Convolutional Neural Networks

Presented by

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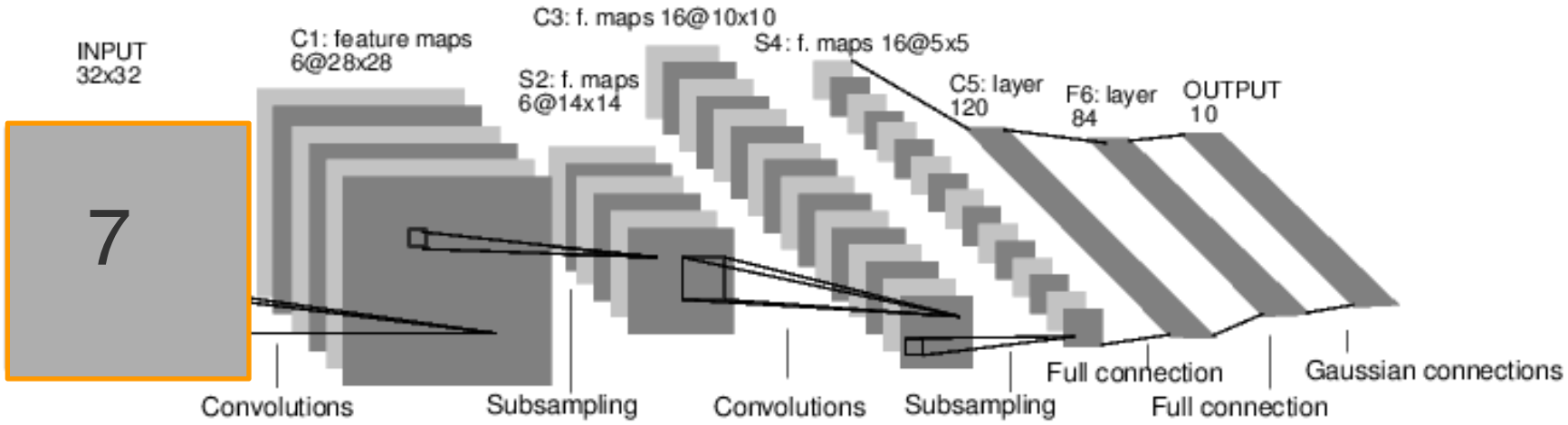
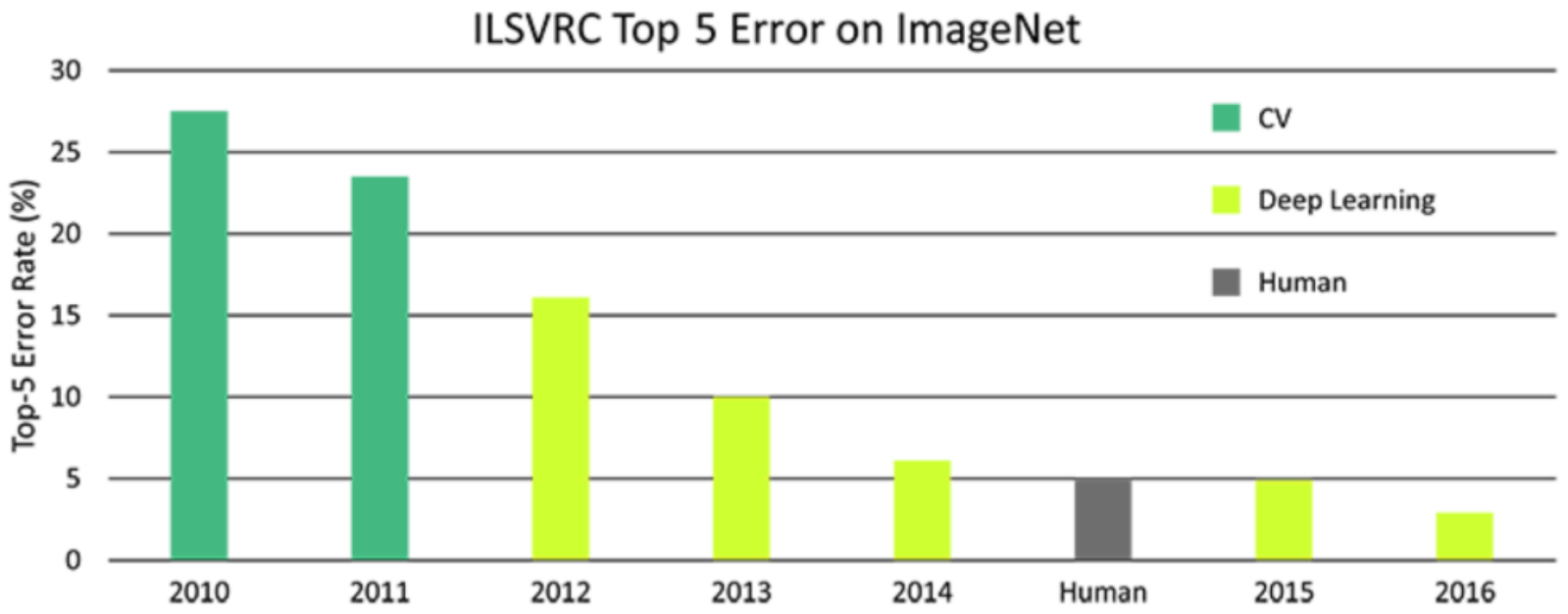
Convolutional Neural Networks

- ConvNets have been around for a long time,
- One of the seminal works came from LeCun et al. 1989
- MNIST digit and OC recognition
- Most recent version LeNet-5



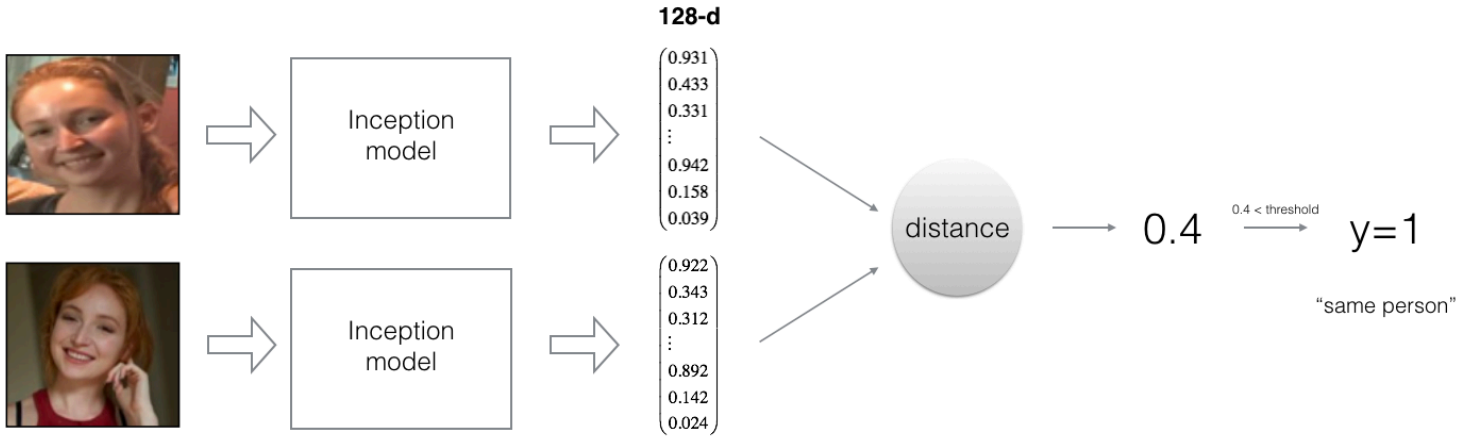
- Approx. 14 M labeled images, 20 K classes
- Images gathered from internet
- Human labels via Amazon Turk
- For object recognition challenge 1.2 M training images and 1000 classes
  http://image-net.org/

Performance on ImageNet



source: https://www.dsiac.org/resources/journals/dsiac/winter-2017-volume-4-number-1/real-time-situ-intelligent-video-analytics

Face recognition and verification system using FaceNet and DeepFace Algorithms - Implementation



DeepFace: Closing the Gap to Human-Level Performance in Face Verification

Yaniv Taigman, Ming Yang, Marc' Aurelio Ranzato and Lior Wolf (2014) *in Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition 2014*.

FaceNet: A Unified Embedding for Face Recognition and Clustering

Florian Schroff, Dmitry Kalenichenko and James Philbin (2015) *in Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition 2015*.

Object Detection for autonomous car driving application - YOLO Algorithm Implementation

- You OnlySee Once (YOLO) is an object detection model
- It runs on an input image through a Convolution Neural Network

You Only Look Once: Unified, Real-Time Object Detection

Joseph Redmon, Santos Divvala, Ross Girschick and Ali Farhadi (2016) *in Proceedings of the IEEE Computer*

Deep Learning & Art: Neural Style Transfer

- Implementation of neural style transfer algorithm
- Generate novel artistic images

content image

louvre museum

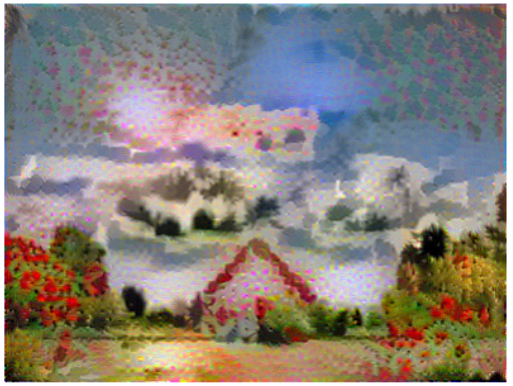
+

style image

impressionist style painting

=

generated image



louvre painting
with impressionist style

A neural algorithm of artistic style

Leon A. Gatys, Alexander S. Ecker, Matthias Bethge (2015) *in Proceedings of the IEEE Computer Society*

Cross-Correlation and Convolution

- Cross-correlation is a similarity measure between two signals when one has a time-lag.

