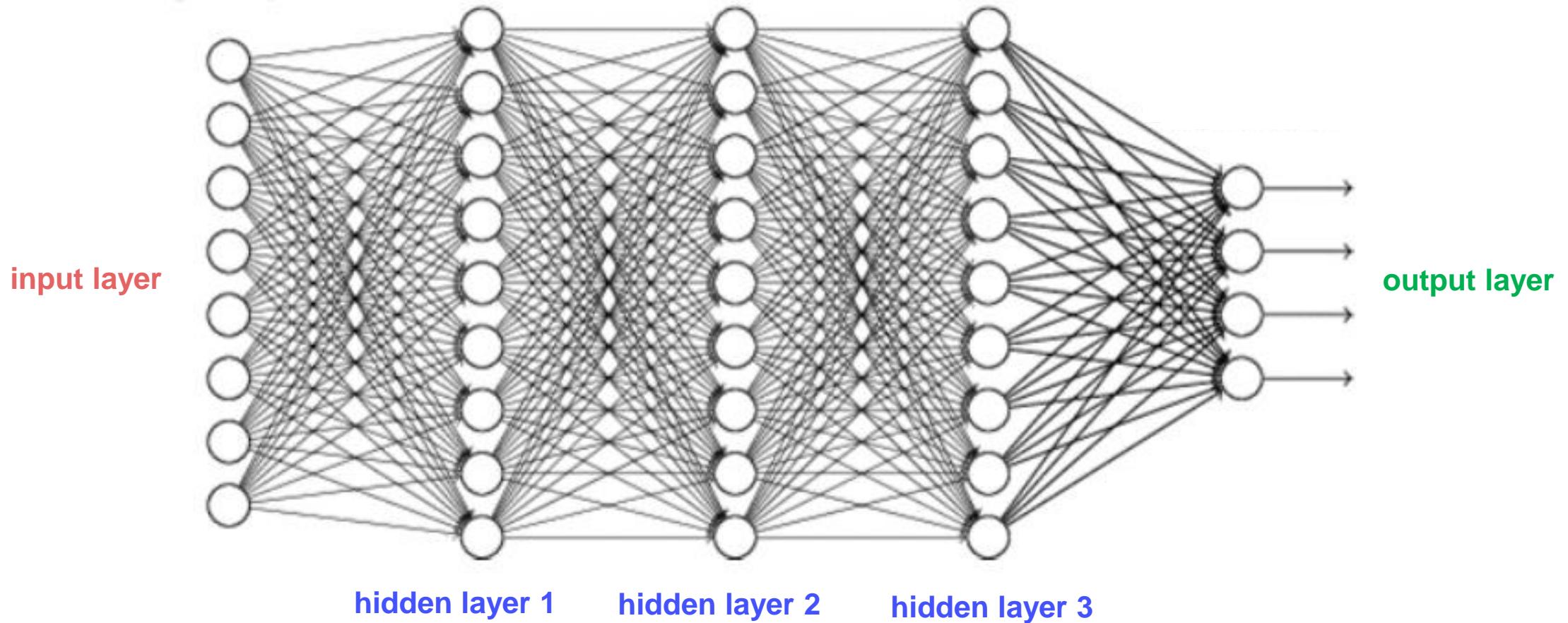
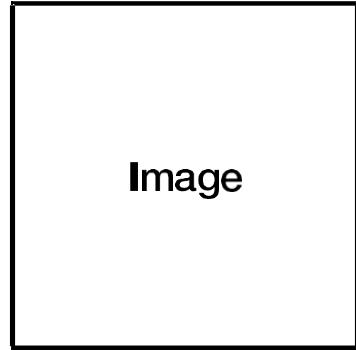


Deep Learning

Deep Neural Network

Deep Neural Network





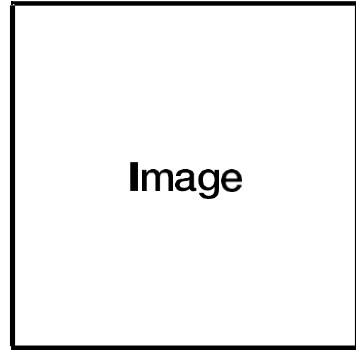
Image

28

28

Input Layer

28 x 28 features



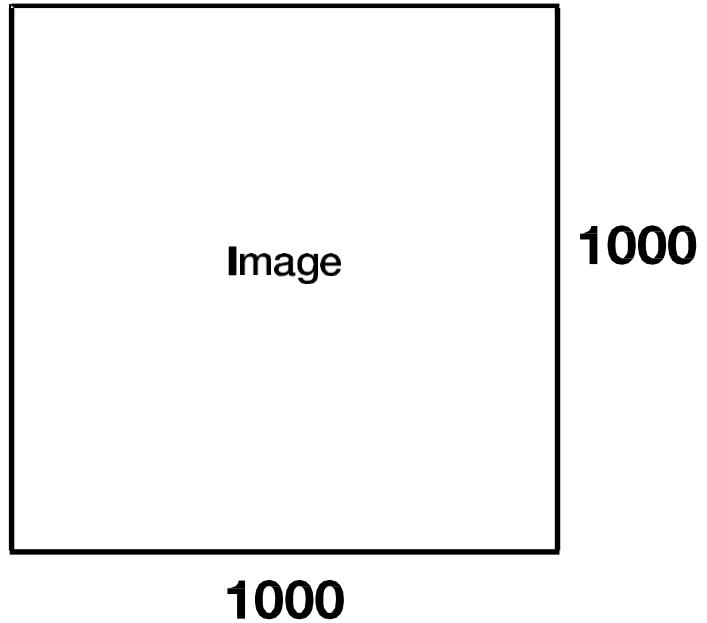
Image

28

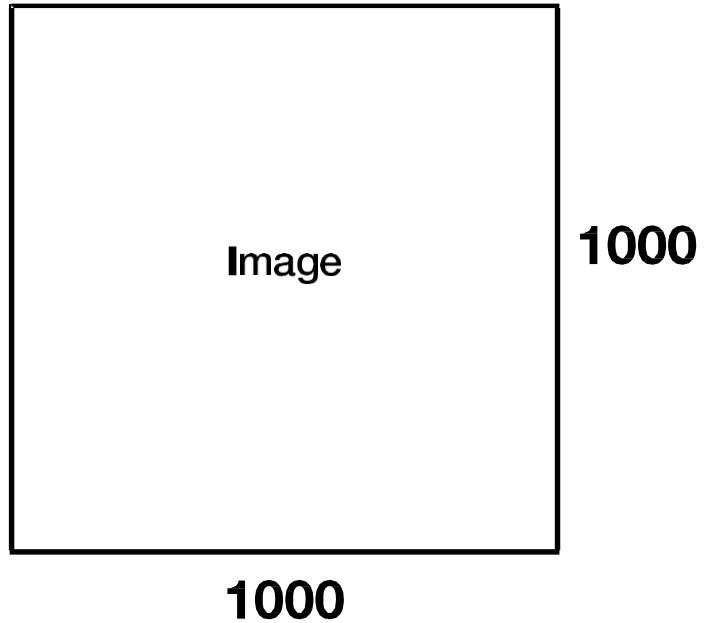
28

Input Layer

$28 \times 28 = 784$ features

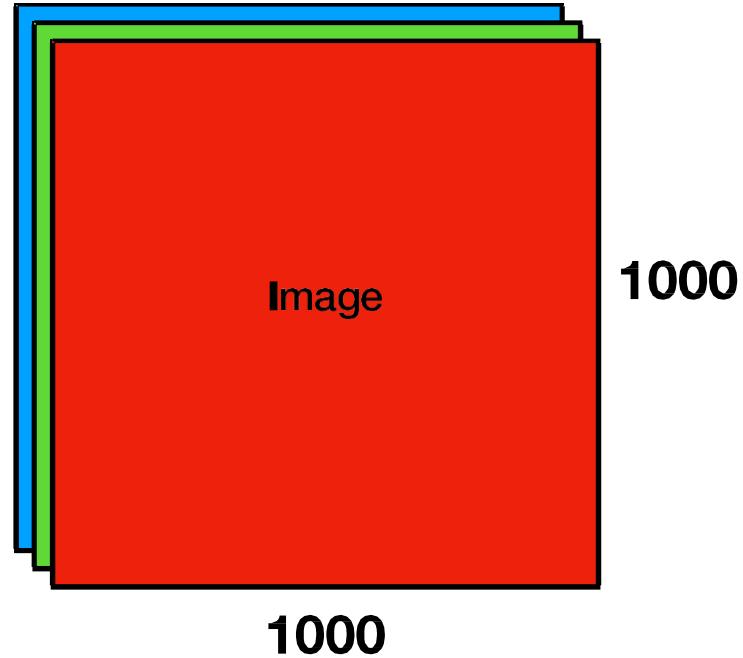


Input Layer
1000 x 1000 features



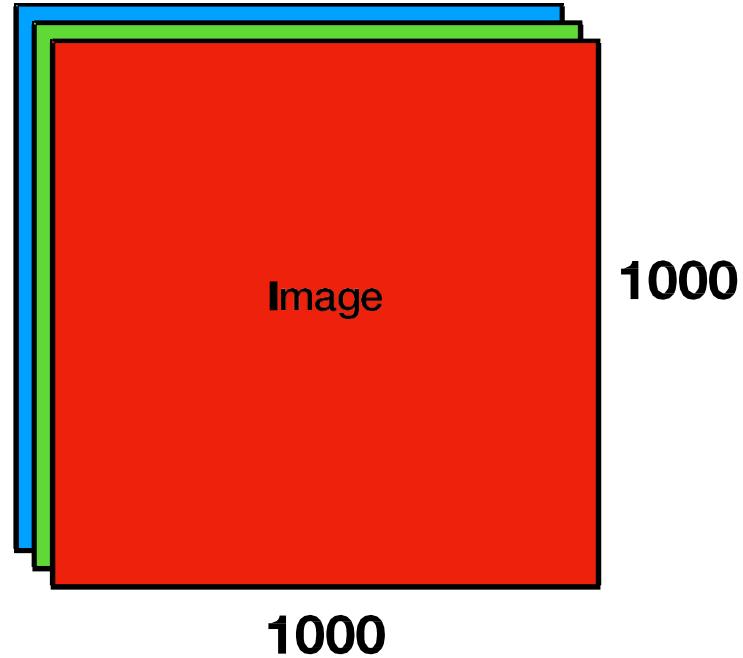
Input Layer

$1000 \times 1000 = 1 \text{ million weights}$



Input Layer

$1000 \times 1000 \times 3 = 3 \text{ million weights}$

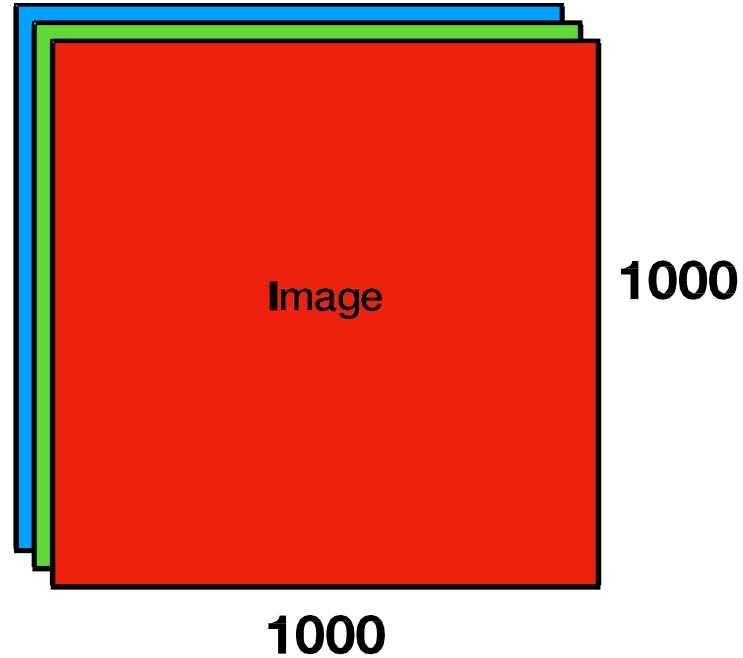


Input Layer

$1000 \times 1000 \times 3 = 3 \text{ million weights}$

Hidden Layer

1 unit

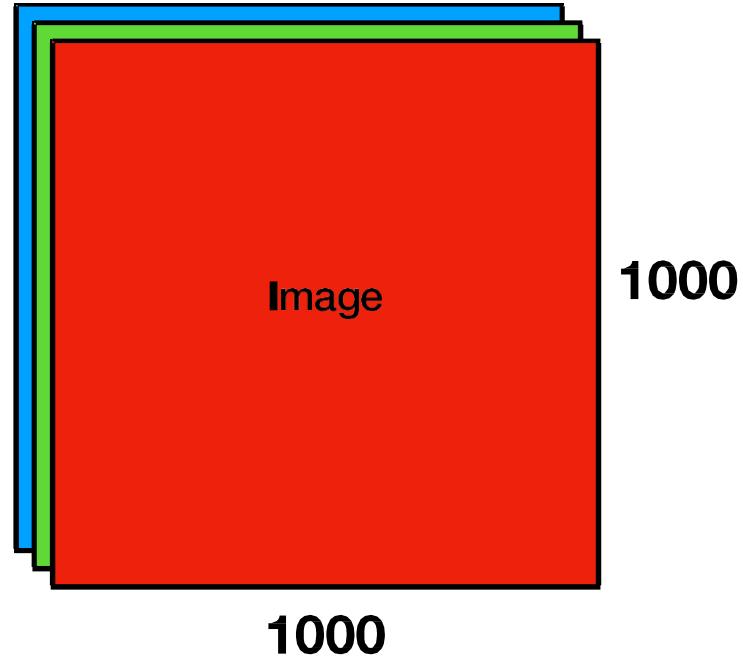


Input Layer

$1000 \times 1000 \times 3 = 3 \text{ million weights}$

Hidden Layer

1000 units

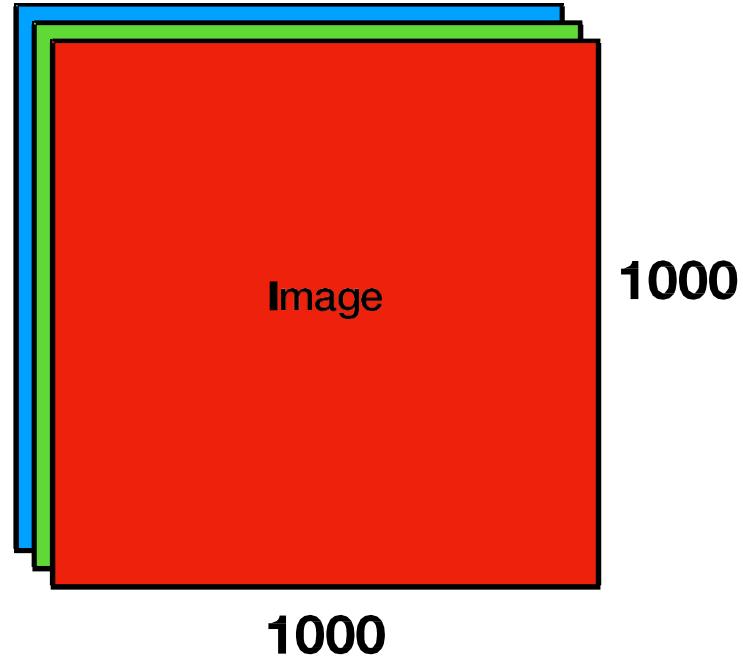


Input Layer

$1000 \times 1000 \times 3 = 3 \text{ million weights}$

Hidden Layer

$1000 \times 3 \text{ million weights}$



Input Layer

$1000 \times 1000 \times 3 = 3 \text{ million weights}$

Hidden Layer

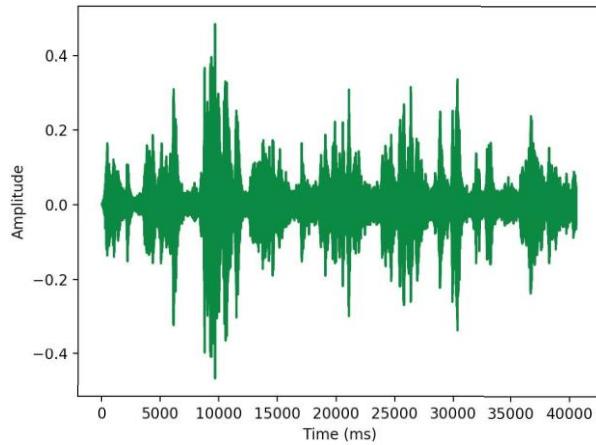
$1000 \times 3 \text{ million} = 3 \text{ Billion weights}$

Deep Learning

Structured Data

Age	Weight	Gender	BMI	Diabetes
47	192	M	23.4	No
53	164	F	27.2	Yes
68	214	M	25.2	Yes
43	151	F	24.8	No

Unstructured Data



Audio



Image

Lorem ipsum dolor sit amet,
consectetuer adipiscing elit. Maecenas
porttitor congue massa. Fusce posuere,
magna sed pulvinar ultricies, purus
lectus malesuada libero, sit amet
commodo magna eros quis urna.

