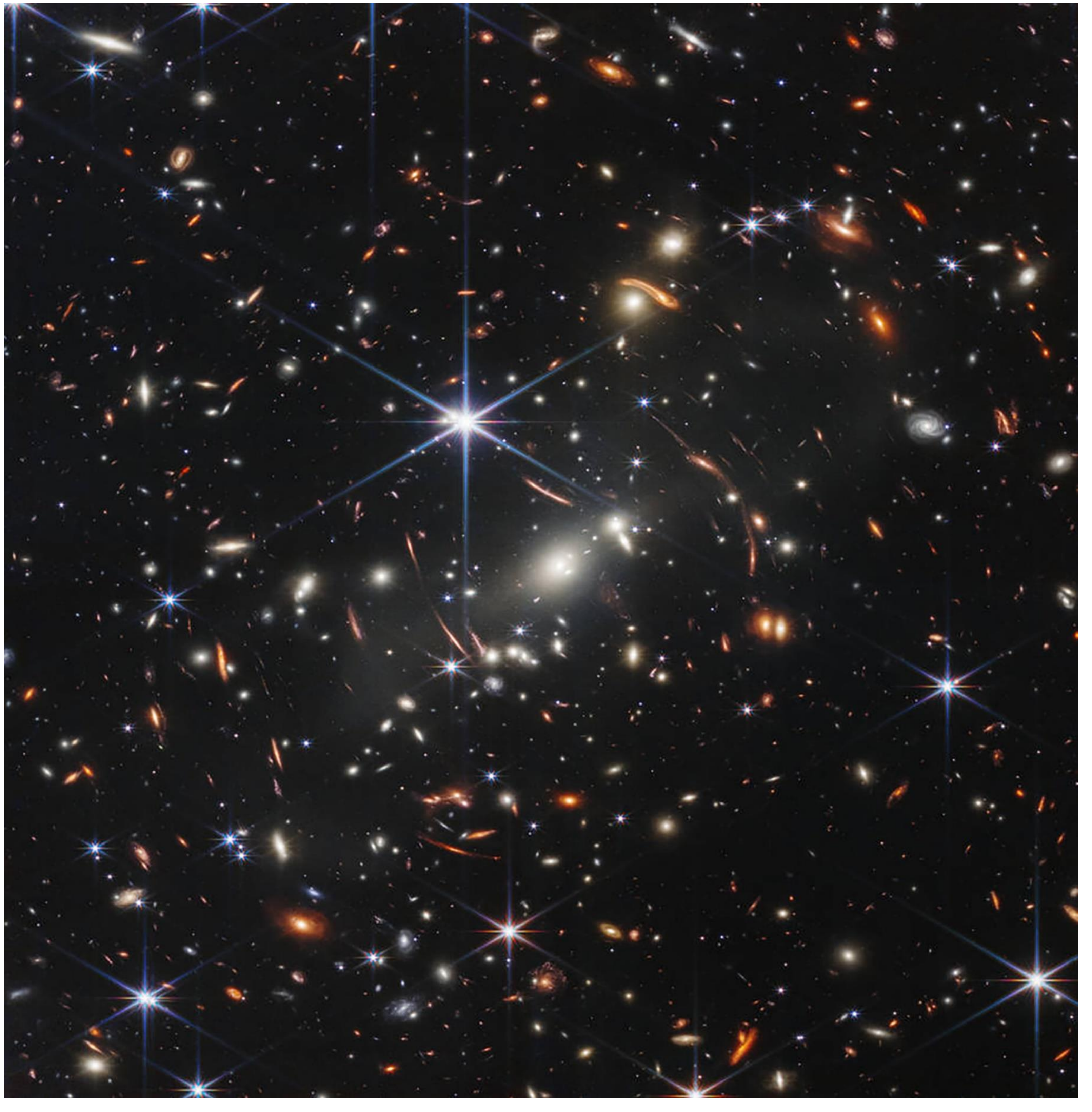
James Webb Space Telescope



The landscape of “mountains” and “valleys”

A visual grouping of five galaxies

CONVOLUTIONAL NEURAL NETWORK

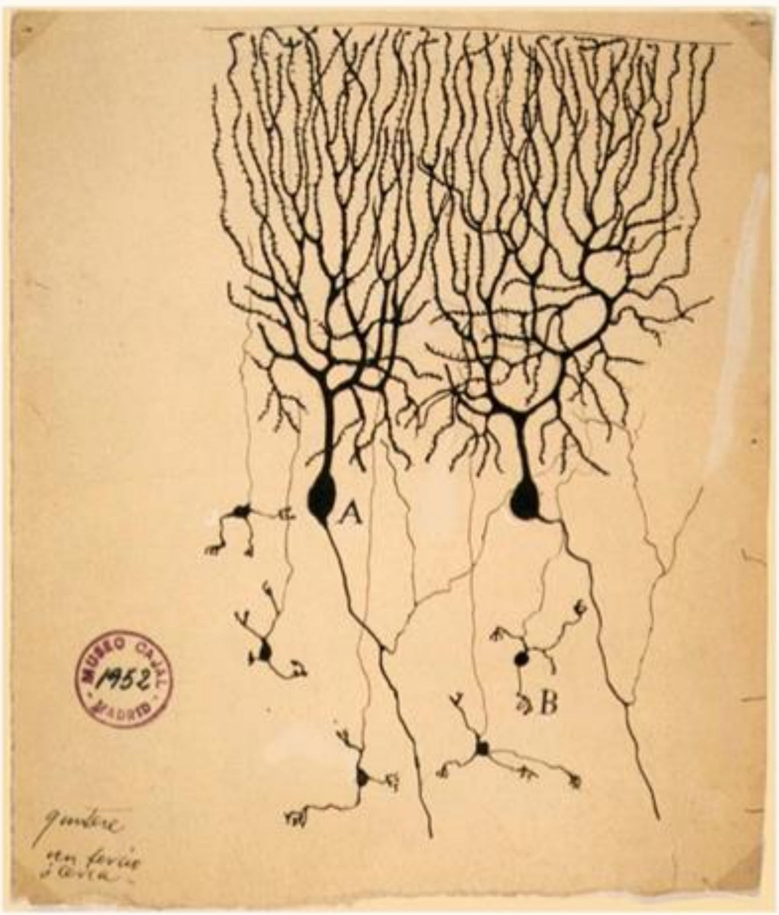
Mahdi Roozbahani

Georgia Tech

Great visualization tool:
https://poloclub.github.io/cnn-explainer/

Slides are based on Ming Li (University of waterloo – Deep learning part) with some modifications

