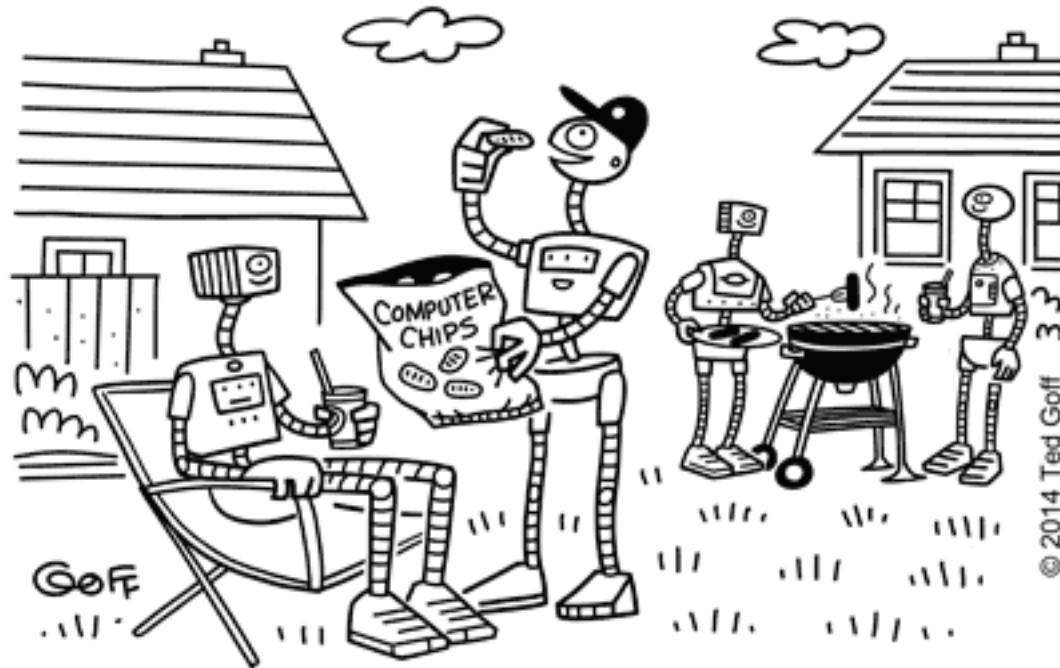
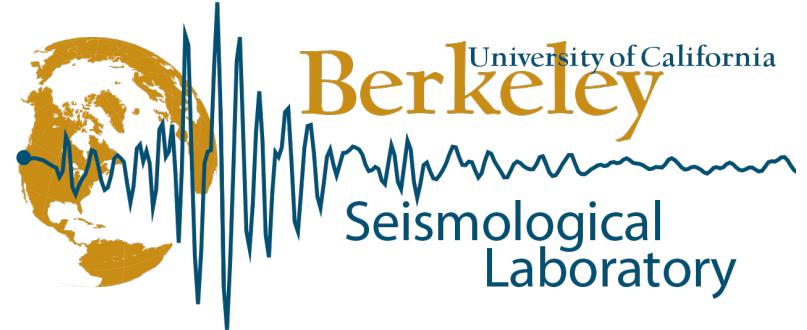


## LABOR DAY BBQ 2050



“Try one of these. They’re salty, and they come with nine new human skills.”

<https://github.com/qingkaikong/20170413 ANN basics DLab>

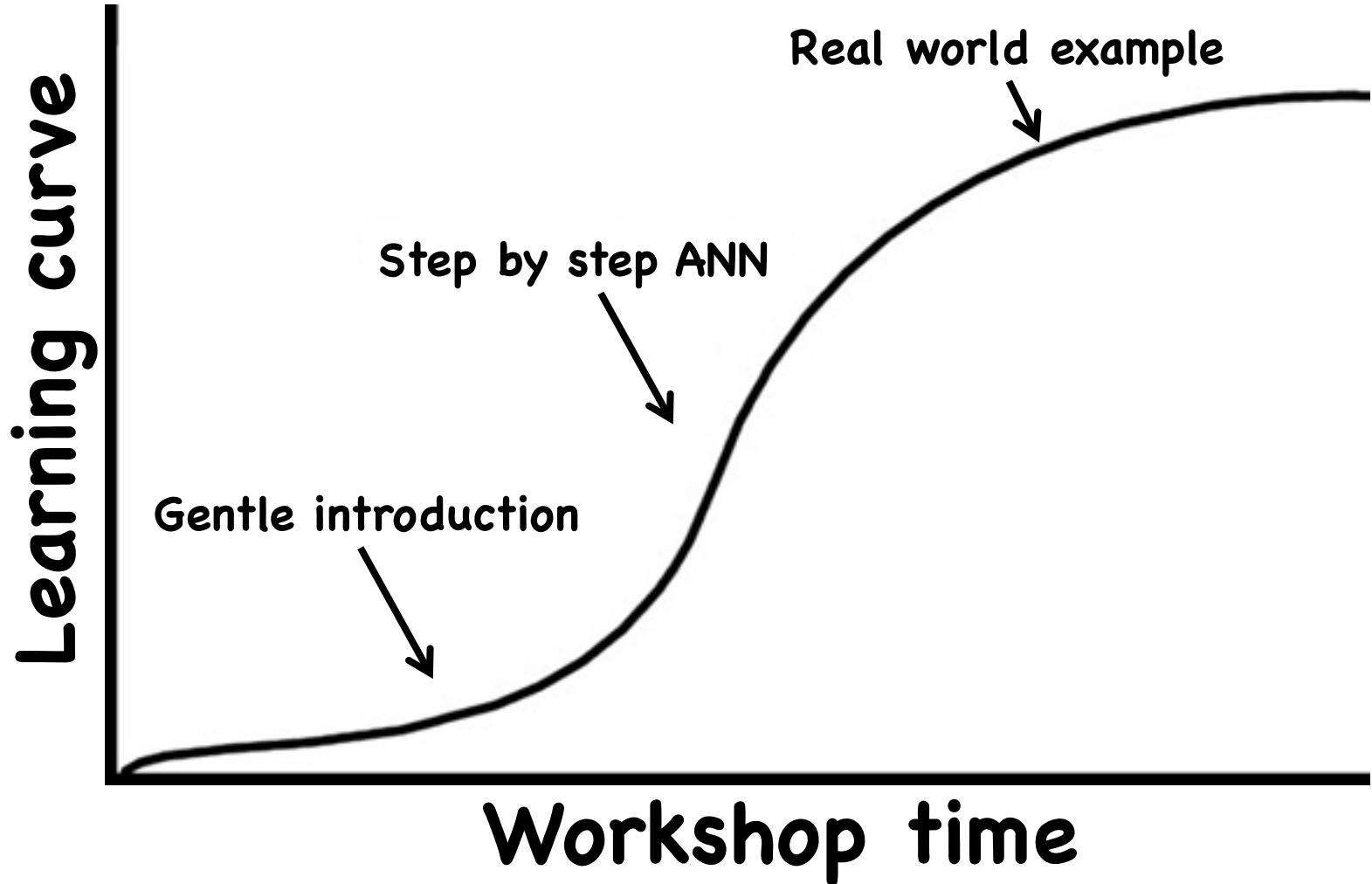


# Introduction to Artificial Neural Networks

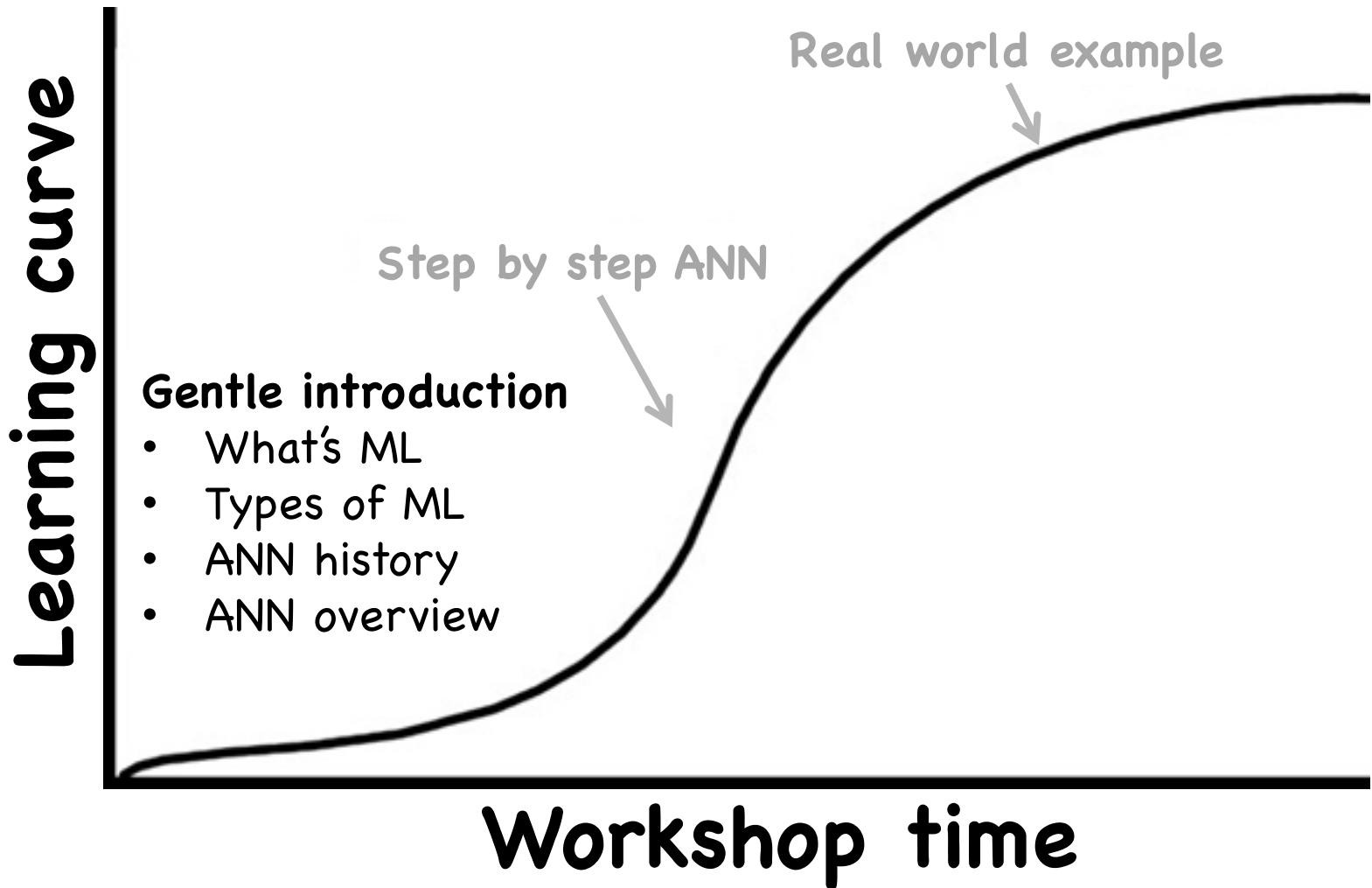
Qingkai Kong  
2017-04-13



<http://seismo.berkeley.edu/qingkaikong/>

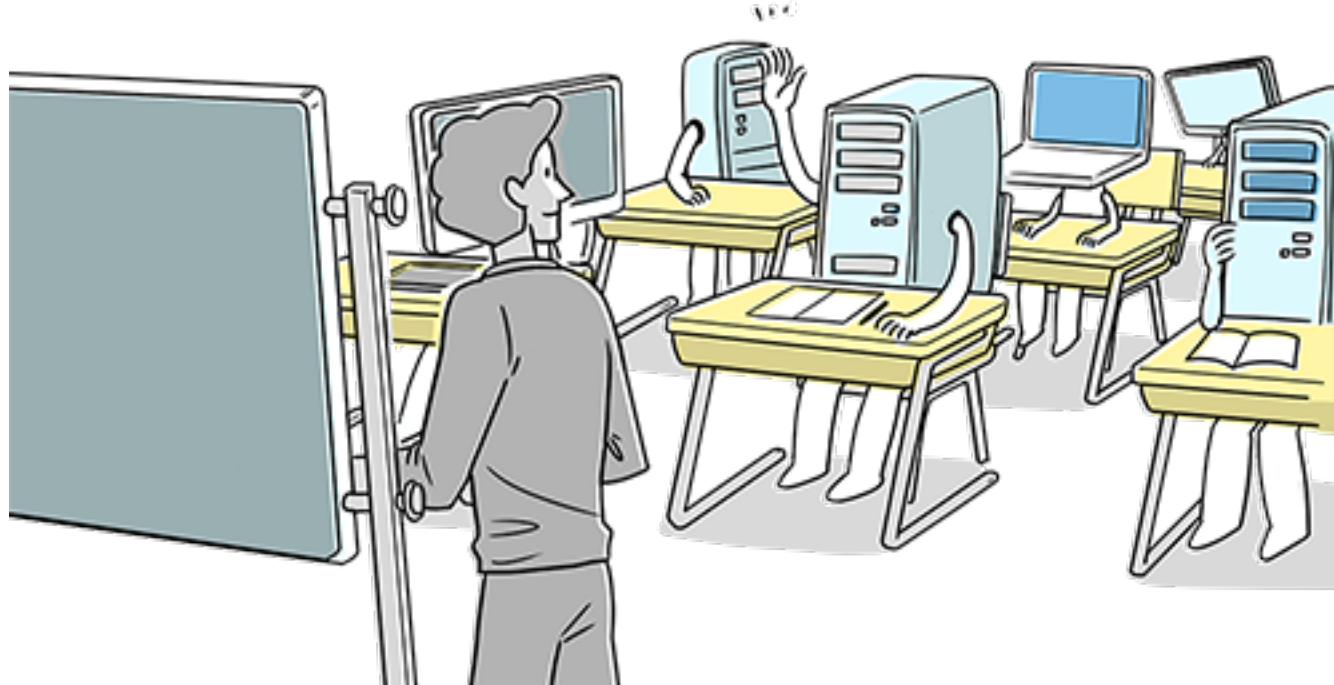


[https://github.com/qingkaikong/20170413\\_ANN\\_basics\\_DLab](https://github.com/qingkaikong/20170413_ANN_basics_DLab)



[https://github.com/qingkaikong/20170413\\_ANN\\_basics\\_DLab](https://github.com/qingkaikong/20170413_ANN_basics_DLab)

# What is machine learning?



[https://github.com/qingkaikong/20170413\\_ANN\\_basics\\_DLab](https://github.com/qingkaikong/20170413_ANN_basics_DLab)



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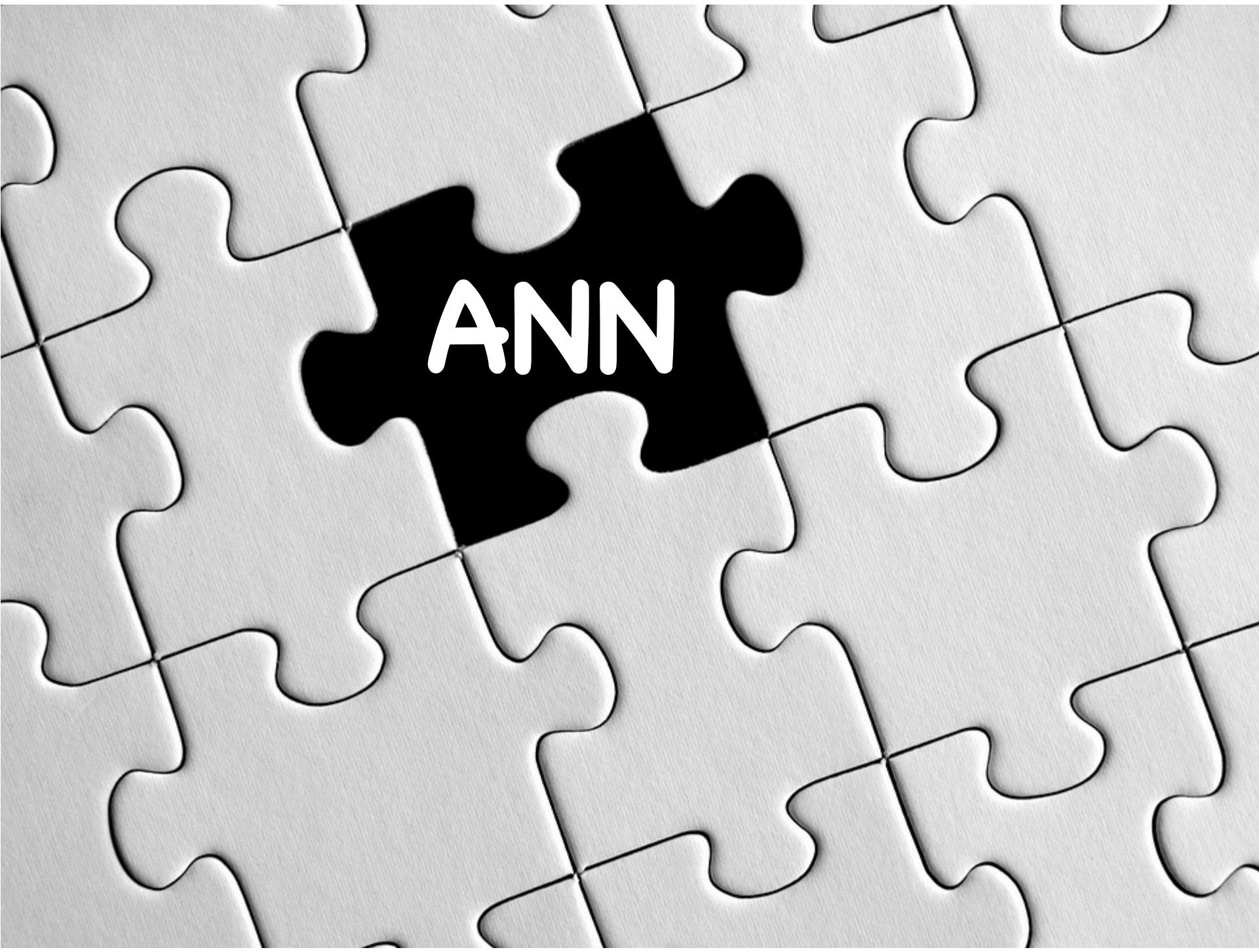
**Self-driving car  
Voice recognition**

...