Text

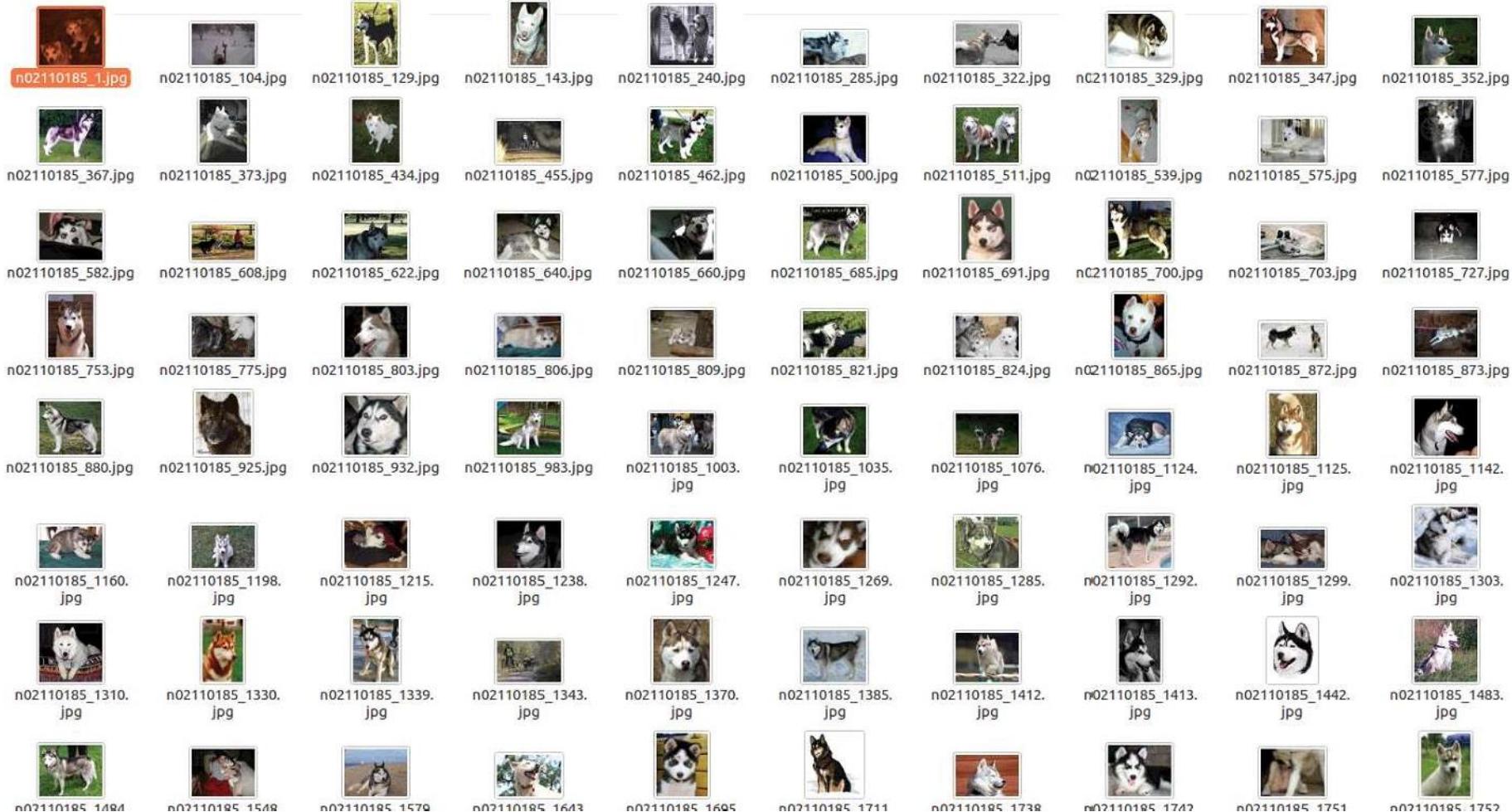




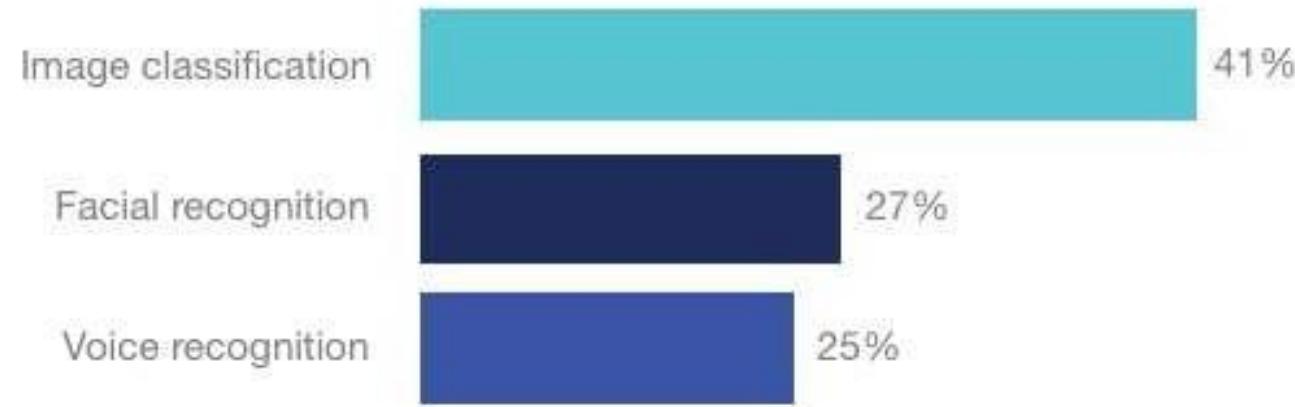


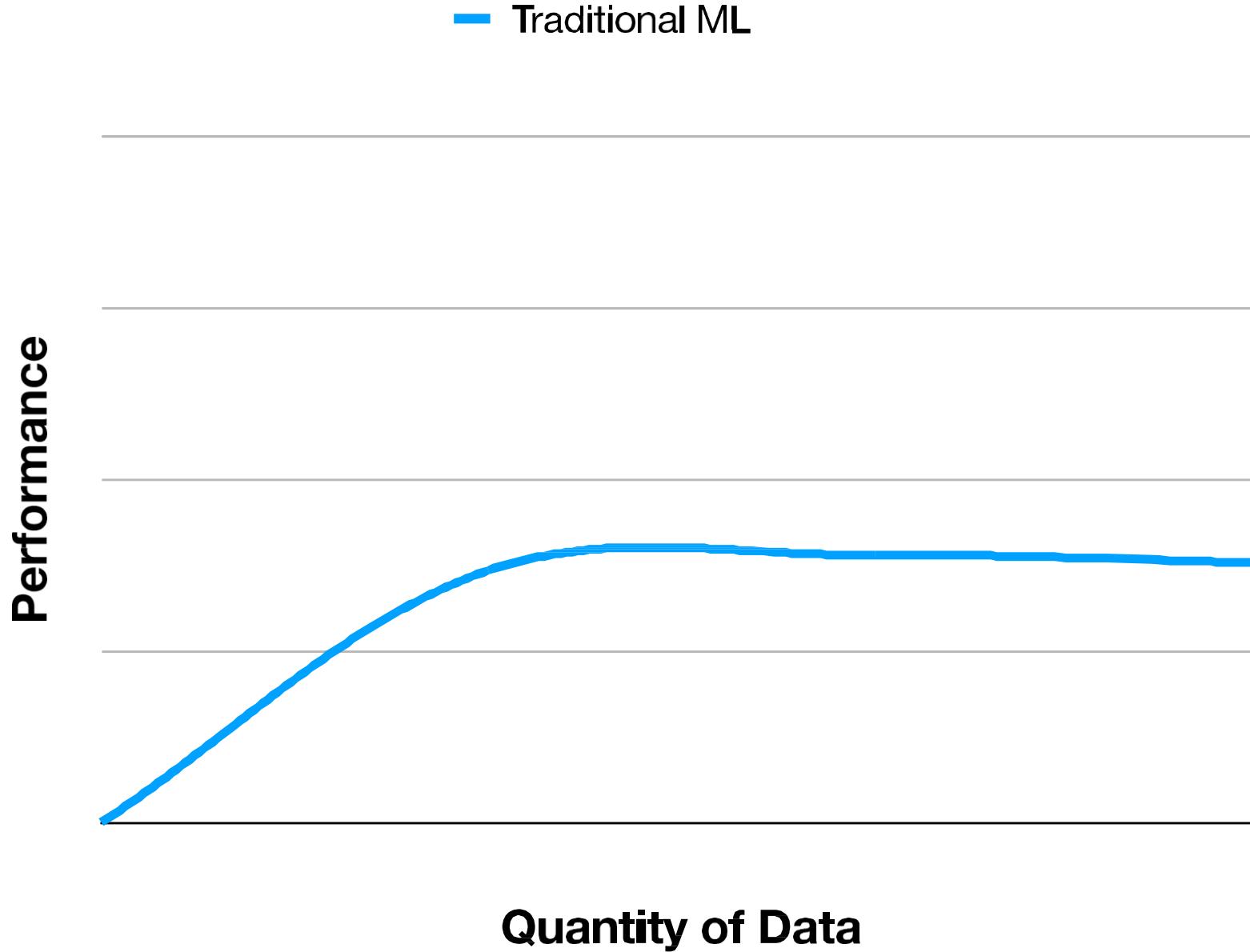


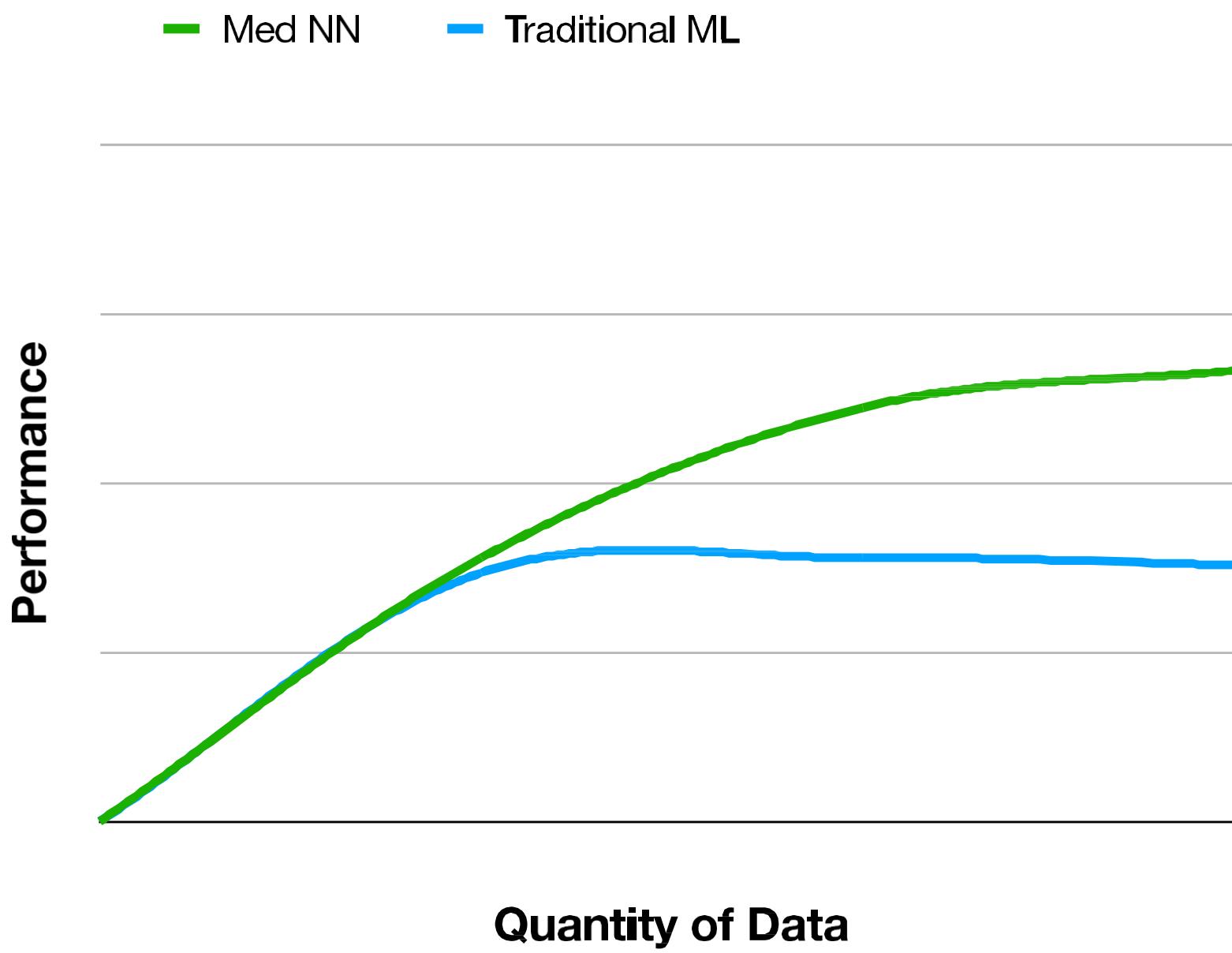
ImageNet

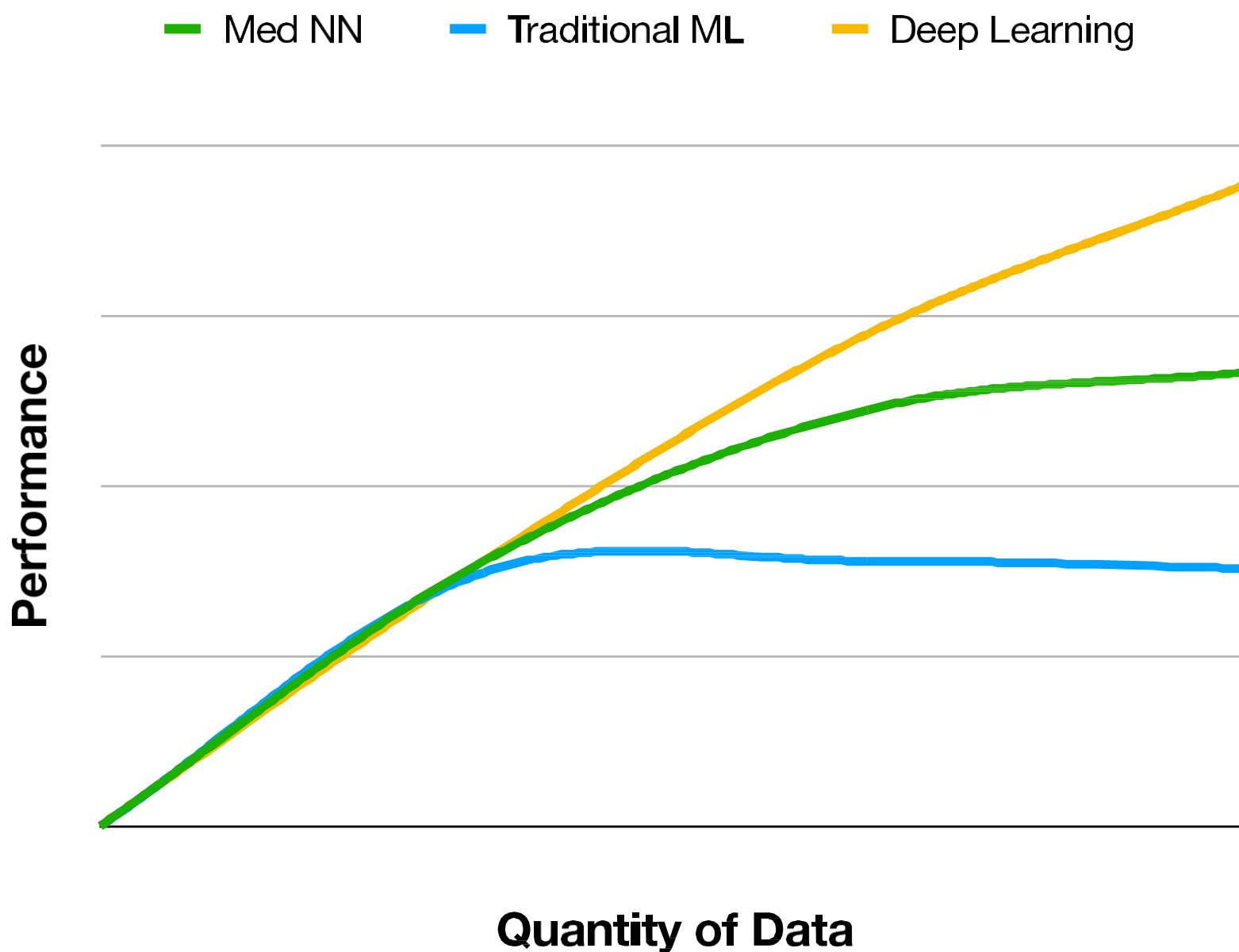


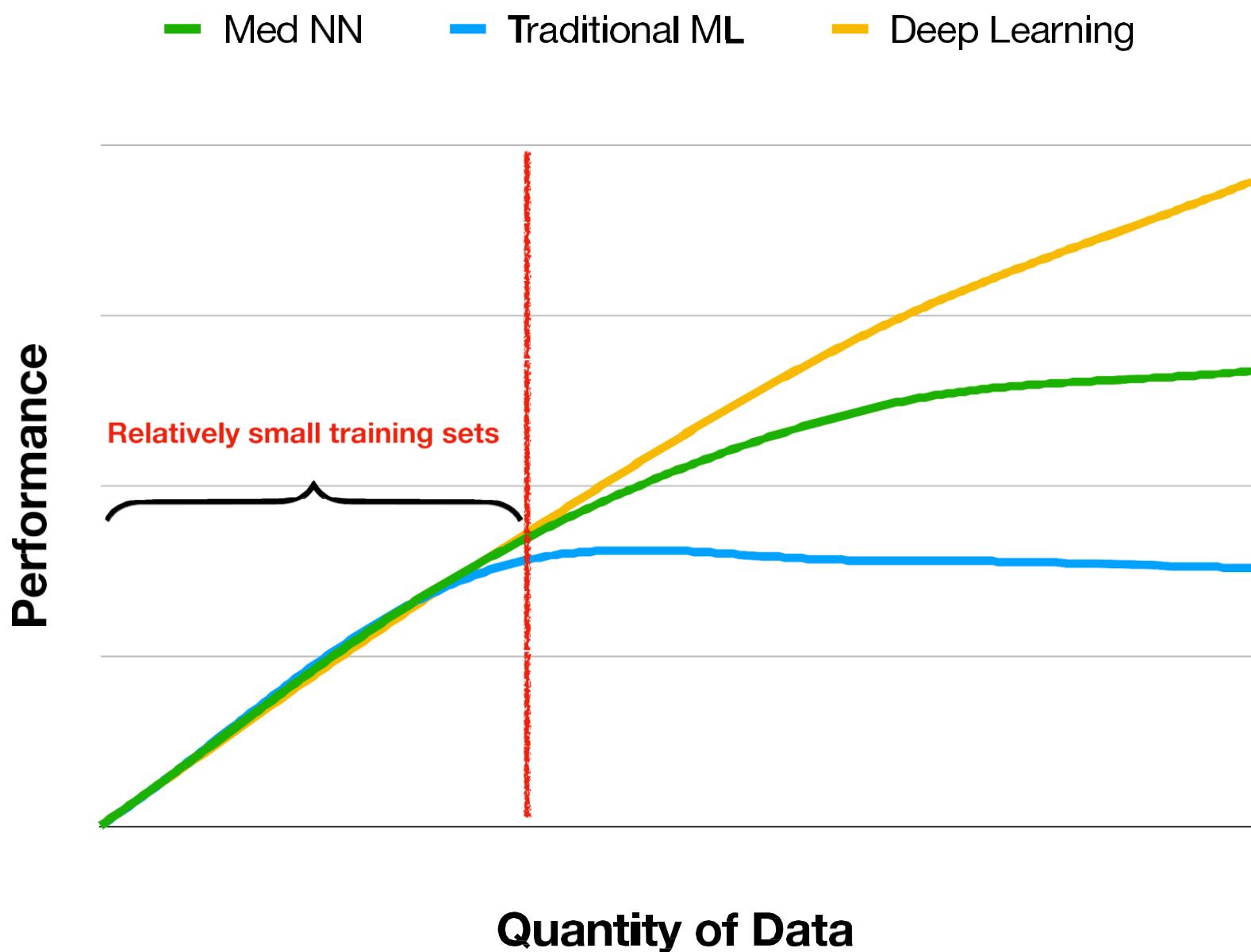
Deep Learning vs Traditional Methods





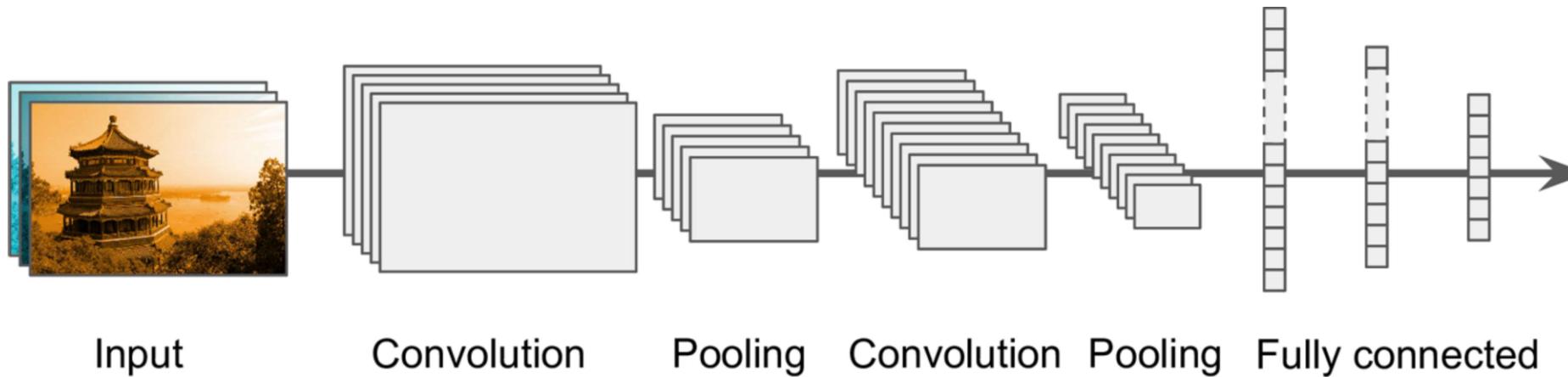


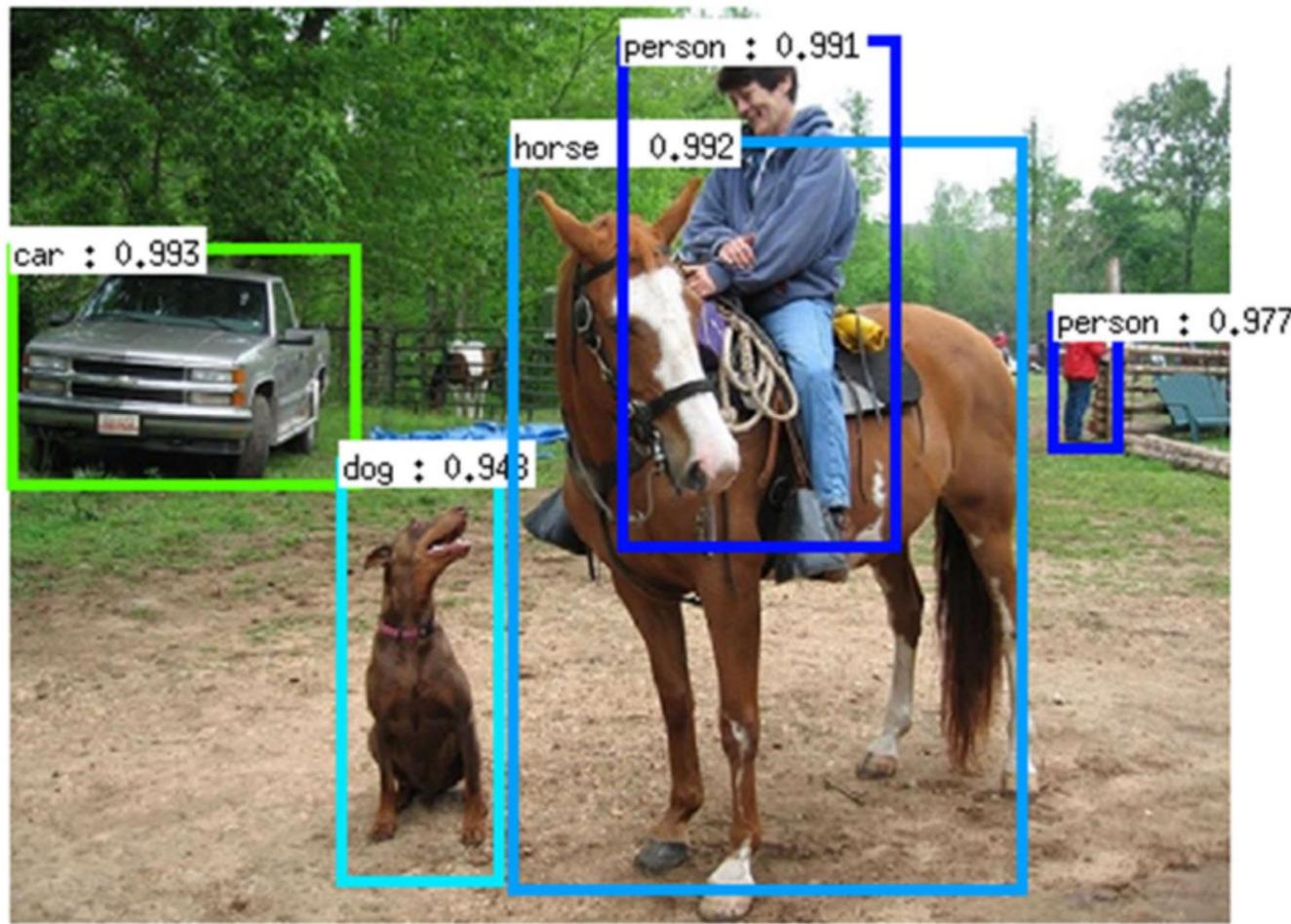