  Continuous domain: $(g * h)(t) = \int g^*(\tau) h(t+\tau) d\tau$

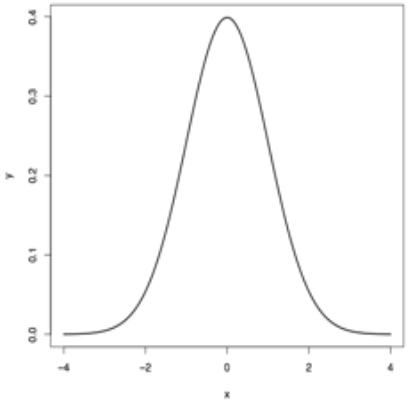
- Convolution is similar, although one signal is reversed

$$f_{conv} = g(-t) * h(t)$$

- They have two key features:
  - shift invariance :
    Same operation is performed at every point in the image
  - linearity
    Every pixel is replaced with a linear combination of its neighbors.

Convolution

Image



Gaussian

Modified Image

Cross-Correlation and Convolution

5	15	4	0	-1
10	1	5	1	0
6	9	11	1	-1
0	-1	5	15	4
1	0	10	1	5

Image

n x n

*

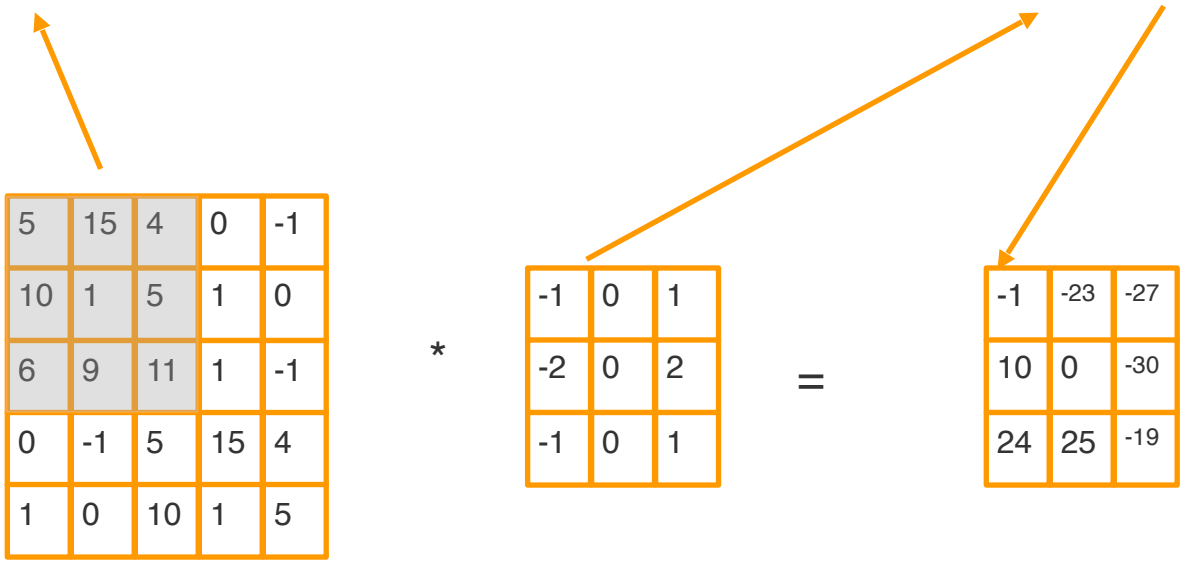
-1	0	1
-2	0	2
-1	0	1

filter

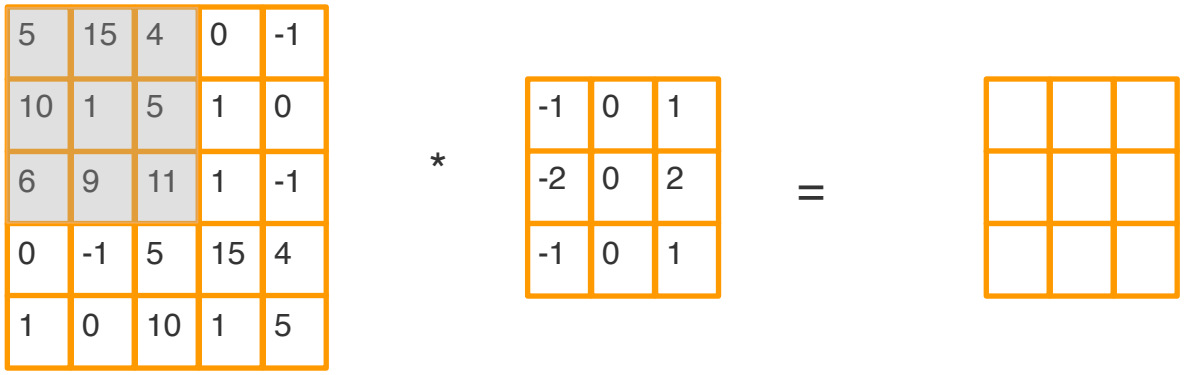
f x f

Cross-Correlation and Convolution

5*(-1)+15*0+4*1+10*(-2)+1*0+5*2+6*(-2)+9*0+11*2 = -1



Cross-Correlation and Convolution



Cross-Correlation and Convolution

-1	0	1	0	-1
-2	0	2	1	0
-1	0	1	1	-1
0	-1	5	15	4
1	0	10	1	5

-1		

Cross-Correlation and Convolution

5	-1	0	1	-1
10	-2	0	2	0
6	-1	0	1	-1
0	-1	5	15	4
1	0	10	1	5

-1	-23	

Cross-Correlation and Convolution

5	15	-1	0	1
10	1	-2	0	2
6	9	-1	0	1
0	-1	5	15	4
1	0	10	1	5

-1	-23	-27

Cross-Correlation and Convolution

5	15	4	0	-1
-1	0	1	1	0
-2	0	2	1	-1
-1	0	1	15	4
1	0	10	1	5

-1	-23	-27
10		

Cross-Correlation and Convolution

5	15	4	0	-1
