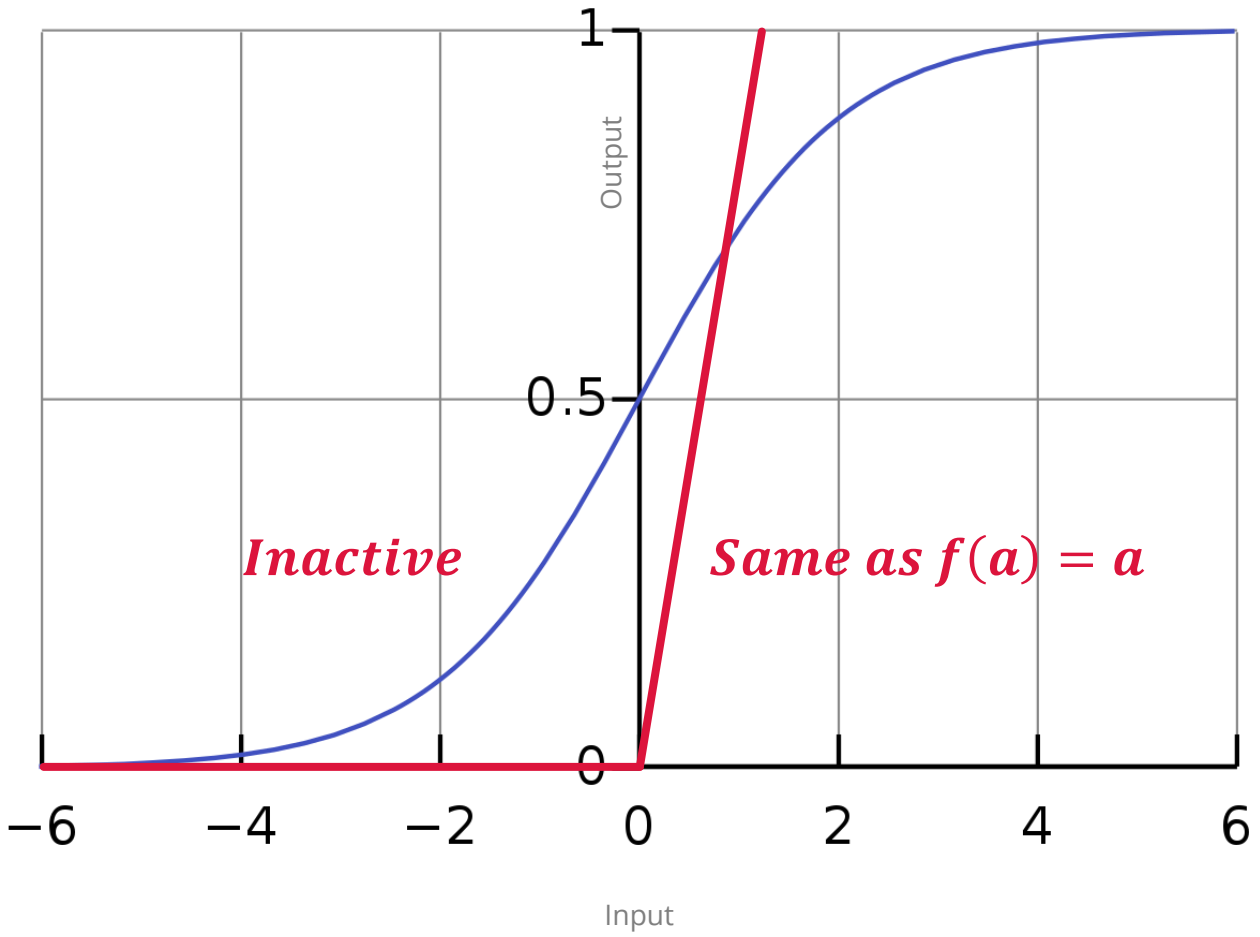
$$\boldsymbol{a^{(1)} = \sigma\left(W a^{(0)} + b\right)}$$