Convolutional Neural Network

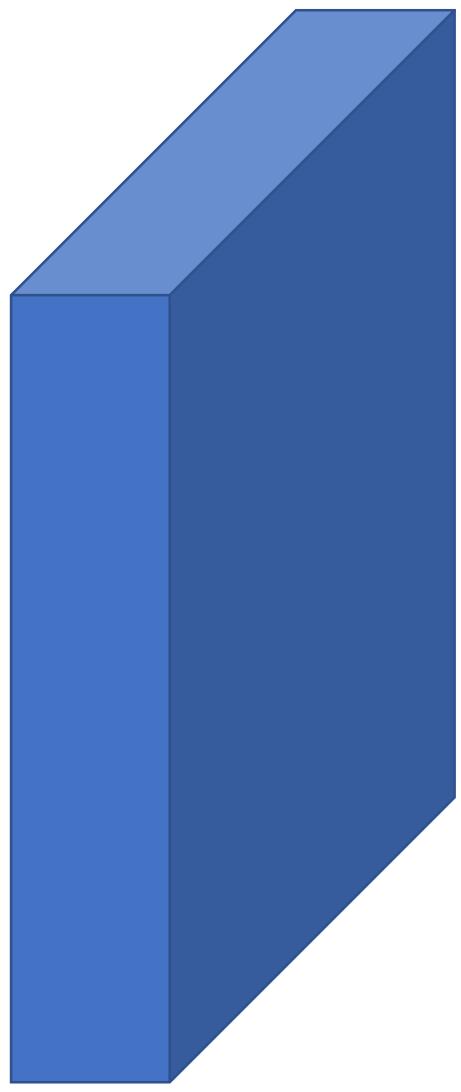
Typical CNN Architecture

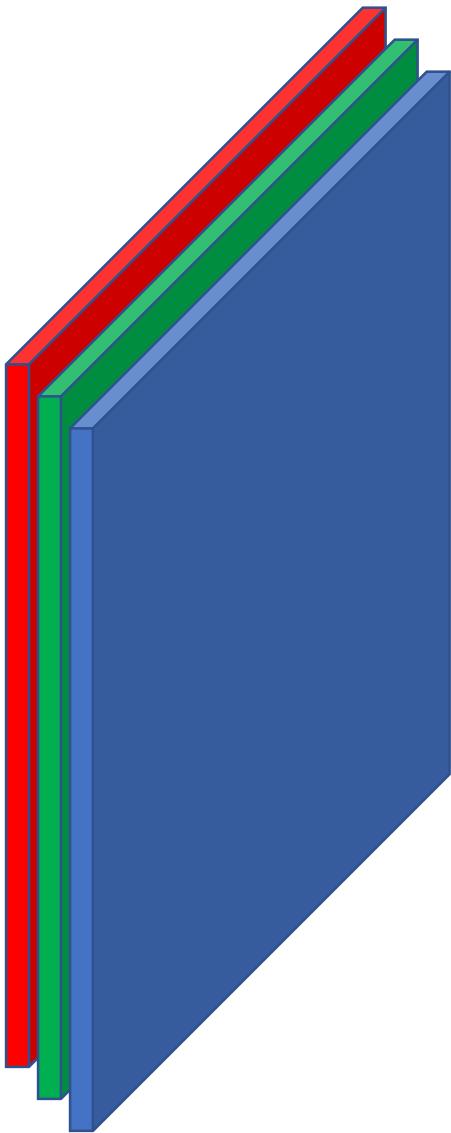


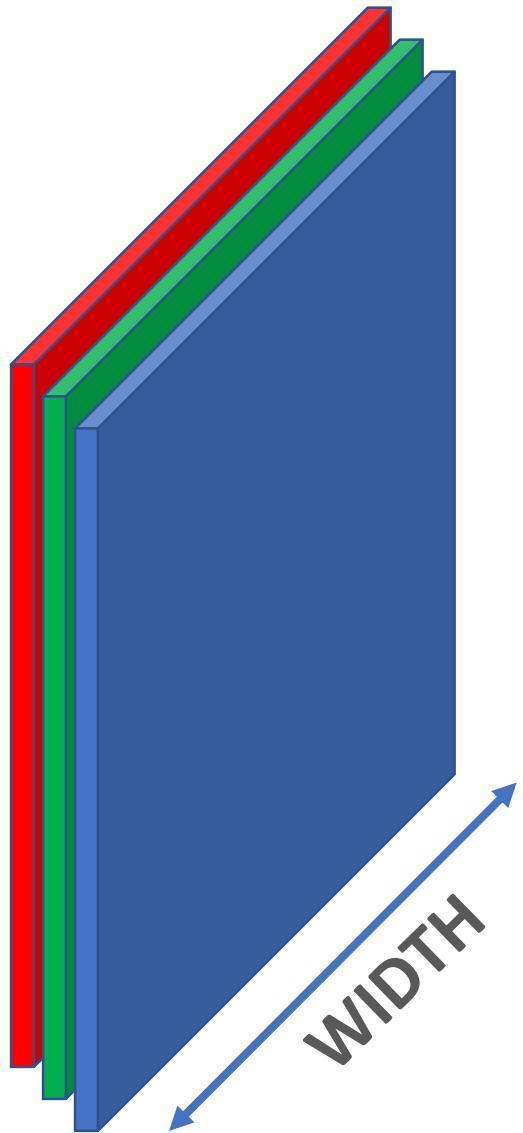


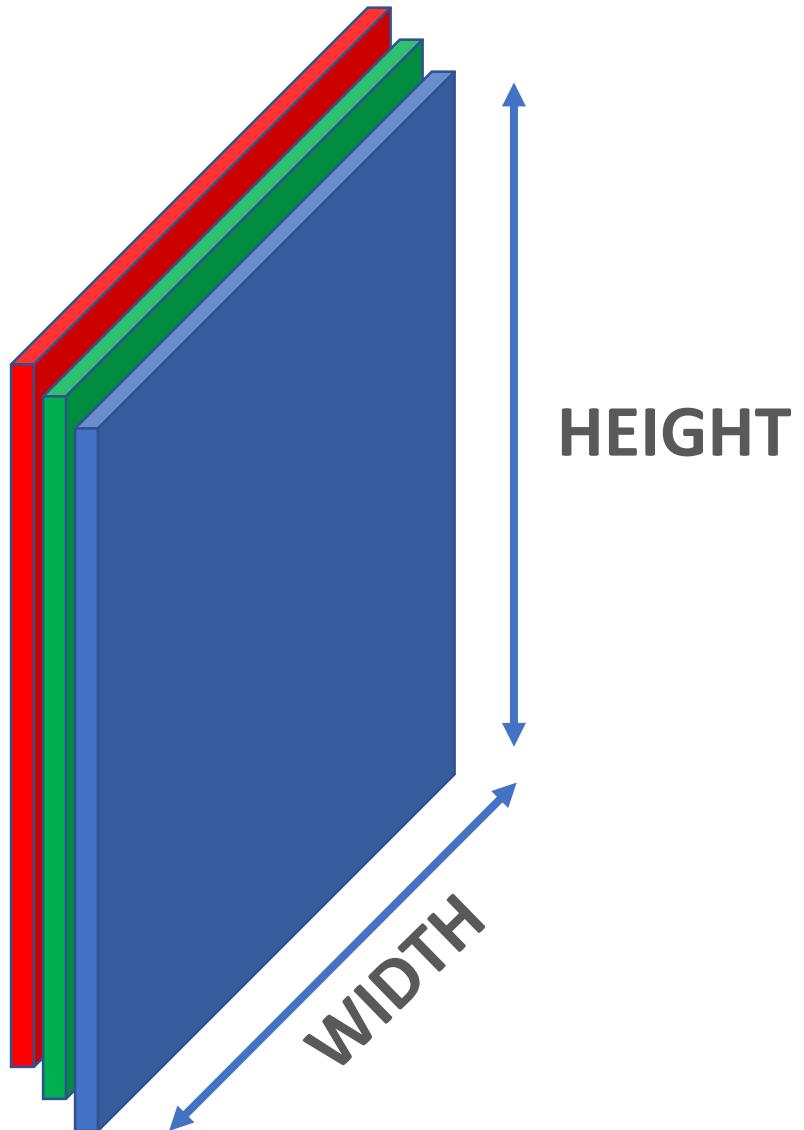


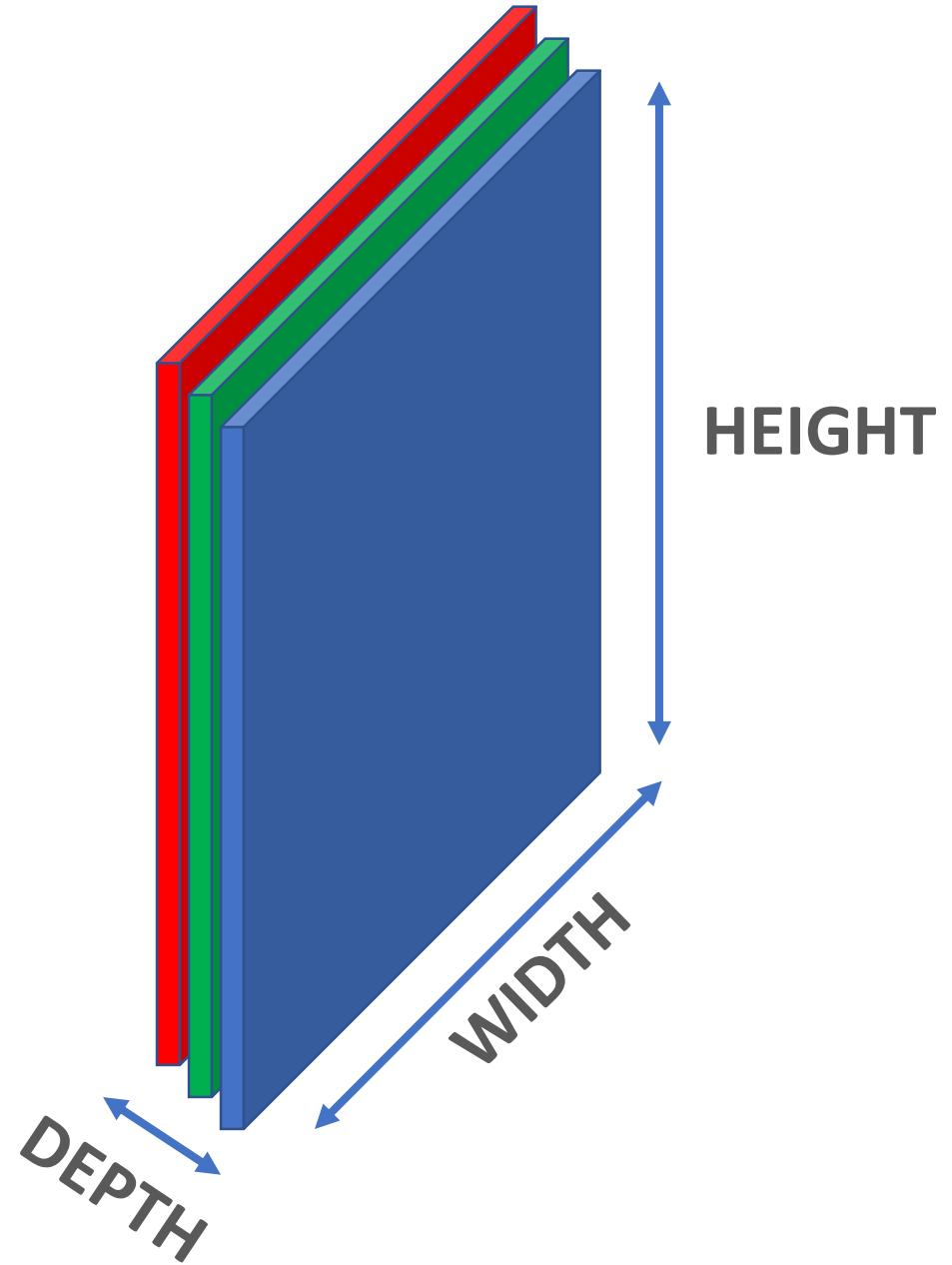
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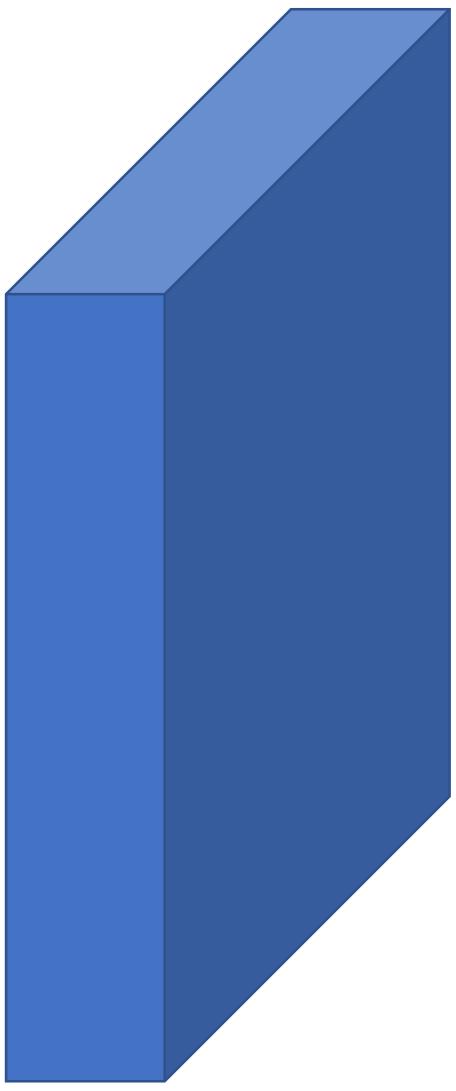


