

Convolutional Neural Networks

Plan of Attack

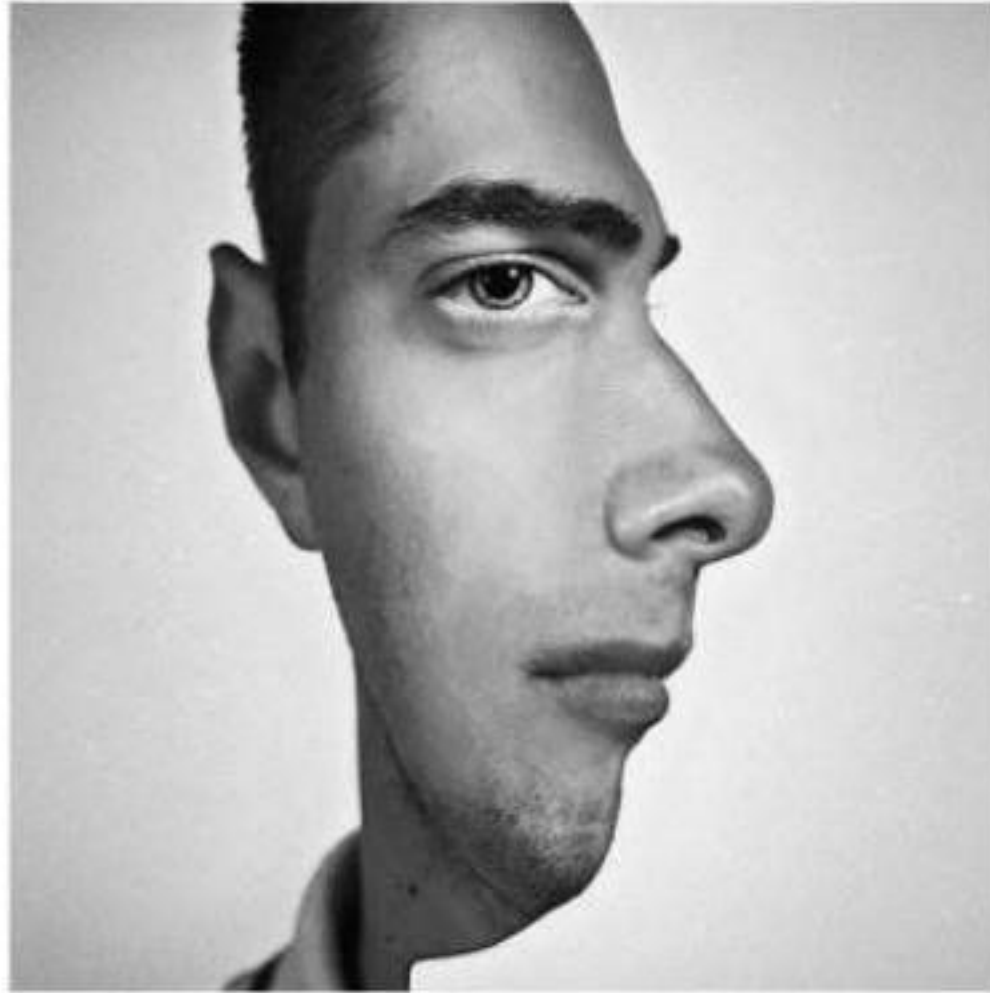
What we will learn in this section:

- What are Convolutional Neural Networks?
- Step 1 - Convolution Operation
- Step 1(b) - ReLU Layer
- Step 2 - Pooling
- Step 3 - Flattening
- Step 4 - Full Connection
- Summary