10	-1	0	1	0
6	-2	0	2	-1
0	-1	0	1	4
1	0	10	1	5

-1	-23	-27
10	0	

Cross-Correlation and Convolution

5	15	4	0	-1
10	1	-1	0	1
6	9	-2	0	2
0	-1	-1	0	1
1	0	10	1	5

-1	-23	-27
10	0	-30

Cross-Correlation and Convolution

5	15	4	0	-1
10	1	5	1	0
-1	0	1	1	-1
-2	0	2	15	4
-1	0	1	1	5

-1	-23	-27
10	0	-30
24		

Cross-Correlation and Convolution

5	15	4	0	-1
10	1	5	1	0
6	-1	0	1	-1
0	-2	0	2	4
1	-1	0	1	5

-1	-23	-27
10	0	-30
24	25	

Cross-Correlation and Convolution

5	15	4	0	-1
10	1	5	1	0
6	9	-1	0	1
0	-1	-2	0	2
1	0	-1	0	1

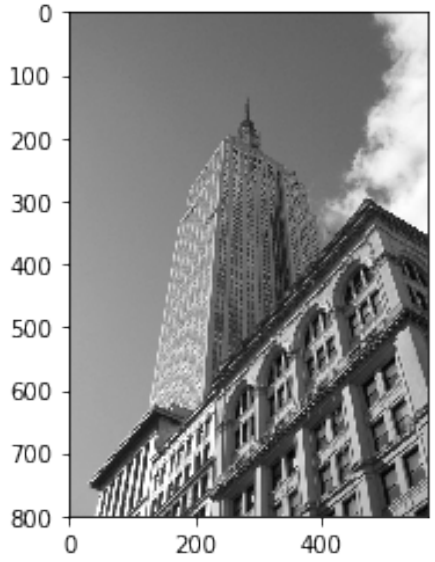
n x n

-1	-23	-27
10	0	-30
24	25	-19

Output Image

n-f+1 x n-f+1

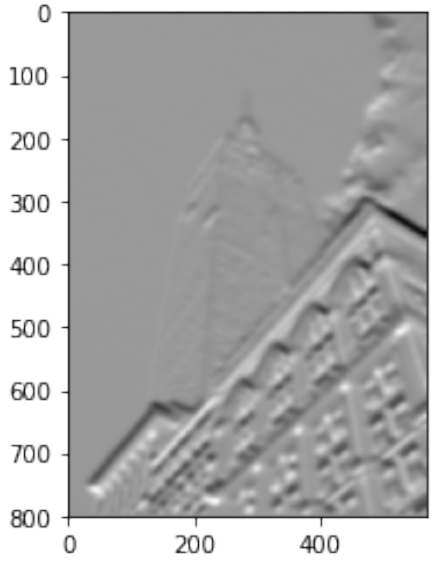
Cross-Correlation and Convolution



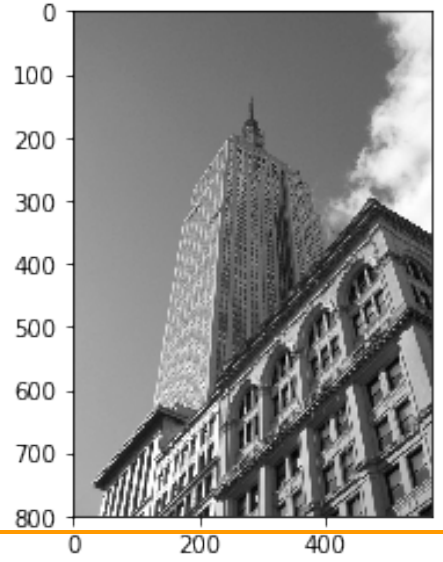
*

-1	0	1
-2	0	2
-1	0	1

=



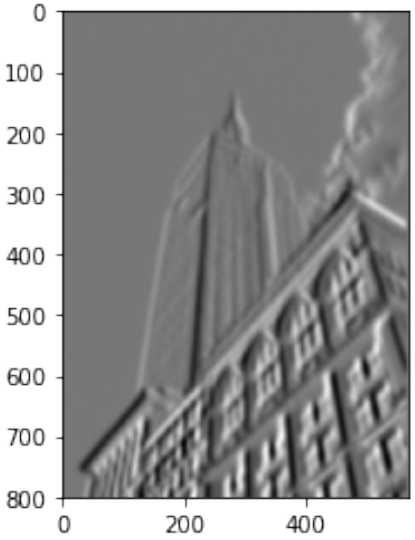
horizontal edge detector



*

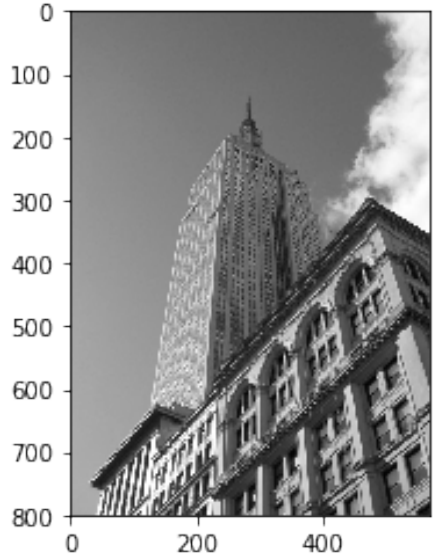
-1	-2	-1
0	0	0
1	2	1

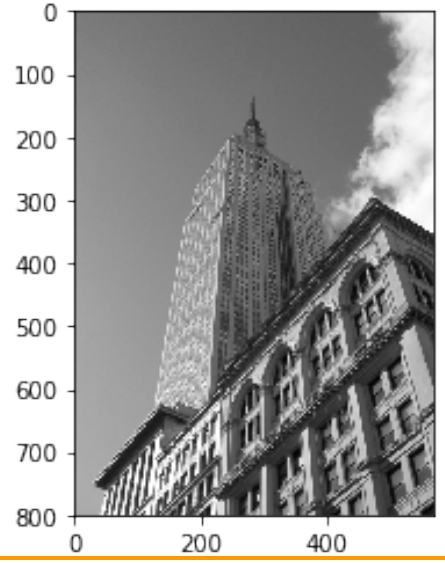
=



vertical edge detector

Cross-Correlation and Convolution





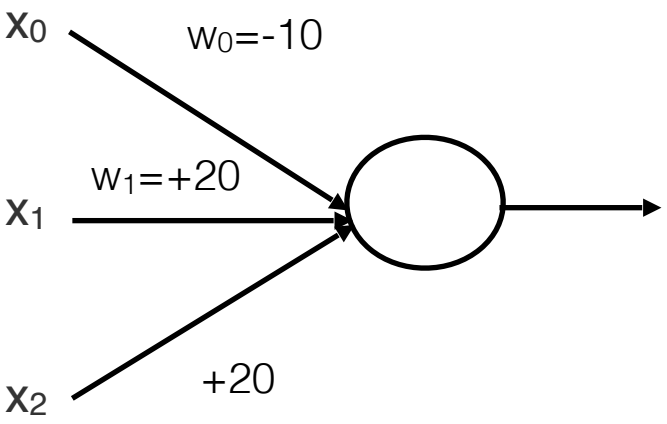
Cross-correlation

-1	0	1
-2	0	2
-1	0	1

1	2	1
0	0	0
-1	-2	-1

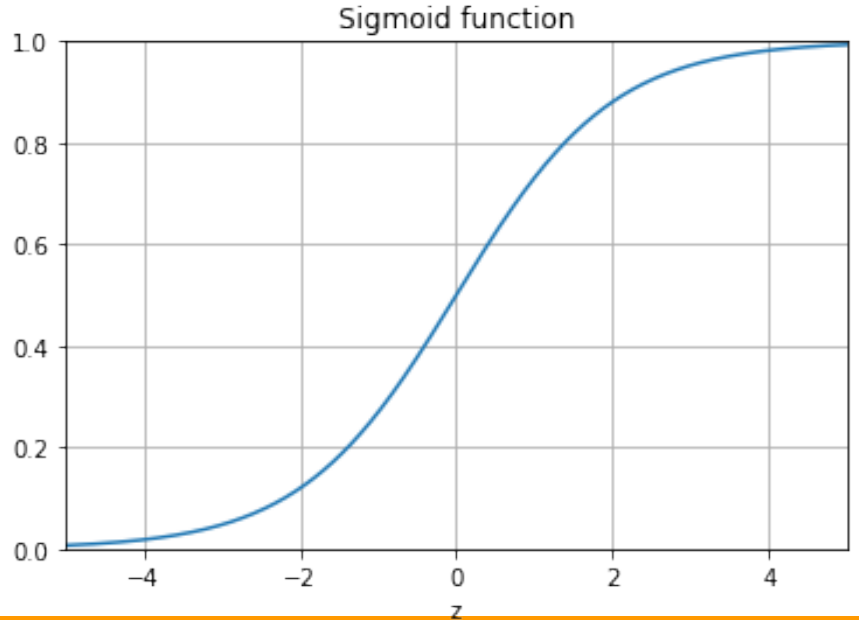
Convolution

Neural Network



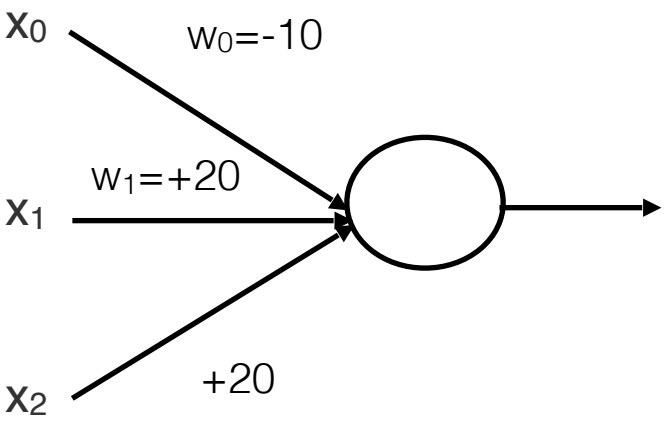
$$y = g(w_0 * x_0 + w_1 * x_1 + w_2 * x_2)$$