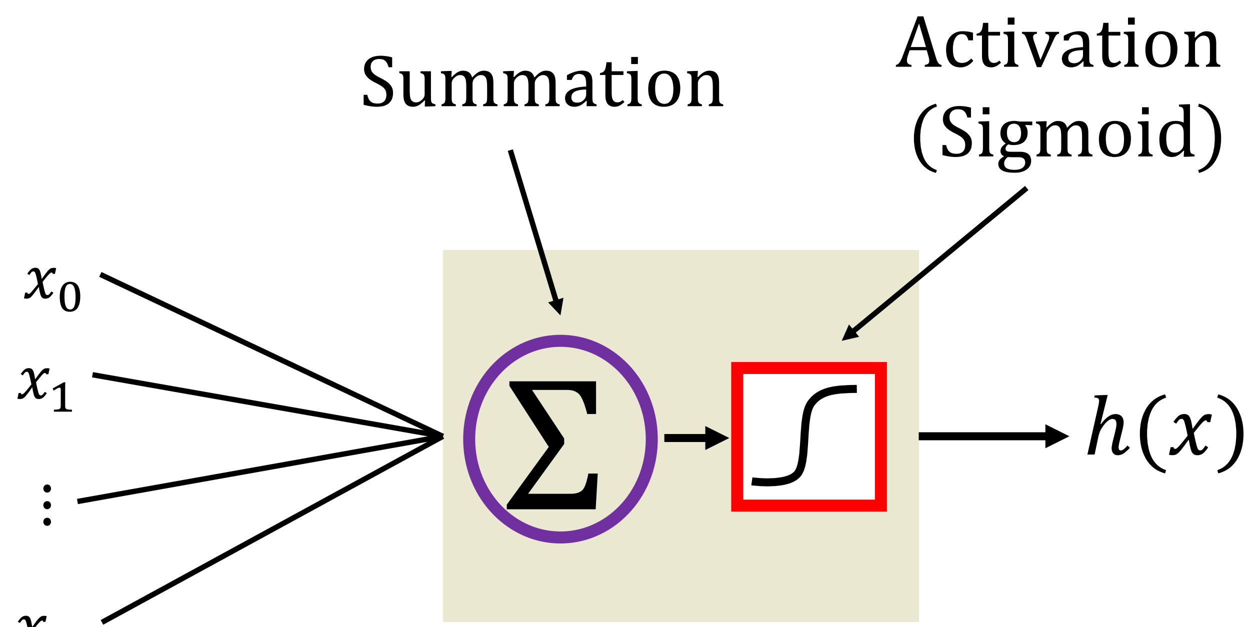
Inspiration from Biological Neurons



The first drawing of a brain cells by Santiago Ramón y Cajal in 1899

Neurons: core components of brain and the nervous system consisting of

1. Dendrites that collect information from other neurons
2. An axon that generates outgoing spikes

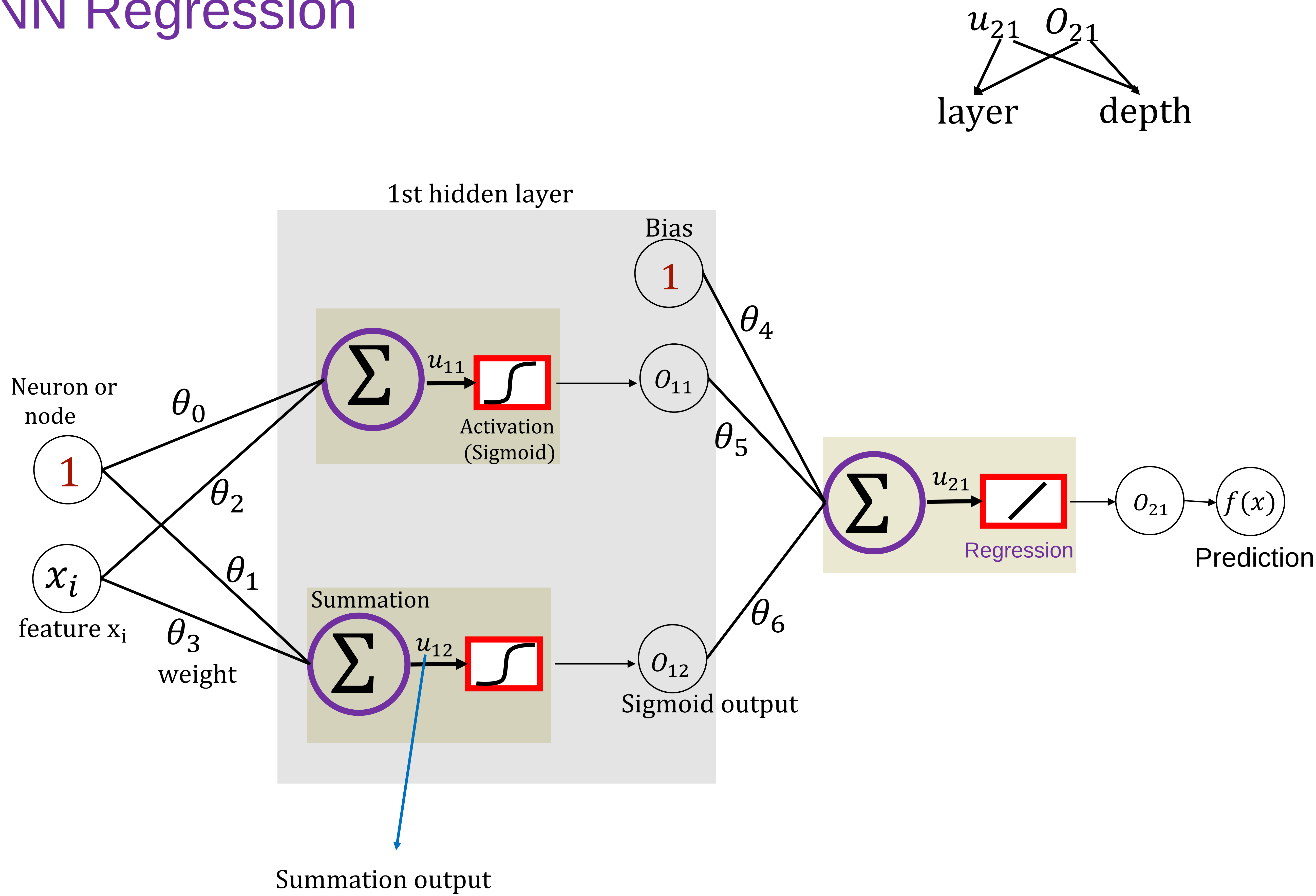


$h(x) = u(x\theta) \rightarrow$ logistic regression

$$output = activation(x\theta \ + b)$$

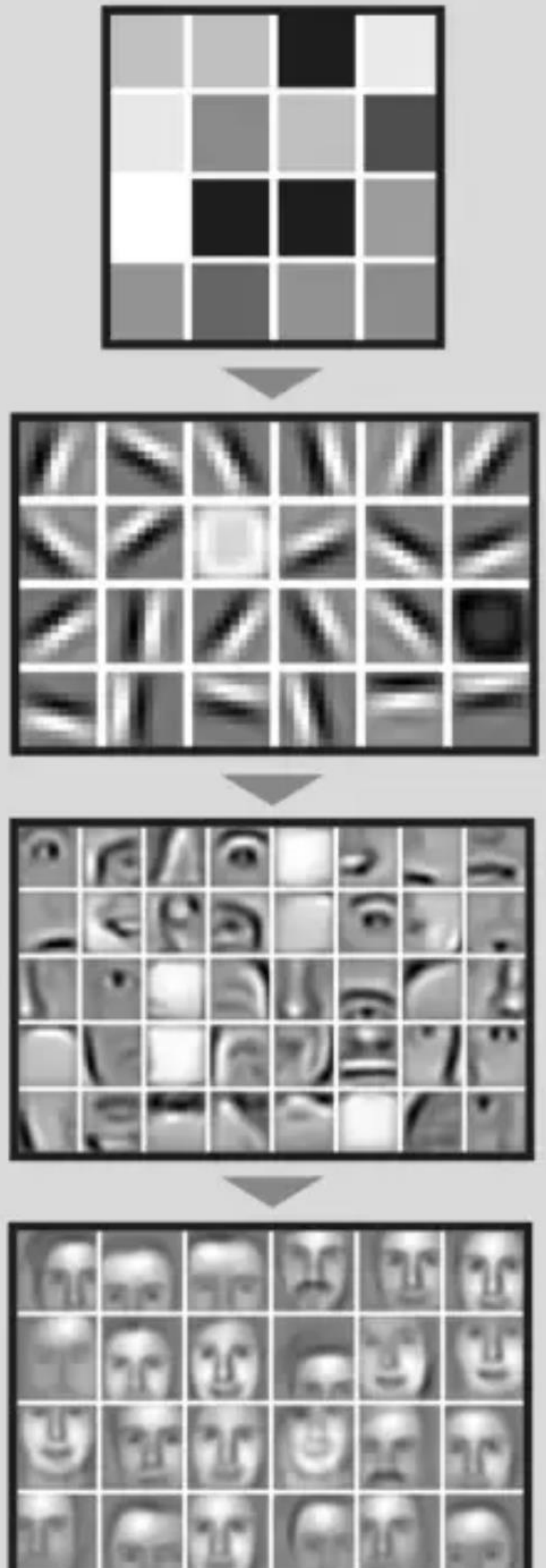
Name of the neuron	**Activation function:** $activation(z)$
Linear unit	$x\theta$
Threshold/sign unit	$sign(x\theta)$
Sigmoid unit	$\frac{1}{1+\exp(x\theta)}$
Rectified linear unit (ReLU)	$\max(0, x\theta)$
Tanh unit	$\tanh(x\theta)$

NN Regression



FACIAL RECOGNITION

Deep-learning neural networks use layers of increasingly complex rules to categorize complicated shapes such as faces.



Layer 1: The computer identifies pixels of light and dark.

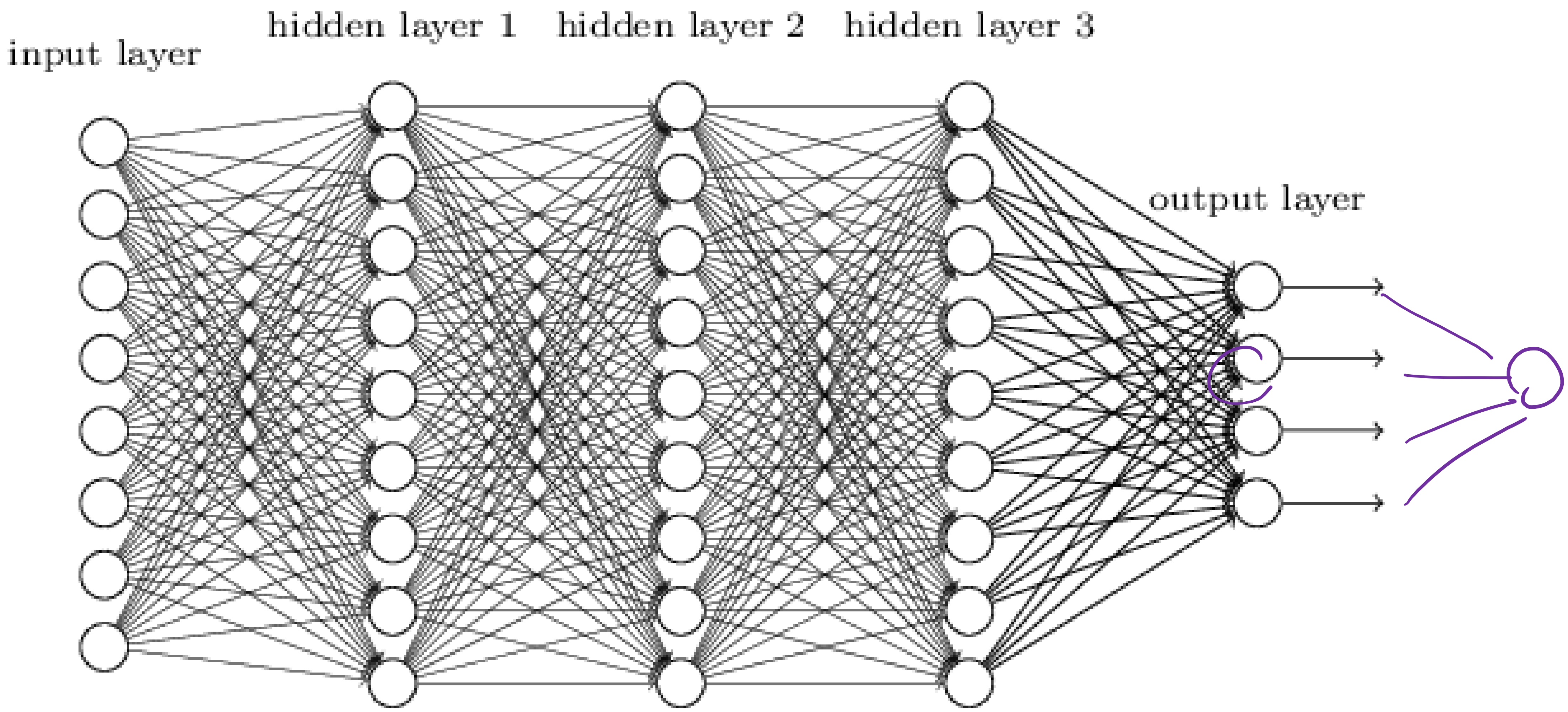
Layer 2: The computer learns to identify edges and simple shapes.

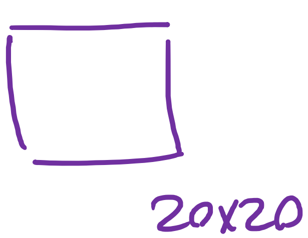
Layer 3: The computer learns to identify more complex shapes and objects.

Layer 4: The computer learns which shapes and objects can be used to define a human face.

Smaller Network: CNN

- We know it is good to learn a small model.
- From this fully connected model, do we really need all the edges?
- Can some of these be shared?

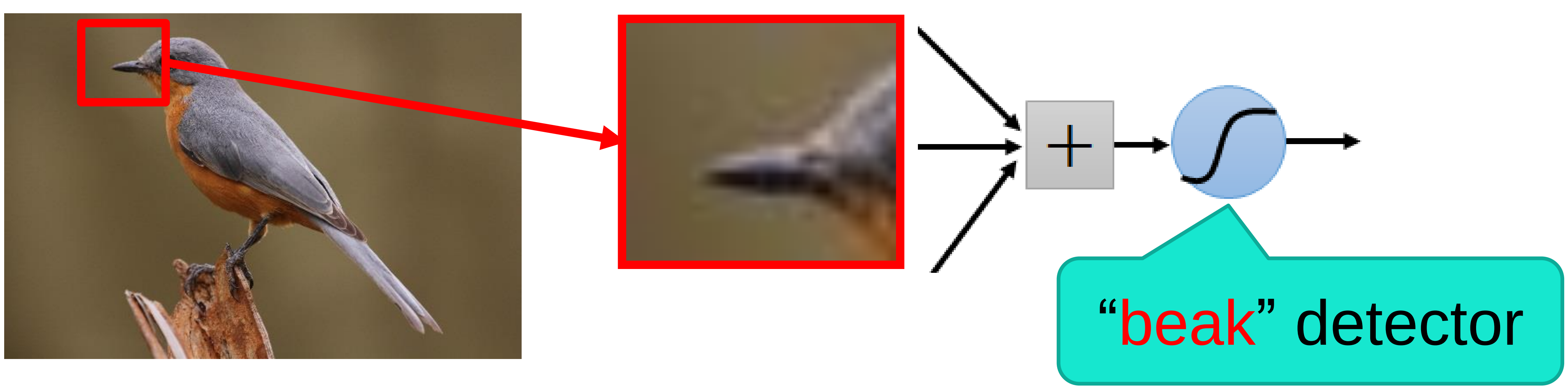




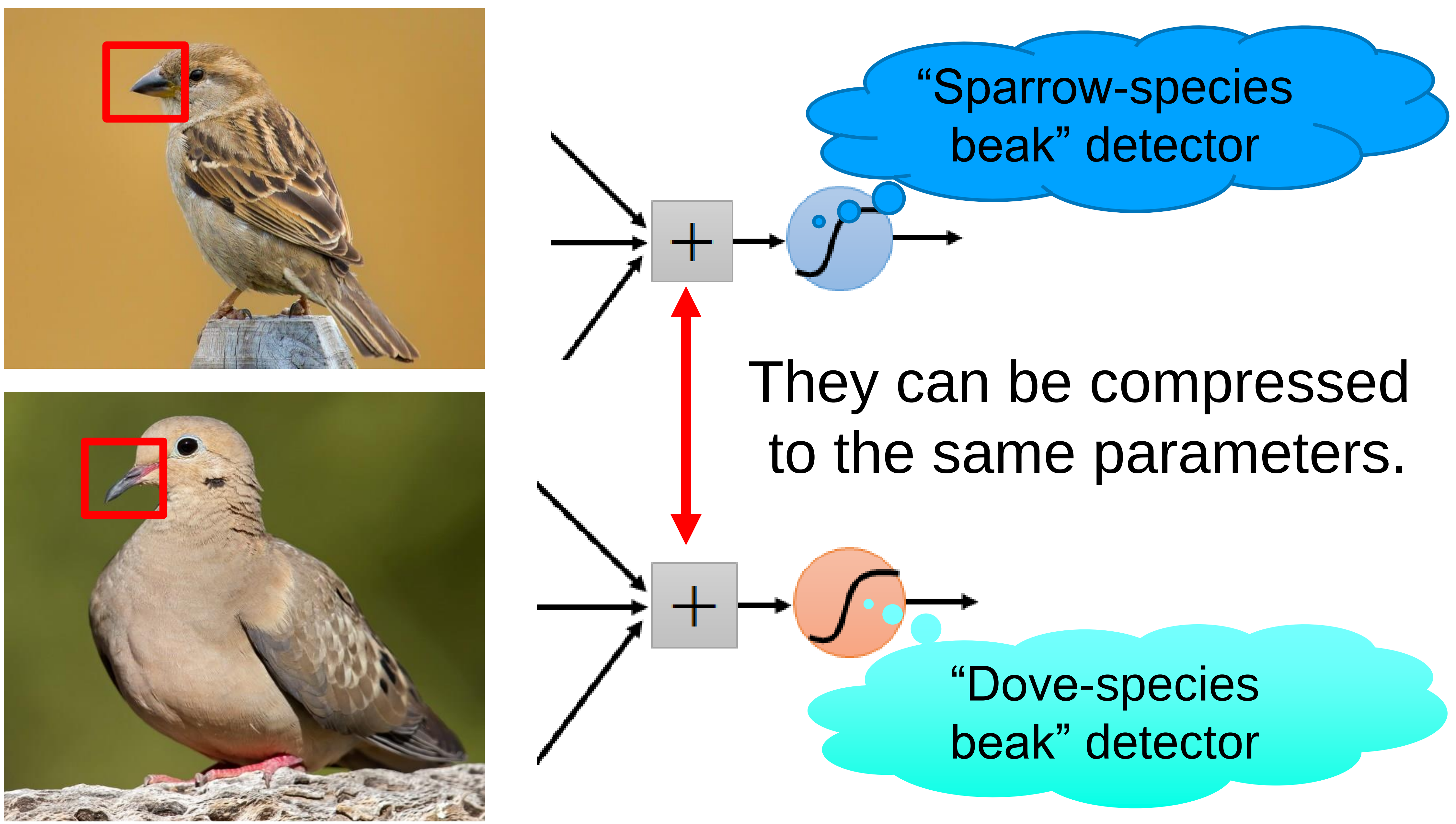
Consider learning an image:

- Some patterns are much smaller than the whole image

Can represent a small region with fewer parameters

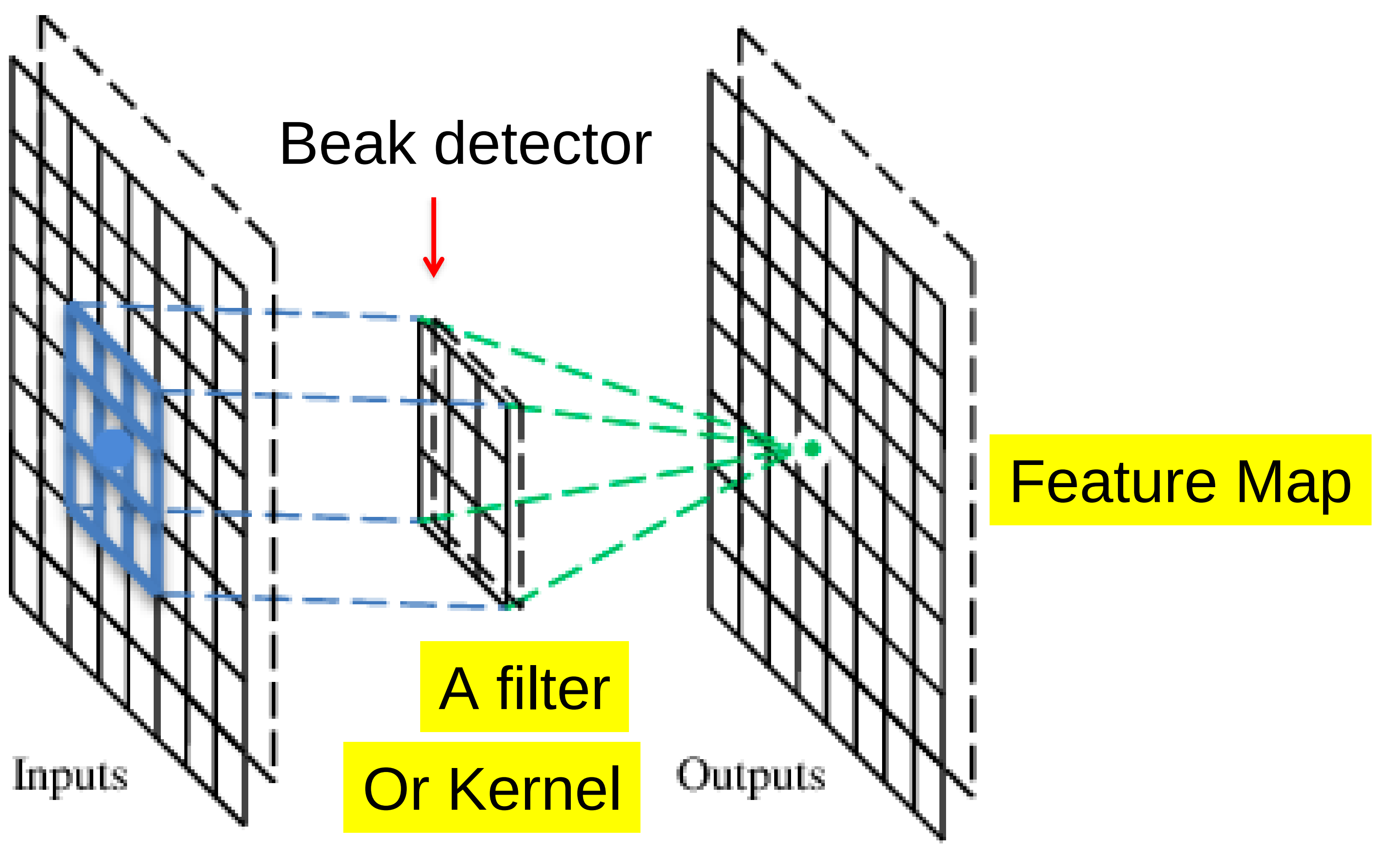


Same pattern appears in different places:
They can be compressed!
What about training a lot of such "small" detectors
and each detector must "move around".



A convolutional layer

A CNN is a neural network with some convolutional layers (and some other layers). A convolutional layer has a number of filters that does convolutional operation.



Convolution

These 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

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

Filter 2

⋮ ⋮

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

Convolution

[1 -1 -1 -1 1 -1 -1 -1 1] → sum product
[1 0 0 0 1 0 0 0 1]

