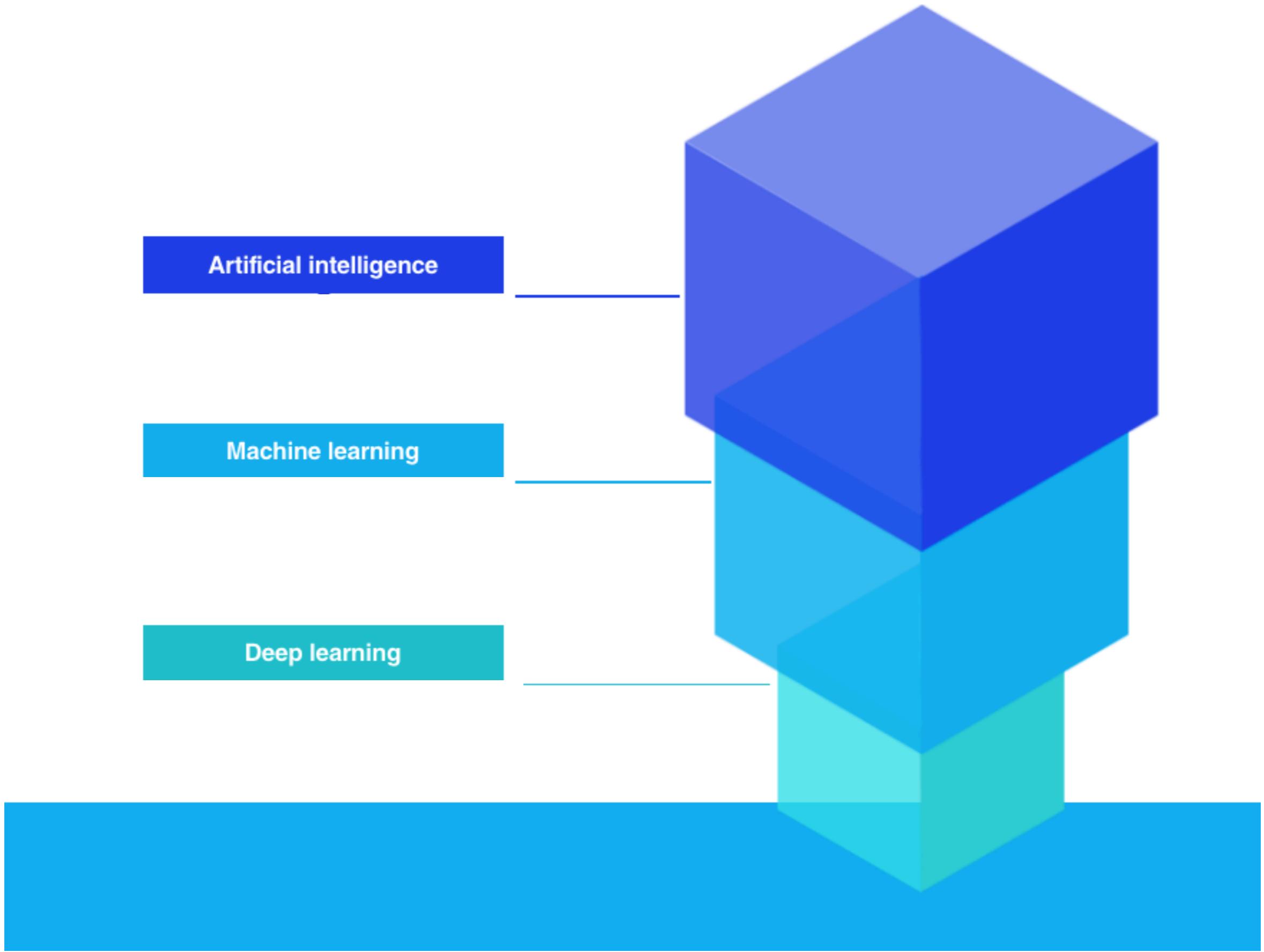


# **Introduction to Understanding Deep Learning**

## Antony Ross

Silicon Valley Code Camp  
October 13, 2018



# **Machine Learning**

## **Regression and Classification**

# Regression

continuous value

$$\hat{y} = 66.5$$

# Classification

probability

$\hat{y} = .85$

# Classification

prediction

$$\hat{y} = 1$$

# Classification

prediction

$$\hat{y} = 0$$

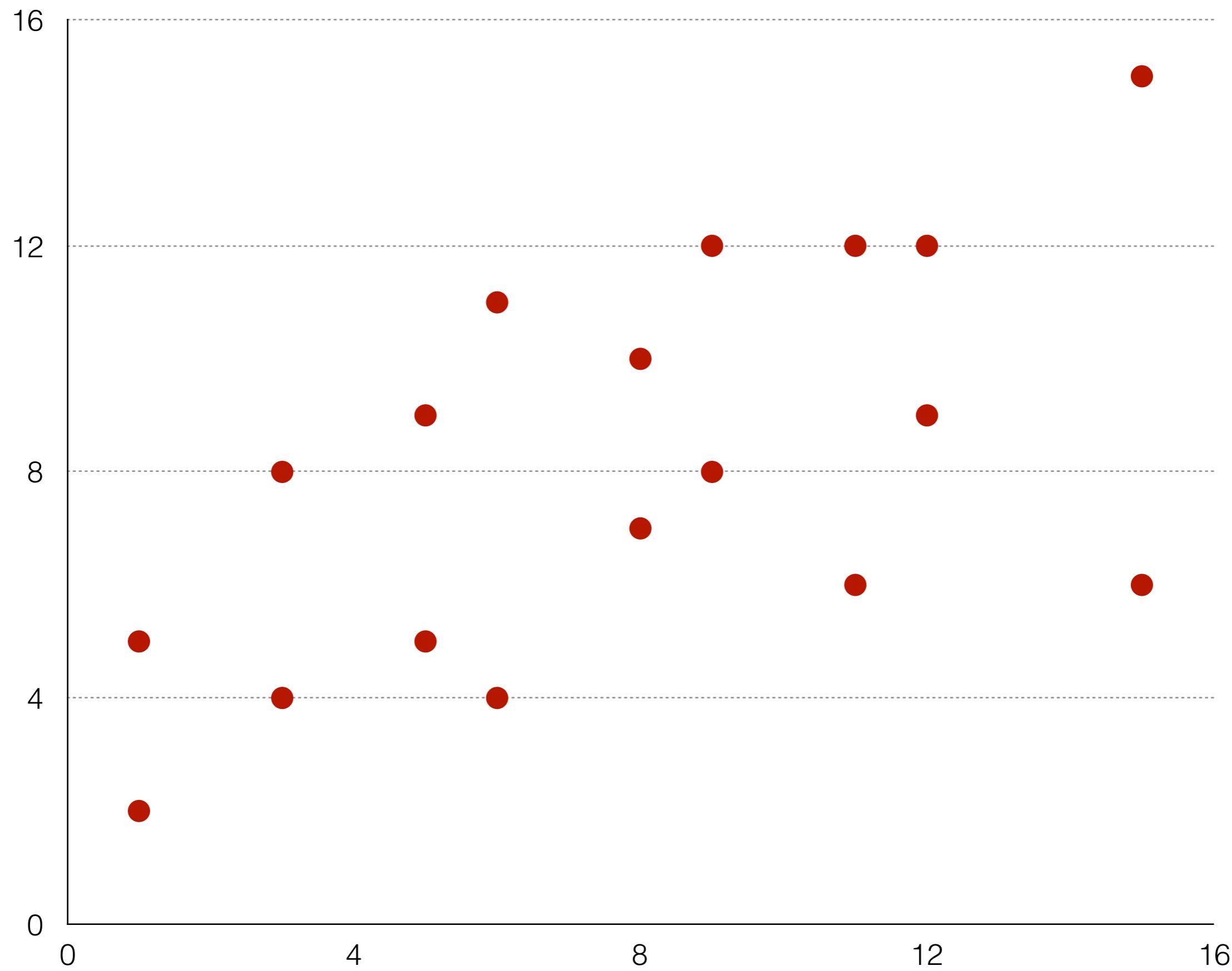
# Linear Regression

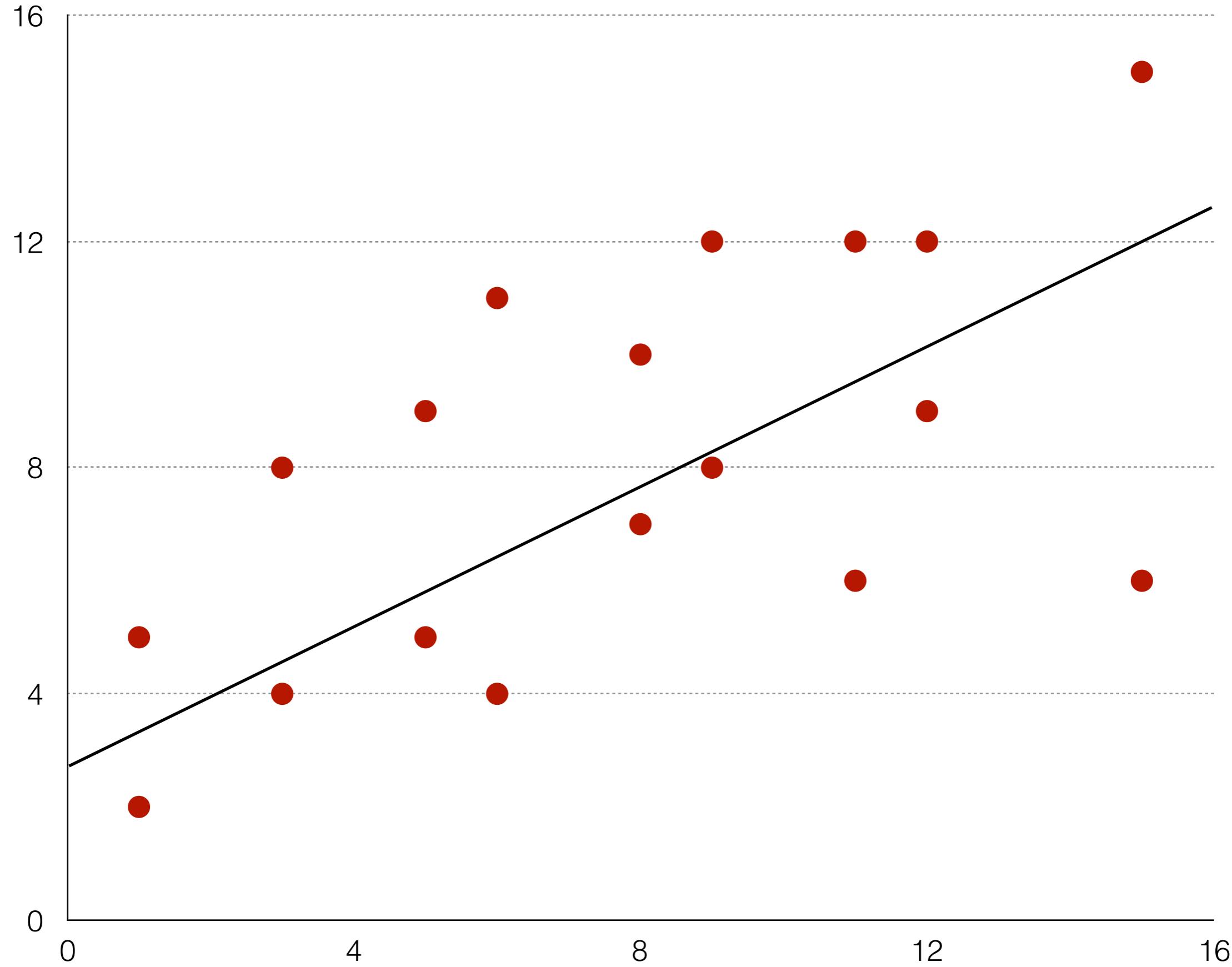
# Linear Regression

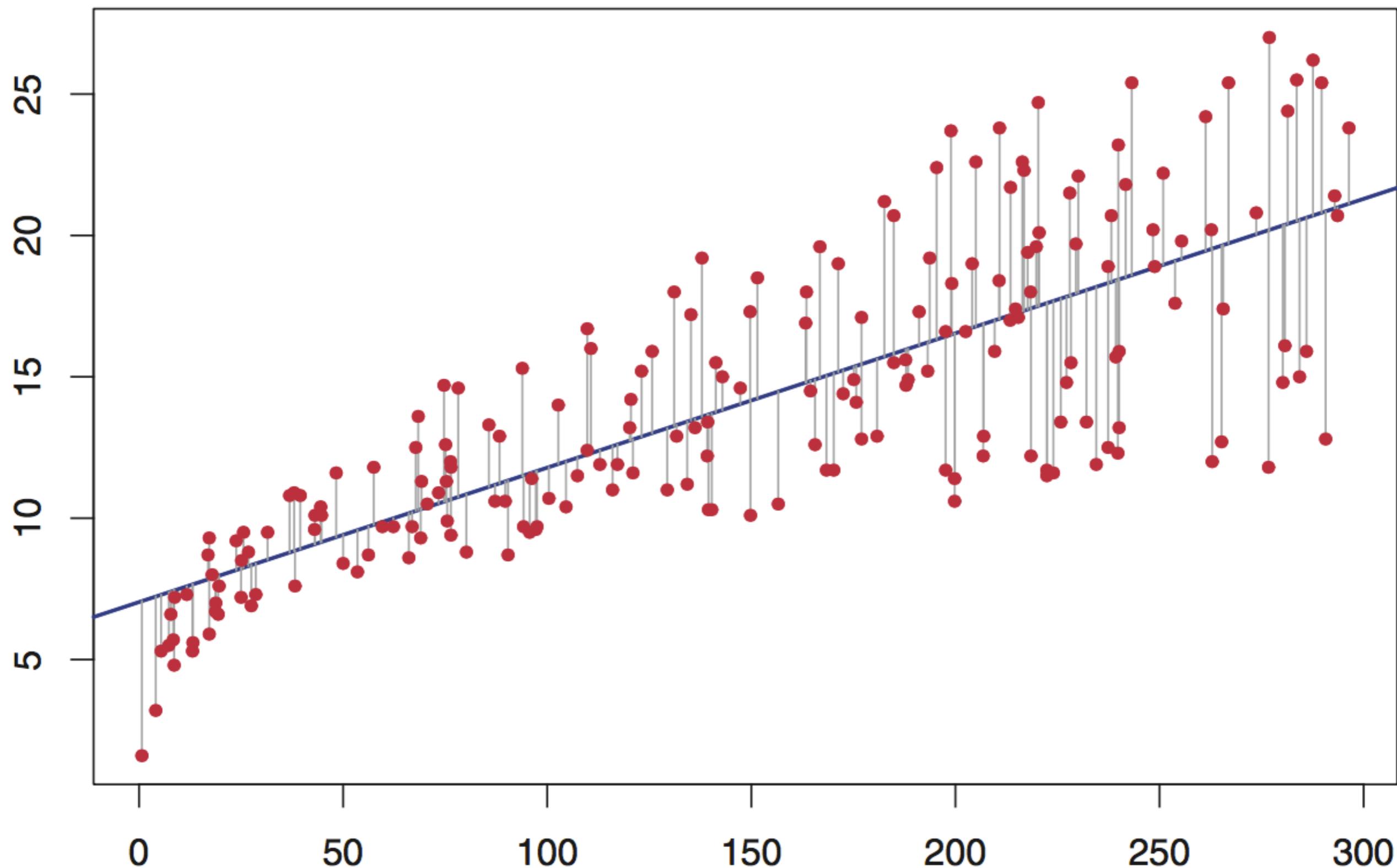
$$y = \beta_0 + \beta_1 x$$

equation of a line

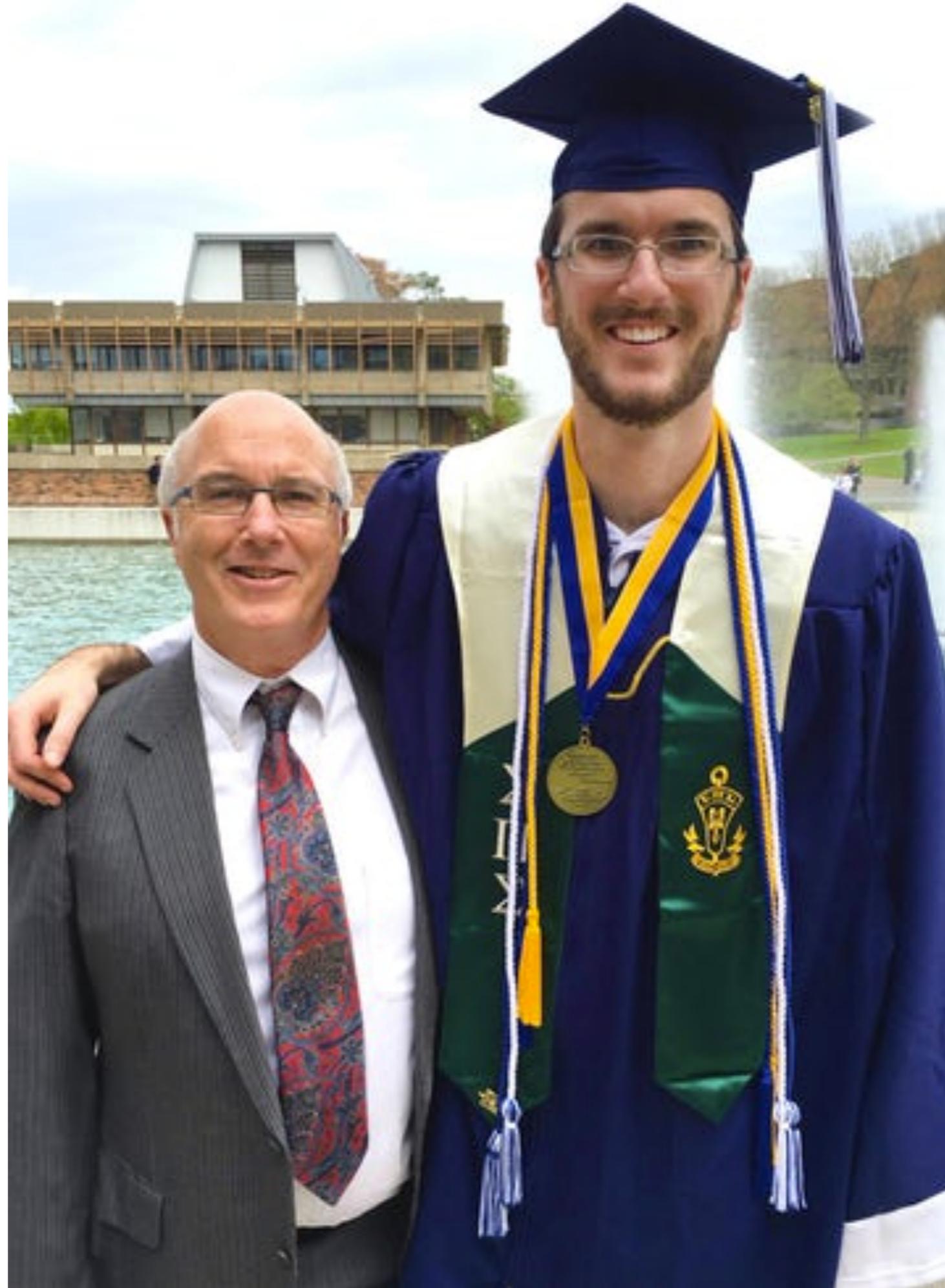
$$y = mx + b$$











# HEIGHT

6'4"  
6'0"  
5'8"  
5'4"  
5'0"  
4'8"  
4'4"

FATHER

MOTHER



A MALE  
WILL GROW TO  
BE ABOUT THE  
**HEIGHT OF**

THE MOTHER (INCHES)

+

FATHER (INCHES)

+ 5 INCHES,  
DIVIDED BY TWO.

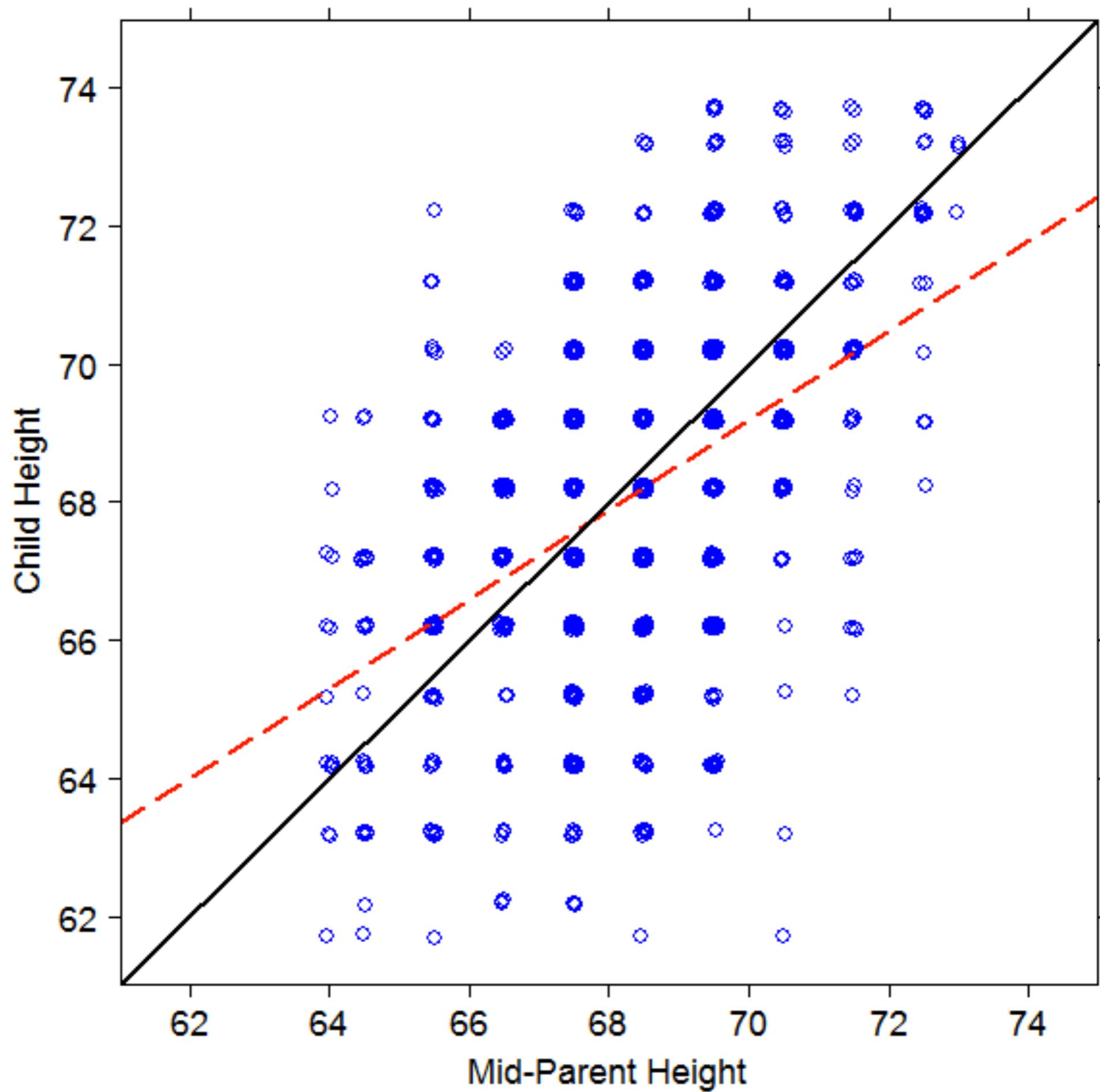
A FEMALE  
WILL GROW TO  
BE ABOUT THE  
**HEIGHT OF**

THE MOTHER (INCHES)

+

FATHER (INCHES)

- 5 INCHES,  
DIVIDED BY TWO.





5'7"



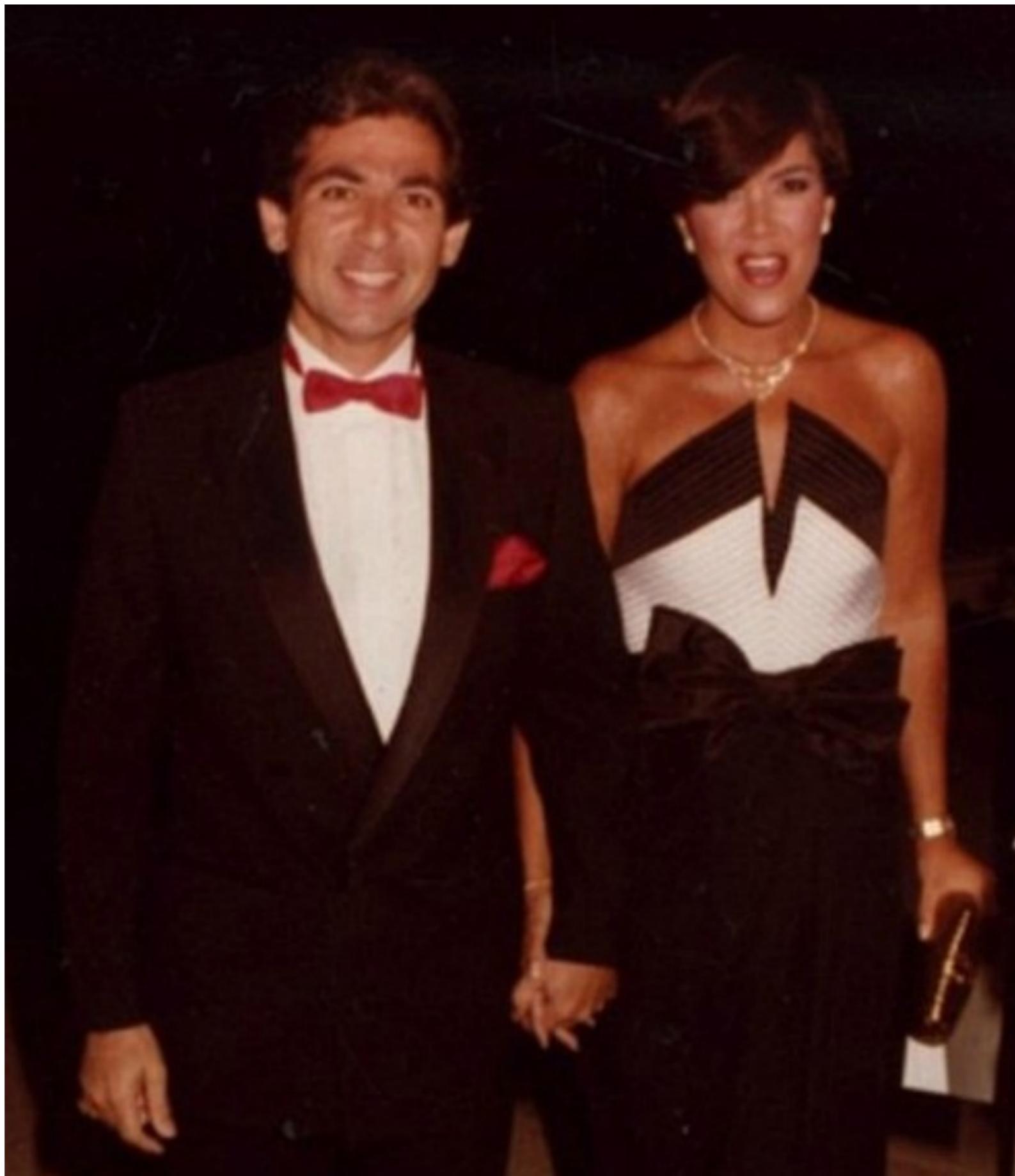
**5'7"**



**"—5'6**

Mid-parent Height  
**5'6.5**

**5'7** —



— **5'6**

5'0



**5'3** —



5'10



**5'10**

**5'3**

**5'0**



Average  
**5'4 1/3**



**6'1**

**5'3**

**5'0**

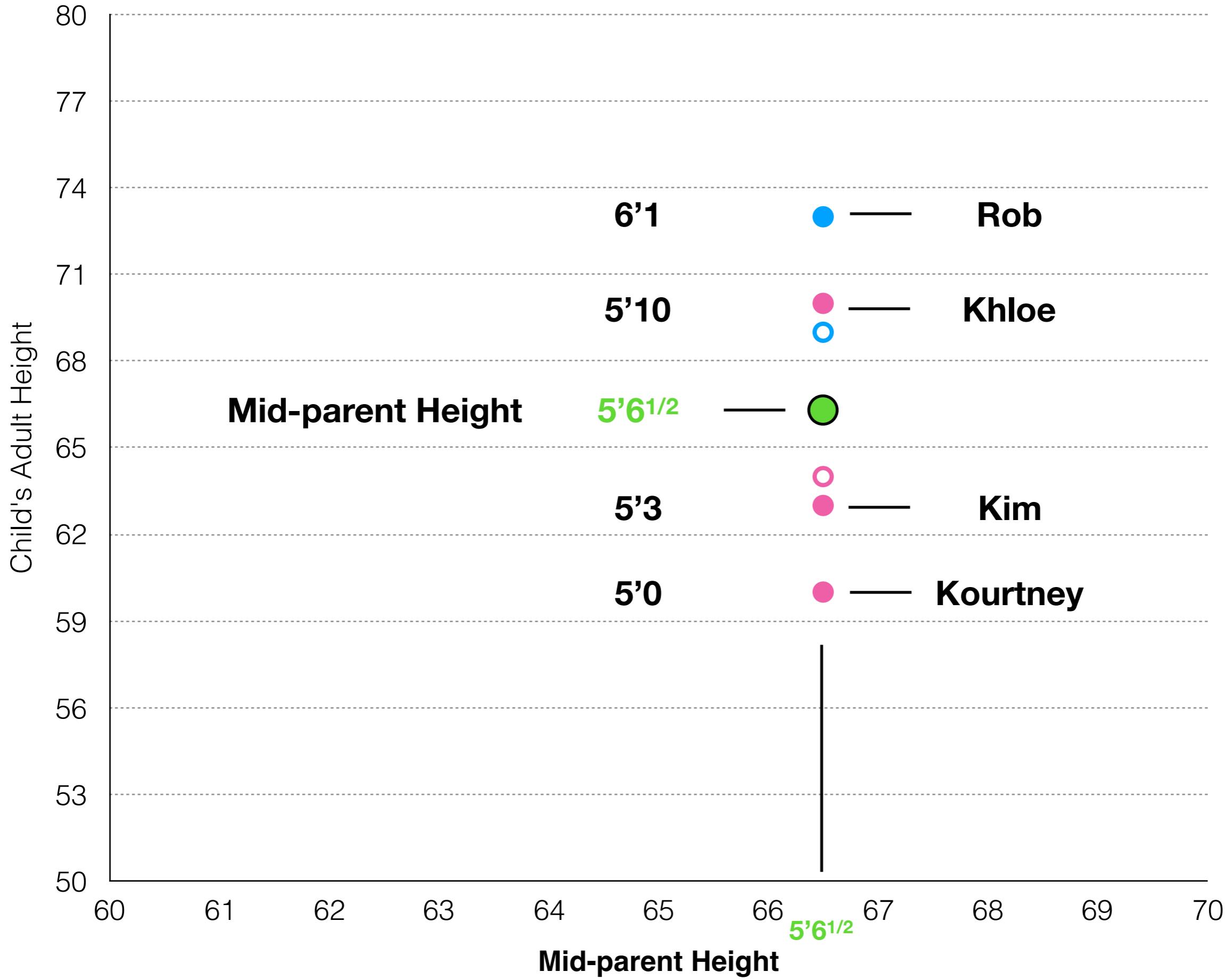
**5'10**



# Mid-parent Height

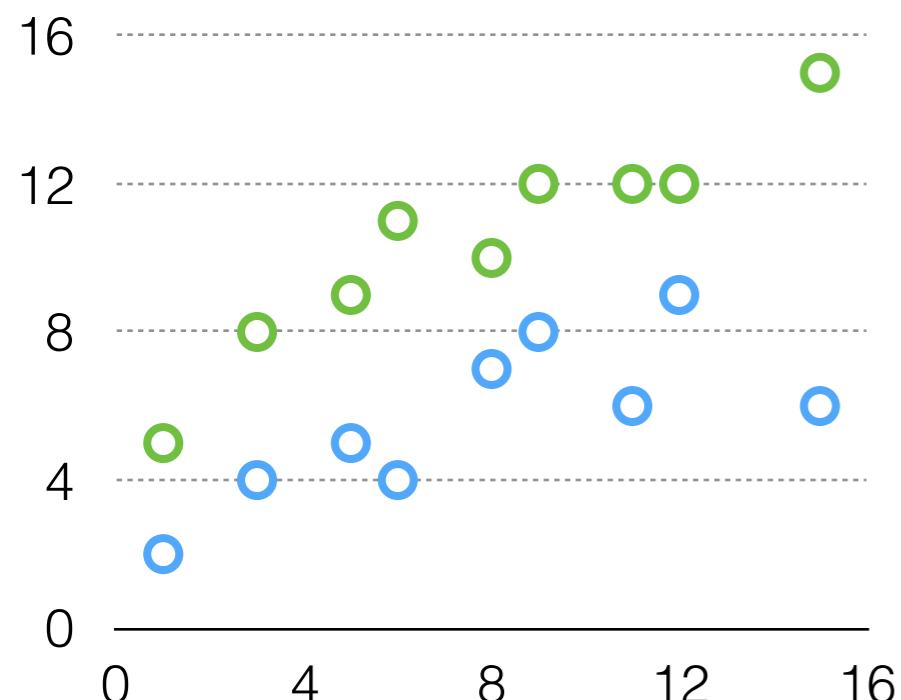
5'6.5



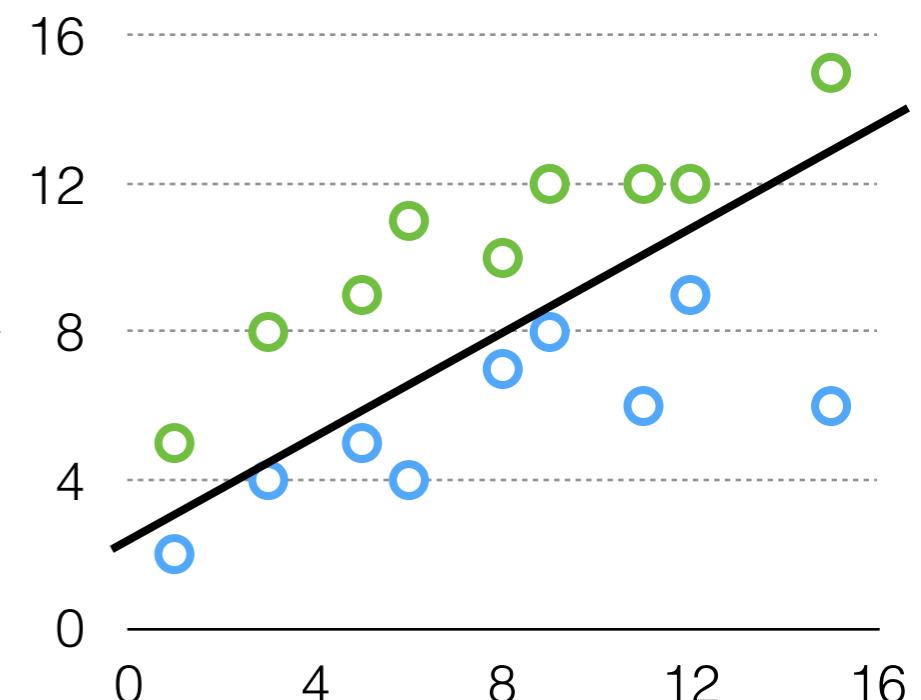


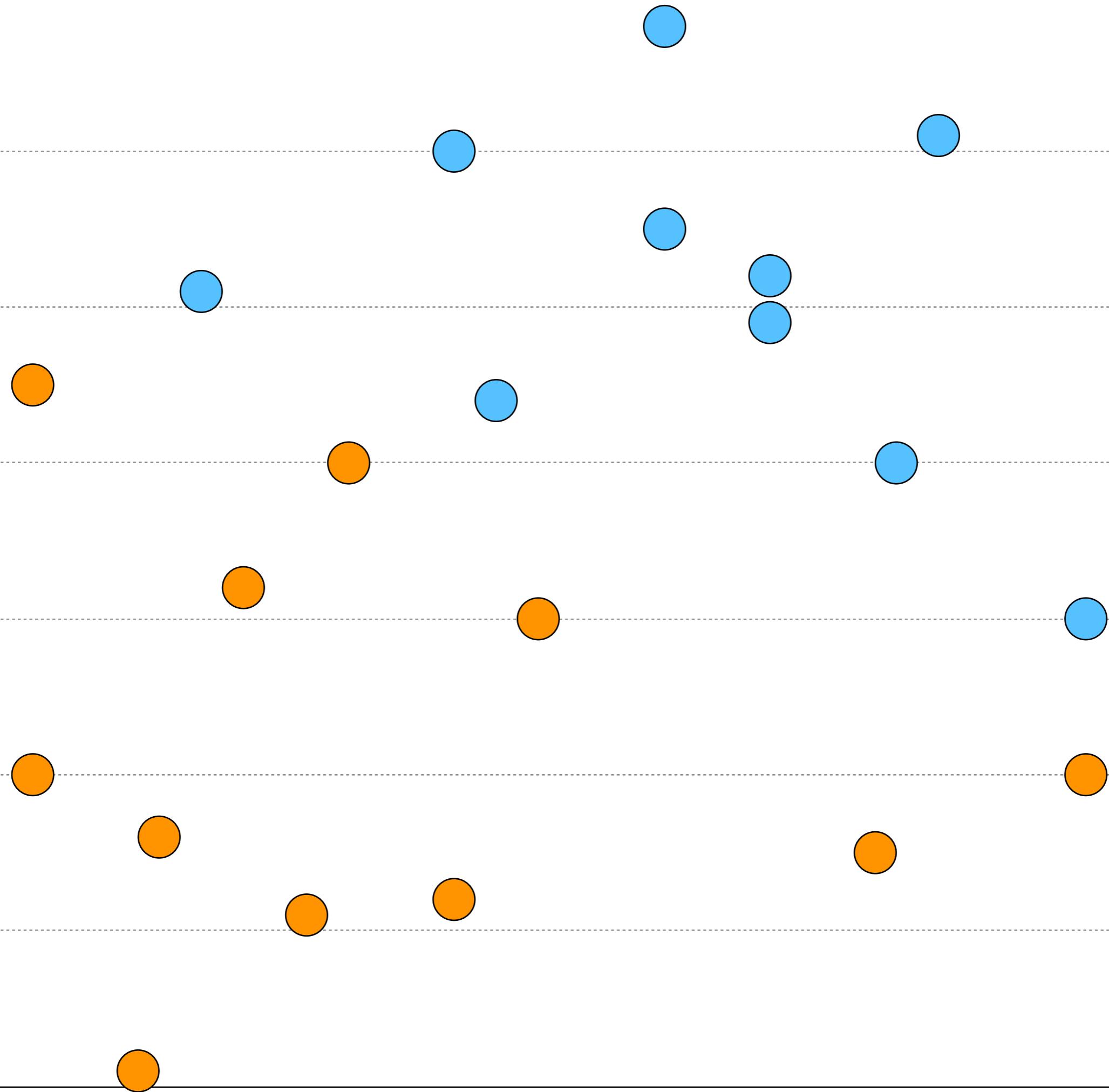
# CLASSIFICATION

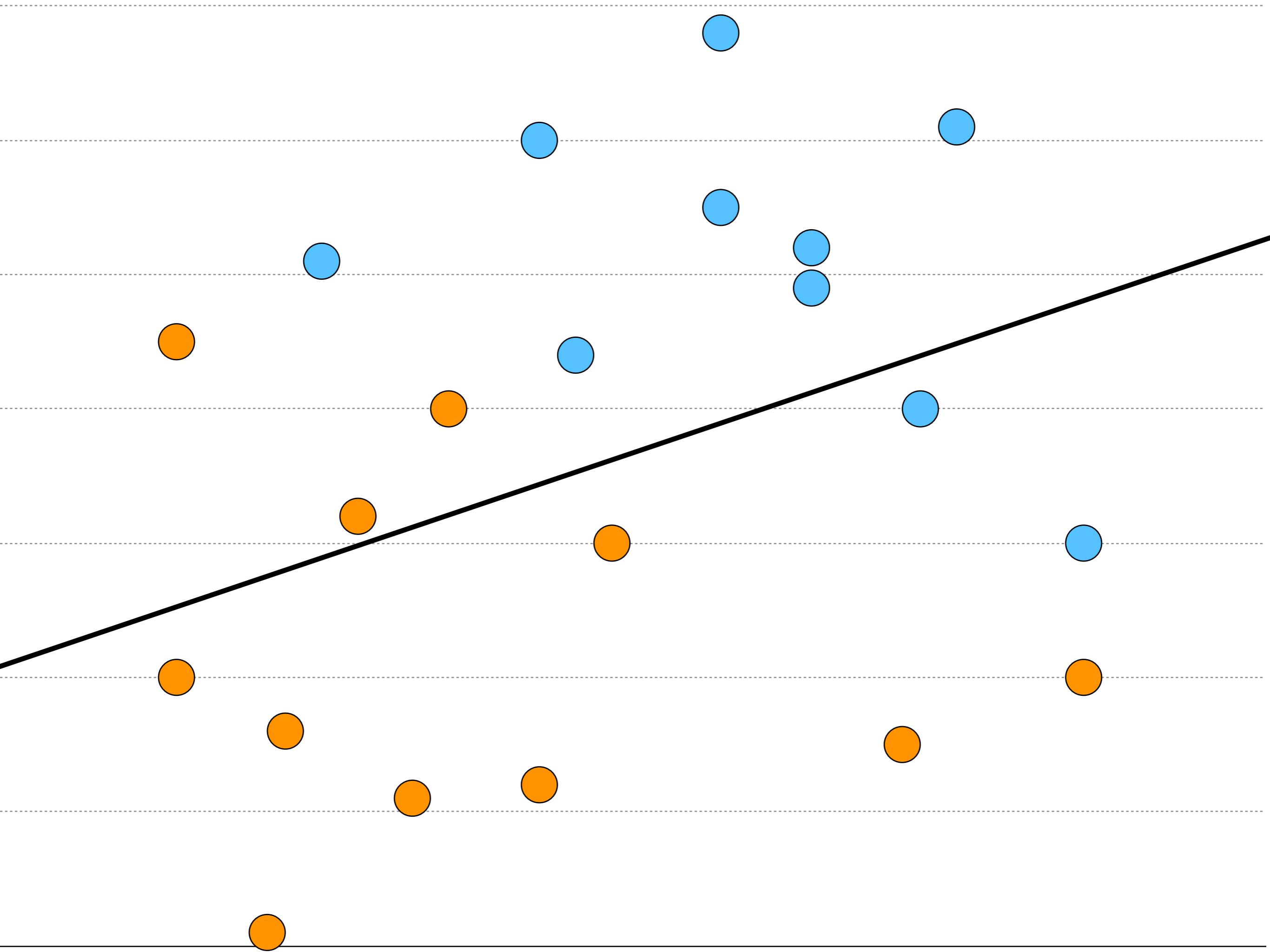
# What is a classifier?