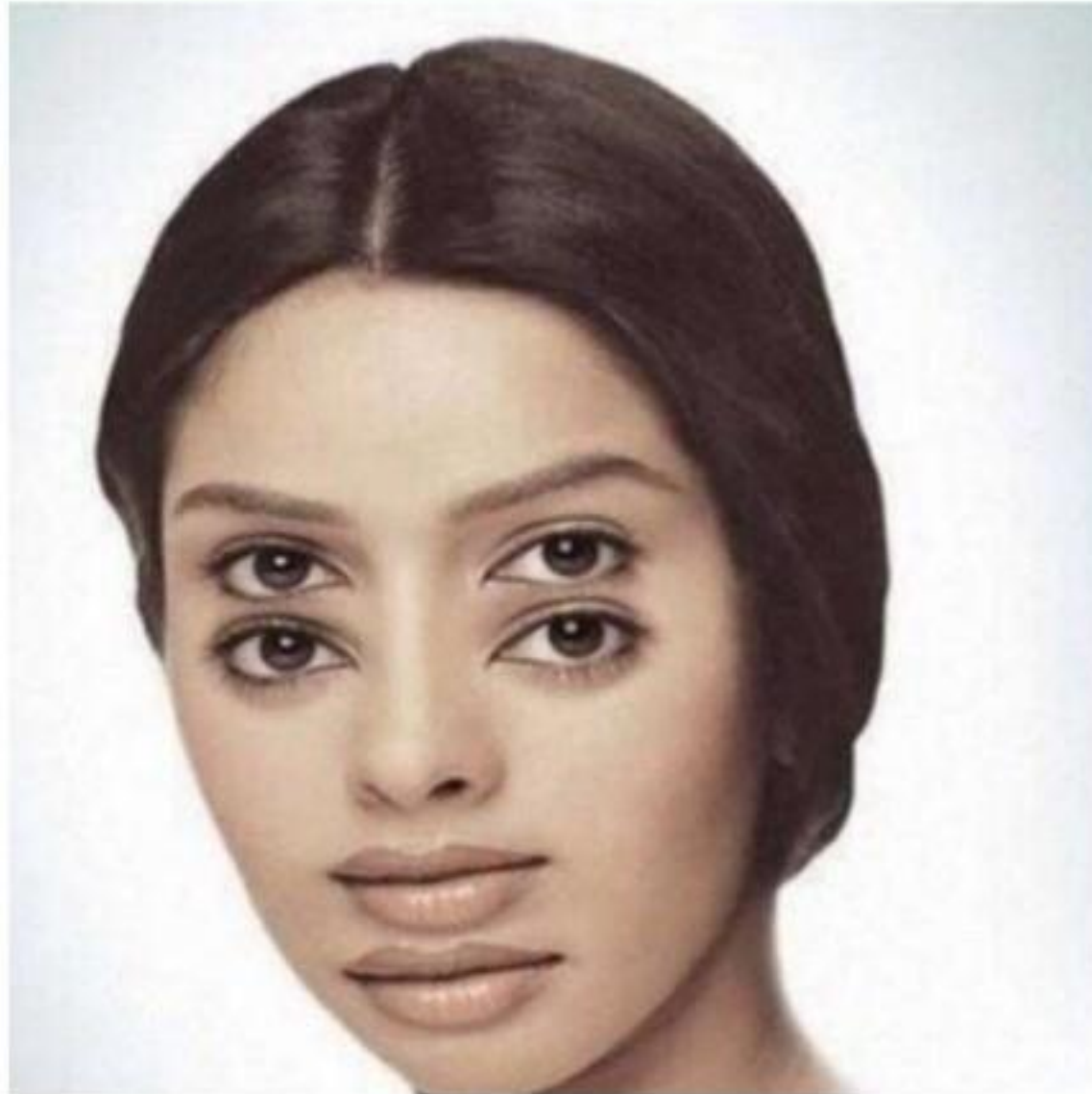
- EXTRA: Softmax & Cross-Entropy

What are convolutional neural networks?