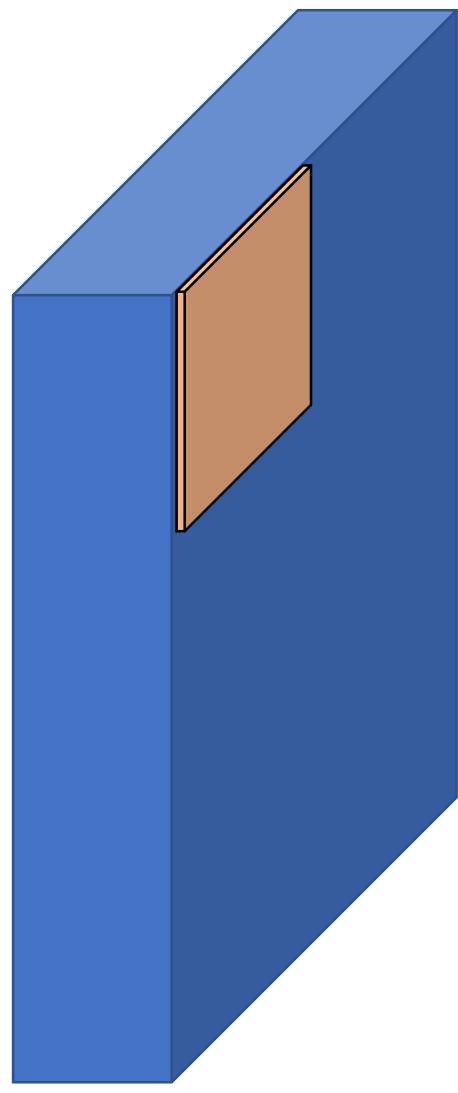


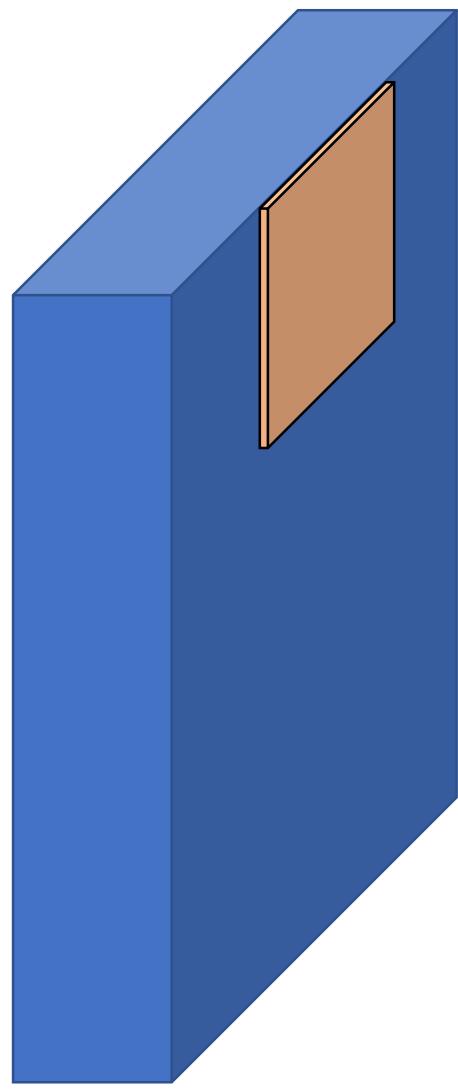


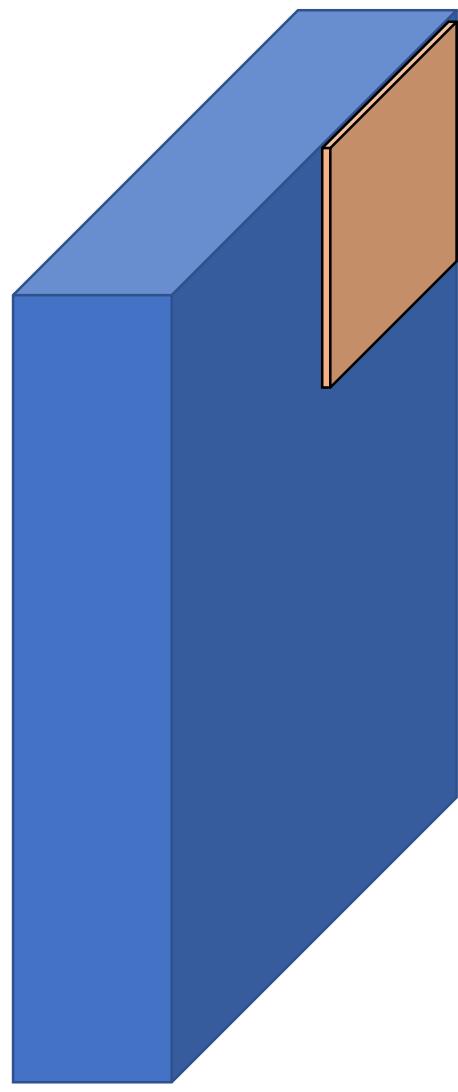


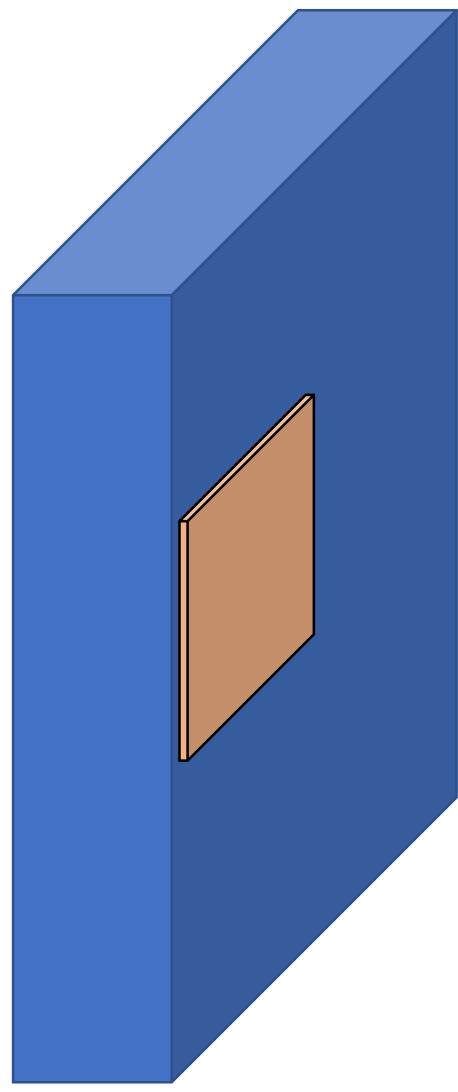


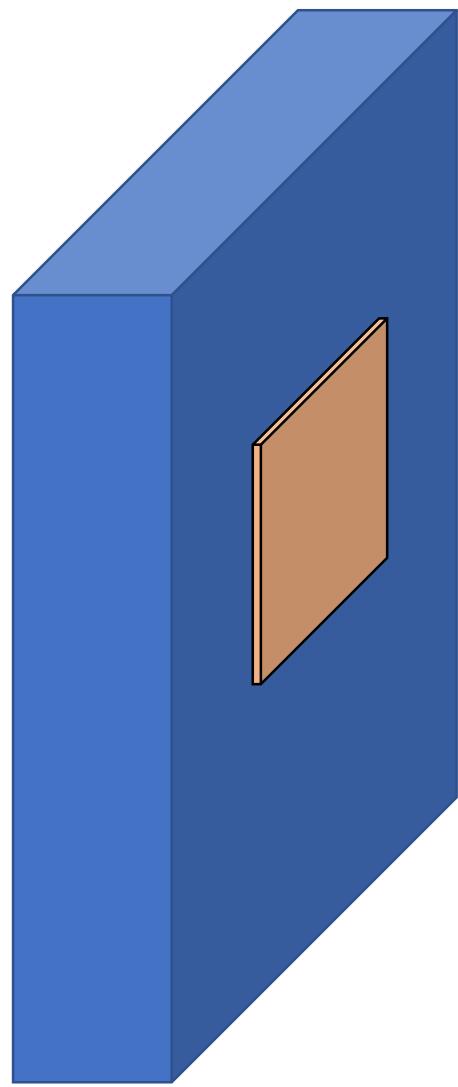


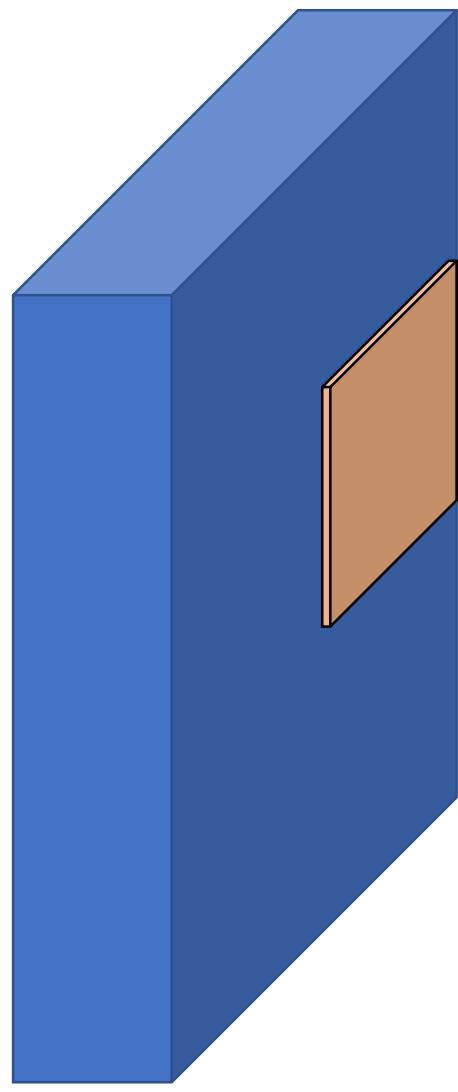


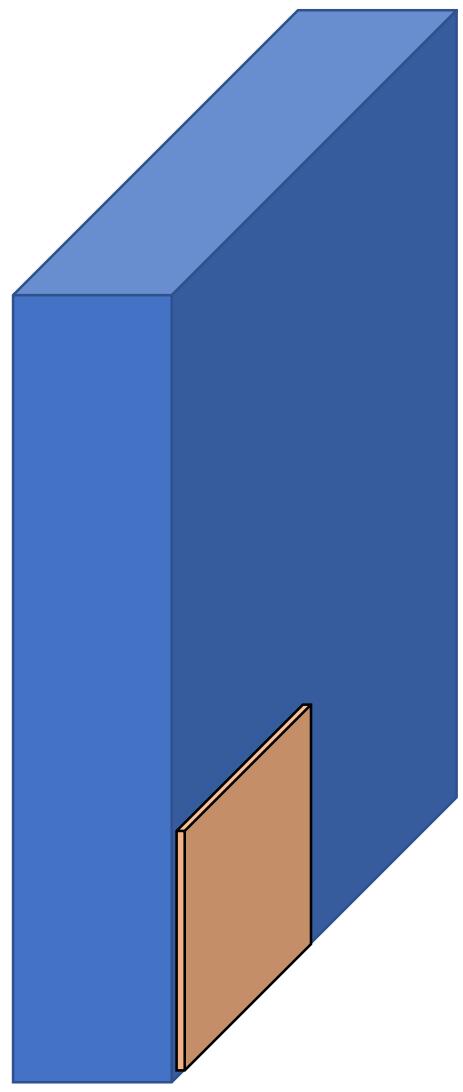


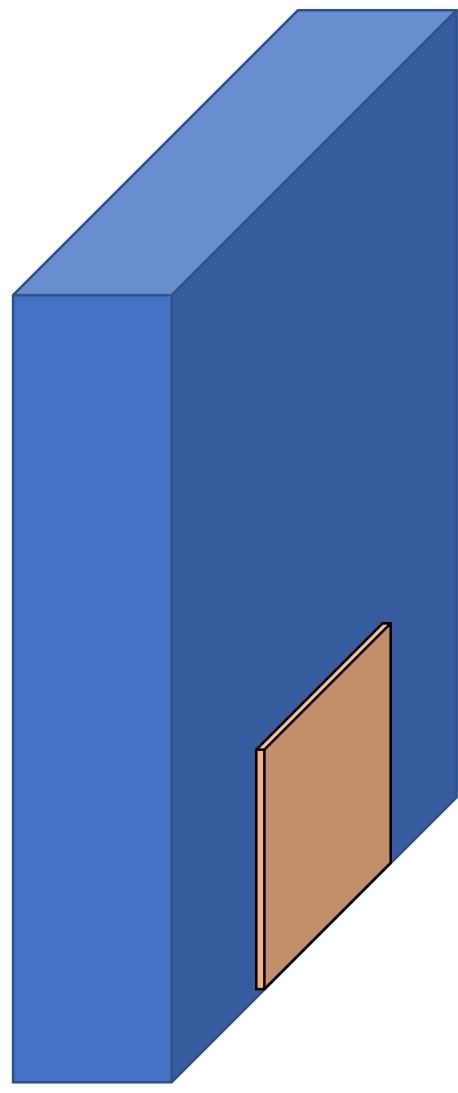


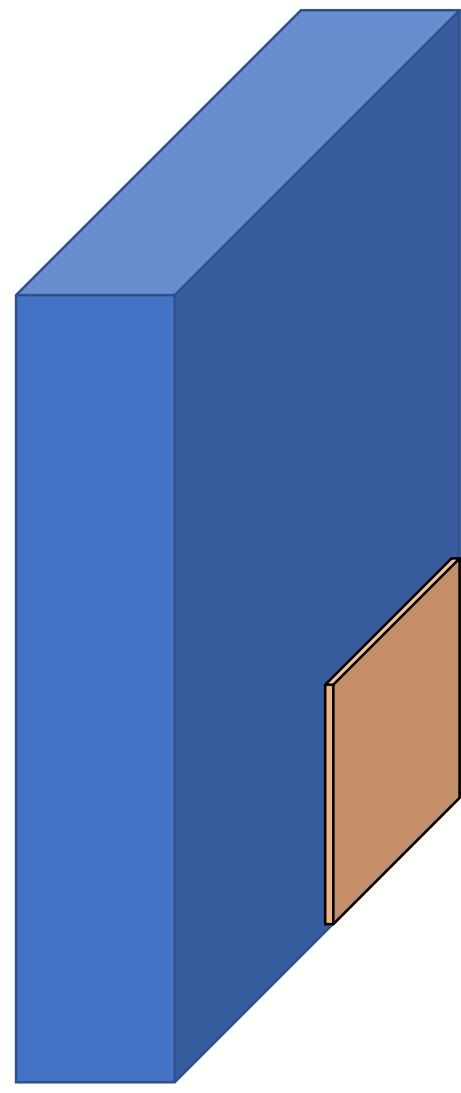


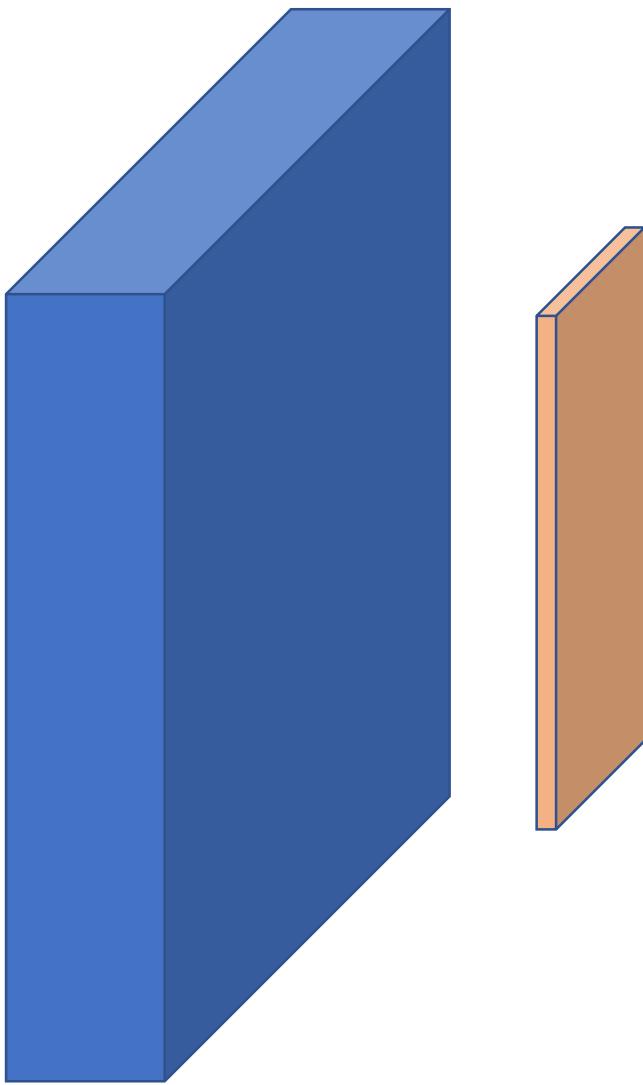












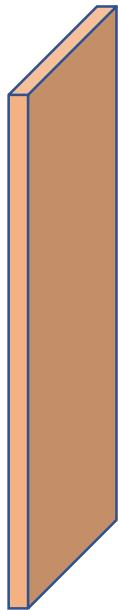
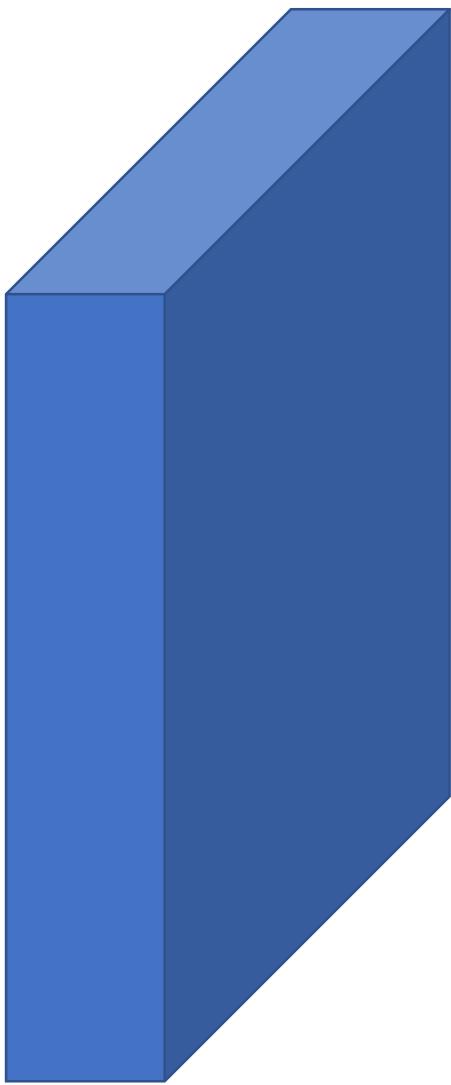
Feature Map

1 _{x1}	1 _{x0}	1 _{x1}	0	0
0 _{x0}	1 _{x1}	1 _{x0}	1	0
0 _{x1}	0 _{x0}	1 _{x1}	1	1
0	0	1	1	0
0	1	1	0	0

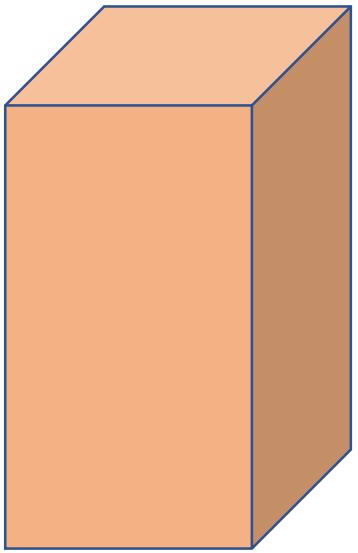
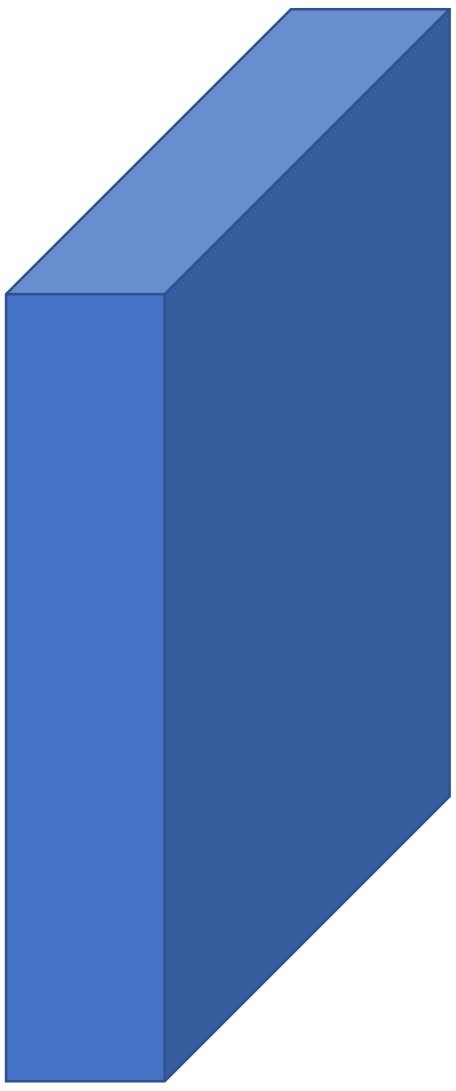
Image

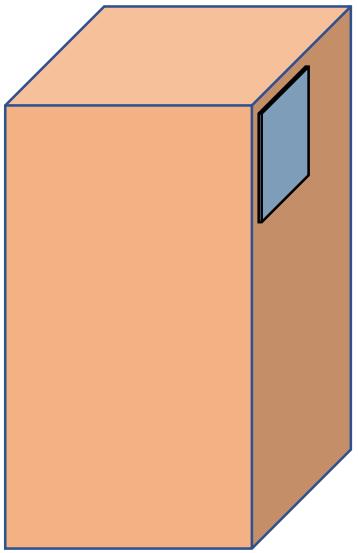
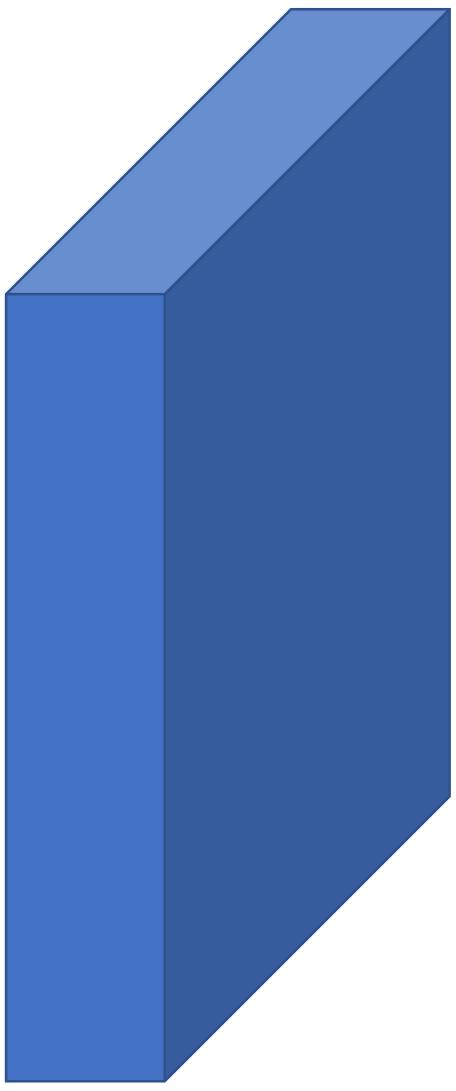
4		