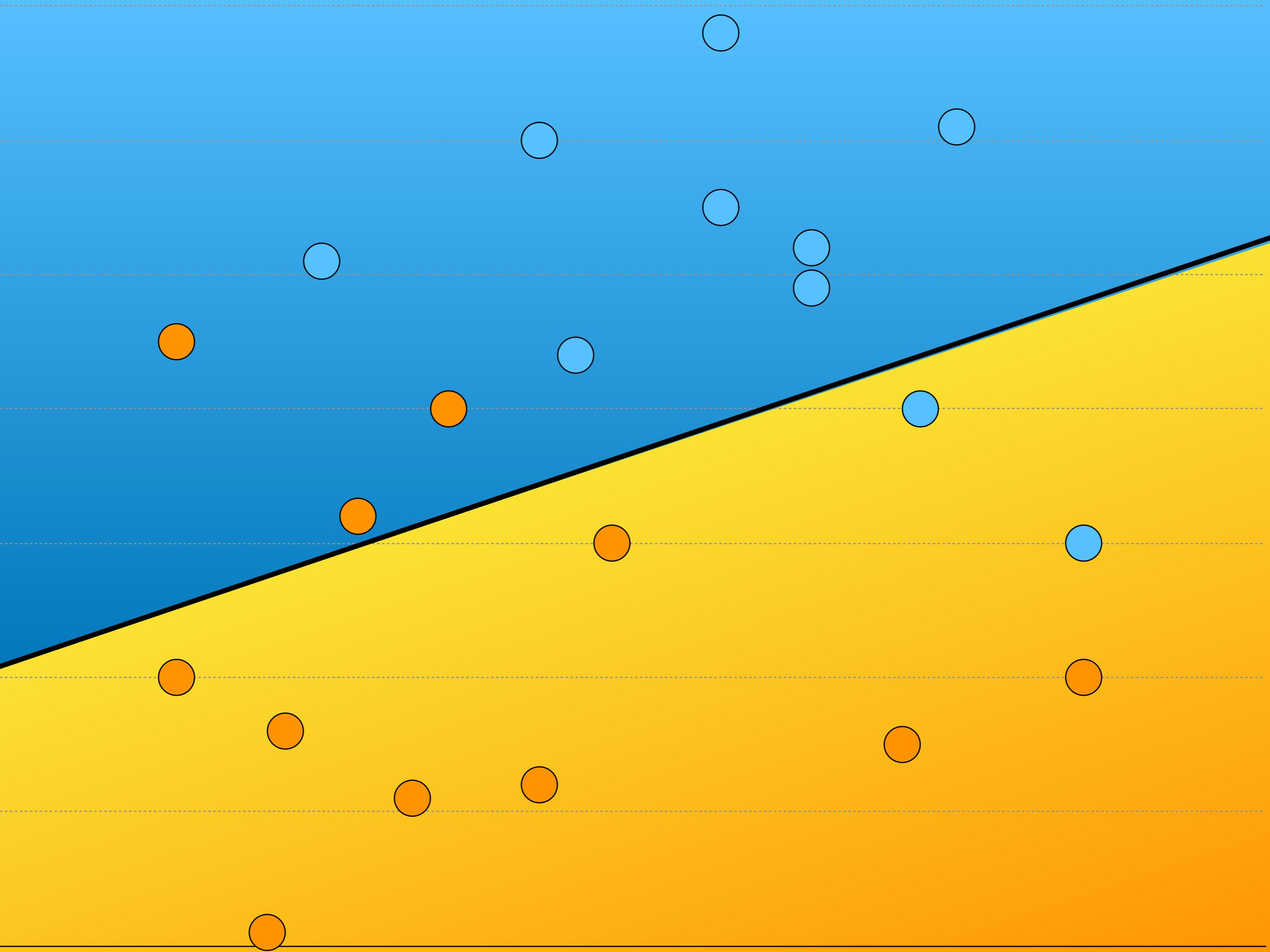


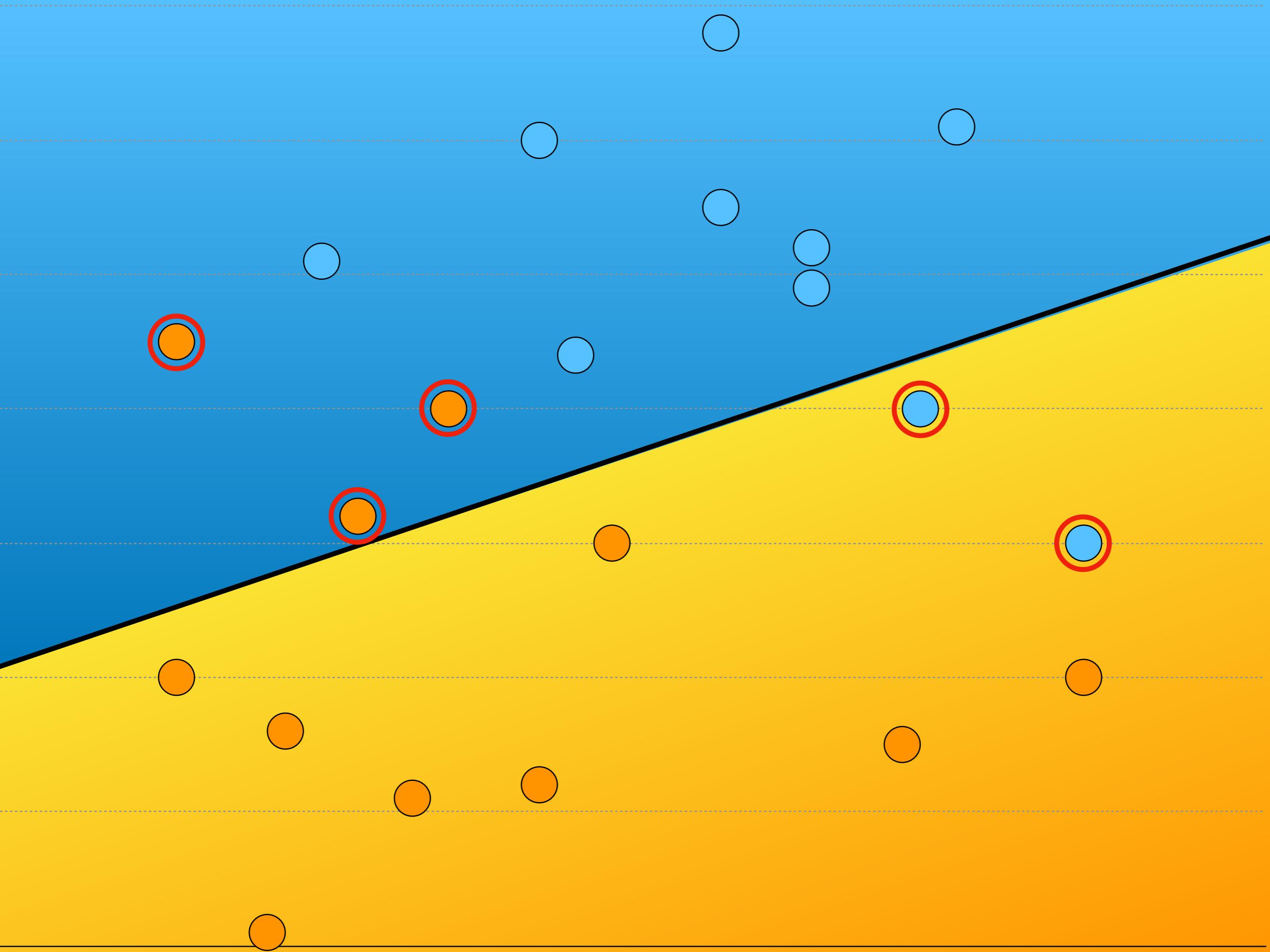
Machine  
Learning



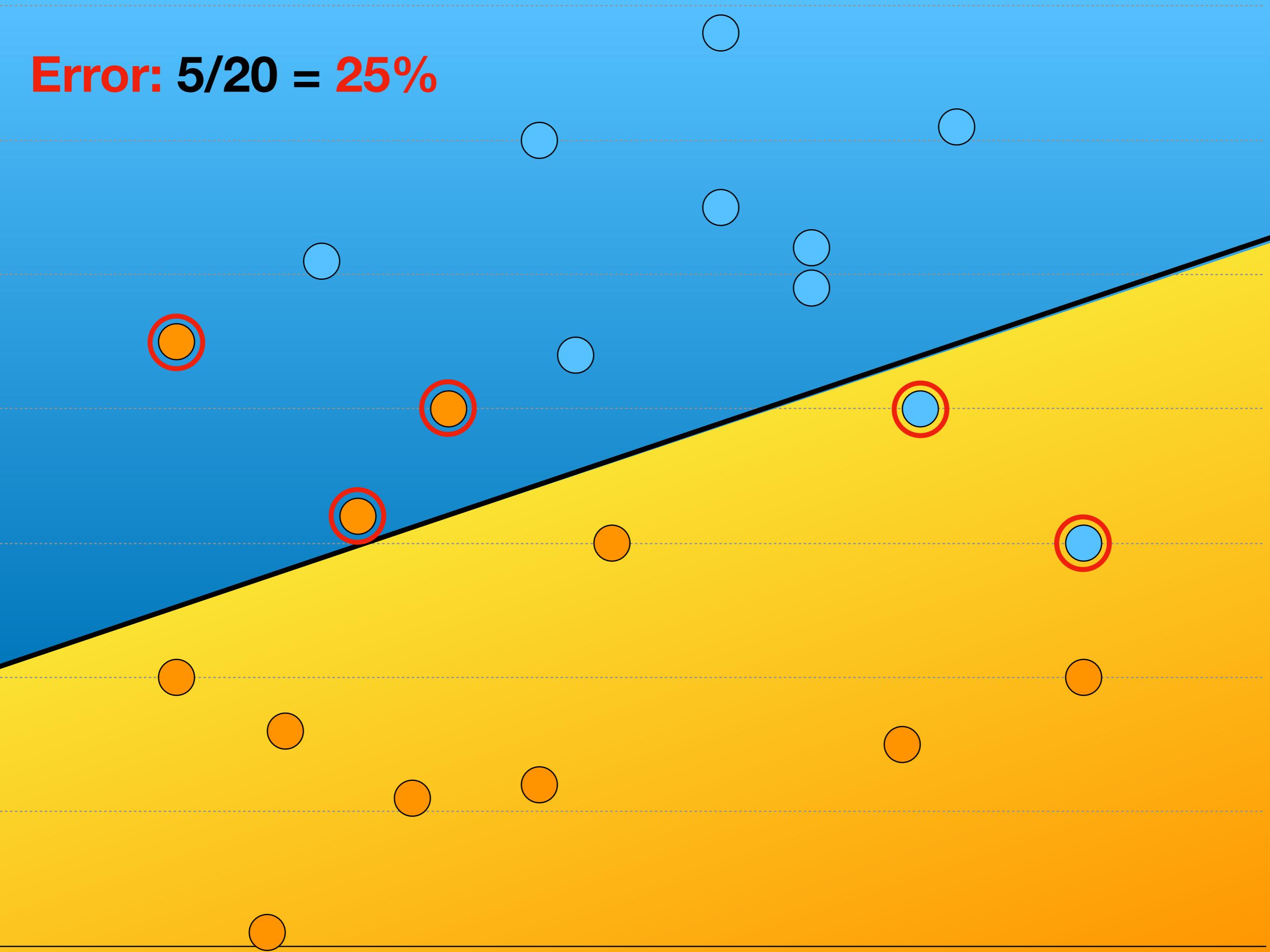


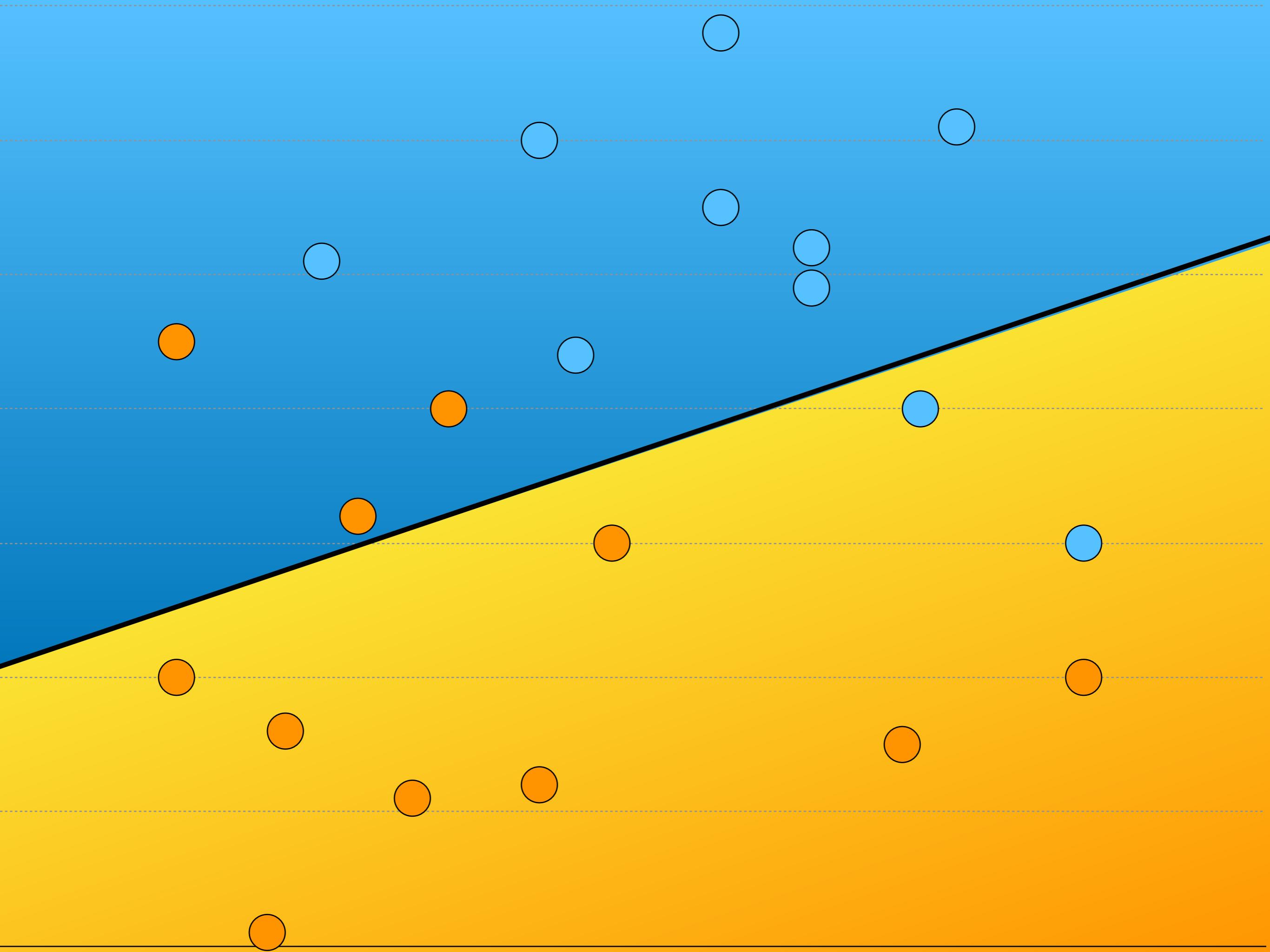


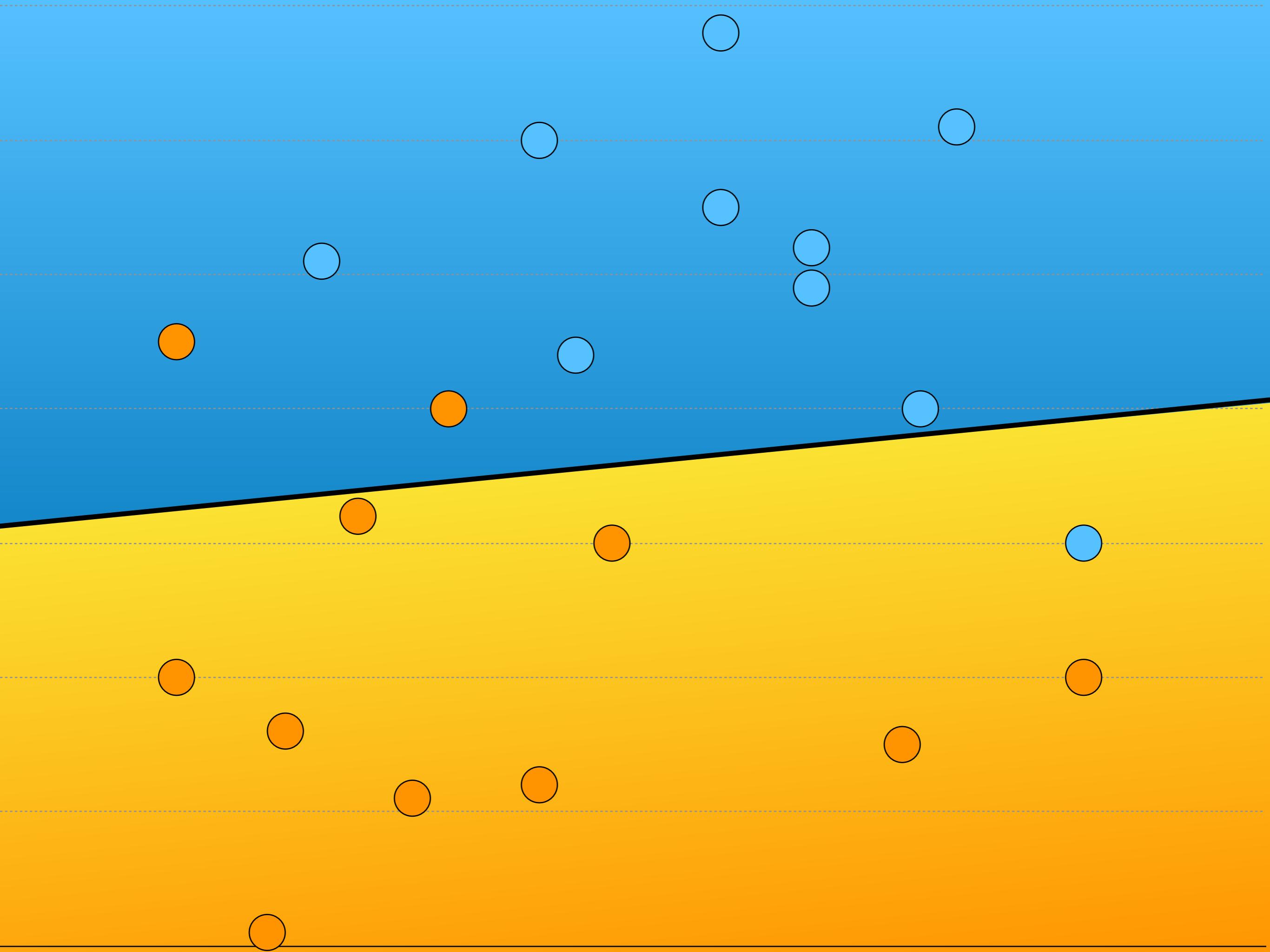


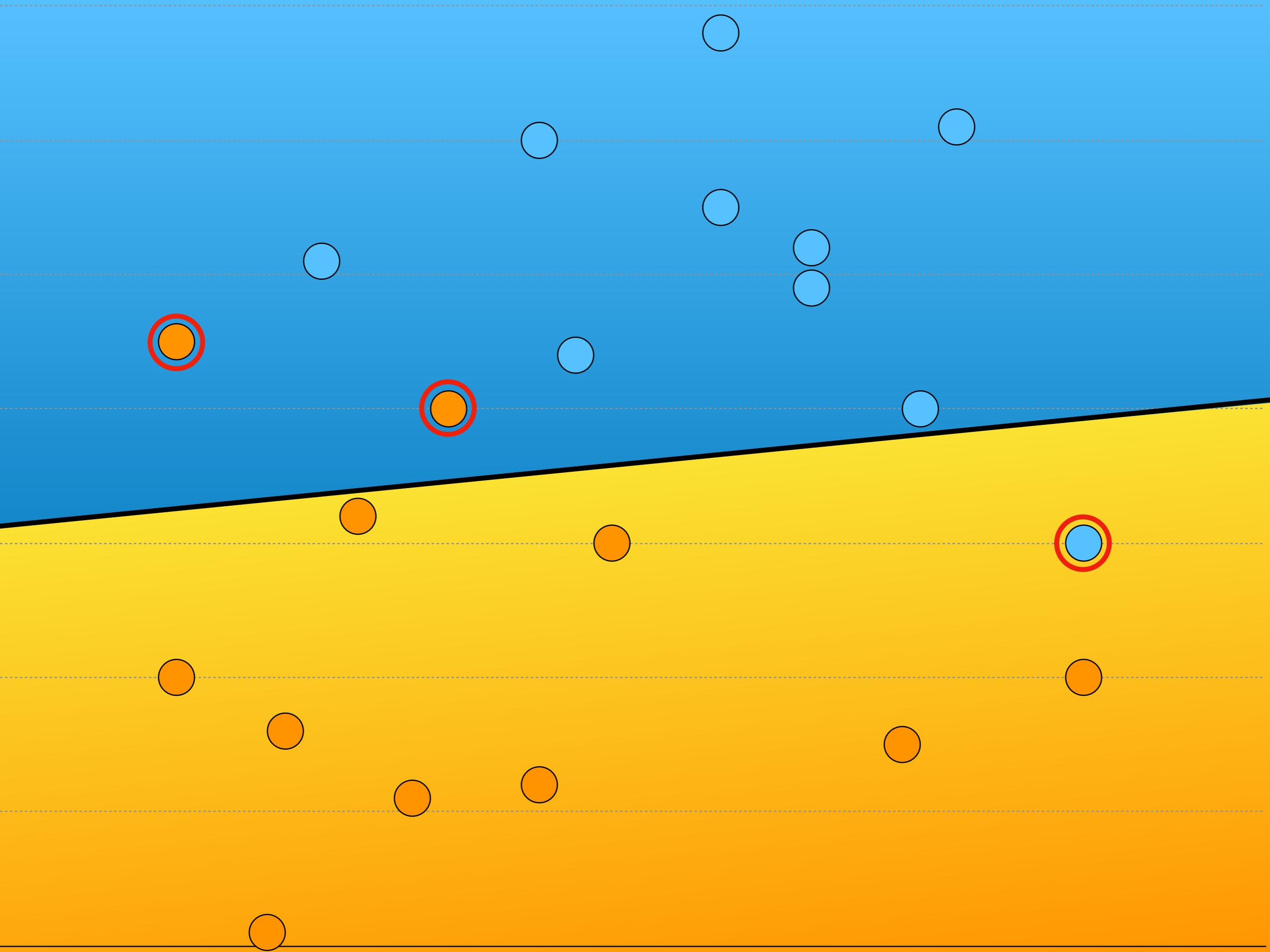


Error:  $5/20 = 25\%$

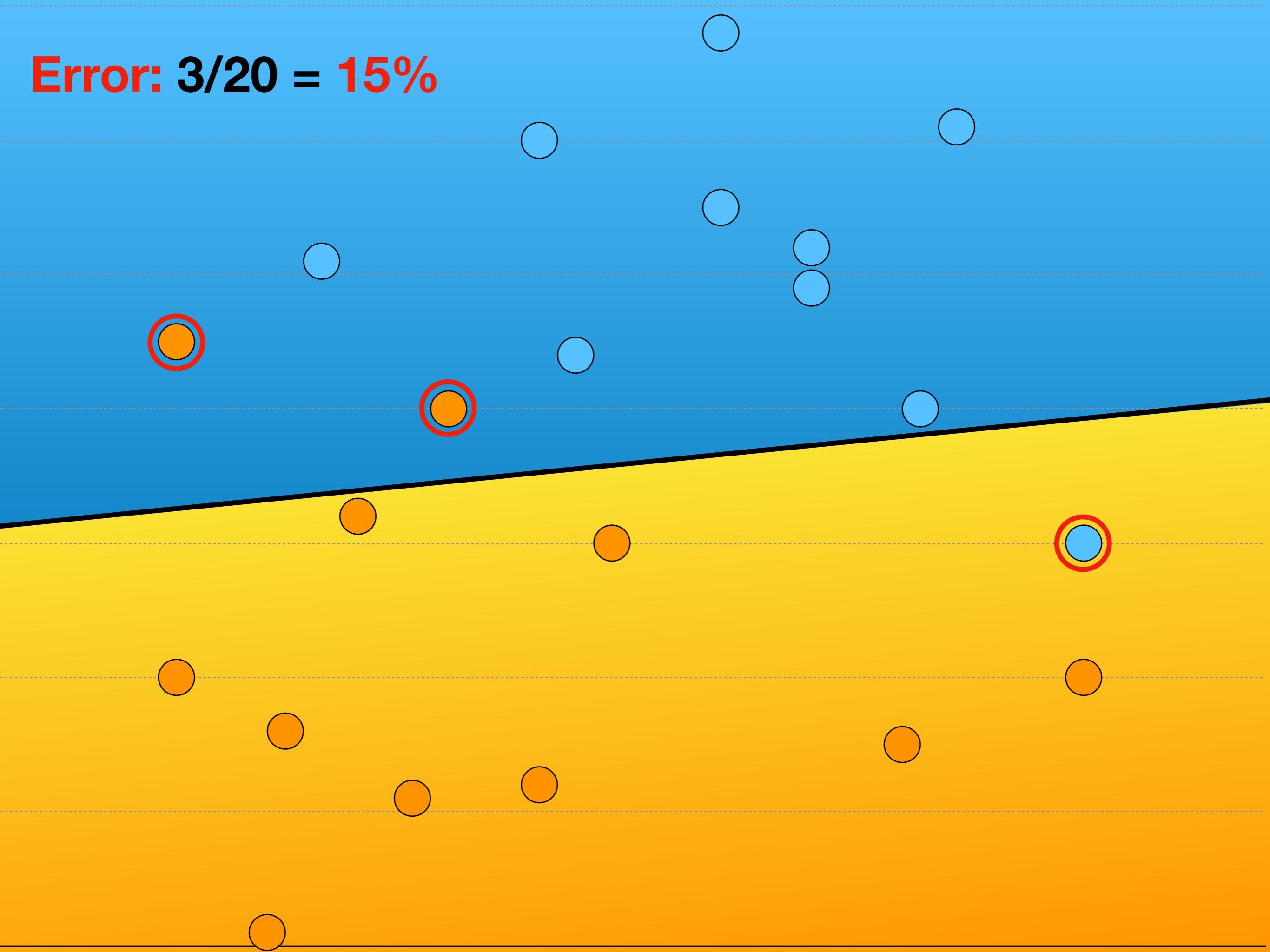


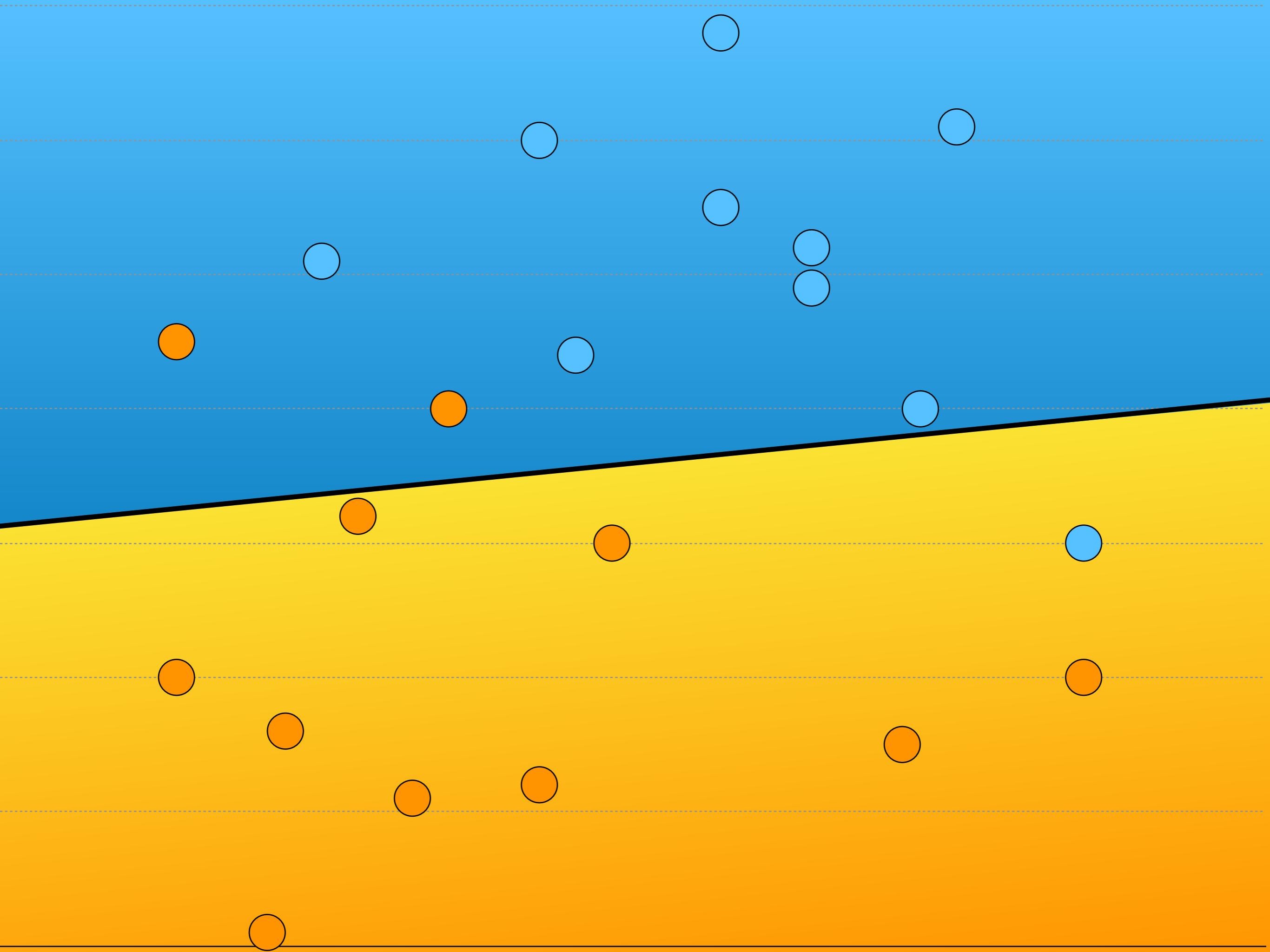


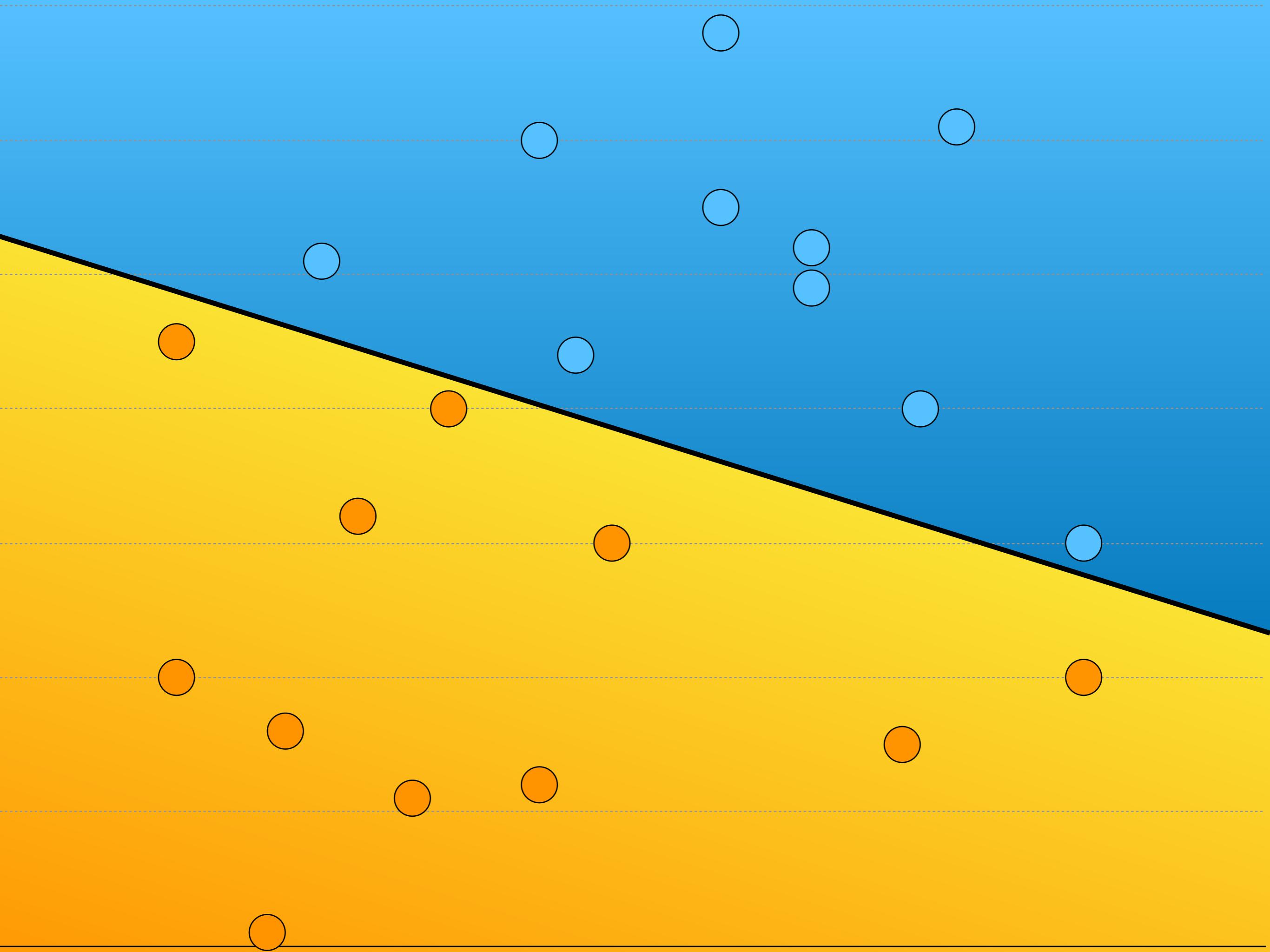




**Error:  $3/20 = 15\%$**

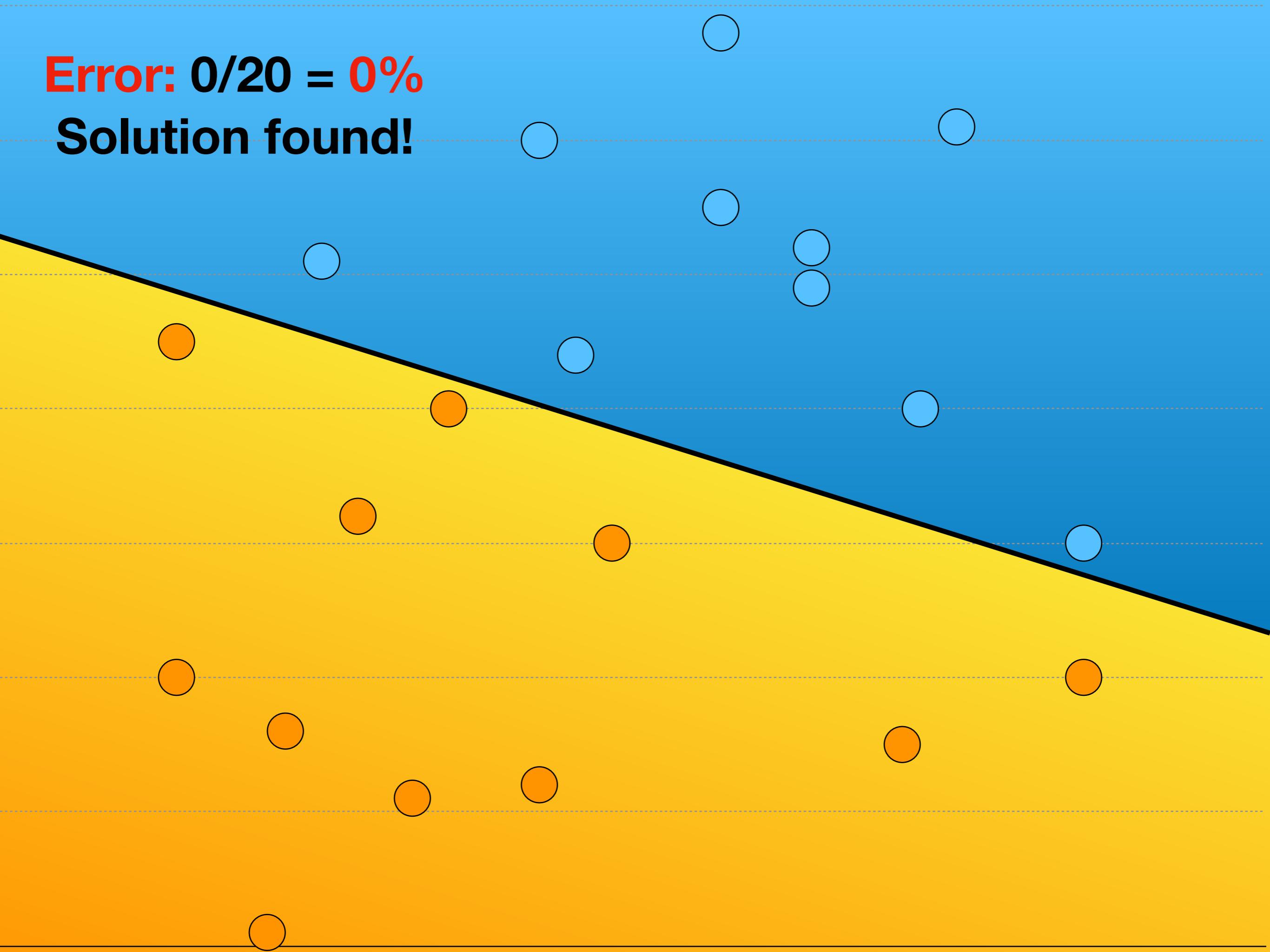






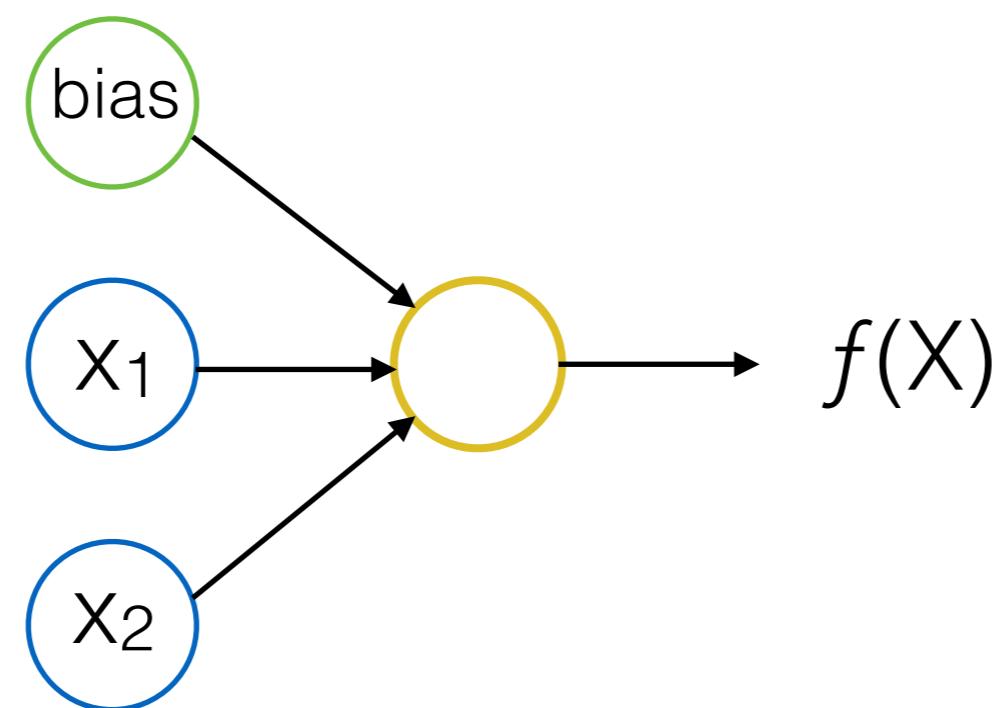
**Error: 0/20 = 0%**

**Solution found!**

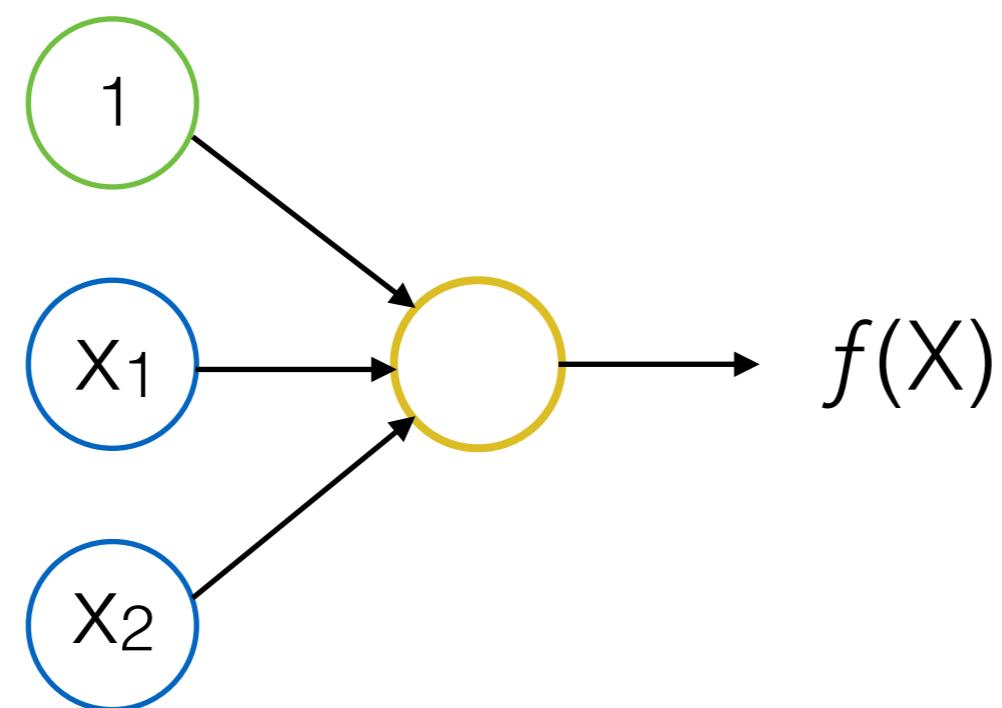


# Neural Network

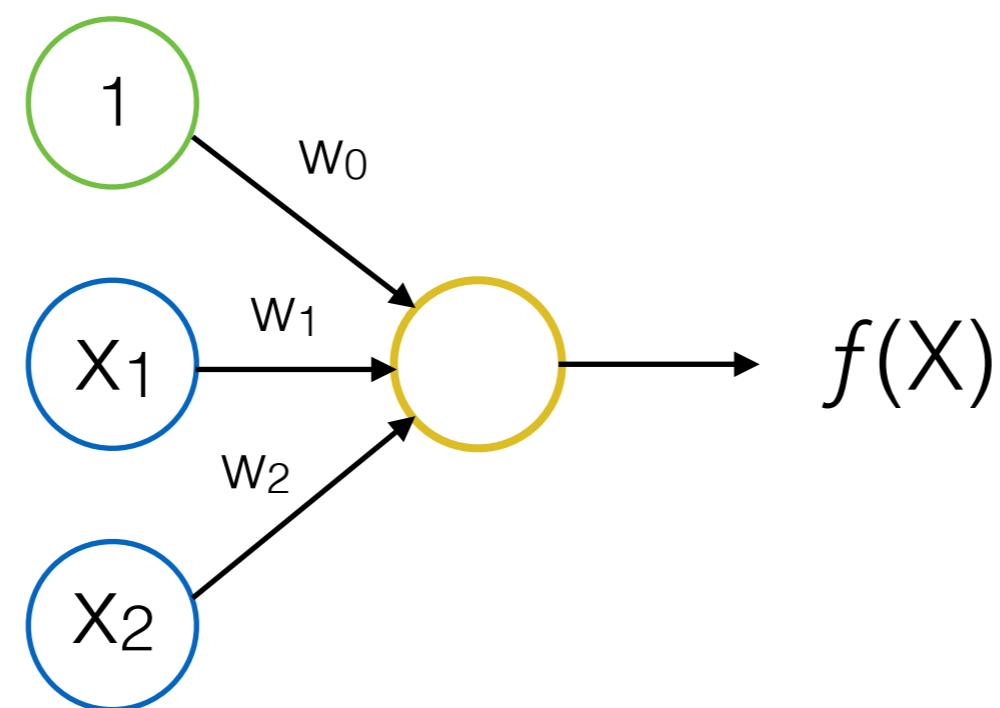
# Perceptron



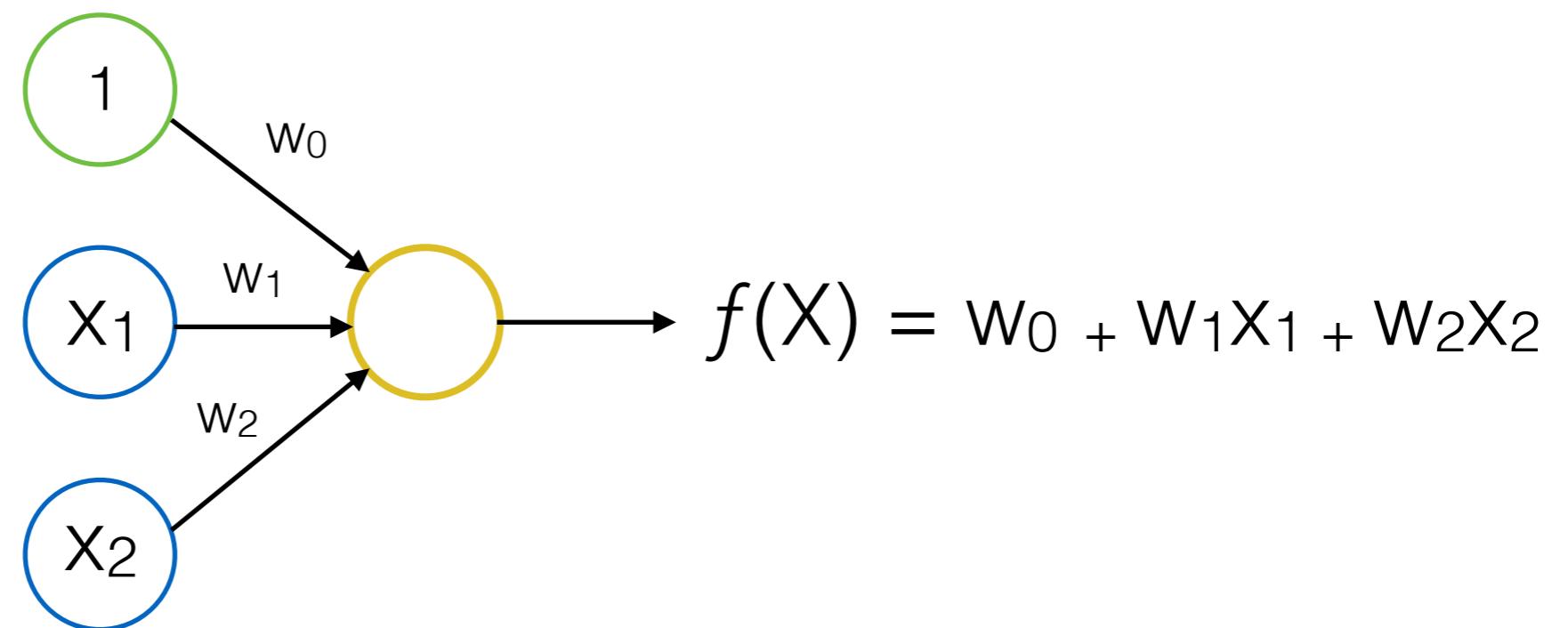
# Perceptron



# Perceptron

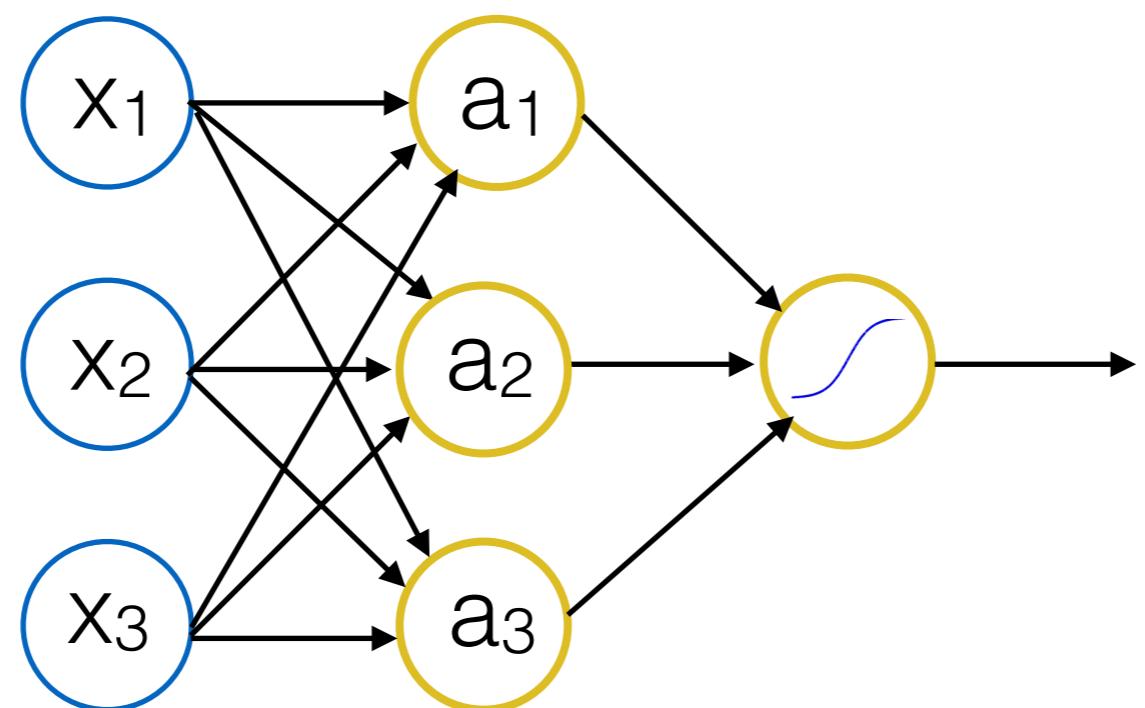


# Perceptron

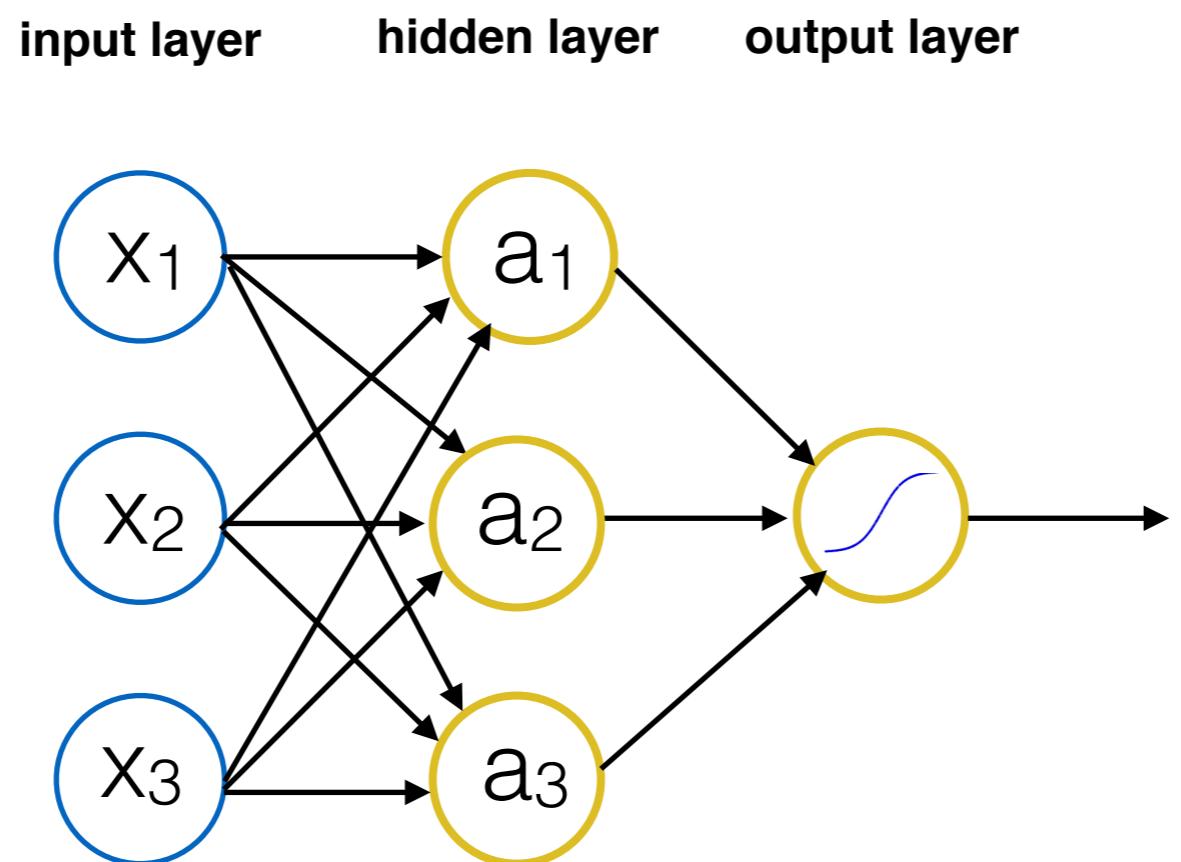


# Neural Network

(feed forward network)



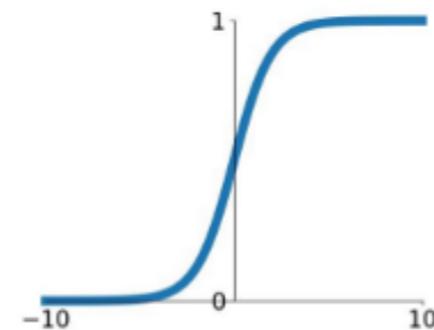
# Multi-Layer Perceptron (MLP)



# Activation Functions

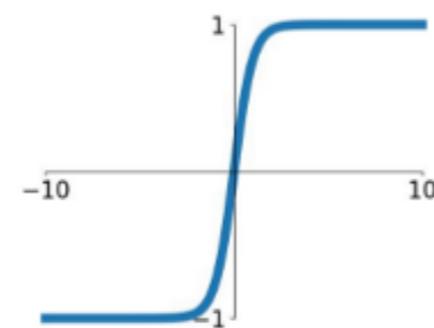
