Topic 04

Well Known DL Architecture
CNN

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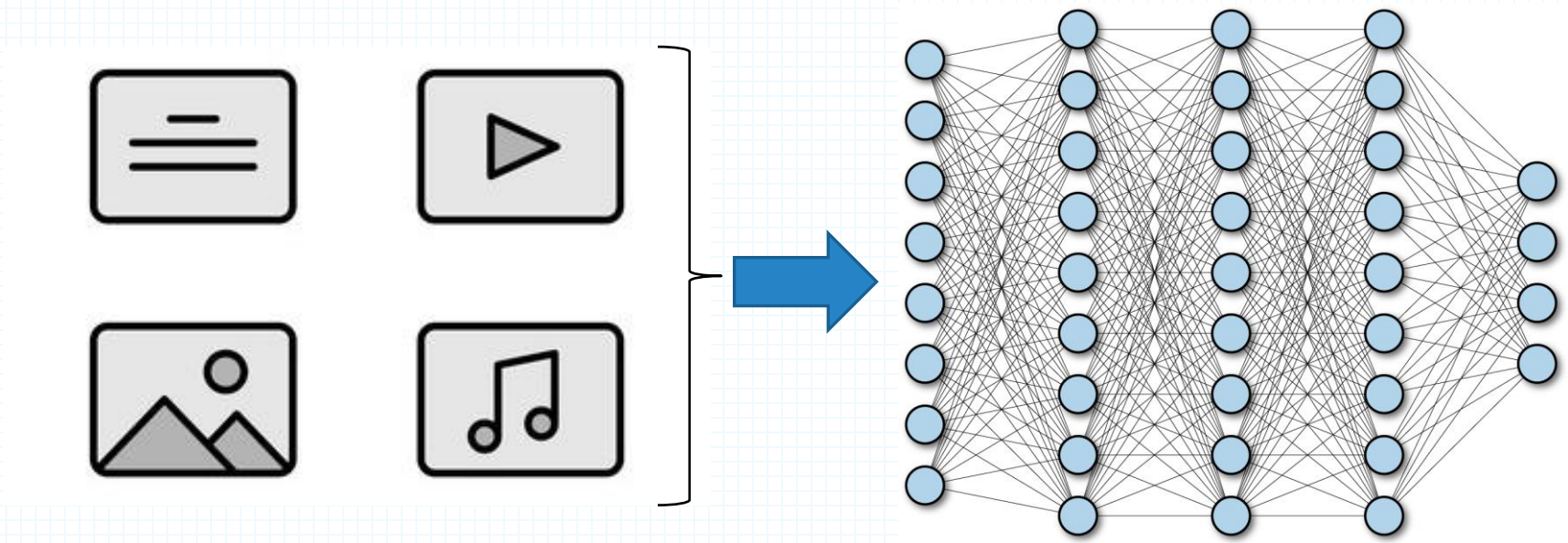
Large networks

- What kind of neural networks can be used for large or variable length input vectors (e.g., time series)?
- Common networks:
  - CNN, RNN, etc



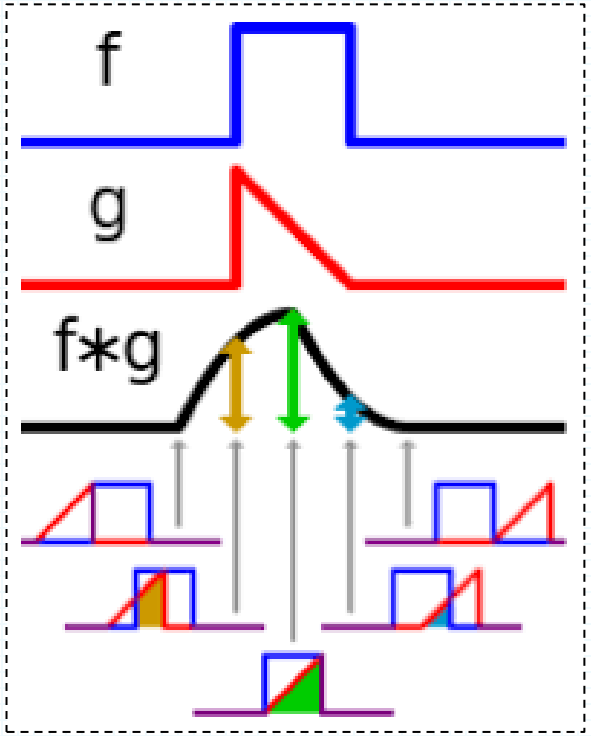
الشبكة العصبونية التلافيفية
Convolutional Neural Network (CNN)

Convolution

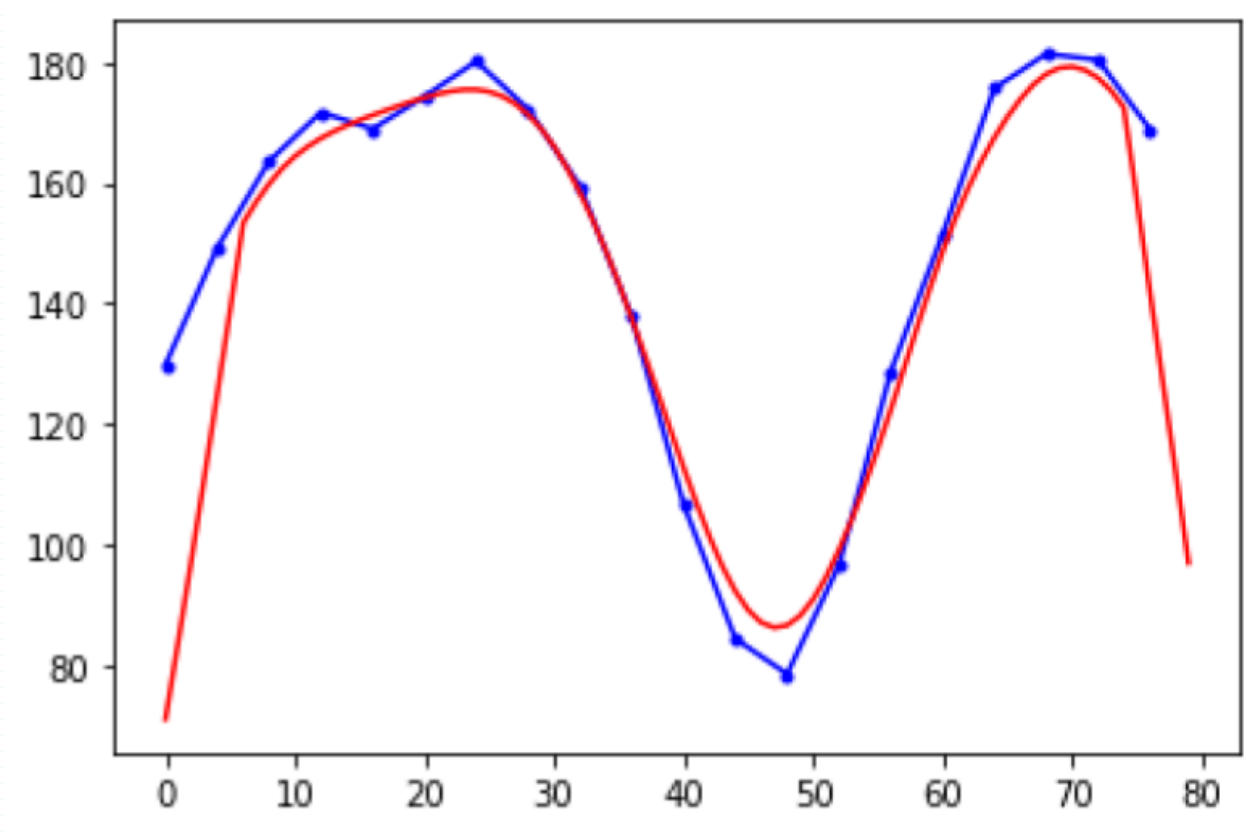
- **Convolution:** mathematical operation on two functions $x()$ and $w()$ that produces a third function $y()$ that can be viewed as a modified version of one of the original functions $x()$