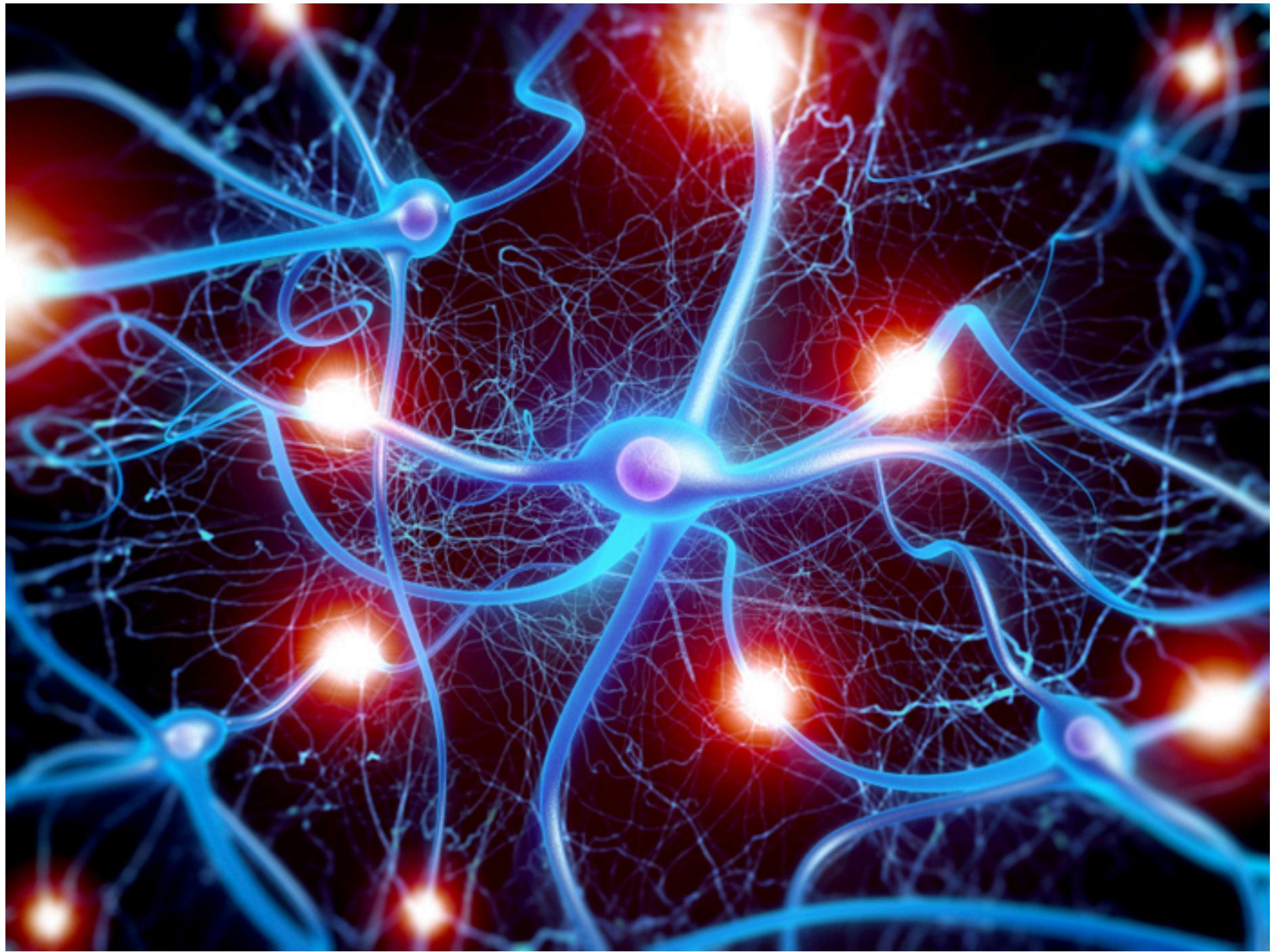
<https://github.com/qingkaikong/20170413 ANN basics DLab>

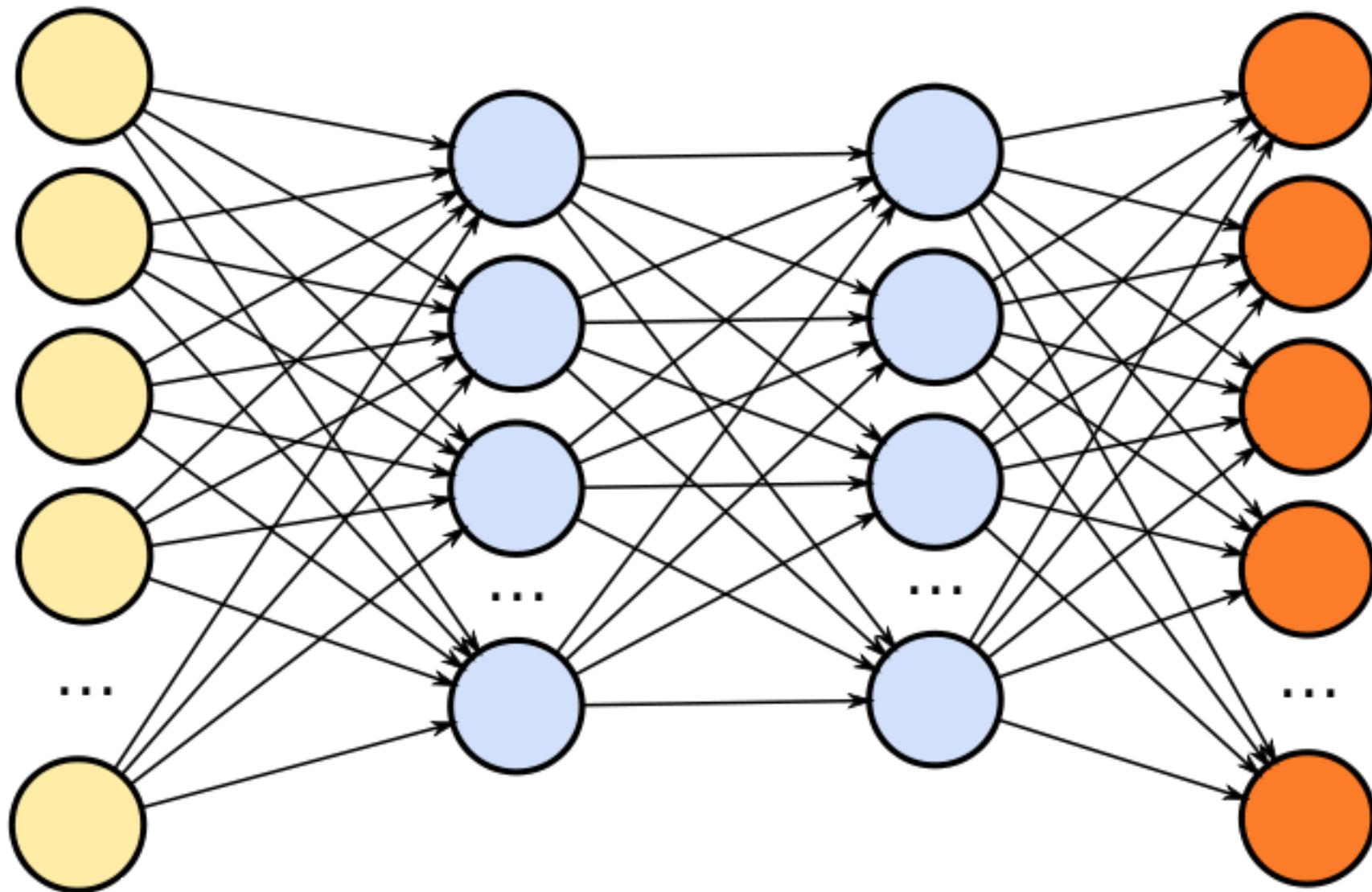
Not always  
working

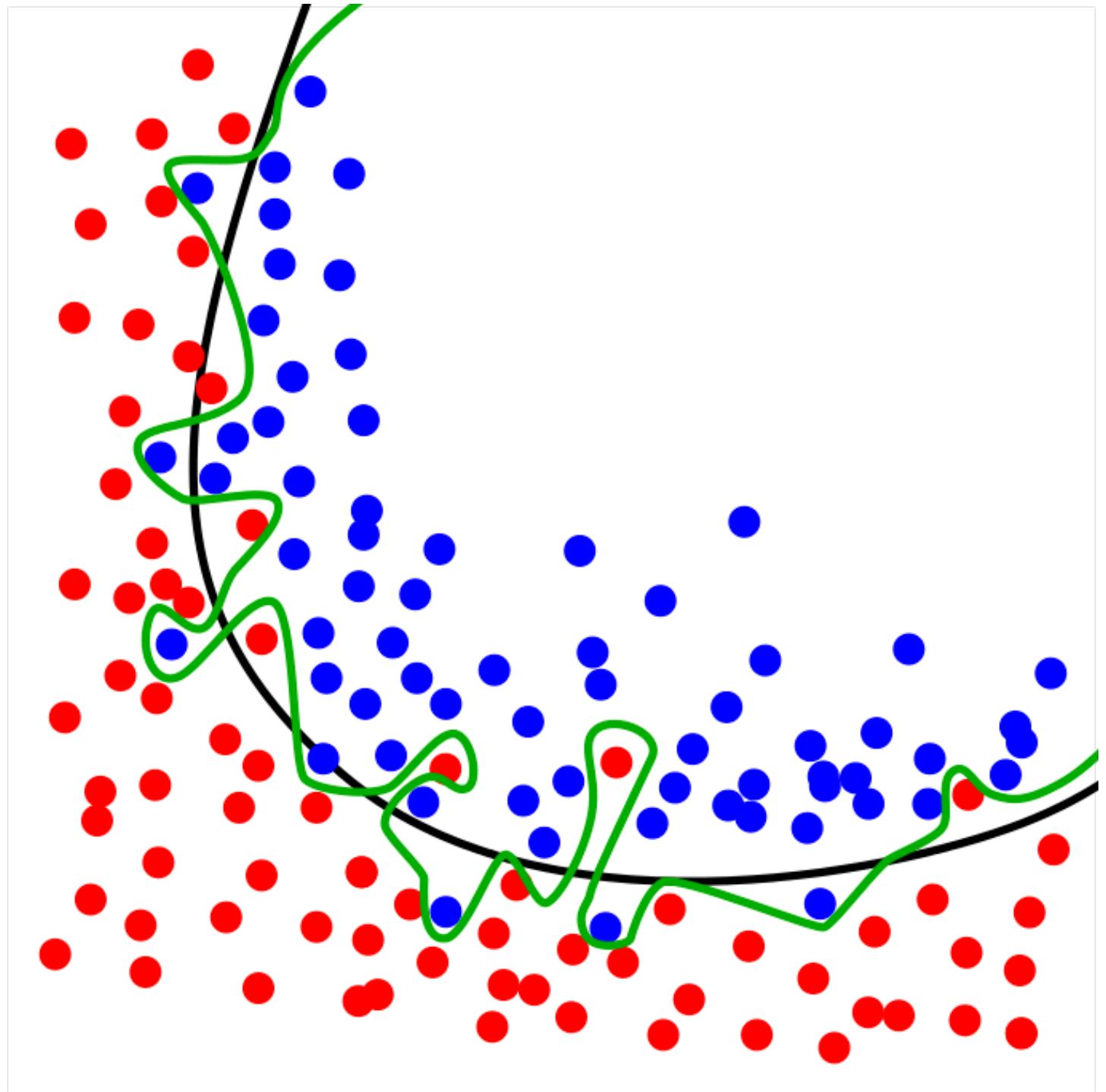




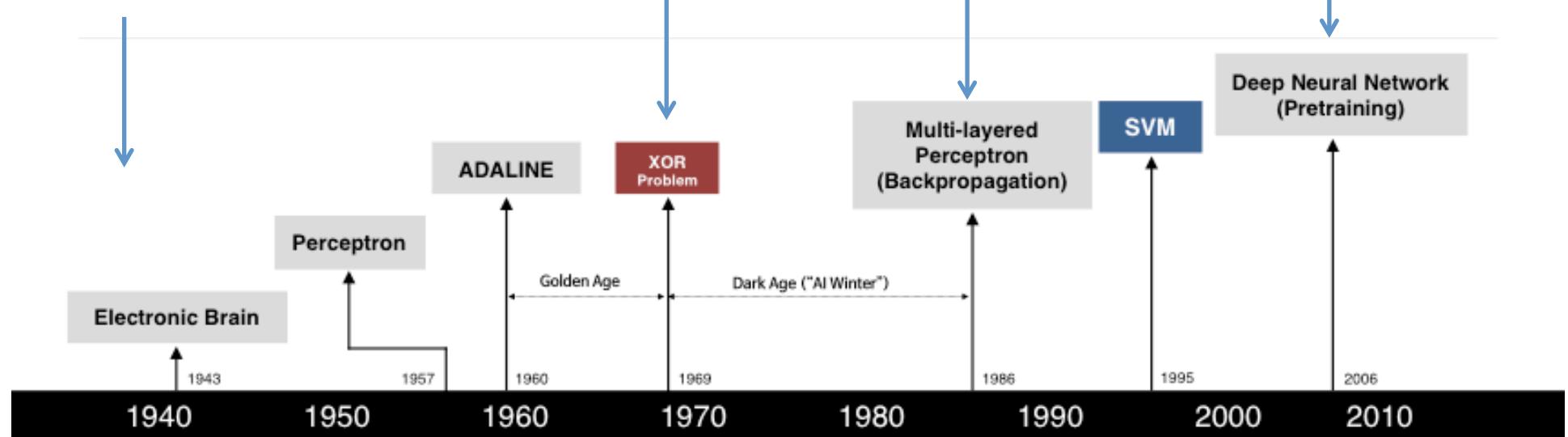
ANN







# 1940s Birth



S. McCulloch - W. Pitts



- Adjustable Weights
- Weights are not Learned



F. Rosenblatt



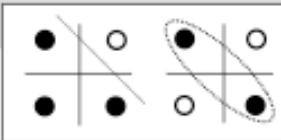
B. Widrow - M. Hoff



- Learnable Weights and Threshold



M. Minsky - S. Papert



• XOR Problem



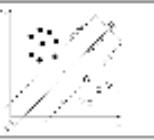
D. Rumelhart - G. Hinton - R. Williams



- Solution to nonlinearly separable problems
- Big computation, local optima and overfitting