## Sigmoid

$$\sigma(x) = \frac{1}{1+e^{-x}}$$



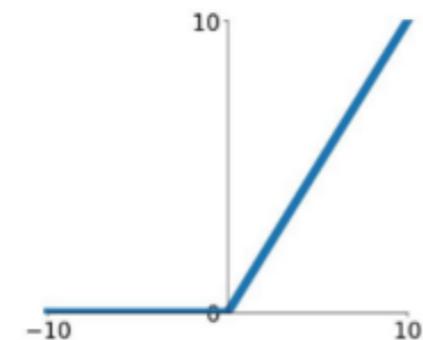
## tanh

$$\tanh(x)$$



## ReLU

$$\max(0, x)$$



# Job Interview

Gender	Years Exp.	Phone Screen	On-site Interview
F	3	9	Yes
M	2	7.5	No
M	2	7	No
M	4	8.5	Yes
F	4	9.5	Yes
F	2	6.5	No
M	3	8	No
F	2	8	No
F	4	9	Yes

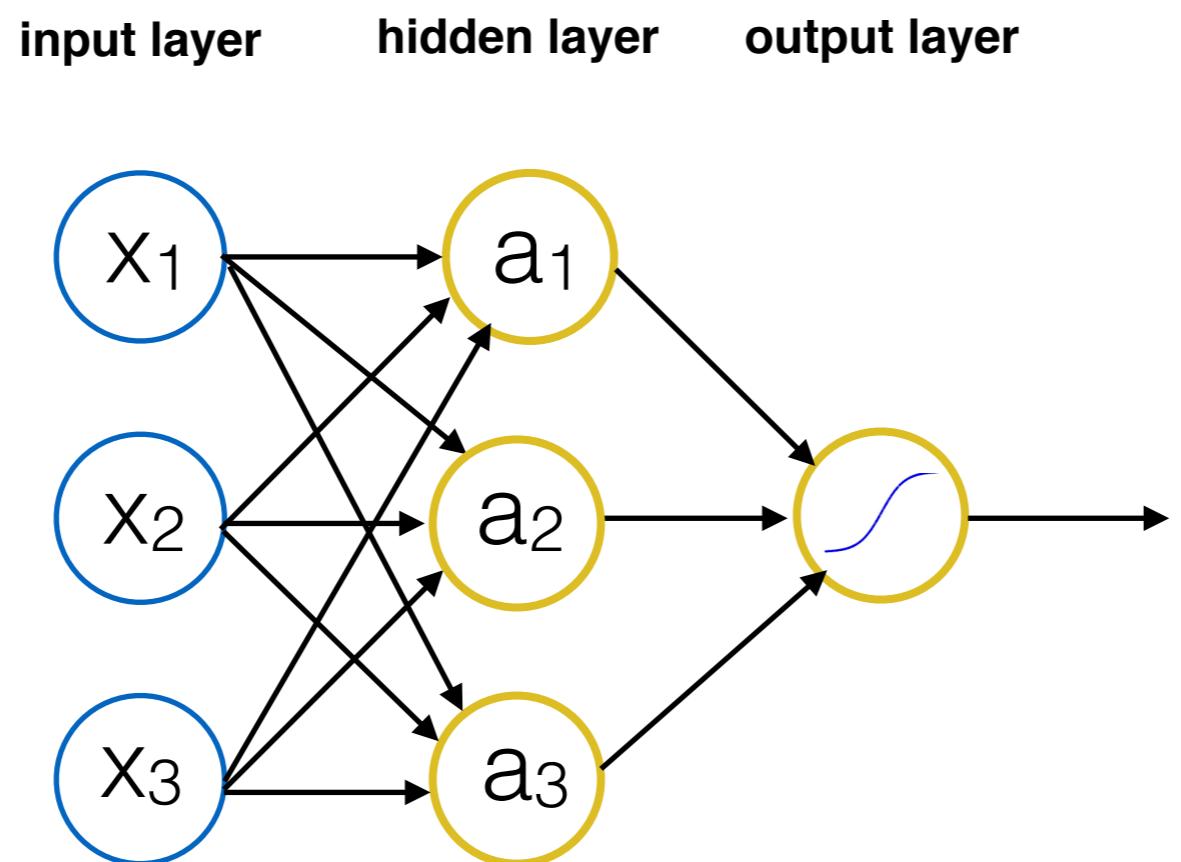
# Job Interview

features → (X)	Gender	Years Exp.	Phone Screen	On-site Interview
	F	3	9	Yes
	M	2	7.5	No
	M	2	7	No
	M	4	8.5	Yes
	F	4	9.5	Yes
	F	2	6.5	No
	M	3	8	No
	F	2	8	No
	F	4	9	Yes

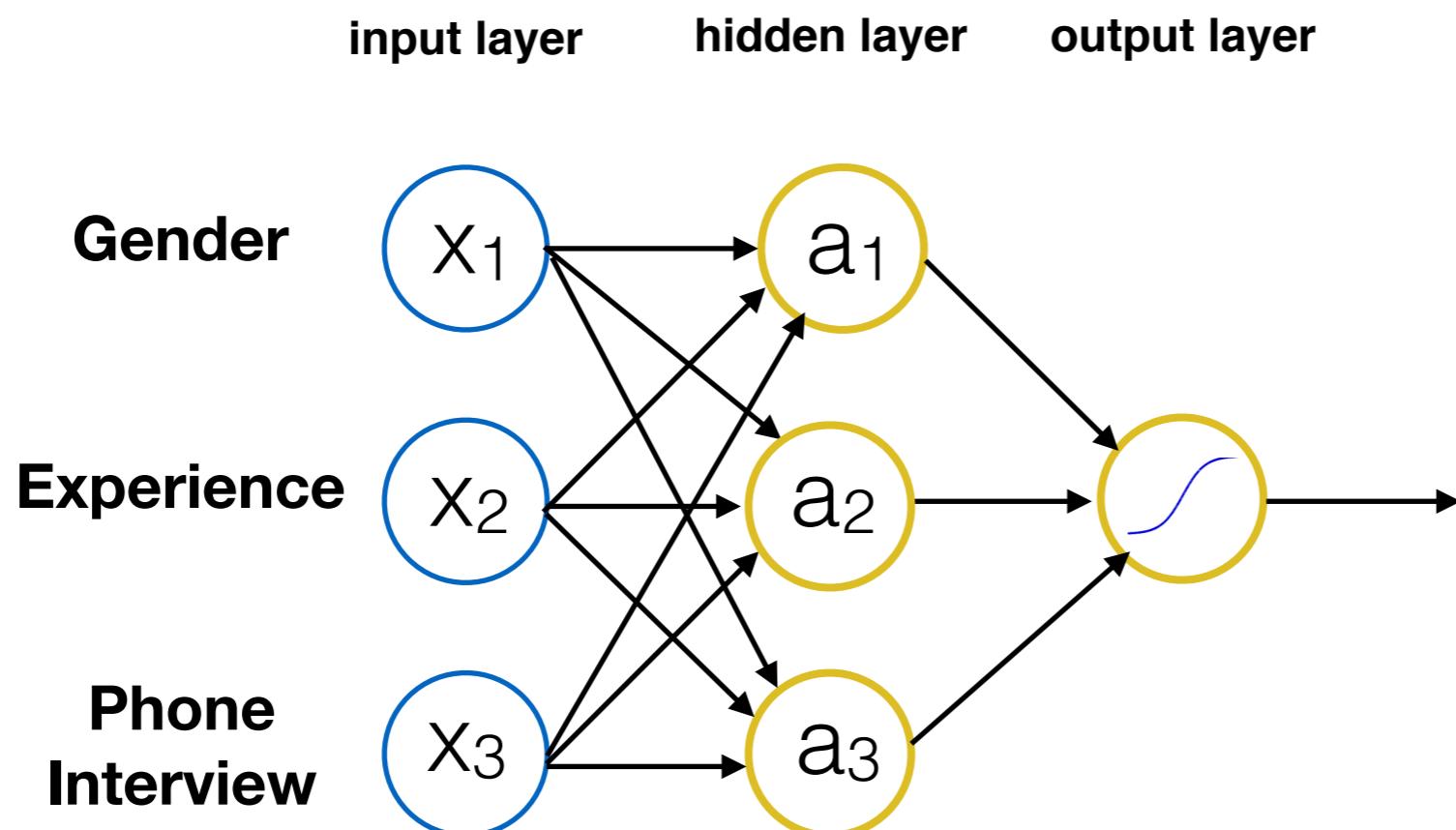
# Job Interview

Gender	Years Exp.	Phone Screen	On-site Interview	← target (y)
F	3	9	Yes	
M	2	7.5	No	
M	2	7	No	
M	4	8.5	Yes	
F	4	9.5	Yes	
F	2	6.5	No	
M	3	8	No	
F	2	8	No	
F	4	9	Yes	

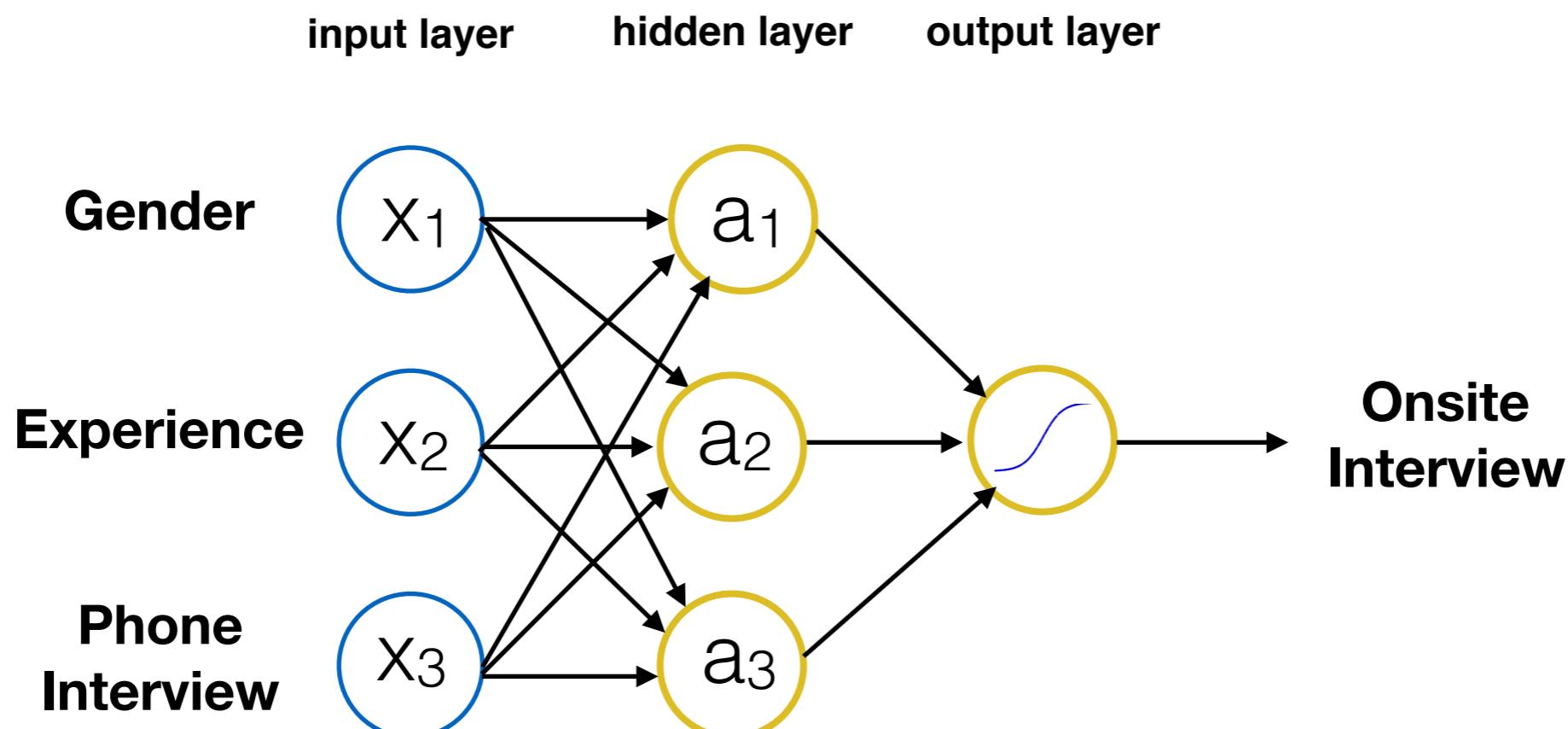
# Multi-Layer Perceptron (MLP)



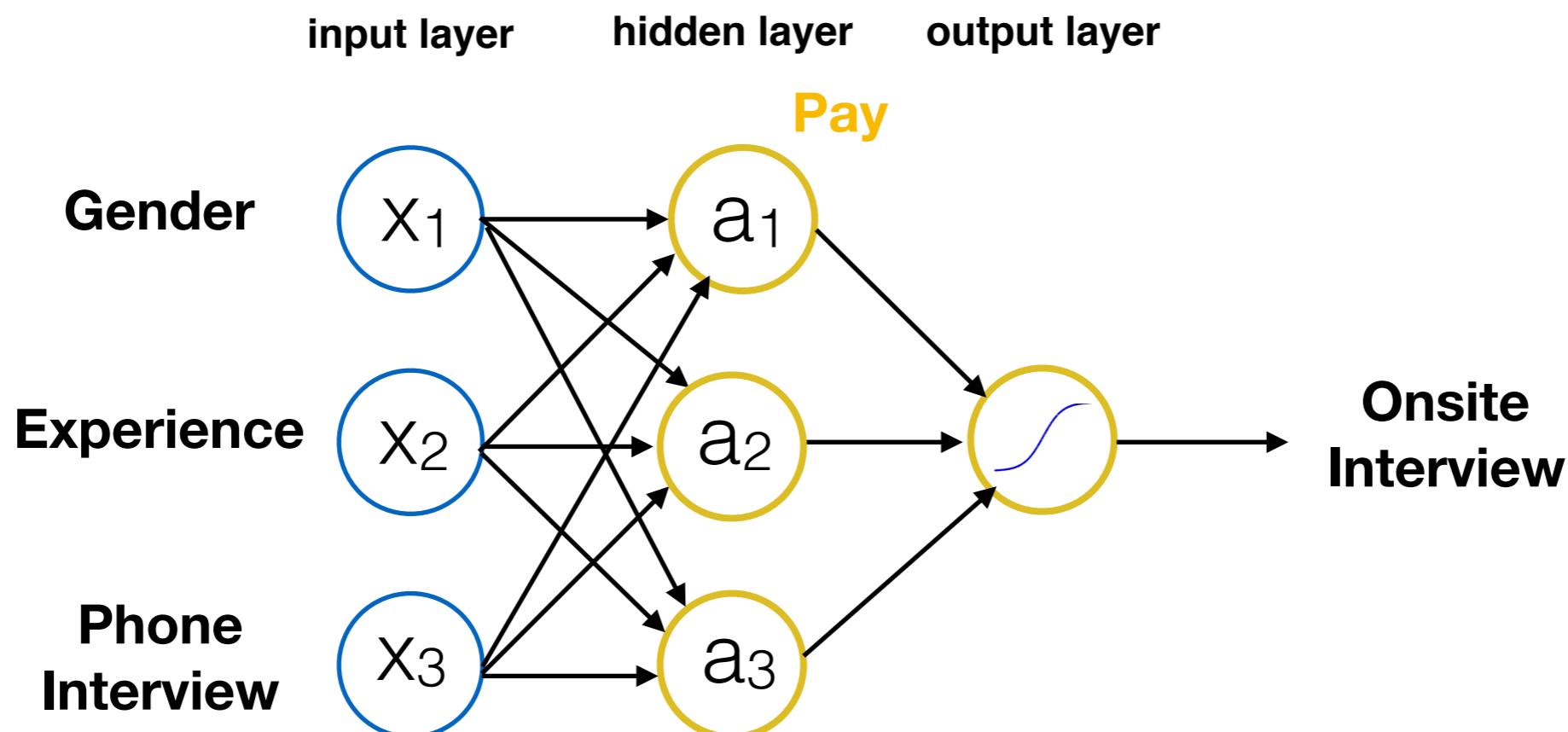
# Multi-Layer Perceptron (MLP)



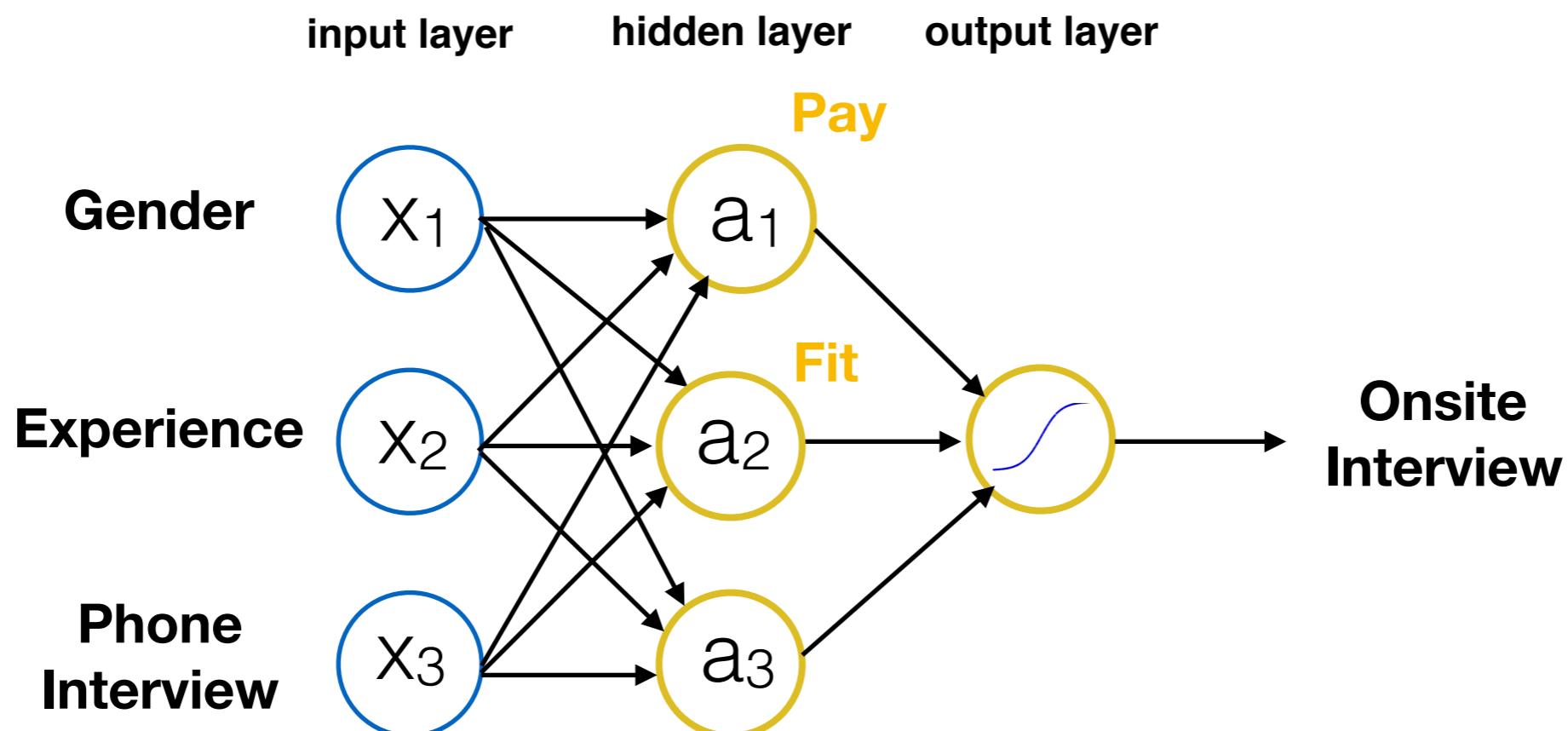
# Multi-Layer Perceptron (MLP)



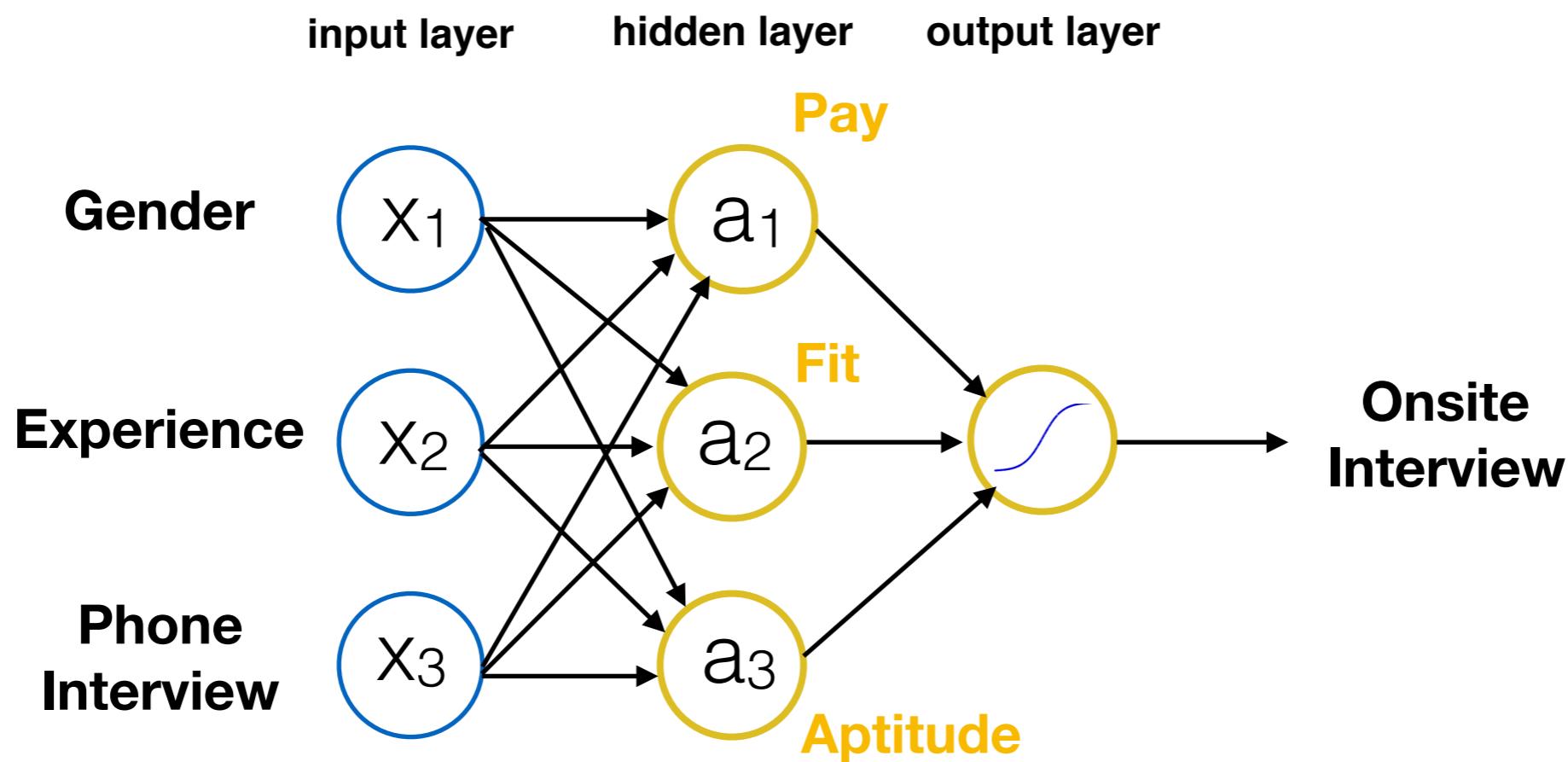
# Multi-Layer Perceptron (MLP)