Convolutional Neural Networks

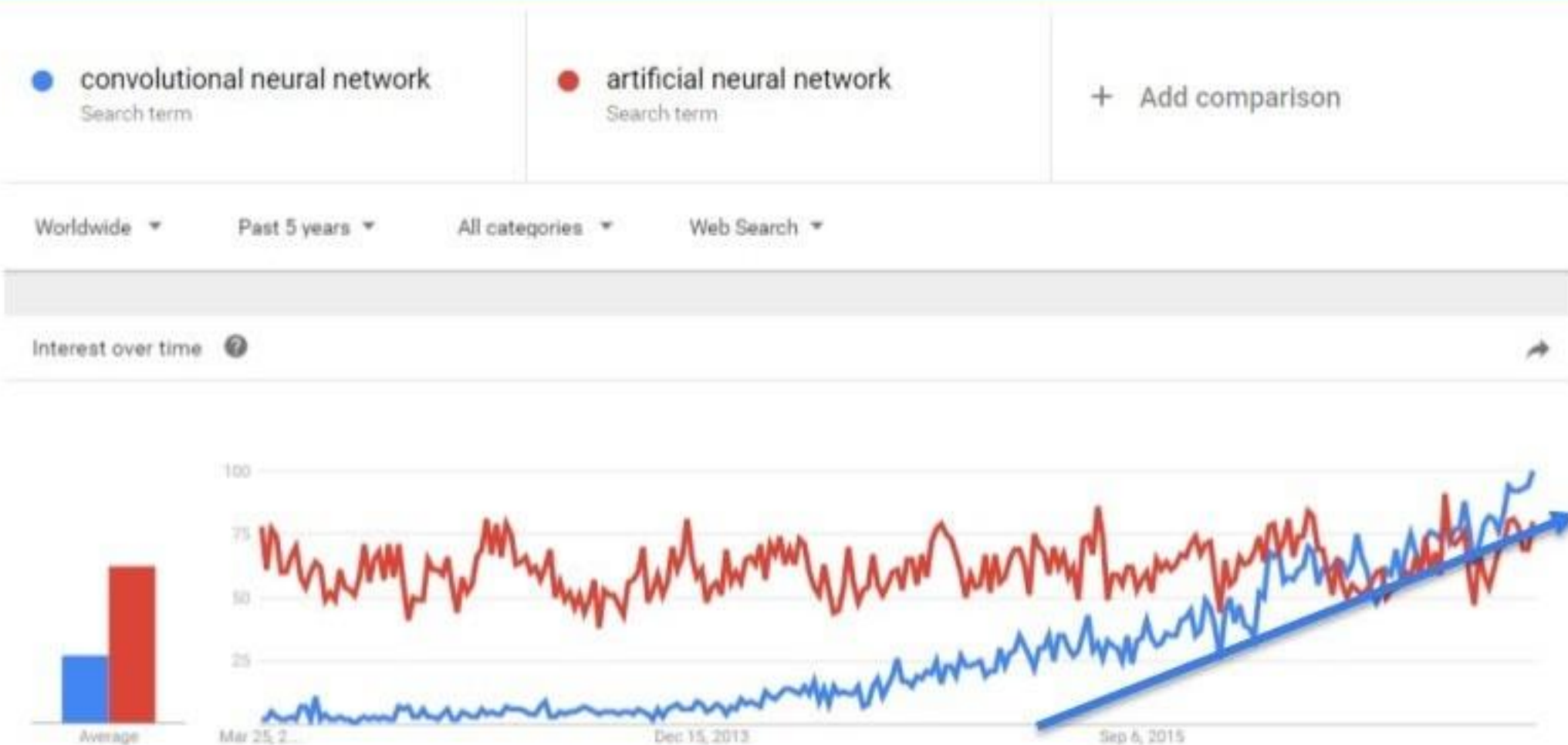


Convolutional Neural Networks



CNN

Convolutional Neural Networks



Source: google trends

Convolutional Neural Networks



Yann Lecun