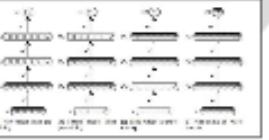
V. Vapnik - C. Cortes



- Limitations of learning prior knowledge
- Kernel function: Human Intervention



G. Hinton - S. Ruslan

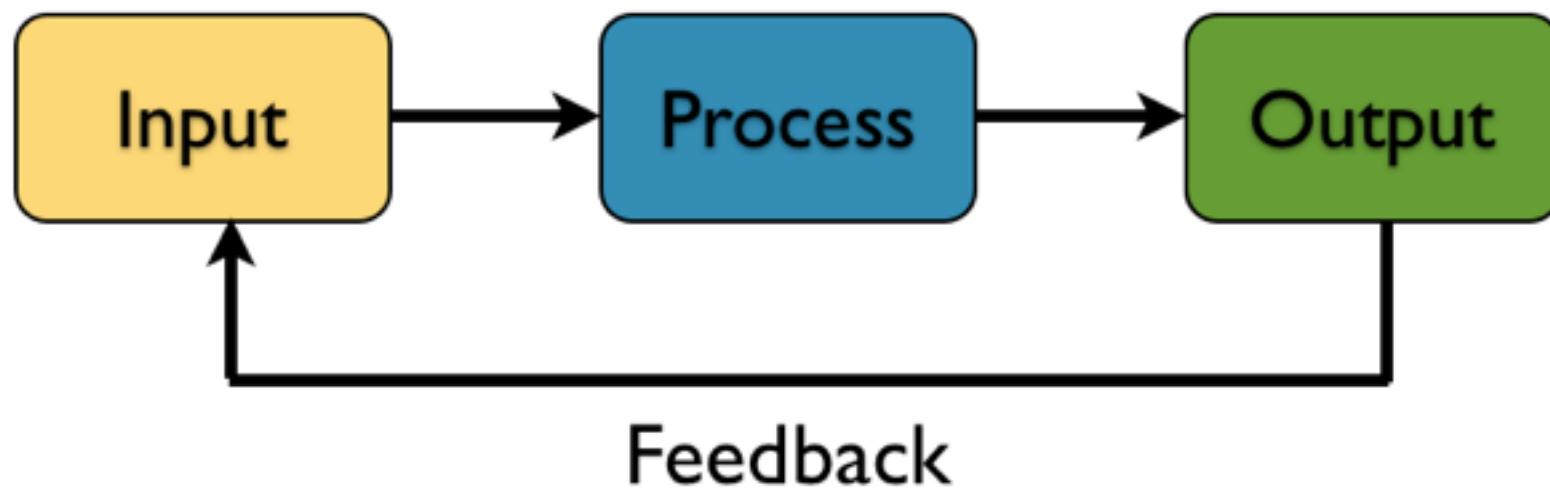


- Hierarchical feature Learning

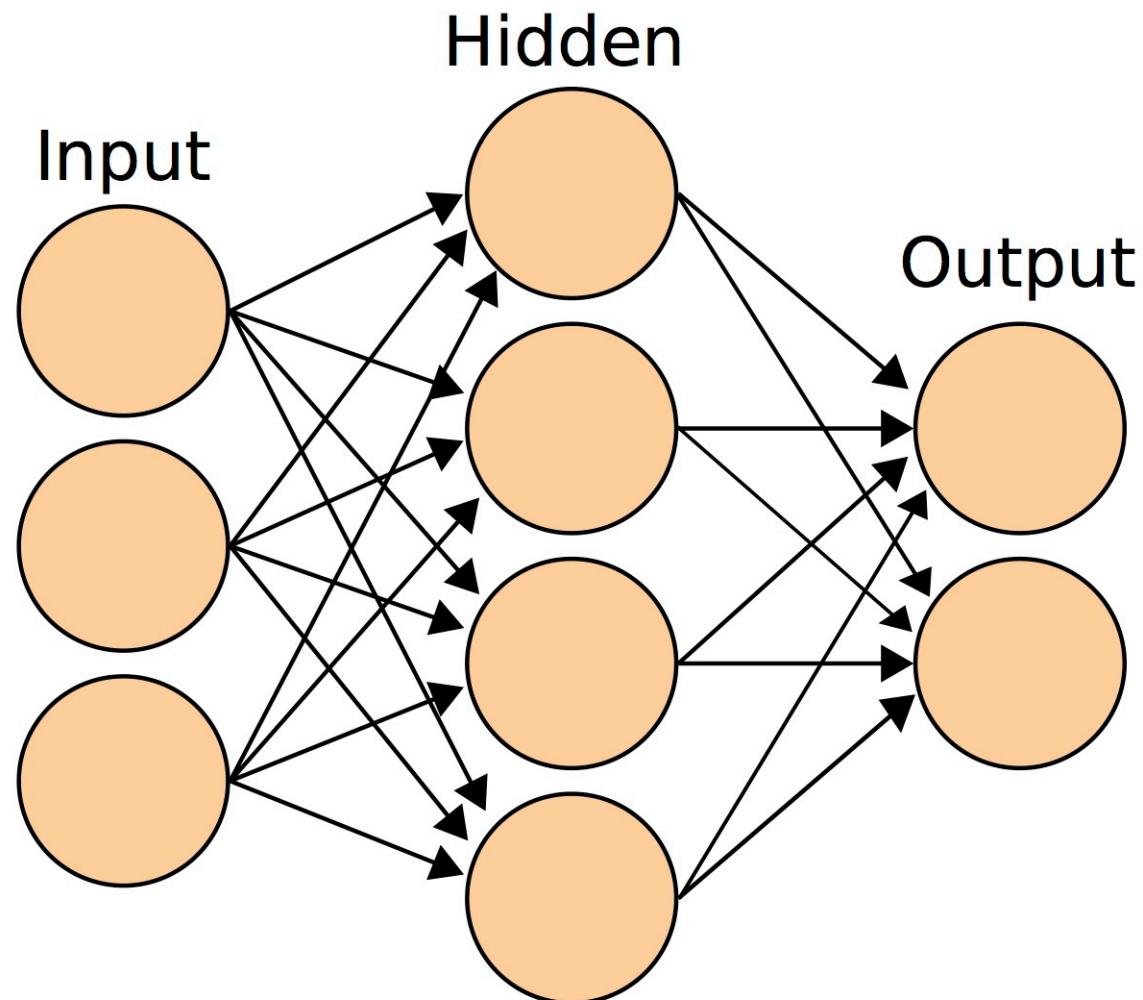
$\psi(g) = g$        $f(\bar{T}_P) = \perp \text{ on } V_E$        $\Leftrightarrow \exists E \in (\mathcal{C})^{(\pi^{\alpha} + p^{\alpha}, y)} \text{ such that } M = X(E|F_{\infty})$   
 $x^2 + ax + b$        $x^2 + x + 1$   
 $(x + \frac{a}{1+\alpha}) \oplus (1 + \frac{a}{1+\alpha})$   
 $\frac{a^2 + 2a}{1+\alpha} = \alpha \frac{(a+2)}{\alpha+1}$   
 $K_g = 1318$   
 $N_{R_L} = D_{S,L} K$   
 $\psi(f) = f$   
 $D = (1+T) \frac{d}{dT}$   
 $0 \rightarrow \text{Sh}(E/\mathbb{G}_m) \rightarrow H^1(G, E, \omega) \rightarrow H^1(E/\mathbb{G}_m, E, \omega)$   
 $\psi(f) = f$   
 $N(f) = \sum_{n=1}^{\infty} a_n T^n = \sum_{n=1}^{\infty} p^n x^n$   
 $\Delta(1) \oplus \Delta(1) \oplus \Delta(1) \oplus \Delta(1)$   
 $T(\mu_p) \oplus T(\mu_p) \oplus T(\mu_p) \oplus T(\mu_p)$   
 $\mathcal{U}_{\alpha} = \{x \in \mathbb{A}^1 : x \neq 0\}$   
 $\mathbb{E} = \{x \in \mathbb{A}^1 : x \neq 0\}$   
 $(x+y)^n = \lim_{m \rightarrow \infty} (x^{\frac{n}{m}} + y^{\frac{n}{m}})^m$   
 $X^1 + X + 1 = Q$   
 $X^2 + X + 1 = S_3$   
 $X^2 - X + 1 = S_3$   
 $X^4 - X^2 + 1 = S_3$   
 $X^8 - X^4 + 1 = S_3$   
 $X^{16} - X^8 + 1 = S_3$   
 $X^{32} - X^{16} + 1 = S_3$   
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 $X^{14615014719092386919882303109644365544} - X^{7307507359546193459944151554822158272} + 1 = S_3$   
 $X^{29230029438184773839764606219288731088} - X^{14615014719092386919882303109644365544} + 1 = S_3$   
 $X^{58460058876369547679529212438577462176} - X^{29230029438184773839764606219288731088} + 1 = S_3$   
 $X^{116920117531390855398588248771548924152} - X^{58460058876369547679529212438577462176} + 1 = S_3$   
 $X^{233840235062781710797176497543097848304} - X^{116920117531390855398588248771548924152} + 1 = S_3$   
 $X^{467680470125563421594352995086195696608} - X^{23384023506278171079717649754$



# ANN in simple view



# ANN jargons



# What're the weights





**YOU'RE IN MY SPOT**

GRAPHICS GARAGE

# Input



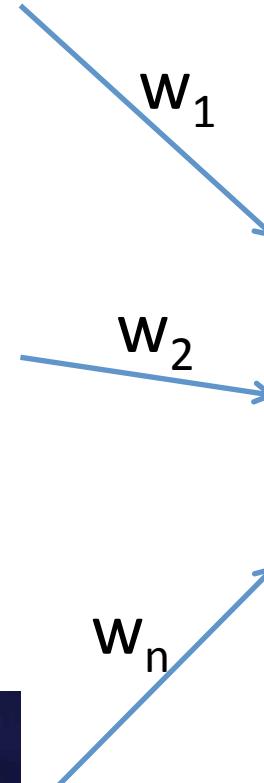
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# Intuitive Artificial Neural Network



# Output



# Input

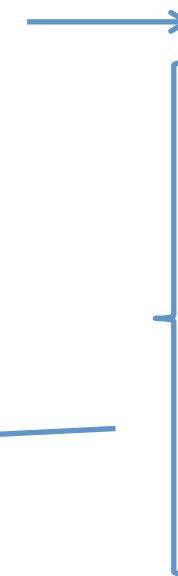


•  
•  
•



# Intuitive Artificial Neural Network

# Output



error  
feedback



# Input



•  
•  
•



# Intuitive Artificial Neural Network

# Output



$$F(\text{eye} \times w_1 + \text{nose} \times w_2 + \dots + \text{mouth} \times w_n)$$



error  
feedback



# Input



.

.

.



# Intuitive Artificial Neural Network

# Output

$$F(\text{eye} \times w_1 + \text{nose} \times w_2 + \dots + \text{mouth} \times w_n)$$



$w_1$

$w_2$

$w_n$



# Learning curve

Workshop time

Gentle introduction

- What's ML
- ANN history
- ANN overview

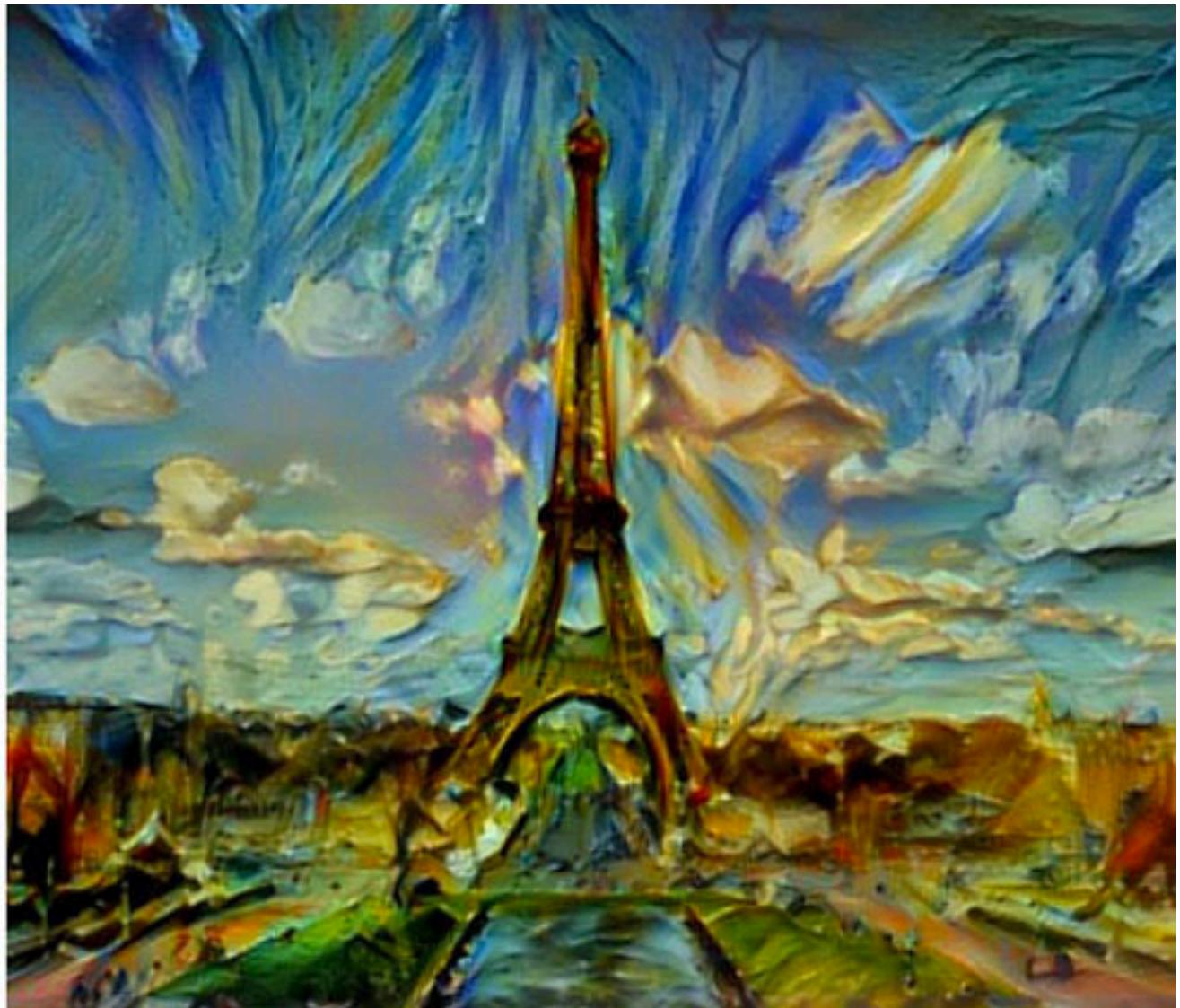
**Step by step ANN**

- Perceptron
- Backpropagation

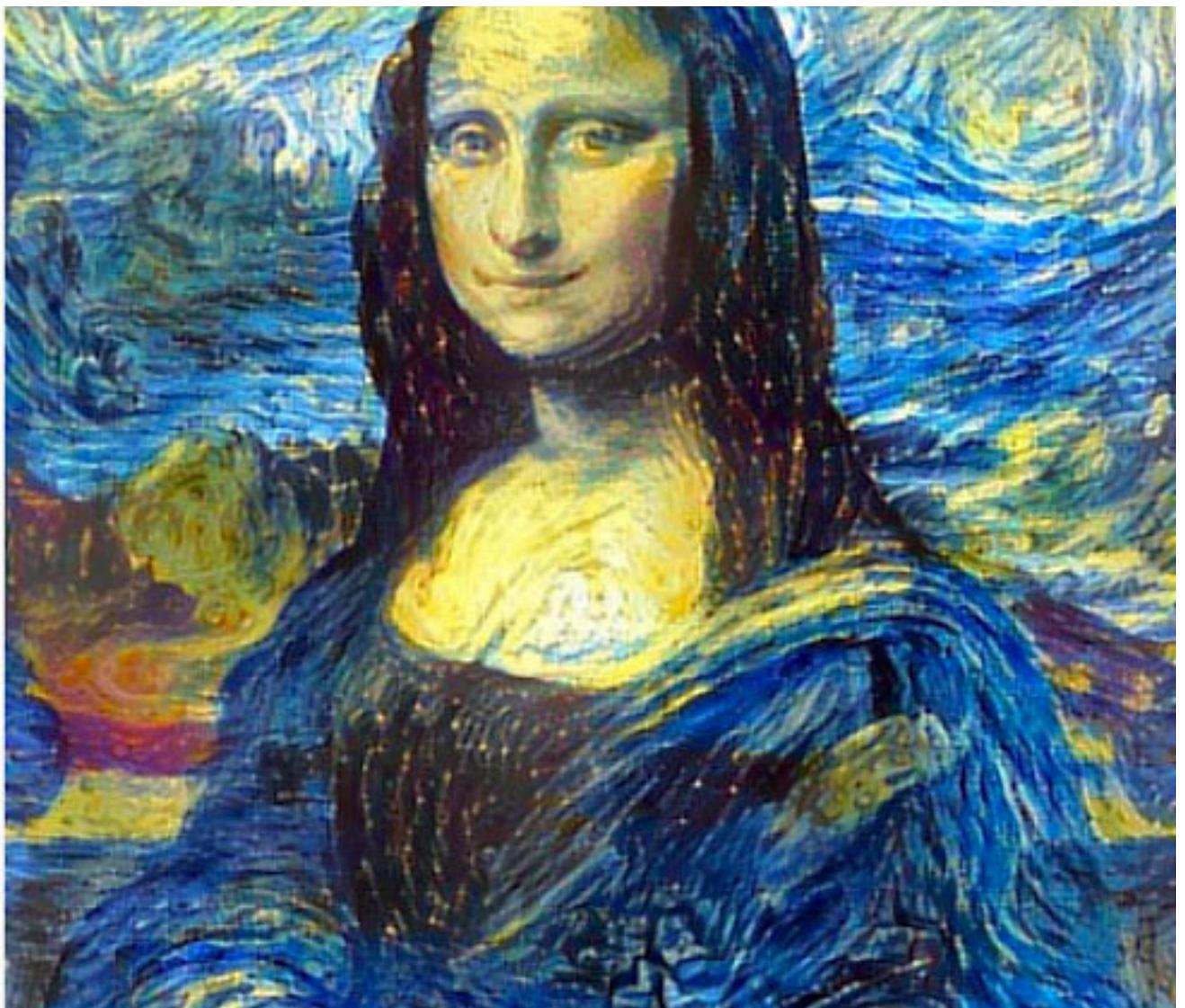
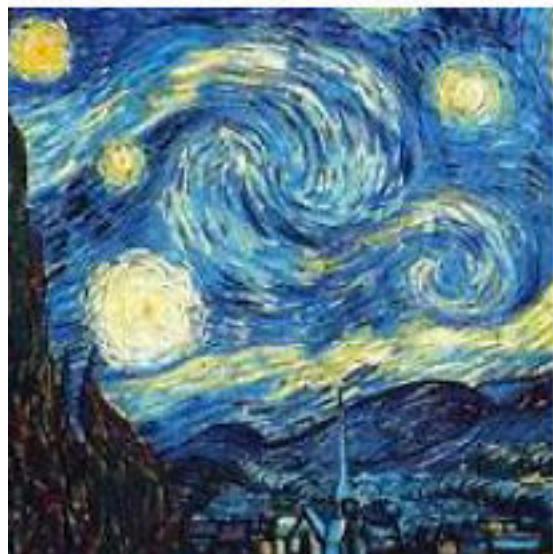
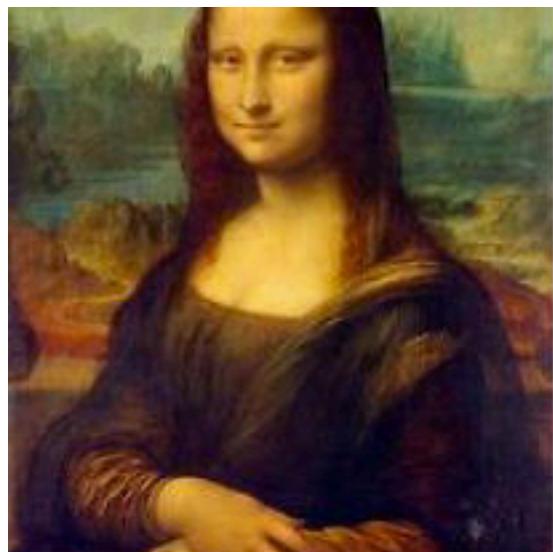
Real world example