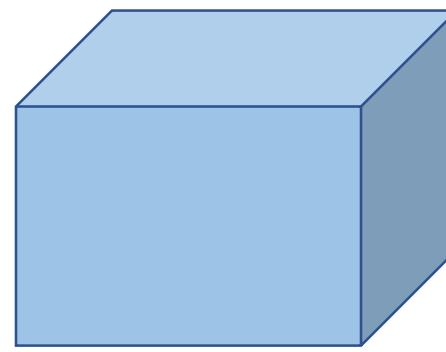
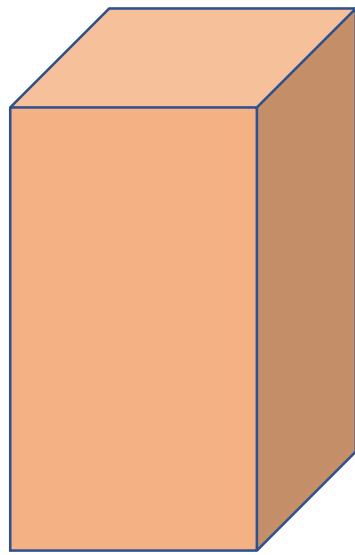
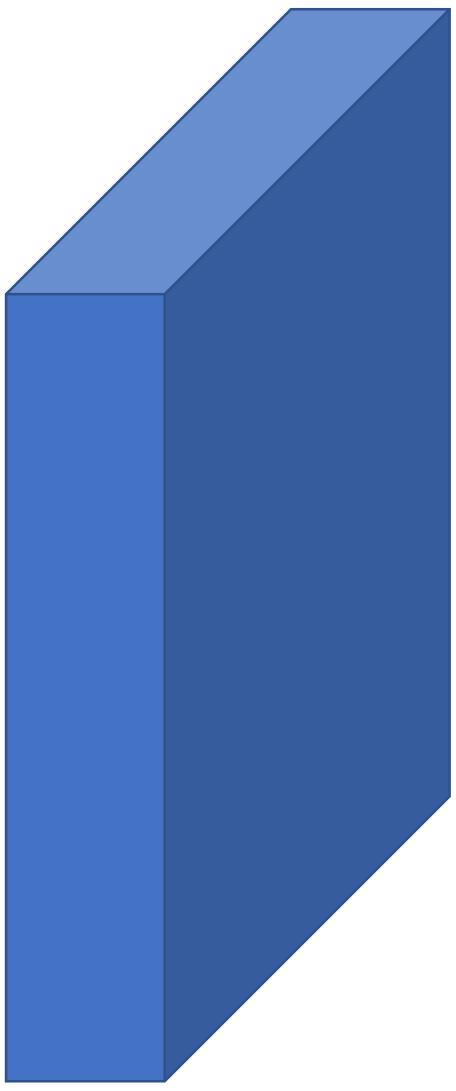
Convolved
Feature

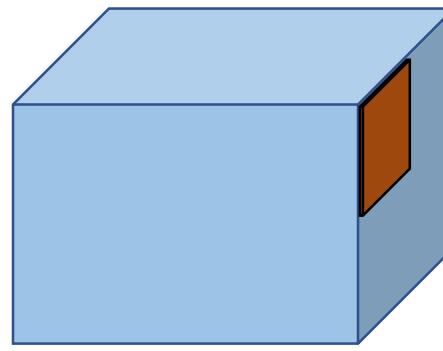
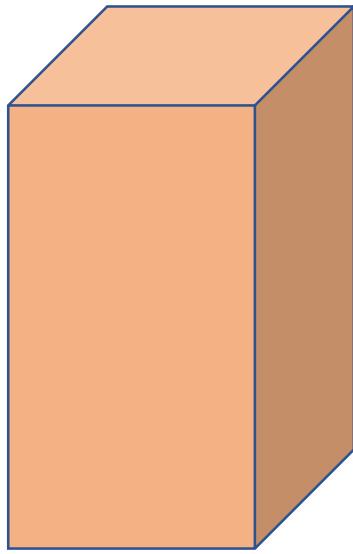
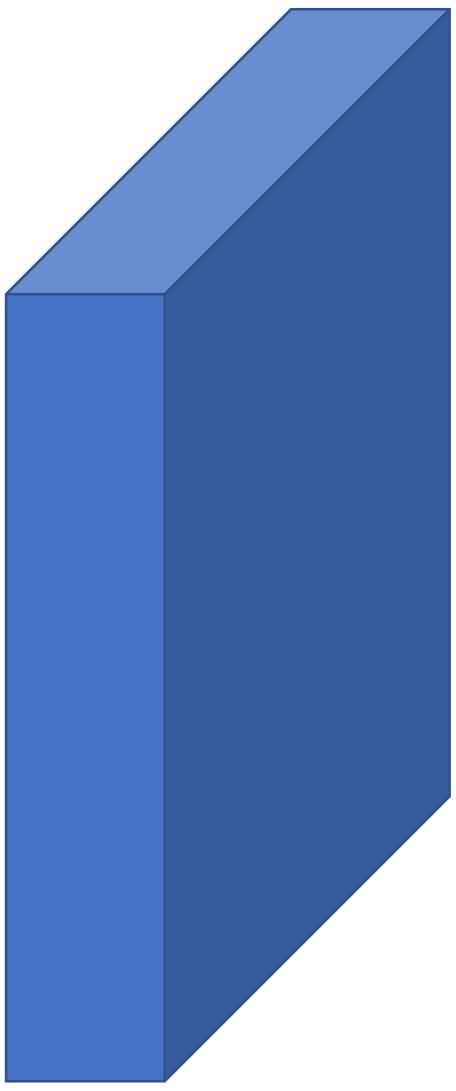


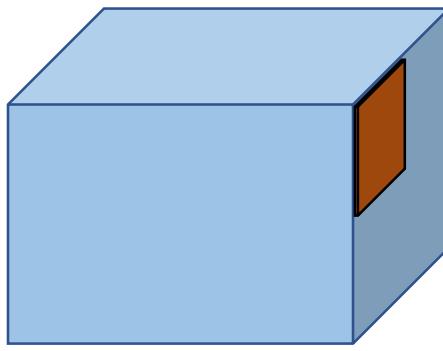
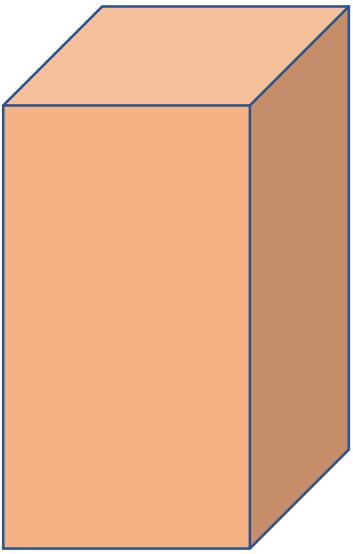
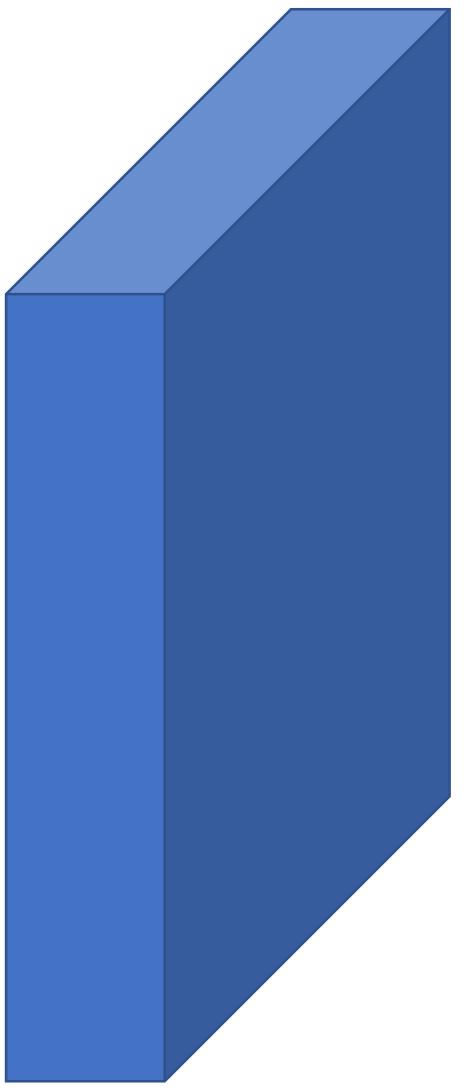
Feature Map







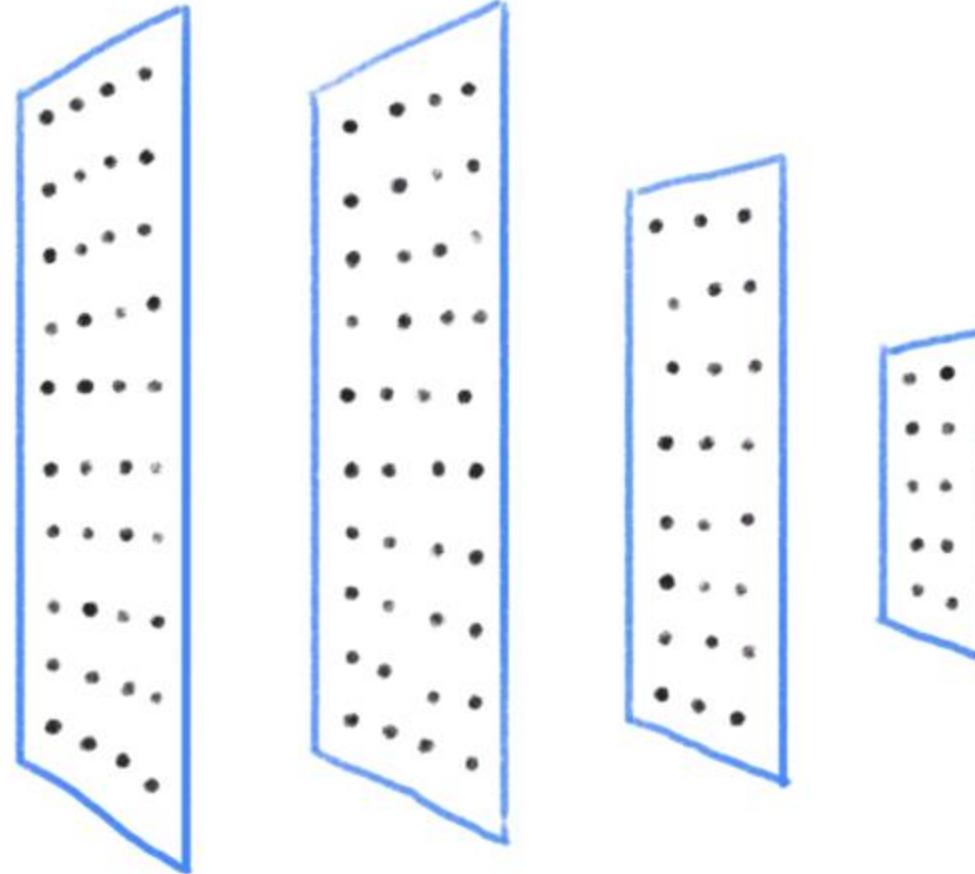
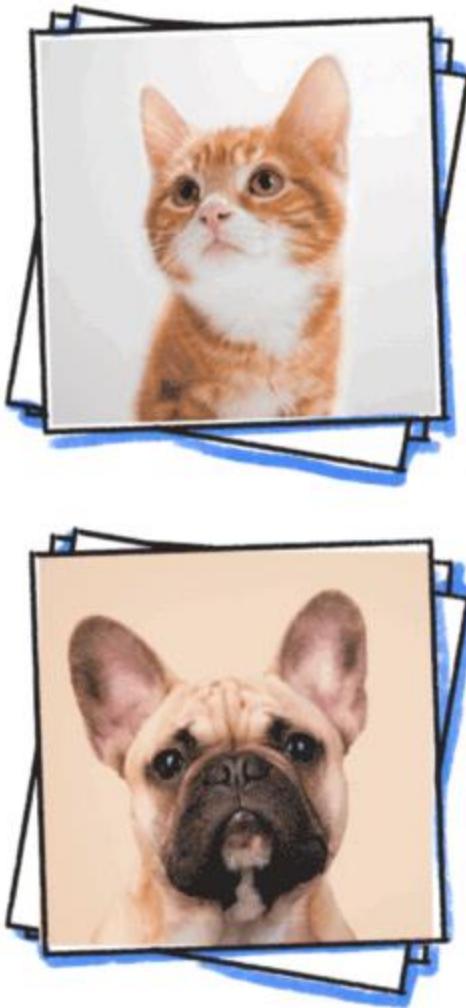




CAT

(LABELED)
PHOTOS

DOG



Convolutional Neural Network

Convolution Layer

Convolutional Neural Network

Convolution Layer

Pooling Layer

Convolutional Neural Network

Convolution Layer

Pooling Layer

Fully Connected Layer

Convolution Layer

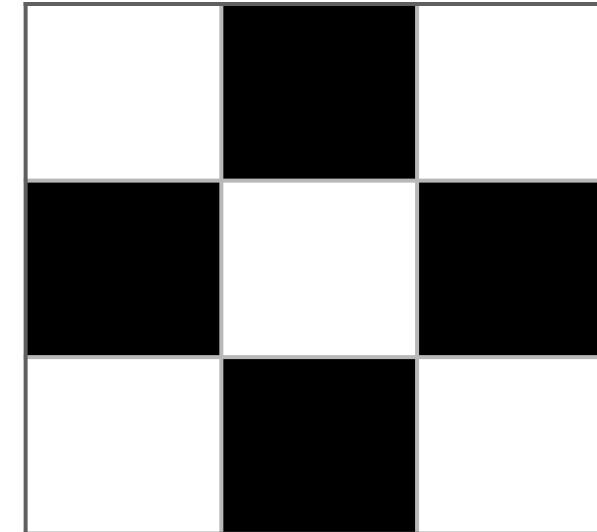
Image



Image



Filter

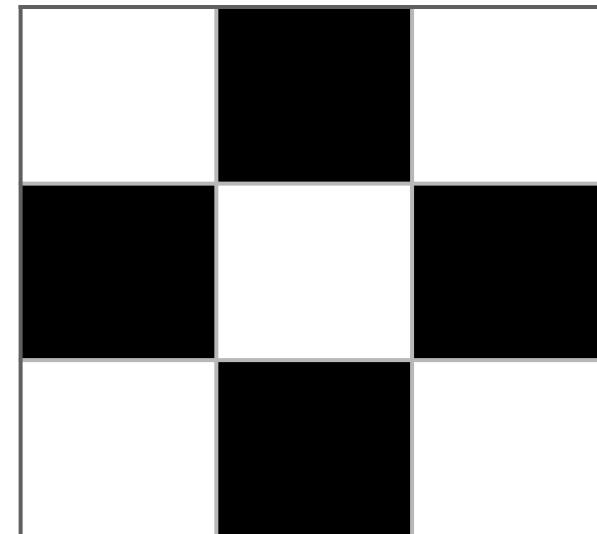


3x3

Image

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

Filter



3x3

Image

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

5x5

Filter

1	0	1
0	1	0
1	0	1

3x3

Image

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

5x5

Filter

1	0	1
0	1	0
1	0	1

3x3

Image

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

5x5

Filter

1	0	1
0	1	0
1	0	1

3x3

Image

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

5x5

Filter

1	0	1
0	1	0
1	0	1

3x3

Image

1 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>	0	0
0 <small>x 0</small>	1 <small>x 1</small>	1 <small>x 0</small>	0	1
0 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>	1	1
0	0	1	0	1
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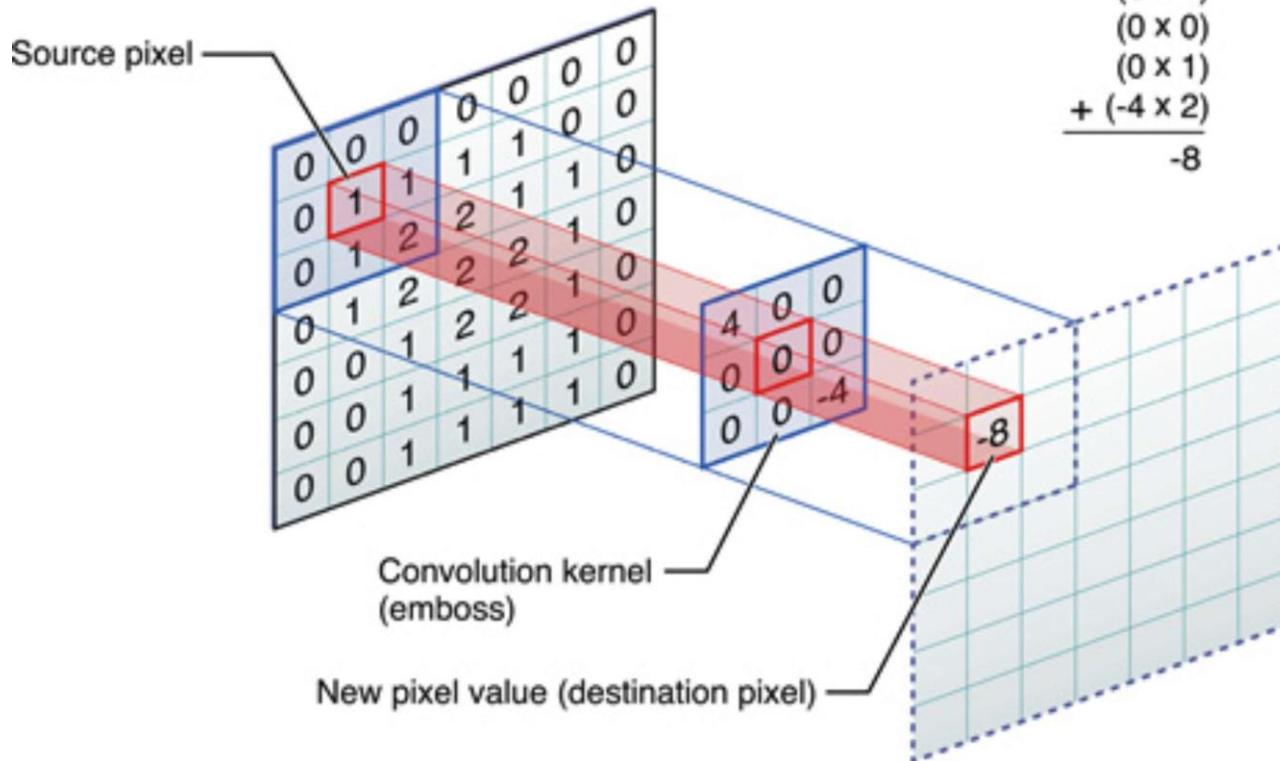
Image

1 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>	0	0
0 <small>x 0</small>	1 <small>x 1</small>	1 <small>x 0</small>	0	1
0 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>	1	1
0	0	1	0	1
0	1	1	0	0

**Output
(feature map)**

Center element of the kernel is placed over the source pixel. The source pixel is then replaced with a weighted sum of itself and nearby pixels.

$$\begin{array}{r} (4 \times 0) \\ (0 \times 0) \\ (0 \times 0) \\ (0 \times 0) \\ (0 \times 1) \\ (0 \times 1) \\ (0 \times 0) \\ (0 \times 1) \\ + (-4 \times 2) \\ \hline -8 \end{array}$$



Image

1 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>	0	0
0 <small>x 0</small>	1 <small>x 1</small>	1 <small>x 0</small>	0	1
0 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>	1	1
0	0	1	0	1
0	1	1	0	0

**Output
(feature map)**

Image

1 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>	0	0
0 <small>x 0</small>	1 <small>x 1</small>	1 <small>x 0</small>	0	1
0 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>	1	1
0	0	1	0	1
0	1	1	0	0

**Output
(feature map)**

3		

Image

1	1 <small>x 1</small>	1 <small>x 0</small>	0 <small>x 1</small>	0
0	1 <small>x 0</small>	1 <small>x 1</small>	0 <small>x 0</small>	1
0	0 <small>x 1</small>	0 <small>x 0</small>	1 <small>x 1</small>	1
0	0	1	0	1
0	1	1	0	0

**Output
(feature map)**

3	3

Image

1	1	1 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>
0	1	1 <small>x 0</small>	0 <small>x 1</small>	1 <small>x 0</small>
0	0	0 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>
0	0	1	0	1
0	1	1	0	0