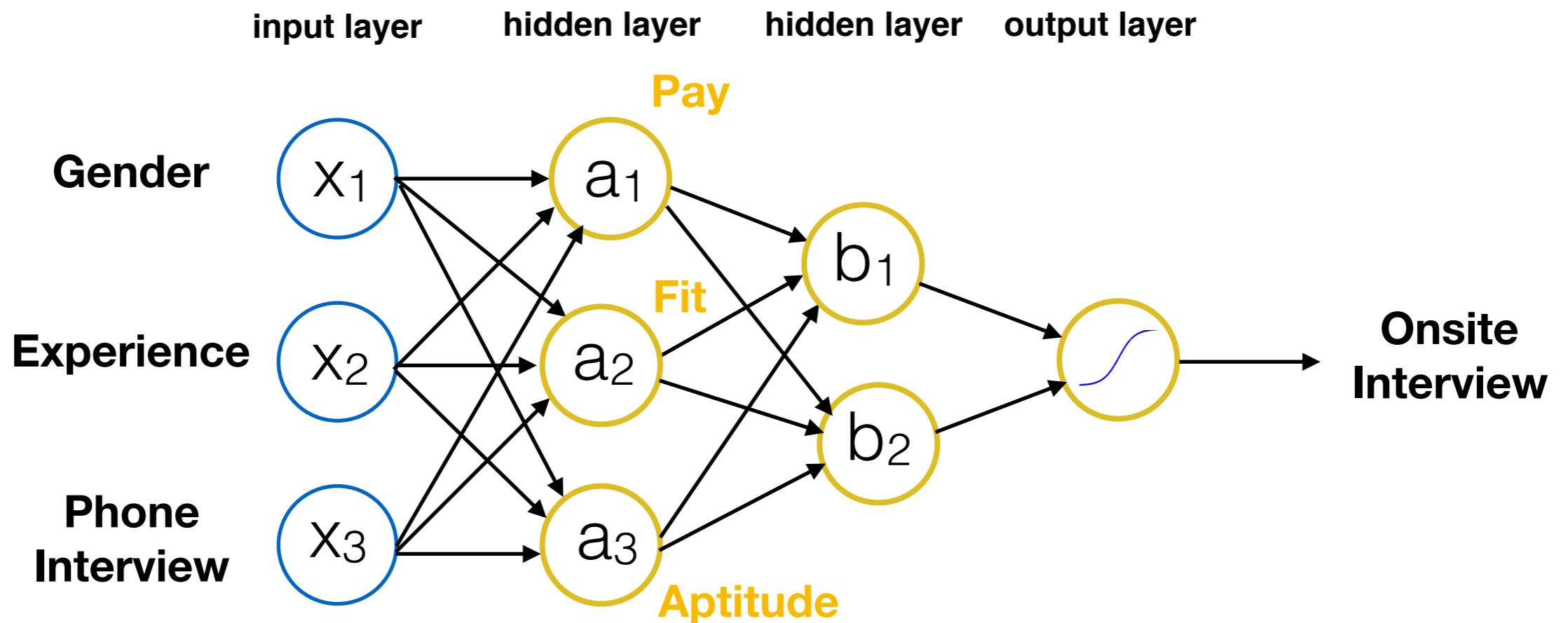
# Multi-Layer Perceptron (MLP)



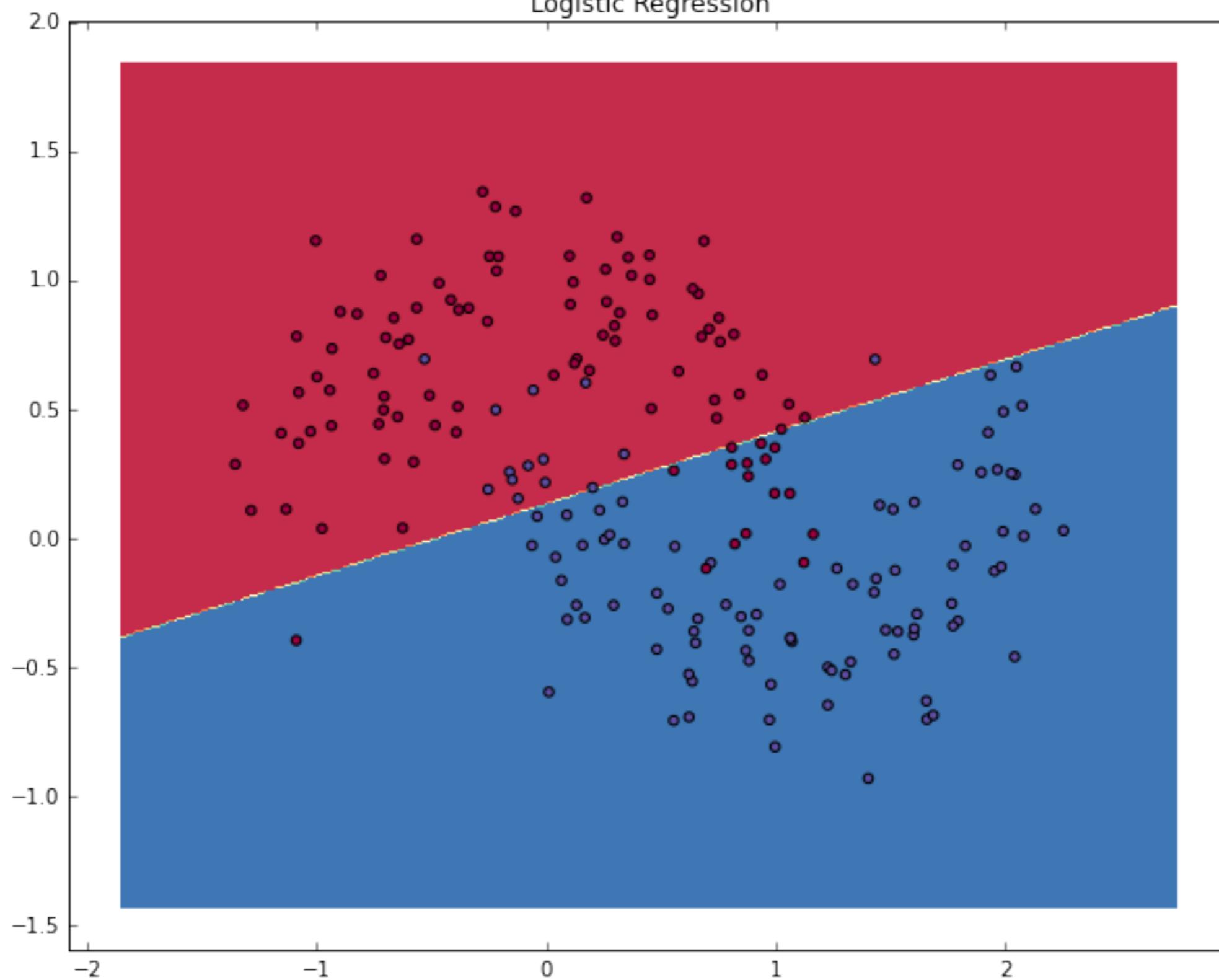
# Multi-Layer Perceptron (MLP)



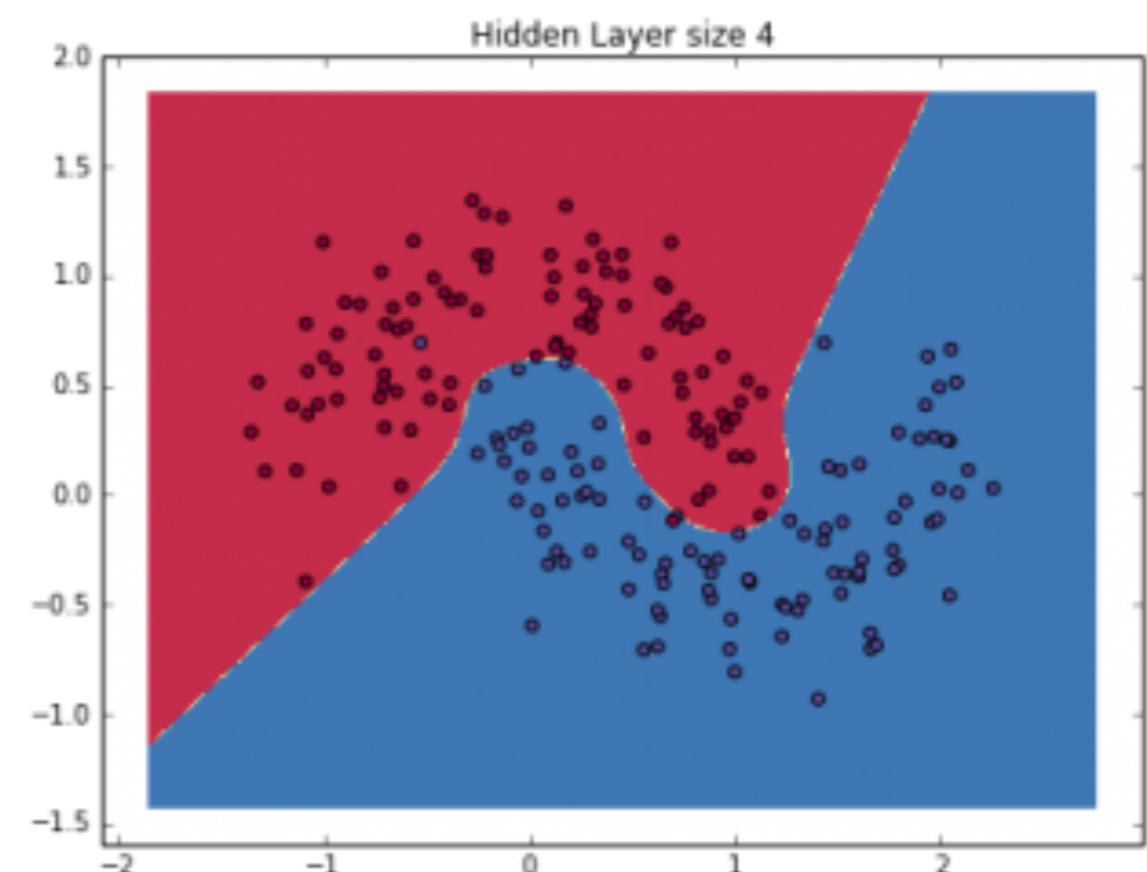
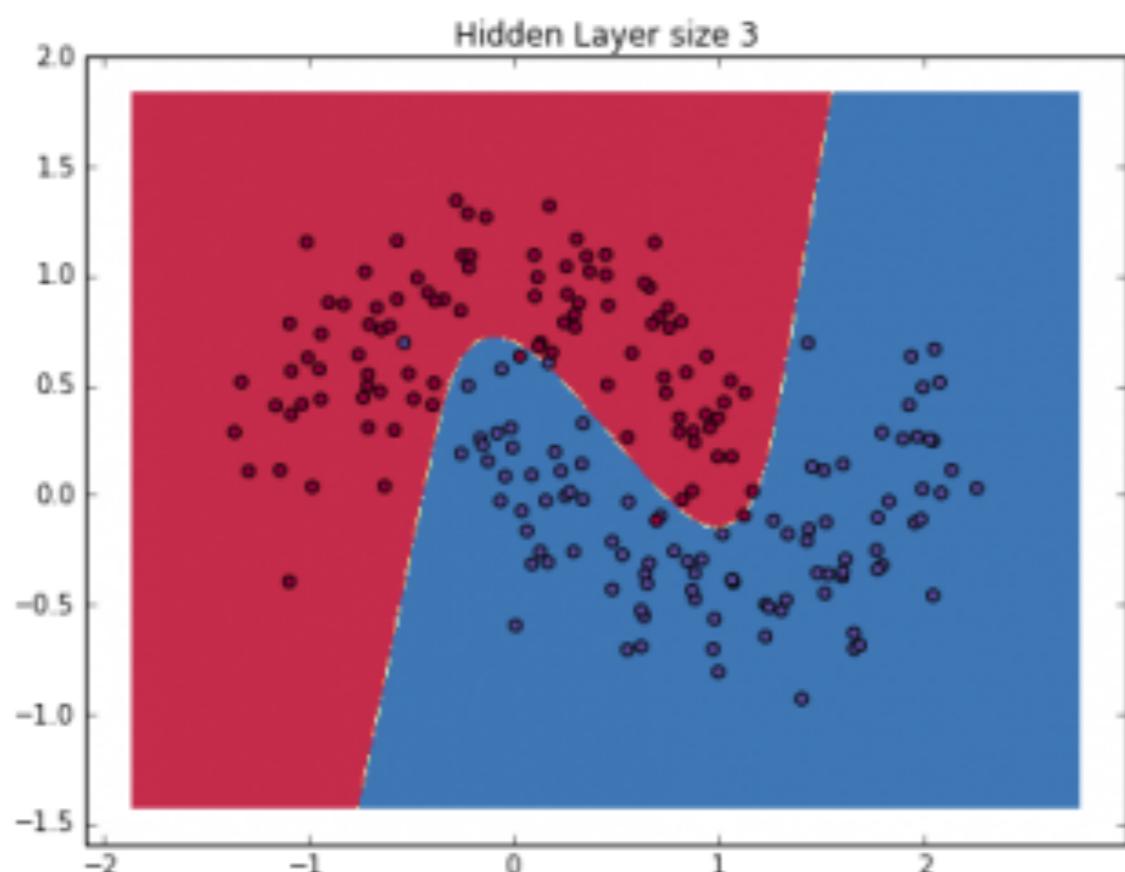
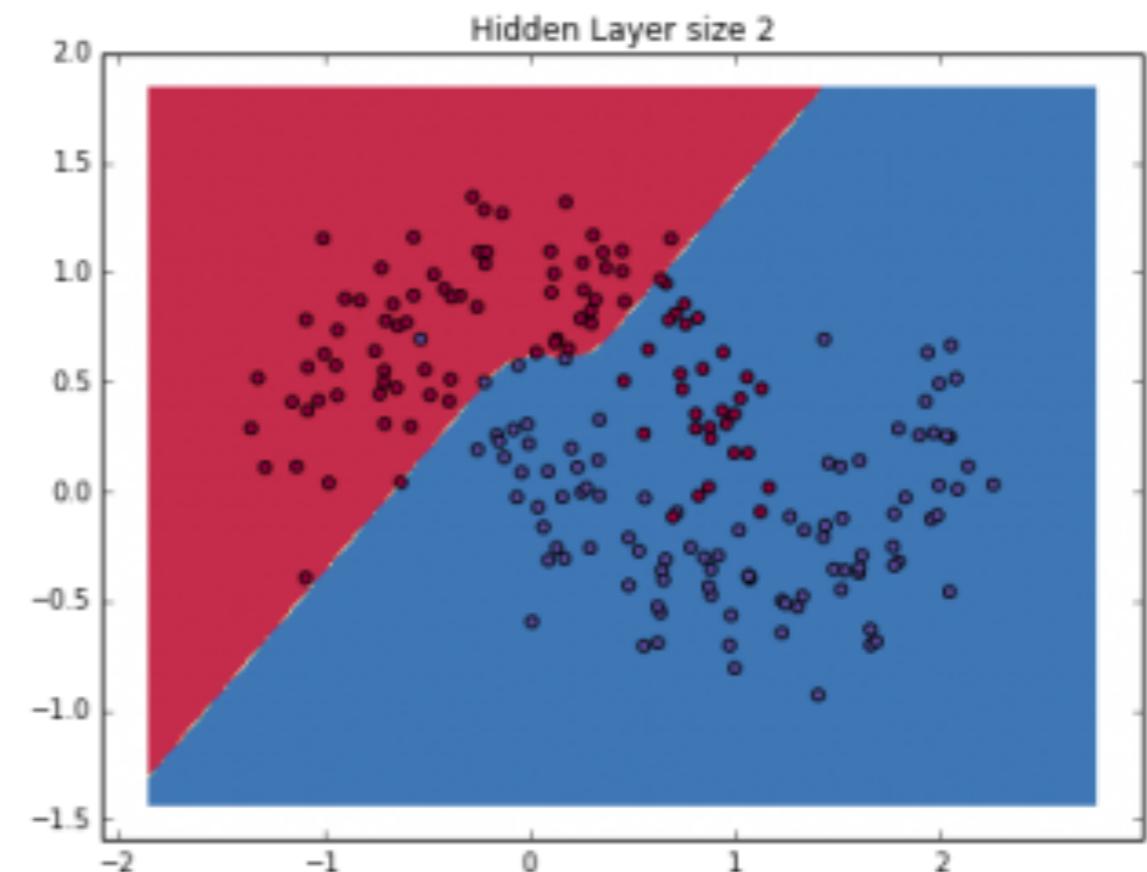
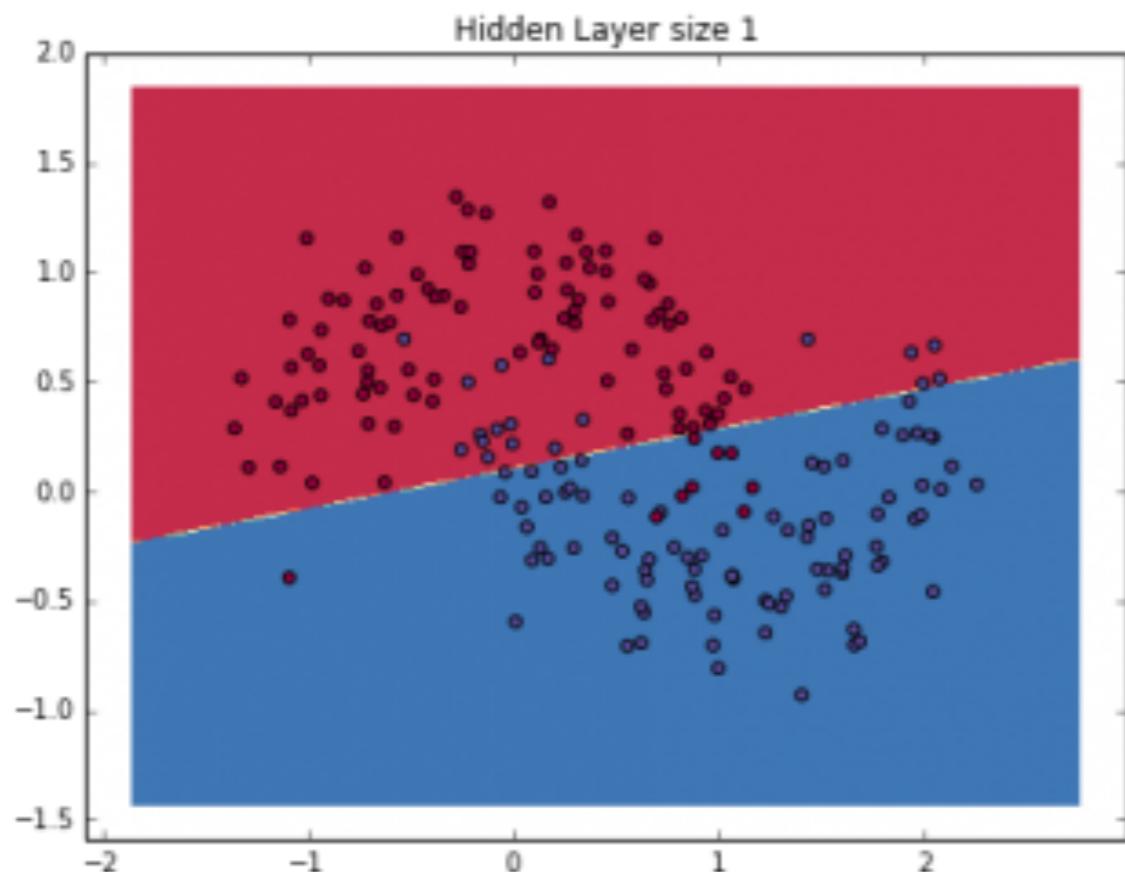
# Multi-Layer Perceptron (MLP)