# Application: Learn arts

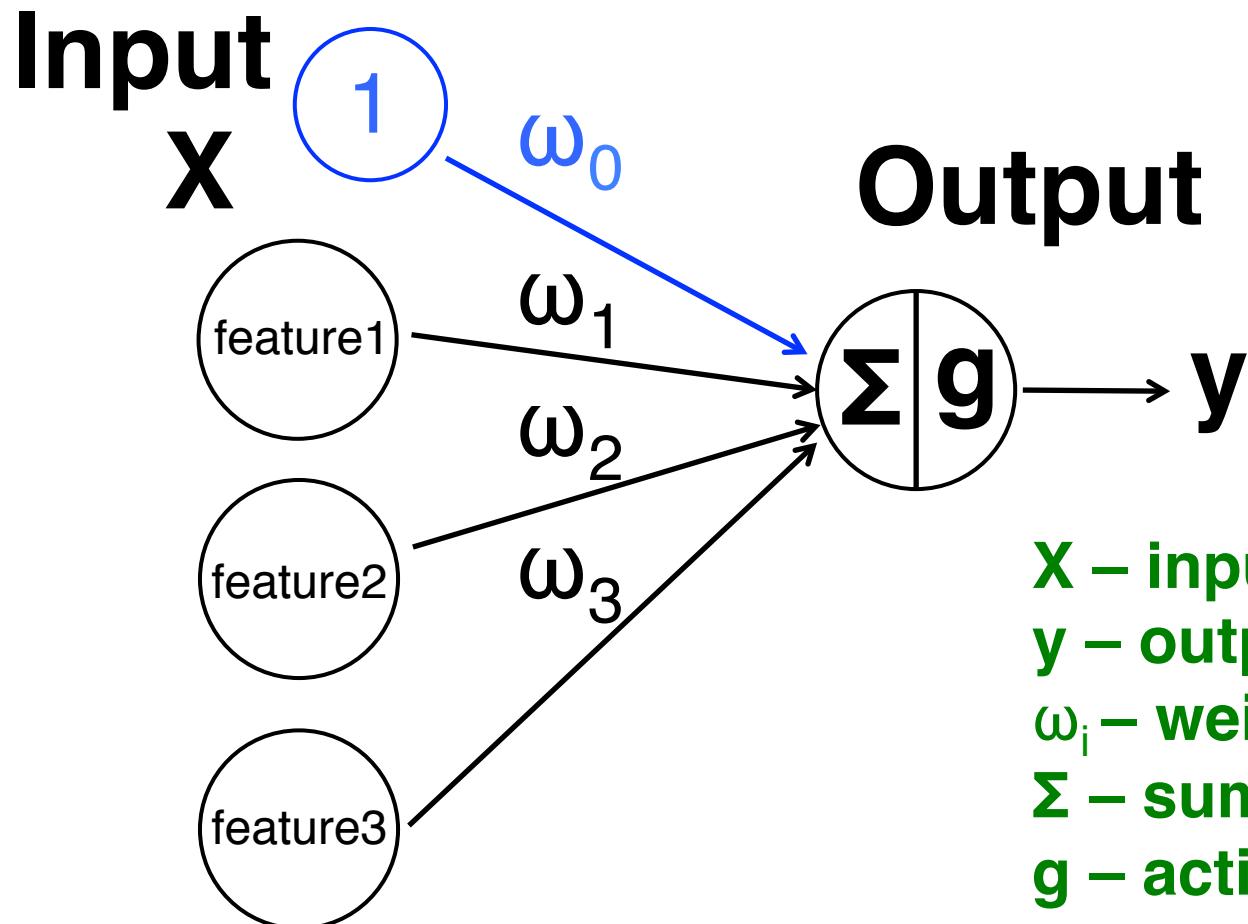


<https://arxiv.org/abs/1508.06576v1>  
<https://deepoch.io/>



<http://junkhost.com/2016/03/man-combines-random-peoples-photos-using-neural-networks-and-the-results-are-amazing/>



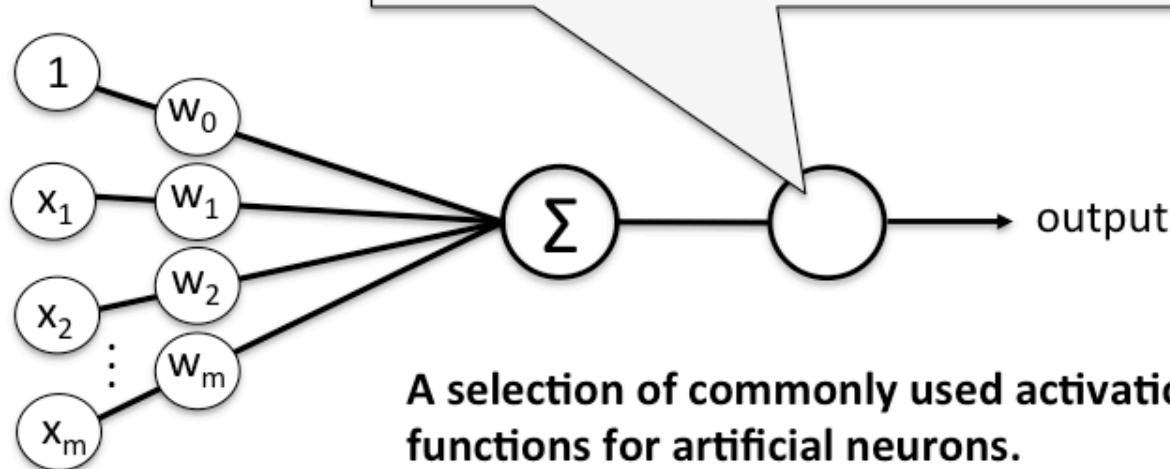


**X – input data**  
**y – output target**  
 **$\omega_i$  – weights**  
 **$\Sigma$  – summation**  
**g – activation function**  
**Blue circle – bias**

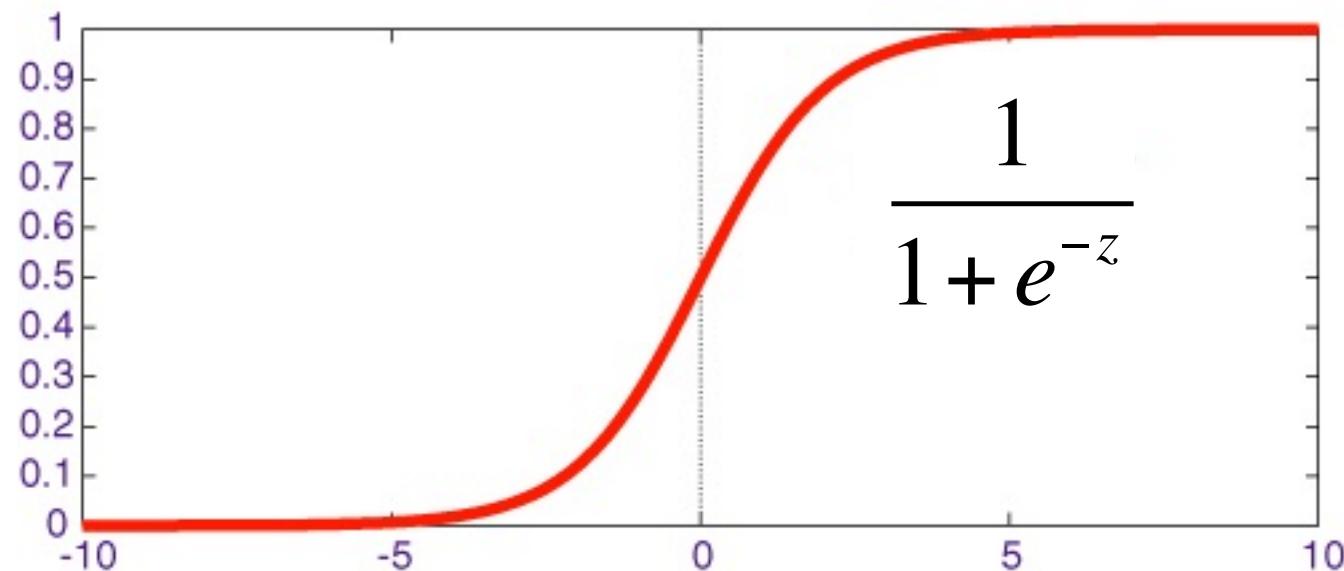
$$Z = \Sigma = \omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3 + \dots + \omega_n x_n$$

$$y = g(\omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3 + \dots + \omega_n x_n)$$

	Unit step	$g(z) = \begin{cases} 1 & \text{if } z \geq 0 \\ -1 & \text{otherwise.} \end{cases}$
		$g(z) = \begin{cases} 1 & \text{if } z \geq 0 \\ 0 & \text{otherwise.} \end{cases}$
	Linear	$g(z) = z$
	Logistic (sigmoid)	$g(z) = 1 / (1 + \exp(-z))$
	Hyperbolic tangent (sigmoid)	$g(z) = \frac{\exp(2z) - 1}{\exp(2z) + 1}$
...		



# More on activation function

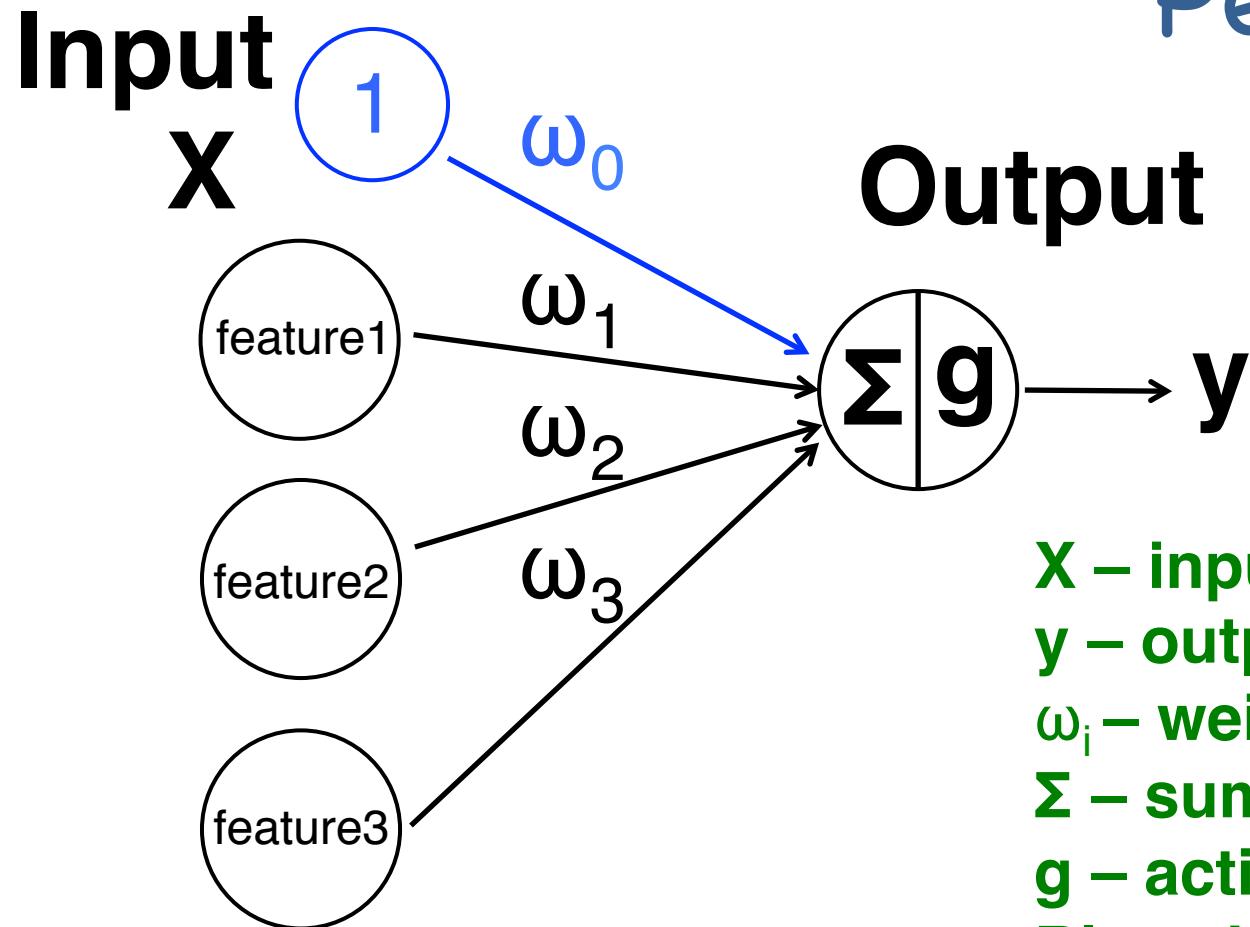


$$z = \omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3 + \dots + \omega_n x_n$$