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

To convolve a kernel with an input signal:
flip the signal, move to the desired time,
and accumulate every interaction with the kernel



Example Smoothing



Discrete convolution

- Discrete convolution

$$y(i) = \sum_{t=-\infty}^{\infty} x(t)w(i-t)$$

- Multidimensional convolution

$$y(i,j) = \sum_{t_1=-\infty}^{\infty} \sum_{t_2=-\infty}^{\infty} x(t_1,t_2)w(i-t_1,j-t_2)$$

Example: Edge Detection

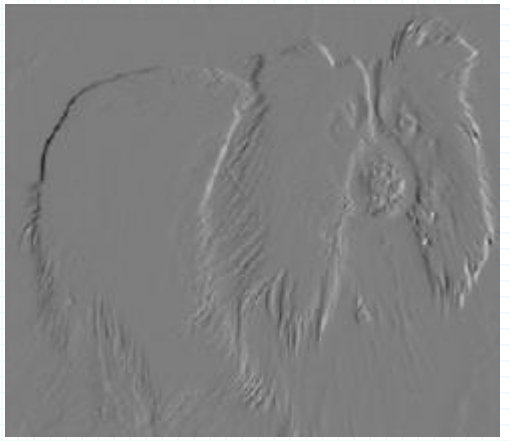
- Detect vertical edges in a grey scale image.

$$y(i,j) = x(i,j) - x(i-1,j)$$

- This subtracts the pixel value **above** from the current pixel, capturing vertical changes (i.e., vertical edge)

$$w(i-t_1, j-t_2) = \begin{cases} 1 & t_1 = i, t_2 = j \\ -1 & t_1 = i-1, t_2 = j \\ 0 & \text{otherwise} \end{cases}$$

i.e. $\begin{bmatrix} -1 \\ 1 \end{bmatrix}$



- Hence:

$$y(i,j) = \sum_{t_1=-\infty}^{\infty} \sum_{t_2=-\infty}^{\infty} x(t_1,t_2) w(i-t_1, j-t_2)$$

Convolutions for feature extraction

- In neural networks:
  - A **convolution** denotes the linear combination of a **subset of units** based on a **specific pattern of weights.**

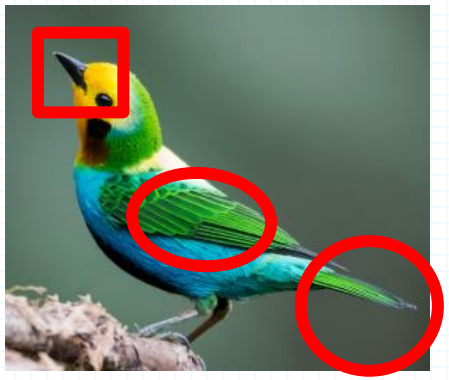
$$a_j = \sum_i w_{ji} z_i$$

  - Convolutions are often combined with an activation function to produce a feature

$$z_j = h(a_j) = h\left(\sum_i w_{ji} z_i\right)$$

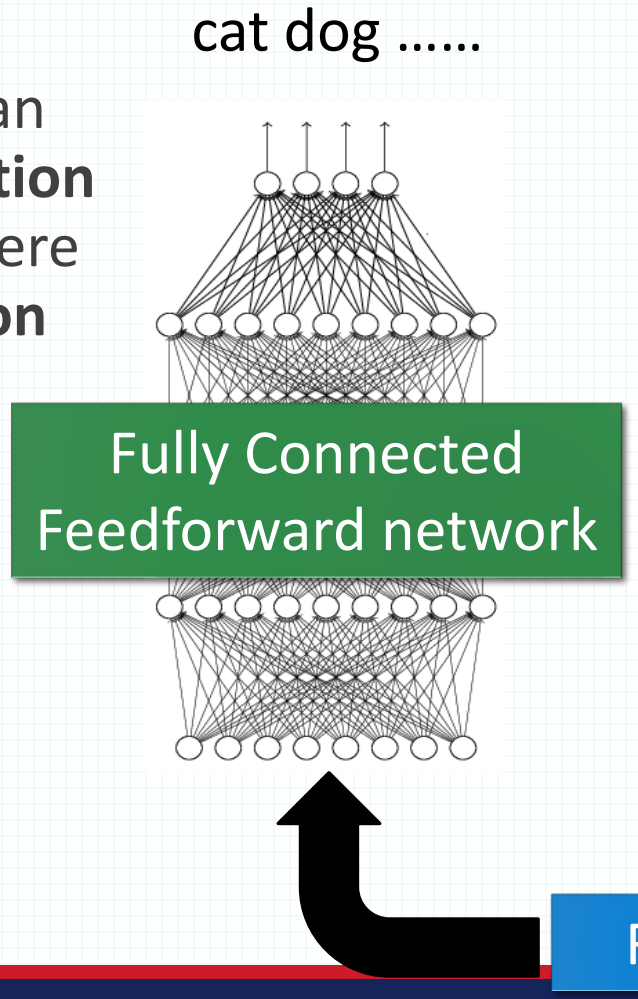
Convolutions for feature extraction

The same patterns appear in different regions.

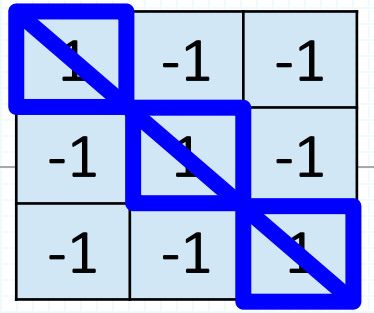


Convolution Neural Network

- A **convolutional neural network** refers to any network that includes an **alternation of convolution and pooling layers**, where **some of the convolution weights are shared.**
- Architecture:

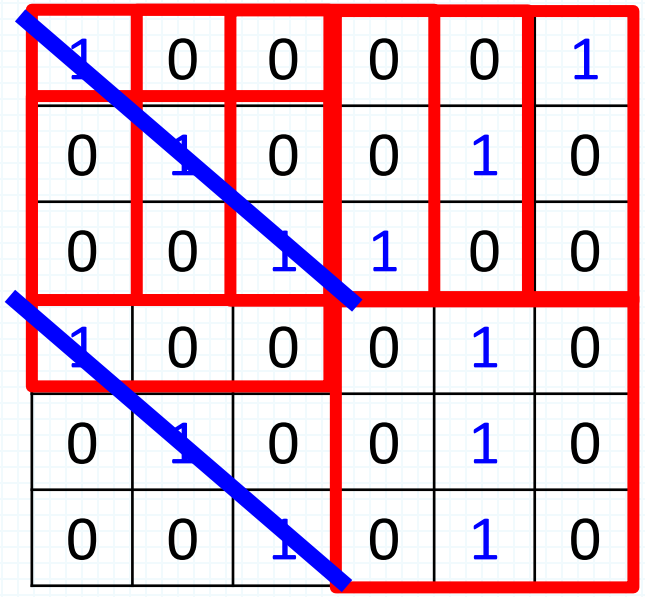


CNN – Convolution

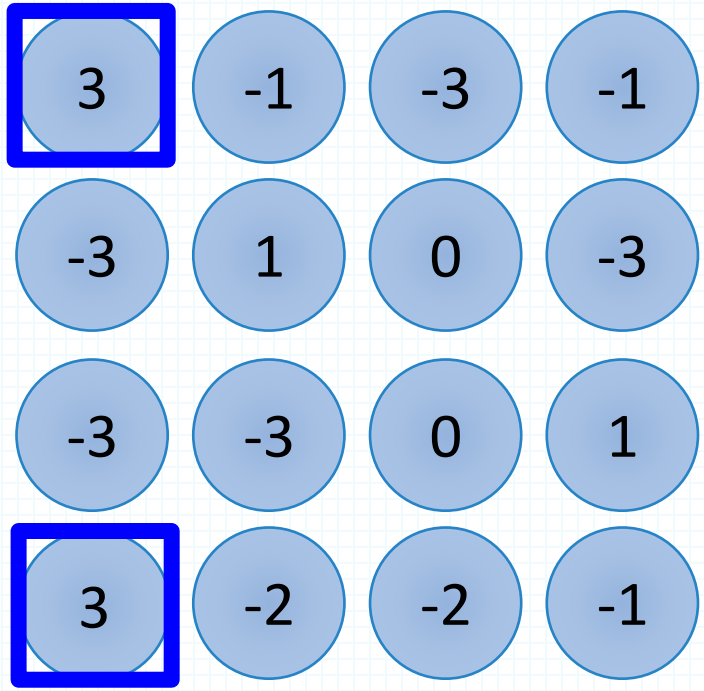


Filter 1

stride=1



6 x 6 image



CNN – Convolution

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

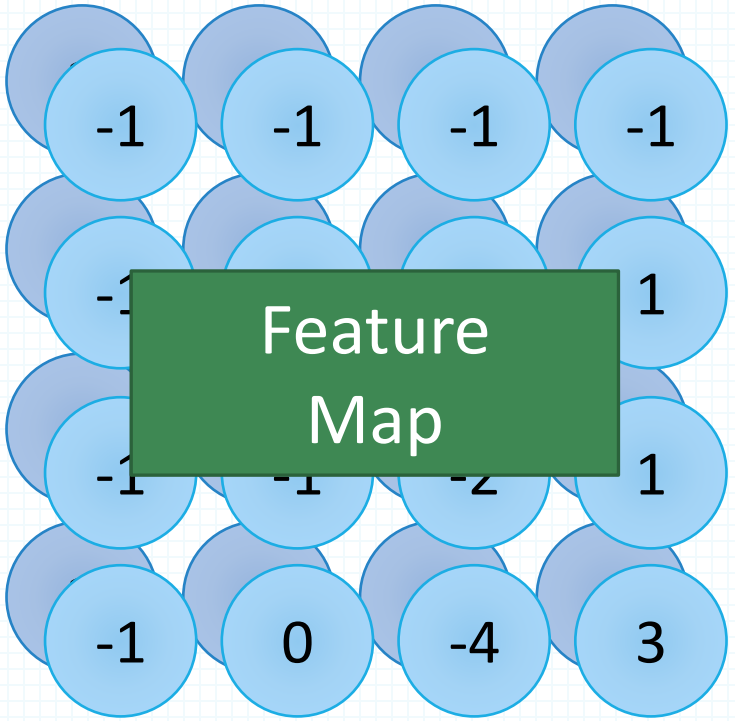
Filter 2

stride=1

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

6 x 6 image

Do the same process for every filter



4 x 4 image

CNN – Convolution

Those are the network parameters to be learned.