**Output
(feature map)**

3	3	2

Image

1	1	1	0	0
0 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>	0	1
0 <small>x 0</small>	0 <small>x 1</small>	0 <small>x 0</small>	1	1
0 <small>x 1</small>	0 <small>x 0</small>	1 <small>x 1</small>	0	1
0	1	1	0	0

**Output
(feature map)**

3	3	2
2		

Image

1	1	1	0	0
0	1 _{x 1}	1 _{x 0}	0 _{x 1}	1
0	0 _{x 0}	0 _{x 1}	1 _{x 0}	1
0	0 _{x 1}	1 _{x 0}	0 _{x 1}	1
0	1	1	0	0

**Output
(feature map)**

3	3	2
2	1	

Image

1	1	1	0	0
0	1	1 <small>x 1</small>	0 <small>x 0</small>	1 <small>x 1</small>
0	0	0 <small>x 0</small>	1 <small>x 1</small>	1 <small>x 0</small>
0	0	1 <small>x 1</small>	0 <small>x 0</small>	1 <small>x 1</small>
0	1	1	0	0

**Output
(feature map)**

3	3	2
2	1	5

Image

1	1	1	0	0
0	1	1	0	1
0 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>	1	1
0 <small>x 0</small>	0 <small>x 1</small>	1 <small>x 0</small>	0	1
0 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>	0	0

**Output
(feature map)**

3	3	2
2	1	5
1		

Image

1	1	1	0	0
0	1	1	0	1
0	0 _{x 1}	0 _{x 0}	1 _{x 1}	1
0	0 _{x 0}	1 _{x 1}	0 _{x 0}	1
0	1 _{x 1}	1 _{x 0}	0 _{x 1}	0

**Output
(feature map)**

3	3	2
2	1	5
1	3	

Image

1	1	1	0	0
0	1	1	0	1
0	0	0 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>
0	0	1 <small>x 0</small>	0 <small>x 1</small>	1 <small>x 0</small>
0	1	1 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>

5x5

**Output
(feature map)**

3	3	2
2	1	5
1	3	2

3x3

zero padding

Image

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

5x5

**Output
(feature map)**

3	3	2		
2	1	5		
1	3	2		

Image

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

5x5

**Output
(feature map)**

2			
3	3	2	
2	1	5	
1	3	2	

Image

0	0	0	0	0	0	0	0
0	1	1	1	0	0	0	0
0	0	1	1	1	0	0	0
0	0	0	1	1	1	0	0
0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0
0	0	0	0	0	0	0	0
5x5							

**Output
(feature map)**

2	2		
3	3	2	
2	1	5	
1	3	2	

Image

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

5x5

**Output
(feature map)**

2	2	3	
3	3	2	
2	1	5	
1	3	2	

Image

0	0	0	0	x_1	0	x_0	0	x_1	0
0	1	1	1	x_0	0	x_1	0	x_0	0
0	0	1	1	x_1	1	x_0	0	x_1	0
0	0	0	1	1	1	1	0		
0	0	0	0	0	0	0	0		
0	0	1	1	0	0	0	0		
0	0	0	0	0	0	0	0		

5x5

**Output
(feature map)**

2	2	3	1	
3	3	2		
2	1	5		
1	3	2		

Image

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

5x5

**Output
(feature map)**

2	2	3	1	1
3	3	2		
2	1	5		
1	3	2		

Image

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

5x5

**Output
(feature map)**

2	2	3	1	1
1	3	3	2	1
1	2	1	5	2
1	1	3	2	1
0	1	1	0	0

5x5

Kernel

Identity

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$



Kernel

Edge
Detection

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$



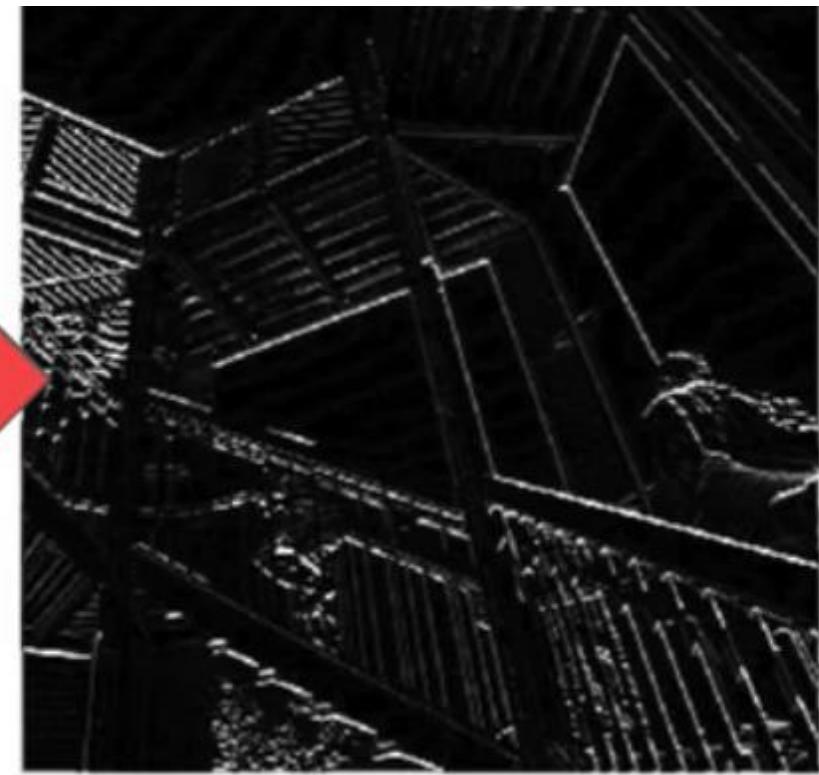


-1	0	1
-2	0	2
-1	0	1

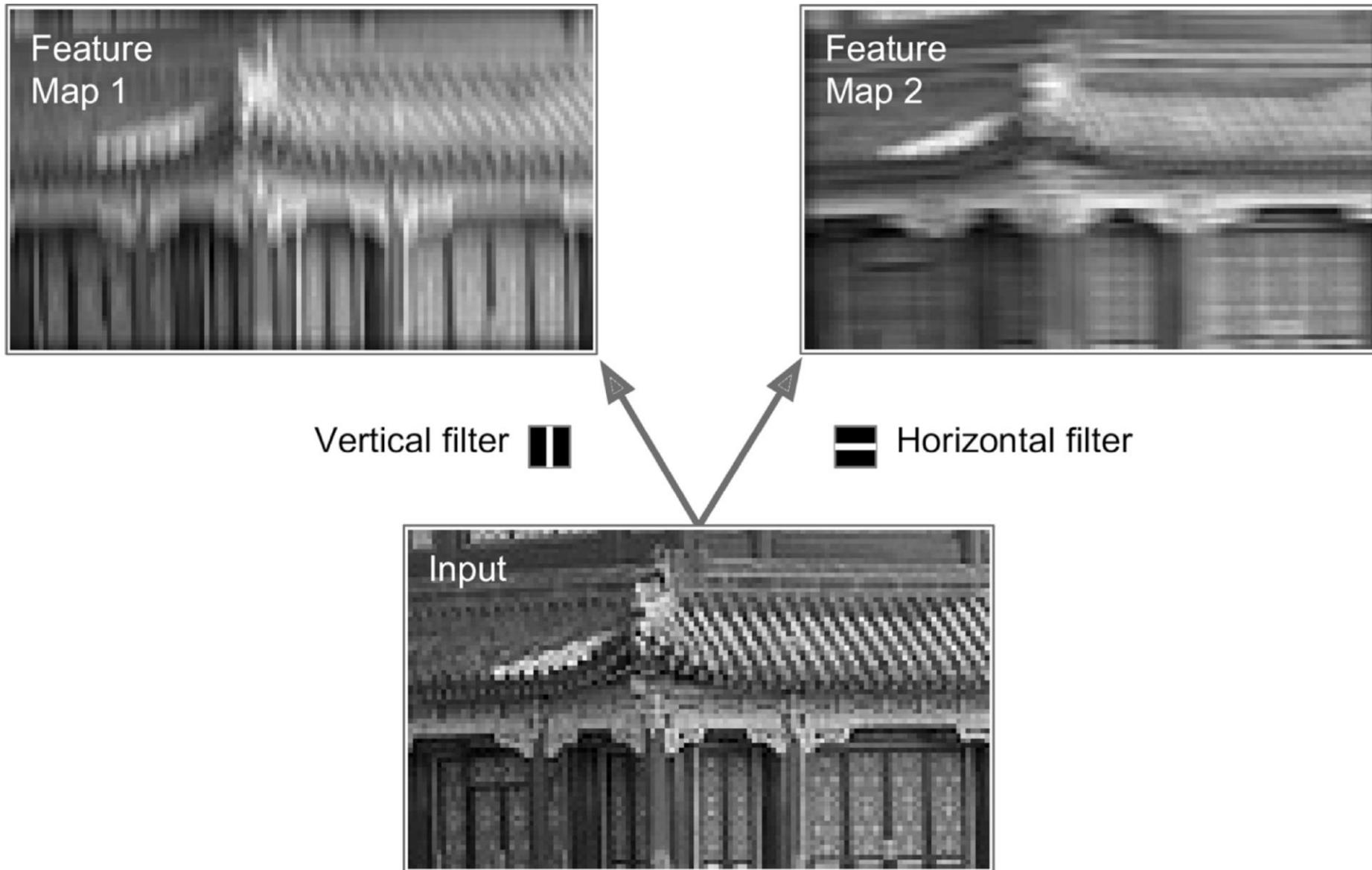




-1	-2	-1
0	0	0
1	2	1



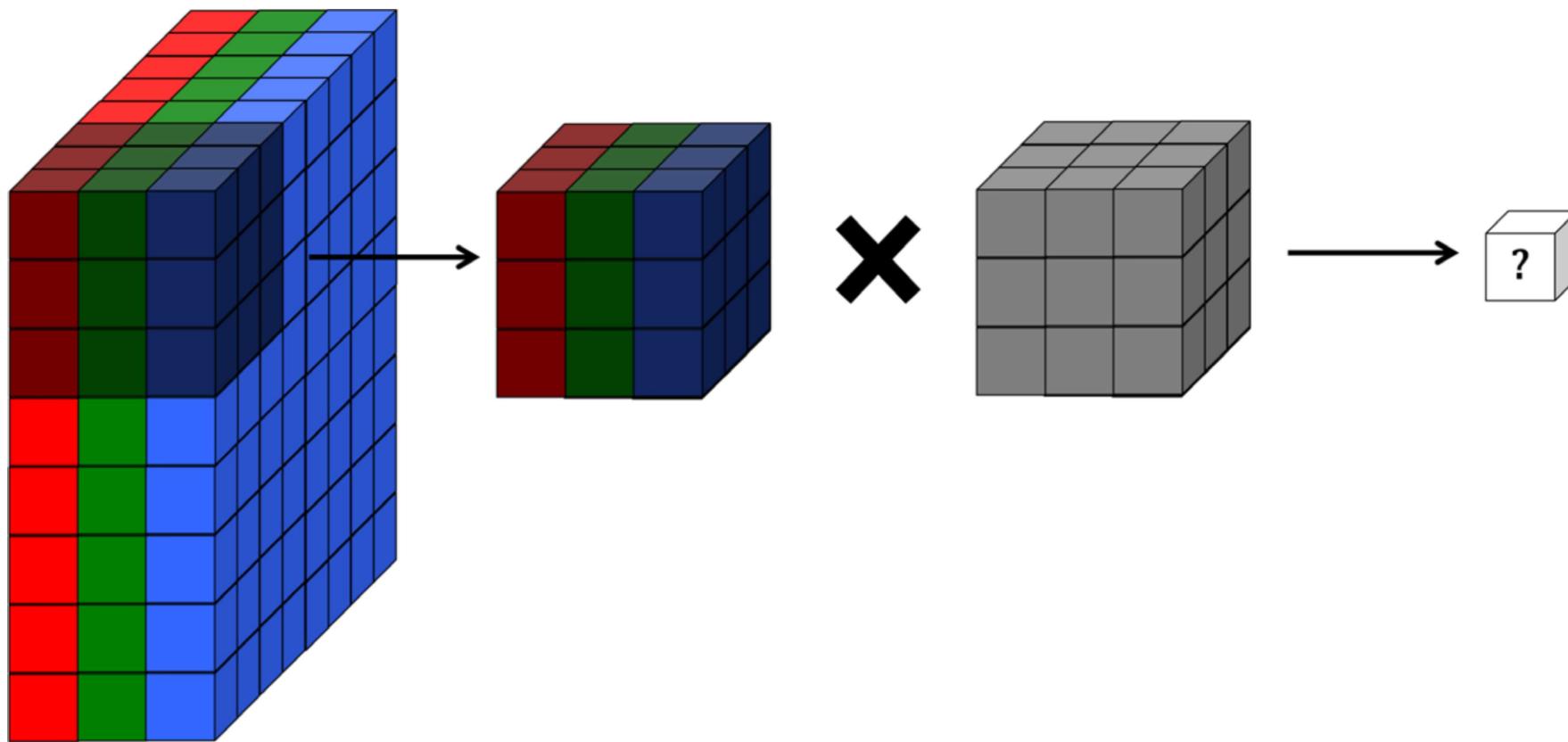
Two different filters produce two feature maps



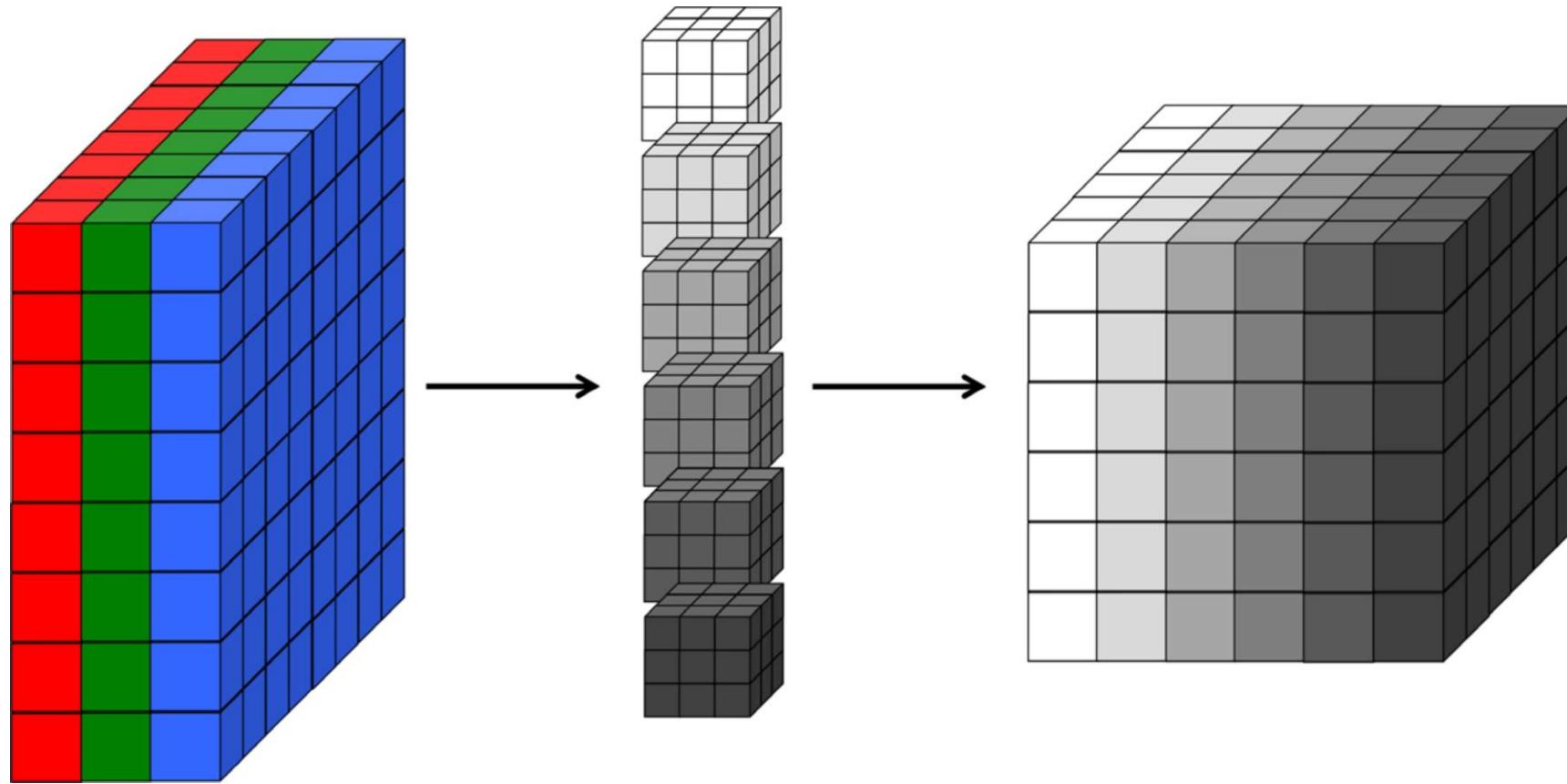
Learned Filters



Convolutional Layers



Convolutional Layers



Convolution Layer Hyperparameters

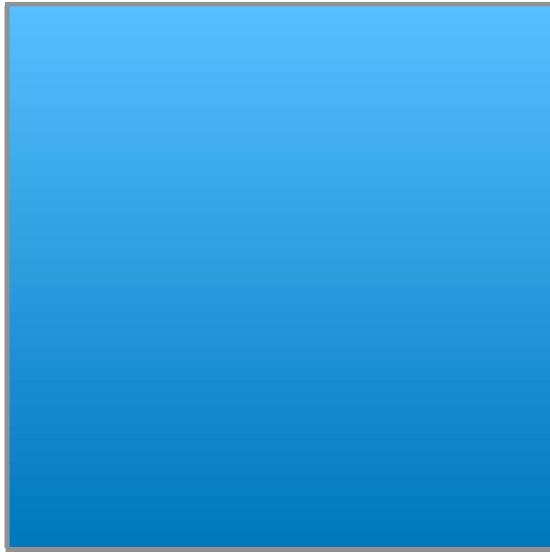
filter size

depth (filter count)