Rectified Linear Unit

Sigmoid

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

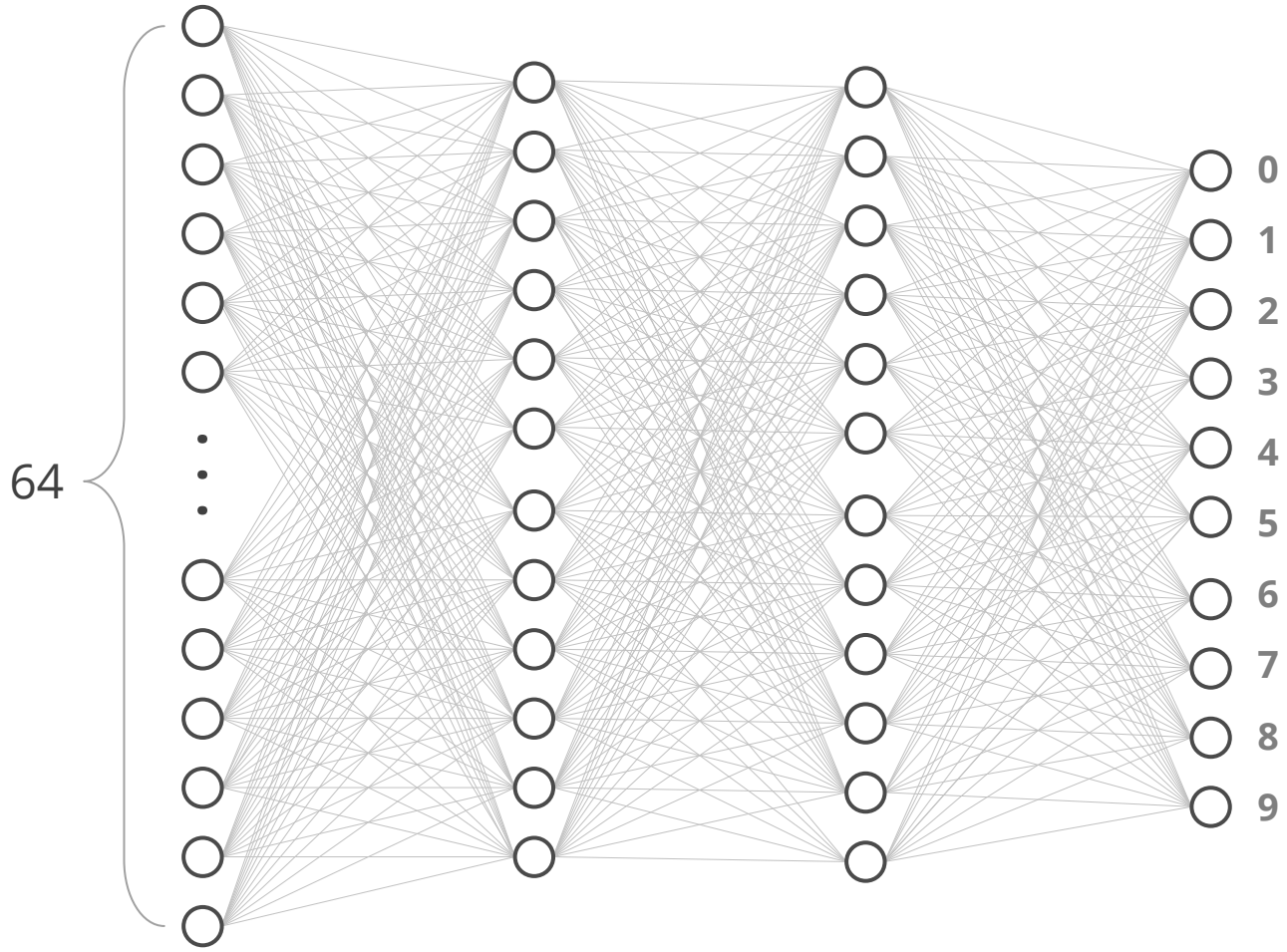
Slow learner



ReLU

$$ReLU(a) = \max(0, a)$$

Neural Network: Model Parameters



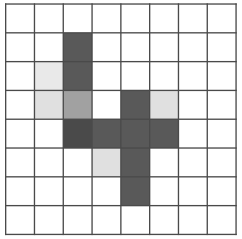
$$64 * 12 + 12 * 12 + 12 * 10$$
$$weights$$