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

6 x 6 image

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

Filter 1

Matrix

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

Filter 2

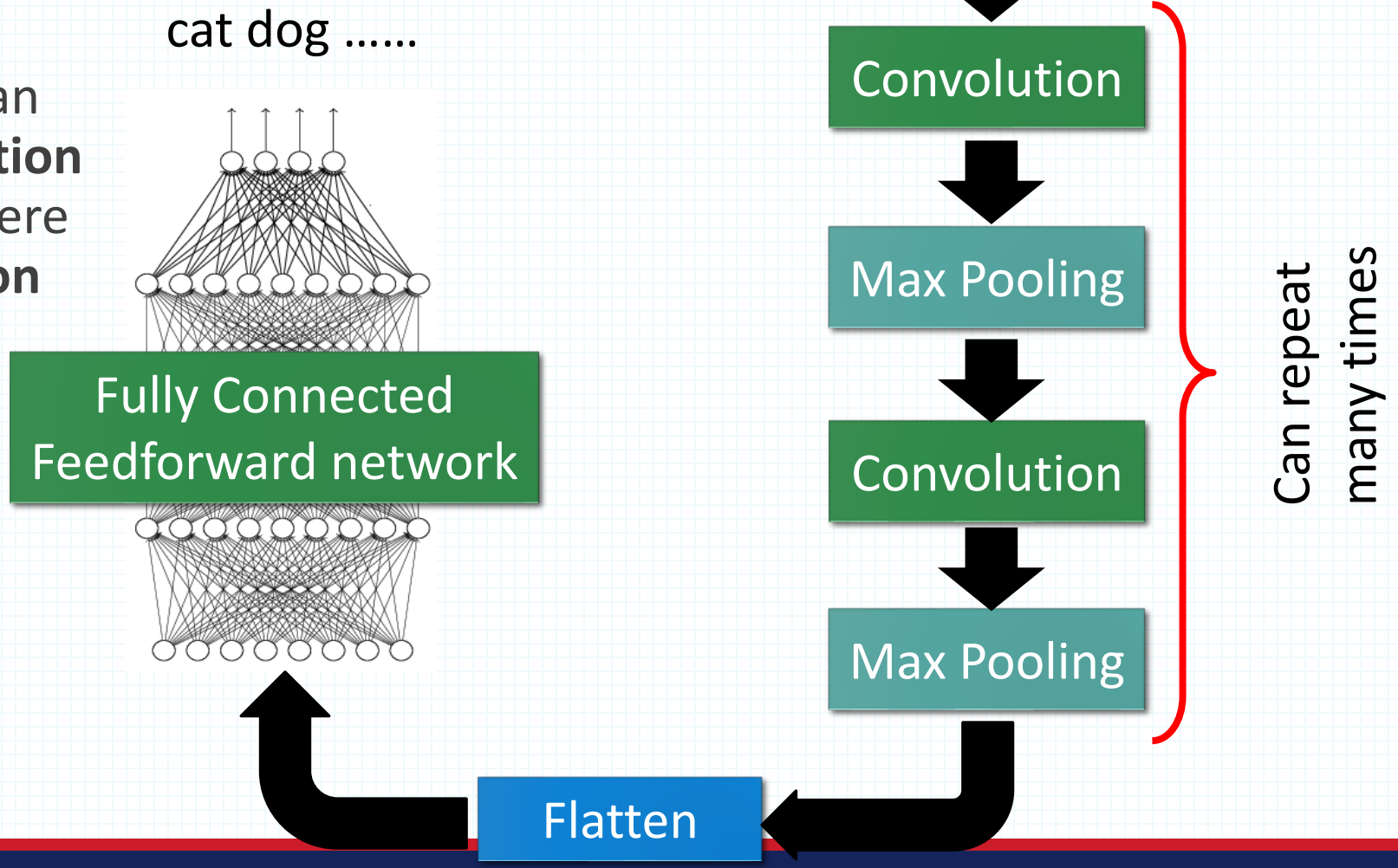
Matrix

⋮

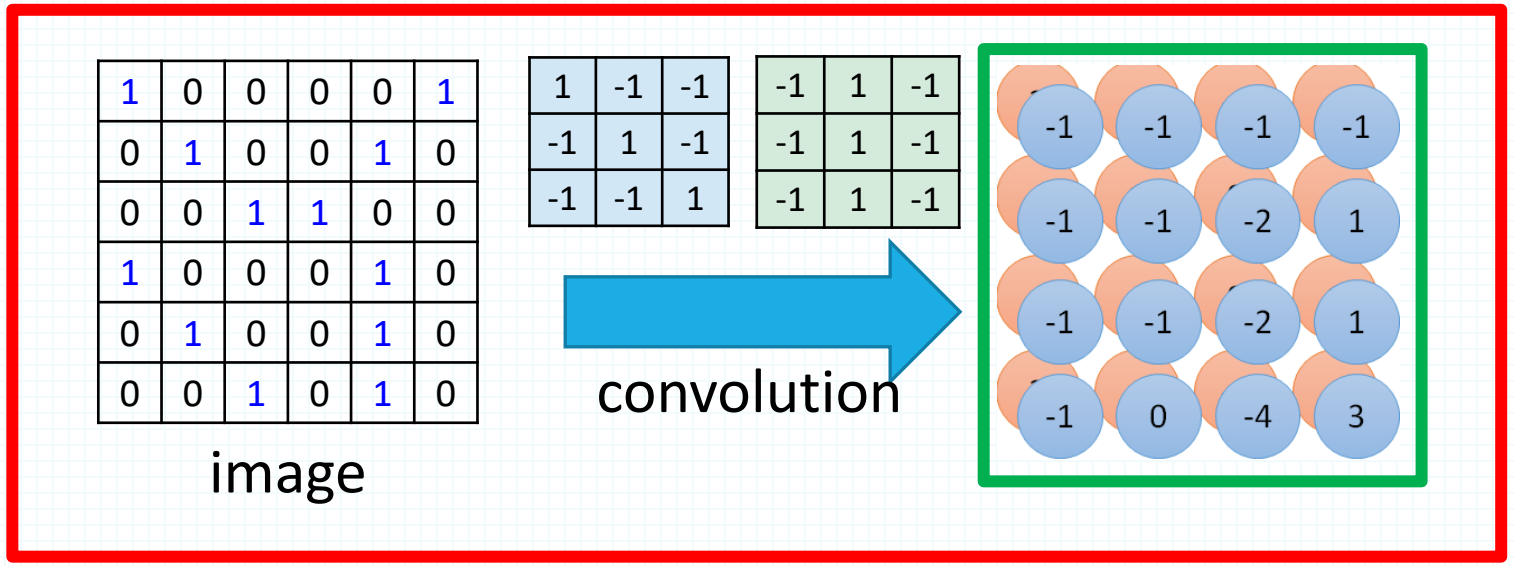
Each filter detects a small pattern (3 x 3).

Convolution Neural Network