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

$$\frac{dg(z)}{dx} = g(z)(1 - g(z))$$

# Perceptron



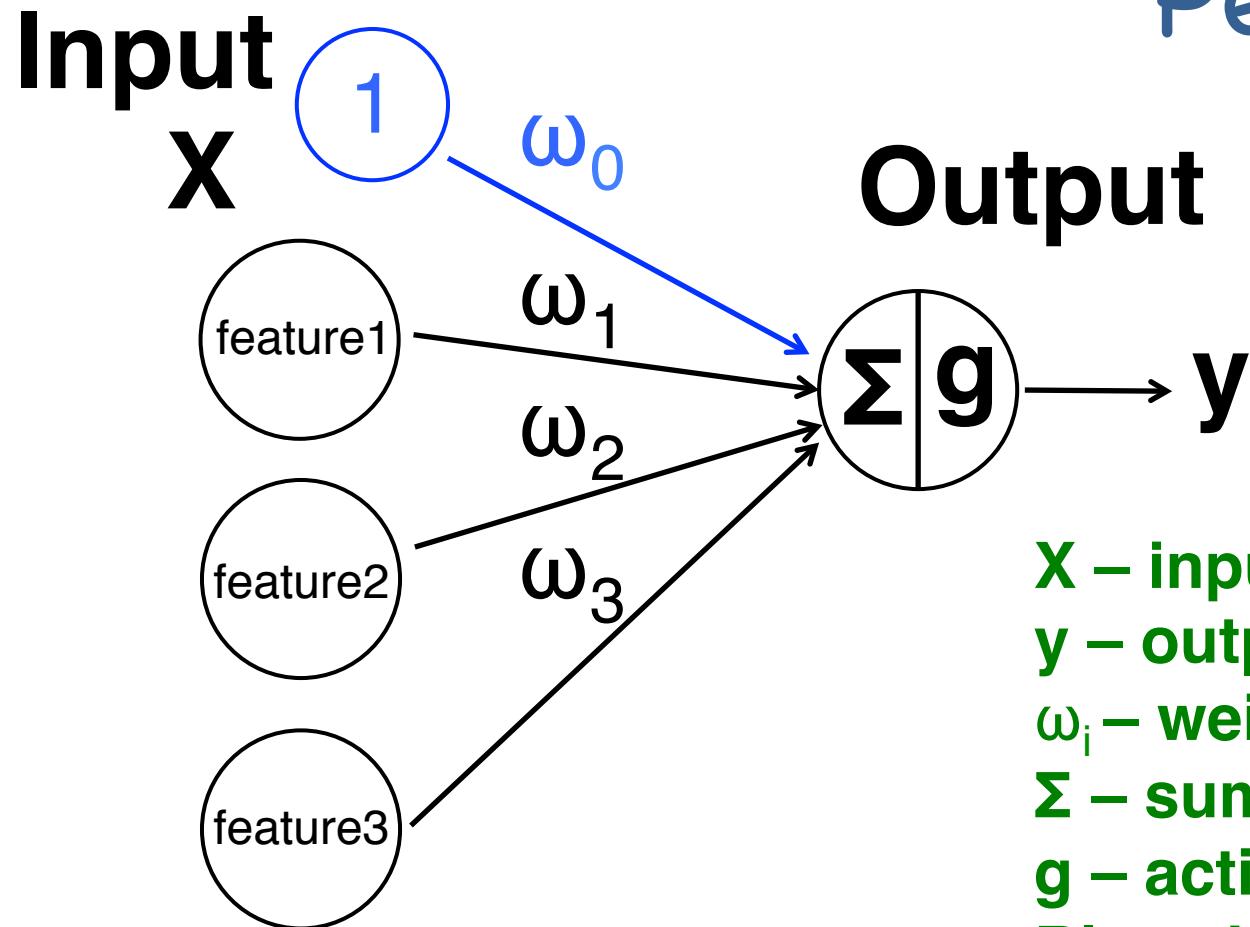
X – input data  
y – output target  
 $\omega_i$  – weights  
 $\Sigma$  – summation  
g – activation function  
Blue circle – bias

$$Z = \Sigma = \omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3 + \dots + \omega_n x_n$$

$$y = g(\omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3 + \dots + \omega_n x_n)$$

y            This is our estimation

# Perceptron



X – input data  
y – output target  
 $\omega_i$  – weights  
 $\Sigma$  – summation  
g – activation function  
Blue circle – bias

Error = Target - Estimation

~~Error~~



# How the ANN learns

**Error = Target - Estimation**

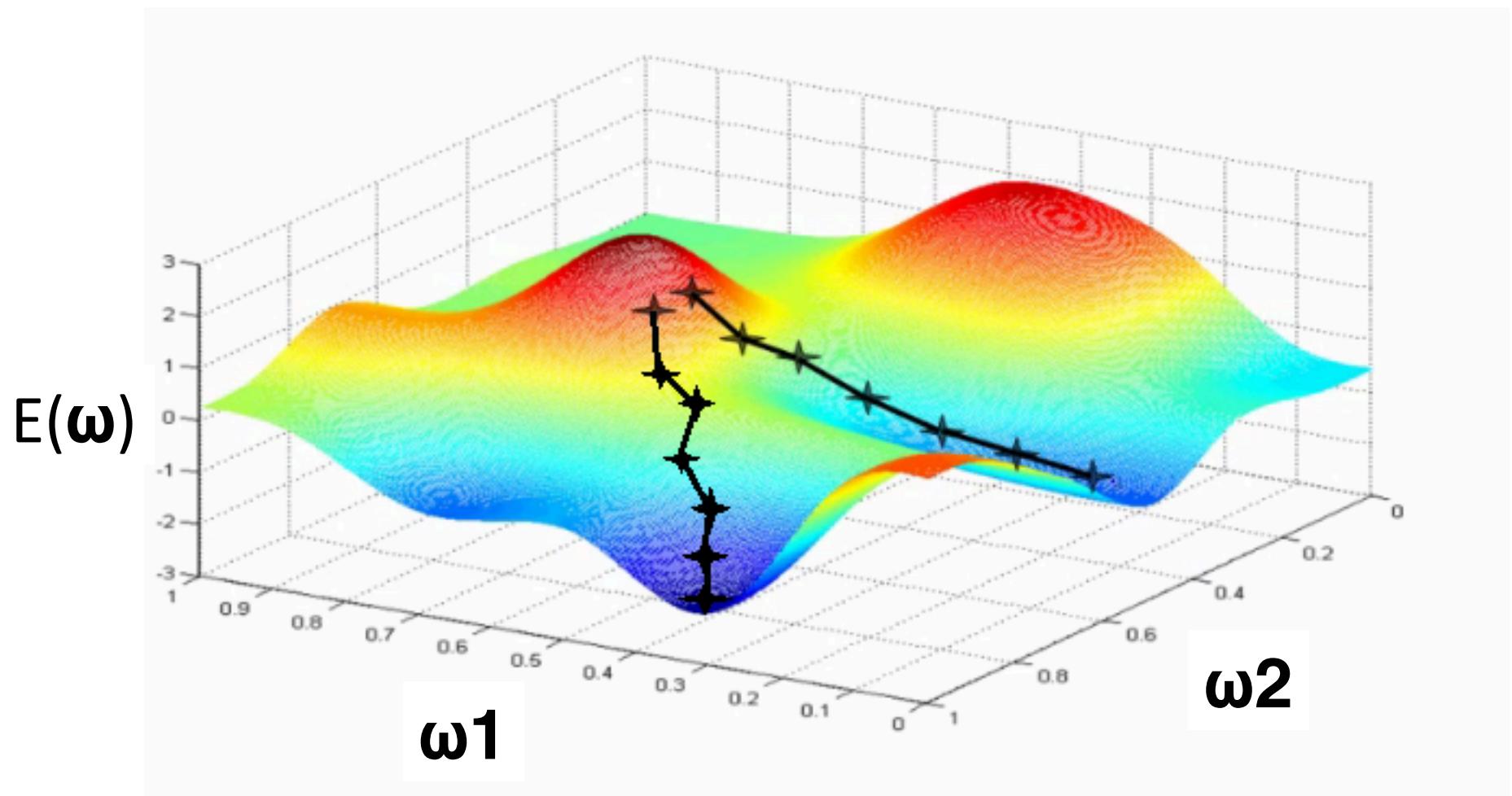
## Learning:

- Measure error
- Update weights to reduce error next time!



HOW?





# View from Gradient Descent

$$Error = \sum_{k=1}^N (y_k - t_k)$$

$y_k$  – estimation  
 $t_k$  – target  
 $\Sigma$  – summation

Estimation 0, Target 1, Error = -1  
Estimation 1, Target 0, Error = 0

If we add them, we got error 0

# View from Gradient Descent

Sum-of-Squares error

$$E(w) = \frac{1}{2} \sum_{k=1}^N (y_k - t_k)^2 = \frac{1}{2} \sum_{k=1}^N [g(\sum_{i=0}^L \omega_{ik} x_i) - t_k]^2$$

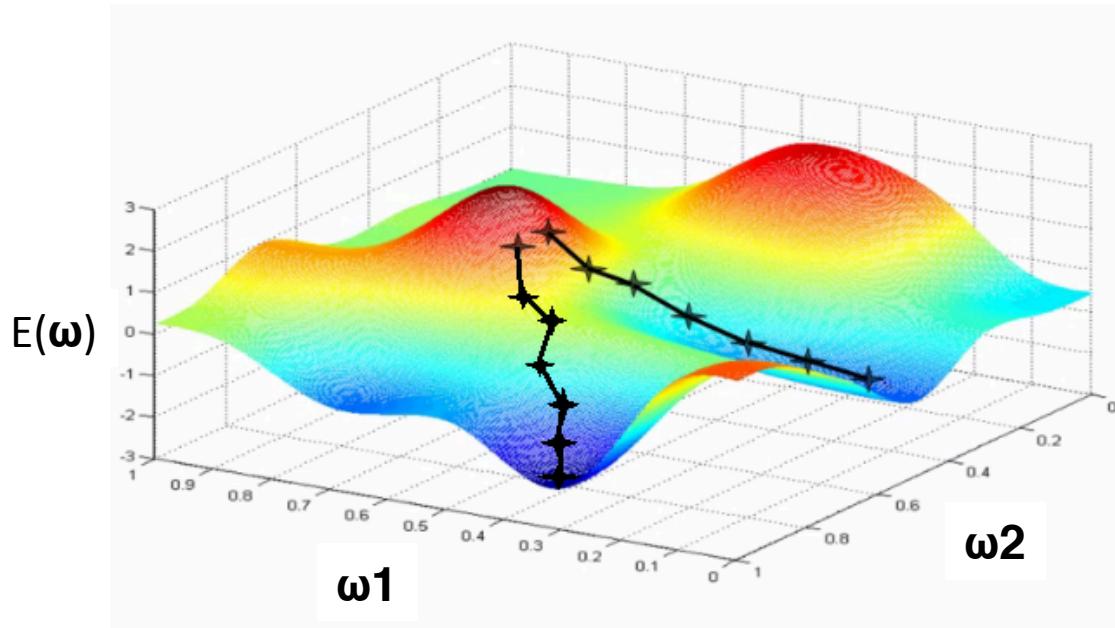
Where  $y_k = g(\sum_{i=0}^L \omega_{ik} x_i)$

**y<sub>k</sub> – estimation**  
**t<sub>k</sub> – target**  
**Σ – summation**  
**g – activation function**  
**x<sub>i</sub> – input**  
**ω - weights**

# View from Gradient Descent

Sum-of-Squares error

$$E(w) = \frac{1}{2} \sum_{k=1}^N (y_k - t_k)^2 = \frac{1}{2} \sum_{k=1}^N [g(\sum_{i=0}^L \omega_{ik} x_i) - t_k]^2$$



**y<sub>k</sub> – estimation**  
**t<sub>k</sub> – target**  
**Σ – summation**  
**g – activation function**  
**x<sub>i</sub> – input**  
**ω - weights**

# View from Gradient Descent

$$\begin{aligned}\frac{\partial E}{\partial \omega_{ik}} &= \frac{\partial}{\partial \omega_{ik}} \left( \frac{1}{2} \sum_{k=1}^N (y_k - t_k)^2 \right) \\ &= \frac{\partial}{\partial \omega_{ik}} \left( \frac{1}{2} \sum_{k=1}^N [g(\sum_{i=0}^L \omega_{ik} x_i) - t_k]^2 \right) \\ &= \frac{1}{2} \sum_{k=1}^N 2(g(\sum_{i=0}^L \omega_{ik} x_i) - t_k) \frac{\partial}{\partial \omega_{ik}} \left( g(\sum_{i=0}^L \omega_{ik} x_i) - t_k \right) \\ &= \sum_{k=1}^N (y_k - t_k) \frac{\partial g}{\partial \omega_{ik}} x_i = \quad \text{Error} \times \text{slope} \times \text{input}\end{aligned}$$

# Weights update rules

**Weights Delta = Error × slope × input**

How much we will update  
the weights for next time



# Look at errors closer

Error = Target - Estimation

Target



# Look at errors closer

Error = Target - Estimation

Target



## Three cases:

- Error < 0: Target is 0, estimation is not 0
- Error > 0: Target is 1, estimation is not 1
- Error = 0: Estimation correct

Look at errors closer  
(assume inputs are positive)

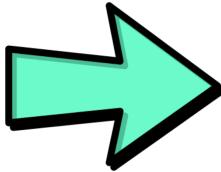
## Cases 1:



- Error < 0: Target is **0**, estimation is not 0

Look at errors closer  
(assume inputs are positive)

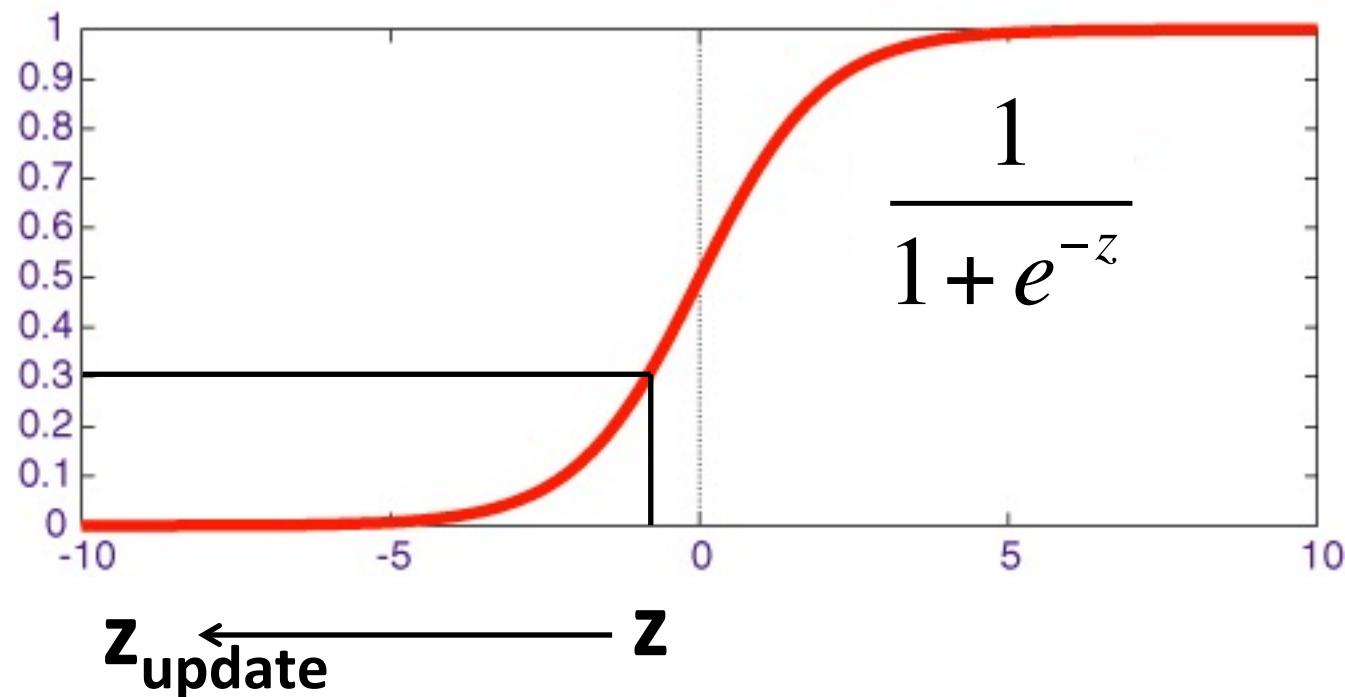
## Cases 1:

- Target is 0
  - Estimation is 0.3
- 
- Error =  $0 - 0.3 = -0.3$

Look at errors closer  
(assume inputs are positive)

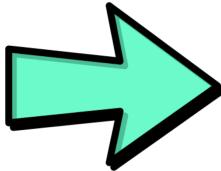
## Cases 1:

- Target is 0
  - Estimation is 0.3
- Error =  $0 - 0.3 = -0.3$



Look at errors closer  
(assume inputs are positive)

## Cases 1:

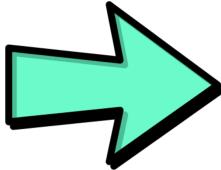
- Target is 0
  - Estimation is 0.3
- 
- Error =  $0 - 0.3 = -0.3$

$$z = \omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3$$

We need **reduce weights!**

Look at errors closer  
(assume inputs are positive)

## Cases 1:

- Target is 0
  - Estimation is 0.3
- 
- Error =  $0 - 0.3 = -0.3$

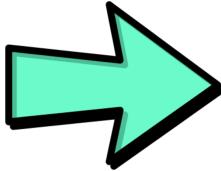
$$z = \omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3$$

We need **reduce weights!**

If we add error to the weights, we will reduce it!