Convolutional Neural Networks

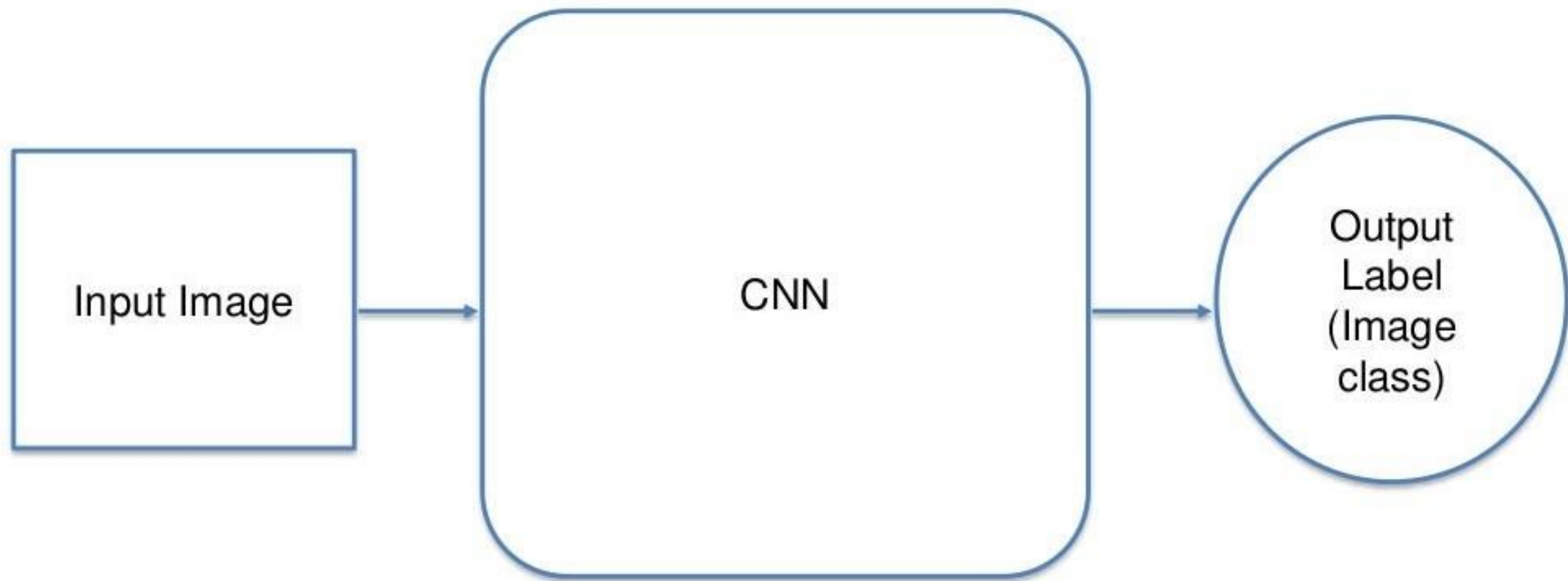
Google

Facebook

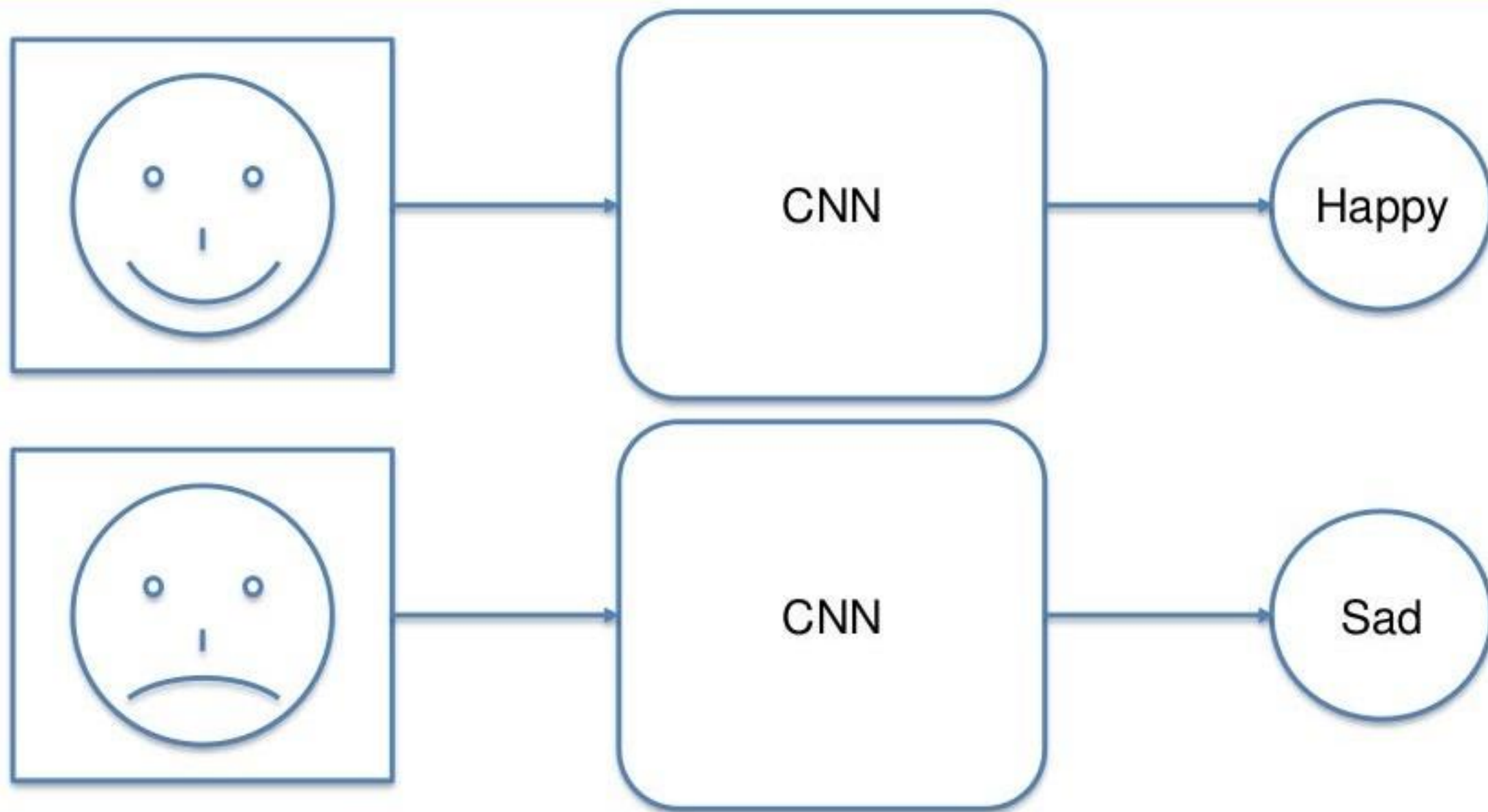


CNN

Convolutional Neural Networks



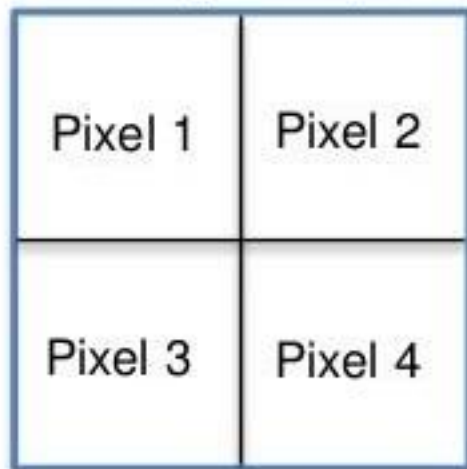
Convolutional Neural Networks