g - activation function



$$g(z) = \frac{1}{1 + e^{-z}}$$

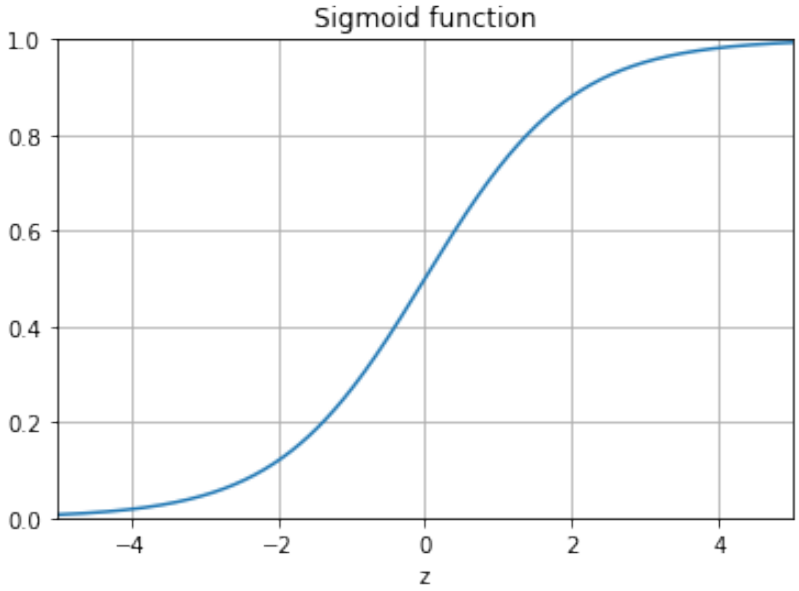
Neural Network



$$y = g(w_0 * x_0 + w_1 * x_1 + w_2 * x_2)$$

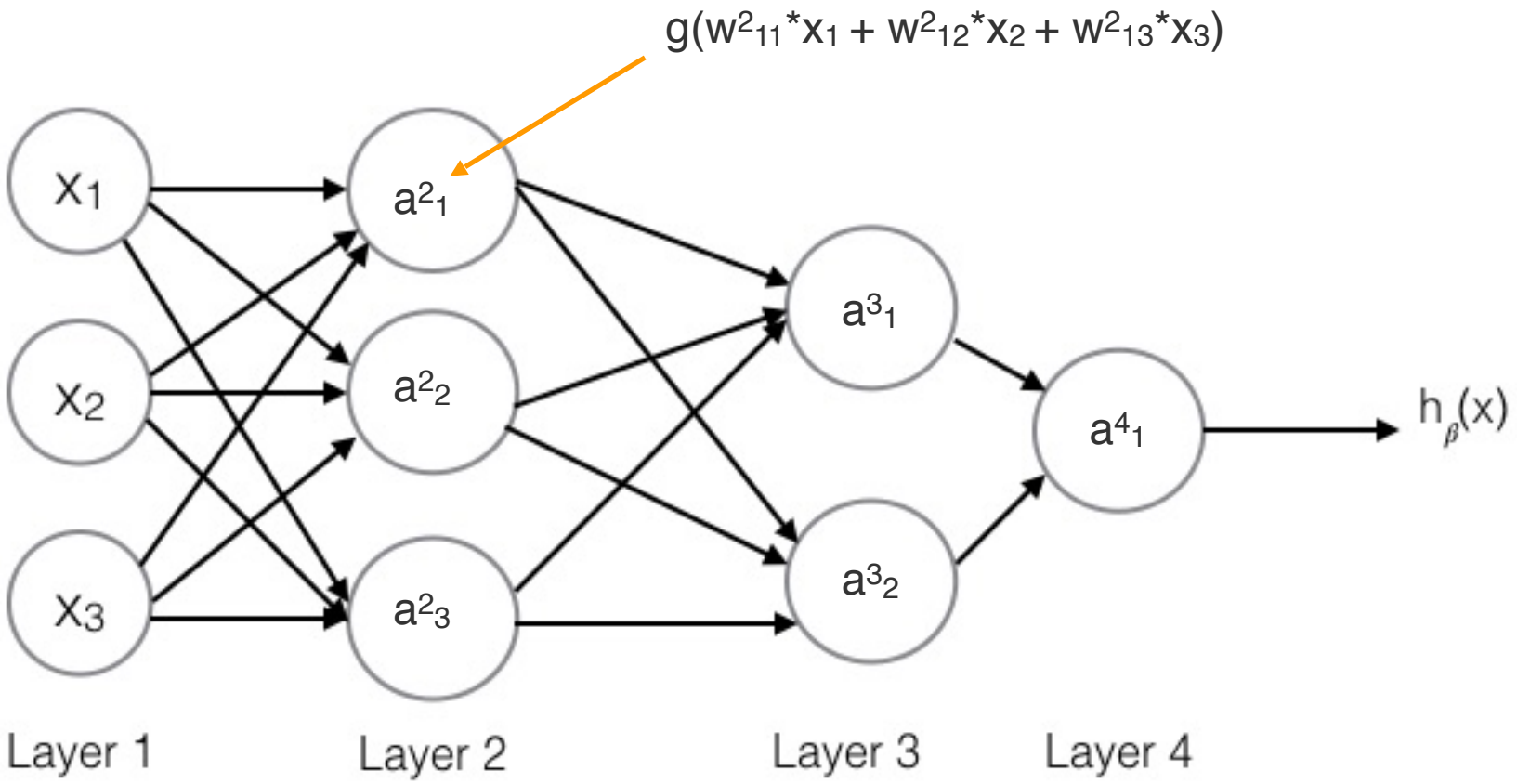
z

g - activation function

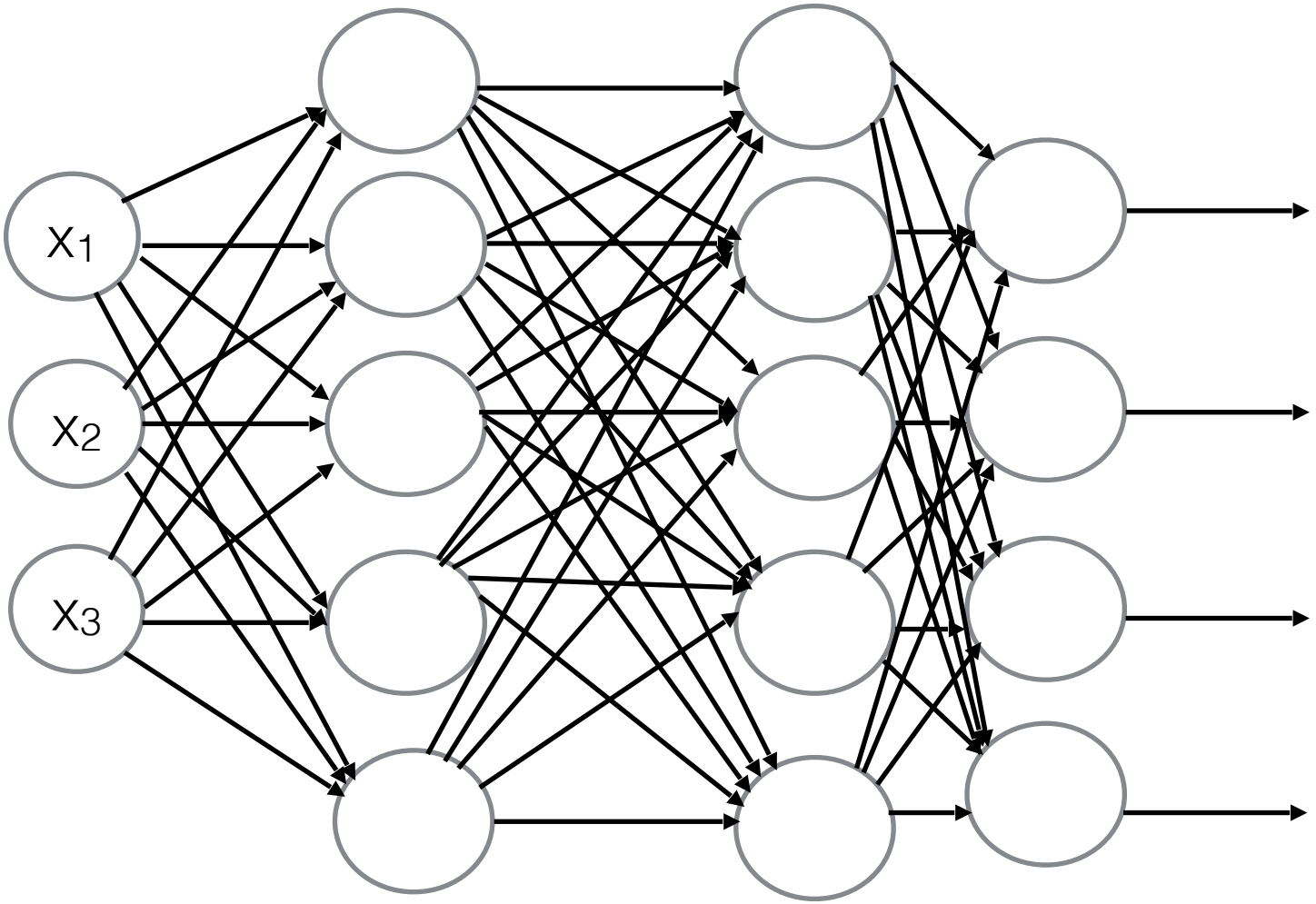


$$g(z) = \frac{1}{1 + e^{-z}}$$

Neural Network

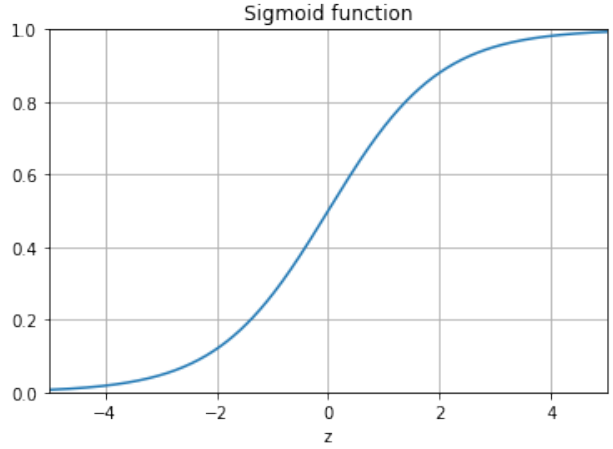


Neural Network

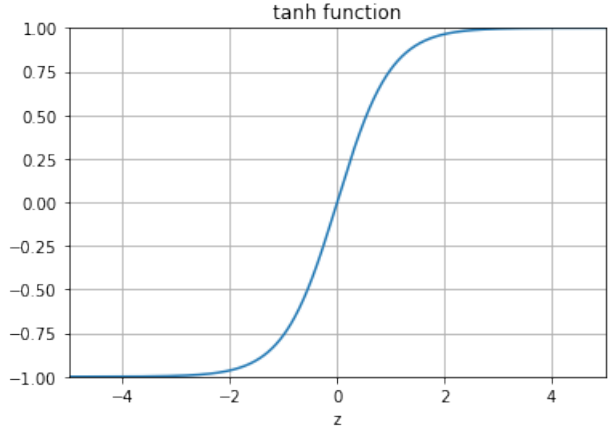


Activation Functions

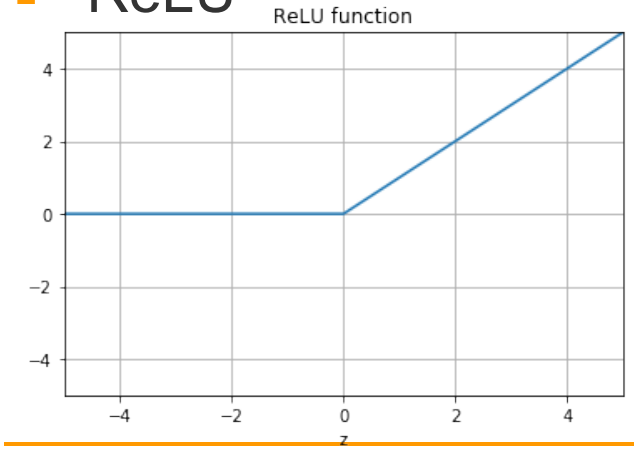
- Sigmoid



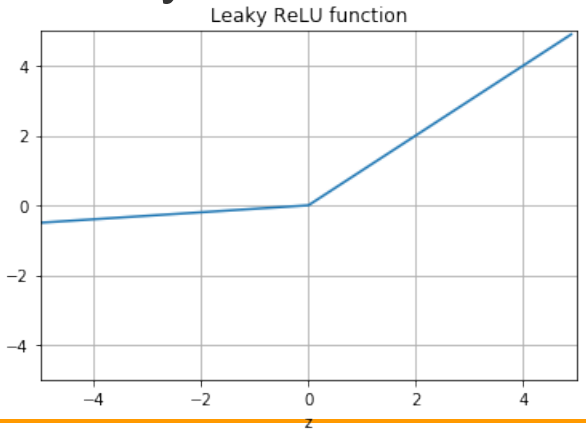
- Hyperbolic tangent



- ReLU



- Leaky ReLU



CNN

5	15	4	0	-1
10	1	5	1	0
6	9	11	1	-1
0	-1	5	15	4
1	0	10	1	5

Image

n x n

*

-1	0	1
-2	0	2
-1	0	1

filter

f x f

CNN

5	15	4	0	-1
10	1	5	1	0
6	9	11	1	-1
0	-1	5	15	4
1	0	10	1	5

Image

n x n

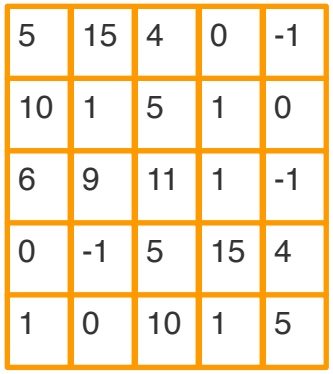
*

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

filter

f x f

CNN



5	15	4	0	-1
10	1	5	1	0
6	9	11	1	-1
0	-1	5	15	4
1	0	10	1	5

Image

n x n

n = 5

*

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