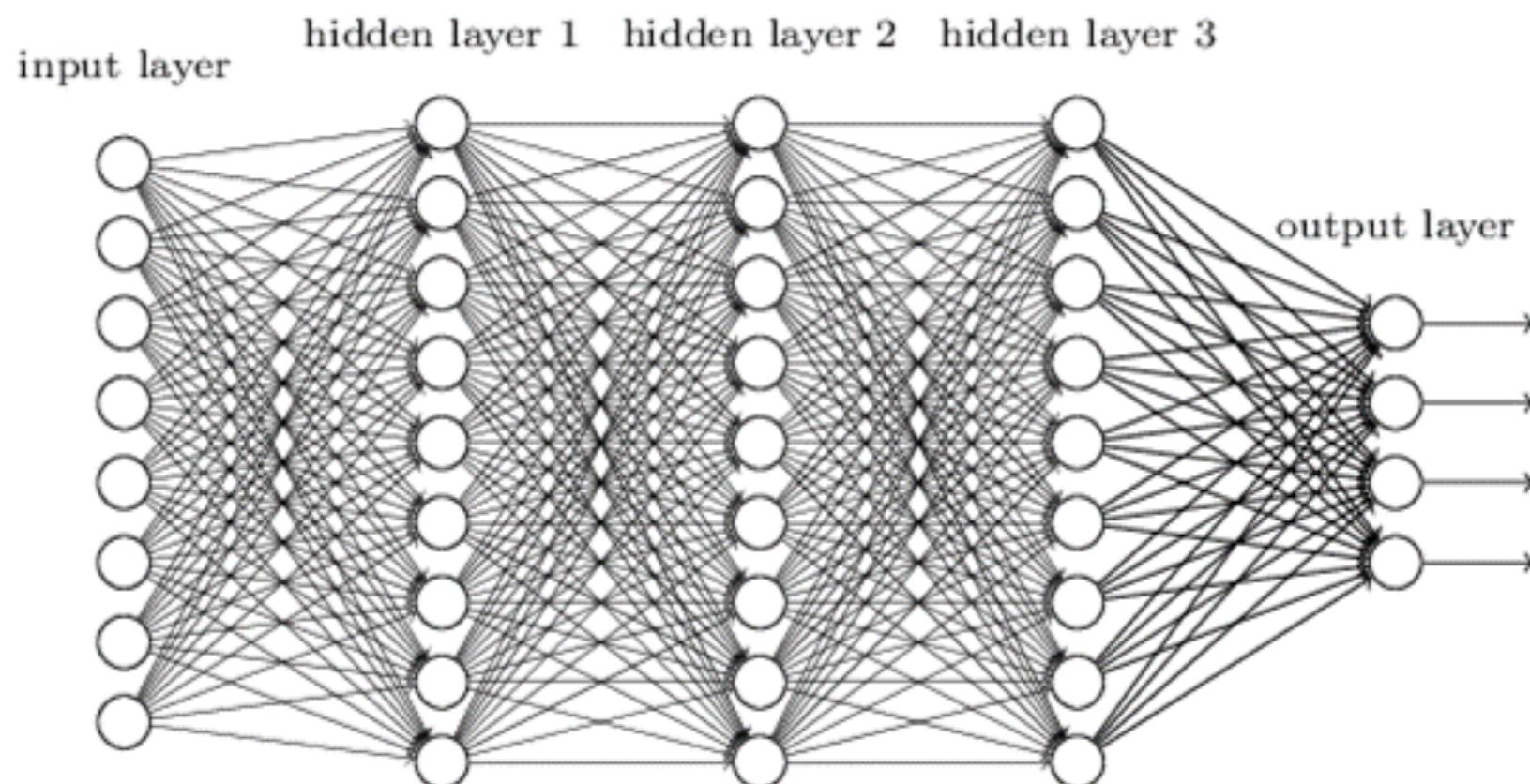
### Logistic Regression

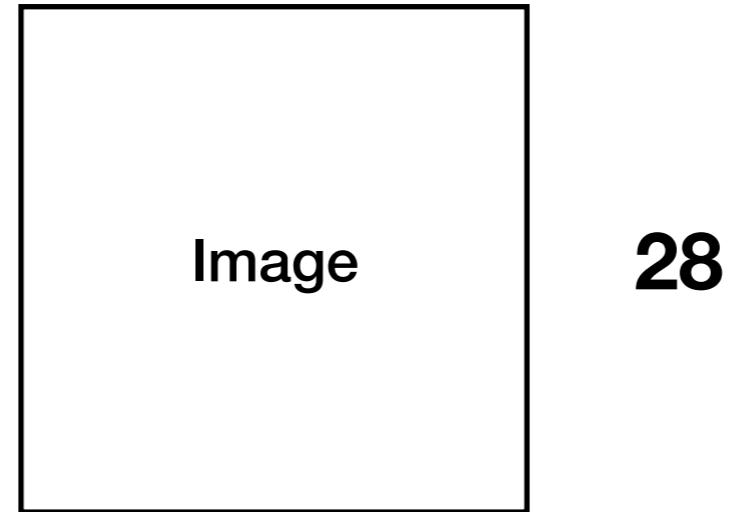


# Neural Network



# Deep Neural Network



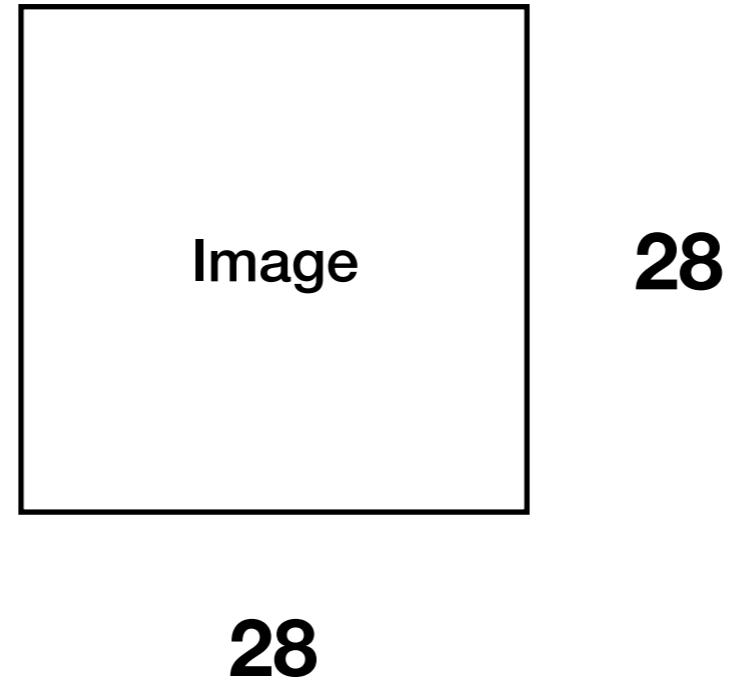


**28**

**28**

**Input Layer**

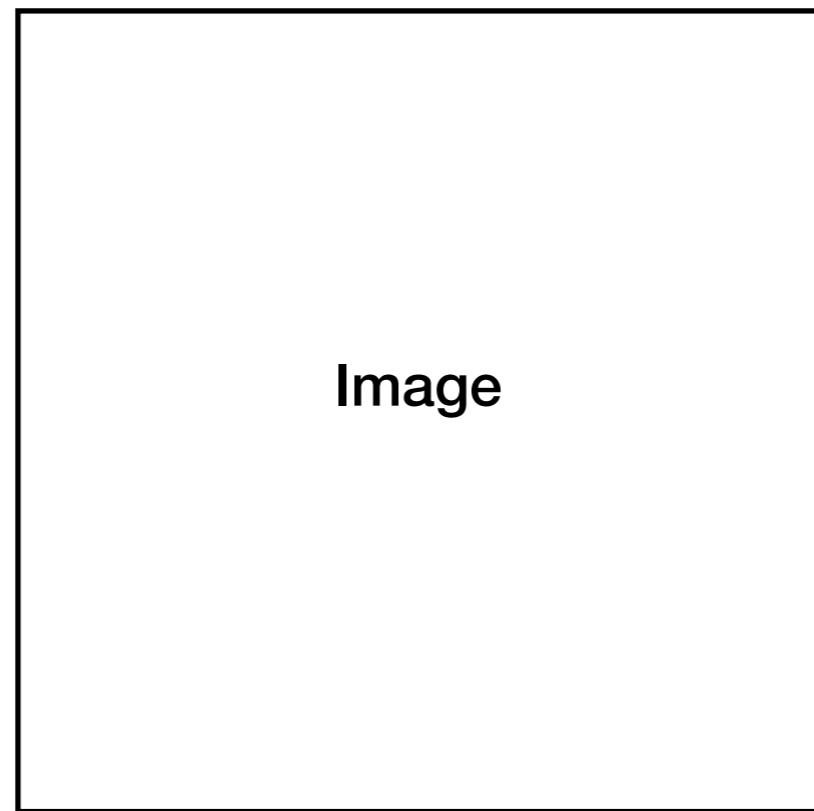
**28 x 28 features**



**28**

## Input Layer

**$28 \times 28 = 784$  features**

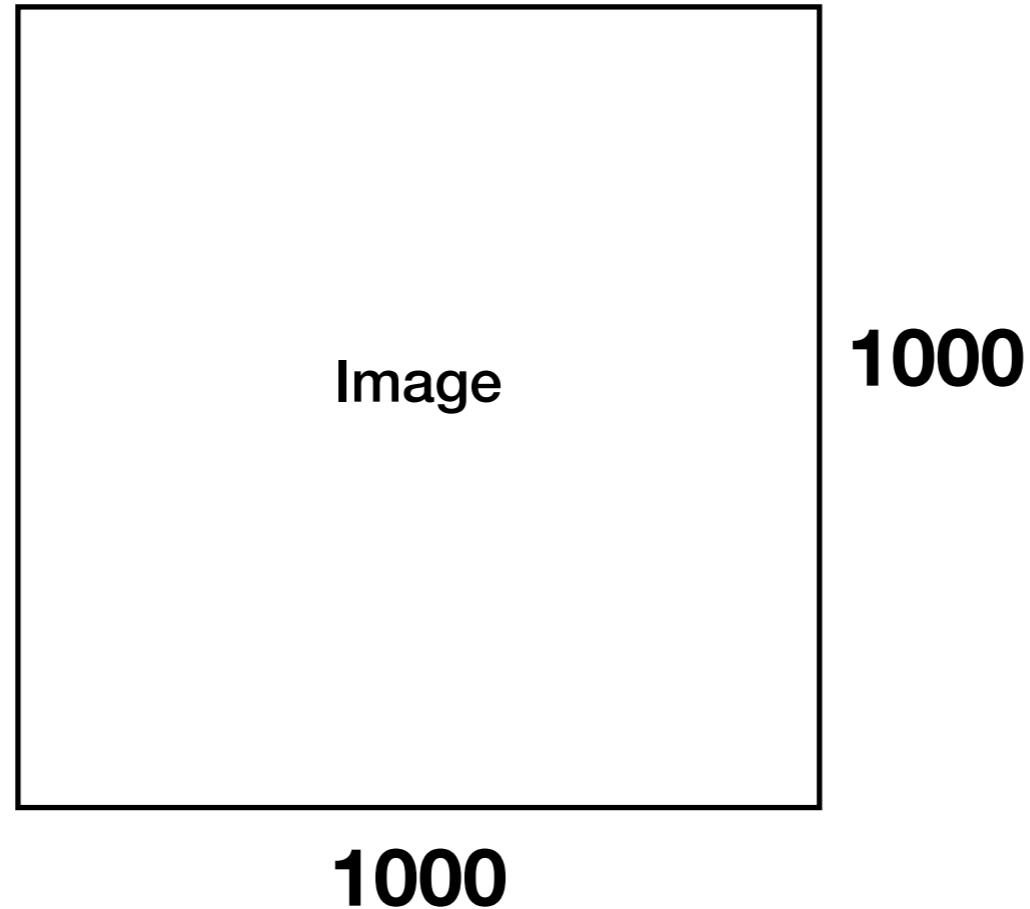


**1000**

**1000**

**Input Layer**

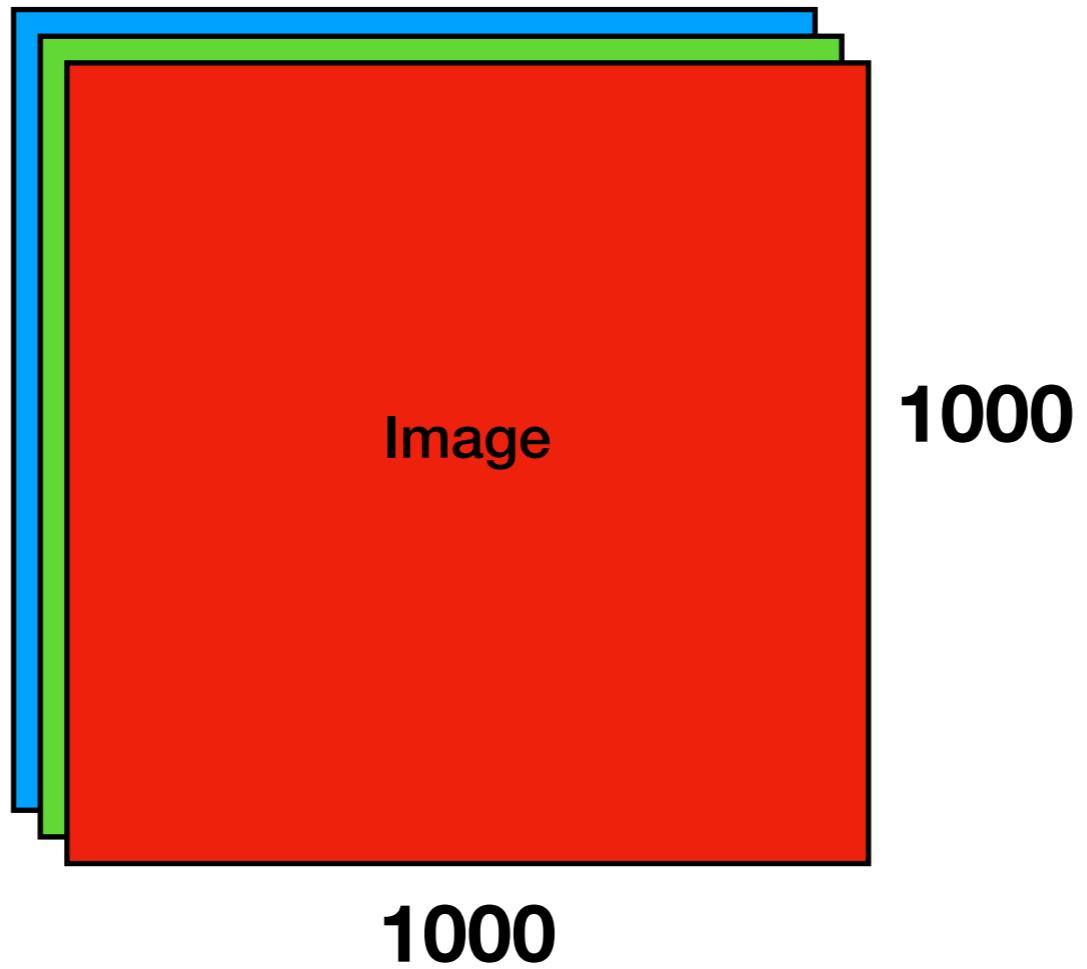
**1000 x 1000 features**



1000

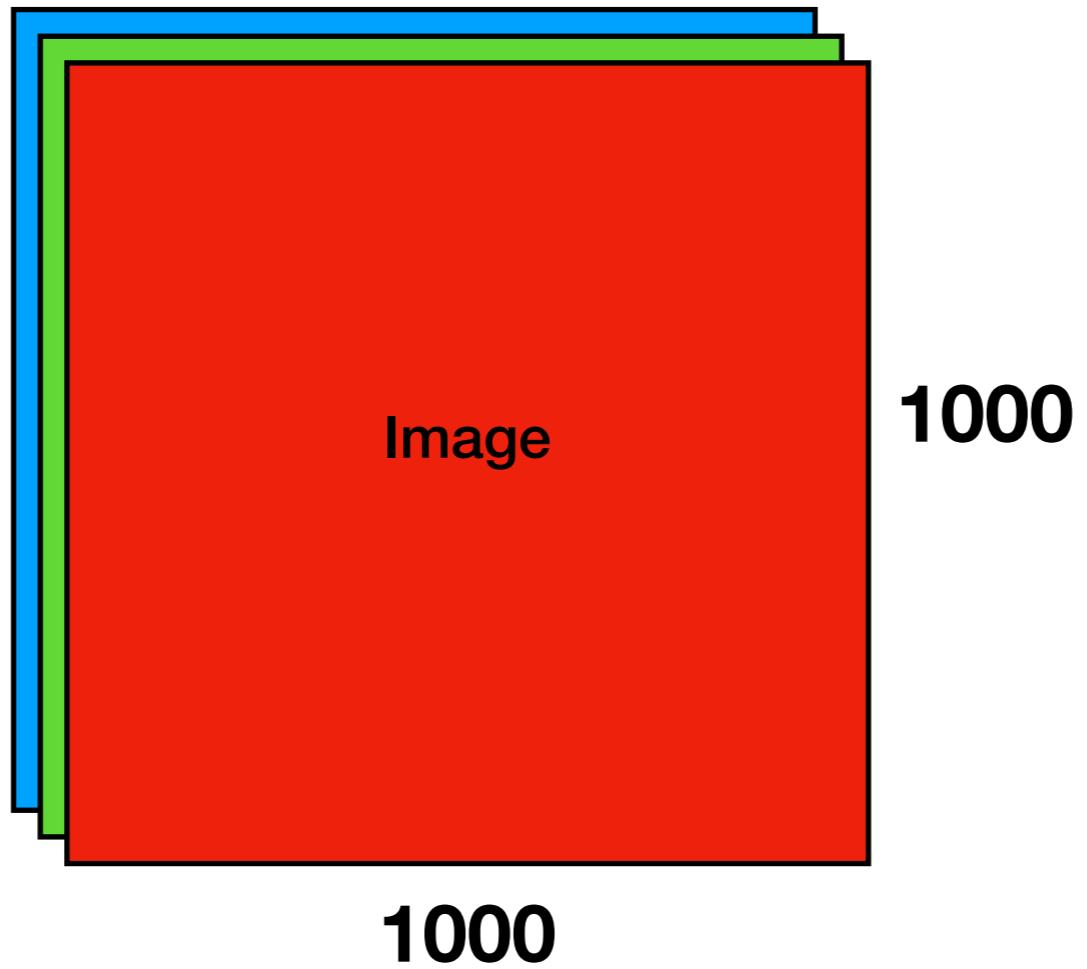
## Input Layer

**1000 x 1000 = 1 million weights**



## Input Layer

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

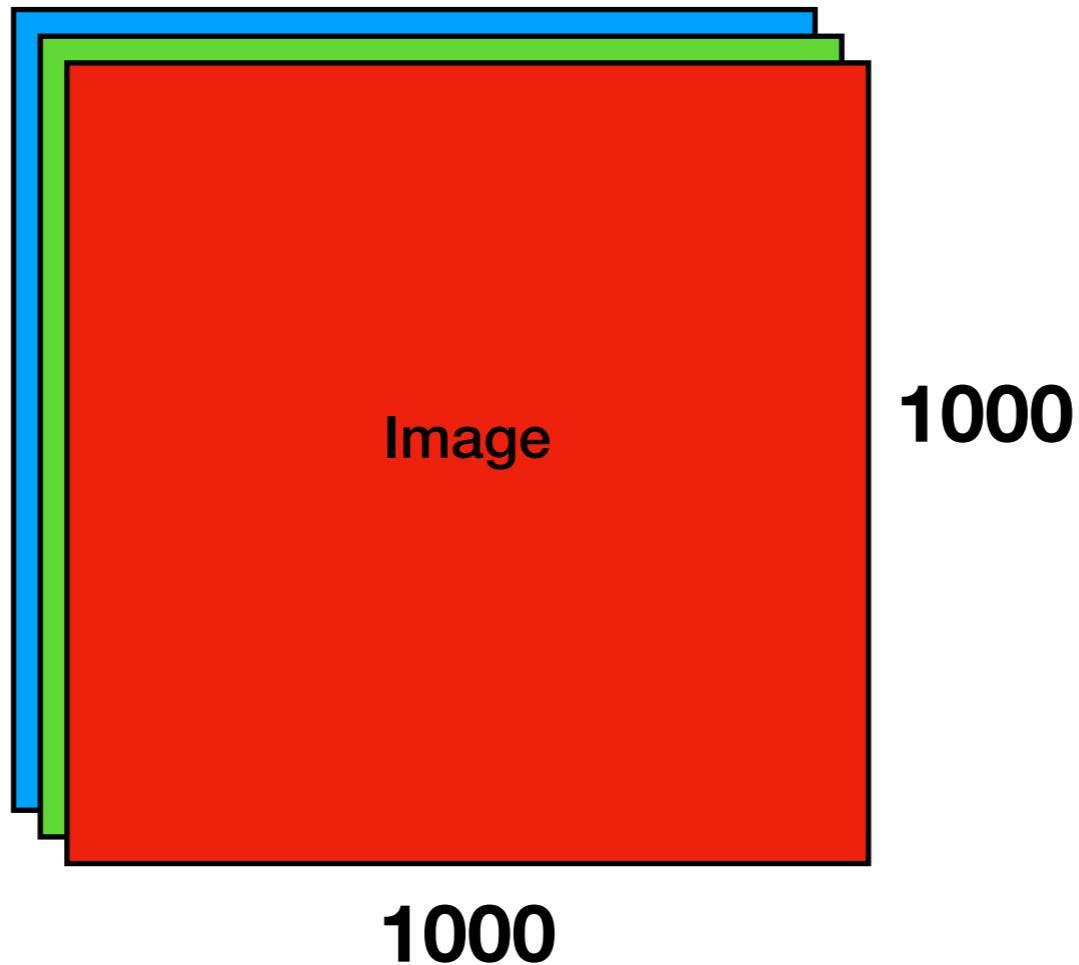


## Input Layer

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

## Hidden Layer

1 units

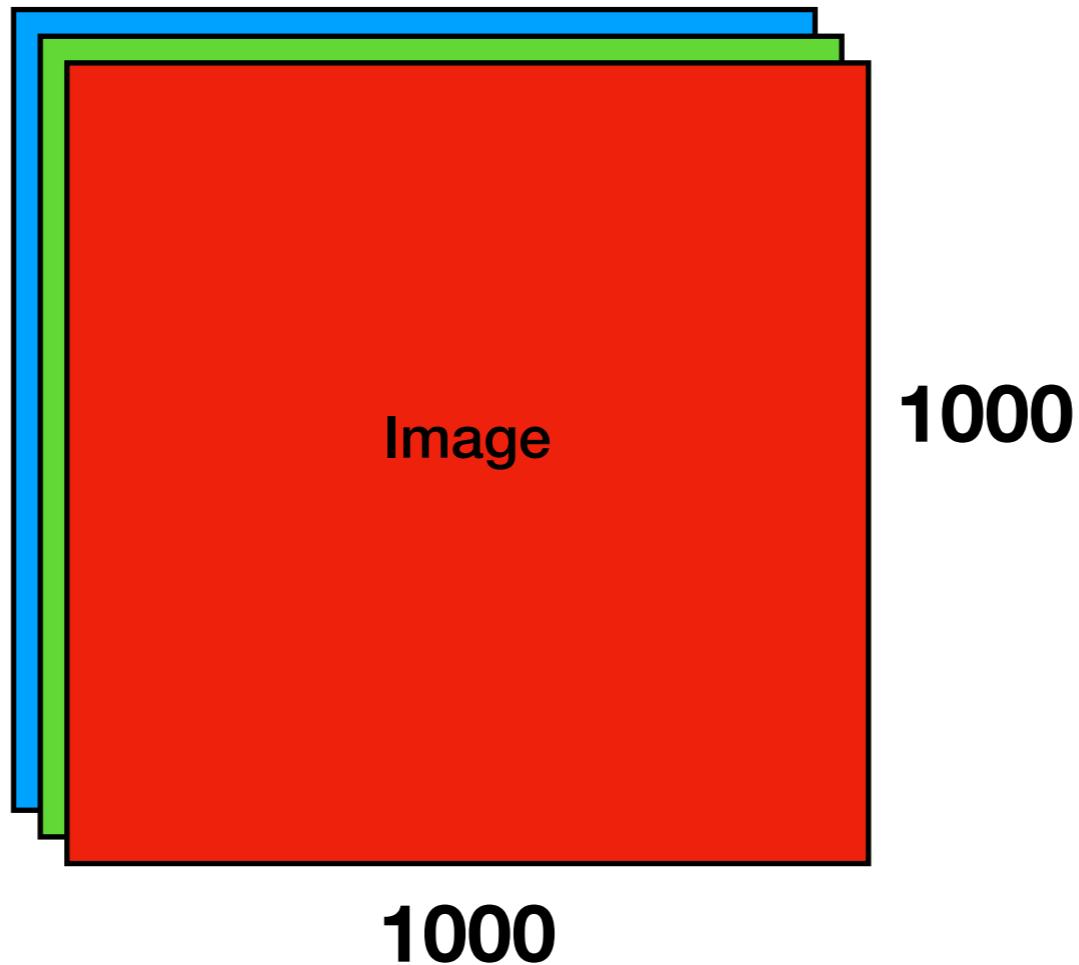


## Input Layer

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

## Hidden Layer

1000 units

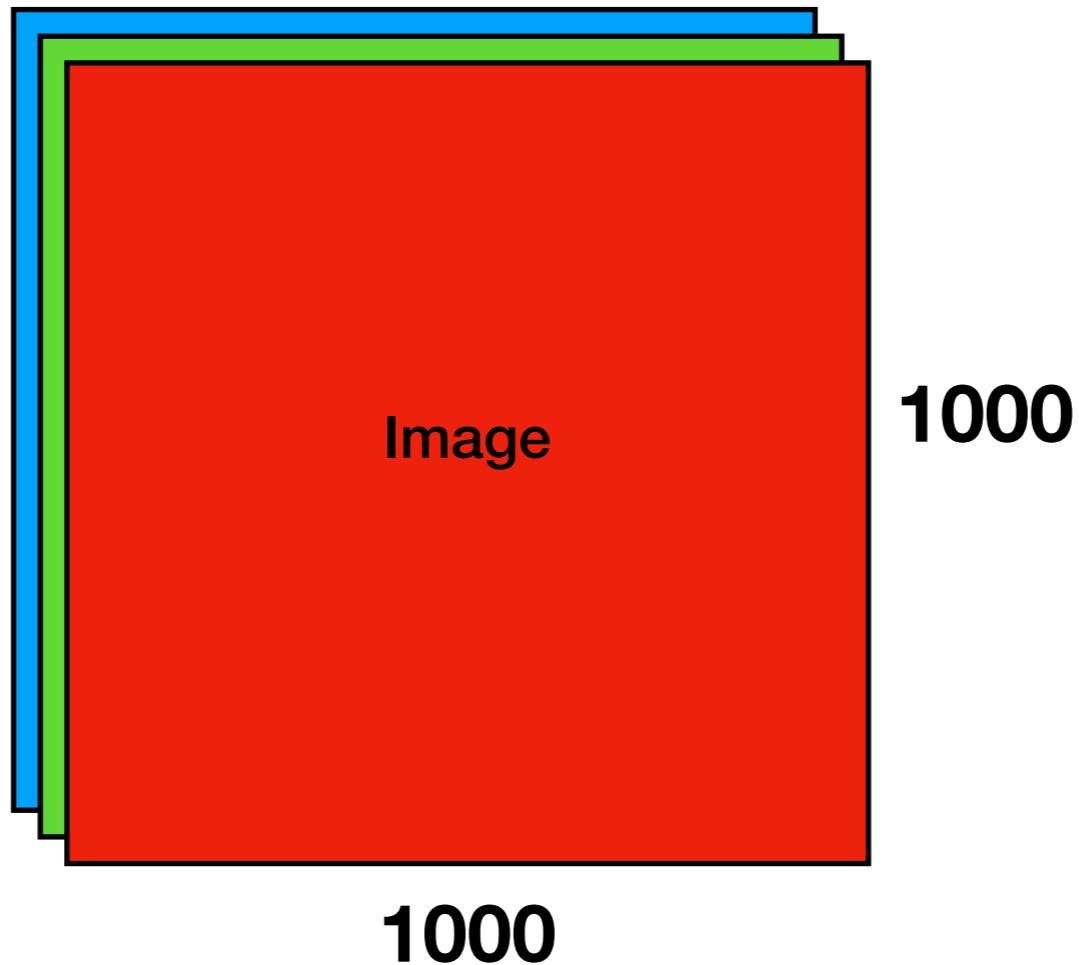


## Input Layer

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

## Hidden Layer

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



## Input Layer

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

## Hidden Layer

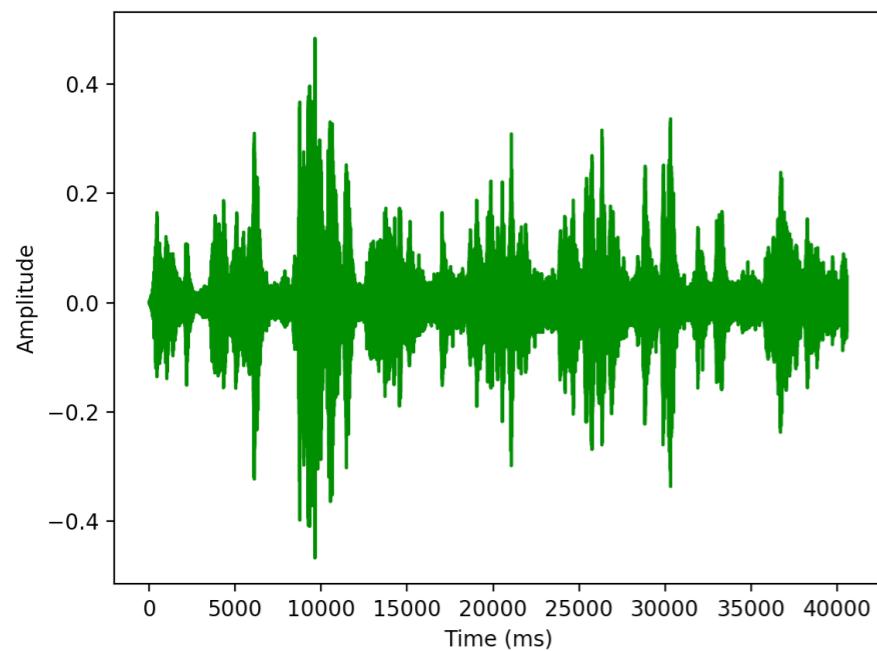
$1000 \times 3 \text{ million} = 3 \text{ Billion weights}$

# 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

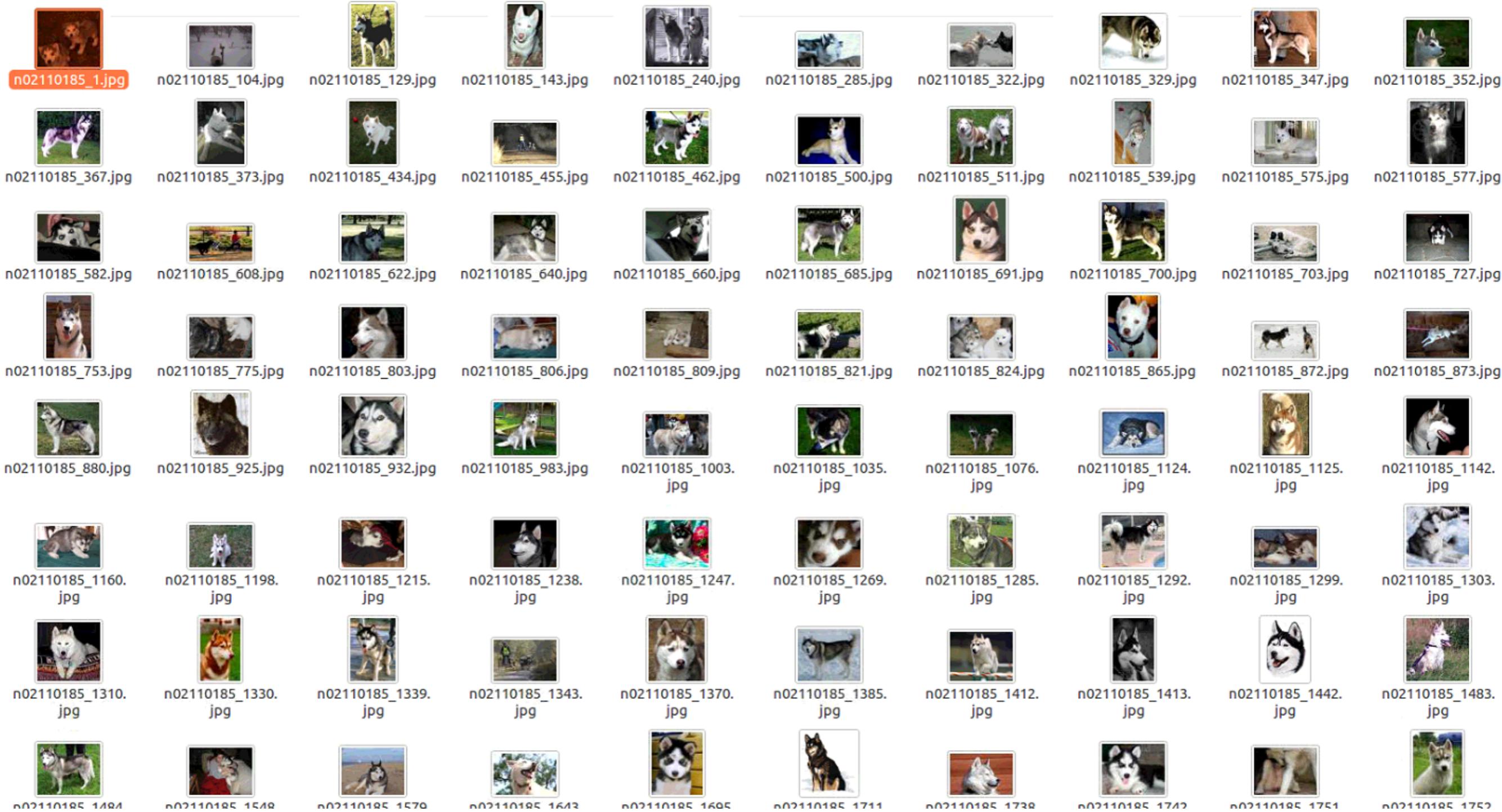




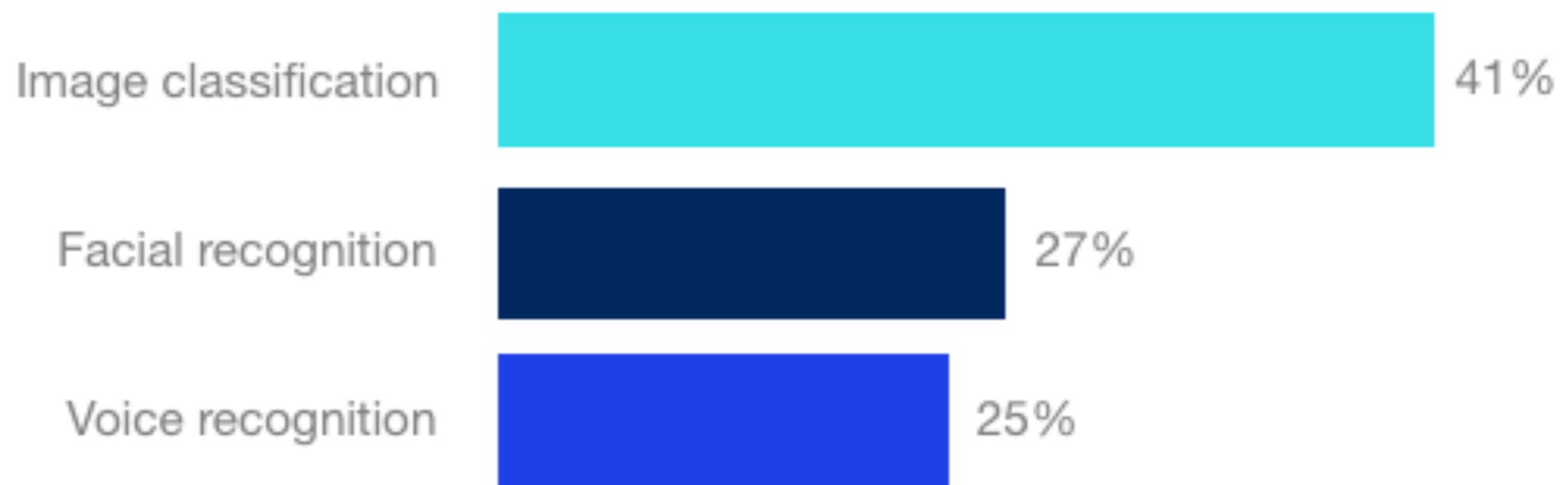




# ImageNet



# Deep Learning vs Traditional Methods



Performance

— Traditional ML

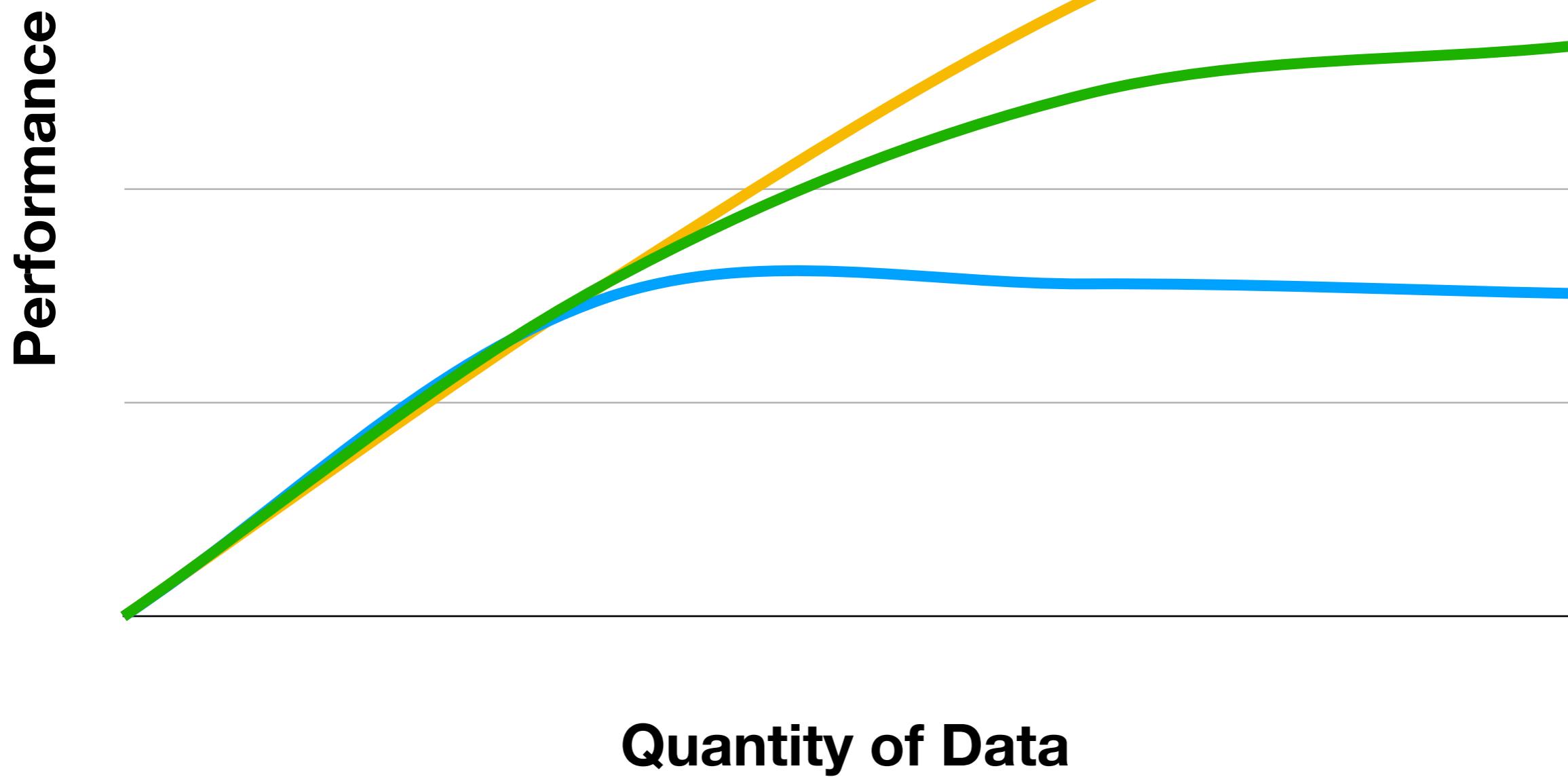
Quantity of Data

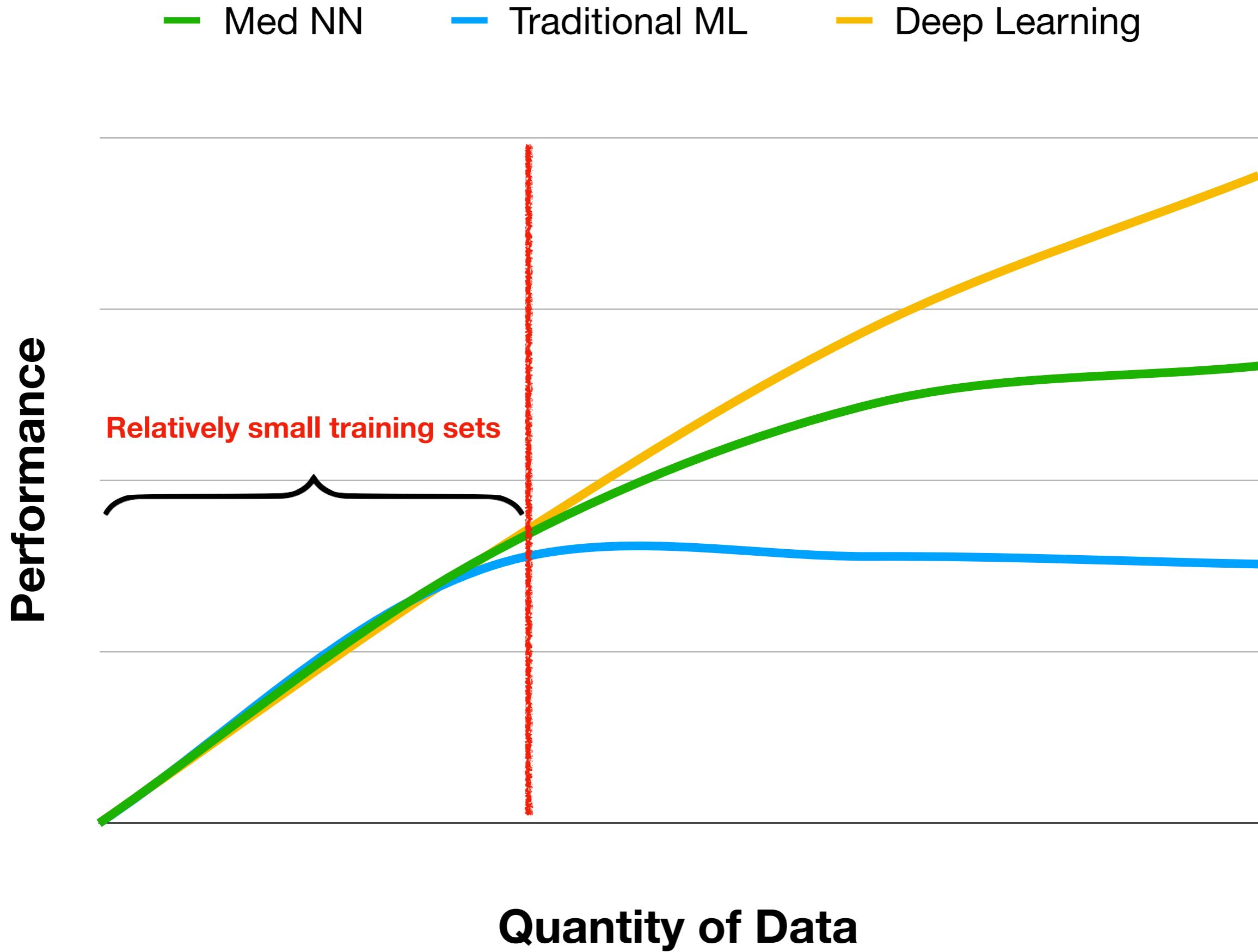
**Performance**

— Med NN      — Traditional ML

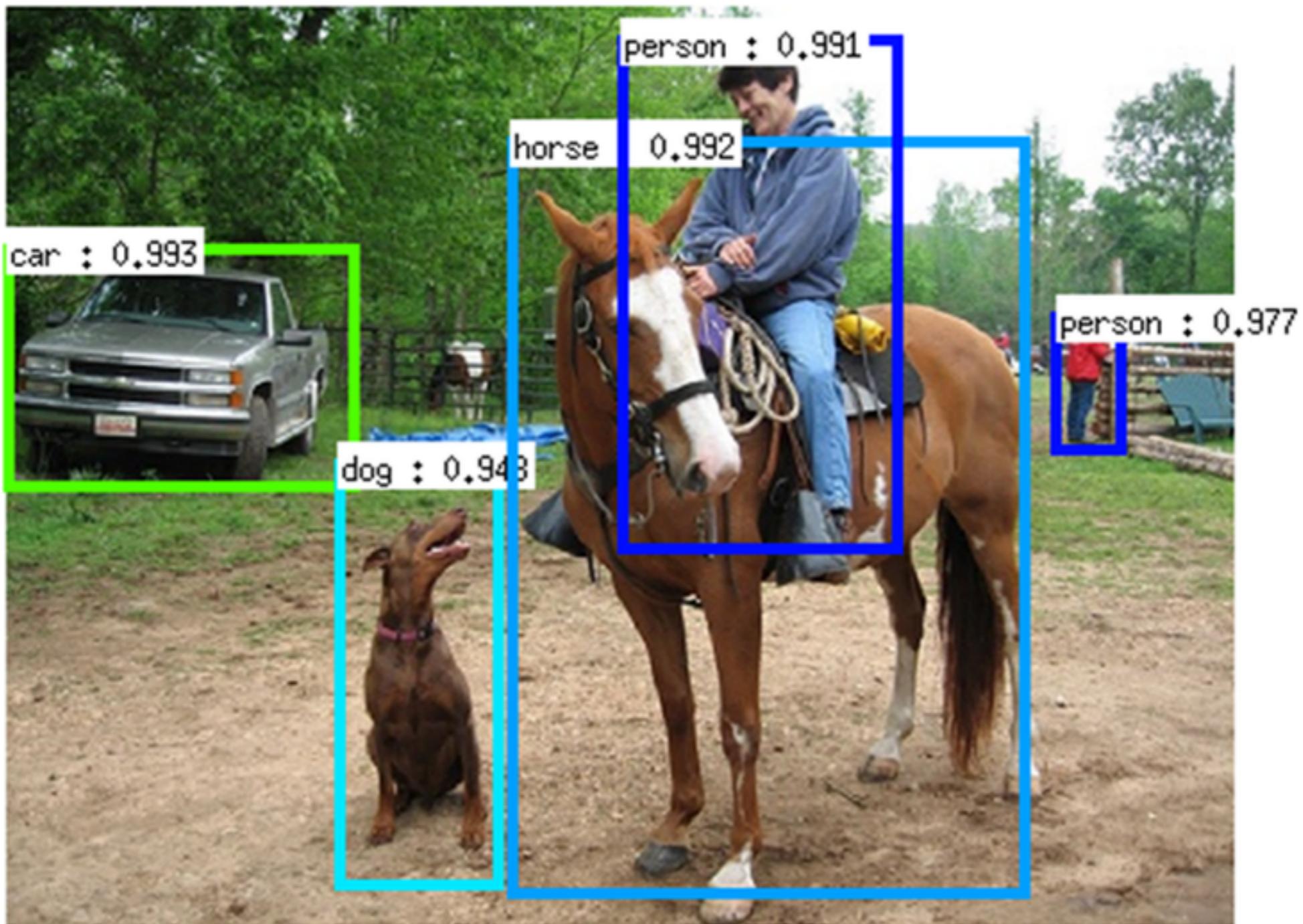
**Quantity of Data**

— Med NN      — Traditional ML      — Deep Learning





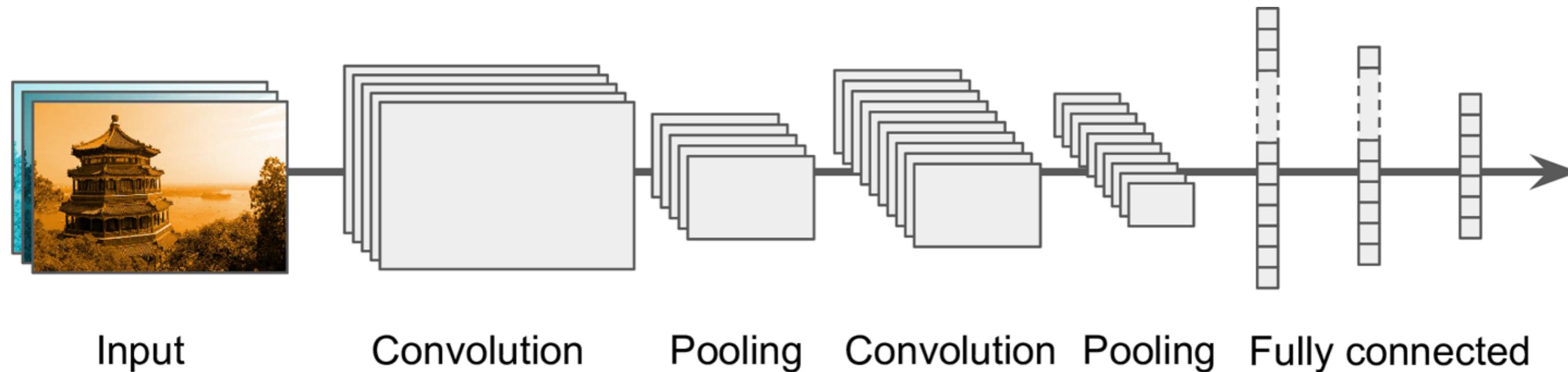
# **Convolutional Neural Network**





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[ 60, 244, 33, 111, 143, 127, 168, 237, 189, 63, 125, 181, 92, 91, 14, 211, 21, 26, 253, 109, 174, 100, 138, 138, 221, 204, 29, 230],  
[ 81, 174, 217, 93, 65, 134, 7, 36, 176, 122, 226, 23, 223, 28, 202, 5, 54, 205, 169, 14, 88, 178, 84, 198, 96, 201, 230, 193],  
[215, 168, 125, 92, 70, 151, 183, 210, 36, 32, 19, 51, 42, 64, 19, 146, 183, 246, 0, 184, 236, 7, 226, 118, 113, 241, 85, 89],  
[ 31, 158, 210, 16, 199, 58, 224, 7, 203, 86, 103, 45, 28, 54, 92, 204, 243, 117, 75, 208, 248, 223, 87, 250, 14, 43, 102, 66],  
[ 13, 236, 138, 67, 236, 109, 113, 46, 115, 19, 214, 154, 199, 248, 55, 172, 214, 249, 125, 154, 139, 141, 188, 78, 107, 200, 196, 16],  
[ 65, 150, 158, 254, 114, 177, 120, 15, 65, 58, 79, 171, 118, 32, 250, 81, 27, 85, 128, 146, 144, 234, 139, 26, 6, 68, 133, 205],  
[123, 68, 216, 34, 139, 34, 34, 175, 213, 72, 76, 19, 32, 138, 132, 111, 242, 249, 177, 89, 61, 72, 252, 79, 20, 171, 174, 177] ]

# Typical CNN Architecture



# **Convolutional Neural Network**

Convolution Layer

# **Convolutional Neural Network**

Convolution Layer

Pooling Layer

# **Convolutional Neural Network**

Convolution Layer

Pooling Layer

Fully Connected Layer

# Convolution Layer

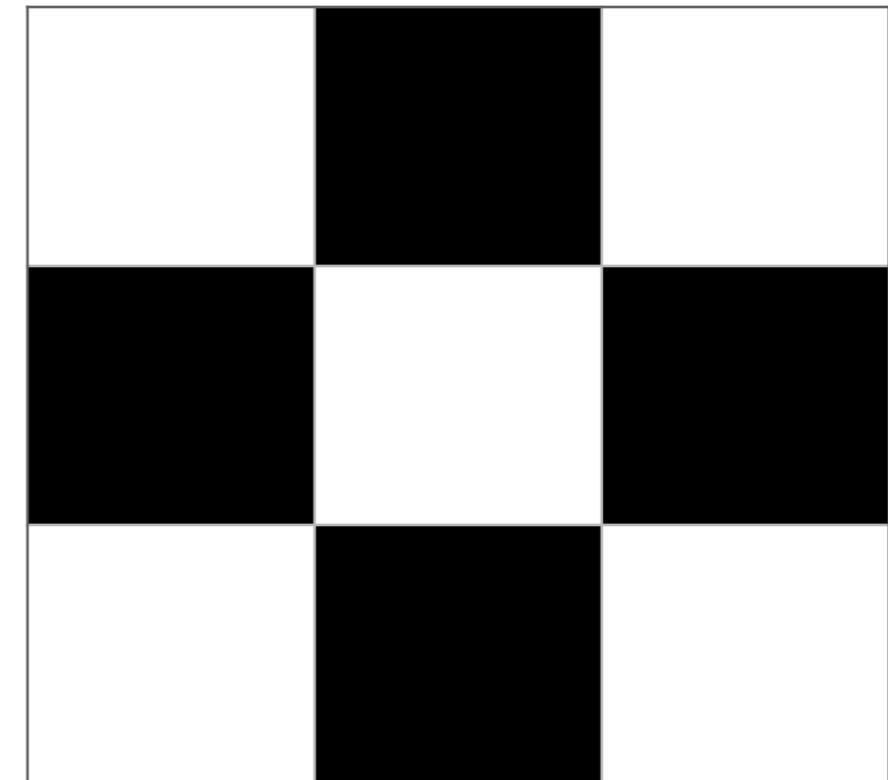
# Image



**Image**



**Filter**

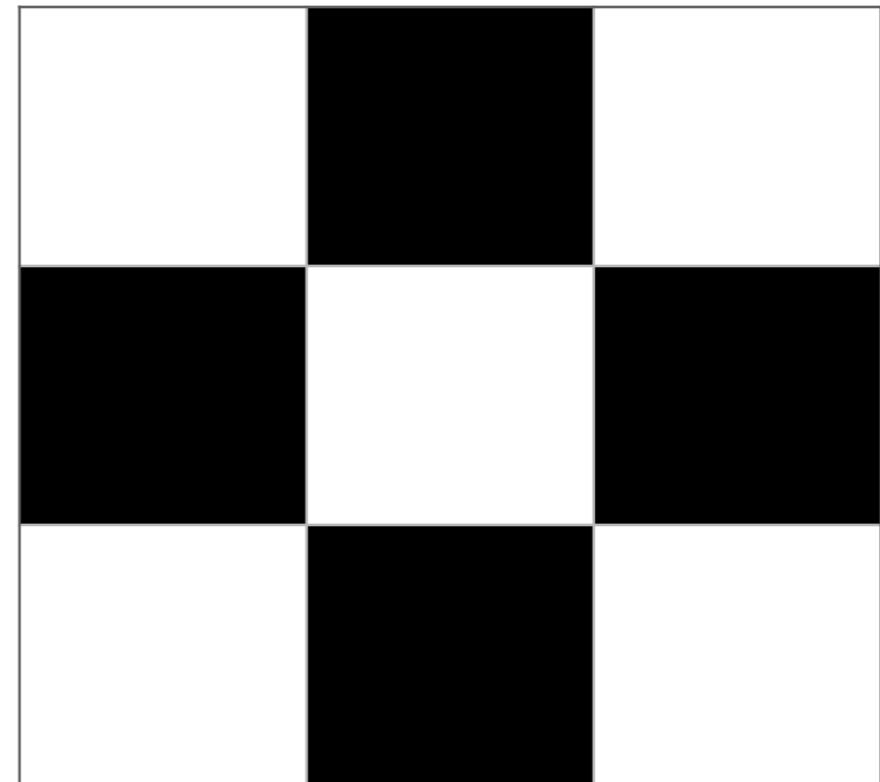


**3x3**

**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 x 1	1 x 0	1 x 1	0	0
0 x 0	1 x 1	1 x 0	0	1
0 x 1	0 x 0	0 x 1	1	1
0	0	1	0	1
0	1	1	0	0