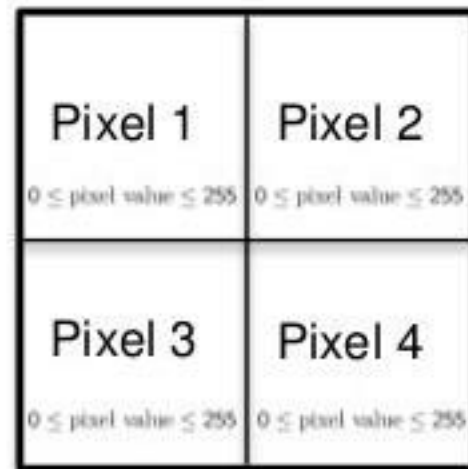
CNN

Convolutional Neural Networks

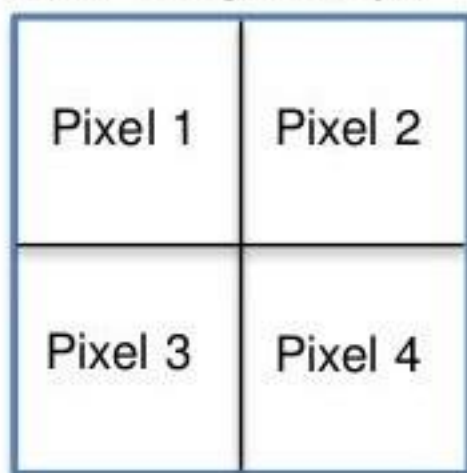
B / W Image 2x2px



2d array



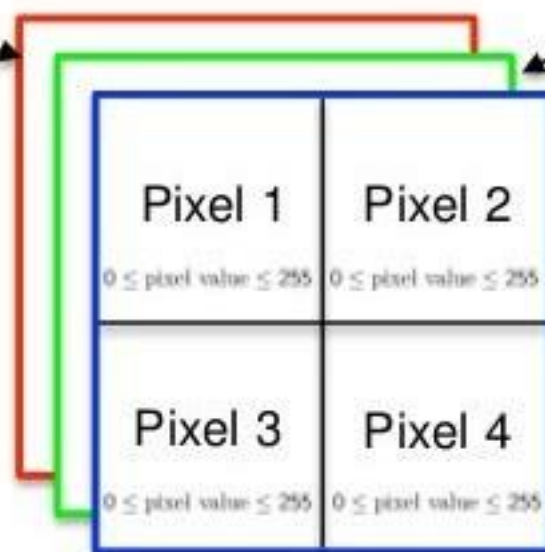
Colored Image 2x2px