filter

f x f

f = 3

# of parameters to learn: 3x3 = 9

CNN

5	15	4	0	-1
10	1	5	1	0
6	9	11	1	-1
0	-1	5	15	4
1	0	10	1	5

Image

5 x 5

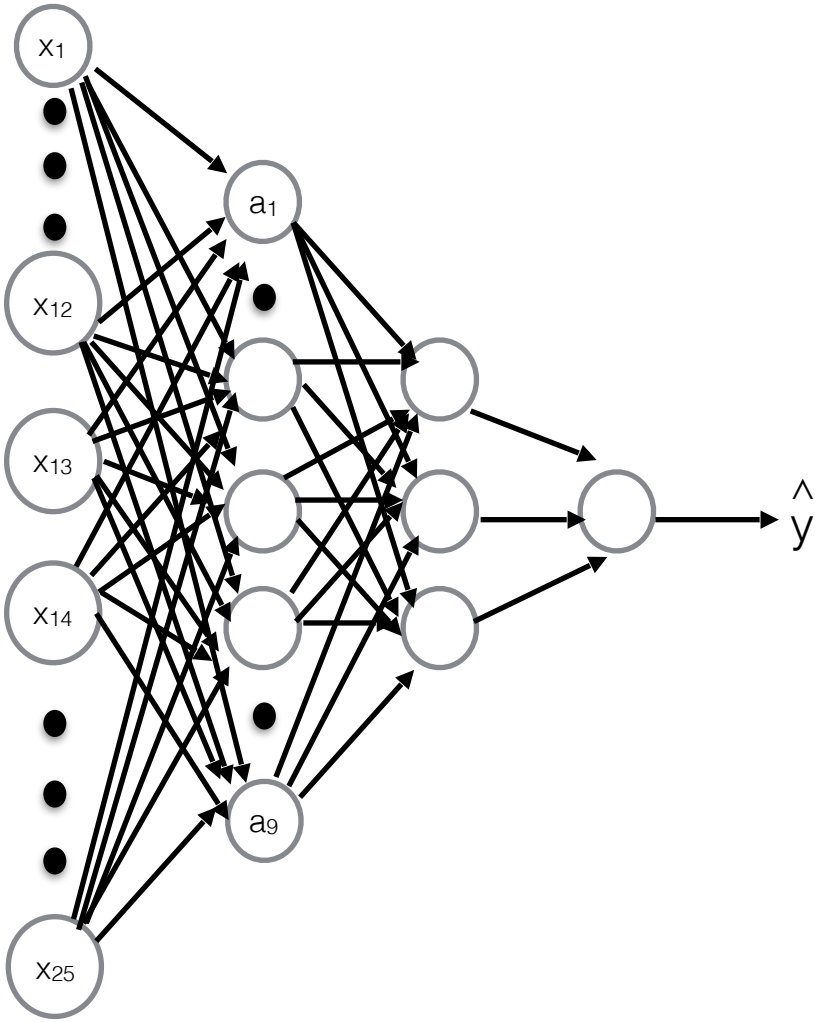
*

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

filter

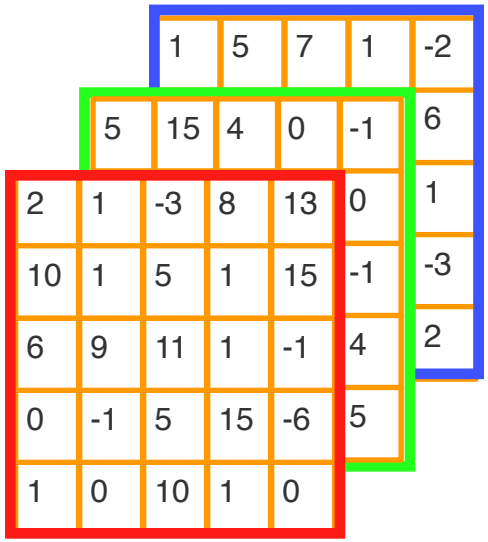
3 x 3

# of parameters to learn: 3x3 = 9



# of parameters to learn: 9x25 = 225

CNN over multiple channels

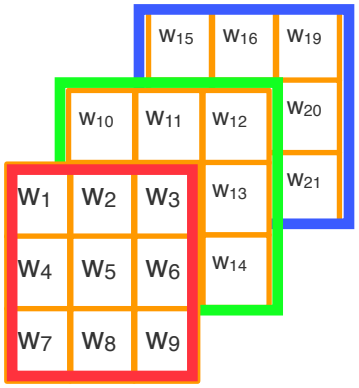


Image

n x n x 3

5 x 5 x 3

*

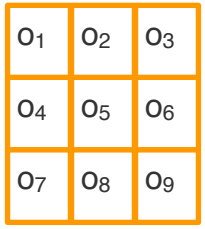


filter

f x f x 3

3 x 3 x 3

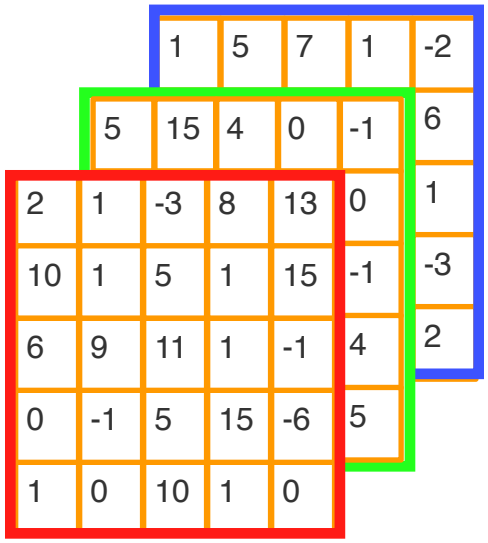
=



n - f +1 x n - f + 1

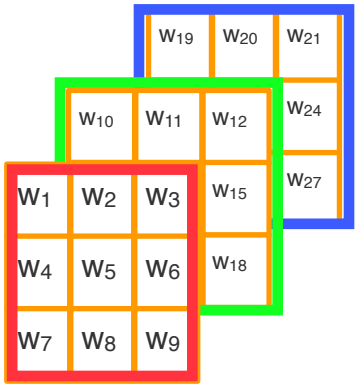
3 x 3 x 1

CNN using multiple filters



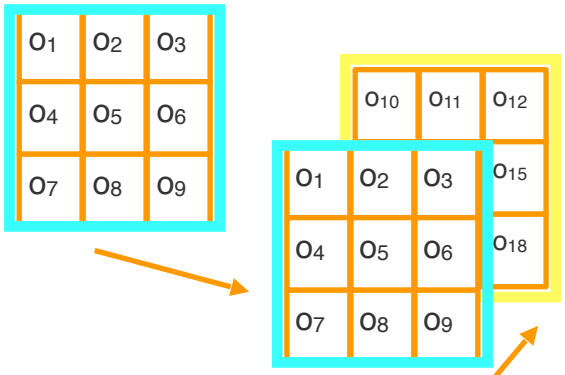
Image

n x n x 3

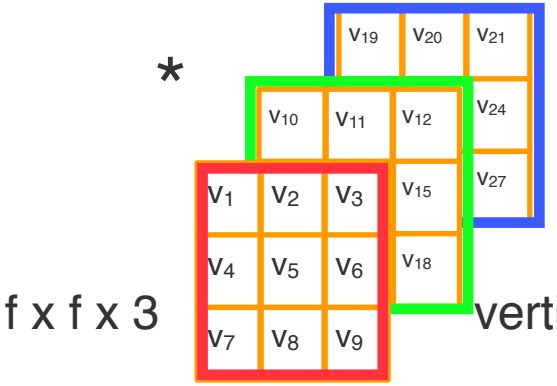


horizontal edge filter

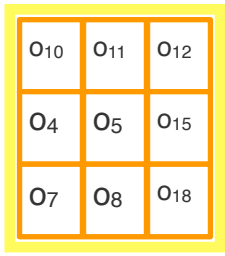
f x f x 3



(n - f +1) x (n - f + 1) x 2

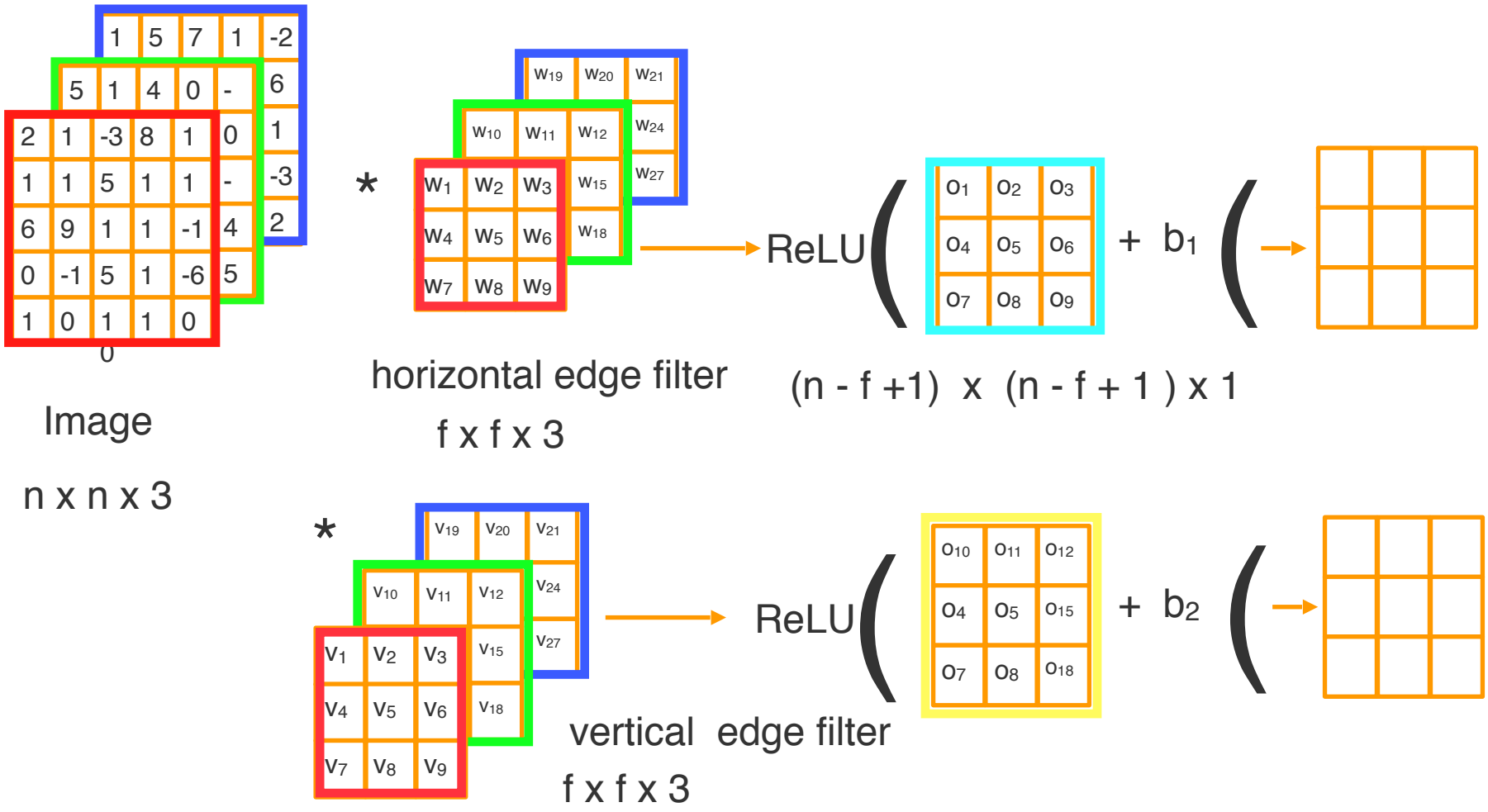


f x f x 3



vertical edge filter

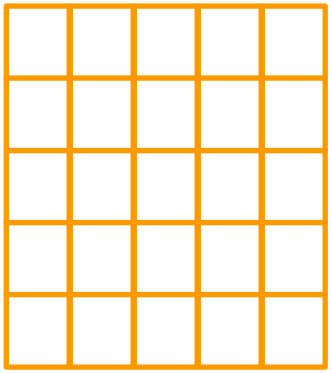