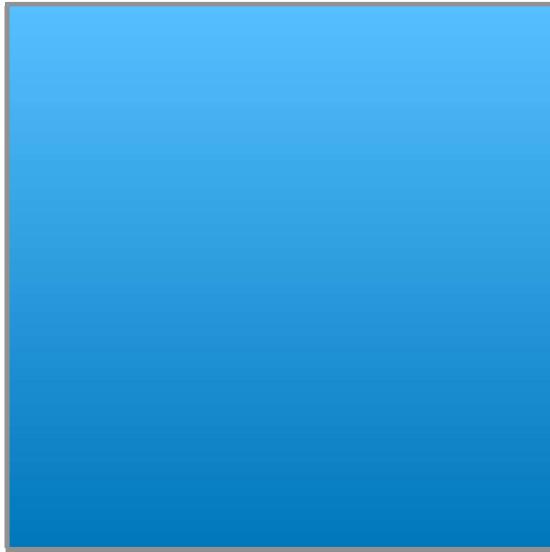
zero-padding

stride

Image

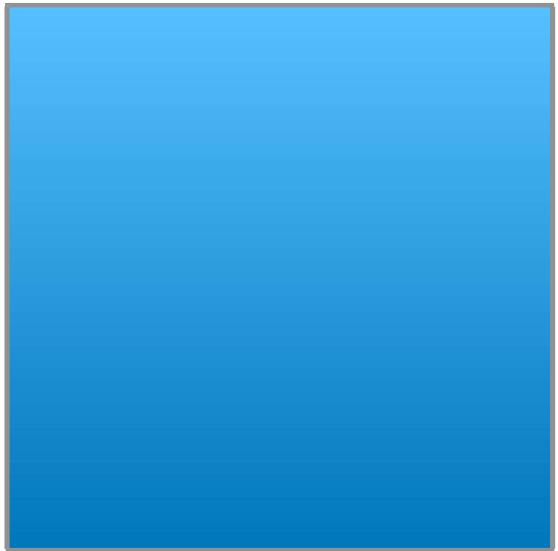


Image



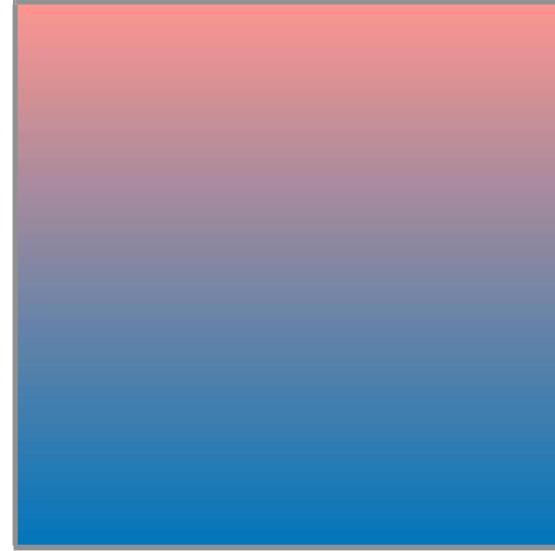
Filters

Image



Filters

Convolution Layer



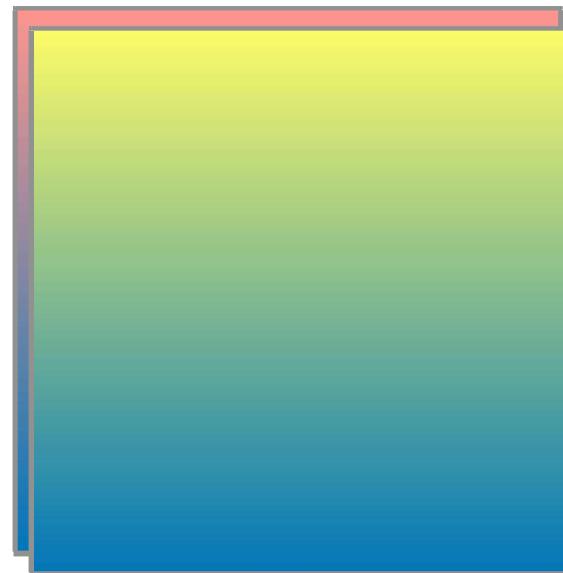
Stacked Feature Maps

Image



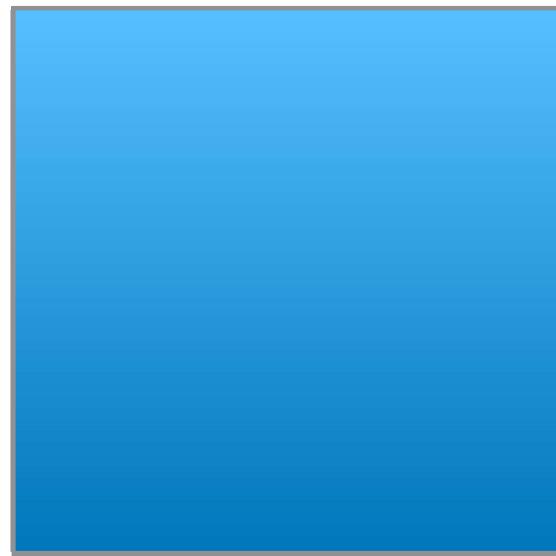
Filters

Convolution Layer



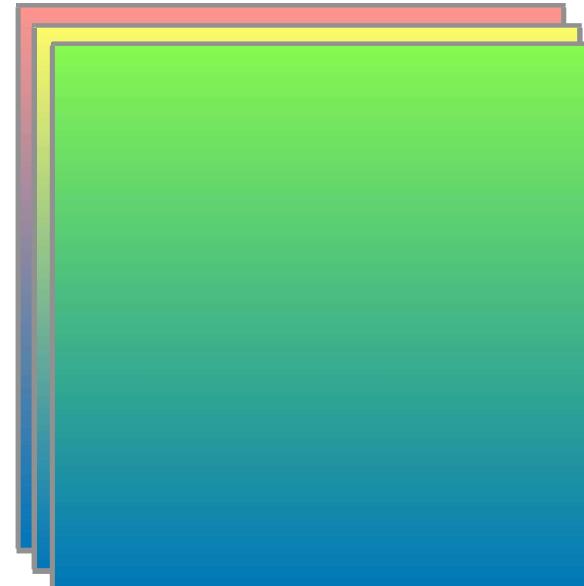
Stacked Feature Maps

Image



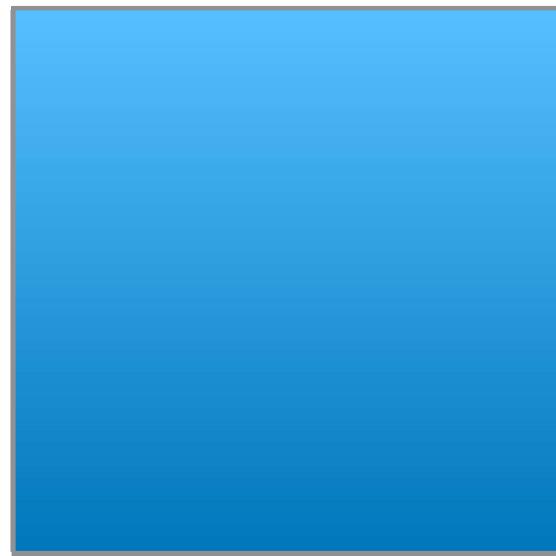
Filters

Convolution Layer



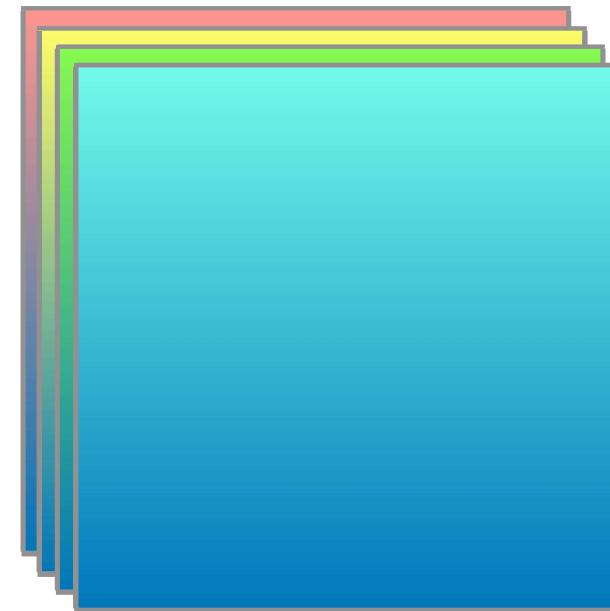
Stacked Feature Maps

Image



Filters

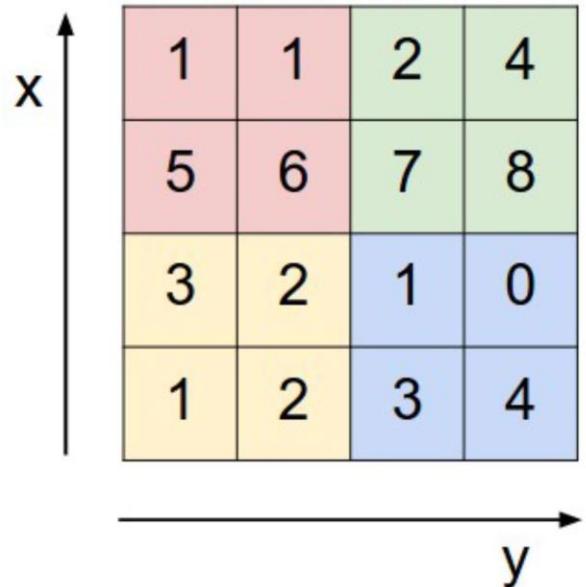
Convolution Layer



Stacked Feature Maps

Pooling

Single depth slice

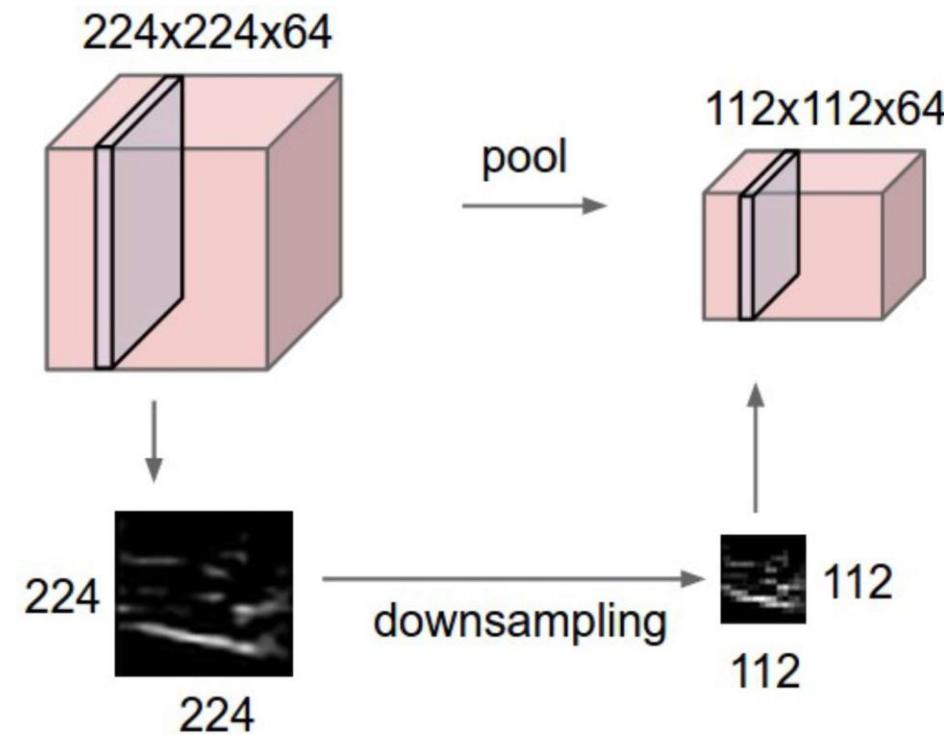


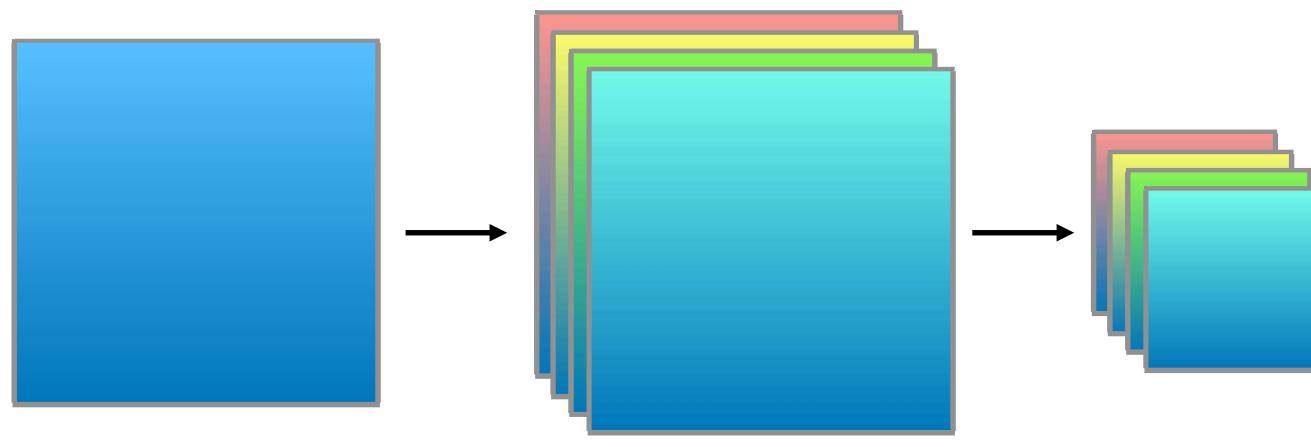
max pool with 2x2 filters
and stride 2

A 2x2 grid representing the output of the max pooling operation. The values are:

6	8
3	4

Downsampling (pooling)





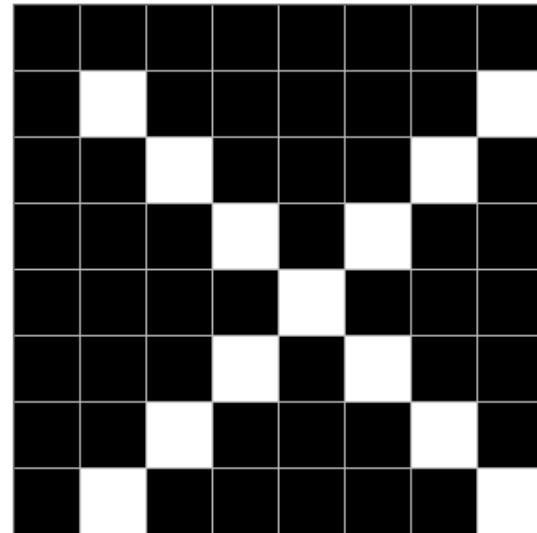
Image

Convolution

Pooling

Convolution Layer

Image

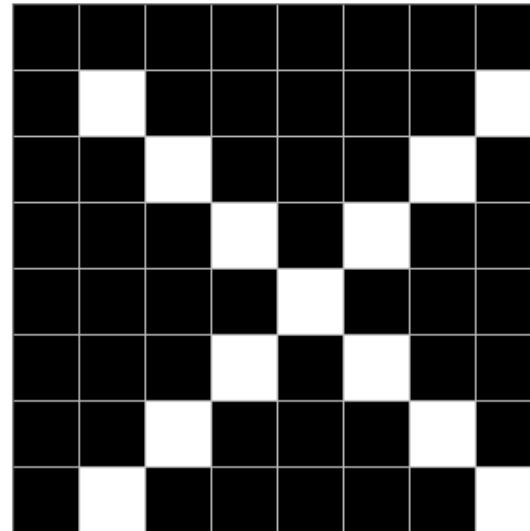


Convolution Layer

Filters

$$\begin{bmatrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{bmatrix}$$

Image



Convolution Layer

Filters

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

Image

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

Convolution Layer

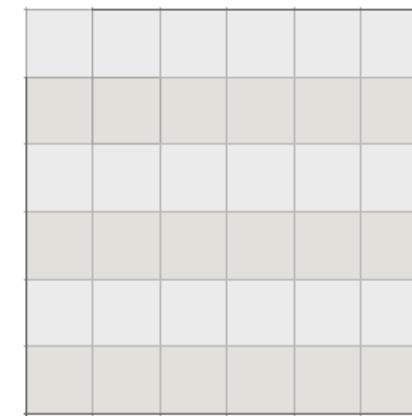
Filters

$$\begin{array}{|c|c|c|} \hline 1 & -1 & -1 \\ \hline -1 & 1 & -1 \\ \hline -1 & -1 & 1 \\ \hline \end{array}$$

Image

-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
-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

Feature Map



Convolution Layer

Filters

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

Image

-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
-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

Feature Map

Convolution Layer

Filters

$$\begin{pmatrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{pmatrix}$$

Image

-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
-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

Feature Map

7

Convolution Layer

Filters

$$\begin{bmatrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & -1 & 1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{bmatrix}$$

Image

-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	-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

Feature Map

7		
	9	

Convolution Layer

Filters

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

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

Image

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

Feature Map

7			
	9		
		9	

Convolution Layer

Filters

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

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

Image

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

Feature Map

7			
	9		
	9		
		5	

Convolution Layer

Filters

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

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

Image

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

Feature Map

7			
	9		
		9	
			5
			9

Convolution Layer

Filters

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

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

Image

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

Feature Map

7			
	9		
		9	
			5
			9
			9

Convolution Layer

Filters

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

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

Image

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

Feature Map

7	-1	1	3	5	-1
-1	9	-1	3	-1	1
1	-1	9	-3	1	-1
3	3	-3	5	-3	3
5	-1	1	-3	9	-1
-1	1	-1	3	-1	9

Convolution Layer

Filters

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

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

Image

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

Feature Map

7	-1	1	3	5	-1	
-1	9	-1	3	-1	1	
1	-1	9	-3	1	-1	
3	3	-3	5	-3	3	
5	-1	1	-3	9	-1	
-1	1	-1	3	-1	9	

Convolution Layer

Filters

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

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

Image

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

Feature Map

3	-1	5	3	1	-1
-1	1	-1	3	-1	9
5	-1	1	-3	9	-1
3	3	-3	5	-3	3
1	-1	9	-3	1	-1
-1	9	-1	3	-1	1

7	-1	1	3	5	-1
-1	9	-1	3	-1	1
1	-1	9	-3	1	-1
3	3	-3	5	-3	3
5	-1	1	-3	9	-1
-1	1	-1	3	-1	9

ReLU

Feature Maps

3	-1	5	3	1	-1
-1	1	-1	3	-1	9
5	-1	1	-3	9	-1
3	3	-3	5	-3	3
1	-1	9	-3	1	-1
-1	9	-1	3	-1	1

7	-1	1	3	5	-1
-1	9	-1	3	-1	1
1	-1	9	-3	1	-1
3	3	-3	5	-3	3
5	-1	1	-3	9	-1
-1	1	-1	3	-1	9

ReLU

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3		

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	9

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	9
5		

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	9
5	5	

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	9
5	5	9

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	9
5	5	9
9		

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	9
5	5	9
9	9	

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	0	5	3	1	0
0	1	0	3	0	9
5	0	1	0	9	0
3	3	0	5	0	3
1	0	9	0	1	0
0	9	0	3	0	1

Max Pooling

3	5	9
5	5	9
9	9	1

7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

Pooling

Feature Maps

3	-1	5	3	1	-1
-1	1	-1	3	-1	9
5	-1	1	-3	9	-1
3	3	-3	5	-3	3
1	-1	9	-3	1	-1
-1	9	-1	3	-1	1

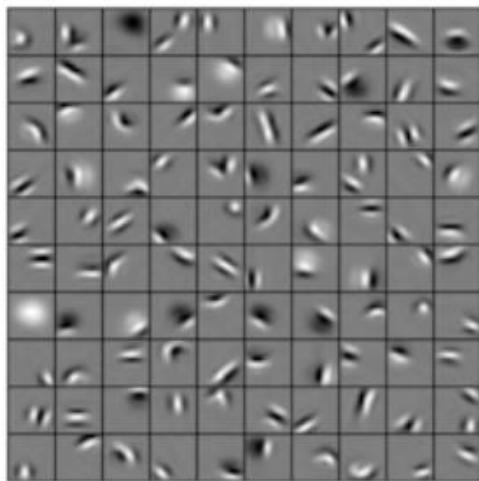
Max Pooling

3	5	9
5	5	9
9	9	1

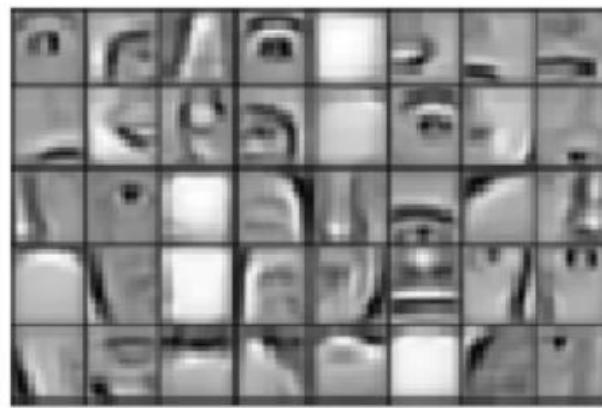
7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