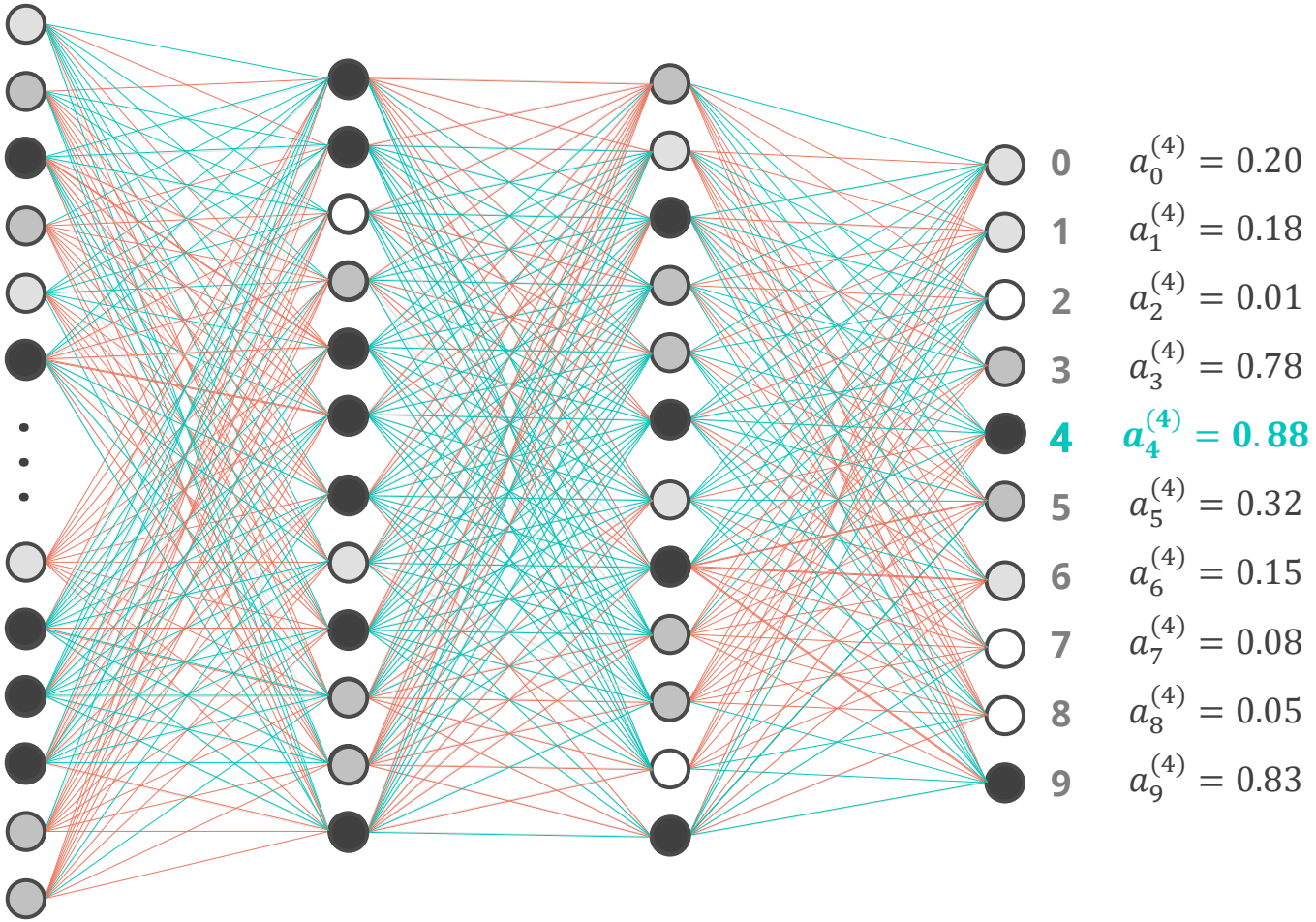
$$12 + 12 + 10$$
$$biases$$

4,394

Learning → Finding the right weights and biases

The Cost Function





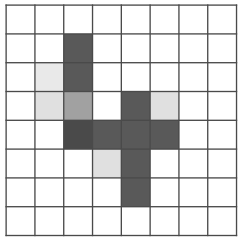
0	$a_0^{(4)} = 0.20$
1	$a_1^{(4)} = 0.18$
2	$a_2^{(4)} = 0.01$
3	$a_3^{(4)} = 0.78$
4	$\boldsymbol{a_4^{(4)} = 0.88}$
5	$a_5^{(4)} = 0.32$
6	$a_6^{(4)} = 0.15$
7	$a_7^{(4)} = 0.08$
8	$a_8^{(4)} = 0.05$
9	$a_9^{(4)} = 0.83$

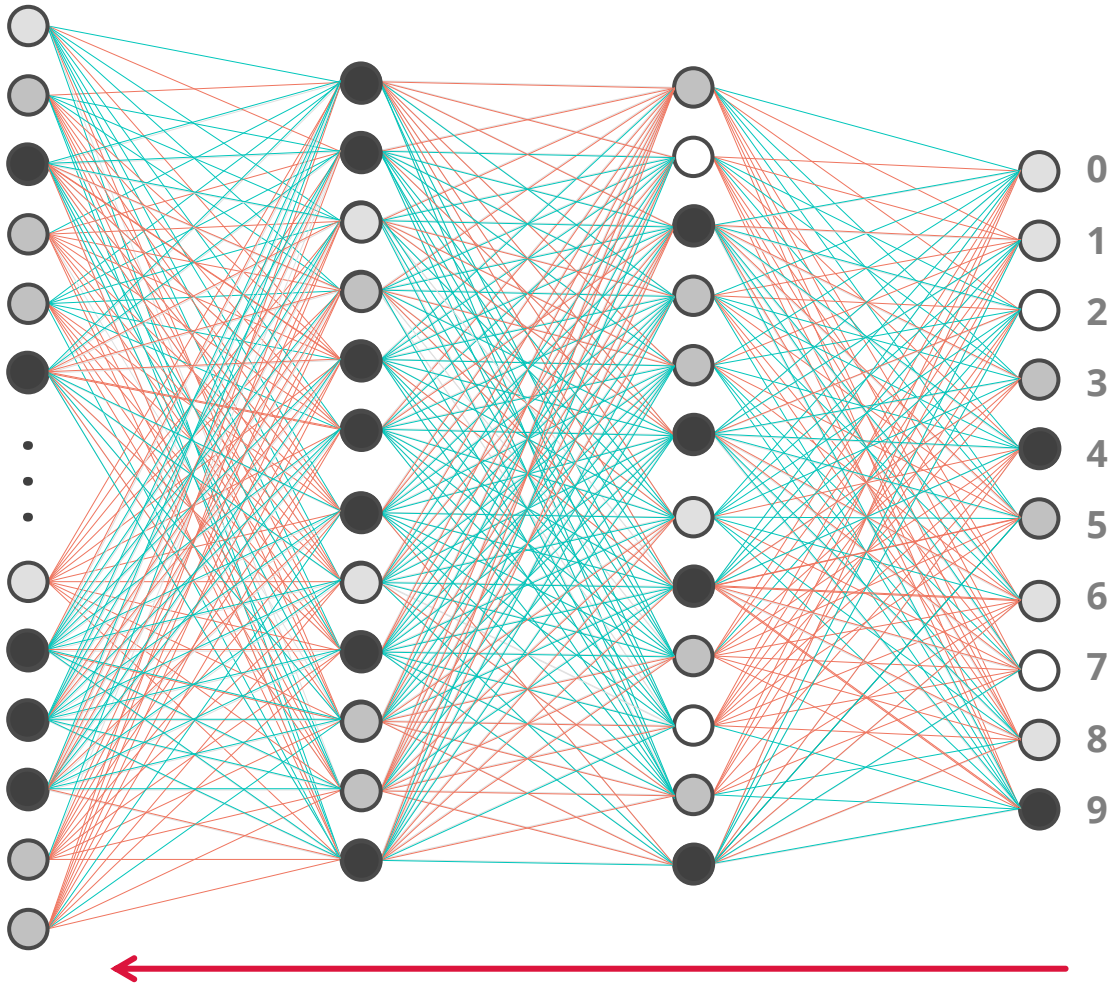
Weights and biases → Training data → Cost

Input **Output**

Mean Squared Error (Quadratic cost),
Cross-entropy cost, etc.