CNN layer


1 5 7 1 -2
5 1 4 0 -
2 1 -3 8 1 0
1 1 5 1 1 -
6 9 1 1 -1 4
0 -1 5 1 -6 5
1 0 1 1 0 2
0 6 1 -3
Image
n x n x 3
*
w19 w20 w21
w10 w11 w12 w24
w1 w2 w3 w15 w27
w4 w5 w6 w18
w7 w8 w9
horizontal edge filter
f x f x 3
ReLU
o1 o2 o3
o4 o5 o6
o7 o8 o9
+ b1
(n - f +1) x (n - f + 1) x 1
*
v19 v20 v21
v10 v11 v12 v24
v1 v2 v3 v15 v27
v4 v5 v6 v18
v7 v8 v9
vertical edge filter
f x f x 3
ReLU
o10 o11 o12
o4 o5 o15
o7 o8 o18
+ b2

Padding

5	15	4	0	-1
10	1	5	1	0
6	9	-1	0	1
0	-1	-2	0	2
1	0	-1	0	1

n x n

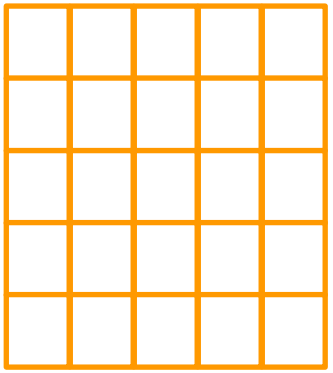


Output Image

(n + 2p - f + 1) x (n + 2p - f + 1)

Padding

0	0	0	0	0	0	0
0	5	15	4	0	-1	0
0	10	1	5	1	0	0
0	6	9	-1	0	1	0
0	0	-1	-2	0	2	0
0	1	0	-1	0	1	0
0	0	0	0	0	0	0



Output Image

(n + 2p - f + 1) x (n + 2p - f + 1)

n x n

n + 2p - f + 1 = n

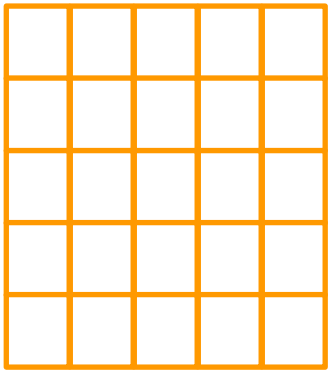
p = f - 1 / 2

5 + 2 *1 - 3 + 1 = 5

Strides

5	15	4	0	-1
10	1	5	1	0
6	9	-1	0	1
0	-1	-2	0	2
1	0	-1	0	1

n x n



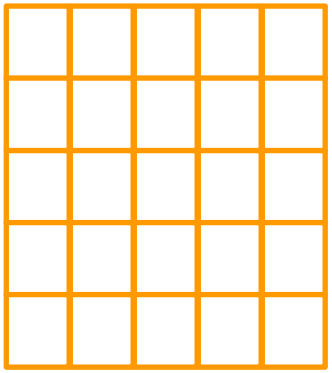
Output Image

(n + 2p - f + 1) x (n + 2p - f + 1)