Look at errors closer  
(assume inputs are positive)

## Cases 1:

- Target is 0
  - Estimation is 0.3
- 
- Error = 0 – 0.3 = -0.3

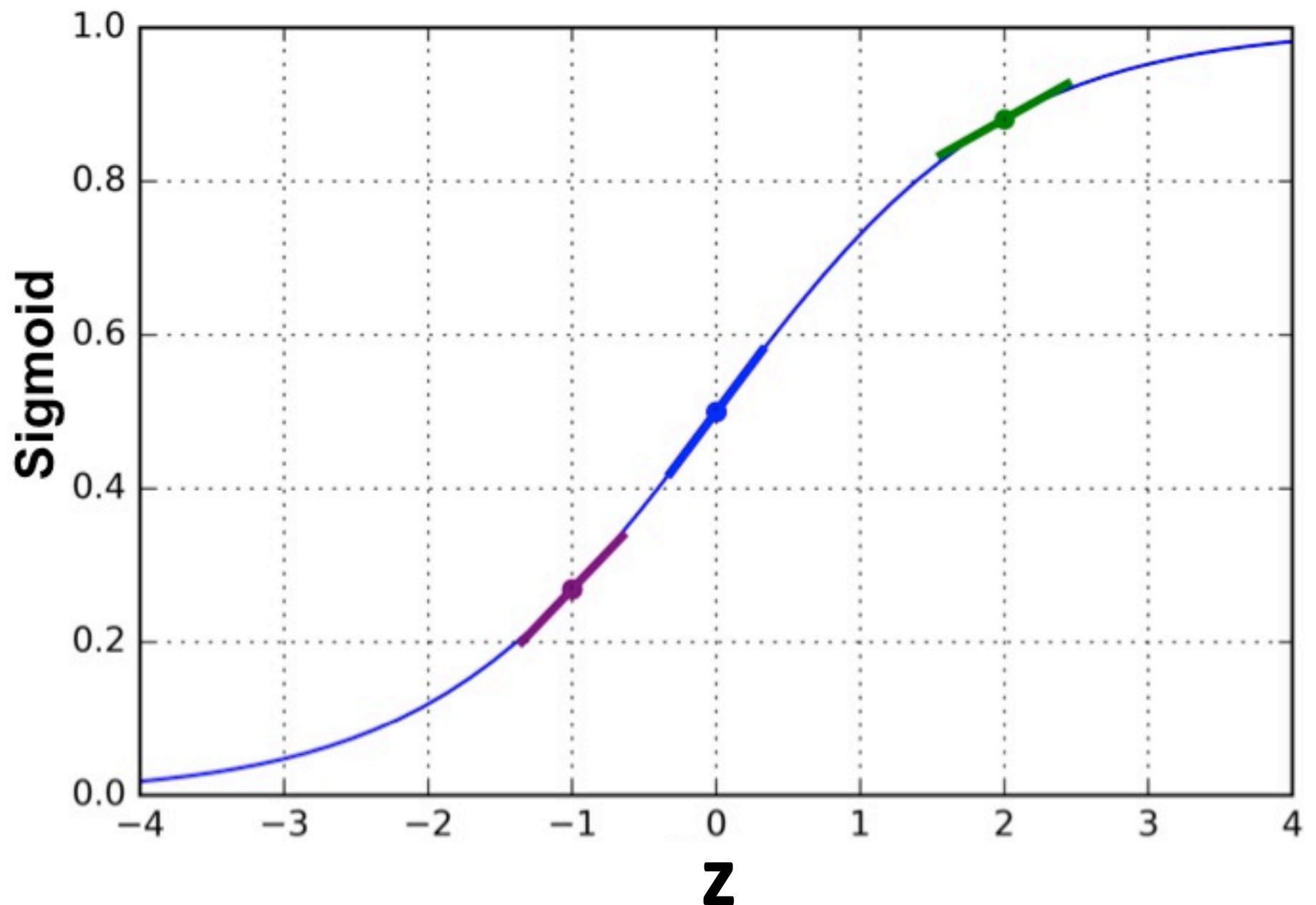
$$z = \omega_0 x_0 + \omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3$$

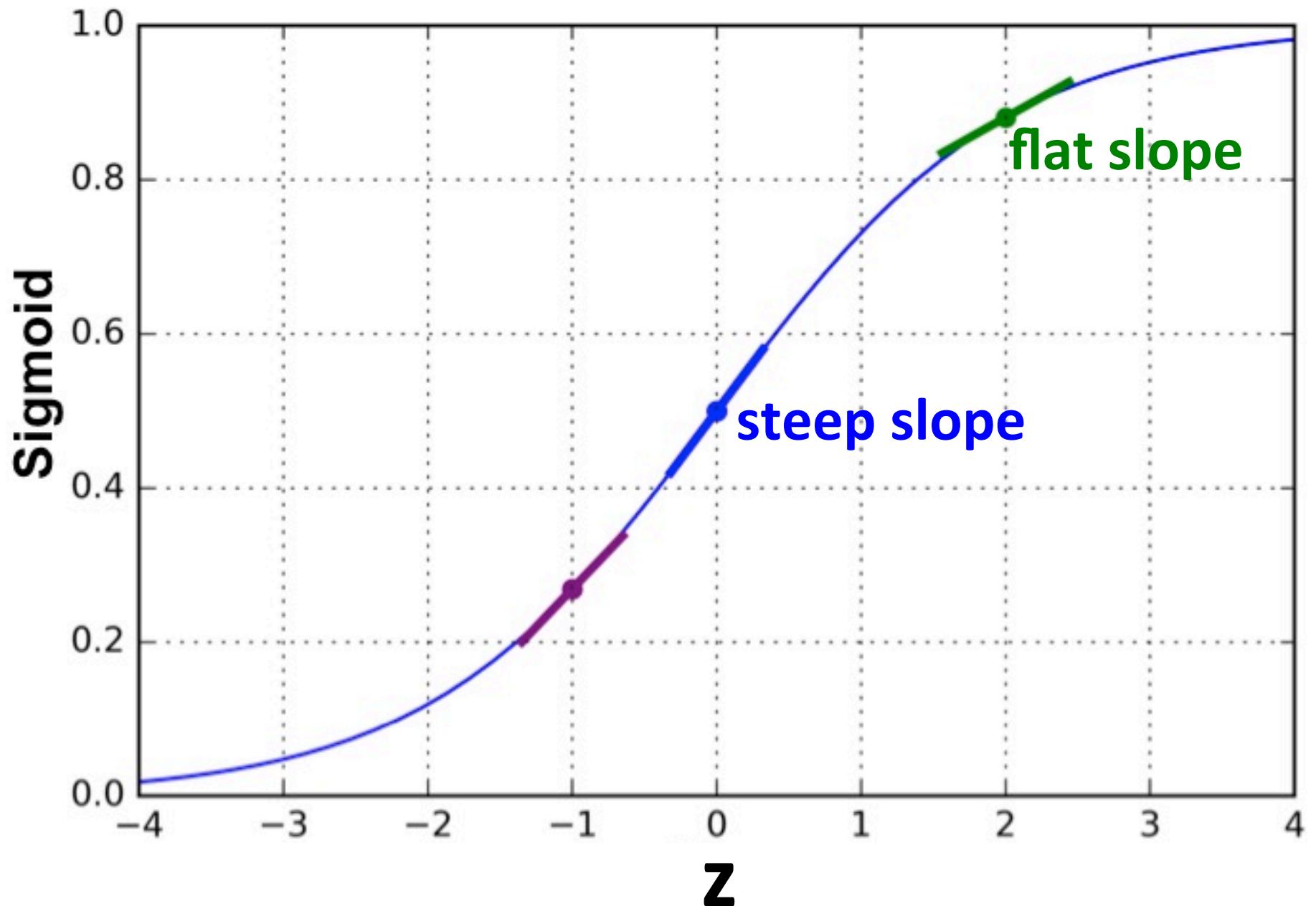
We need **reduce weights!**

But what if the inputs are negative

# Weights update rules

**Weights Delta = Error × input**



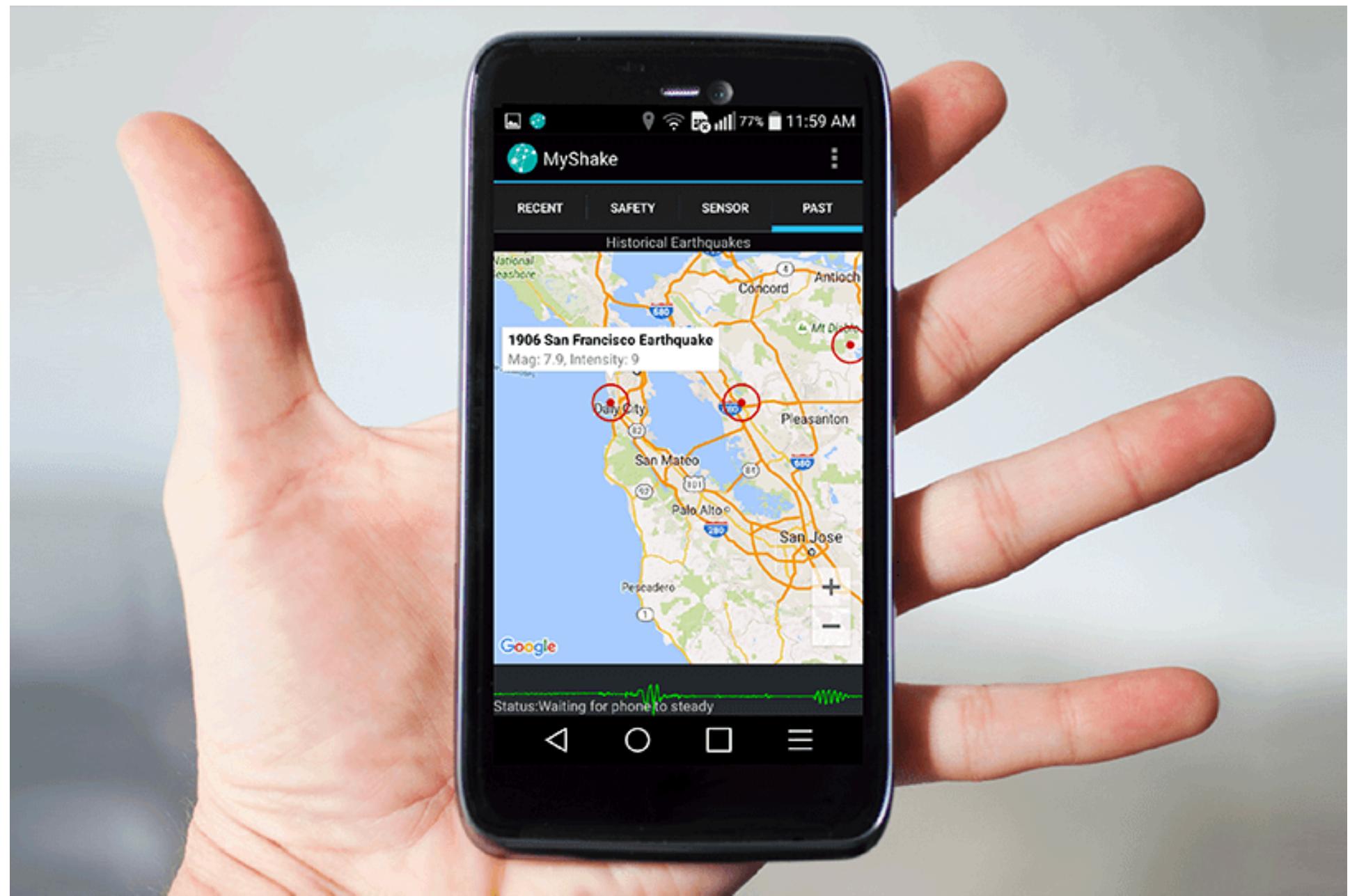


# Weights update rules

**Weights Delta = Error × slope × input**

# Learn from example



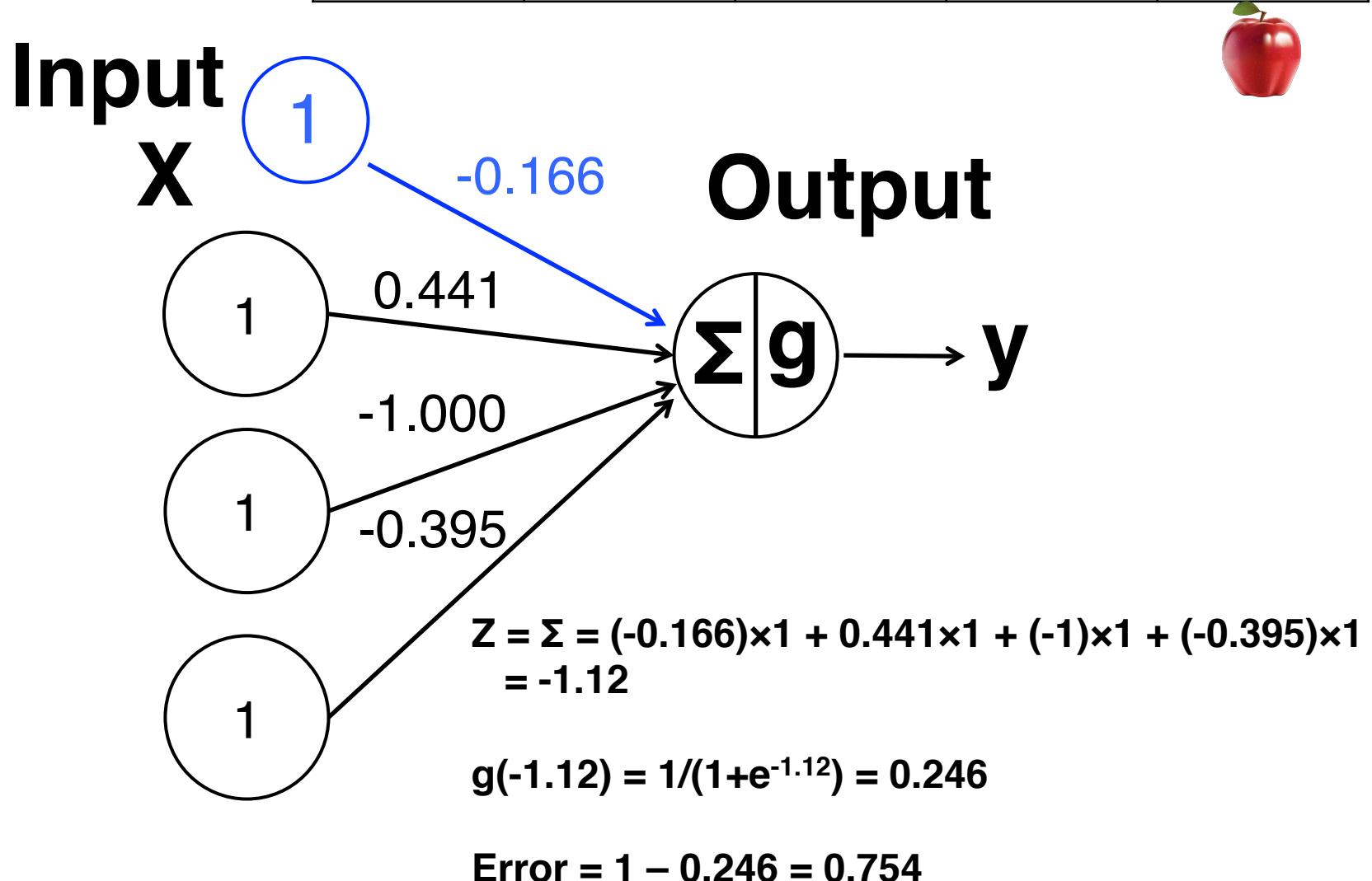


# Learn from Example

Sample	Feature 1	Feature 2	Feature 3	Target
Sample 1	0	0	1	0 
Sample 2	1	1	1	1 
Sample 3	1	0	1	1 
Sample 4	0	1	1	0 
Sample 5	0	1	0	1 