3d array

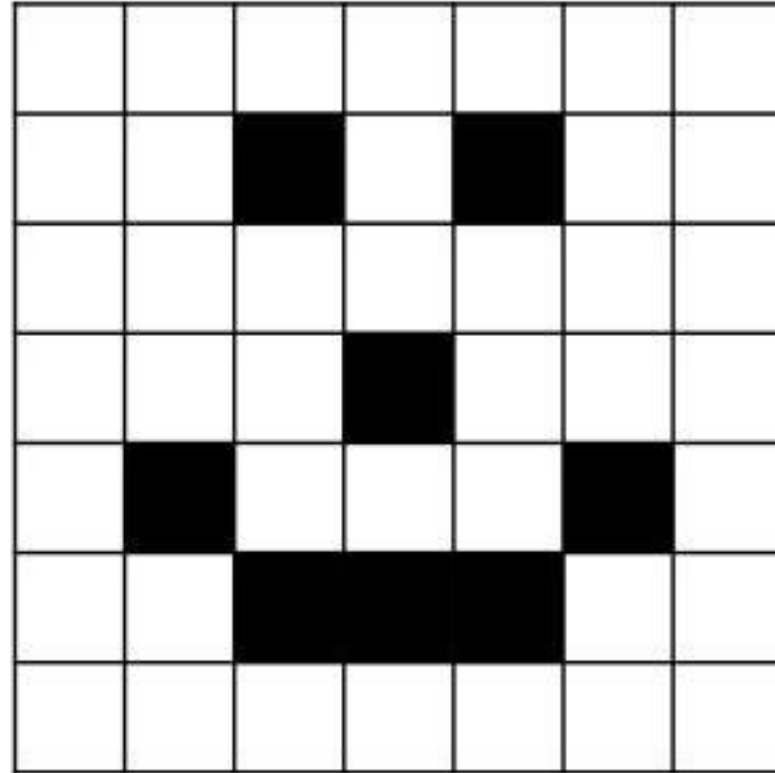
Red channel

Green channel



Blue channel

Convolutional Neural Networks



0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Convolutional Neural Networks