Strides

5	15	4	0	-1
10	1	5	1	0
6	9	-1	0	1
0	-1	-2	0	2
1	0	-1	0	1

n x n



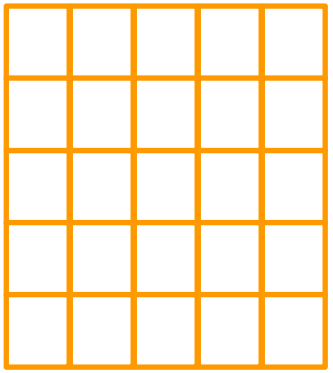
Output Image

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

Strides

5	15	4	0	-1
10	1	5	1	0
6	9	-1	0	1
0	-1	-2	0	2
1	0	-1	0	1

n x n



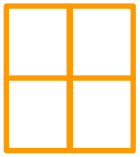
Output Image

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

Strides

5	15	4	0	-1
10	1	5	1	0
6	9	-1	0	1
0	-1	-2	0	2
1	0	-1	0	1

n x n



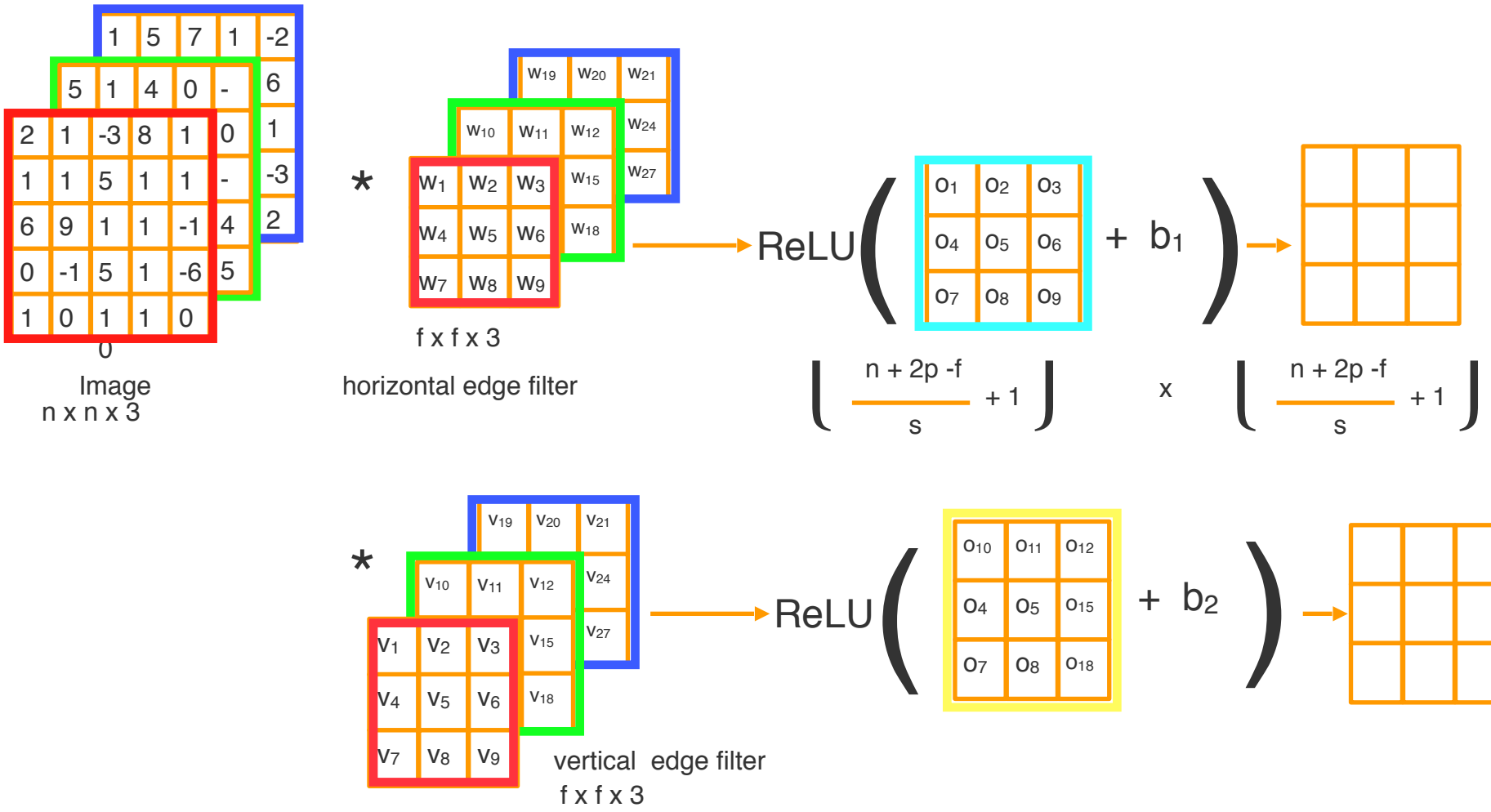
Output Image

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \quad x \quad \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

$$\frac{5 + 2x0 - 3}{2} \quad x \quad \frac{5 + 2x0 - 3}{2}$$

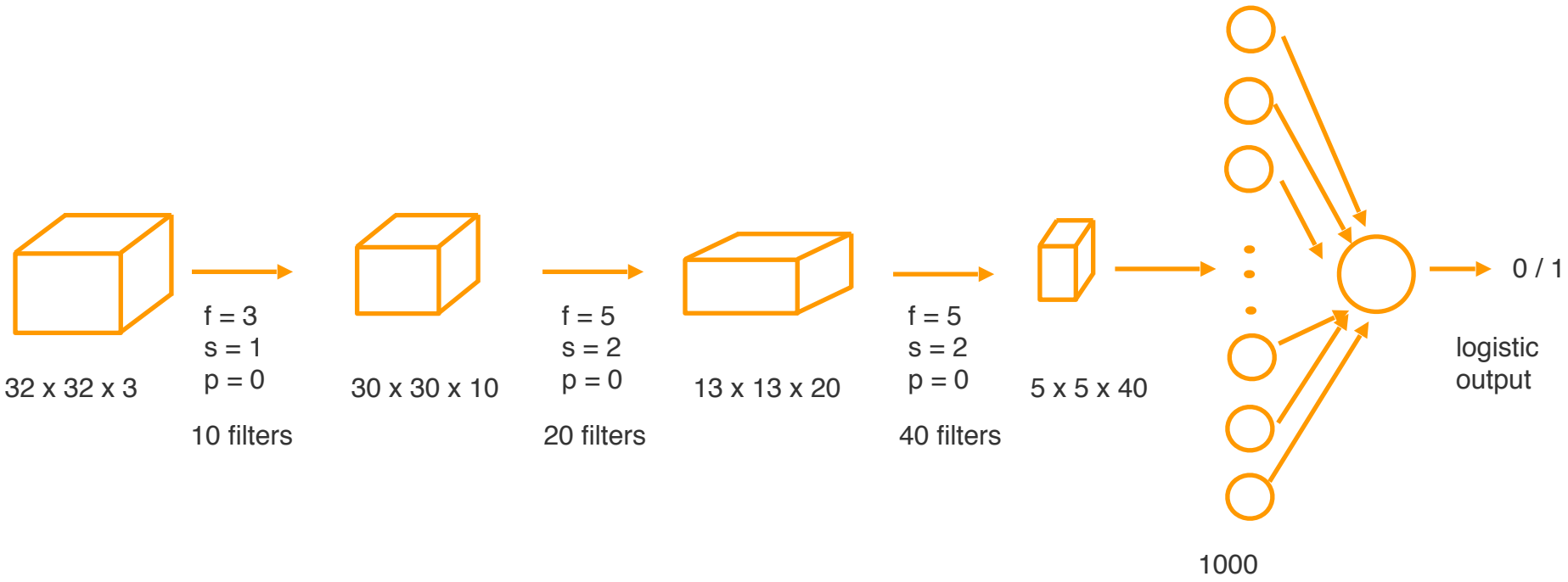
2 X 2

CNN layer


1 5 7 1 -2
5 1 4 0 -
2 1 -3 8 1 0
1 1 5 1 1 -
6 9 1 1 -1 4
0 -1 5 1 -6 5
1 0 1 1 0
6 1 -3 2
0
Image
n x n x 3
*
w19 w20 w21
w10 w11 w12 w24
w1 w2 w3 w15 w27
w4 w5 w6 w18
w7 w8 w9
f x f x 3
horizontal edge filter
ReLU
o1 o2 o3
o4 o5 o6
o7 o8 o9
+ b1
n + 2p -f / s + 1
x
n + 2p -f / s + 1
*
v19 v20 v21
v10 v11 v12 v24
v1 v2 v3 v15 v27
v4 v5 v6 v18
v7 v8 v9
vertical edge filter
f x f x 3
ReLU
o10 o11 o12
o4 o5 o15
o7 o8 o18
+ b2