Backpropagation





Actual Output	Desired Output	Adj.
0.20	0	-
0.18	0	-
0.01	0	
0.78	0	-
0.88	1	+
0.32	0	-
0.15	0	-
0.08	0	-
0.05	0	
0.83	0	-

Resources

3Blue1Brown series S3 • E1

But what is a Neural Network? | Deep learning, chapter 1

8,866,833 views • Oct 5, 2017 227K 2K SHARE SAVE

Introduction | Deep Learning Tutorial 1 (Tensorflow Tutorial, Keras & Python)

56,034 views • Premiered Jul 11, 2020

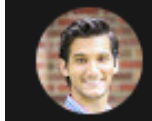
codebasics

277K subscribers

TensorFlow, Keras and deep learning, without a PhD

MIT 6.S191 (2020): Convolutional Neural Networks

195,647 views • Premiered Feb 21, 2020



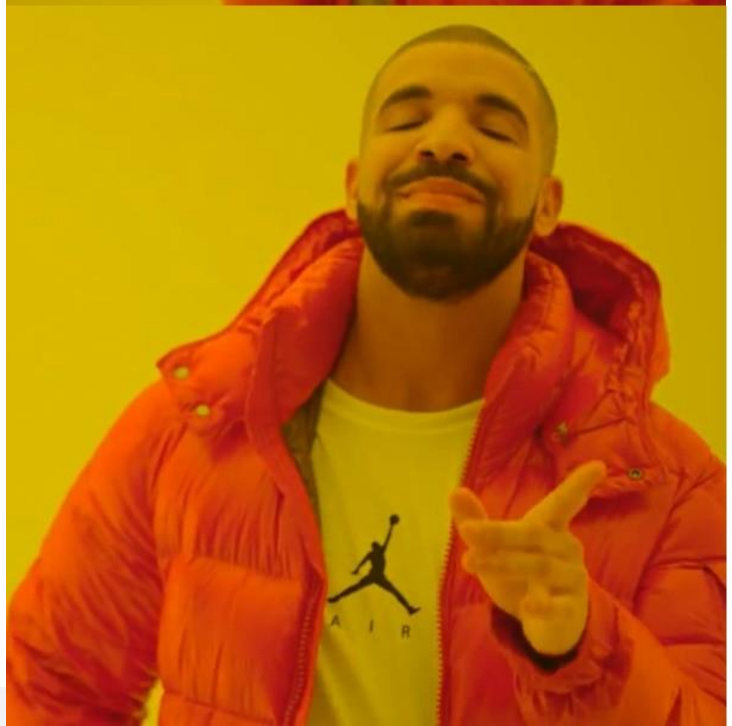
Alexander Amini

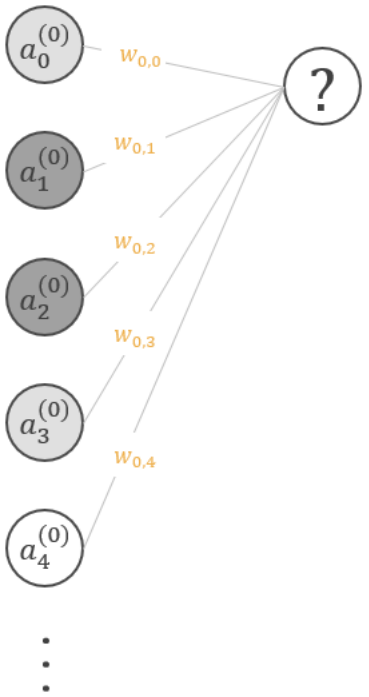
102K subscribers

Deep Learning: CS 182 Spring 2021

44 videos • 14,902 views • Last updated on Mar 13, 2021

Lectures for UC Berkeley CS 182: Deep Learning.





$$a_0^{(1)} = \sigma\left(w_{0,0}a_0^{(0)} + w_{0,1}a_1^{(0)} + \cdots + w_{0,n}a_n^{(0)} + b_0 \right)$$

$$\sigma\left(\begin{bmatrix} w_{0,0} & w_{0,1} & \cdots & w_{0,n} \\ w_{1,0} & w_{1,1} & \cdots & w_{1,n} \\ \cdots & \cdots & \cdots & \cdots \\ w_{k,0} & w_{k,1} & \cdots & w_{k,n} \end{bmatrix} \begin{bmatrix} a_0^{(0)} \\ a_1^{(0)} \\ \cdots \\ a_n^{(0)} \end{bmatrix} + \begin{bmatrix} b_0 \\ b_1 \\ \cdots \\ b_n \end{bmatrix} \right)$$

$$\boldsymbol{a}^{(1)} = \boldsymbol{\sigma}\left(\boldsymbol{W}\boldsymbol{a}^{(0)} + \boldsymbol{b}\right)$$