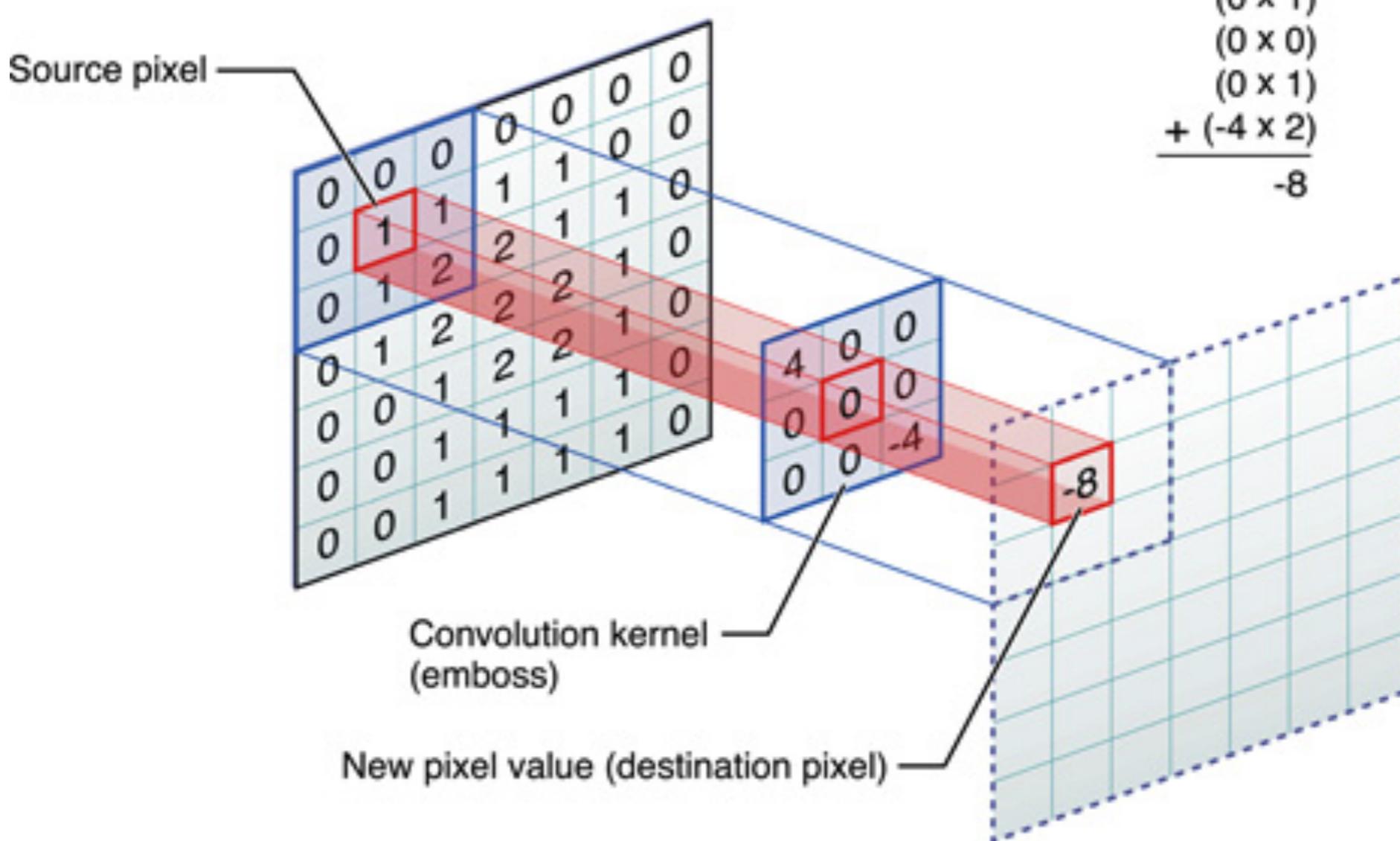
**Image**

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**

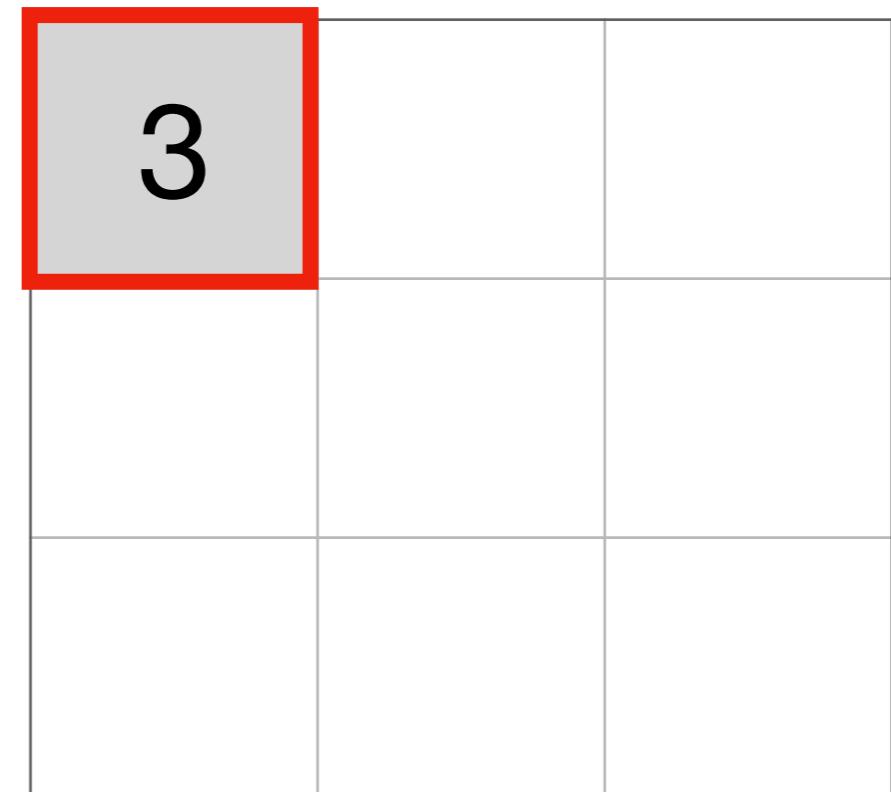
1 <small>x 1</small>	1 <small>x 0</small>	1 <small>x 1</small>	0	0
0 <small>x 0</small>	1 <small>x 1</small>	1 <small>x 0</small>	0	1
0 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>	1	1
0	0	1	0	1
0	1	1	0	0

**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)**



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

**Output  
(feature map)**

3	3	2
2	1	

**Image**

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

**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 <small>x 1</small>	0 <small>x 0</small>	0 <small>x 1</small>	0	0	0	0
0 <small>x 0</small>	1 <small>x 1</small>	1 <small>x 0</small>	1	0	0	0
0 <small>x 1</small>	0 <small>x 0</small>	1 <small>x 1</small>	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			
	3	3	2
2	1	5	
1	3	2	

**Image**

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

**5x5**

**Output  
(feature map)**

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

**Image**

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

**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**

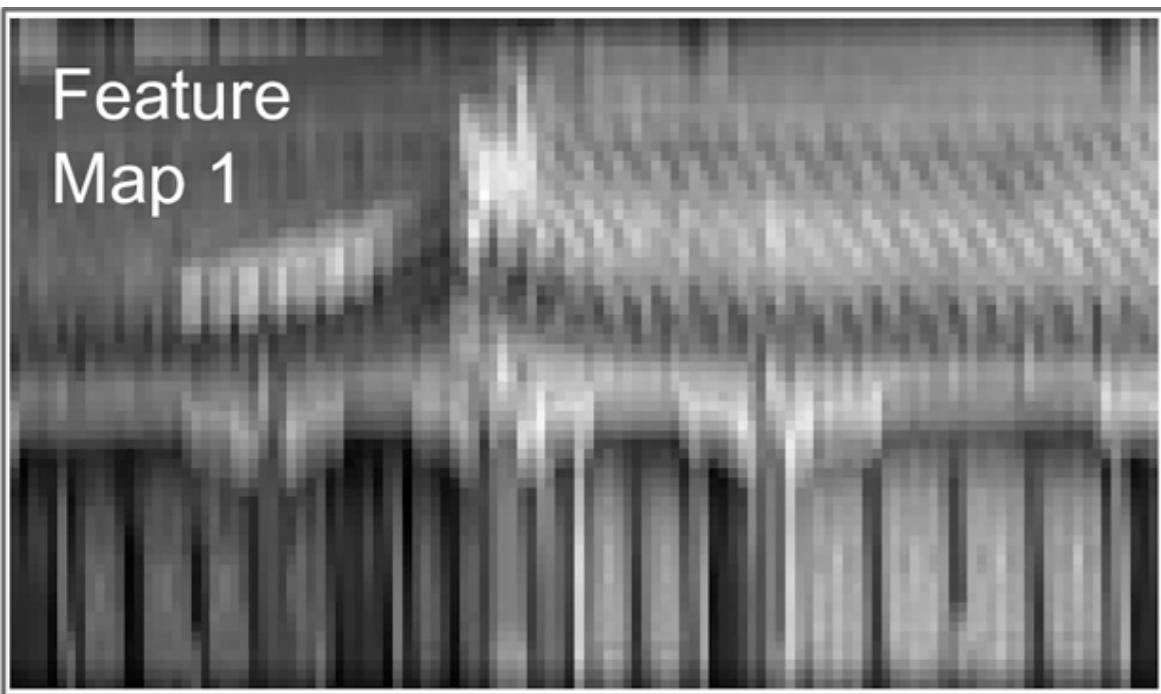
**Output  
(feature map)**

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

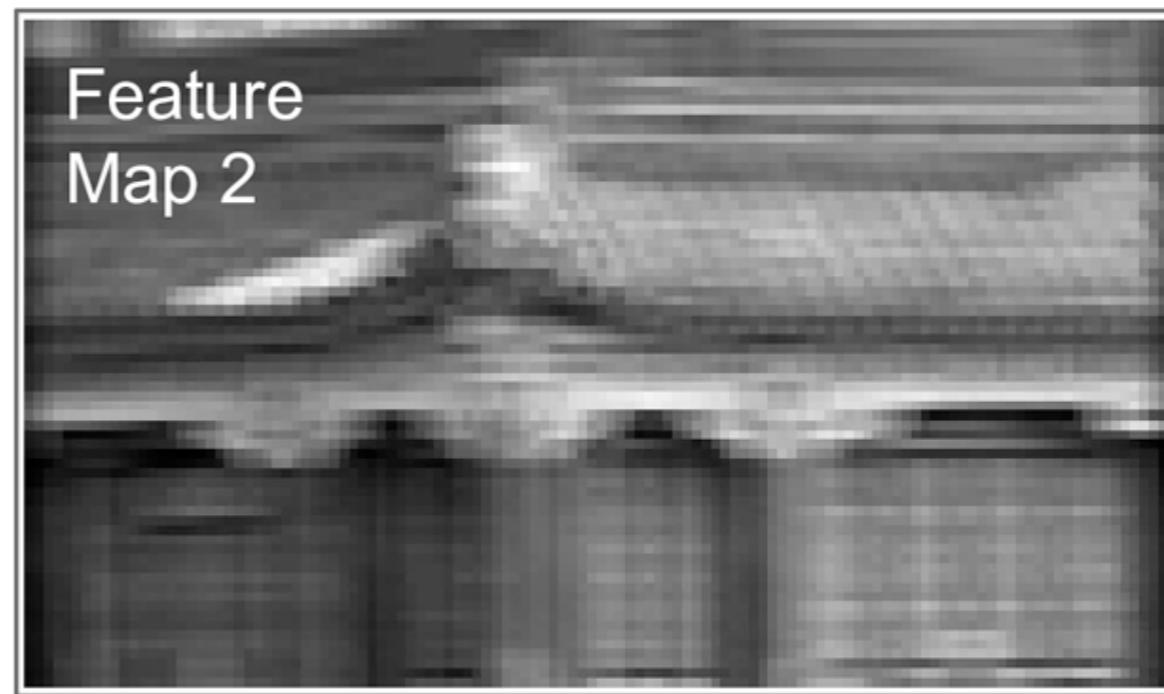
**5x5**

## Two different filters produce two feature maps

Feature  
Map 1



Feature  
Map 2



Vertical filter 

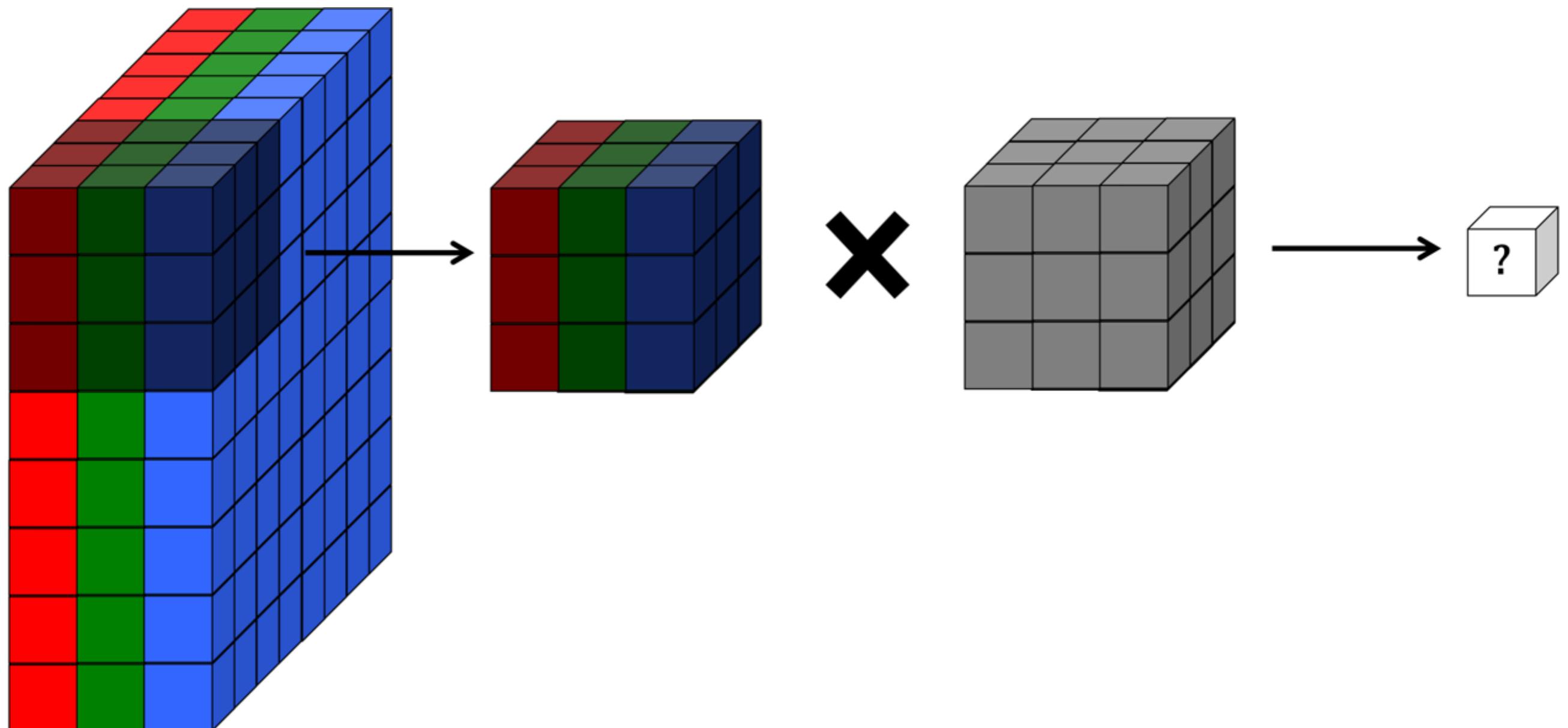
Horizontal filter 



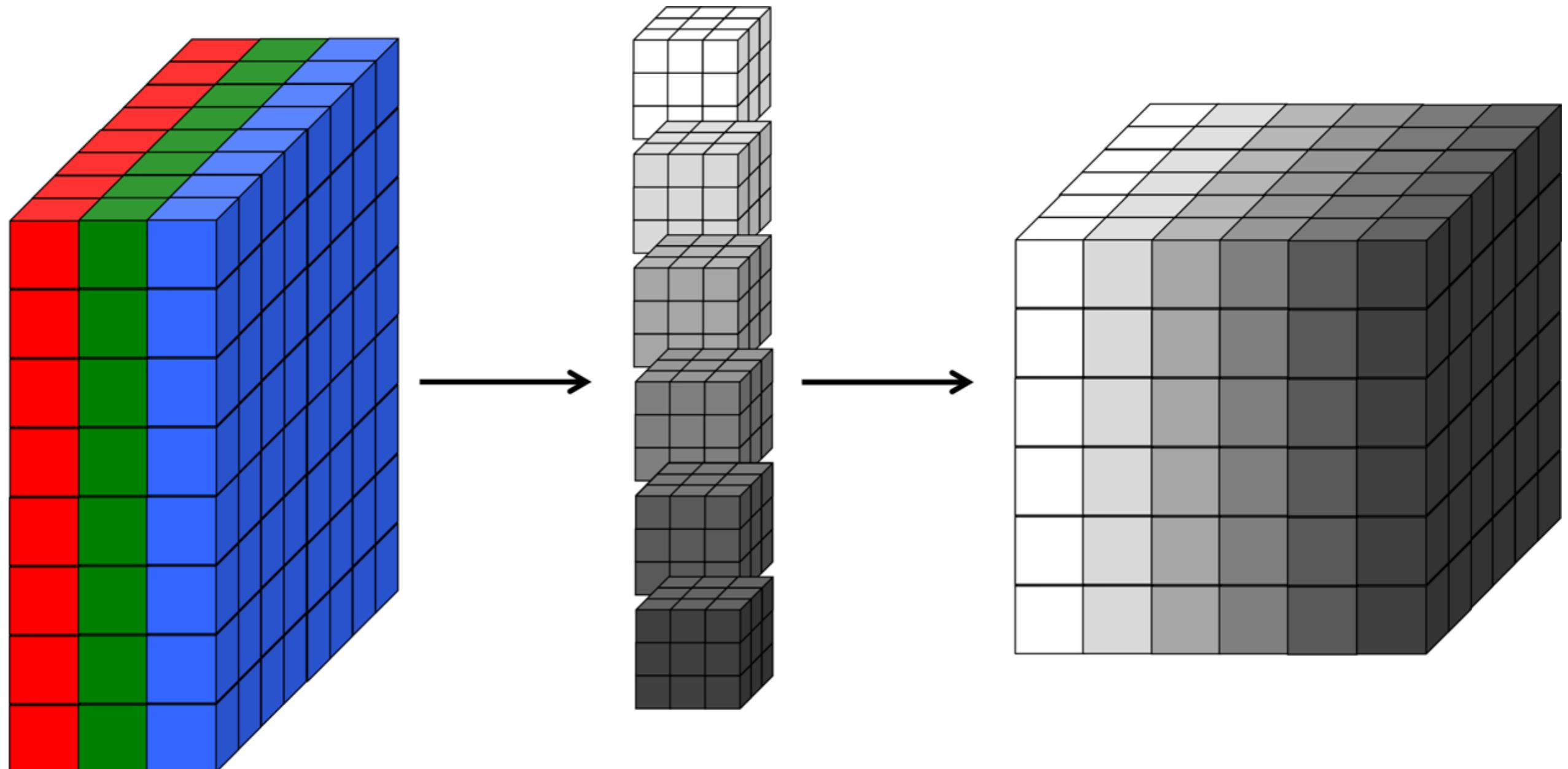
# Learned Filters



# Convolutional Layers



# Convolutional Layers



# Convolution Layer Hyperparameters

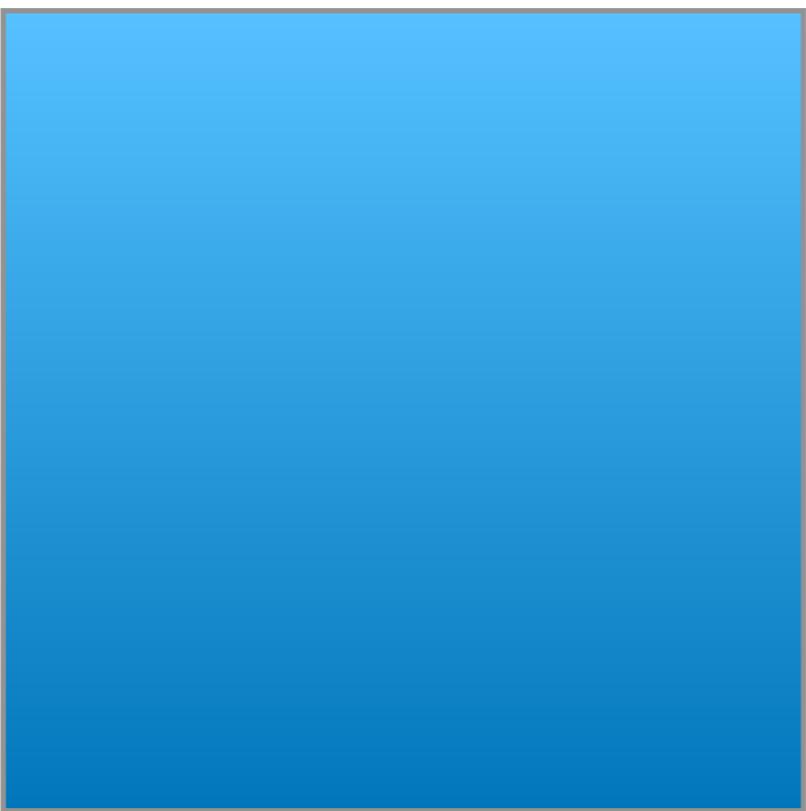
filter size

depth (filter count)