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

Filter 1

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

Dot product → 3 -1

Convolution

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

Filter 1

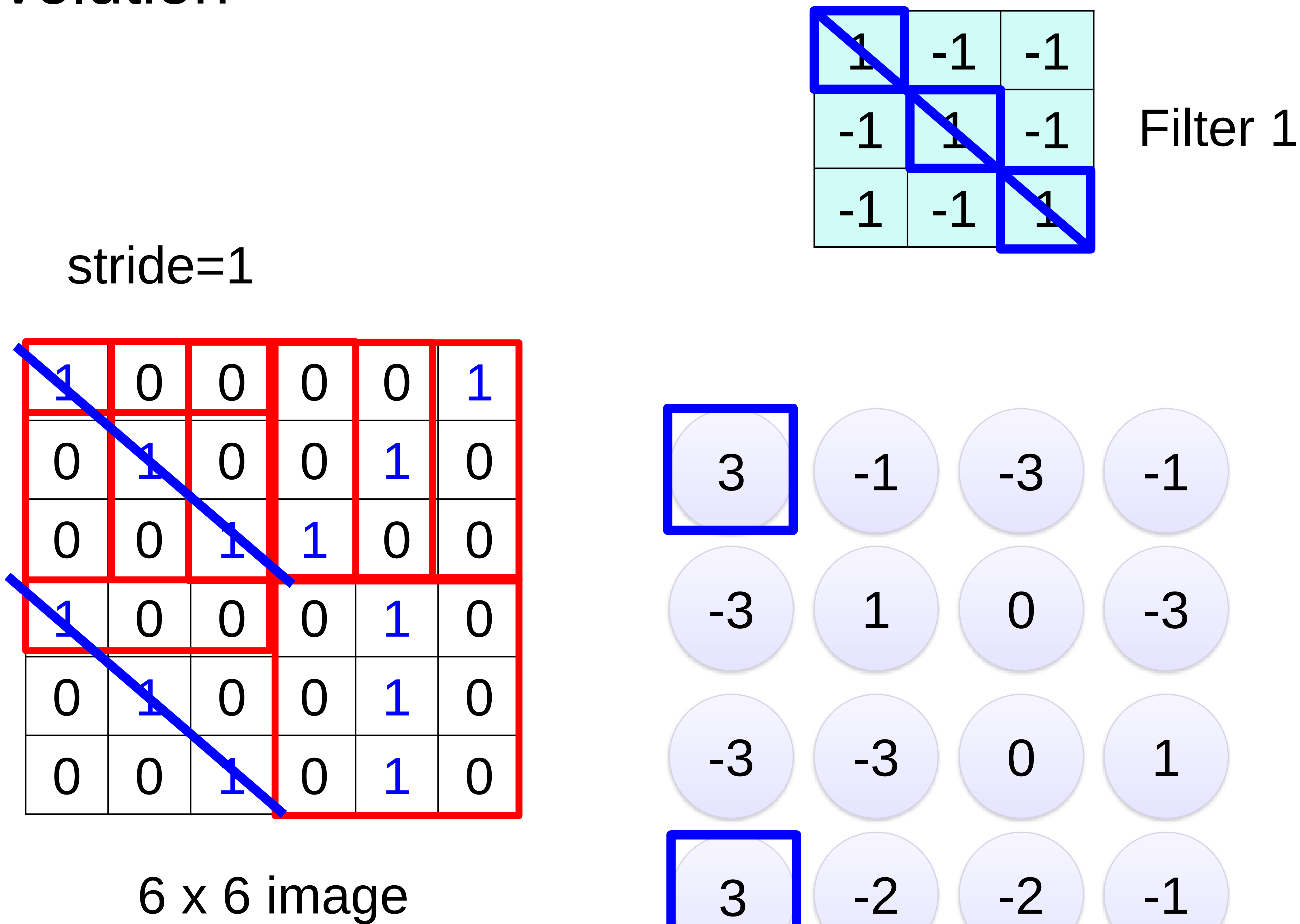
If stride=2

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

3 -3

Convolution



Convolution

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

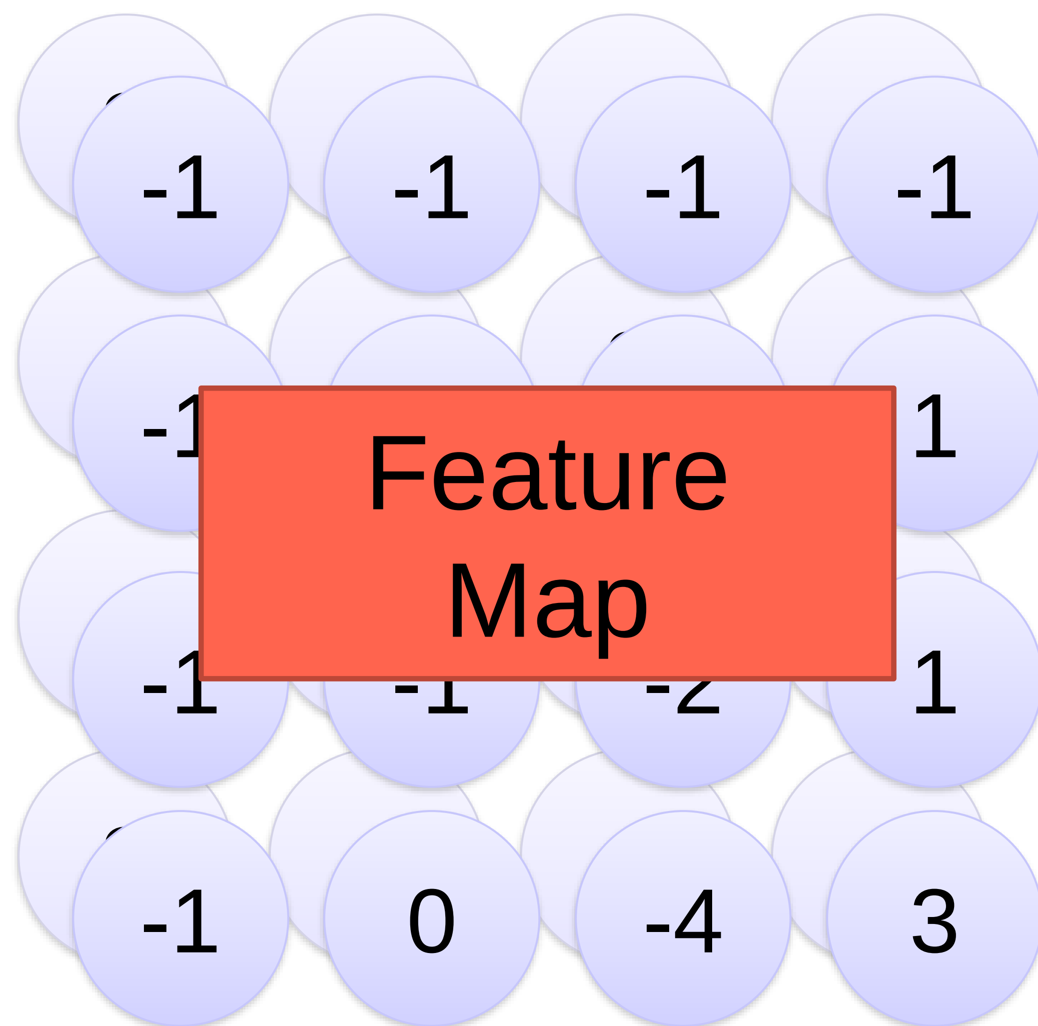
Filter 2

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

Repeat this for each filter

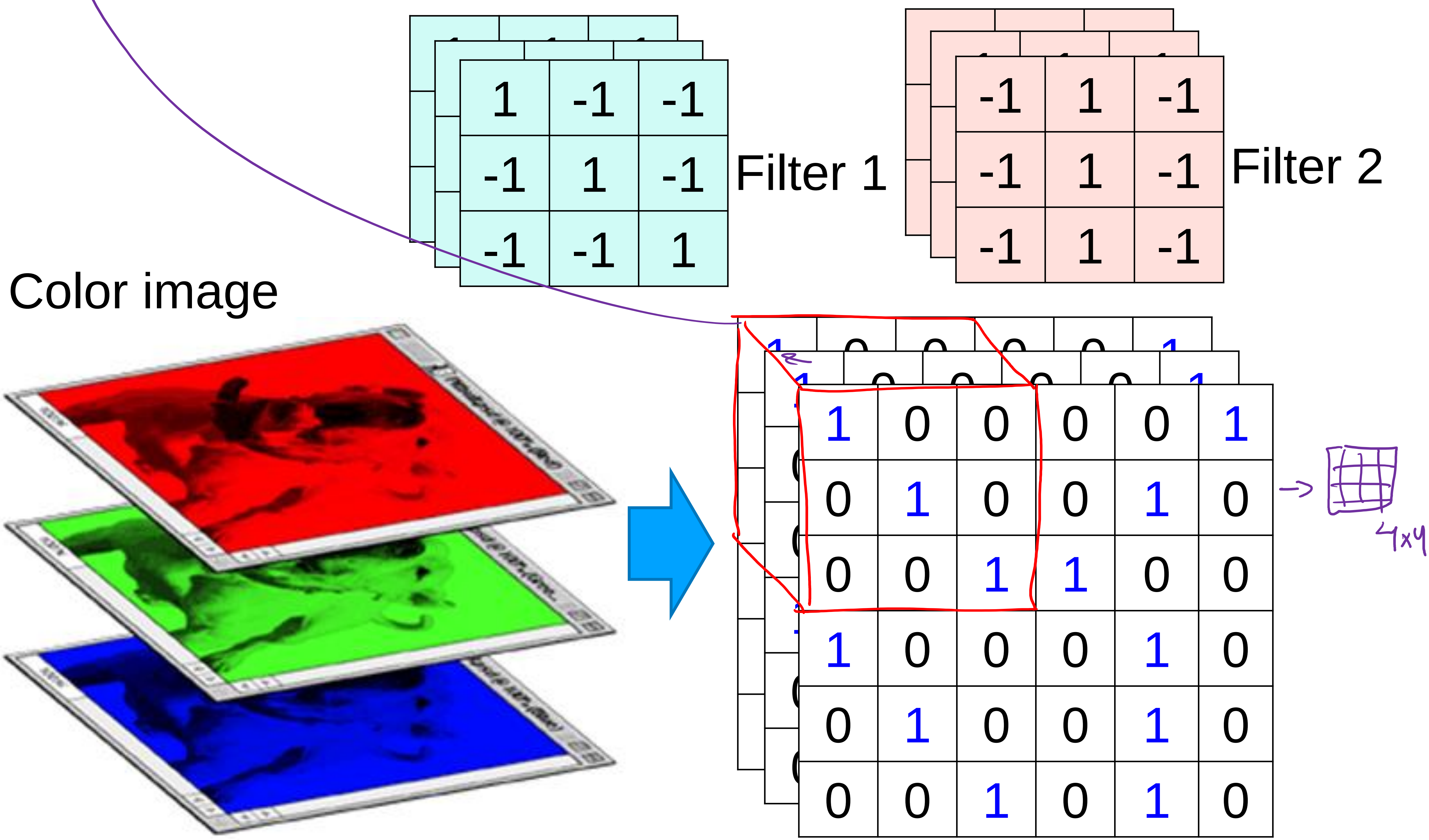


Two 4 x 4 images
Forming 2 x 4 x 4 matrix

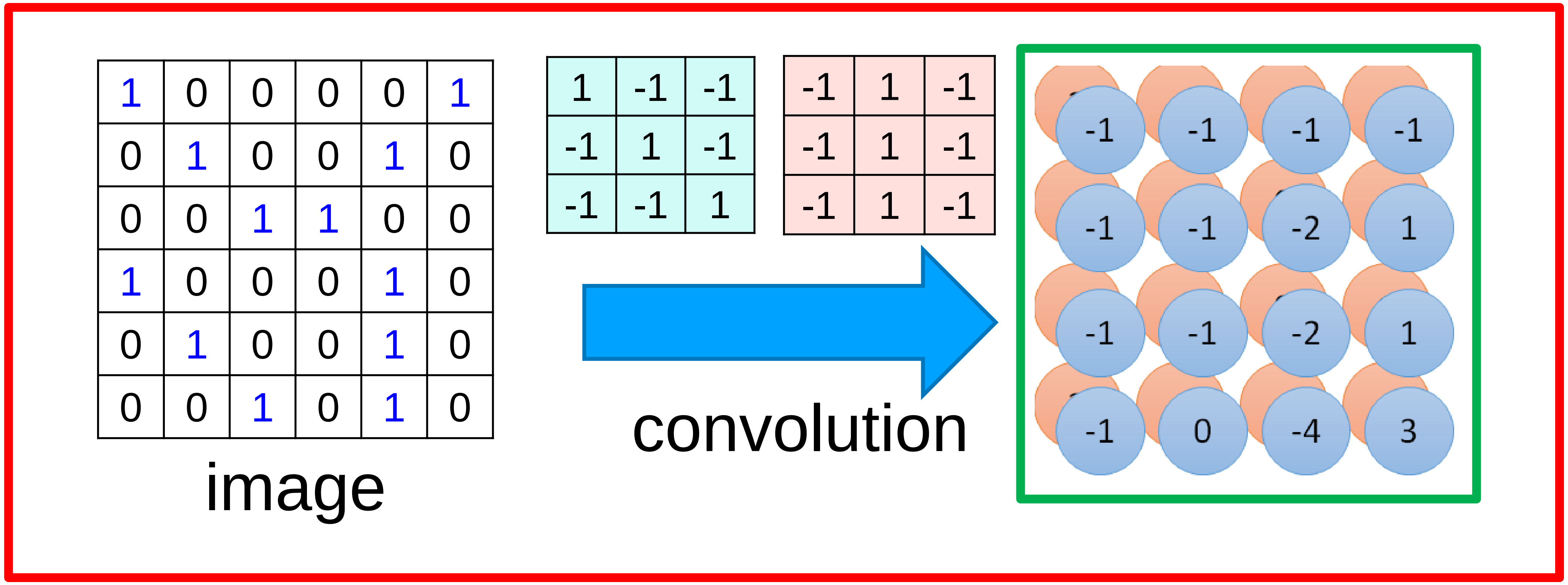
Color image: RGB 3 channels

sub-matrix [1 0 0 0 1 0 0 0 1 1 ------] length = 27

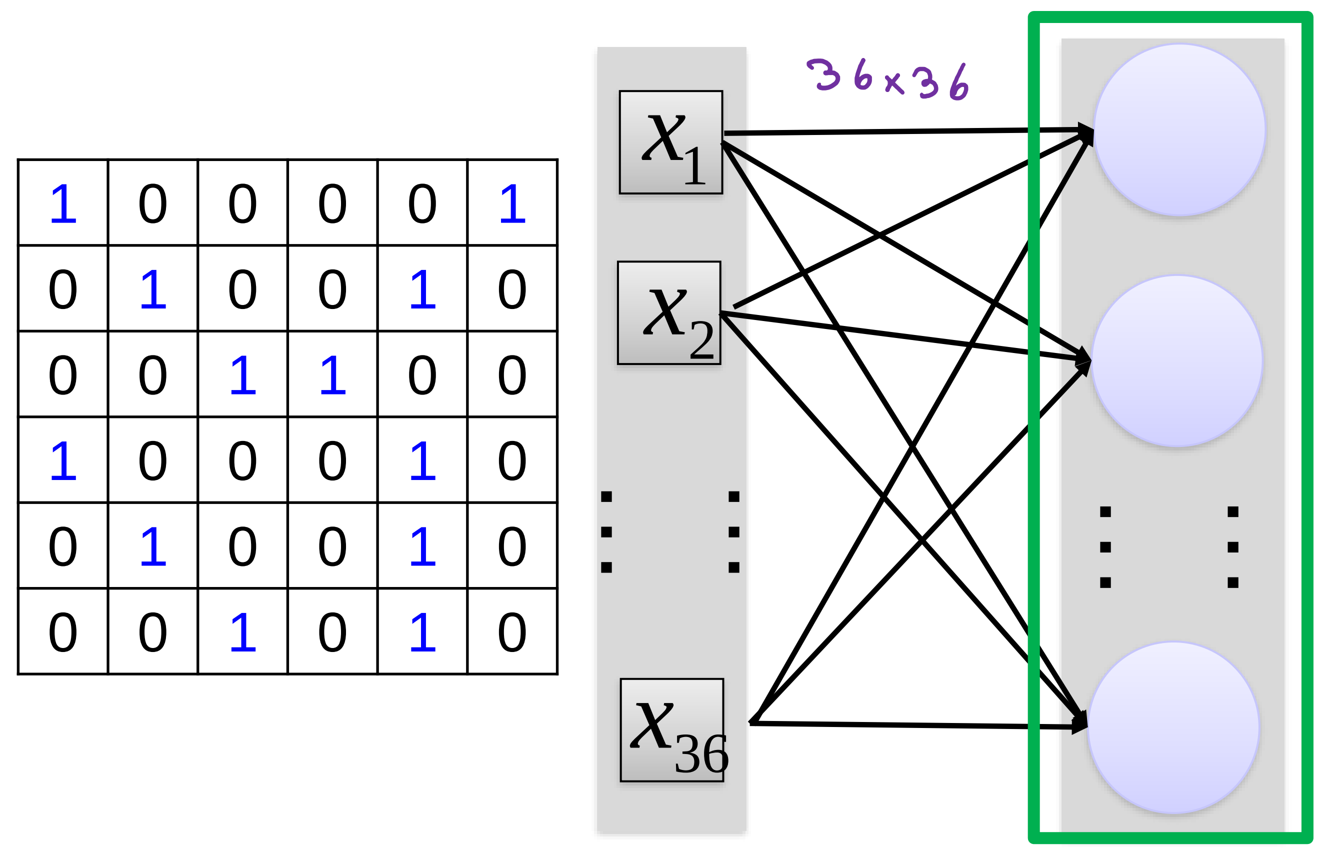
Filter [1 -1 -1 -1 1 -1 -1 -1 1 1 -----] length = 27