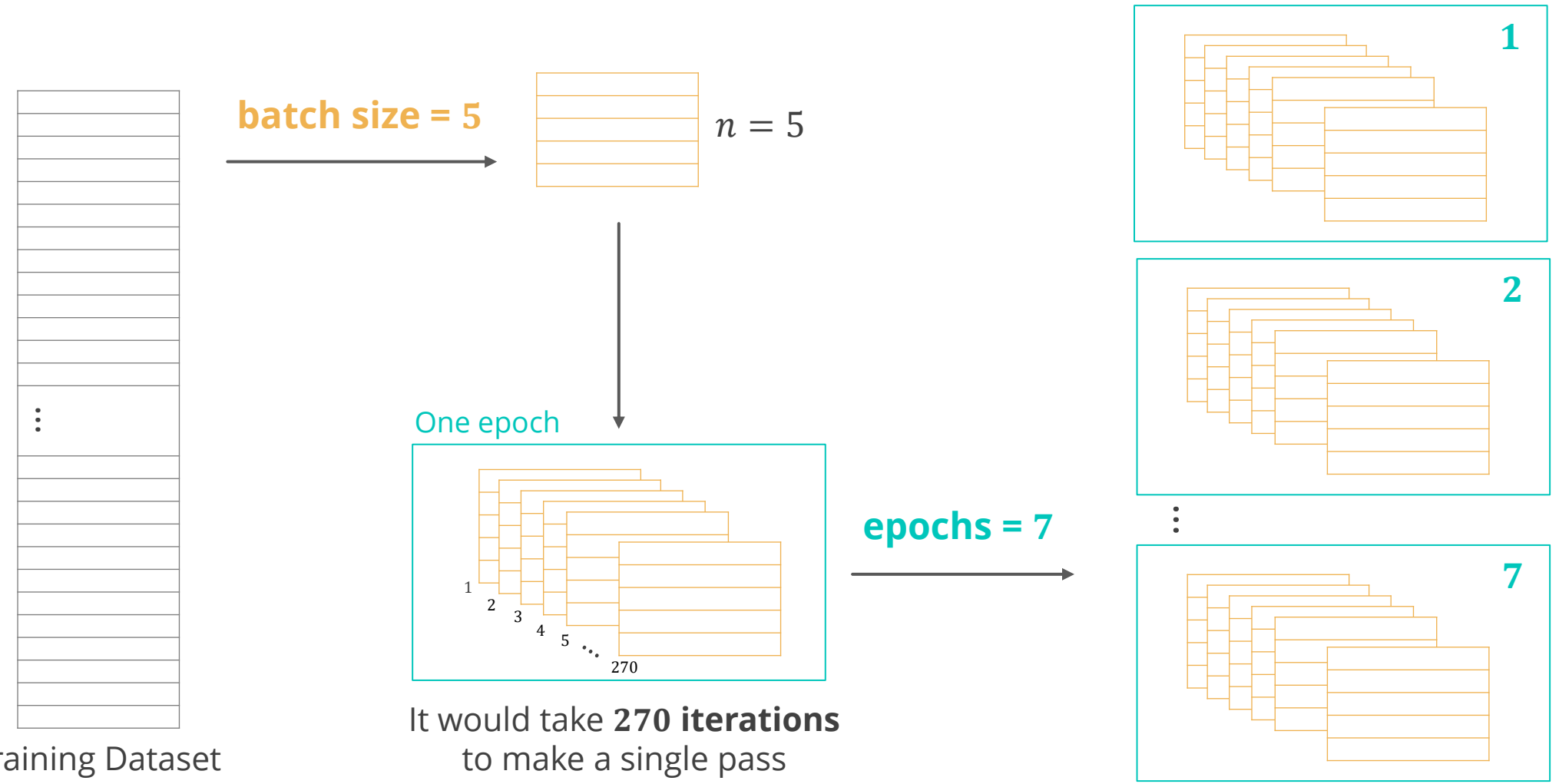
```
import tensorflow as tf
```

Neural Network Tutorial

12_digits_recognition_model.ipynb

13_intro_neural_net.ipynb

batch, iterations, and epoch



Training Dataset

$n = 1{,}357$

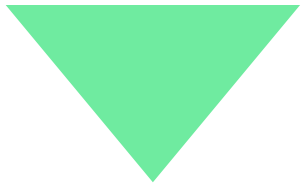
It would take **270 iterations** to make a single pass through the entire dataset.

$(5\ x\ 270\ \approx\ 1{,}357)$

Since epoch=7, the model will make 7 passes through the entire dataset.

Fully Connected MLP

- Computationally expensive
- Spatial information is lost
- Sensitive to location of objects within an image



Convolutional Neural Networks (CNNs)

convolve

[kənˈvälv]

VERB *rare*

convolve *(verb)* · ***convolves*** *(third person present)* · ***convolved*** *(past tense)* · ***convolved*** *(past participle)* · ***convolving*** *(present participle)*