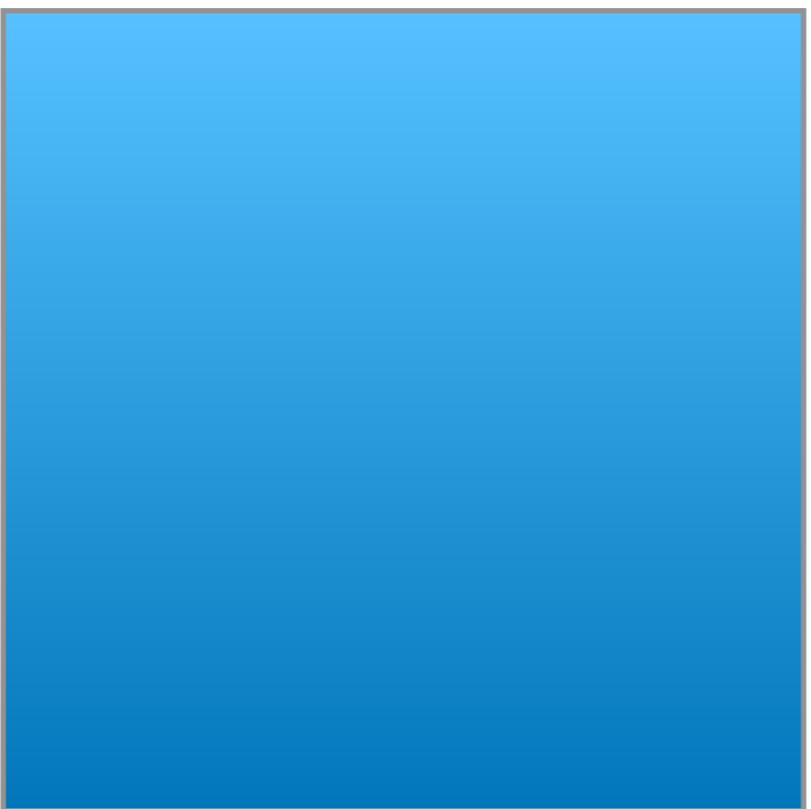
zero-padding

stride

# **Image**

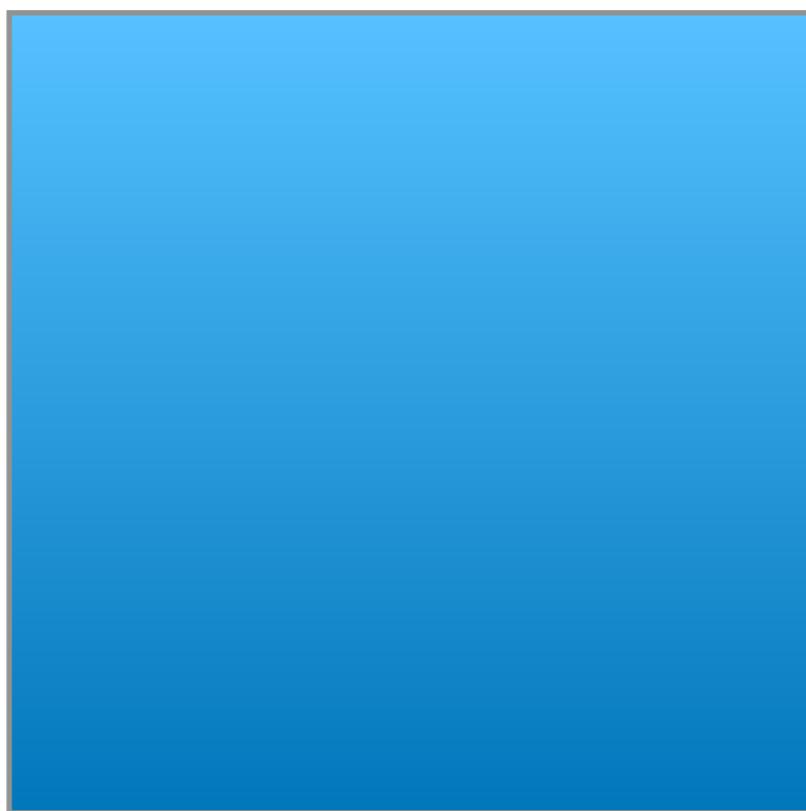


# Image

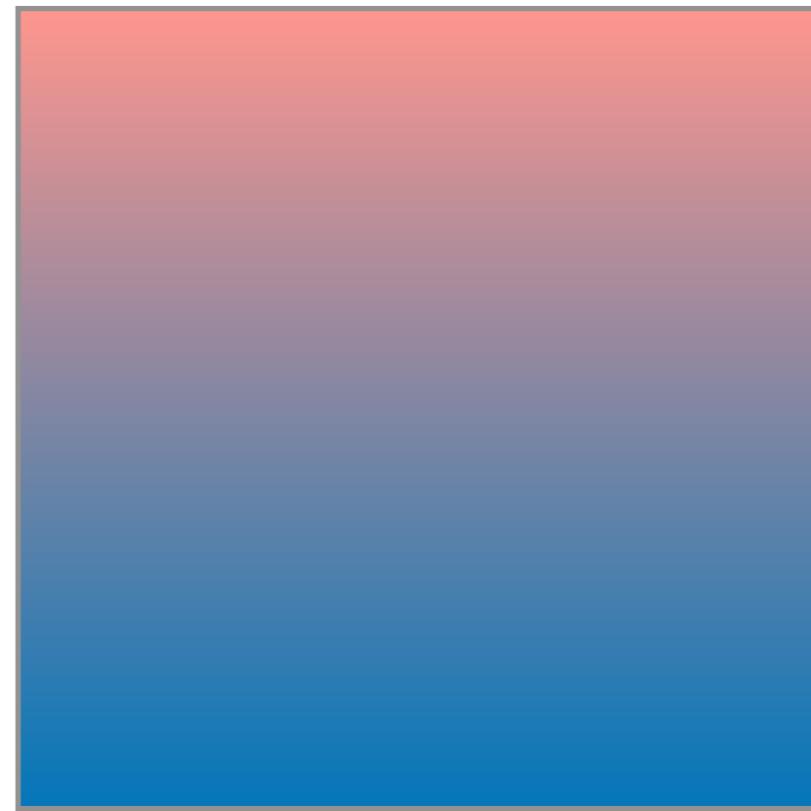


## Filters

**Image**



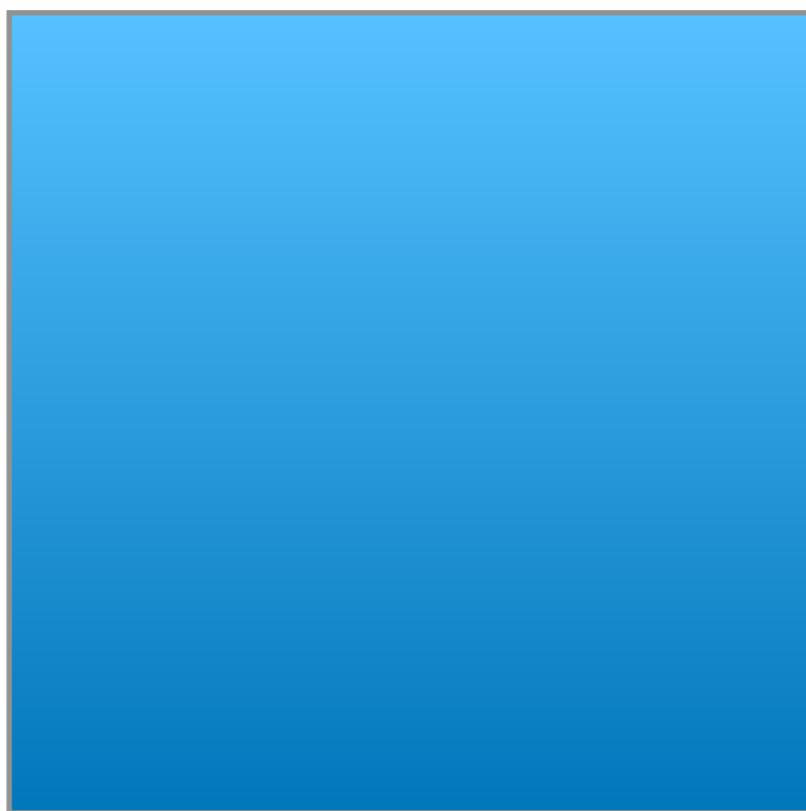
**Convolution Layer**



**Filters**

**Stacked Feature Maps**

**Image**



**Convolution Layer**

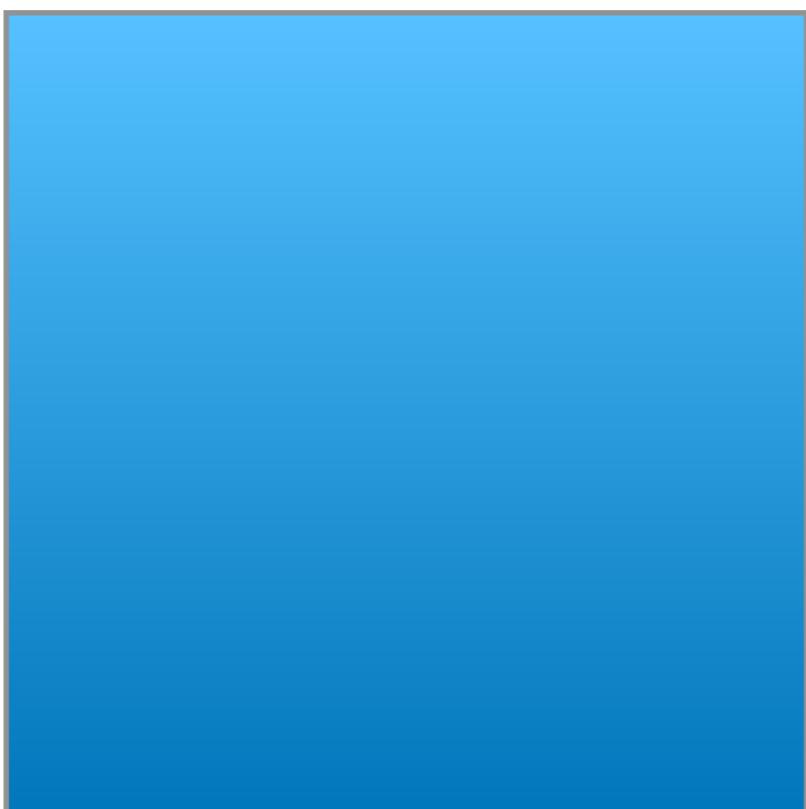


**Filters**



**Stacked Feature Maps**

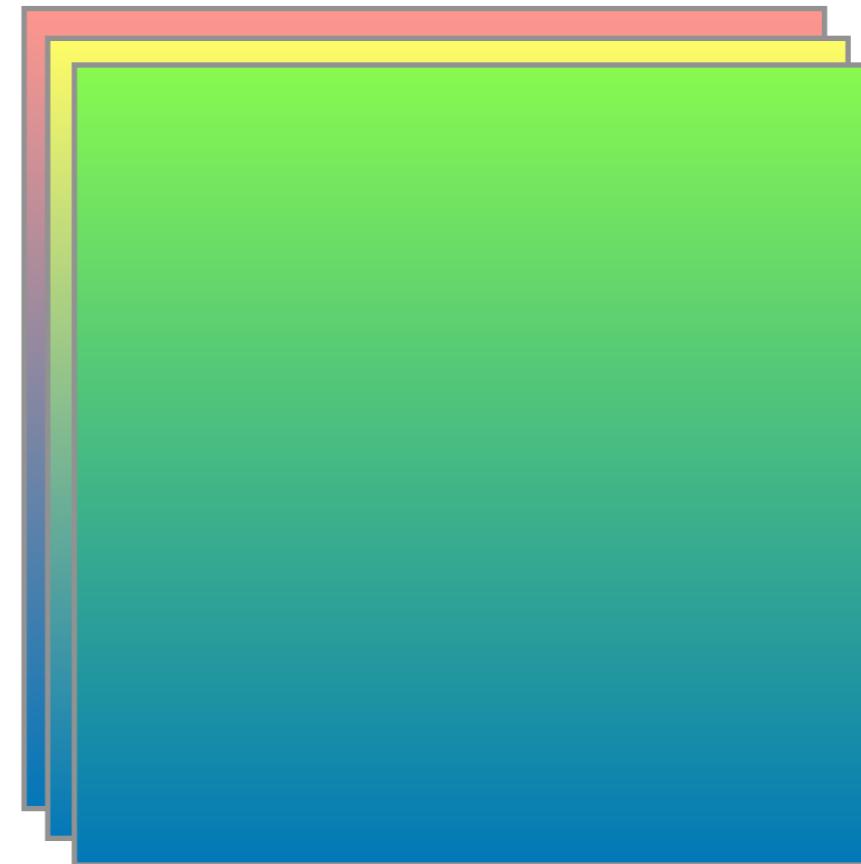
**Image**



**Filters**

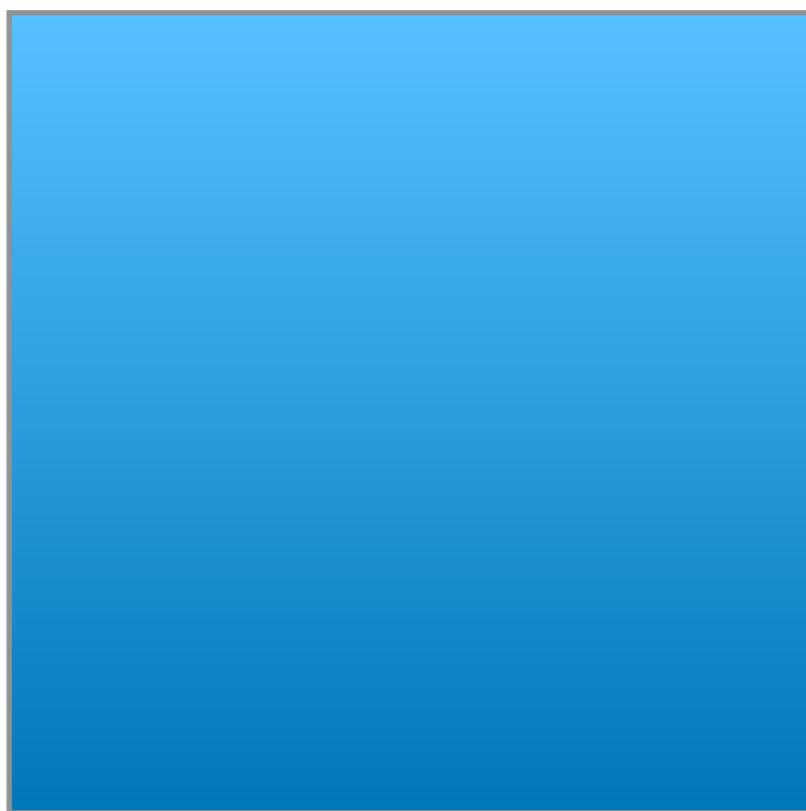


**Convolution Layer**



**Stacked Feature Maps**

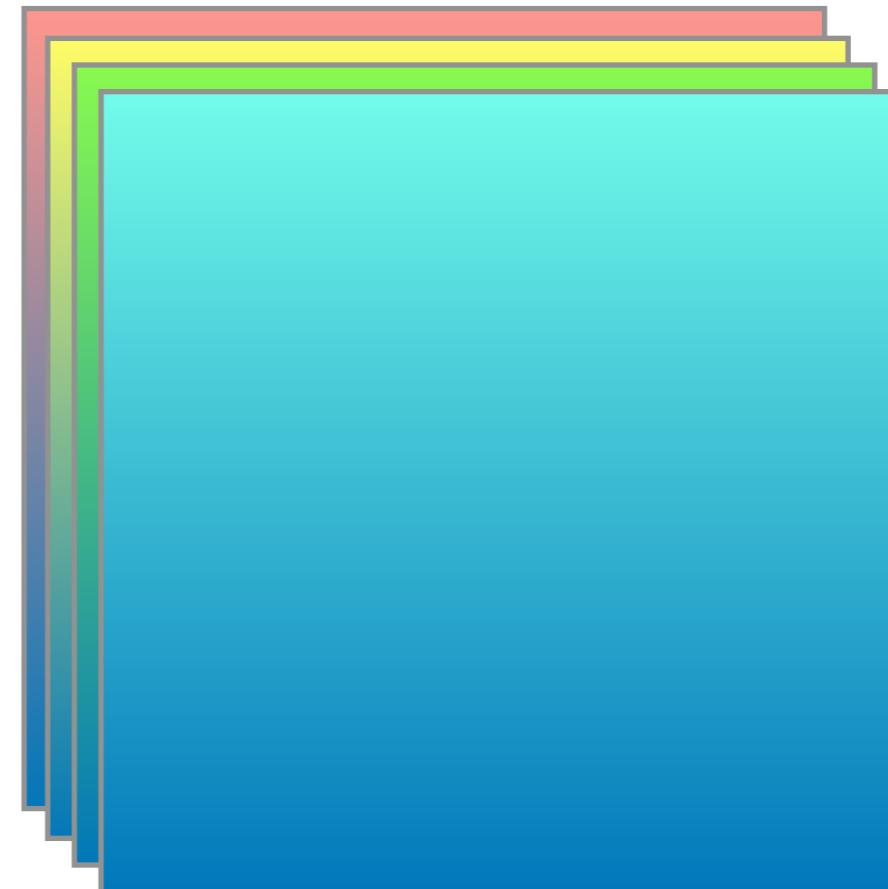
**Image**



**Filters**



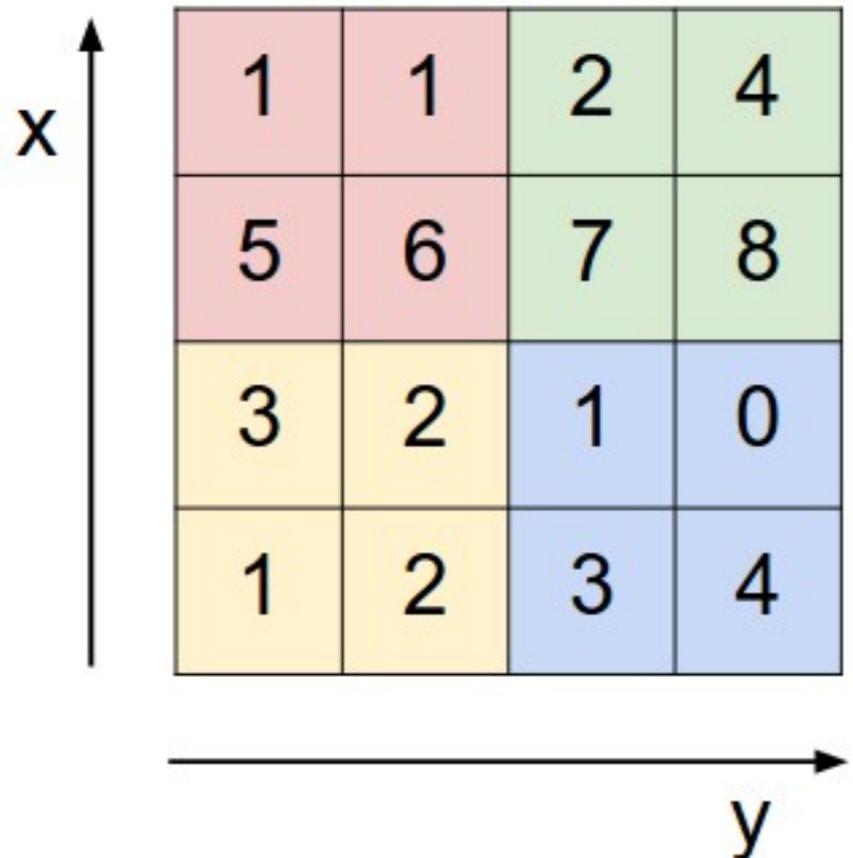
**Convolution Layer**



**Stacked Feature Maps**

# Pooling

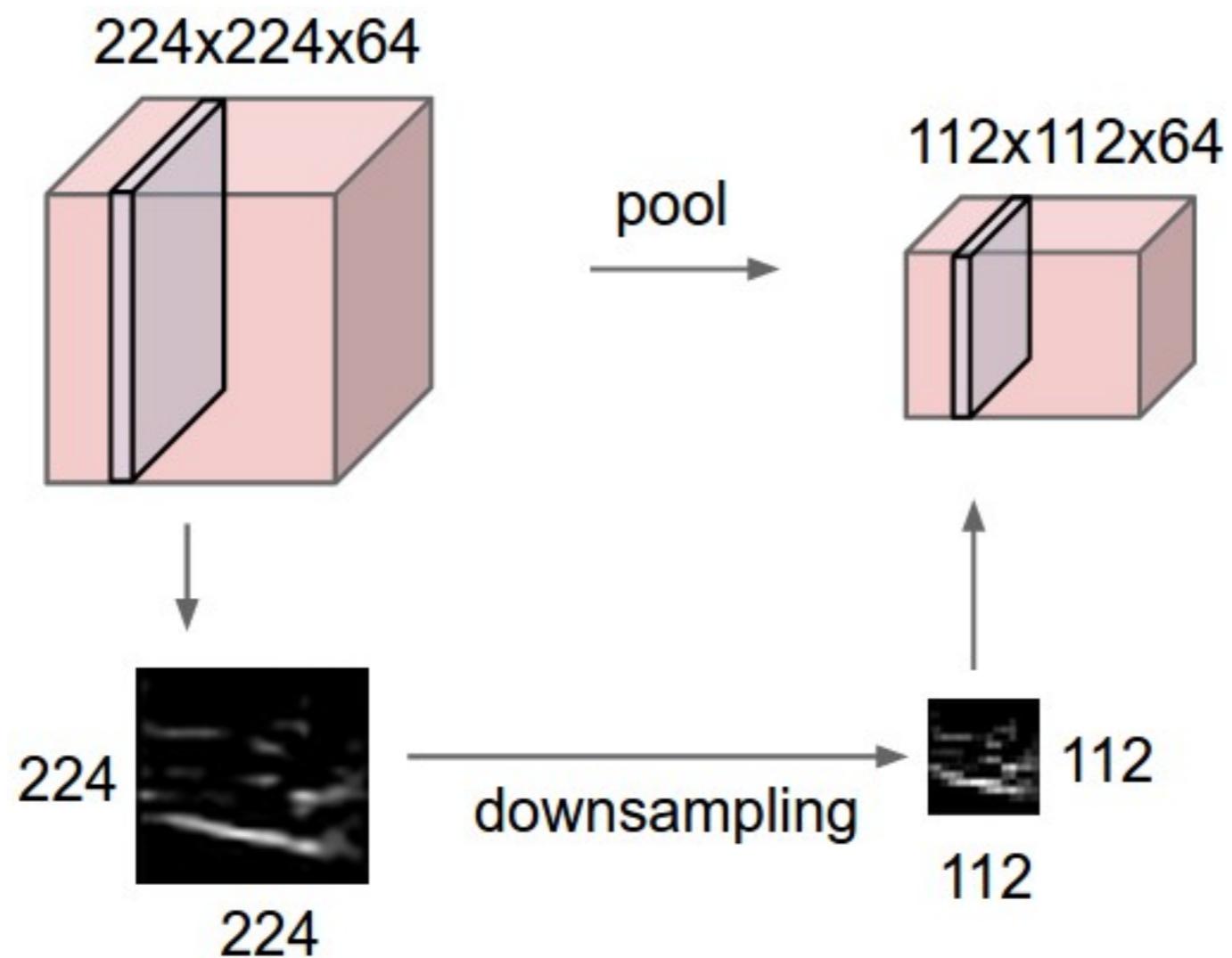
## Single depth slice

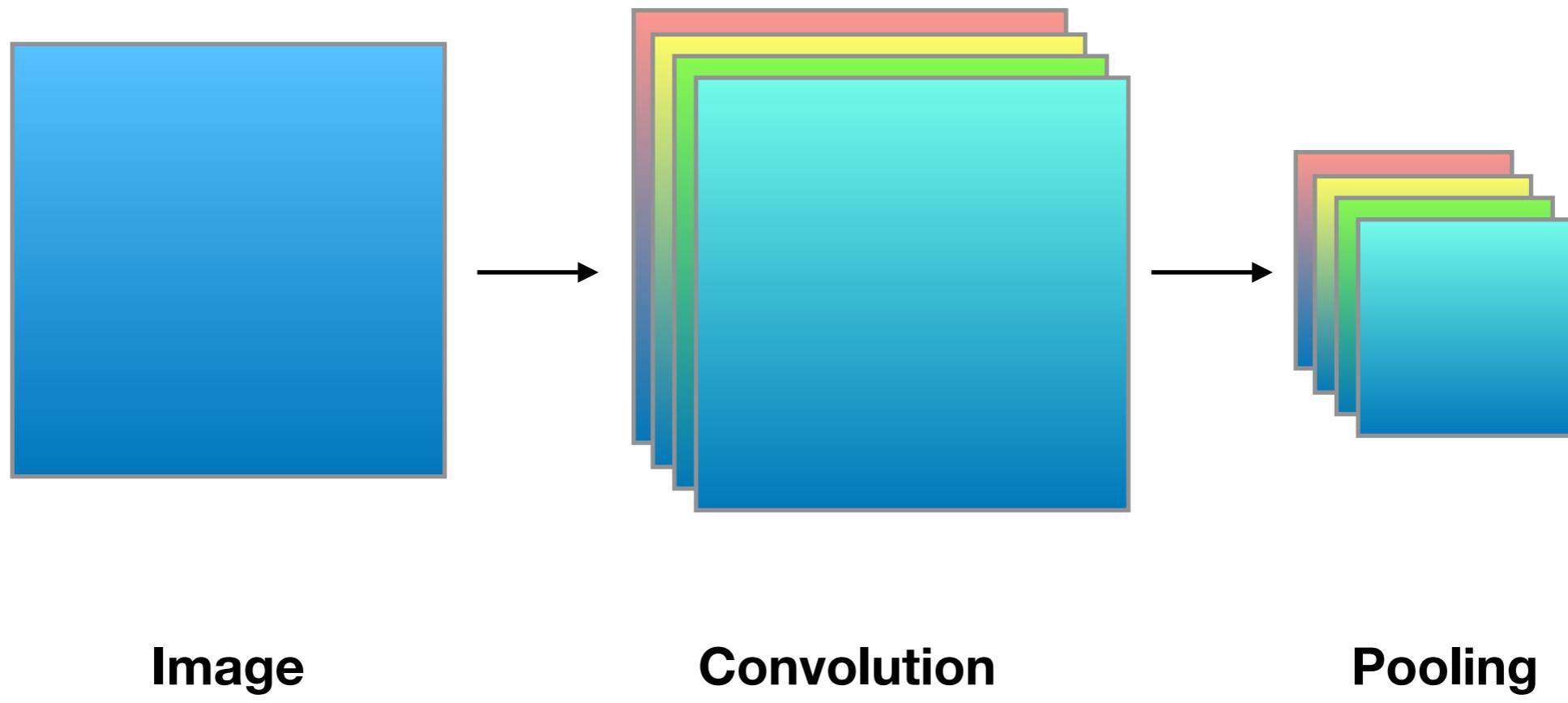


max pool with 2x2 filters  
and stride 2

6	8
3	4

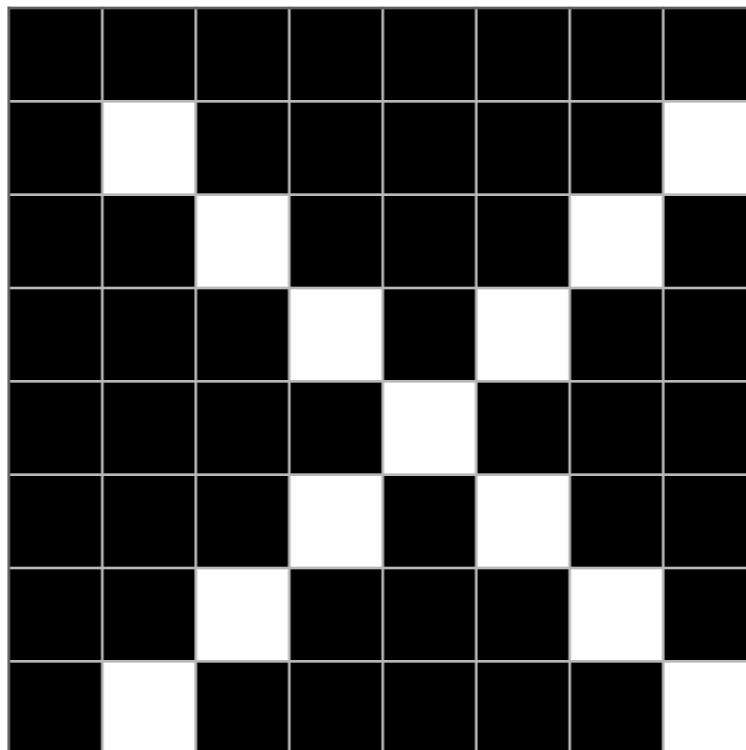
# Downsampling (pooling)





# Convolution Layer

Image

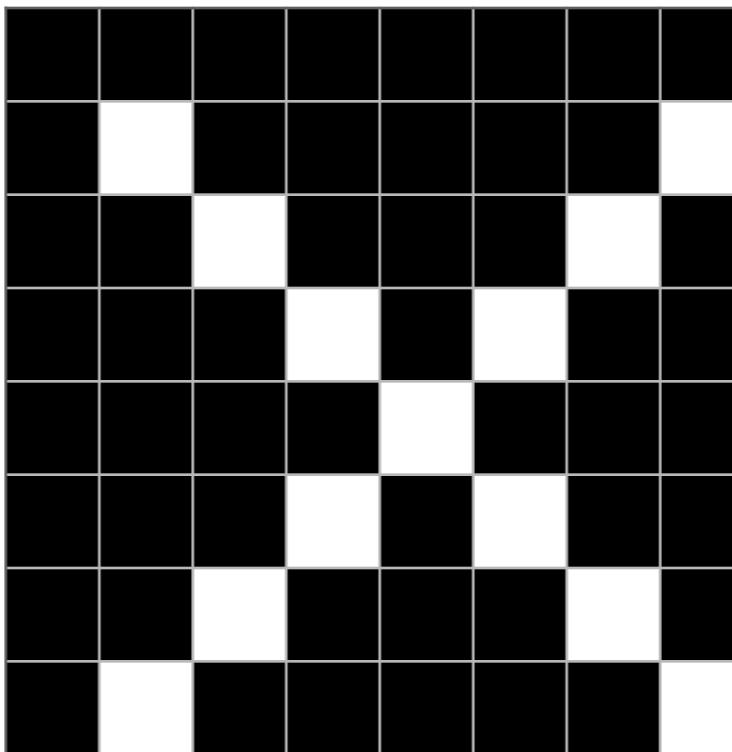


# Convolution Layer

**Filters**

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

**Image**



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

# 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

# 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

# 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

# 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

# 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

# Feature Map

# 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

# 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
-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

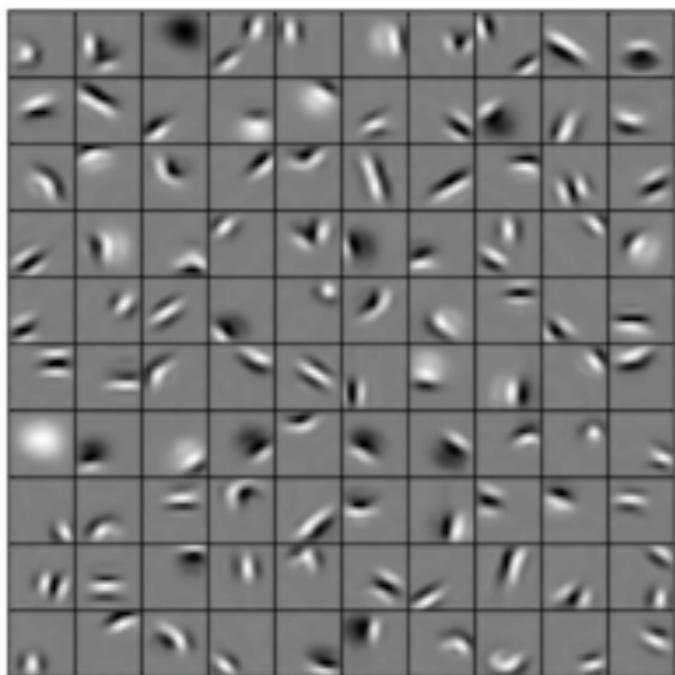
Max Pooling

3	5	9
5	5	9
9	9	1

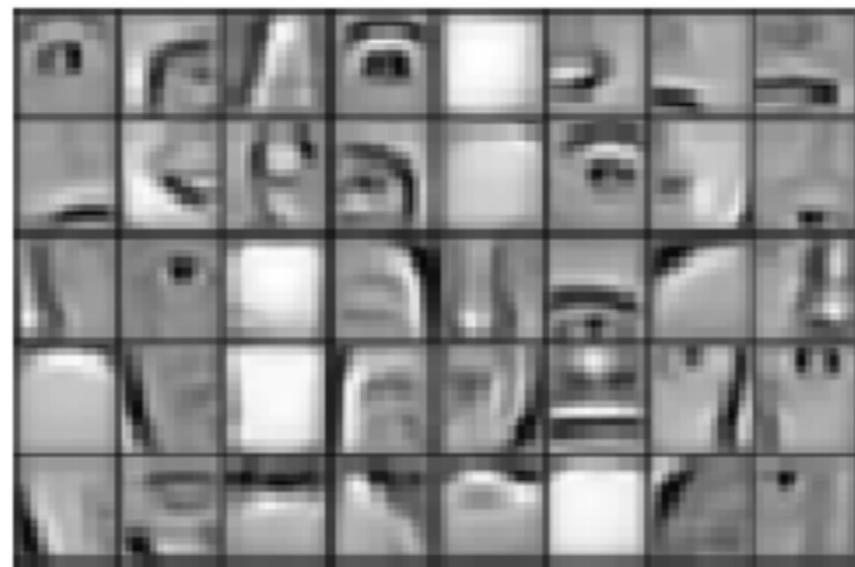
7	0	1	3	5	0
0	9	0	3	0	1
1	0	9	0	1	0
3	3	0	5	0	3
5	0	1	0	9	0
0	1	0	3	0	9

9	3	5
3	9	3
5	3	9

# Hierarchical Feature Learning



Edges



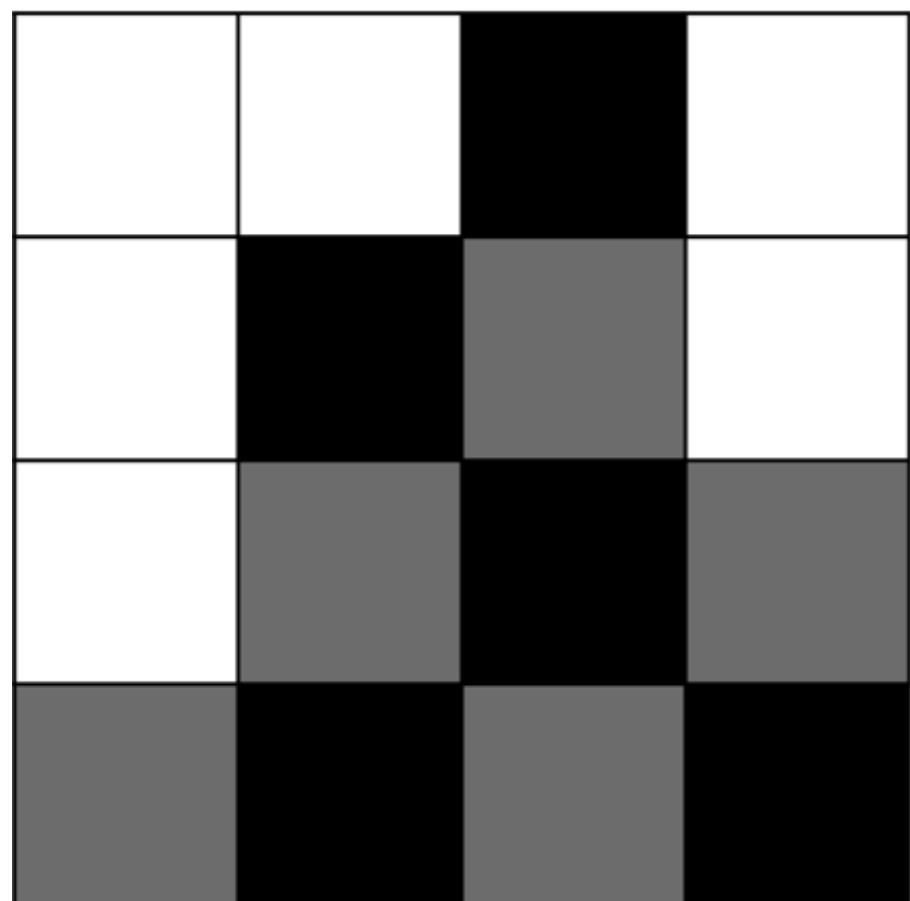
Shapes



Objects

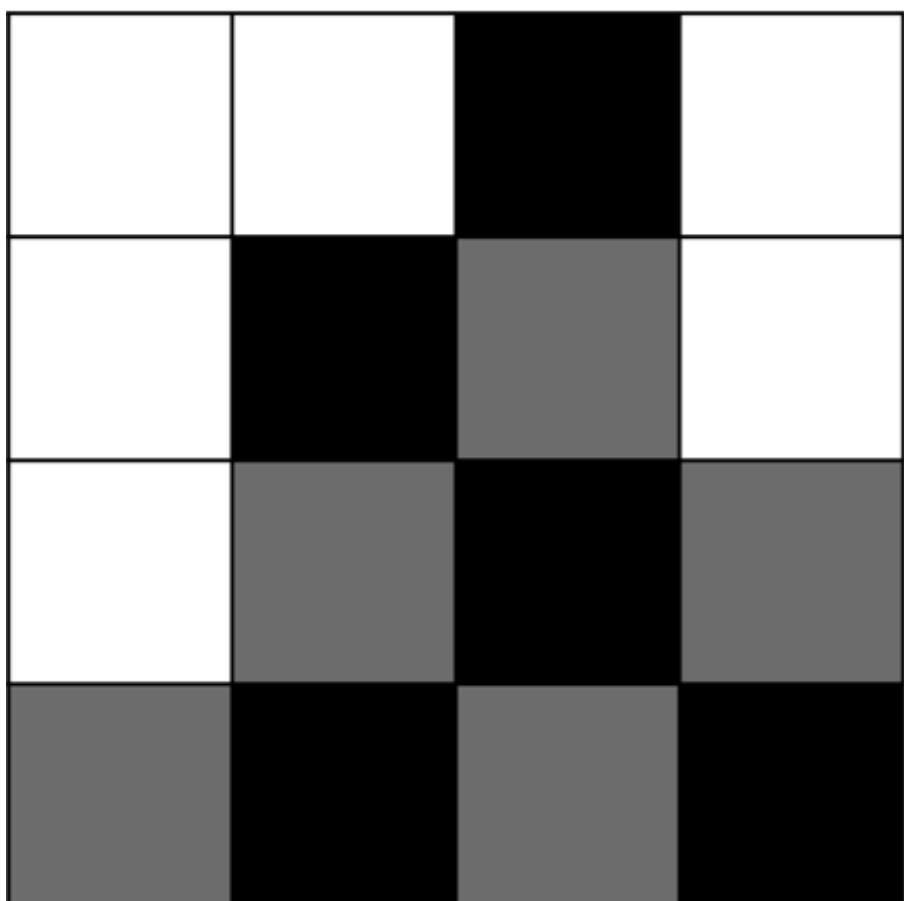
# Fully Connected Layer

# Input

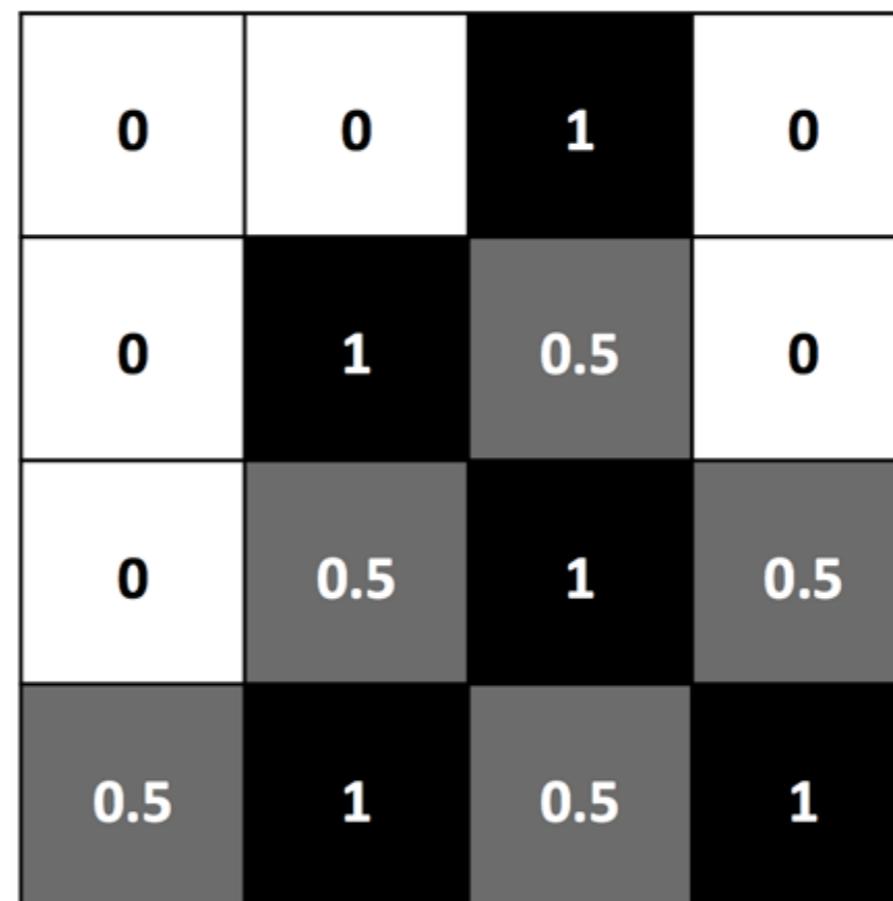


0	0	1	0
0	1	0.5	0
0	0.5	1	0.5
0.5	1	0.5	1

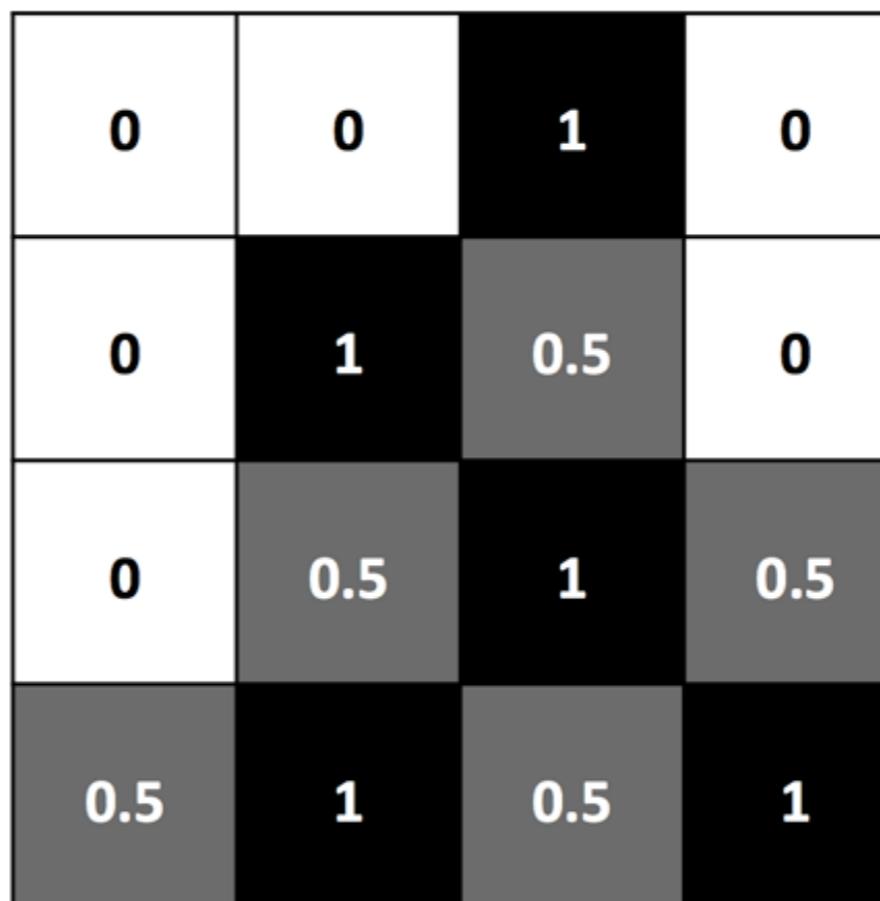
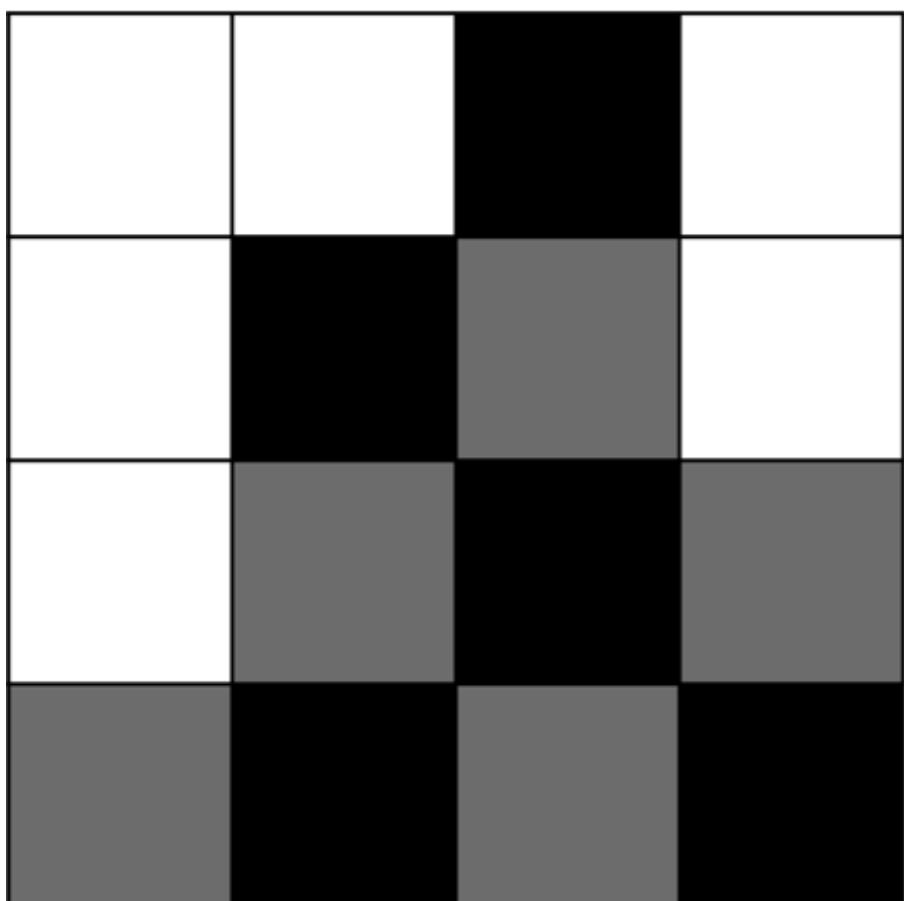
# Input



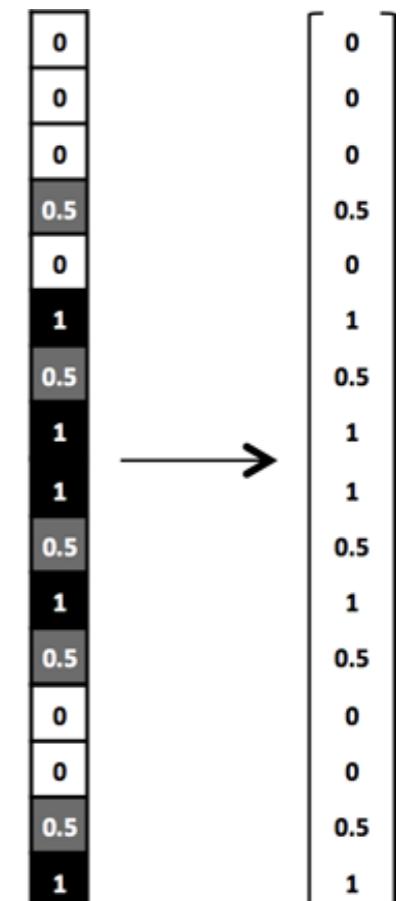
# Flatten



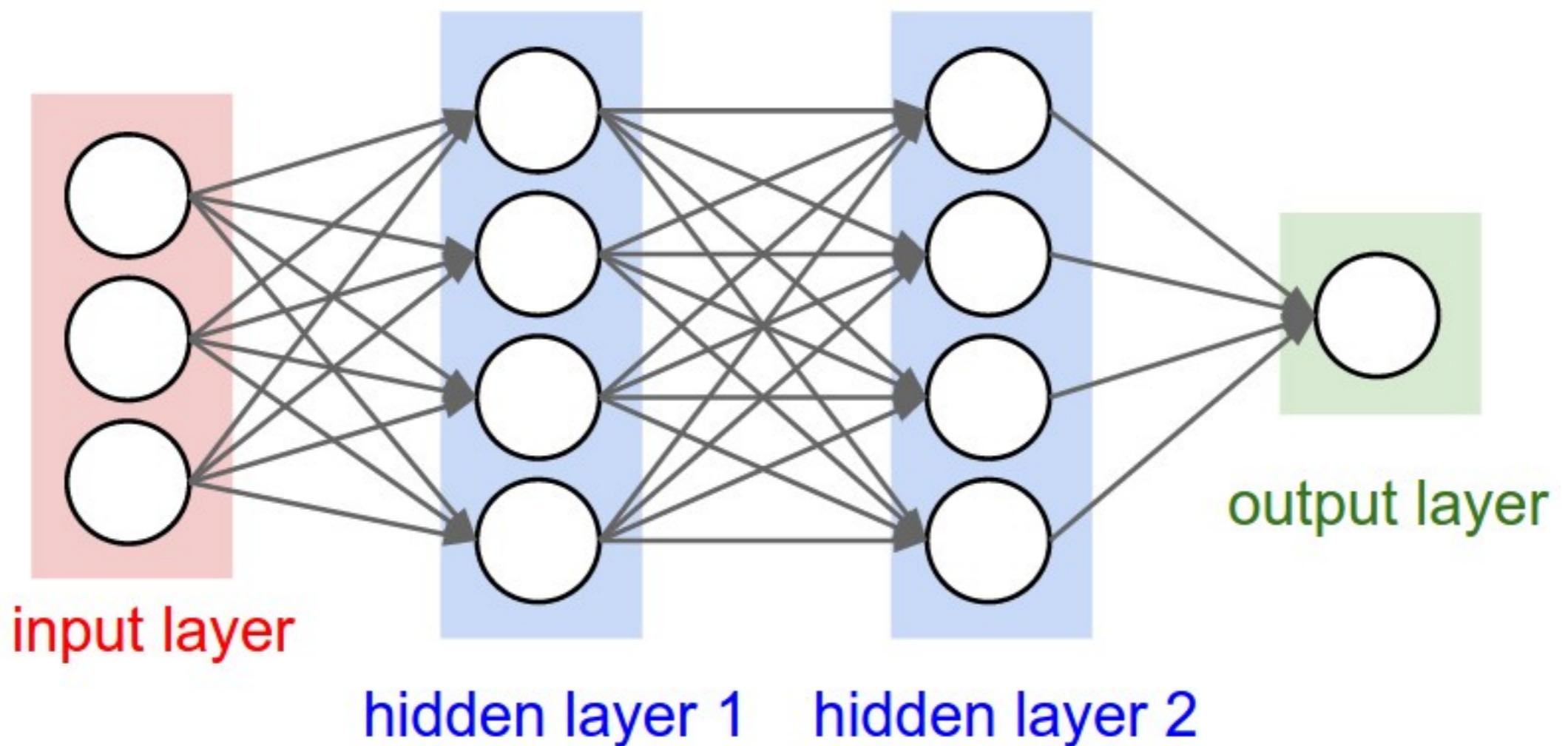
# Input



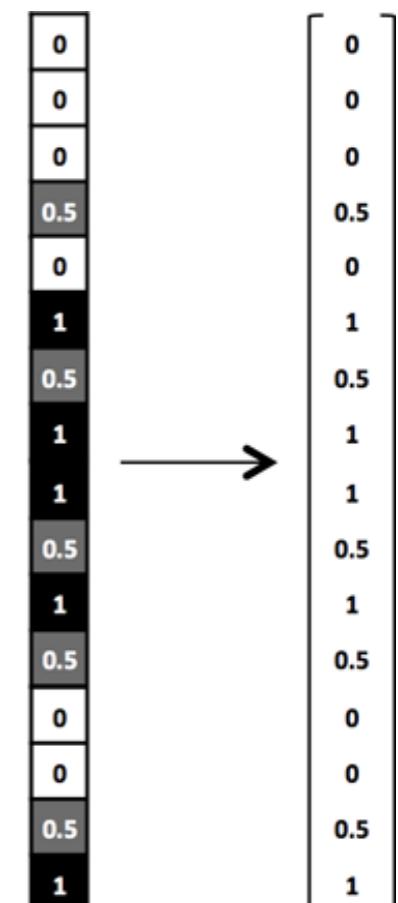
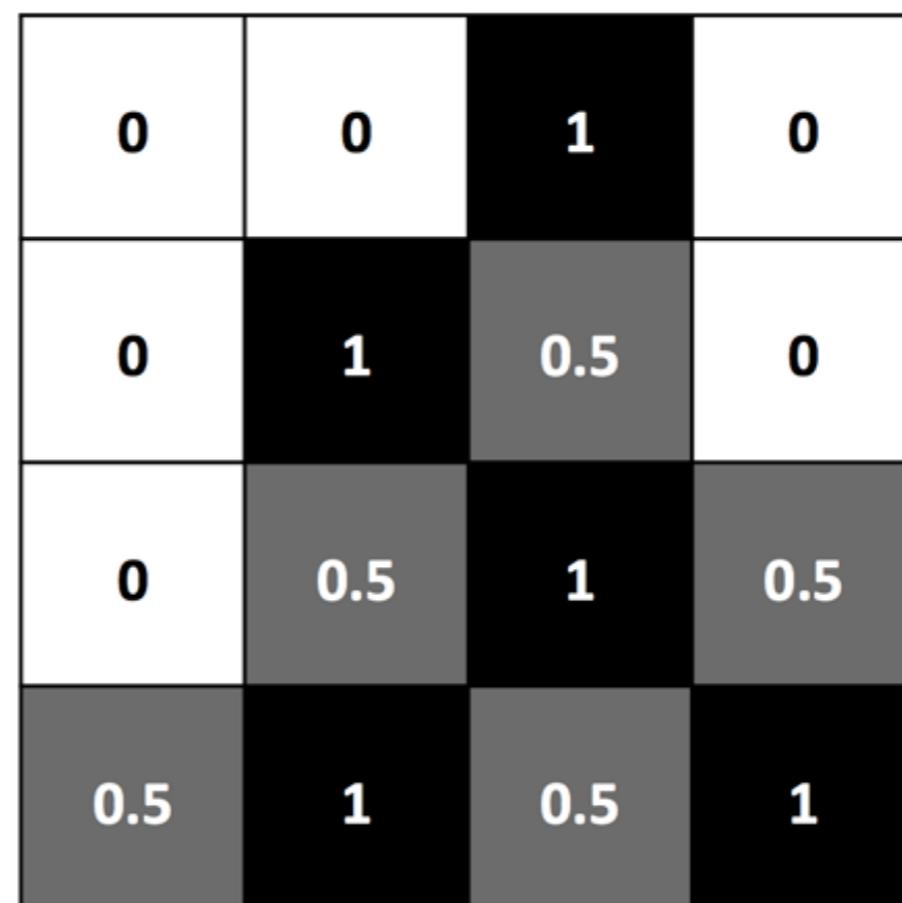
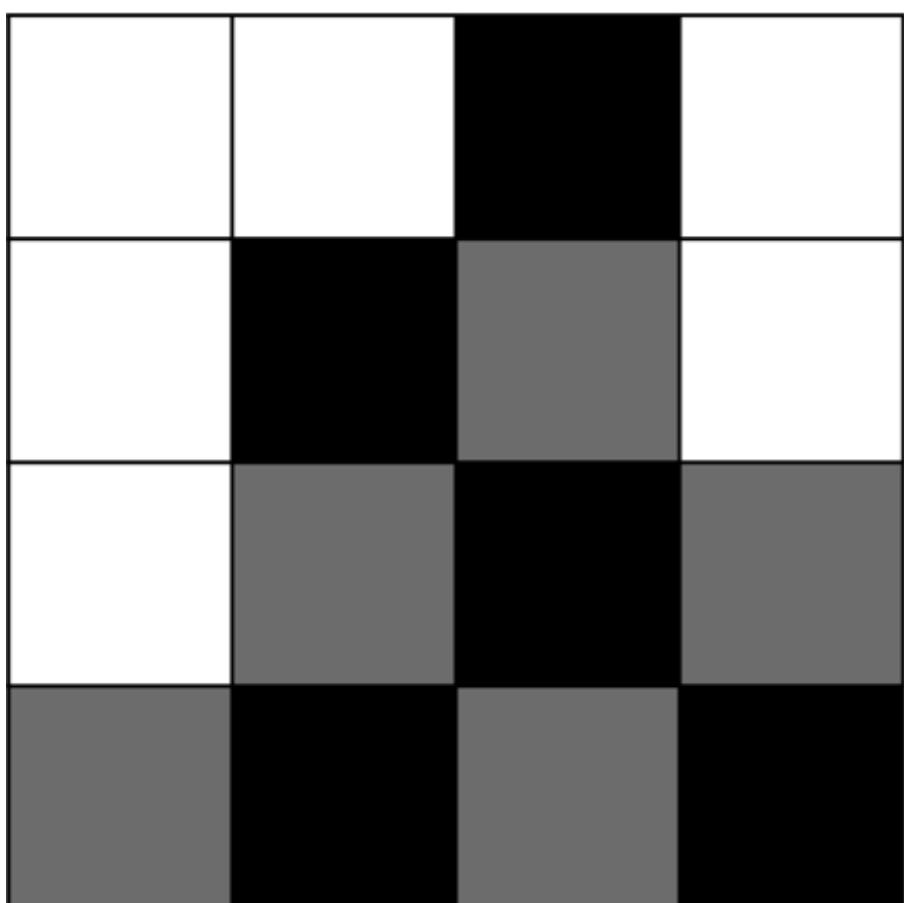
# Flatten