Convolution v.s. Fully Connected



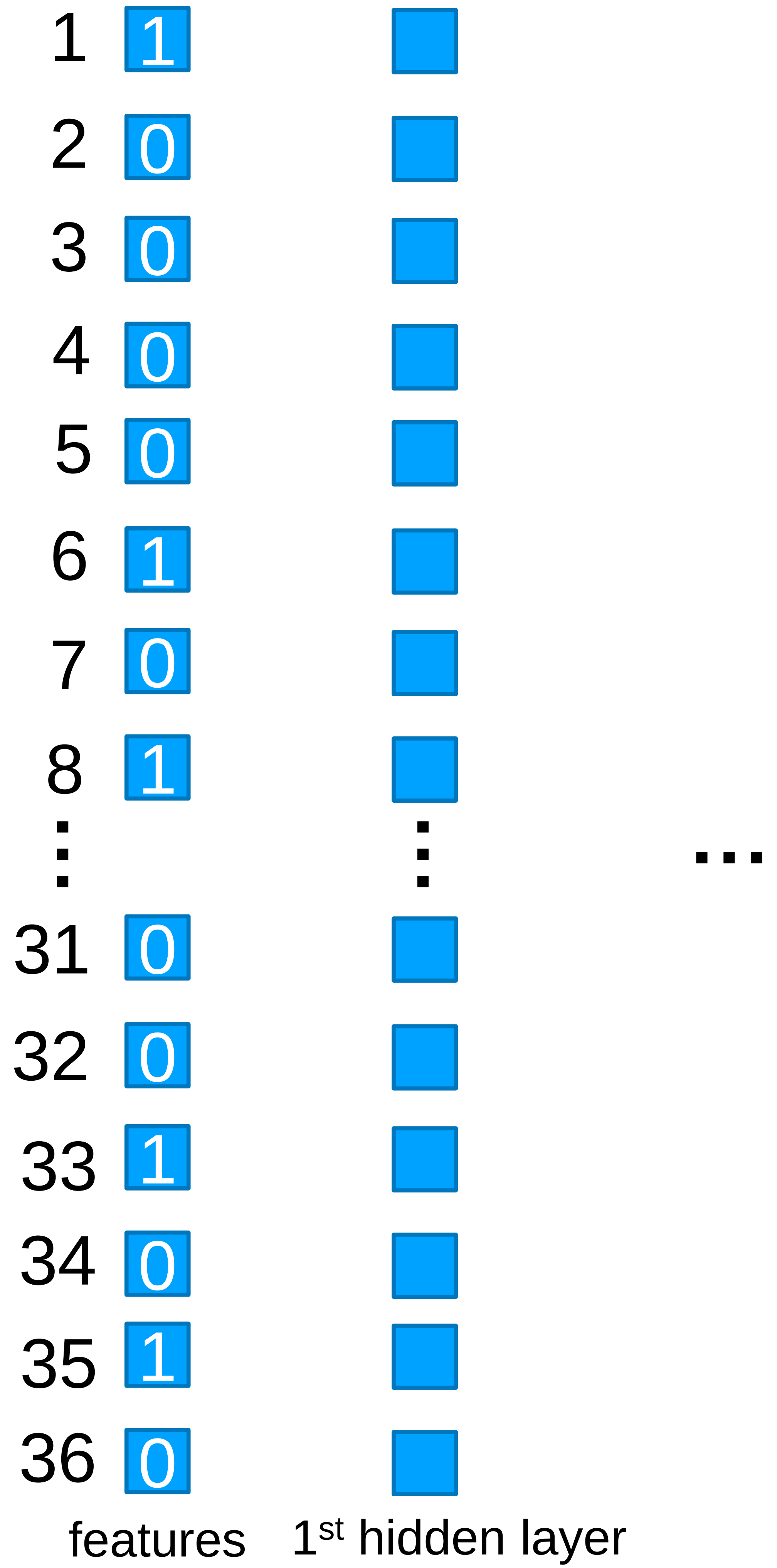
Fully-connected

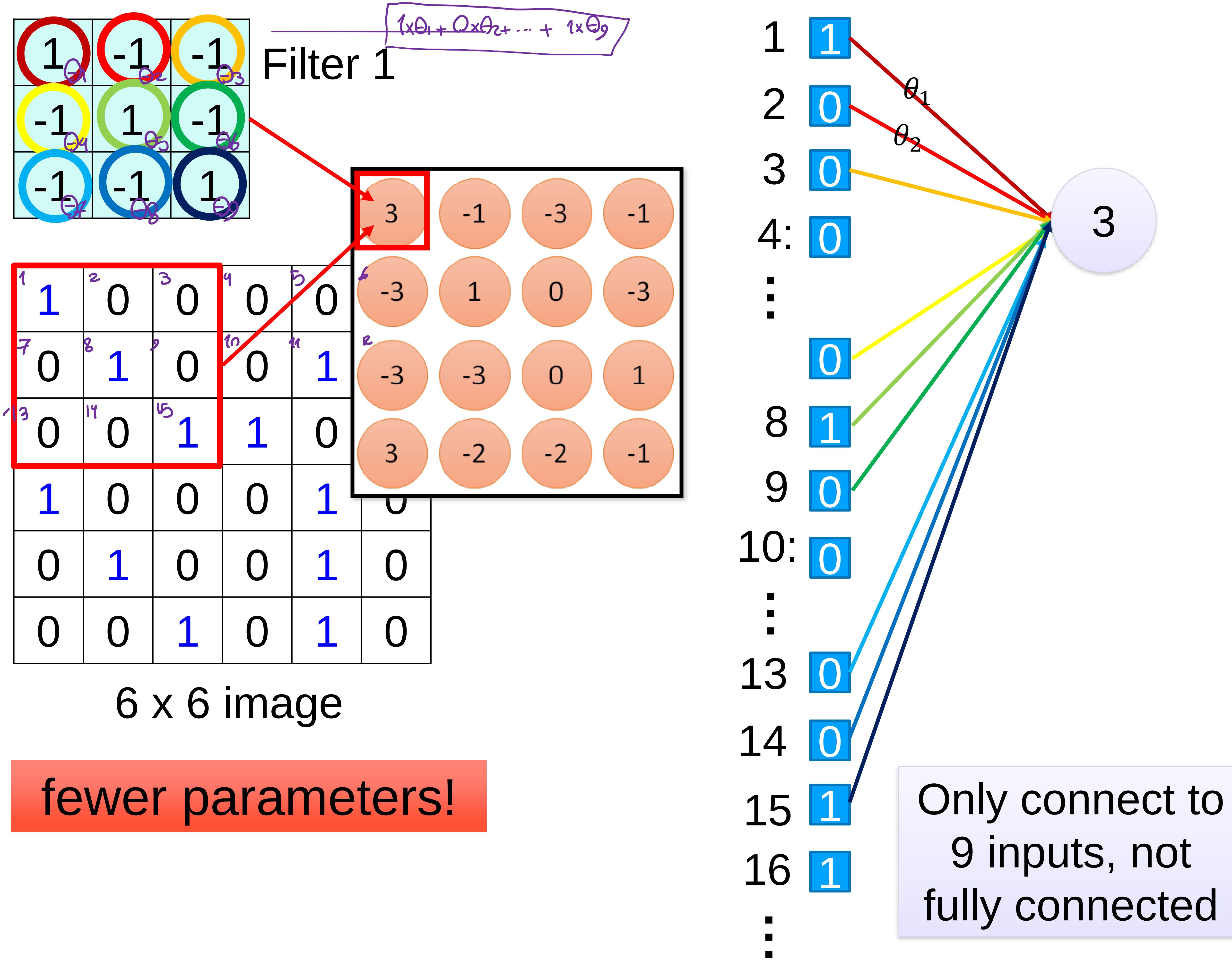


Conventional
Fully Connected
layers
(FC layers)

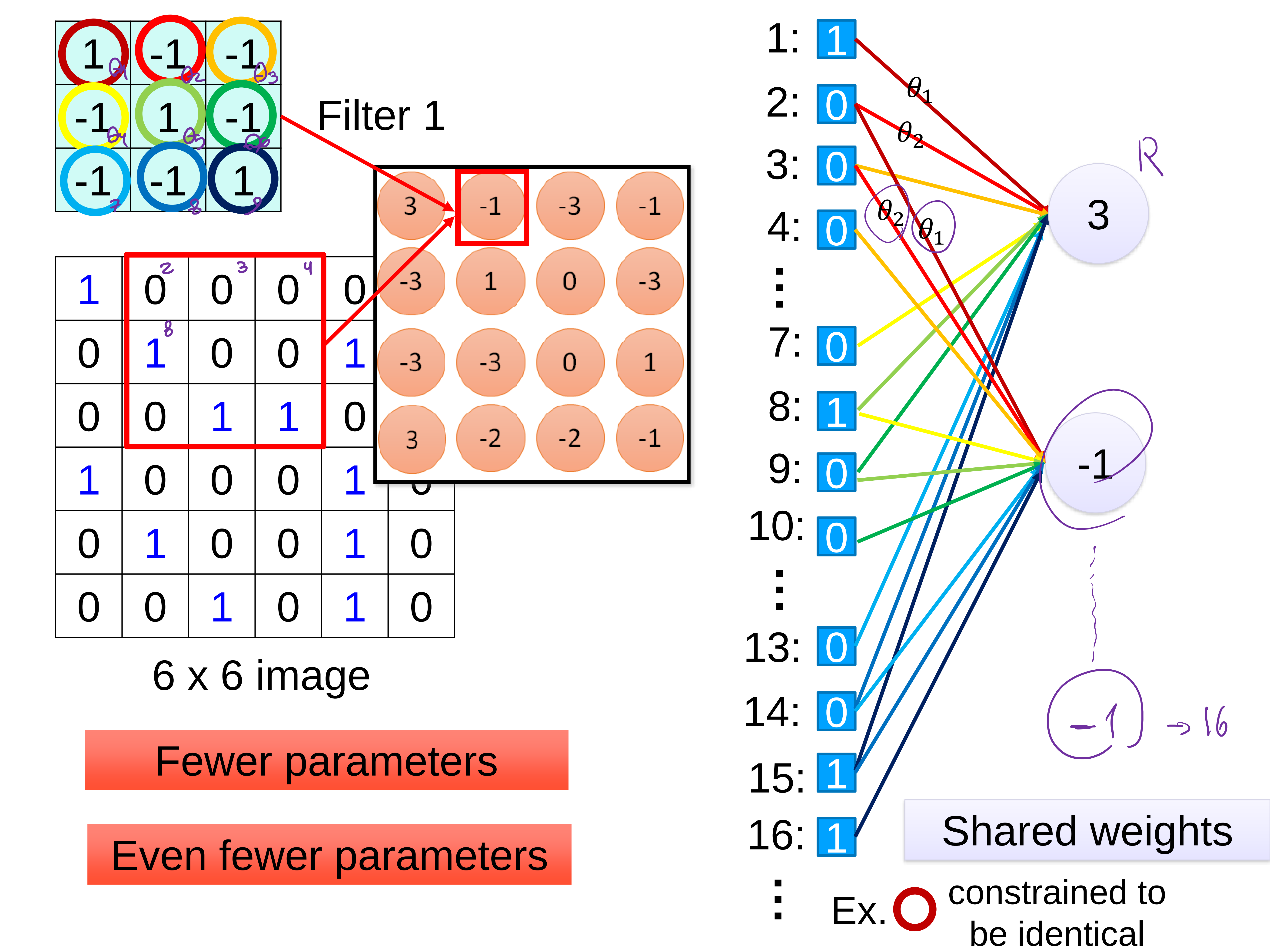
1	0	0	0	0	1
0	1	0	0	1	0
0	0	1	1	0	0
1	0	0	0	1	0
0	1	0	0	1	0
0	0	1	0	1	0

6 x 6 image



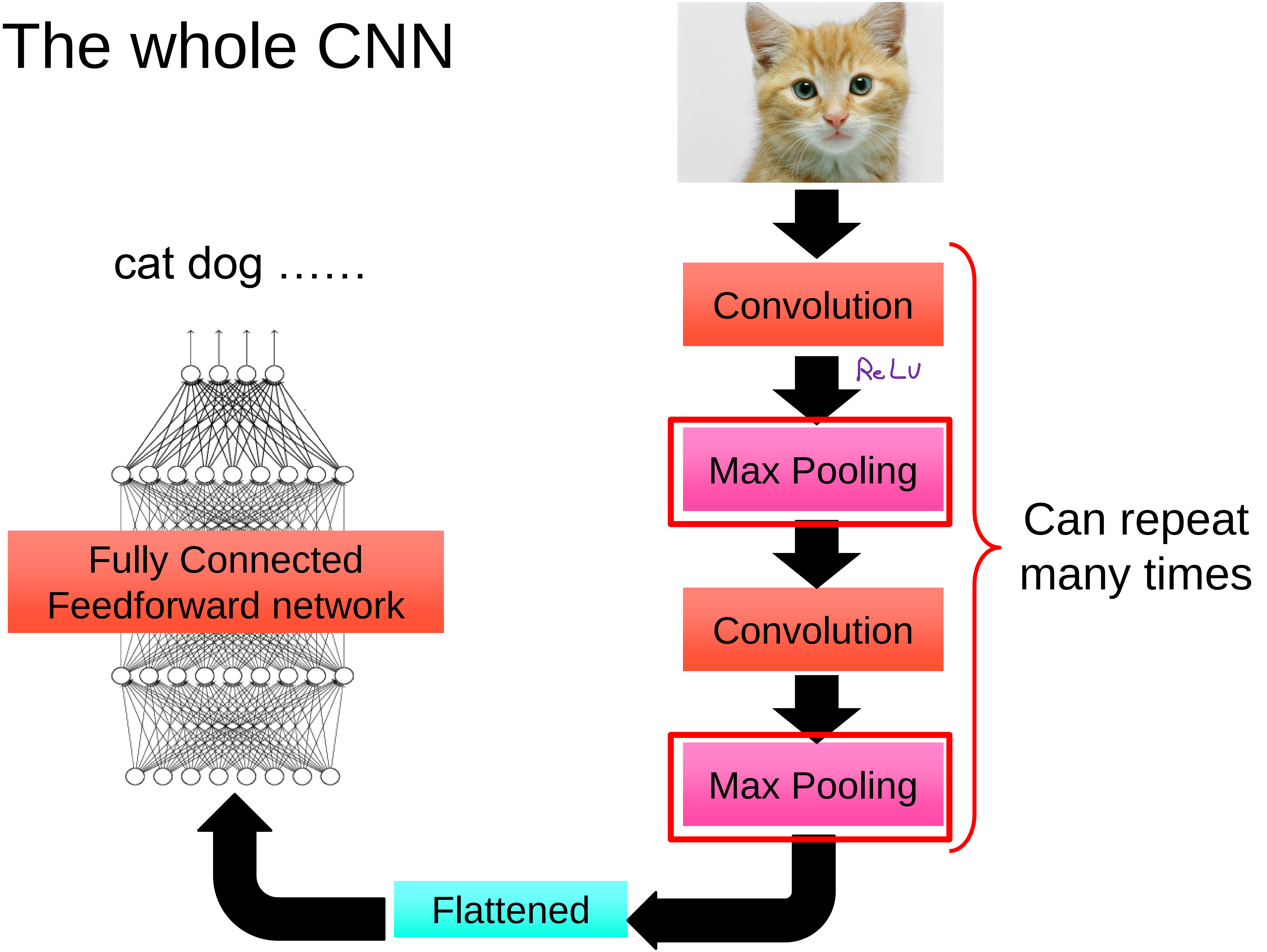


Filter 1
1 -1 -1
-1 1 -1
-1 -1 1
$1\times\theta_1 + 0\times\theta_2 + \cdots + 1\times\theta_9$
3 -1 -3 -1
-3 1 0 -3
-3 -3 0 1
3 -2 -2 -1
6 x 6 image
fewer parameters!
θ_1
θ_2
1 1
2 0
3 0
4: 0
0
8 1
9 0
10: 0
13 0
14 0
15 1
16 1
3
Only connect to 9 inputs, not fully connected



Filter 1
6 x 6 image
Fewer parameters
Even fewer parameters
1: 1
2: 0
3: 0
4: 0
7: 0
8: 1
9: 0
10: 0
13: 0
14: 0
15: 1
16: 1
θ_1
θ_2
3
-1
R
-1 → 16
Shared weights
Ex. constrained to be identical