9	3	5
3	9	3
5	3	9

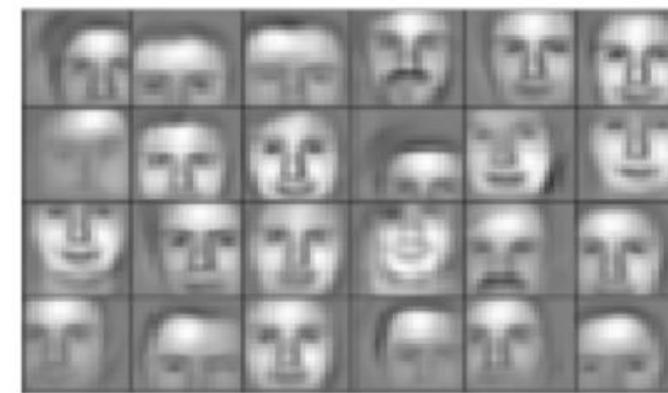
Hierarchical Feature Learning



Edges



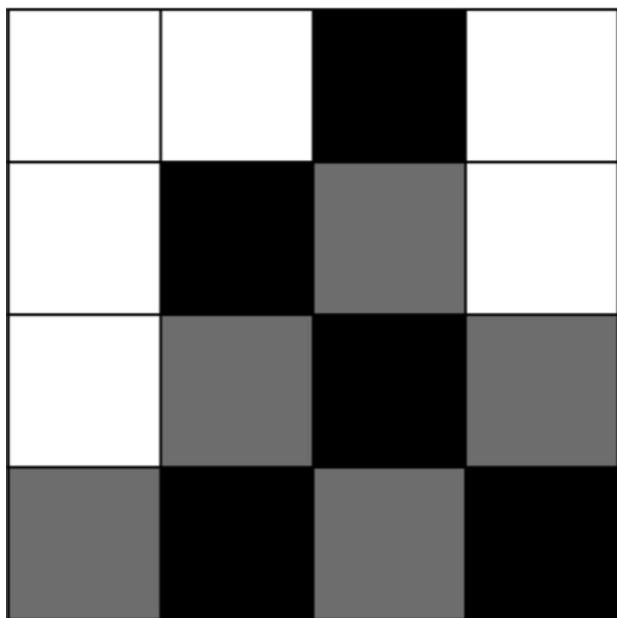
Shapes



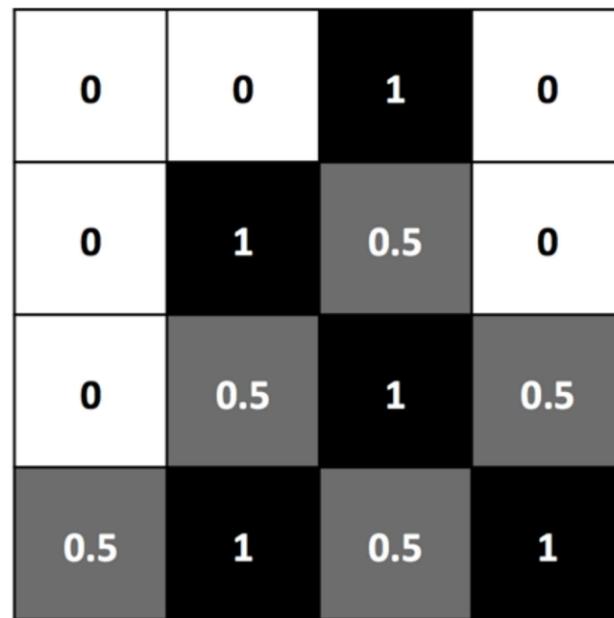
Objects

Fully Connected Layer

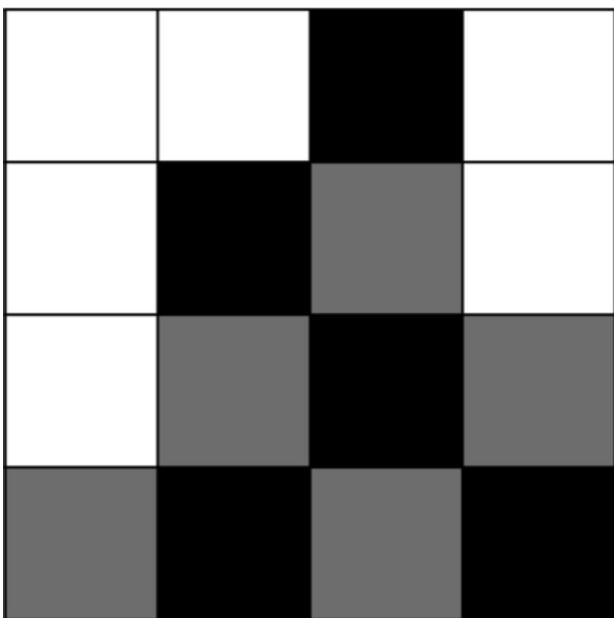
Input



Flatten



Input



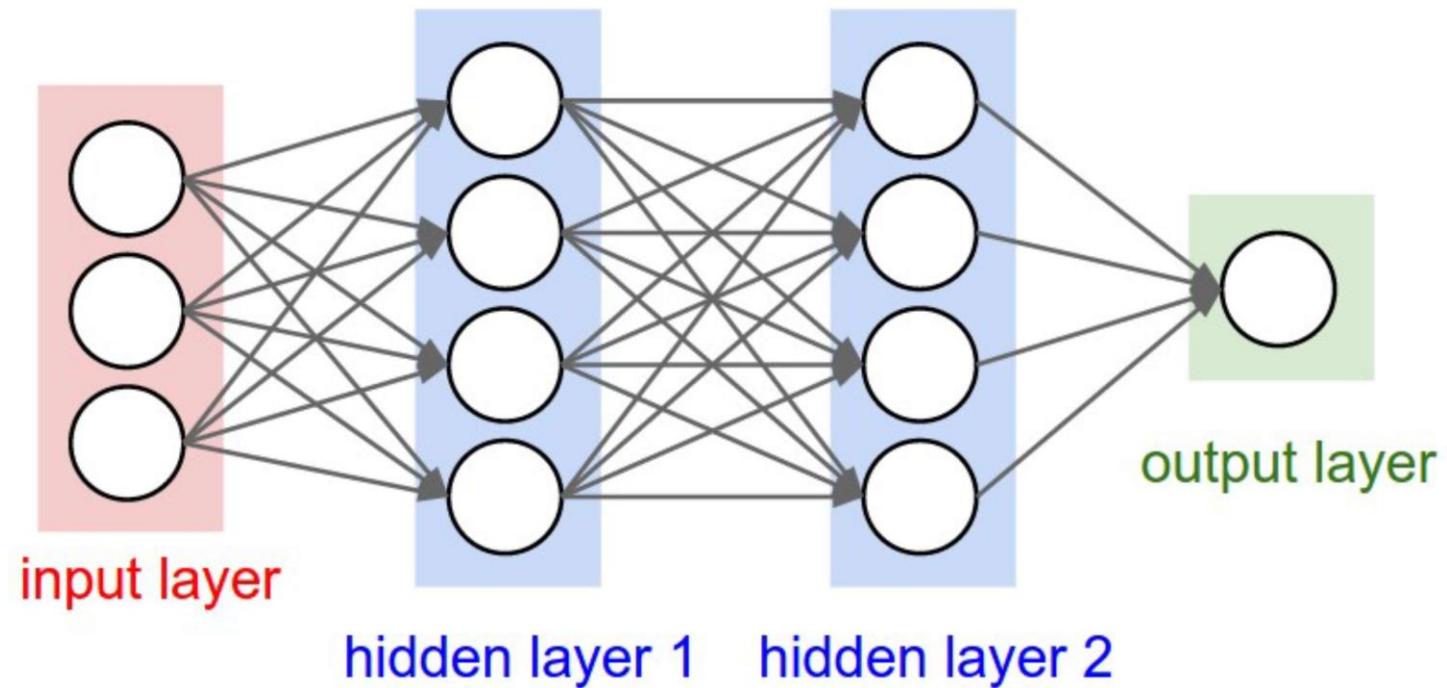
Flatten

0	0	1	0
0	1	0.5	0
0	0.5	1	0.5
0.5	1	0.5	1

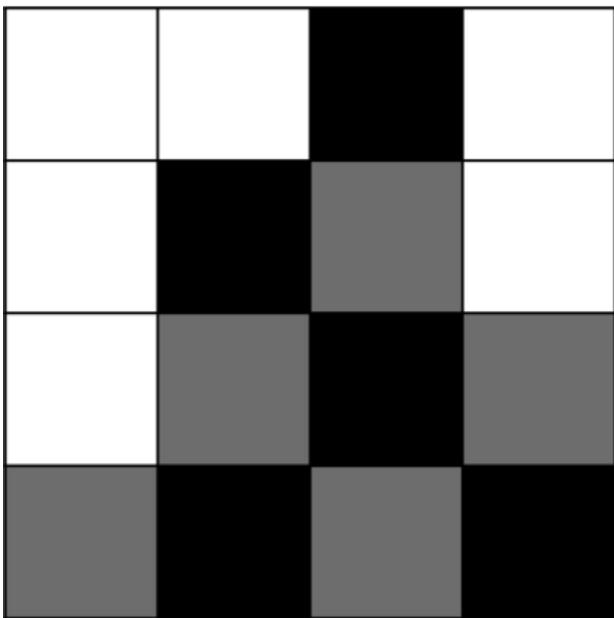
0	0	0	0.5	0	1	0.5	1	0.5	1	1	0.5	1	1	0.5	1	0.5	1	0	0	0.5	0	0	0.5	1
---	---	---	-----	---	---	-----	---	-----	---	---	-----	---	---	-----	---	-----	---	---	---	-----	---	---	-----	---

0	0	0	0.5	0	1	0.5	1	0.5	1	1	0.5	1	1	0.5	1	0.5	1	0	0	0.5	0	0	0.5	1
---	---	---	-----	---	---	-----	---	-----	---	---	-----	---	---	-----	---	-----	---	---	---	-----	---	---	-----	---

Fully-Connected Layer



Input x (pixel intensities)

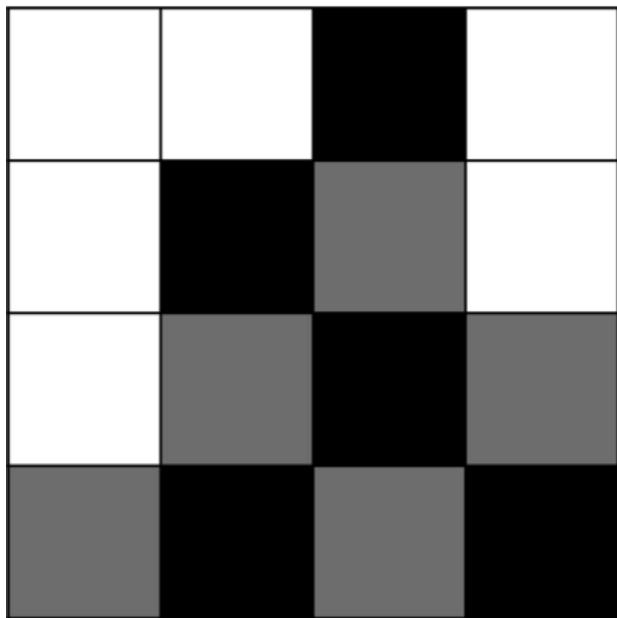


0	0	1	0
0	1	0.5	0
0	0.5	1	0.5
0.5	1	0.5	1

Flatten

0	0	0	0.5	0	1	0.5	1	1	0.5	1	0.5	1	0.5	1	0.5	0	0	0.5	1
---	---	---	-----	---	---	-----	---	---	-----	---	-----	---	-----	---	-----	---	---	-----	---

Input x (pixel intensities)

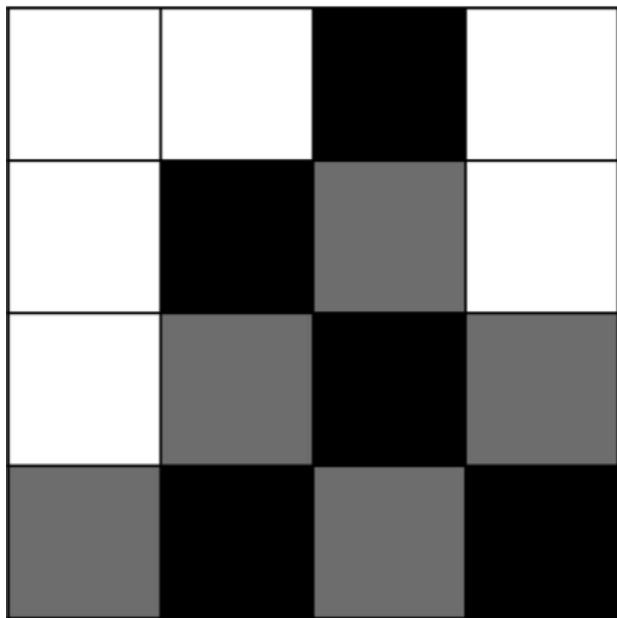


0	0	1	0
0	1	0.5	0
0	0.5	1	0.5
0.5	1	0.5	1

Flatten

0	0	0	0.5	0	1	0.5	1	0.5	1	0.5	1	0.5	1	0	0	0.5	0	0.5	1
---	---	---	-----	---	---	-----	---	-----	---	-----	---	-----	---	---	---	-----	---	-----	---

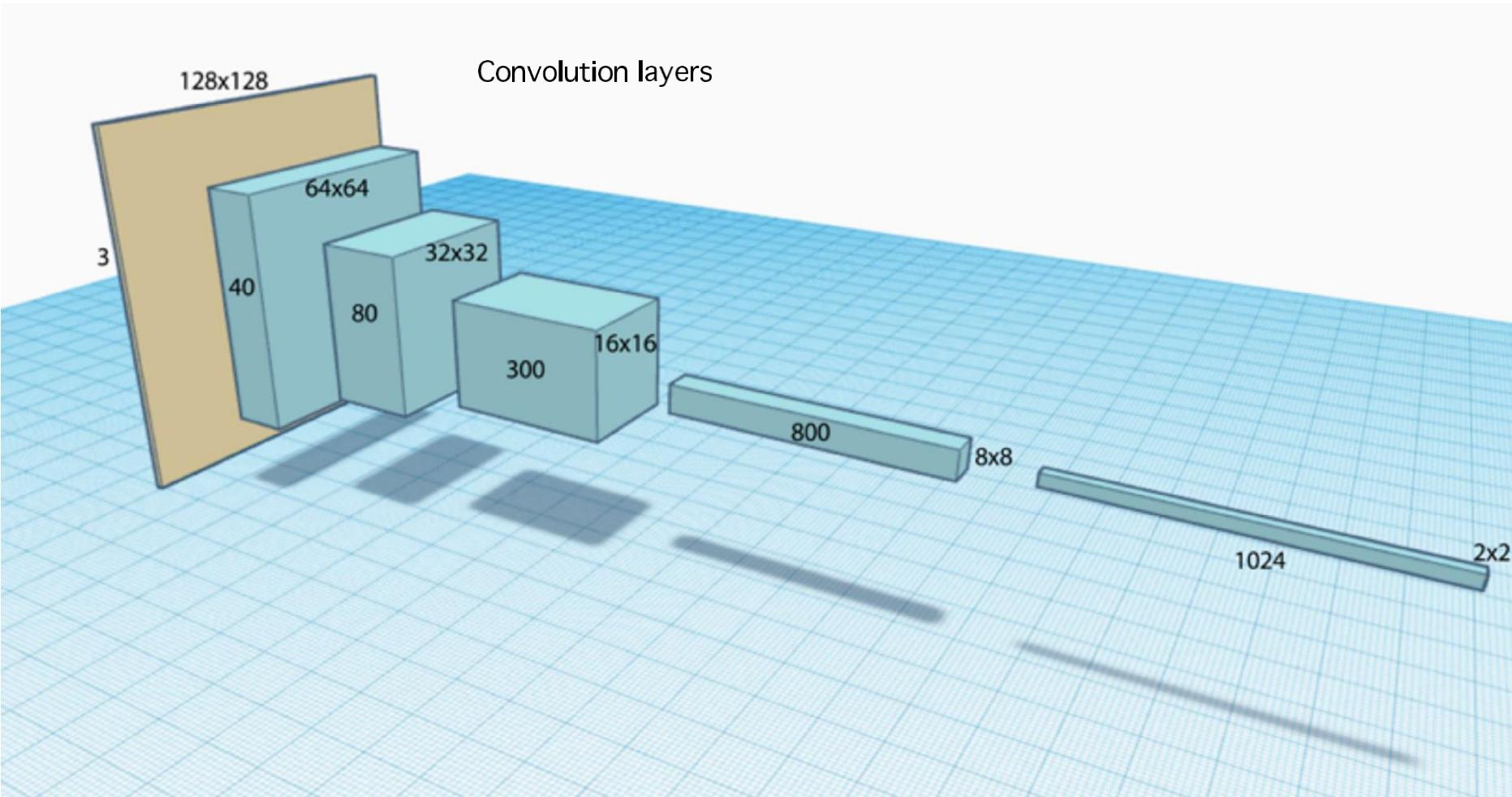
Input x (pixel intensities)

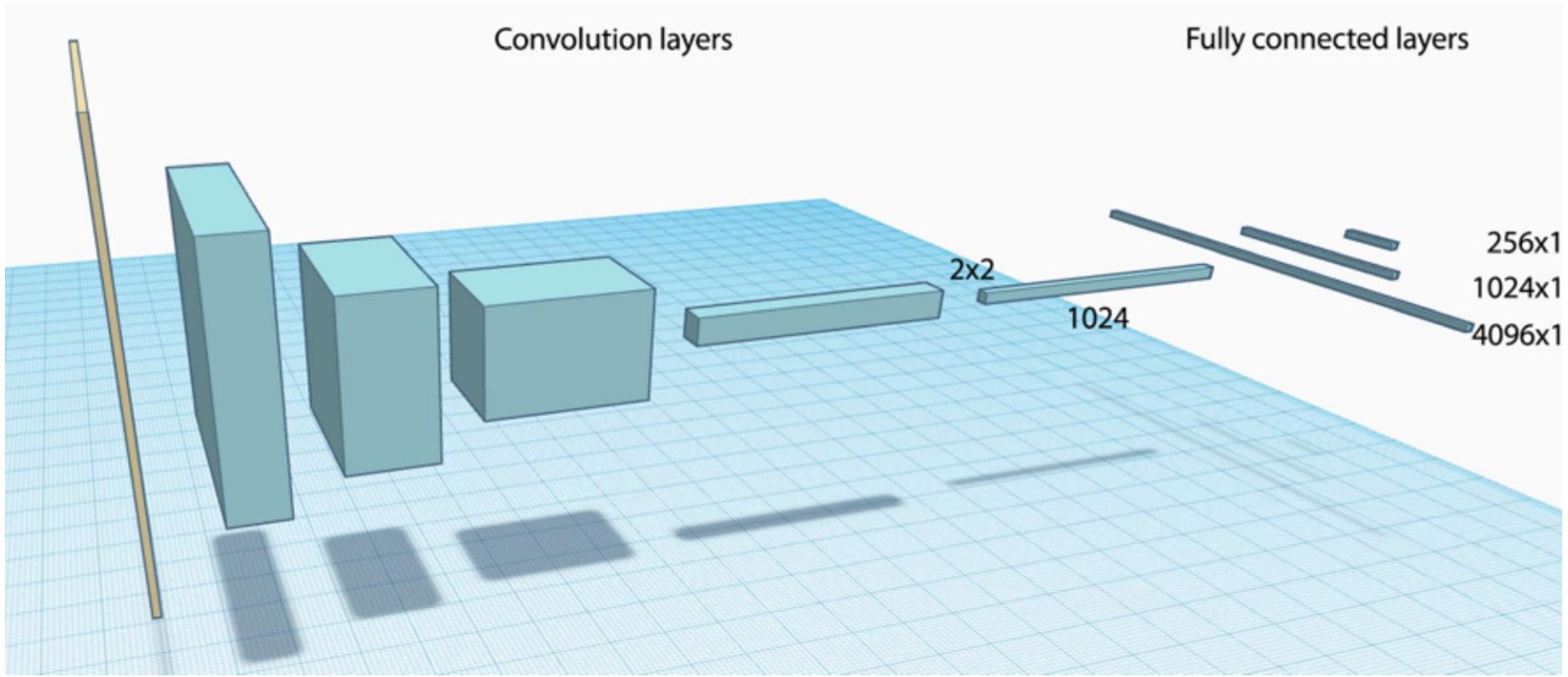


0	0	1	0
0	1	0.5	0
0	0.5	1	0.5
0.5	1	0.5	1

Flatten

0	0	0	0.5	0	1	0.5	1	1	1	0.5	1	0.5	1	0.5	0	0	0.5	1
---	---	---	-----	---	---	-----	---	---	---	-----	---	-----	---	-----	---	---	-----	---





Facebook - DeepFace