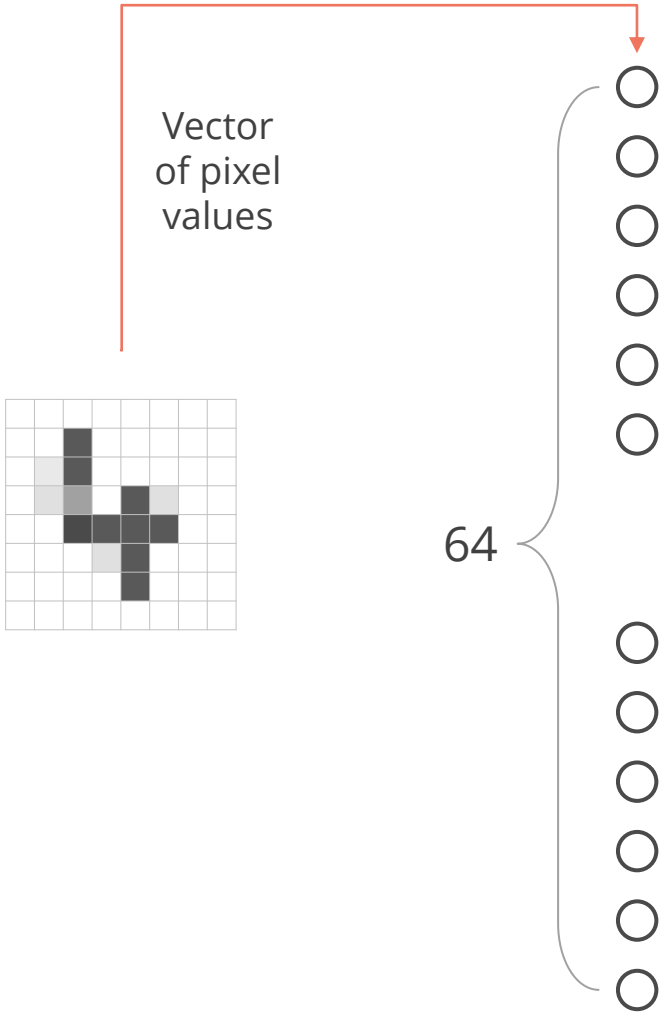
roll or coil together; entwine.

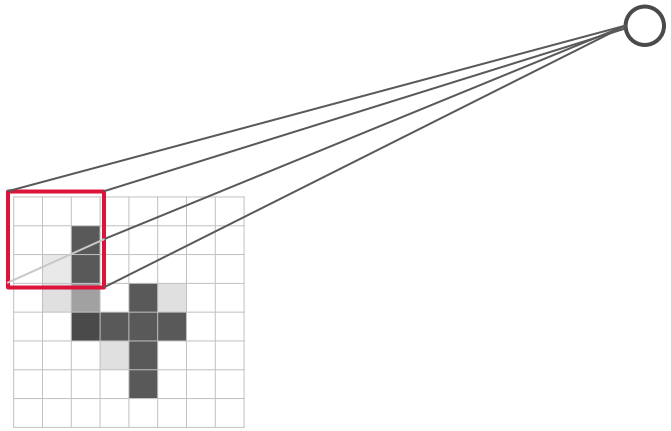
- *mathematics*
  combine (one function or series) with another by forming their convolution.

ORIGIN

late 16th century (in the sense 'enclose in folds'): from Latin convolvere 'roll together', from con- 'together' + volvere 'roll'.

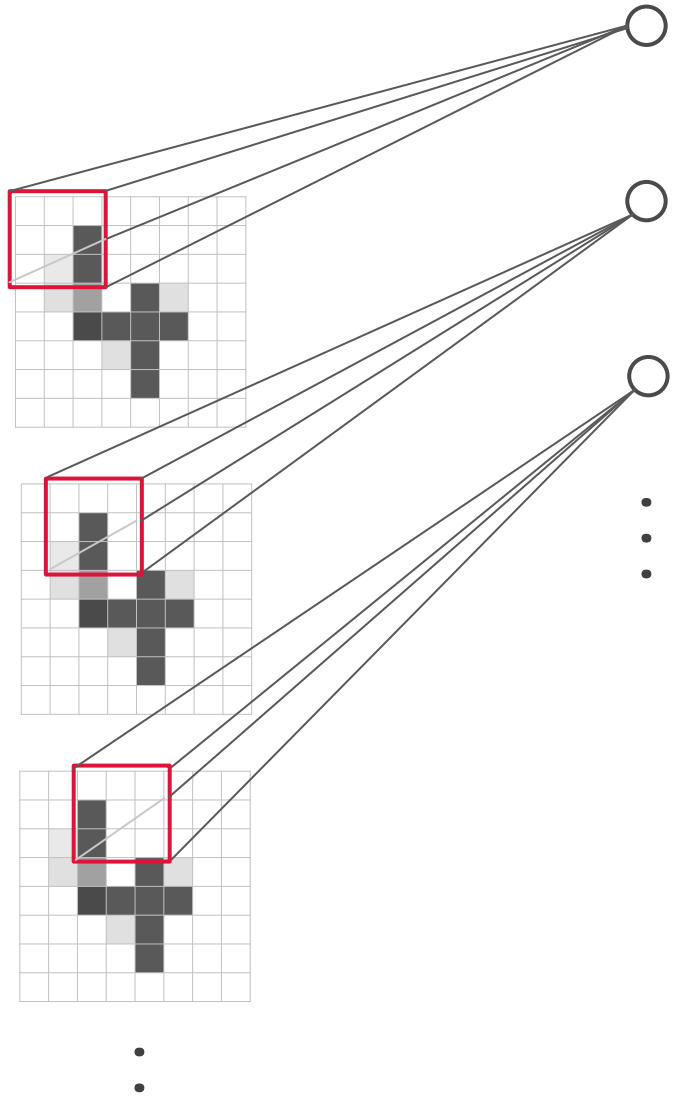
Spatial Structure





Instead of connecting each input (pixel) with a neuron, connect patches of input to a neuron.