The whole CNN



Max Pooling

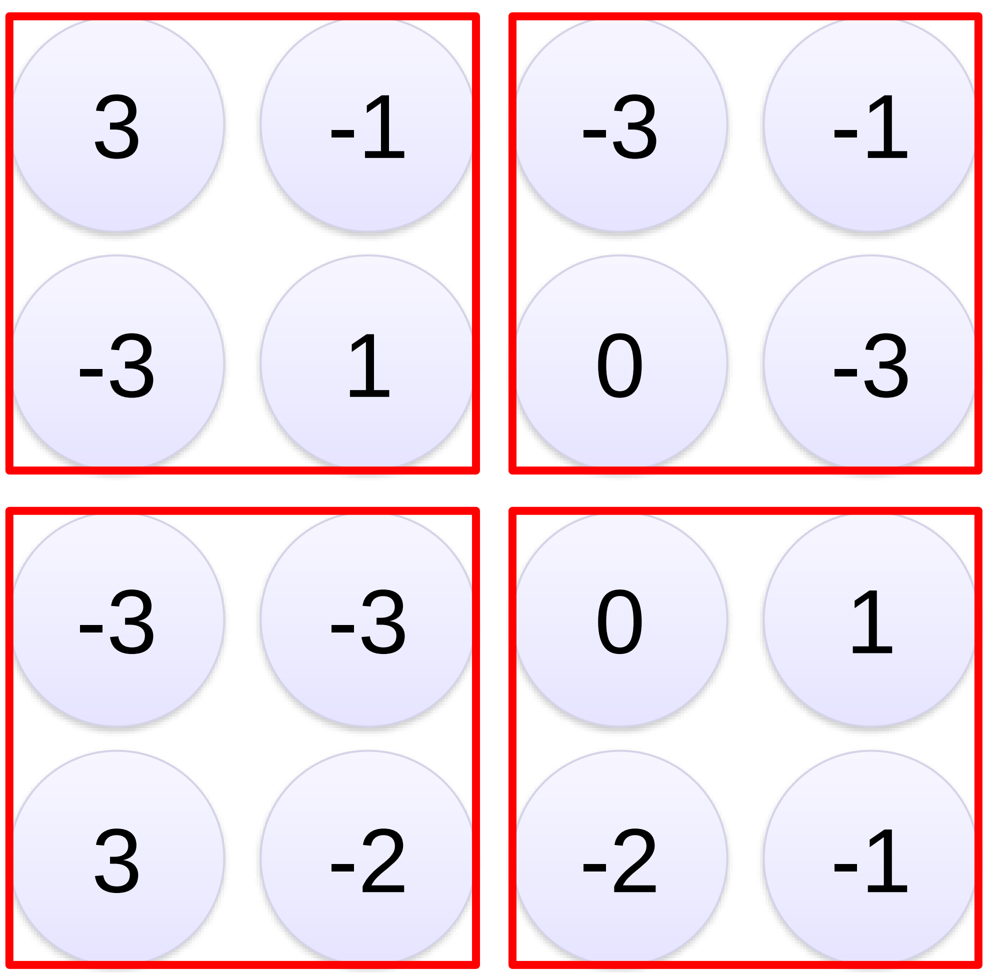
1	-1	-1
-1	1	-1
-1	-1	1

Filter 1

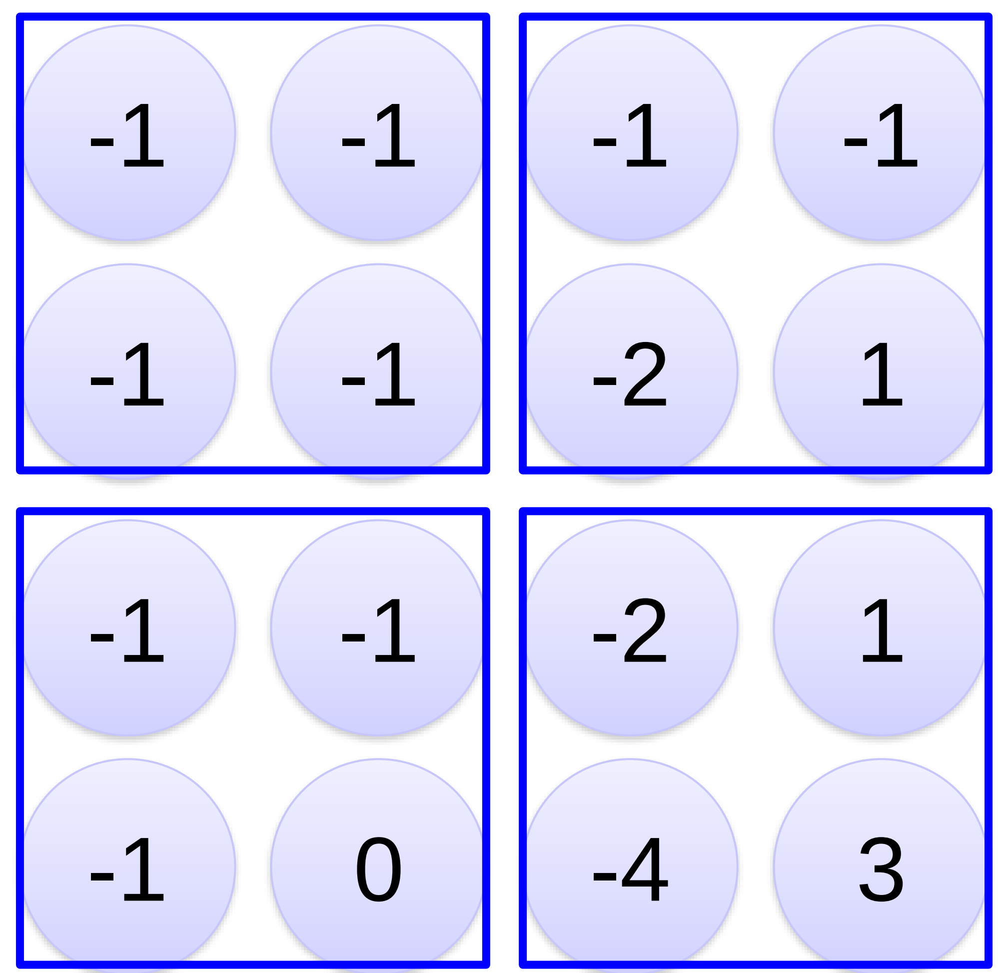
-1	1	-1
-1	1	-1
-1	1	-1

Filter 2

$$\begin{bmatrix} 3 & 0 \\ 3 & 1 \end{bmatrix}_{2\times 2}$$



$$\begin{bmatrix} -1 & 1 \\ 0 & 3 \end{bmatrix}_{2\times 2}$$



Why Pooling

- Subsampling pixels will not change the object

bird

Subsampling

bird

We can subsample the pixels to make image smaller

fewer parameters to characterize the image

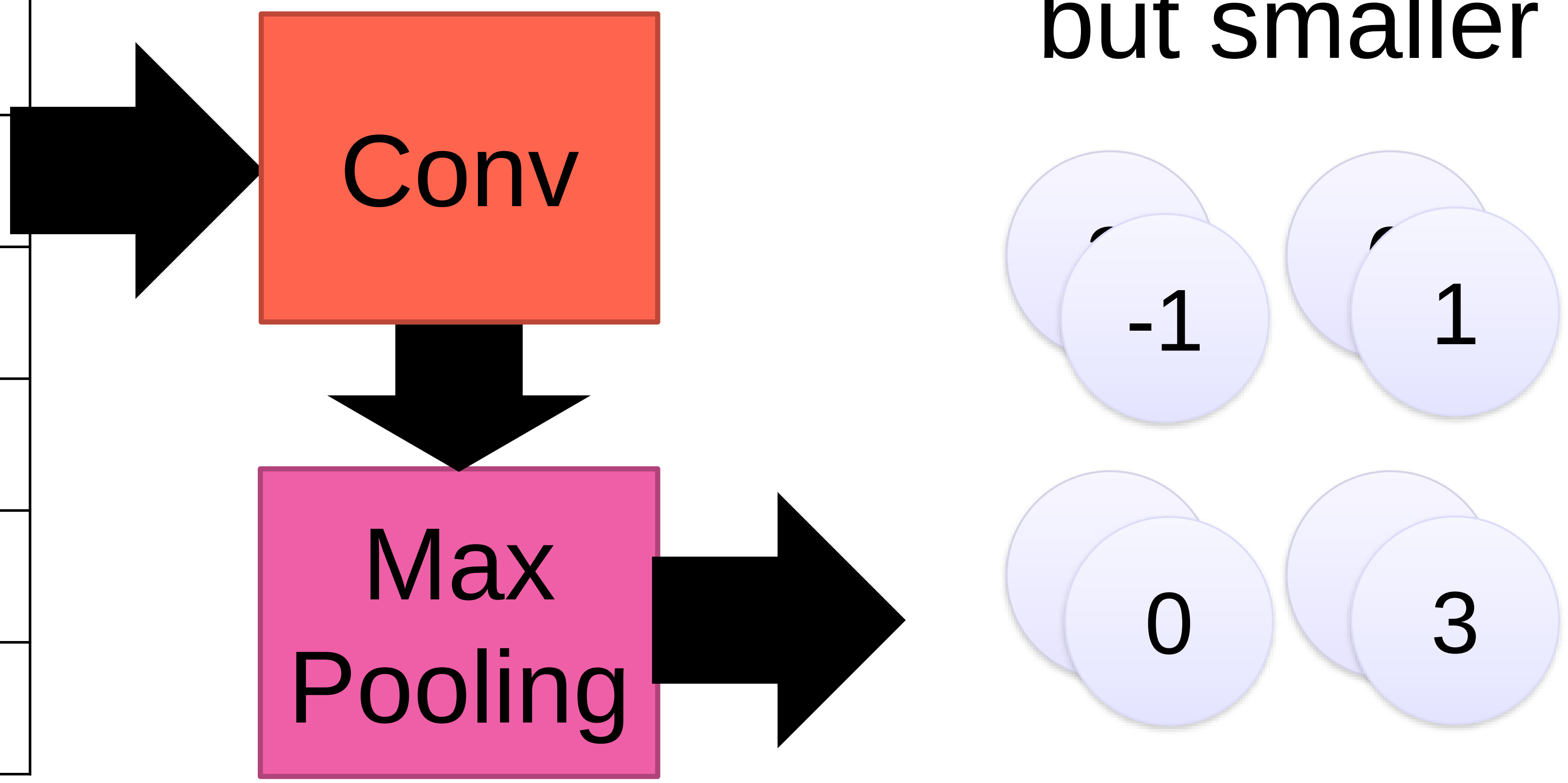
A CNN compresses a fully connected network in three ways:

- Reducing number of connections
- Shared weights on the edges
- Max pooling further reduces the complexity