- A **convolutional neural network** refers to any network that includes an **alternation of convolution and pooling layers**, where **some of the convolution weights are shared.**
- Architecture:

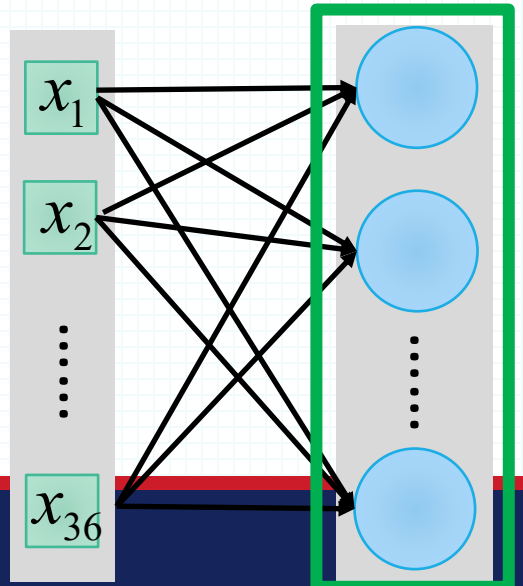


Convolution v.s. Fully Connected



Fully-connected

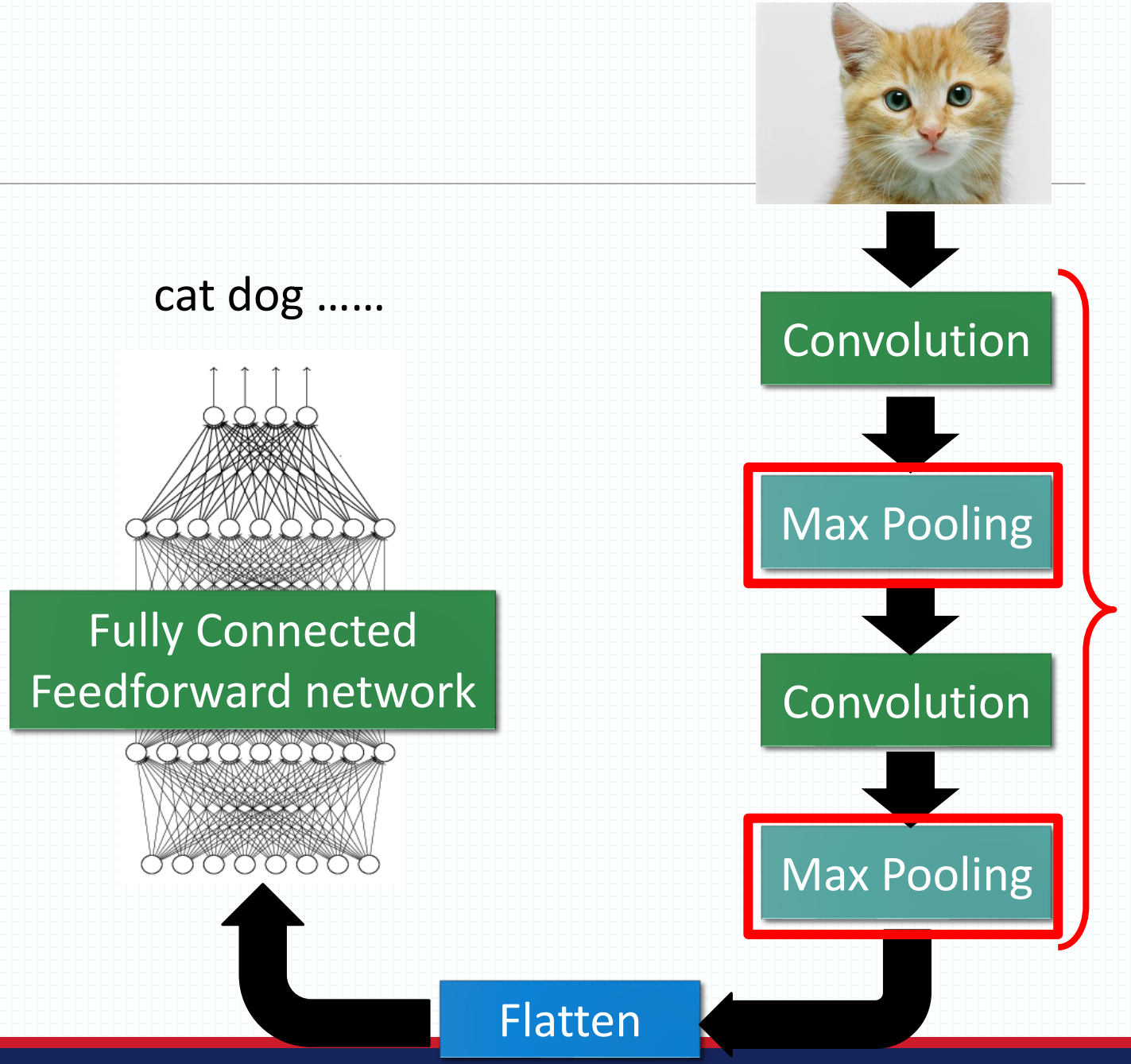
1	0	0	0	0	1
0	1	0	0	1	0
0	0	1	1	0	0
1	0	0	0	1	0
0	1	0	0	1	0
0	0	1	0	1	0