Convolution



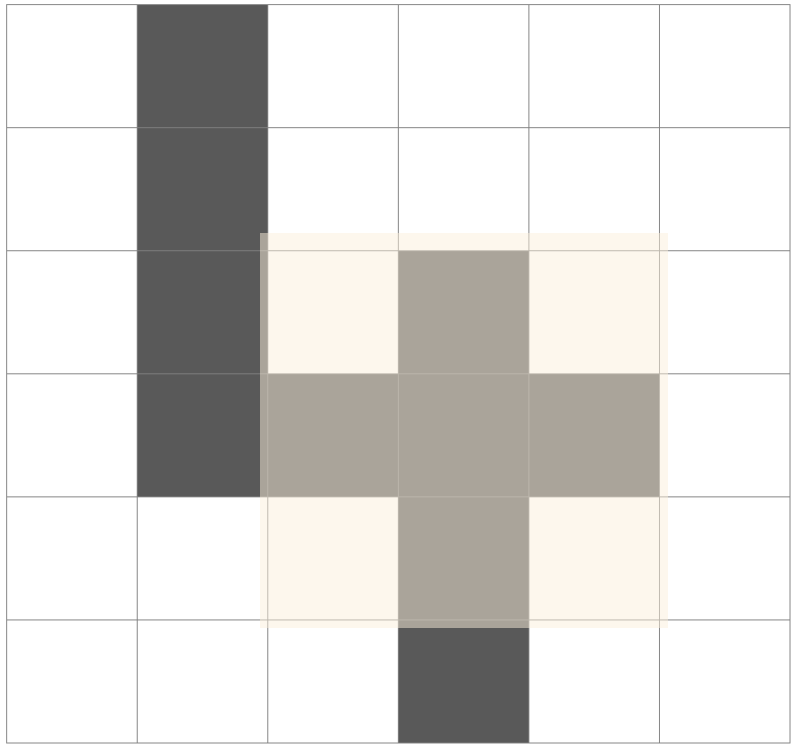
Filter = A **patch** of size 3x3 (in this example)

Instead of taking a straight sum of all pixels within a patch, a set of weights are created which are then used to take a weighted sums.

Multiple filters (i.e., set of weights) are used to extract different features.

Feature Extraction

A Filter to Detect a Feature



Let’s create a filter to identify the cross.

A Filter to Detect a Feature

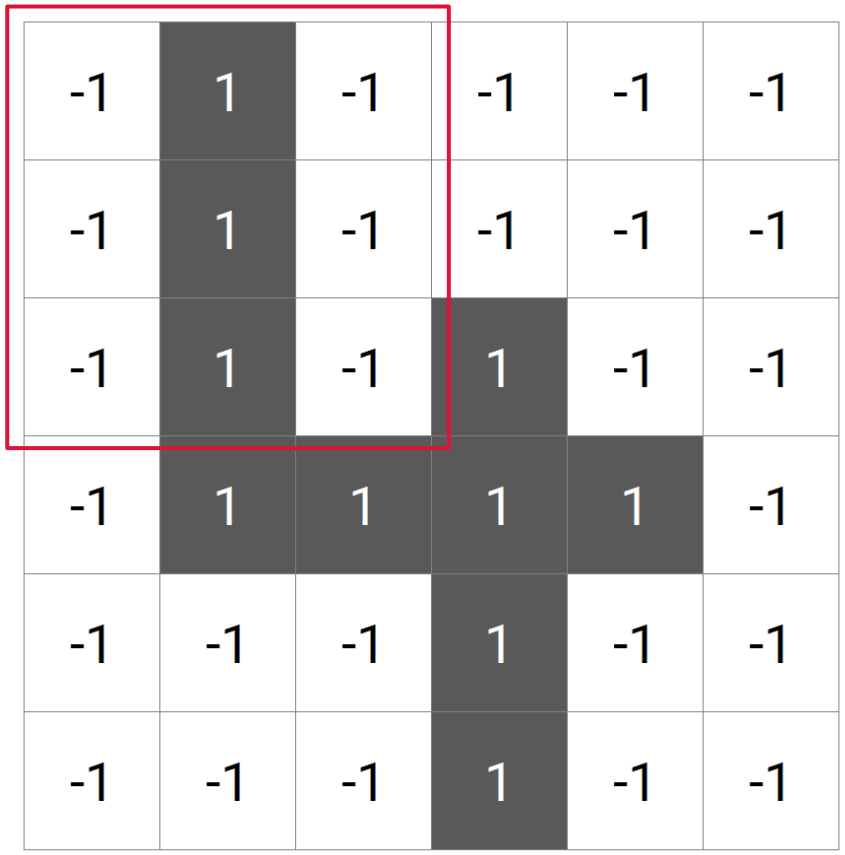
-1	1	-1	-1	-1	-1
-1	1	-1	-1	-1	-1
-1	1	-1	1	-1	-1
-1	1	1	1	1	-1
-1	-1	-1	1	-1	-1
-1	-1	-1	1	-1	-1