# How to deal with errors

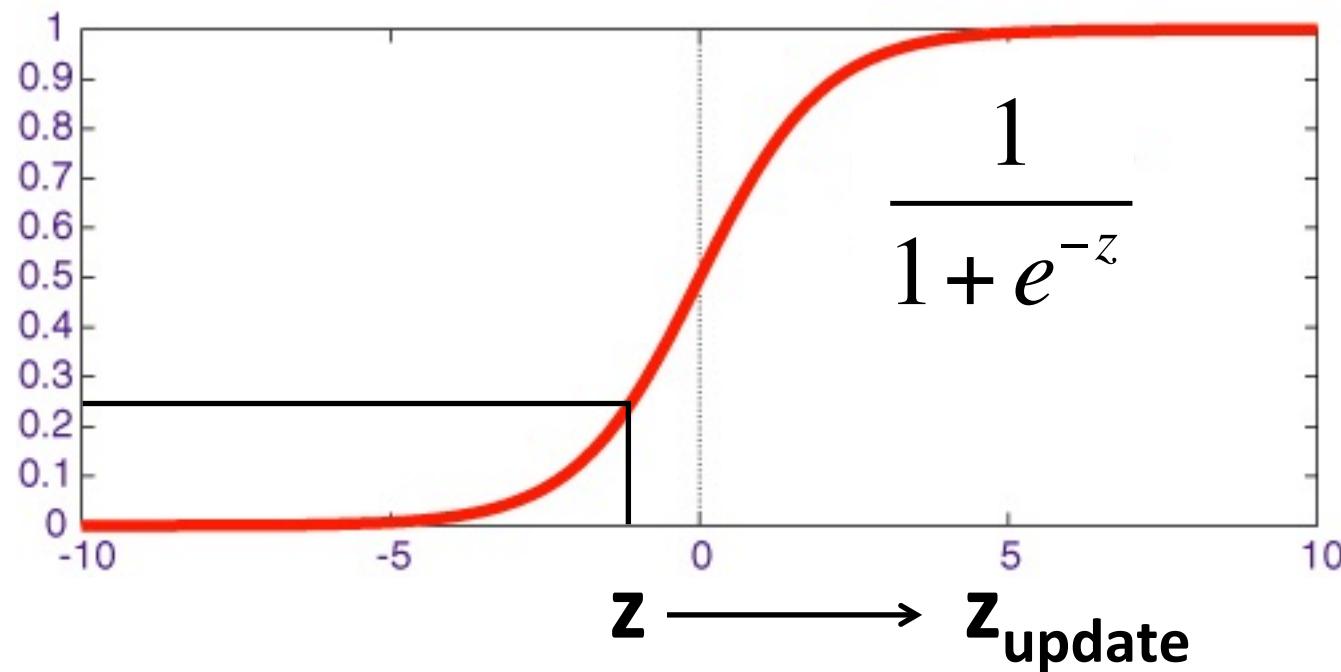
Sample	Feature 1	Feature 2	Feature 3	Target
Sample 1	1	1	1	1



- Target: 1
- Estimation: 0.246



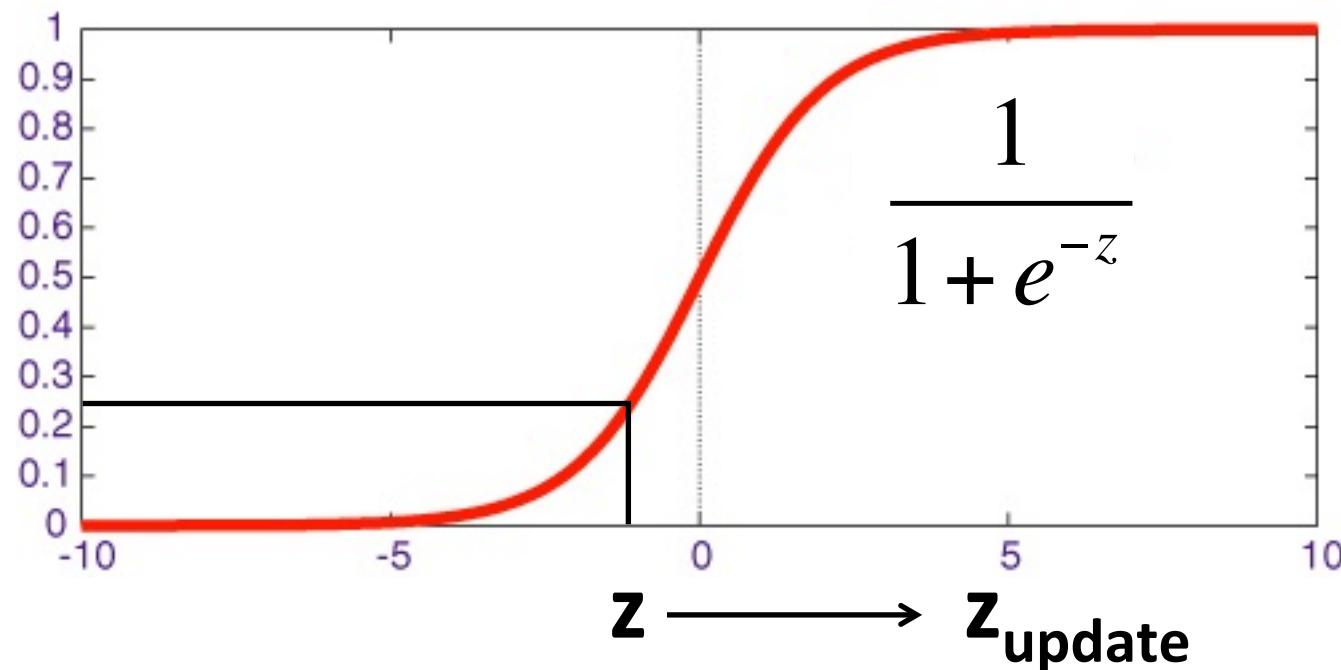
Error 0.754



- Target: 1
- Estimation: 0.246

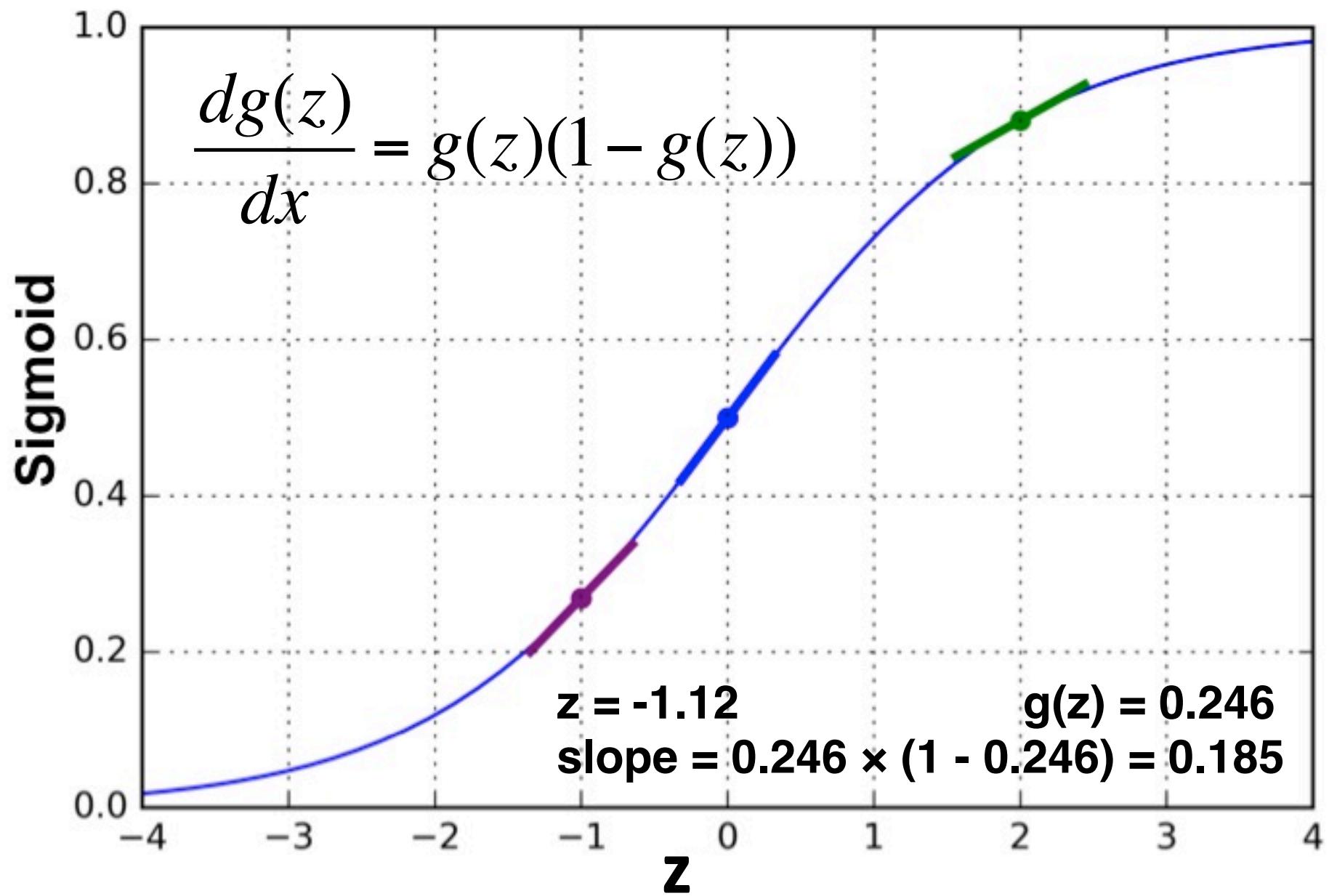


Error 0.754



We want to **increase** the weights next time to have larger  $z$

**Weights delta = 0.754 × slope × input**



$$\begin{aligned}\text{Change item} &= \color{red}{0.754} \times \color{green}{0.185} \times \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \\ &= \begin{bmatrix} 0.139 \\ 0.139 \\ 0.139 \\ 0.139 \\ 0.139 \end{bmatrix}\end{aligned}$$

## Changes of the error

$$\begin{aligned} \text{Updated Weights} &= \begin{bmatrix} -0.166 \\ 0.441 \\ -1.000 \\ -0.395 \end{bmatrix} + \begin{bmatrix} 0.139 \\ 0.139 \\ 0.139 \\ 0.139 \end{bmatrix} = \begin{bmatrix} -0.027 \\ 0.580 \\ -0.861 \\ -0.256 \end{bmatrix} \\ &\quad \begin{array}{c} \nearrow \\ \text{Original Weights} \end{array} \qquad \begin{array}{c} \nearrow \\ \text{updates} \end{array} \end{aligned}$$

# Changes of the error

$$\begin{array}{l} \text{Updated} \\ \text{Weights} \end{array} = \begin{bmatrix} -0.166 \\ 0.441 \\ -1.000 \\ -0.395 \end{bmatrix} + \begin{bmatrix} 0.139 \\ 0.139 \\ 0.139 \\ 0.139 \end{bmatrix} = \begin{bmatrix} -0.027 \\ 0.580 \\ -0.861 \\ -0.256 \end{bmatrix}$$

Error of next iteration

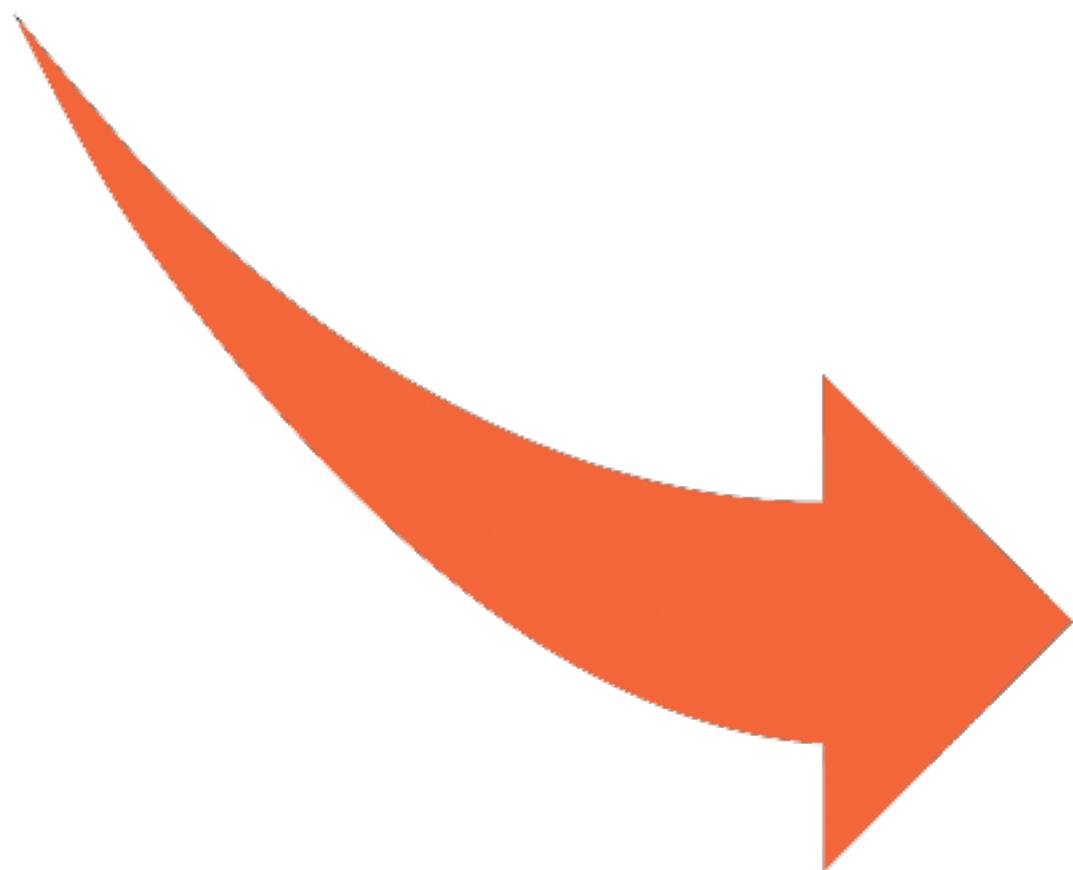
$$z = (-0.027) \times 1 + 0.580 \times 1 + (-0.861) \times 1 + (-0.256) \times 1 = -0.564$$

$$g(z) = 0.637$$

$$\text{Error} = 1 - 0.637 = \textcolor{red}{0.363}$$

## Changes of the error

**0.754**



**0.363**

# Iterate many times



Go to notebook 01

# Application: DeepDrumpf



<https://twitter.com/DeepDrumpf>



DeepDrumpf @DeepDrumpf · Mar 9

I love the states. I win them. Ohio is beautiful, I buy it. Thank you very much. I buy Hillary, it's beautiful and I'm happy about it.



DeepDrumpf @DeepDrumpf · 18h

I'm going to be a good president of the world. Ted can't do that.



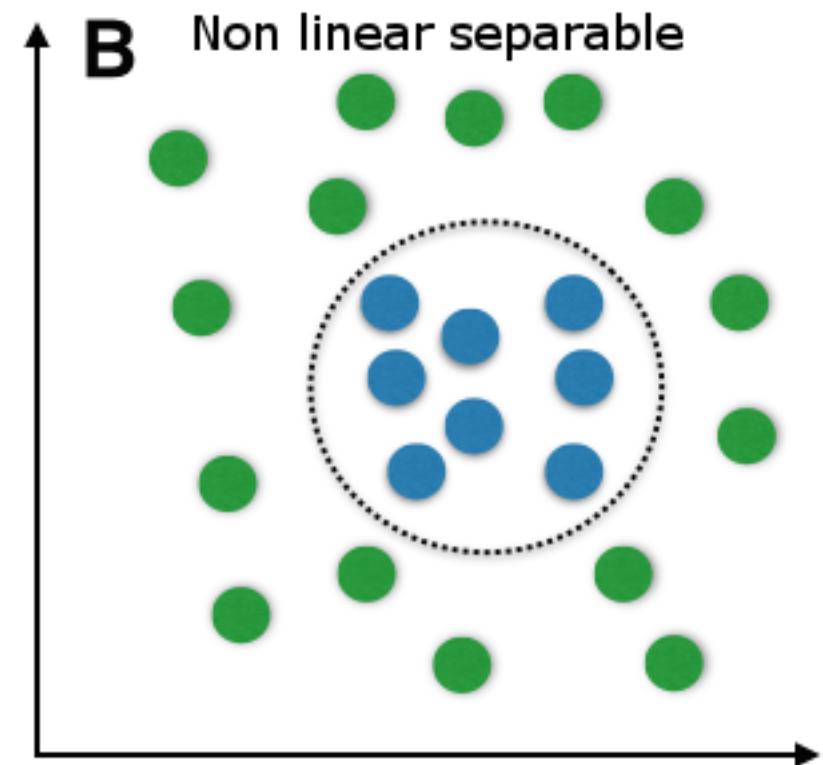
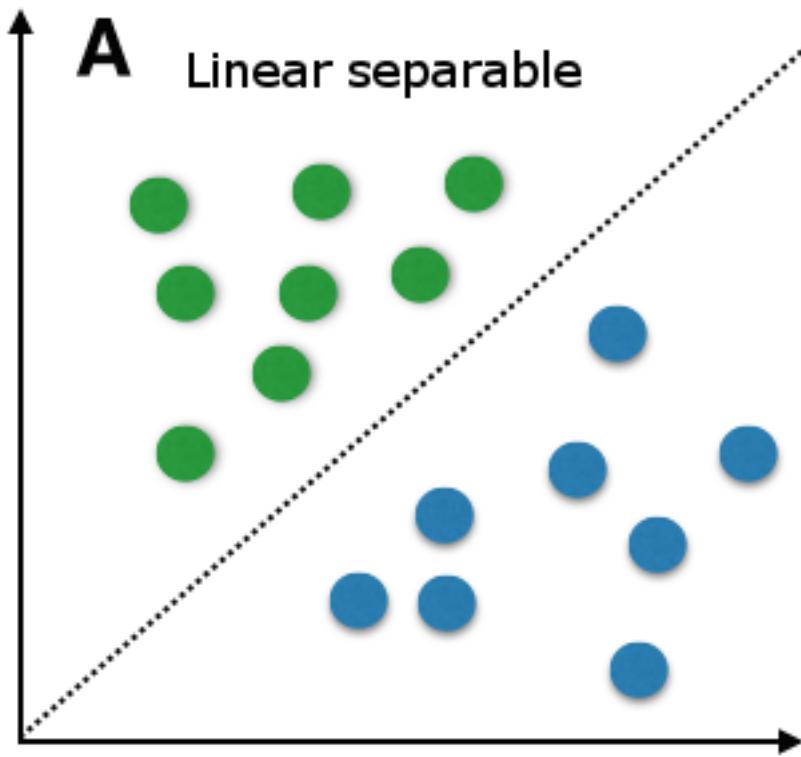
80



152

...