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

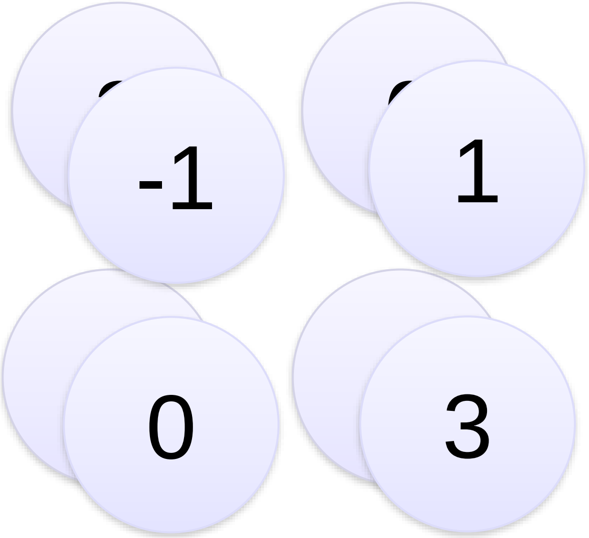


New image but smaller

2x 2 x 2 image

Each filter is a channel

The whole CNN



A new image

Convolution

Max Pooling

Convolution

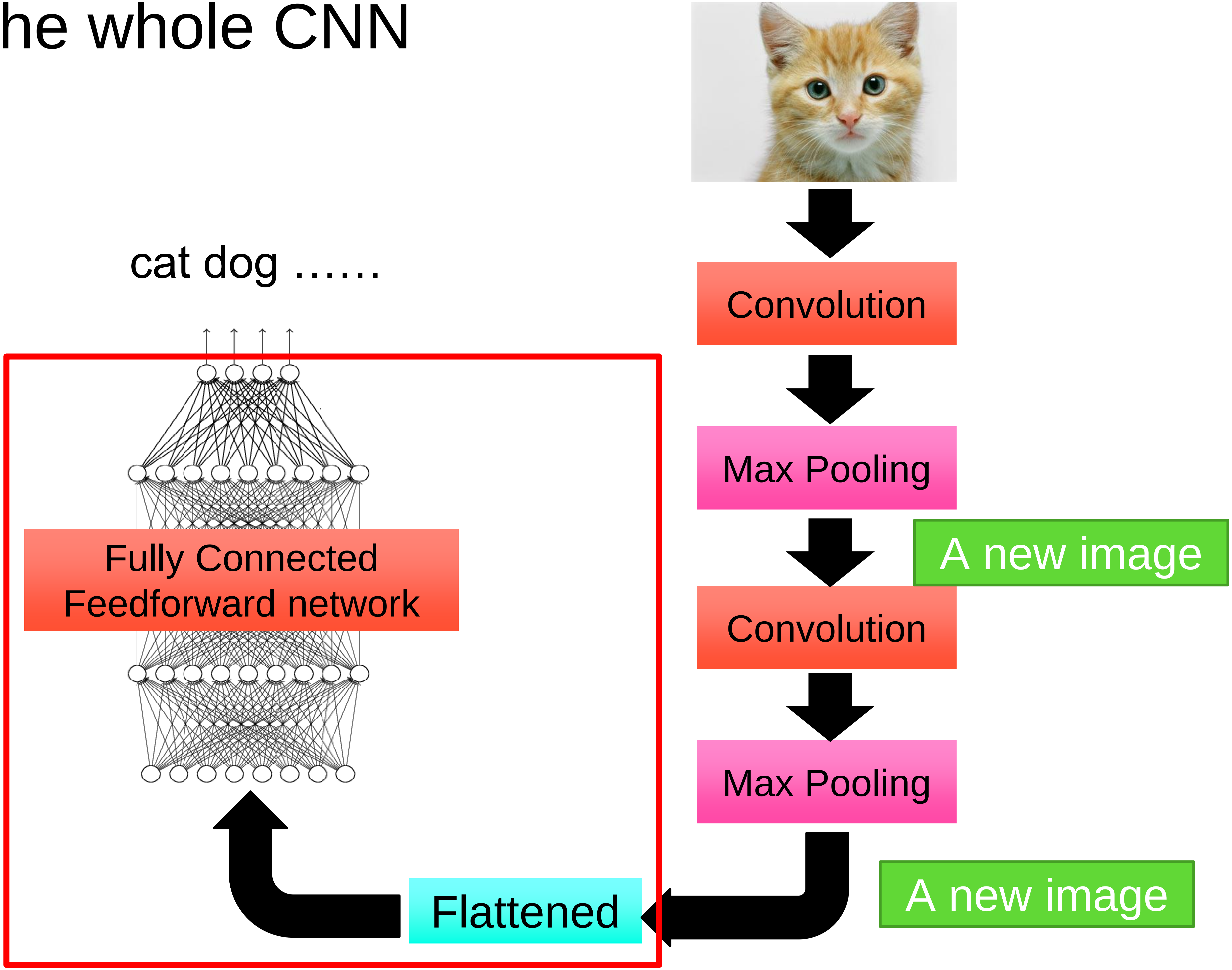
Max Pooling

Can repeat many times

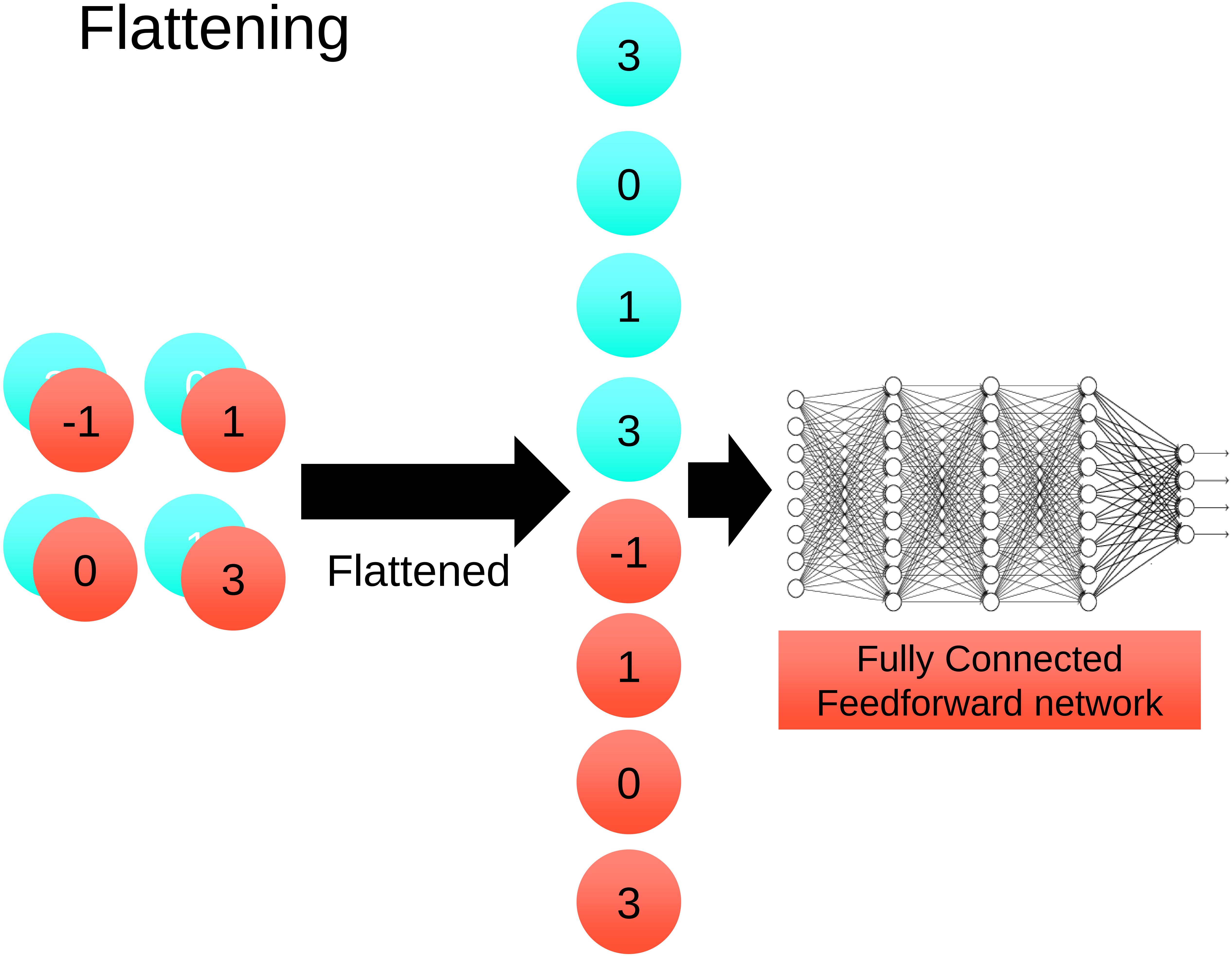
Smaller than the original image

The number of channels is the number of filters

The whole CNN



Flattening

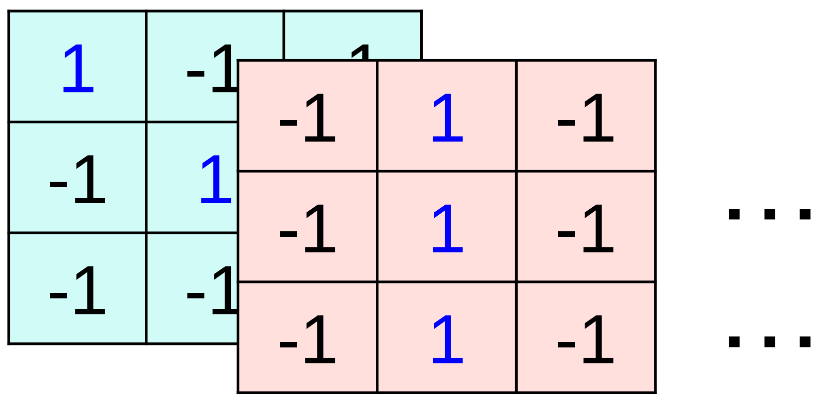

-1
1
0
3
Flattened
3
0
1
3
-1
1
0
3
Fully Connected
Feedforward network

CNN in Keras

Only modified the *network structure* and *input format (vector -> 3-D tensor)*

```
model2.add( Convolution2D( 25,3,3,
            input_shape=(28,28,1)) )
```

25x26x26



There are 25 3x3 filters.

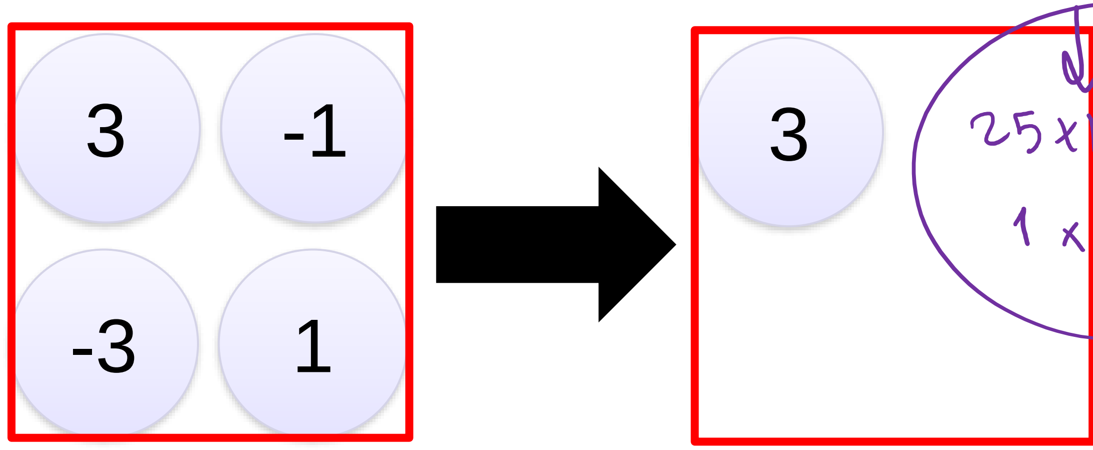
Input_shape = (28 , 28 , 1)

28 x 28 pixels

1: black/white, 3: RGB

25x26x26

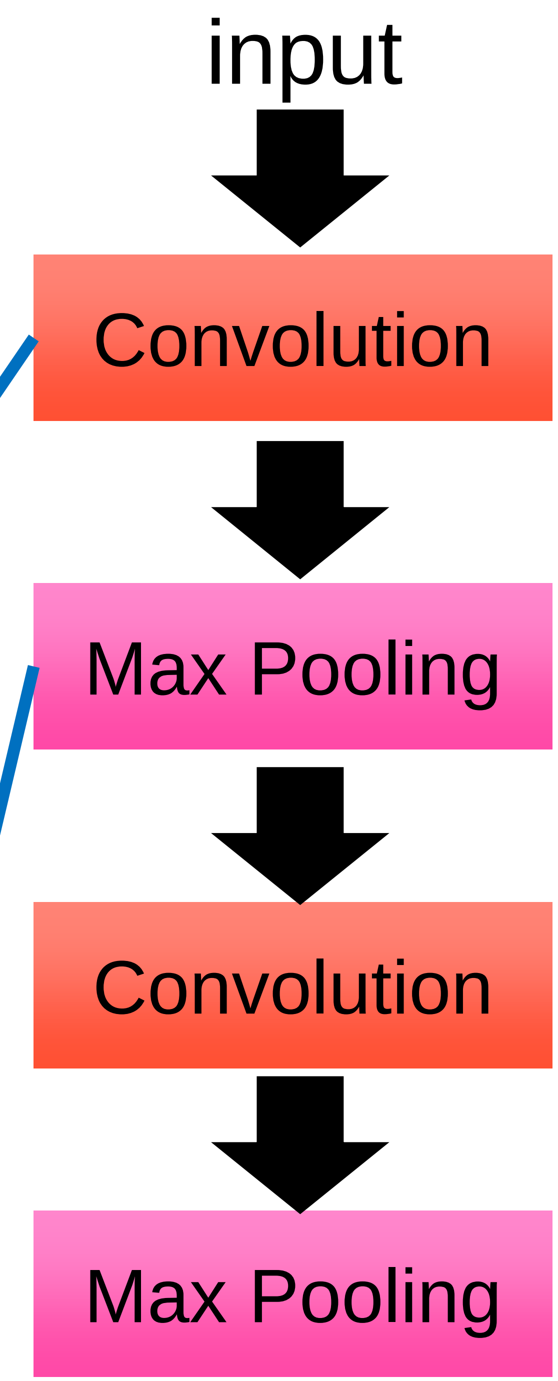
```
model2.add(MaxPooling2D((2,2)))
```



25x13x13

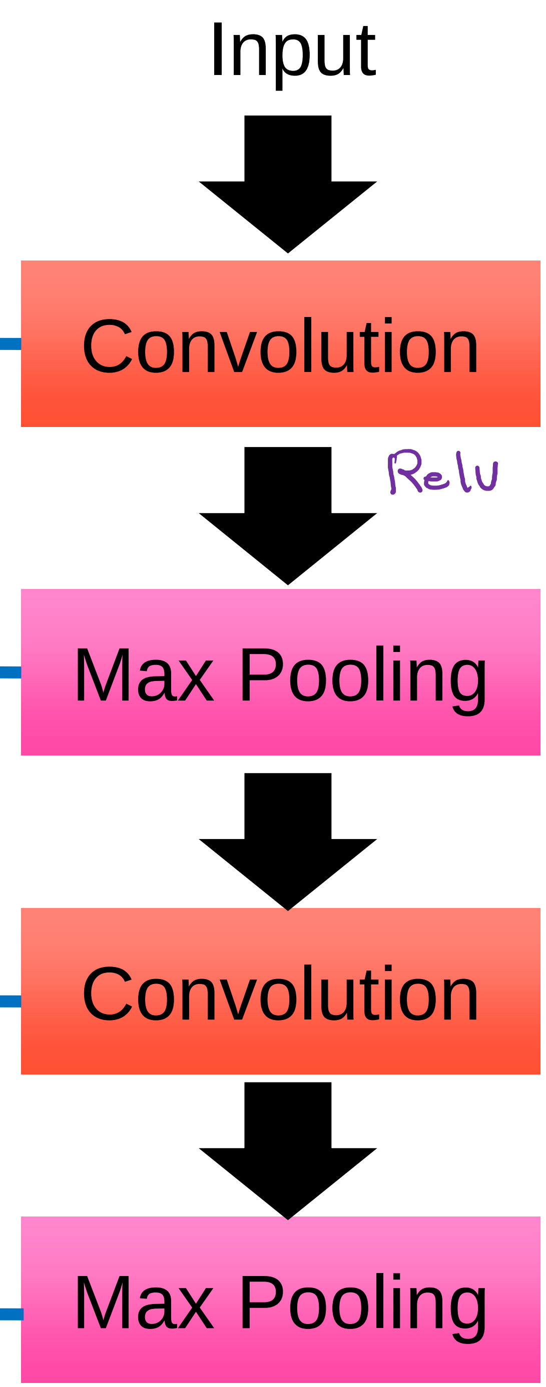
1 x 25 x 3x3

1x11x11



CNN in Keras

Only modified the ***network structure*** and ***input format (vector -> 3-D array)***