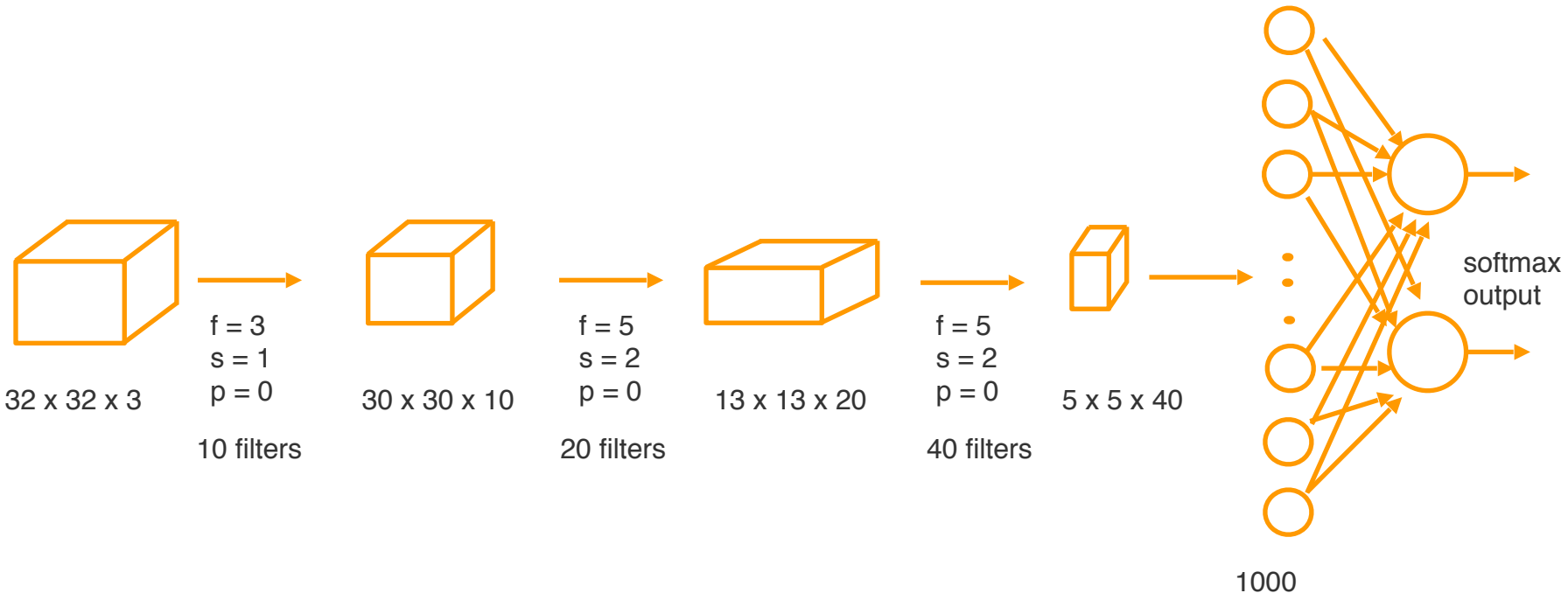
Convolutional Neural Network

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$



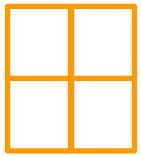
Convolutional Neural Network

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

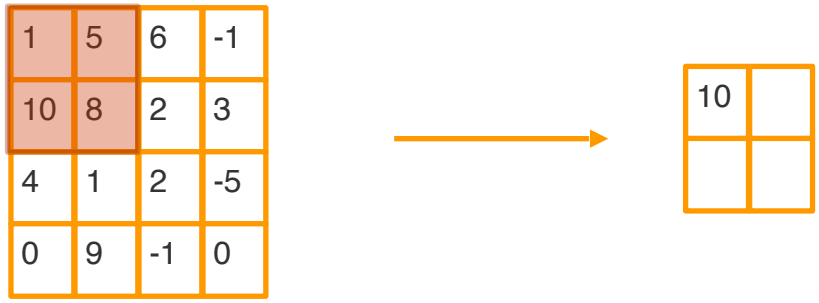


Max Pooling

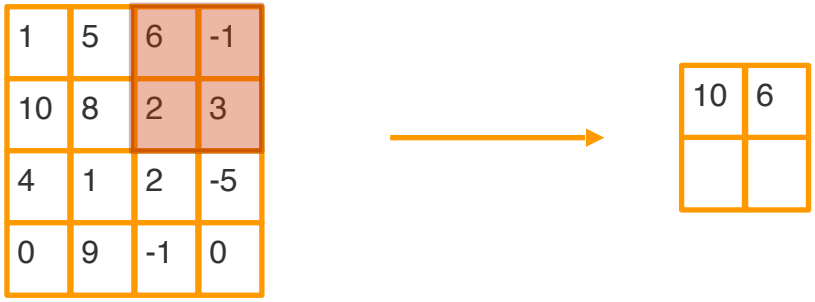
1	5	6	-1
10	8	2	3
4	1	2	-5
0	9	-1	0



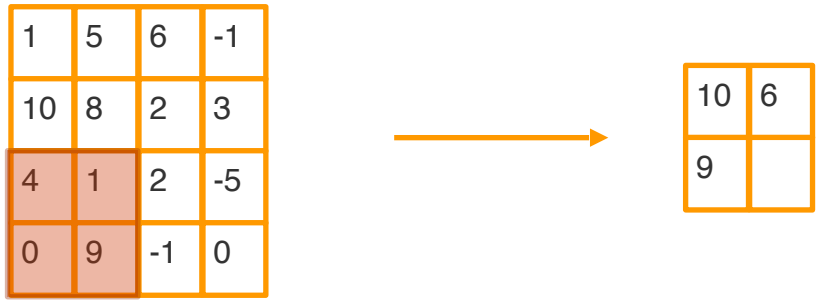
Max Pooling



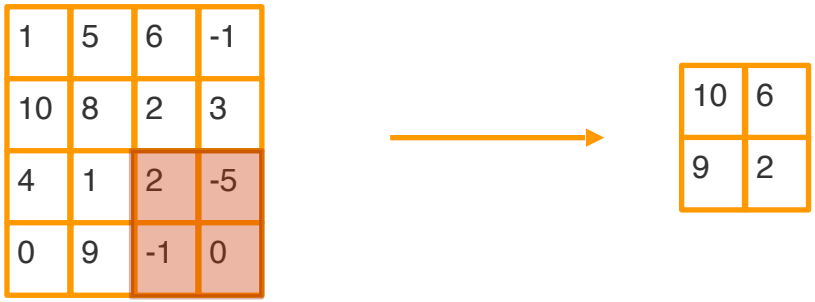
Max Pooling



Max Pooling

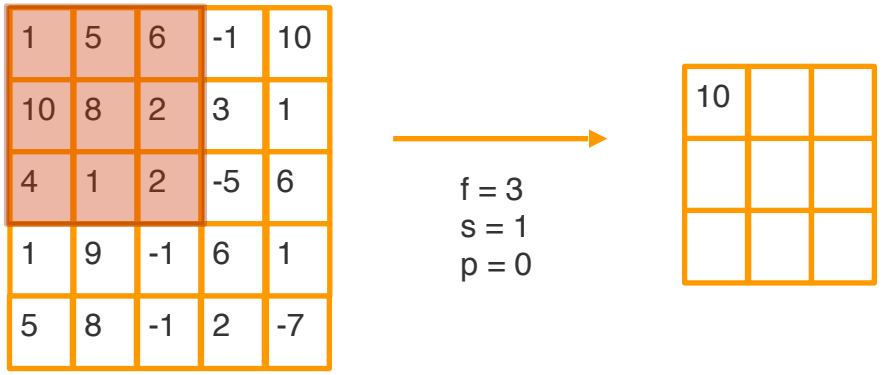


Max Pooling



Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$



Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

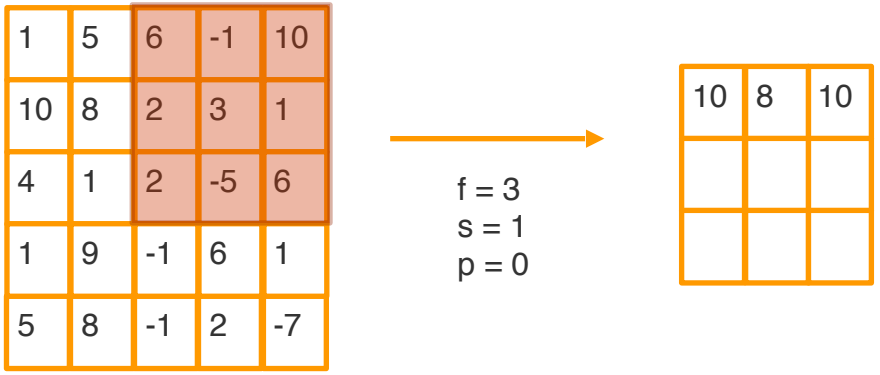
1	5	6	-1	10
10	8	2	3	1
4	1	2	-5	6
1	9	-1	6	1
5	8	-1	2	-7

f = 3
s = 1
p = 0

10	8	

Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$



Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

1	5	6	-1	10
10	8	2	3	1
4	1	2	-5	6
1	9	-1	6	1
5	8	-1	2	-7

f = 3
s = 1
p = 0

10	8	10
10		

Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

1	5	6	-1	10
10	8	2	3	1
4	1	2	-5	6
1	9	-1	6	1
5	8	-1	2	-7

f = 3
s = 1
p = 0

10	8	10
10	9	

Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

1	5	6	-1	10
10	8	2	3	1
4	1	2	-5	6
1	9	-1	6	1
5	8	-1	2	-7

f = 3
s = 1
p = 0

10	8	10
10	9	6

Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

1	5	6	-1	10
10	8	2	3	1
4	1	2	-5	6
1	9	-1	6	1
5	8	-1	2	-7

f = 3
s = 1
p = 0

10	8	10
10	9	6
9		

Max Pooling

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

1	5	6	-1	10
10	8	2	3	1
4	1	2	-5	6
1	9	-1	6	1
5	8	-1	2	-7

f = 3
s = 1
p = 0

10	8	10
10	9	6
9	9	

Max Pooling

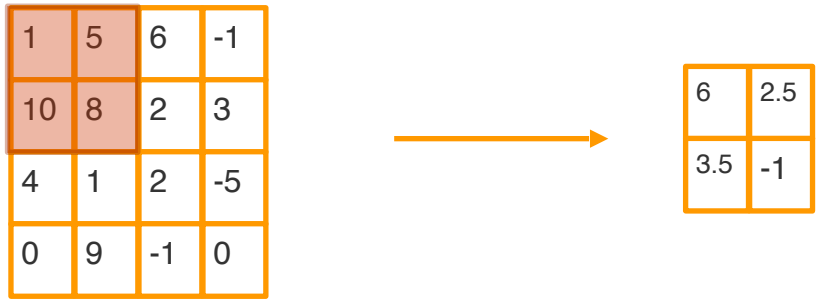
$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$

1	5	6	-1	10
10	8	2	3	1
4	1	2	-5	6
1	9	-1	6	1
5	8	-1	2	-7

f = 3
s = 1
p = 0

10	8	10
10	9	6
9	9	6

Average Pooling



LeNet - 5

$$\left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor \times \left\lfloor \frac{n + 2p - f}{s} + 1 \right\rfloor$$