# Fully-Connected Layer

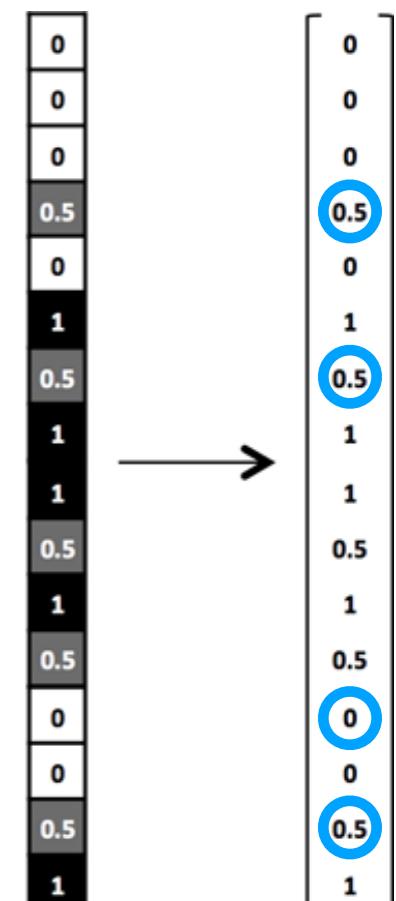
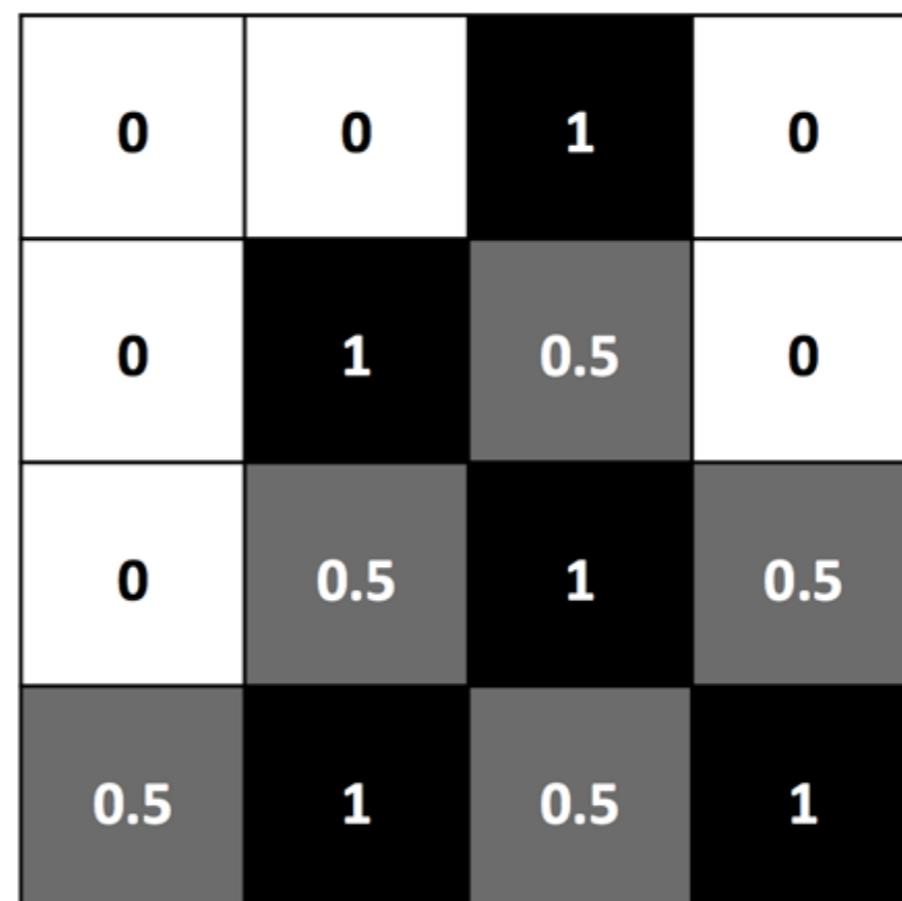
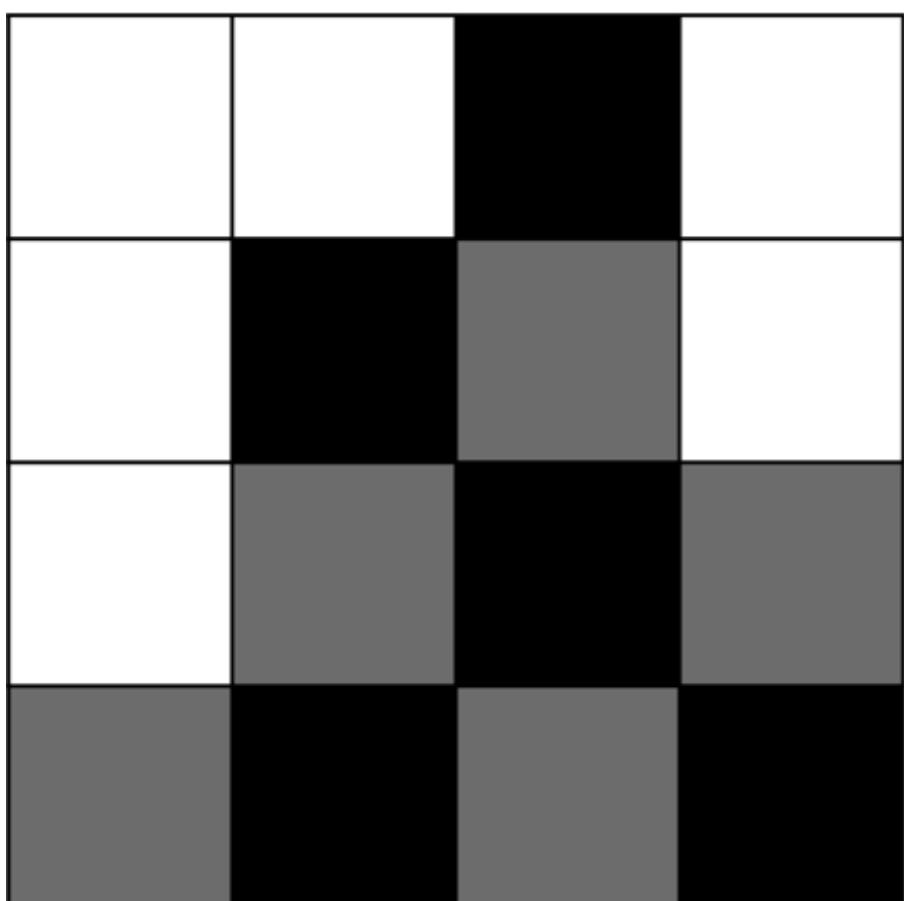


**Input  $x$**   
(pixel intensities)



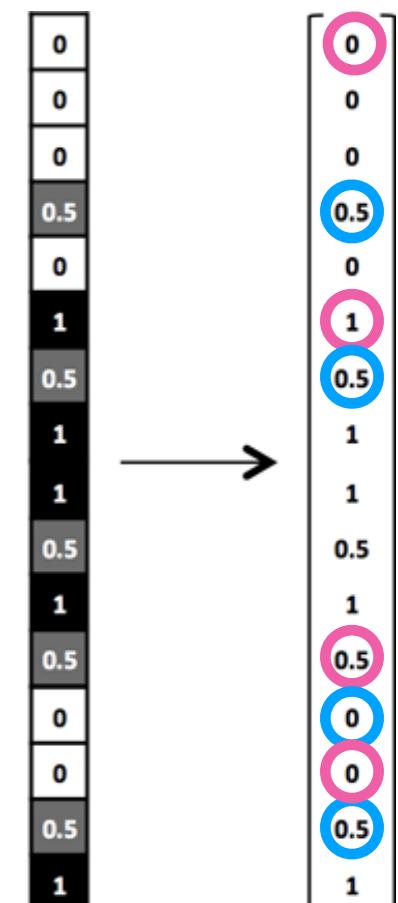
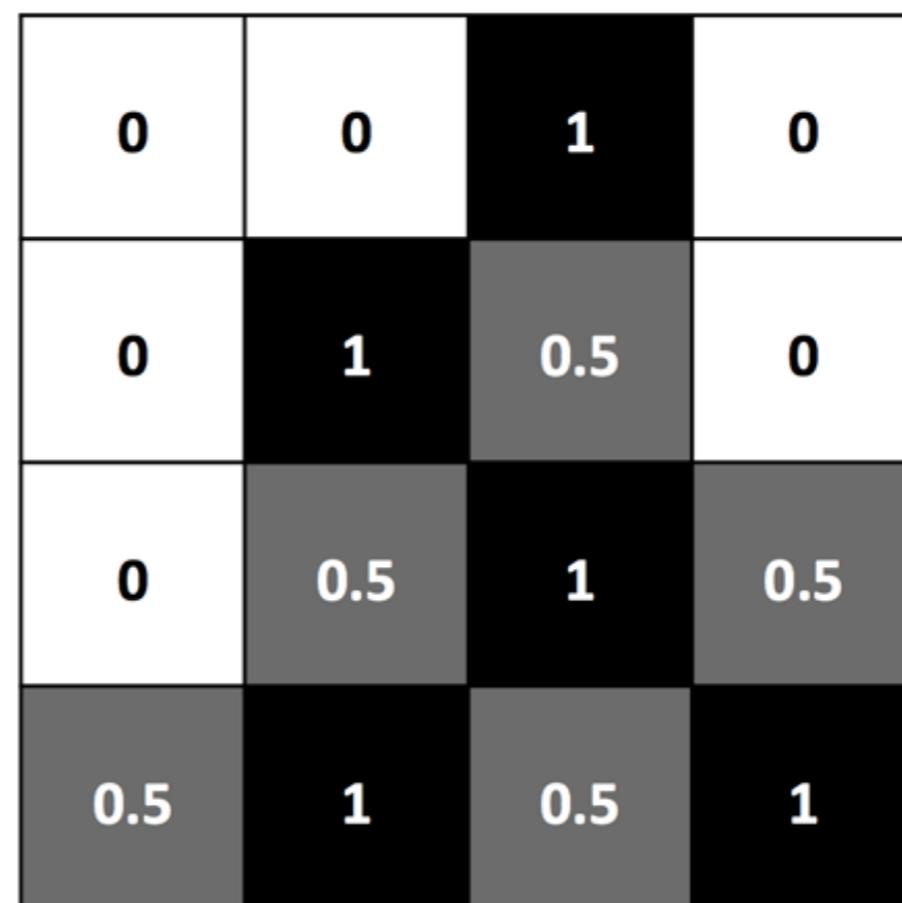
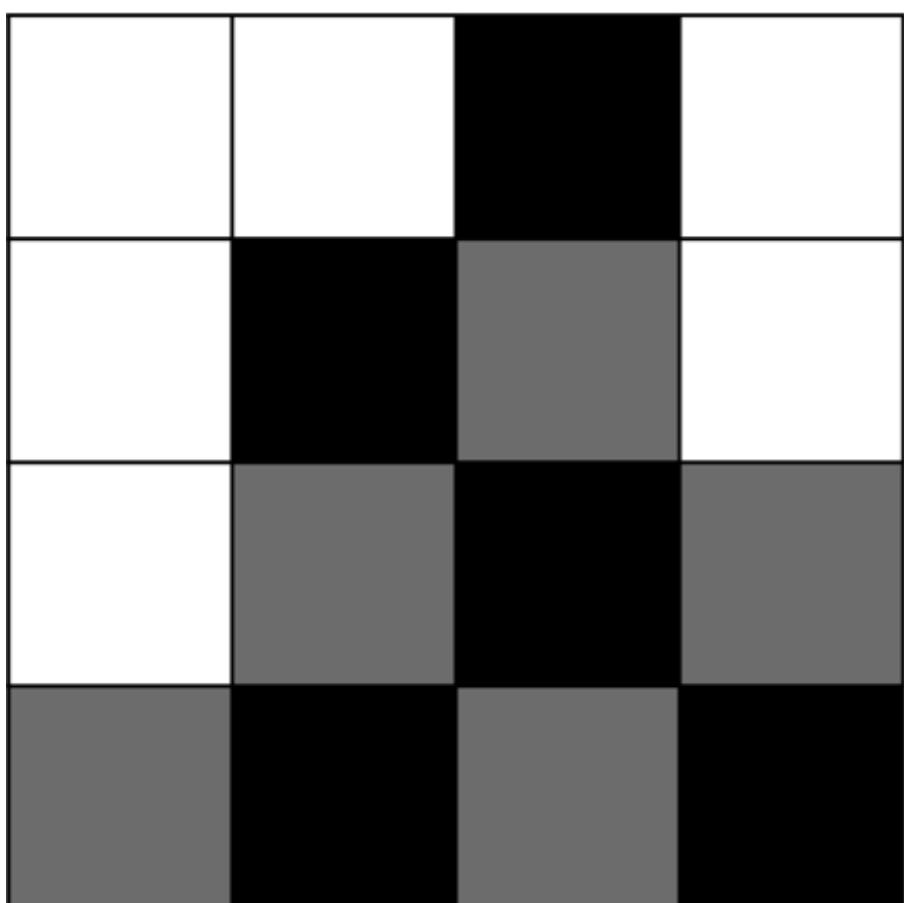
**Flatten**

**Input  $x$**   
(pixel intensities)

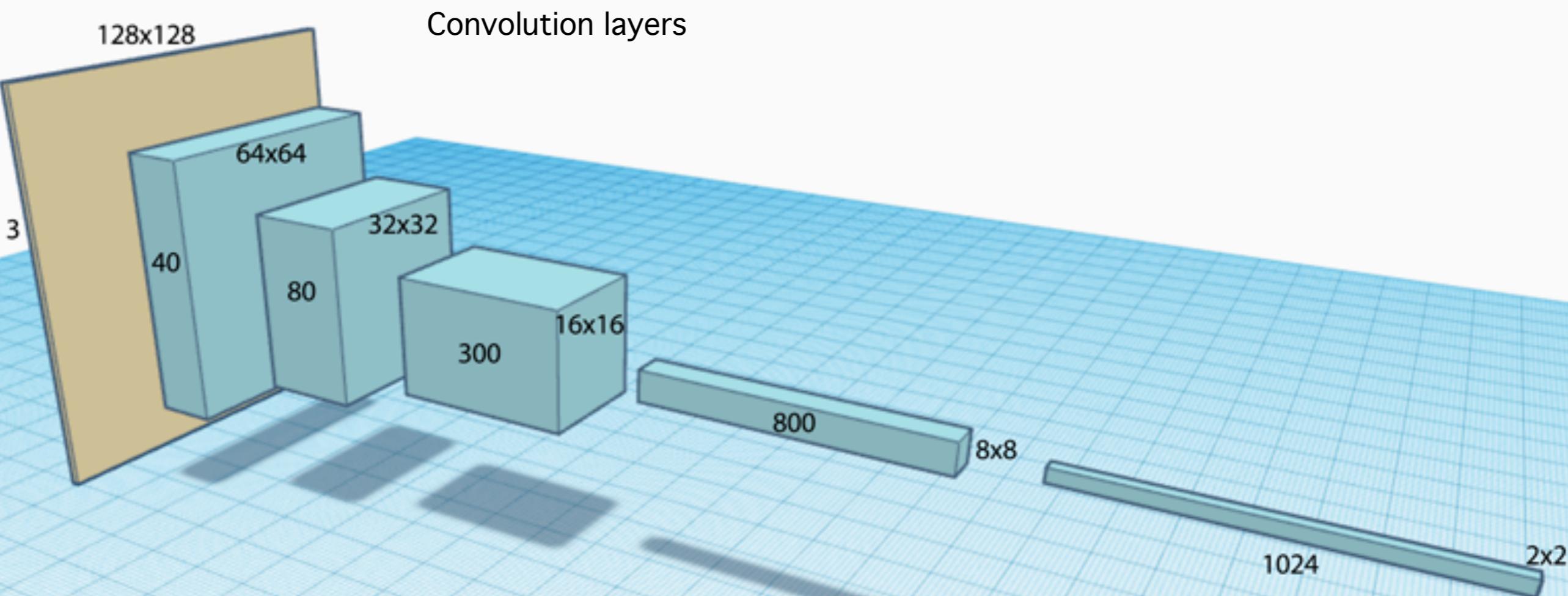


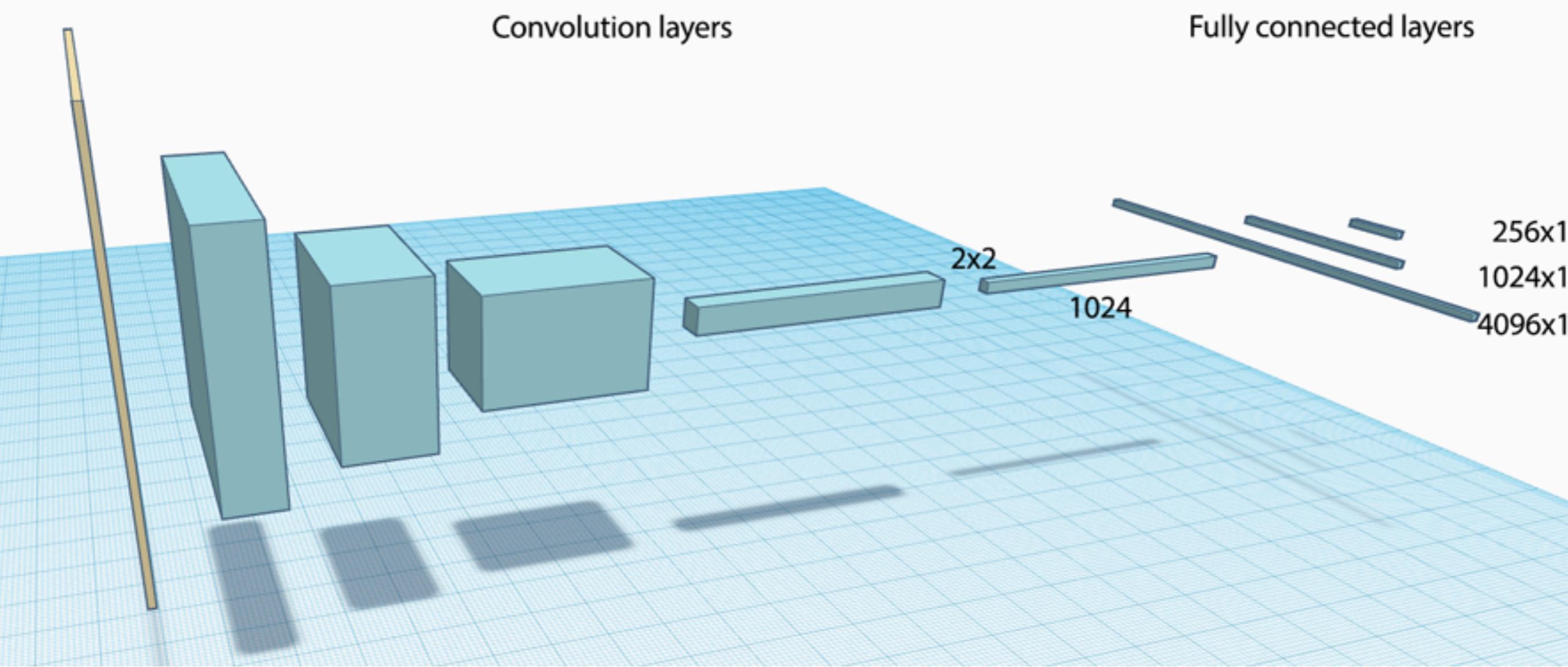
**Flatten**

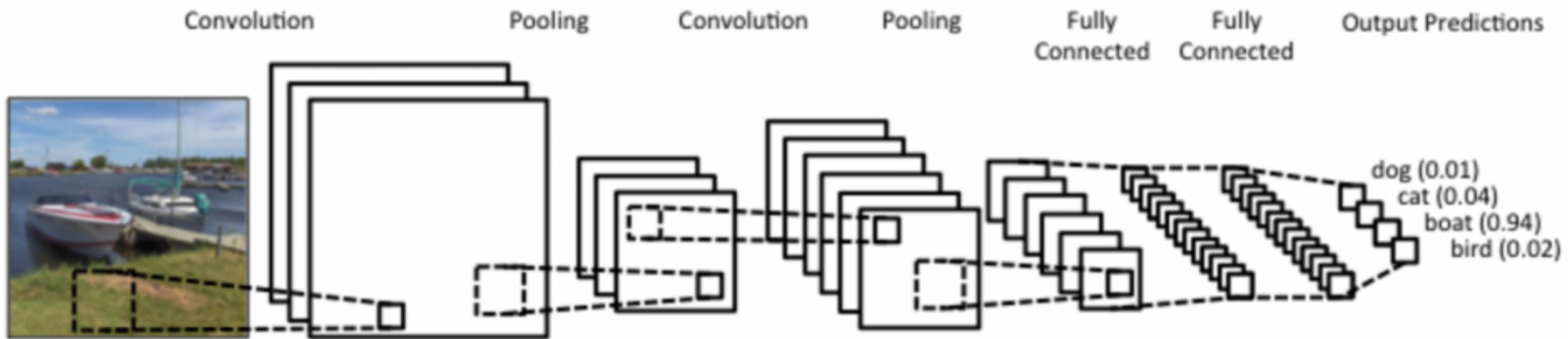
**Input  $x$**   
(pixel intensities)

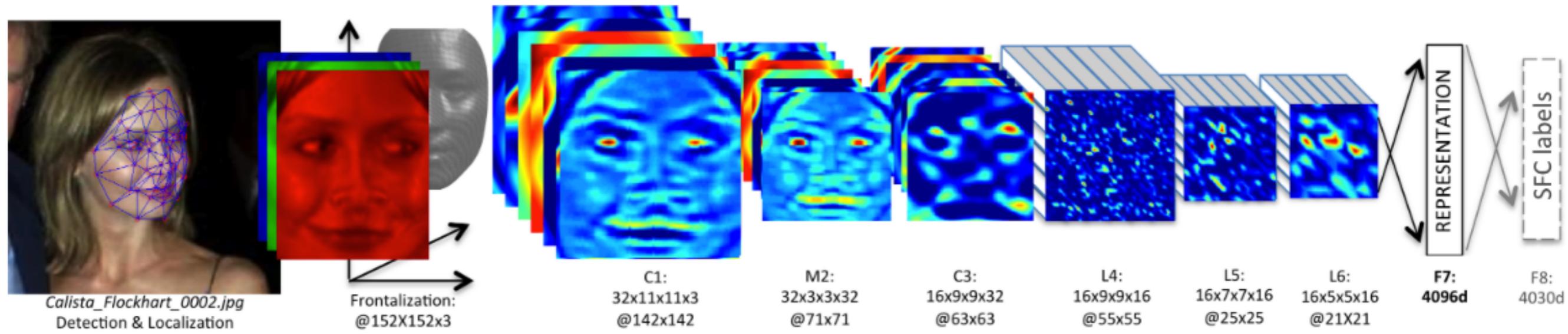


**Flatten**

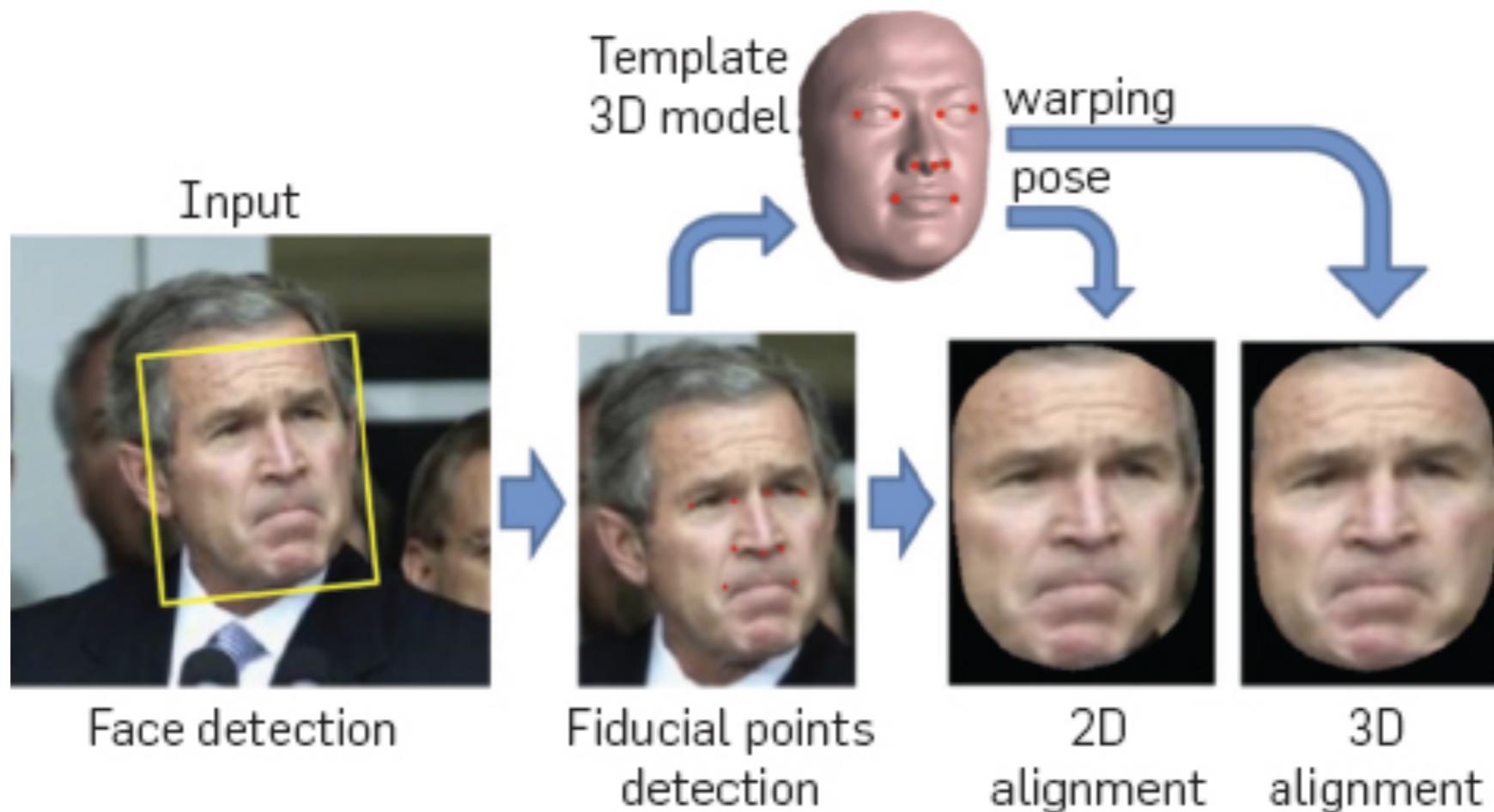








# Facebook - DeepFace



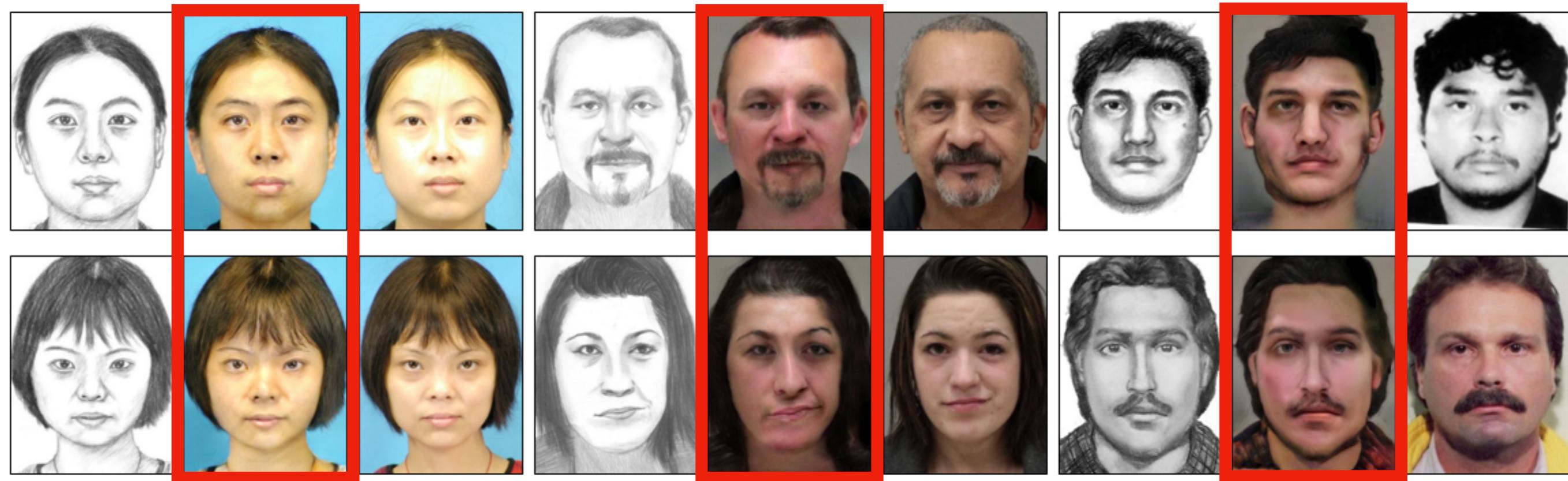
# Facial Recognition



# Sketch-Photo Recognition



# Synthesized Photos





PLAYLIST

# Discover Weekly

Your weekly mixtape of fresh music. Enjoy new discoveries and deep cuts chosen just for you. Updated every Monday, so save your favourites!

Created by: Spotify • 30 songs, 2 hr 48 min

PLAY

FOLLOWING

...

FOLLOWER

1

Filter

Download 

SONG

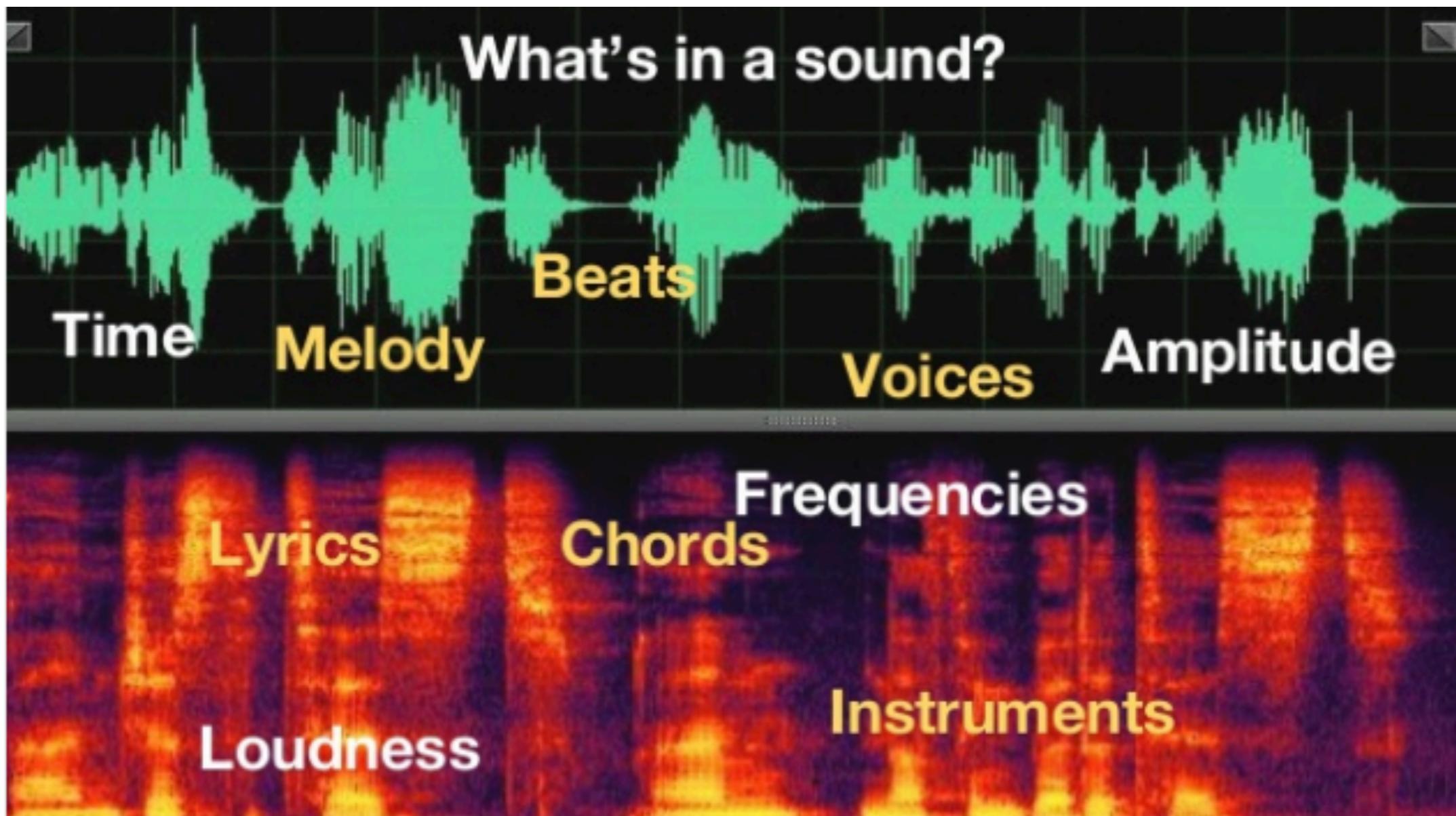
ARTIST

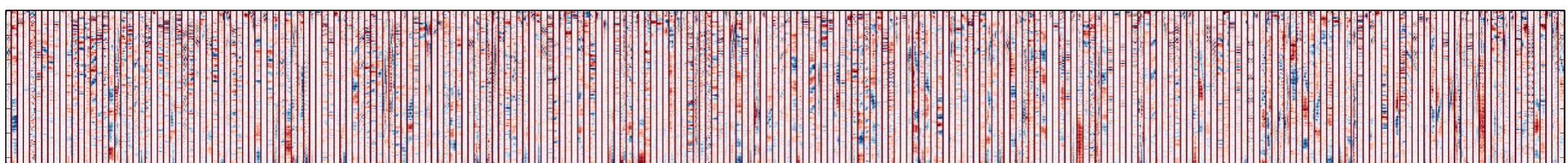
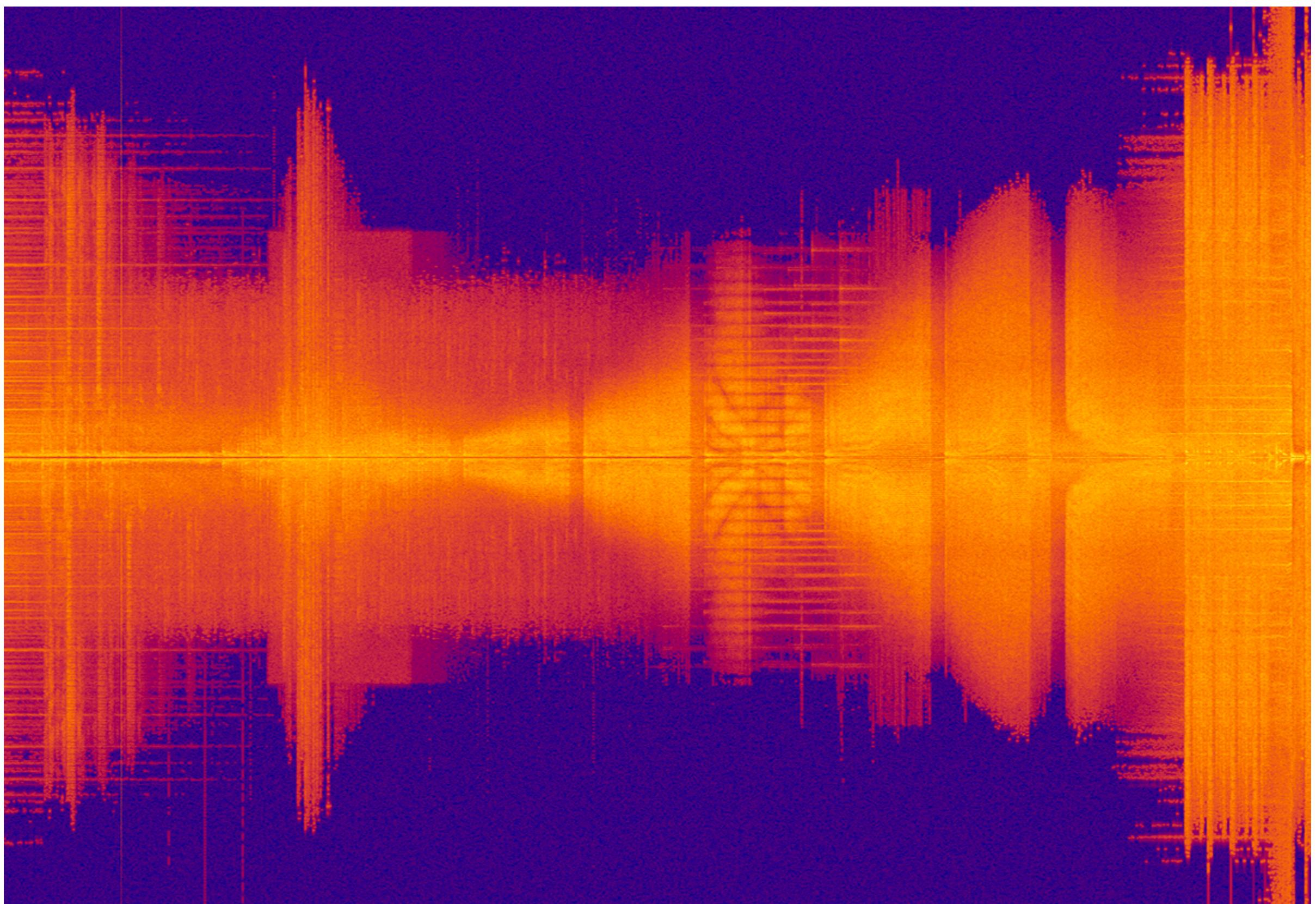
ALBUM

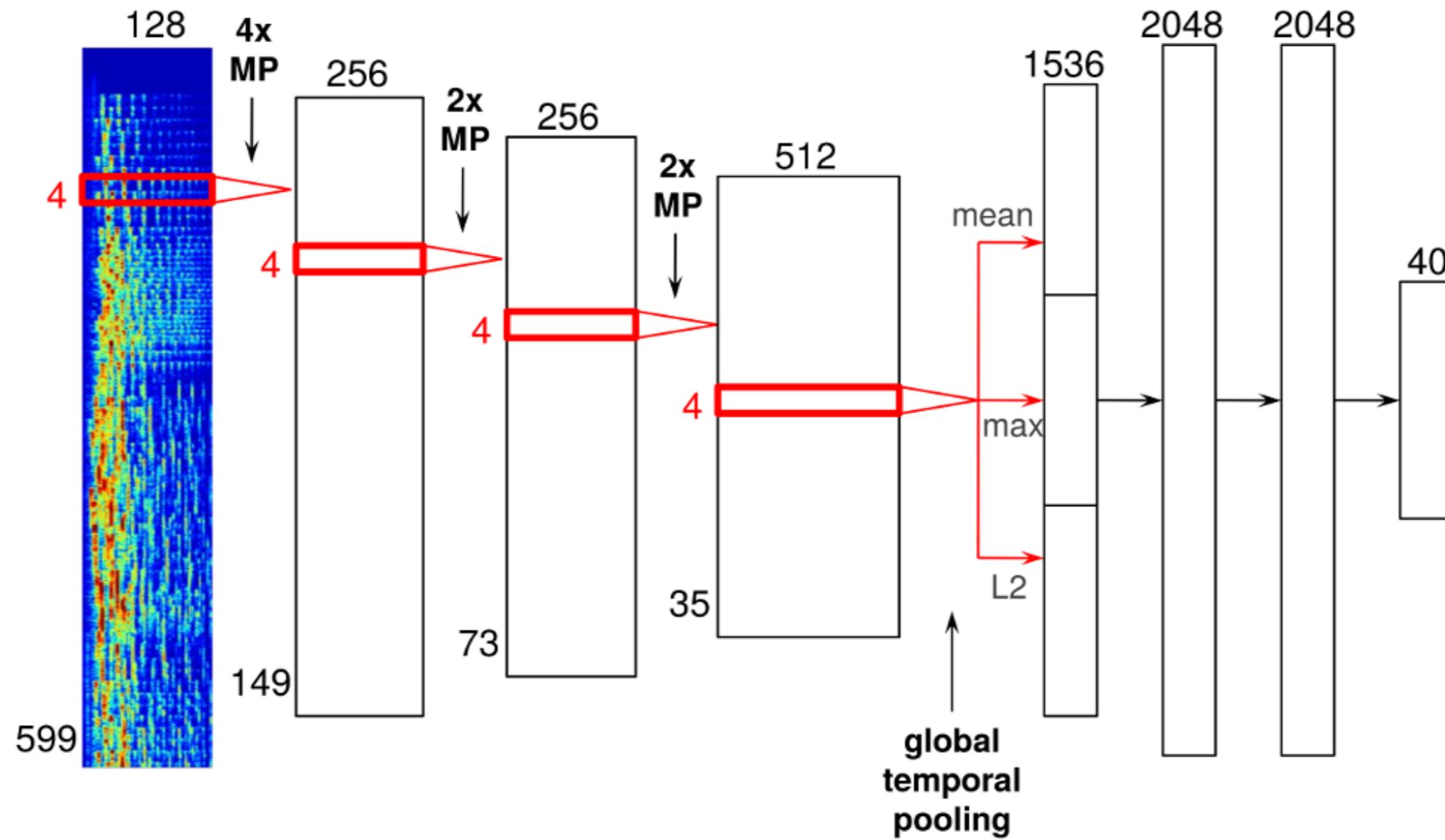
1

🕒

+	The Sky out of Your Window	Melorman	Waves	4 days ago	3:21
+	You Have Love	Axel Thesleff	You Have Love	4 days ago	7:21
+	You're Still In It	Chihei Hatakeyama	You're Still In It	4 days ago	18:26
+	Morning Mountain	Essay	Morning Mountain	4 days ago	6:42









# Recognizing Race by Voice