1 x 28 x 28

```
model2.add( Convolution2D( 25,3,3,
        input_shape=(28,28,1)) )
```

25 x 26 x 26

```
model2.add(MaxPooling2D((2,2)))
```

25 x 13 x 13

```
model2.add(Convolution2D(50,3,3))
```

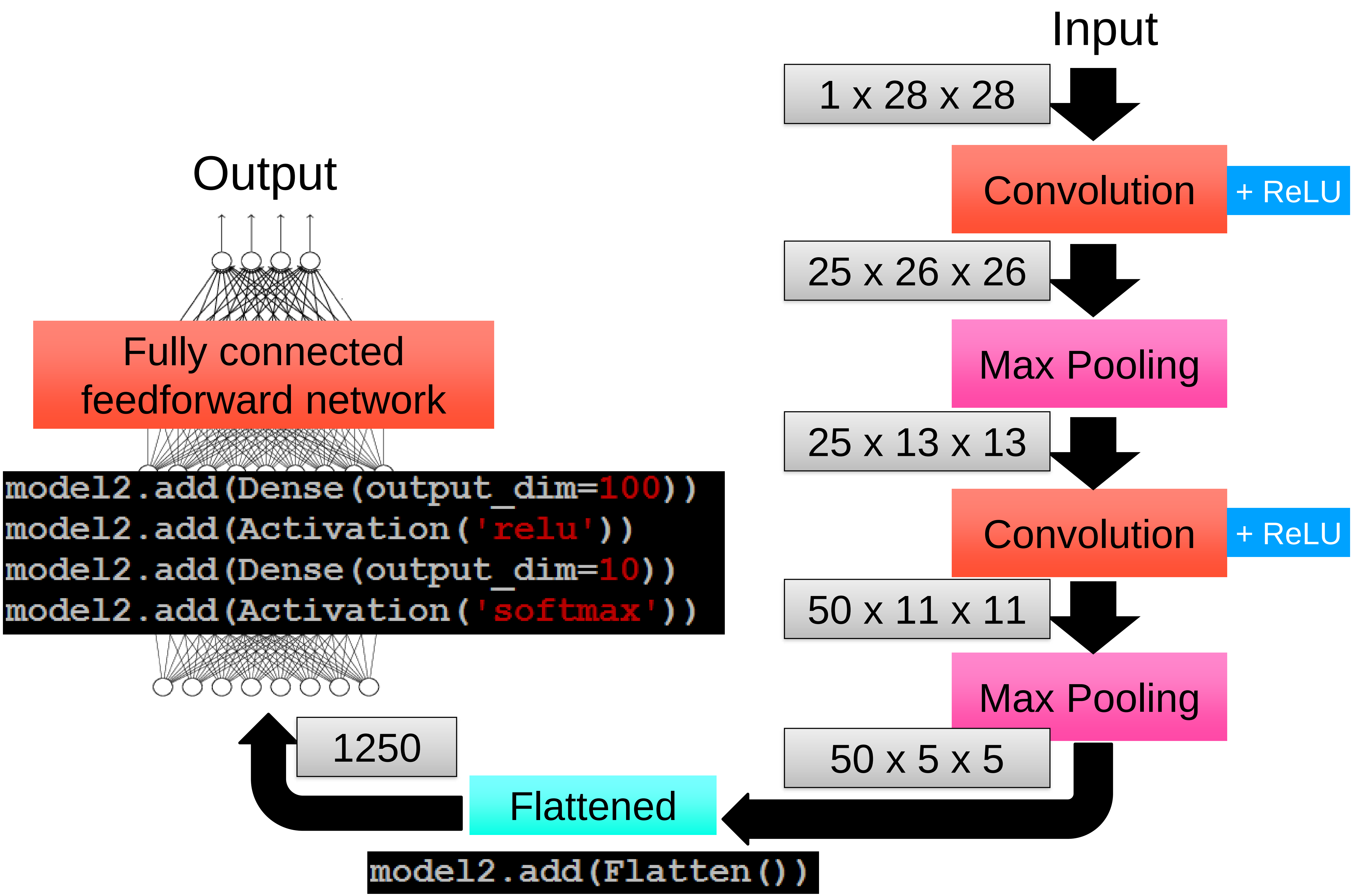
50 x 11 x 11

```
model2.add(MaxPooling2D((2,2)))
```

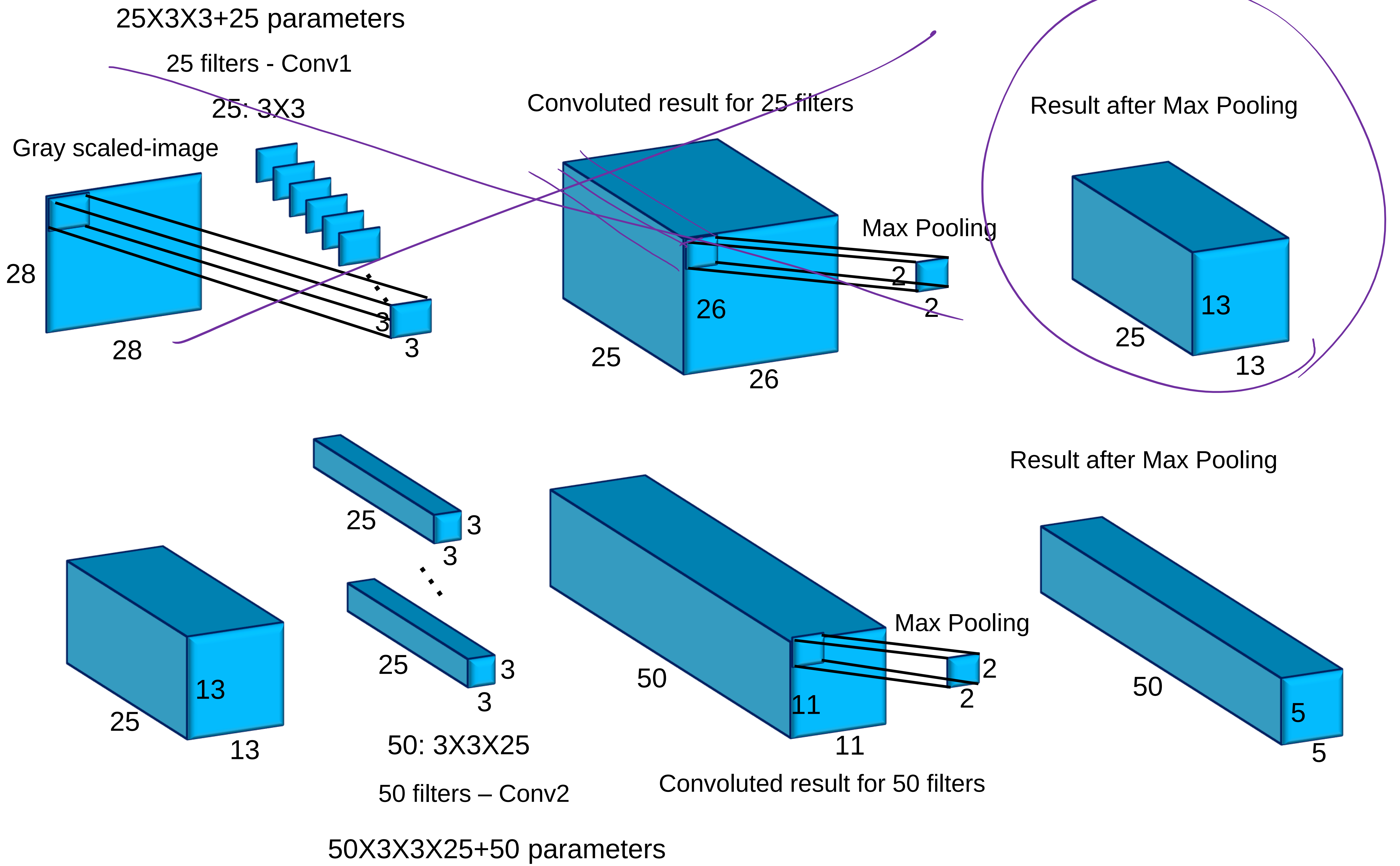
50 x 5 x 5

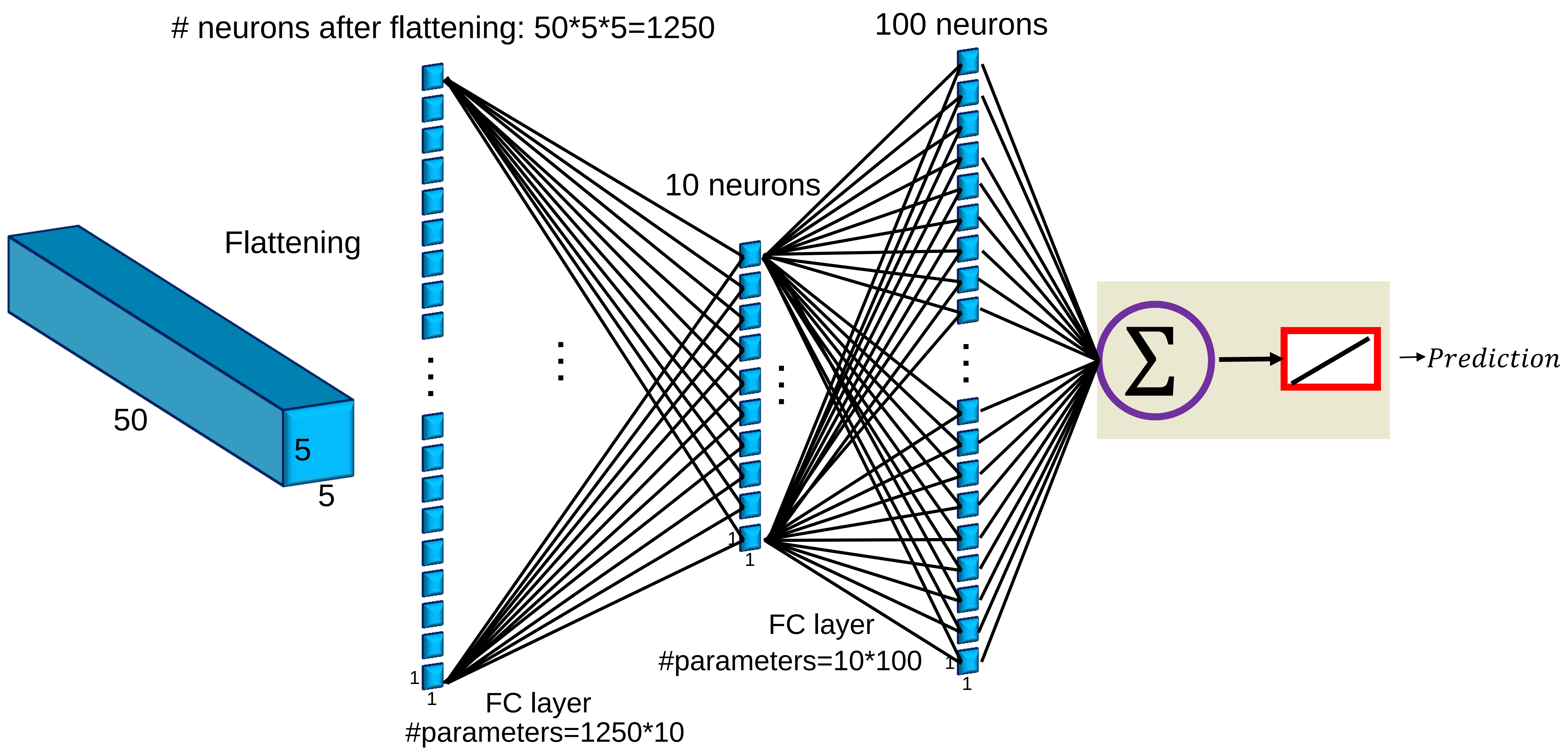
CNN in Keras

Only modified the ***network structure*** and ***input format (vector -> 3-D array)***



Number of Parameters





10 CNN Architecture