- Sparse interactions: Fewer connections
- Parameter sharing: Fewer weights
- Handle inputs of varying length

Pooling

- Pooling: commutative mathematical operation that combines several units
- Examples:
  - max, sum, product, average, Euclidean norm, etc.
- Commutative property (order does not matter):
  - max a, b = max(b, a)



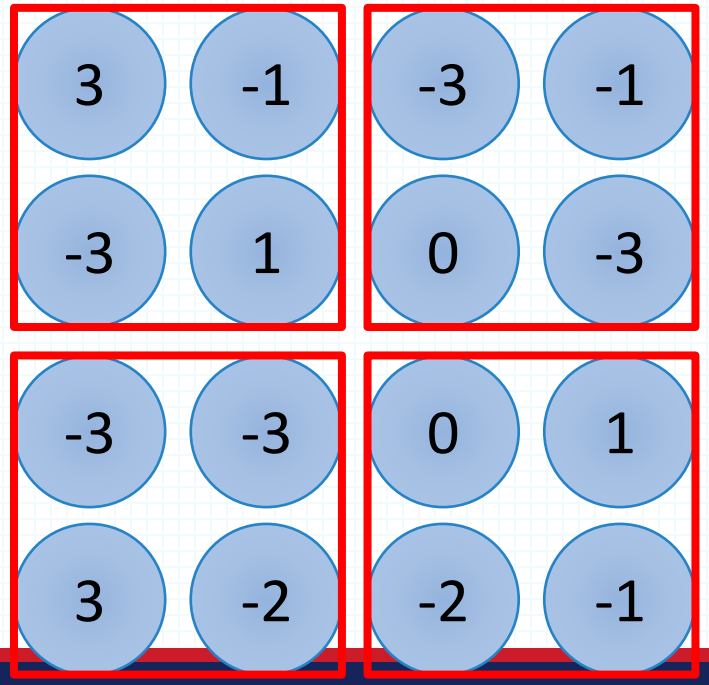
CNN – Max Pooling

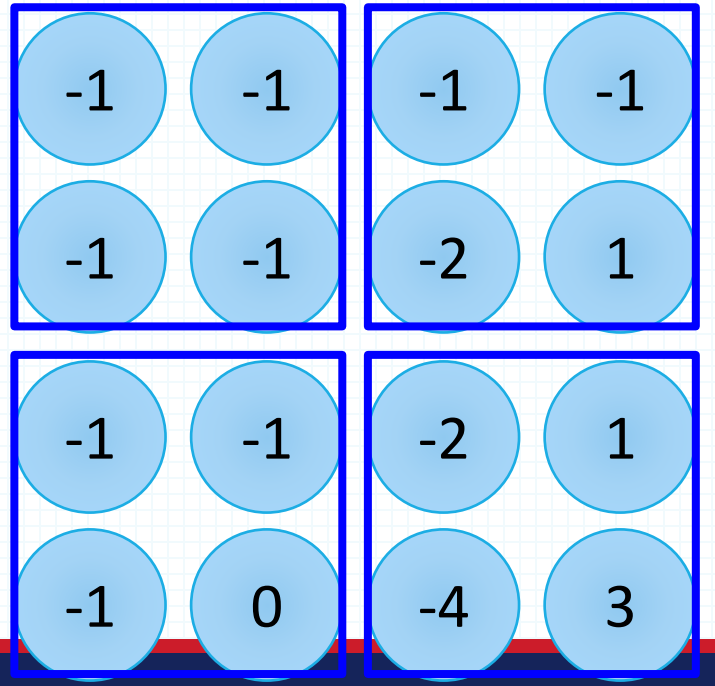
1	-1	-1
-1	1	-1
-1	-1	1

Filter 1

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

Filter 2

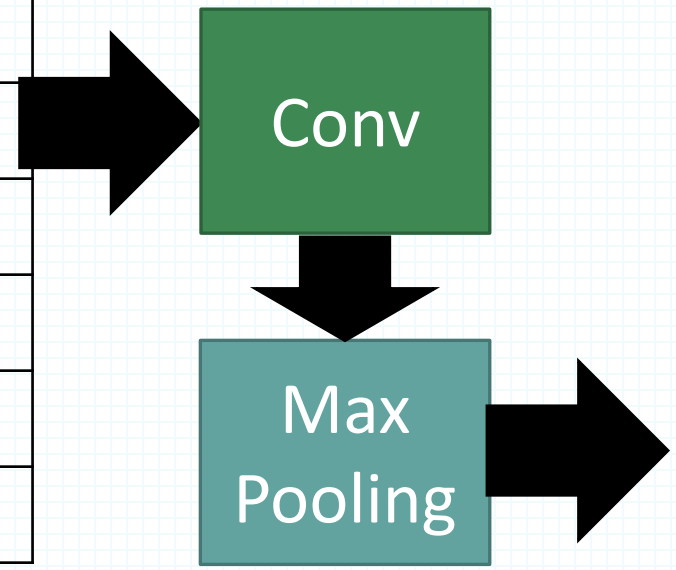




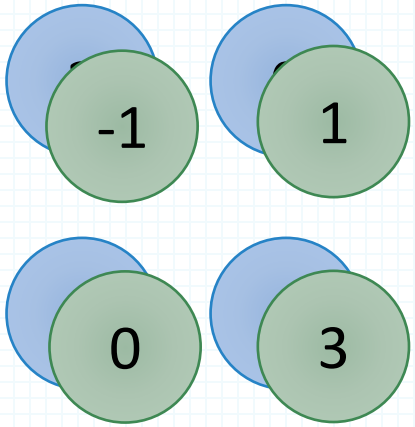
CNN – Max Pooling

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

6 x 6 image



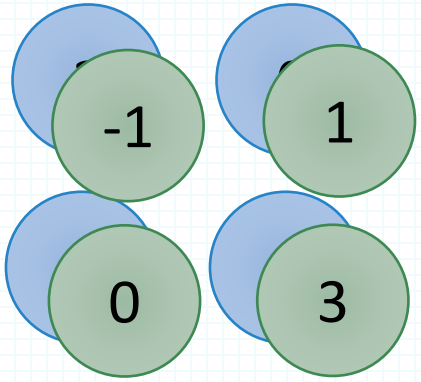
New image but smaller



2 x 2 image

Each filter is a channel

The whole CNN



A new image