Input

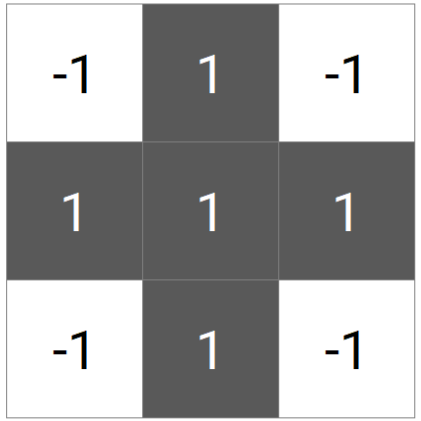
-1	1	-1
1	1	1
-1	1	-1

Filter

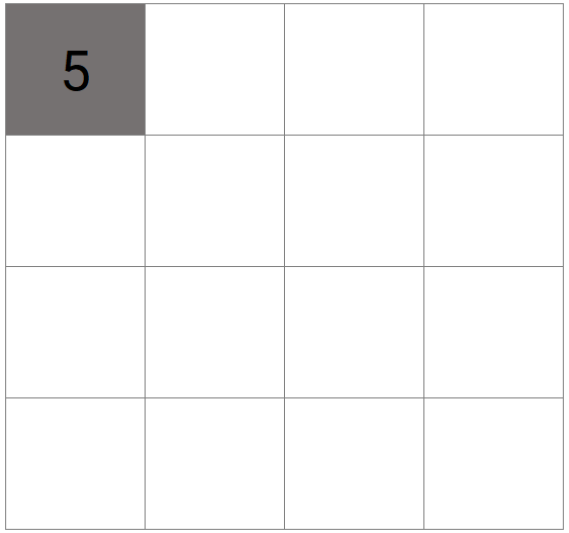
A Filter to Detect a Feature



Input



Filter



$$(-1 * -1) + (1 * 1) + (-1 * -1) + (-1 * 1) + (1 * 1) + (-1 * 1) + (-1 * -1) + (1 * 1) + (-1 * -1)$$

$$1 + 1 + 1 - 1 + 1 - 1 + 1 + 1 + 1 = 5$$

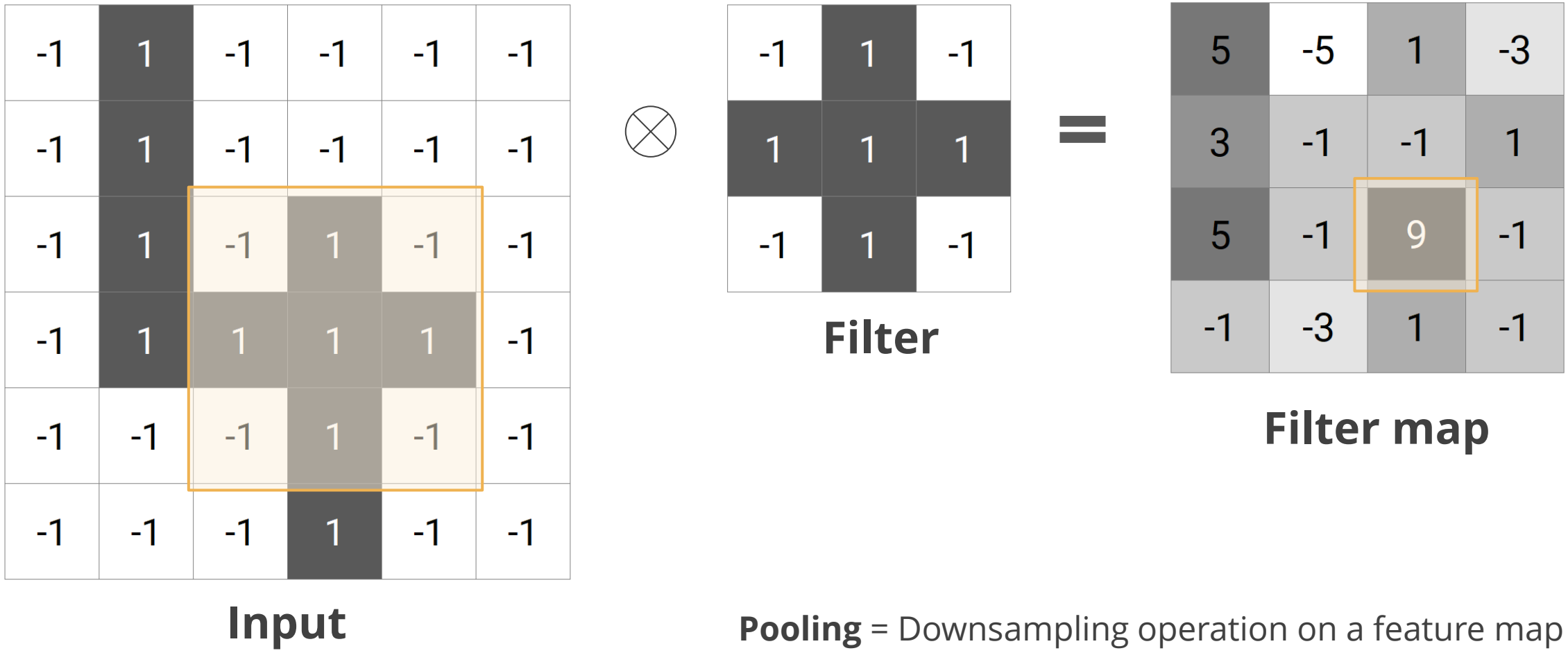
A Filter to Detect a Feature

-1	1	-1	-1	-1	-1
-1	1	-1	-1	-1	-1
-1	1	-1	1	-1	-1
-1	1	1	1	1	-1
-1	-1	-1	1	-1	-1
-1	-1	-1	1	-1	-1

-1	1	-1
1	1	1
-1	1	-1

5	-5		

A Filter to Detect a Feature



Pooling = Downsampling operation on a feature map

CNN Tutorial

14_image_classification_cnn.ipynb