STEP 1: Convolution



STEP 2: Max Pooling



STEP 3: Flattening



STEP 4: Full Connection

Convolutional Neural Networks

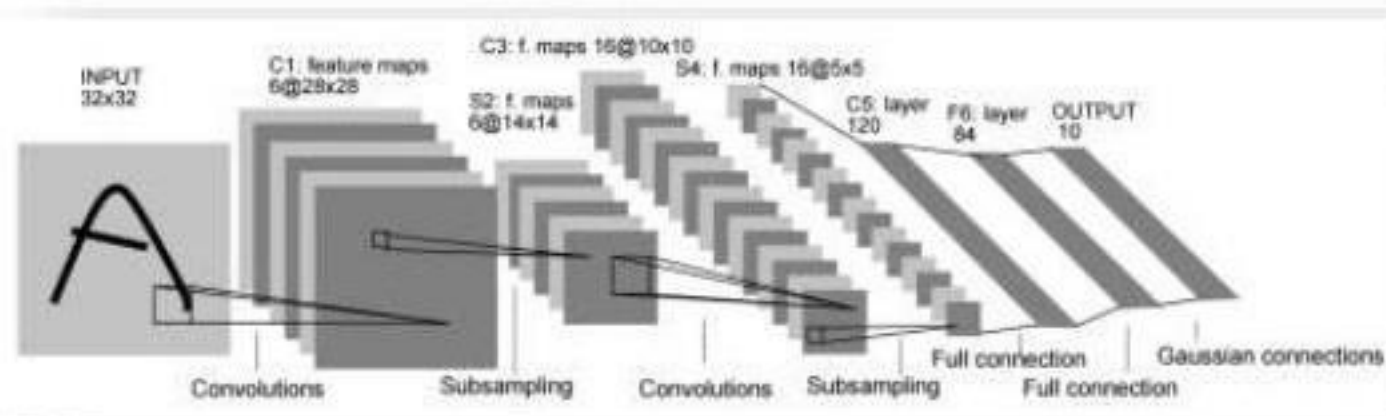
Additional Reading:

*Gradient-Based Learning
Applied to Document
Recognition*

By Yann LeCun et al. (1998)

Link:

<http://yann.lecun.com/exdb/publis/pdf/lecun-01a.pdf>



Step 1 – Convolution

Step 1 - Convolution

$$(f * g)(t) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} f(\tau) g(t - \tau) d\tau$$

Step 1 - Convolution

Additional Reading:

Introduction to Convolutional Neural Networks

By Jianxin Wu (2017)

Link:

<http://cs.nju.edu.cn/wujx/paper/CNN.pdf>

$$\begin{aligned}\frac{\partial z}{\partial (\text{vec}(\mathbf{y})^T)} (F^T \otimes I) &= \left((F \otimes I) \frac{\partial z}{\partial \text{vec}(\mathbf{y})} \right)^T \\ &= \left((F \otimes I) \text{vec} \left(\frac{\partial z}{\partial Y} \right) \right)^T \\ &= \text{vec} \left(I \frac{\partial z}{\partial Y} F^T \right)^T \\ &= \text{vec} \left(\frac{\partial z}{\partial Y} F^T \right)^T,\end{aligned}$$

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image

0	0	1
1	0	0
0	1	1

Feature Detector

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0				

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1			

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0		

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0				

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1			

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1		

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1				

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0			

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1		

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1				

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4			

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2		

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2	1	

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2	1	0

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2	1	0
0				

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2	1	0
0	0			

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2	1	0
0	0	1		

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2	1	0
0	0	1	2	

Feature Map

Step 1 - Convolution

0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	1	0	0	0	1	0
0	0	1	1	1	0	0
0	0	0	0	0	0	0

Input Image



0	0	1
1	0	0
0	1	1

Feature Detector



0	1	0	0	0
0	1	1	1	0
1	0	1	2	1
1	4	2	1	0
0	0	1	2	1

Feature Map