Convolution

Max Pooling

Convolution

Max Pooling

Can repeat many times

Smaller than the original image

The number of the channel is the number of filters

The whole CNN

Convolution

Max Pooling

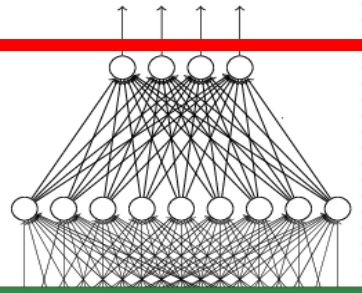
A new image

Convolution

Max Pooling

A new image

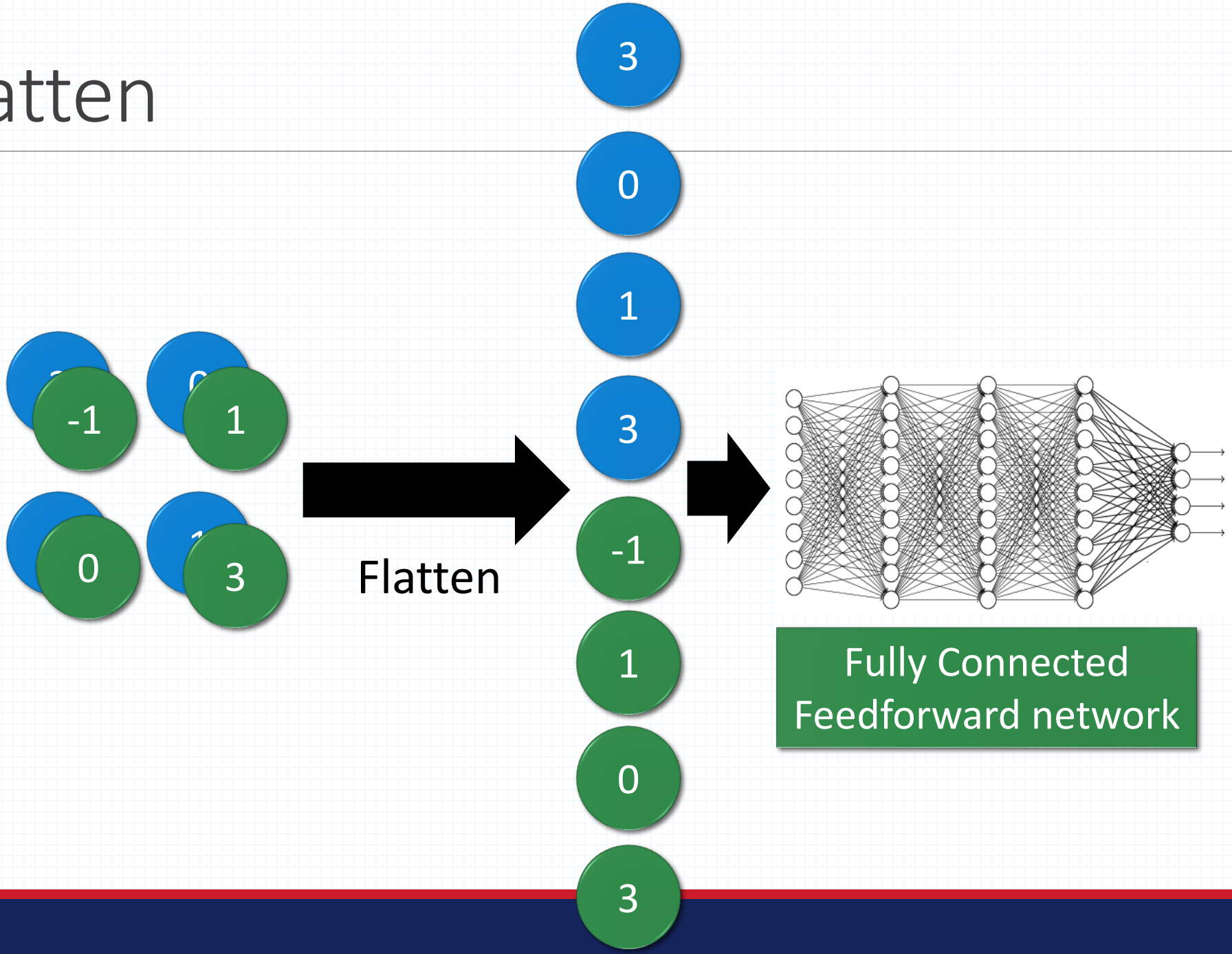
Flatten



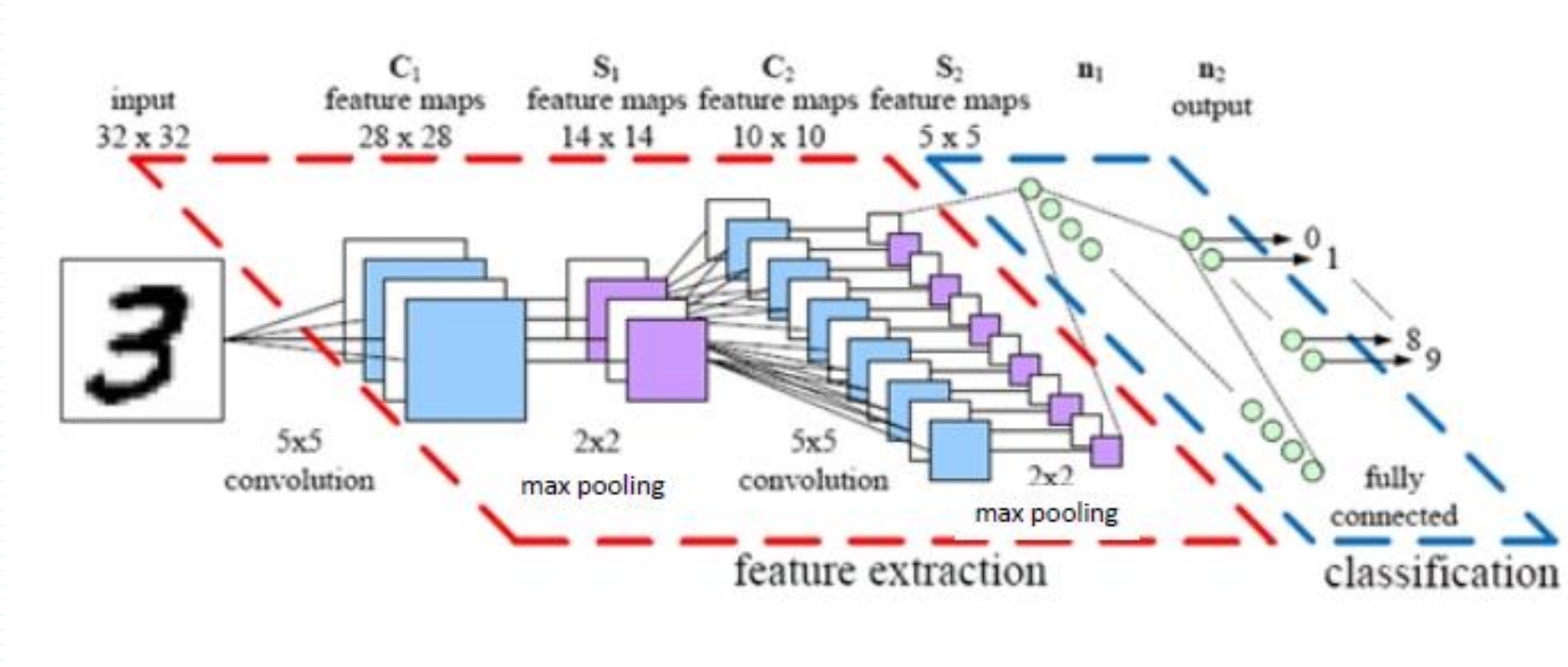
Fully Connected Feedforward network

cat dog ……

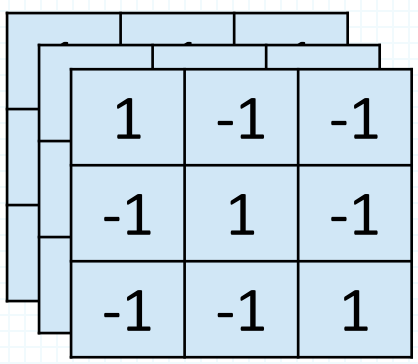
Flatten


-1
1
0
3
Flatten
3
0
1
3
-1
1
0
3
Fully Connected
Feedforward network

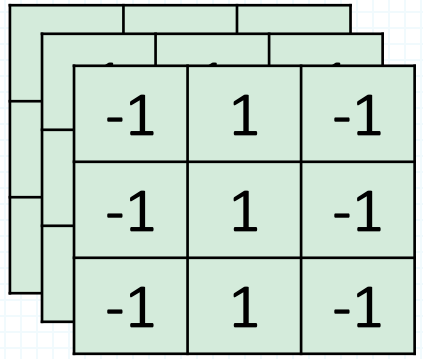
Example


input
32 x 32
C1
feature maps
28 x 28
S1
feature maps
14 x 14
C2
feature maps
10 x 10
S2
feature maps
5 x 5
n1
n2
output
0
1
8
9
5x5
convolution
2x2
max pooling
5x5
convolution
2x2
max pooling
fully
connected
feature extraction
classification

CNN – Colorful image

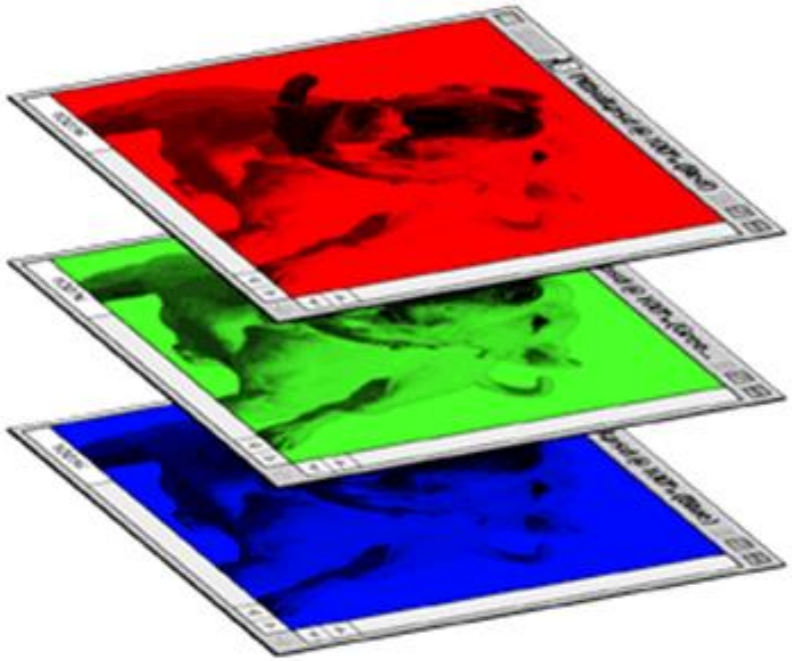


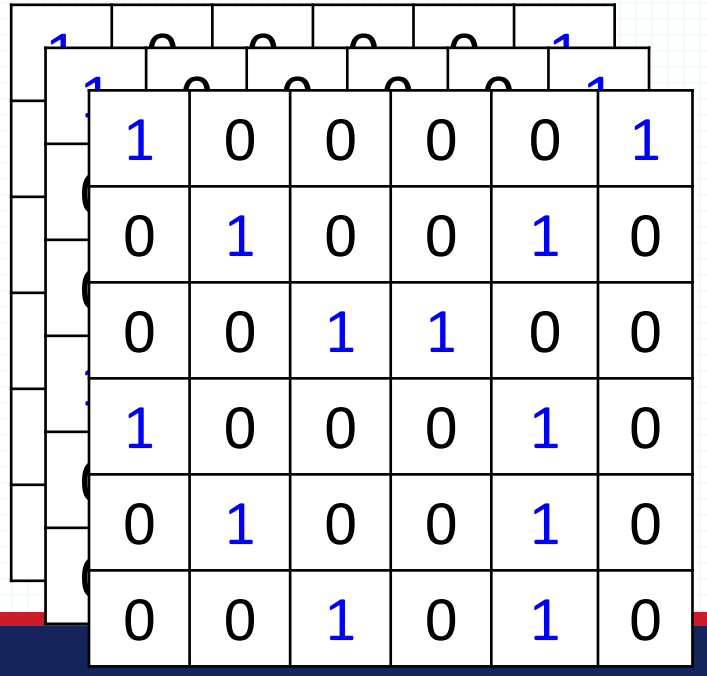
Filter 1



Filter 2

Colorful image

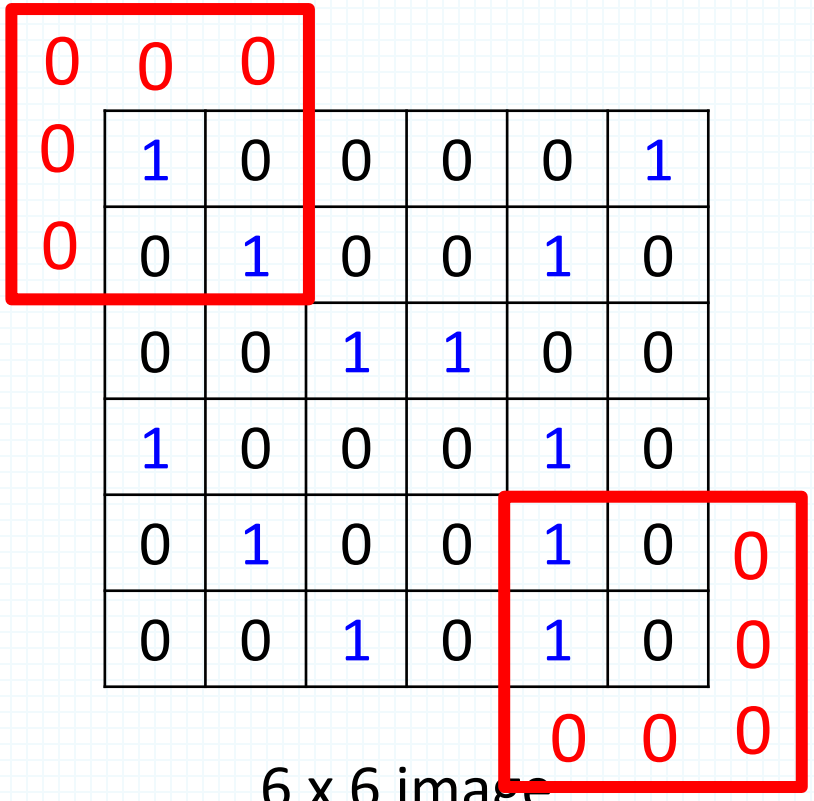




CNN – Zero Padding

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

Filter 1



You will get another 6 x 6 images in this way

Zero padding

More Application: Playing Go

19 x 19 matrix (image)

Network

Next move (19 x 19 positions)

19 x 19 vector

Black: 1

white: -1

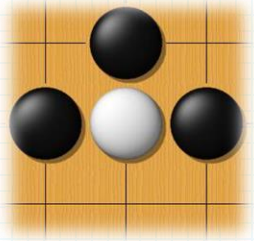
none: 0

Fully-connected feedforward network can be used

But CNN performs much better.

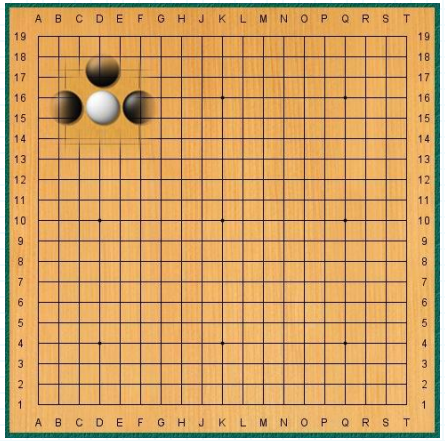
Why CNN for playing Go?

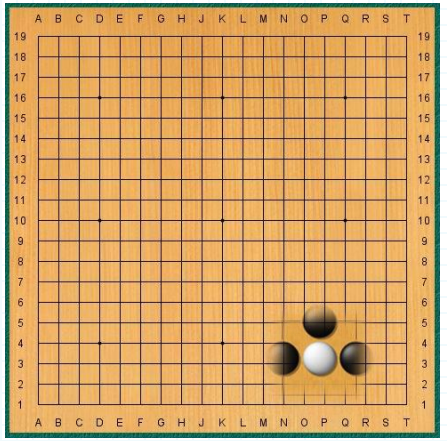
- Some patterns are much smaller than the whole image



- The same patterns appear in different regions.

Alpha Go uses 5 x 5 for first layer



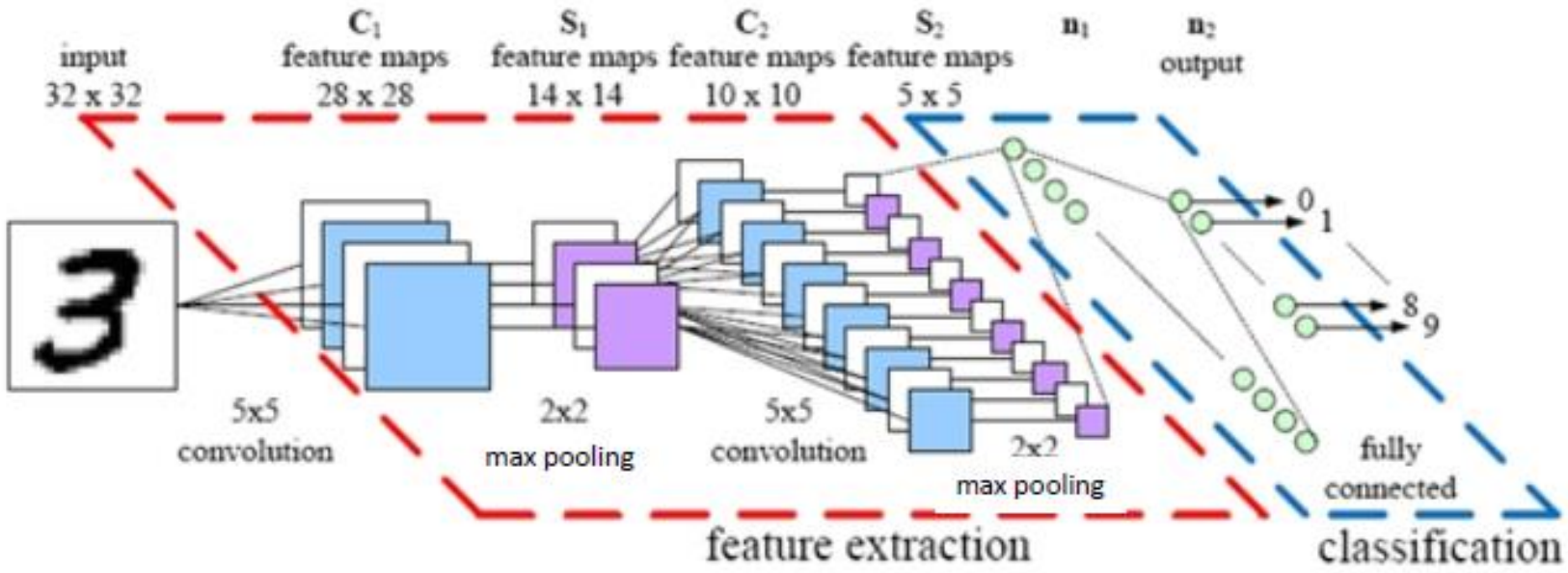


Parameters

- **# of filters**: integer indicating the # of filters applied to each window.
- **kernel size:** tuple (width, height) indicating the size of the window.
- **Stride:** tuple (horizontal, vertical) indicating the horizontal and vertical shift between each window.
- **Padding:** “valid” or ”same”. Valid indicates no input padding. Same indicates that the input is padded with a border of zeros to ensure that the output has the same size as the input.

Training

- Convolutional neural networks are trained in the same way as other neural networks
  - backpropagation
- Weight sharing:
  - Combine gradients of shared weights into a single gradient



Architecture design: VGG

- What is the preferred filter size?
- VGG (Visual Geometry Group at Oxford, 2014): stack of small filters is often preferred to single large filter
  - Fewer parameters
  - Deeper network