# Perceptron limitations

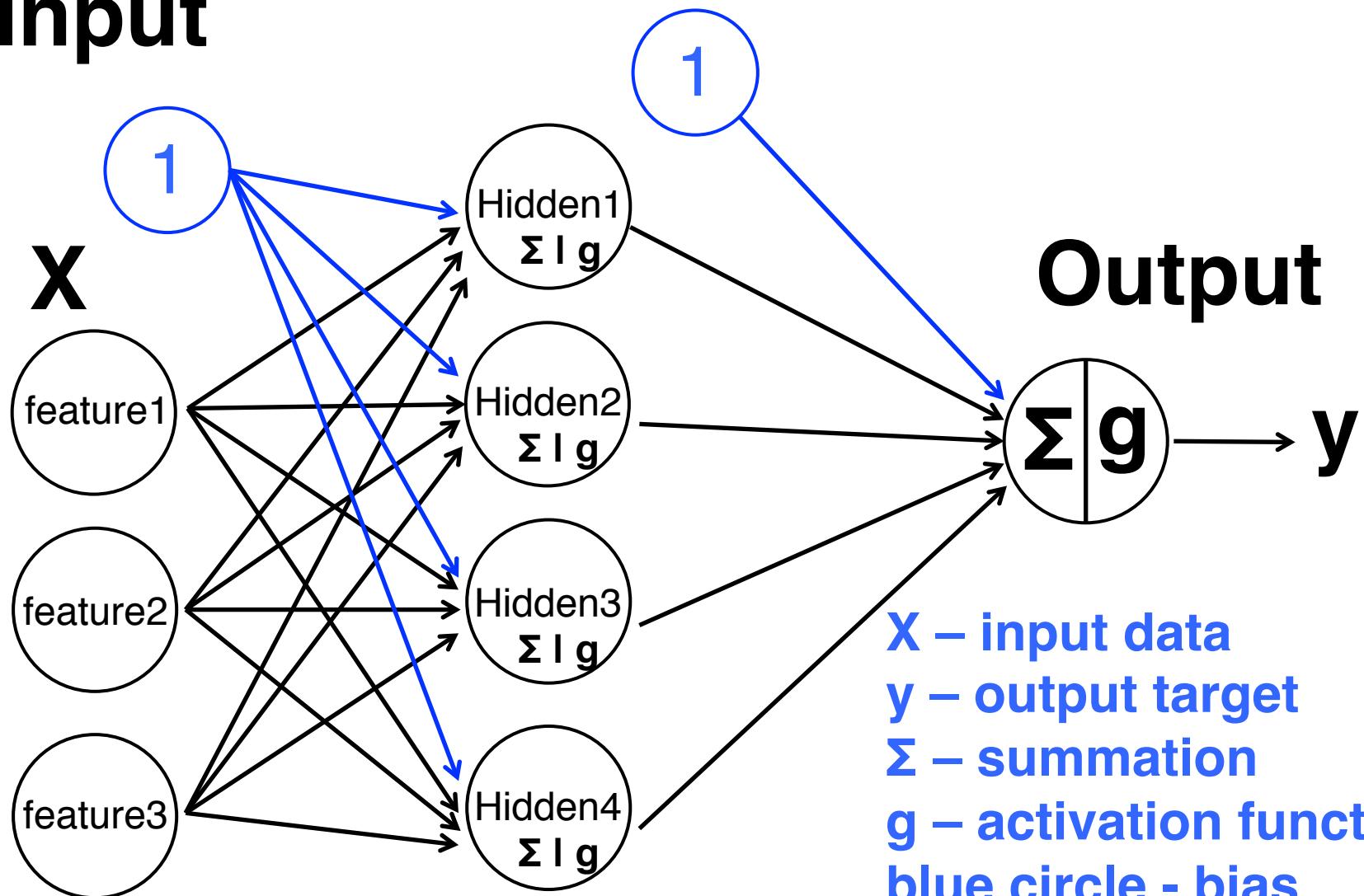


# Winter of ANN



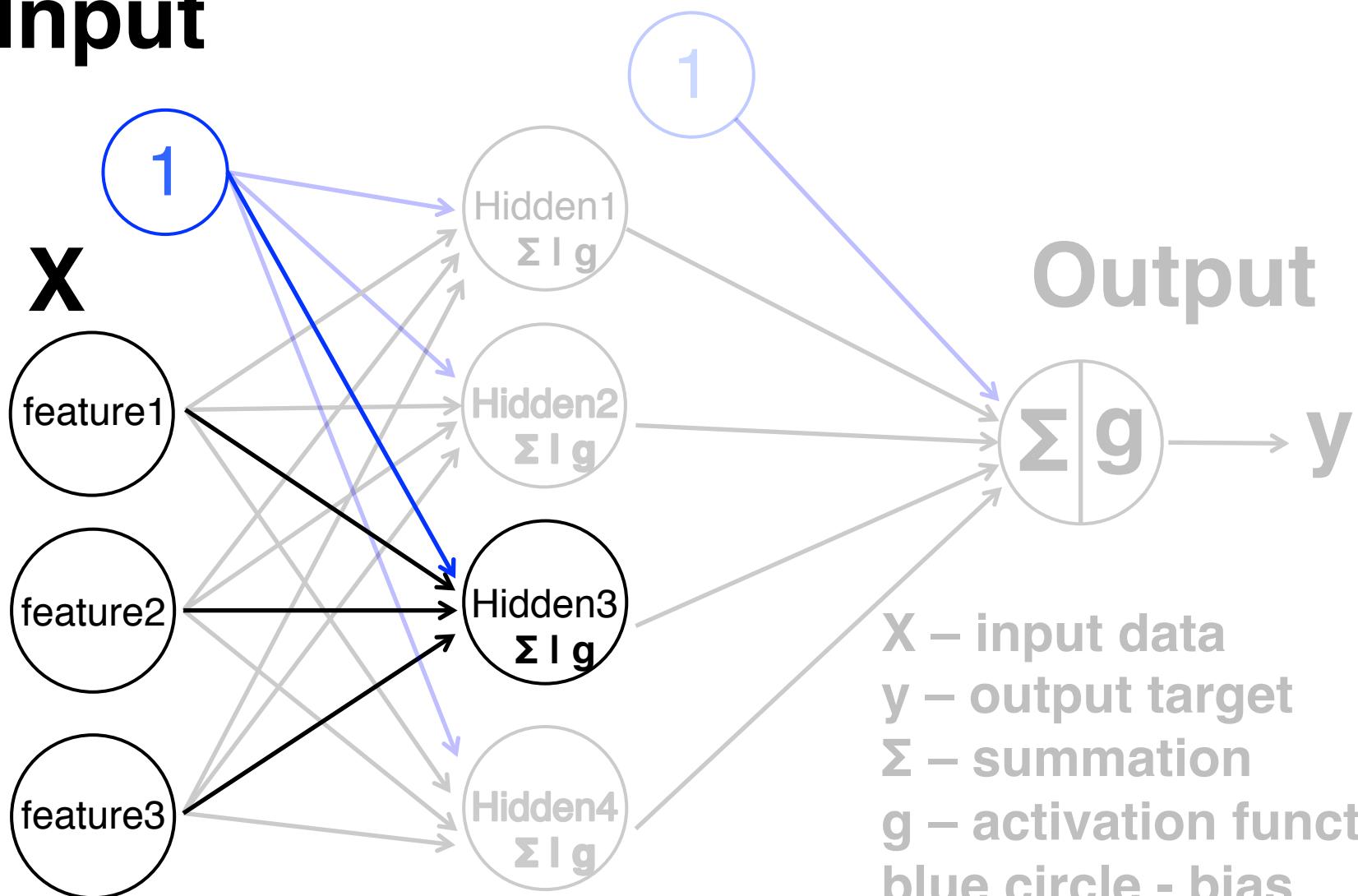
# Multi-Layer Perceptron

# Input

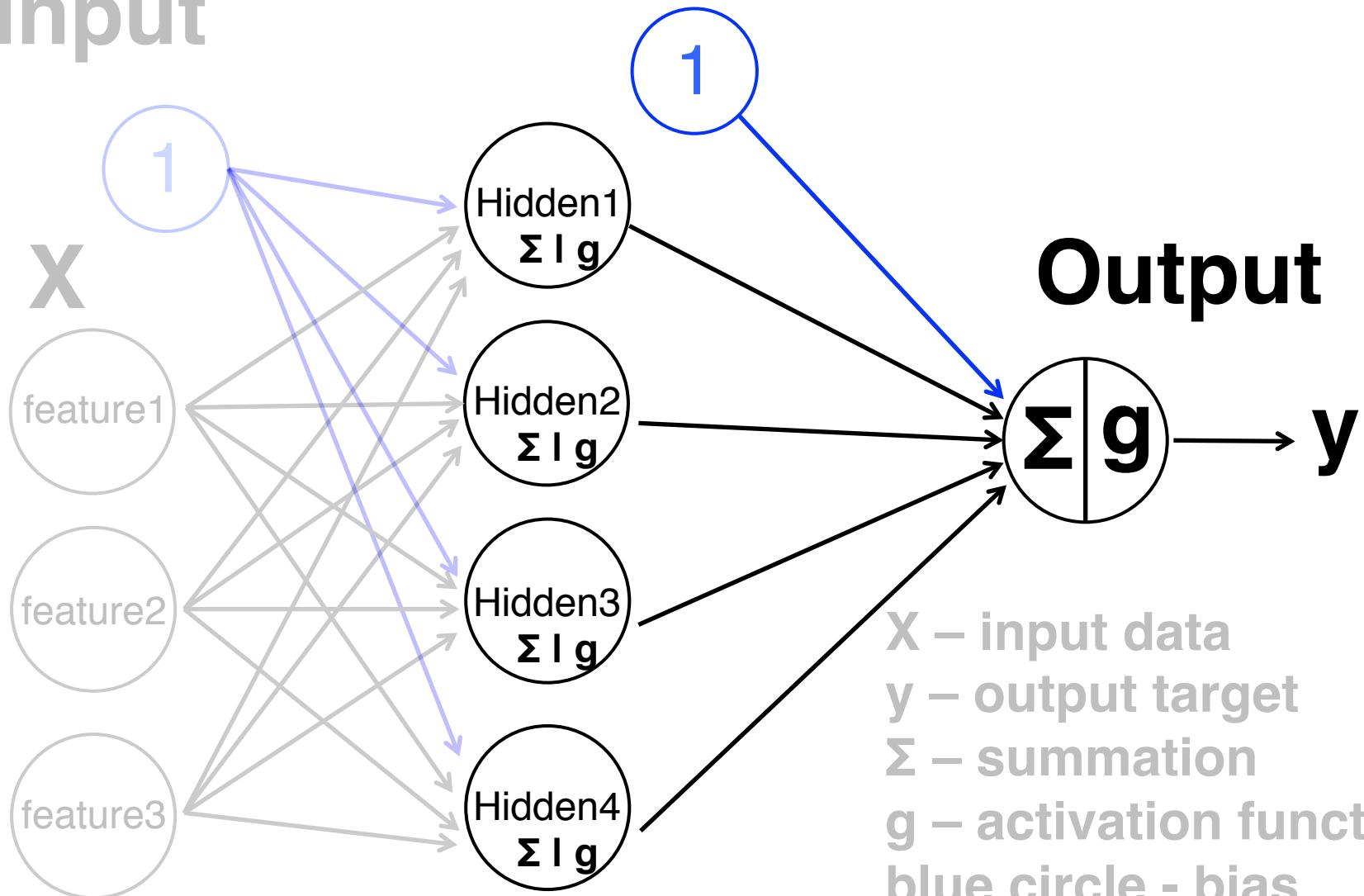


X – input data  
y – output target  
 $\Sigma$  – summation  
g – activation function  
blue circle - bias

# Input



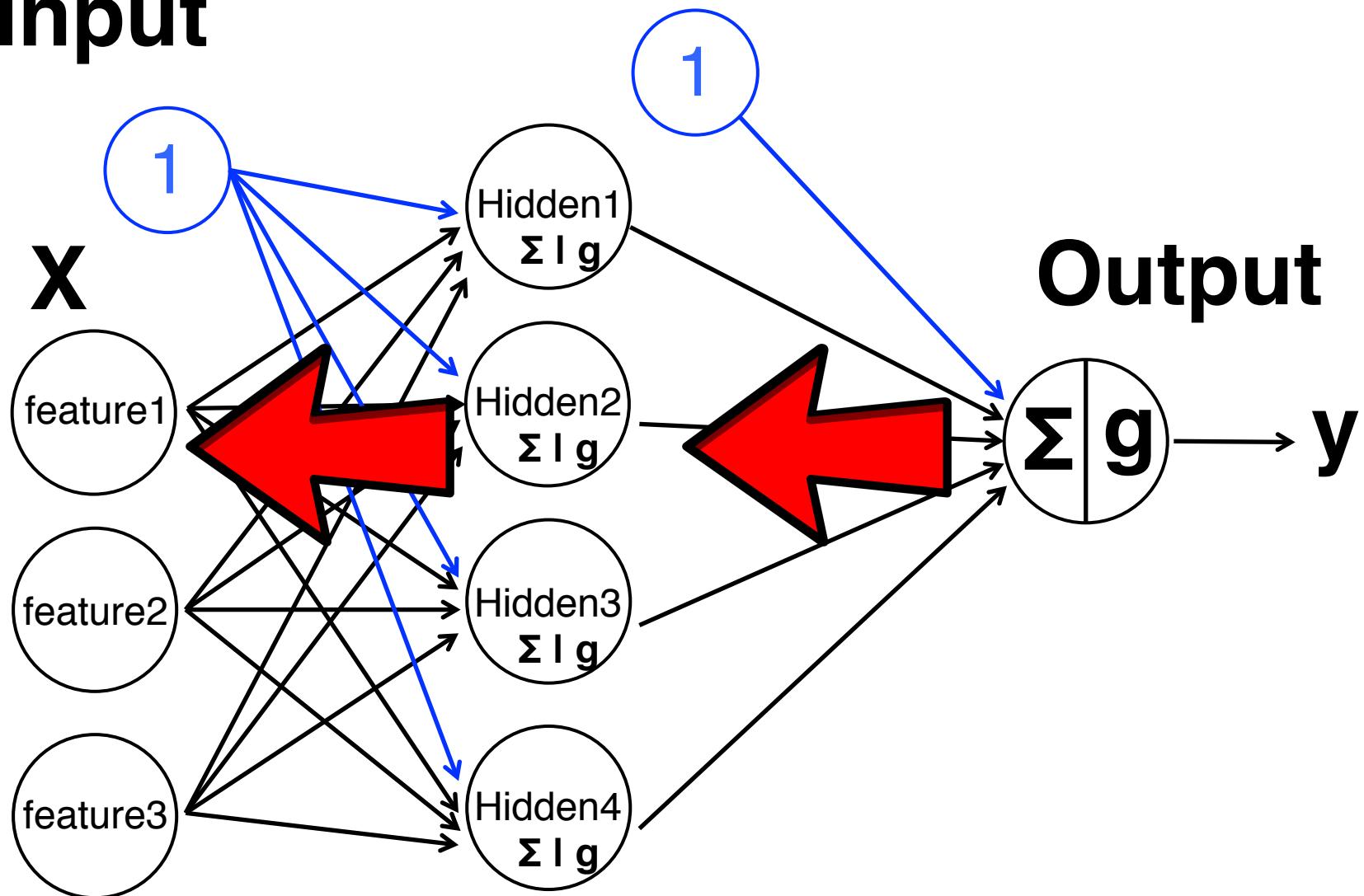
# Input



# Output

X – input data  
y – output target  
 $\Sigma$  – summation  
g – activation function  
blue circle - bias

# Input



# Output

Go to notebook 02

# Learning curve

Workshop time

Gentle introduction

- What's ML
- ANN history
- ANN overview

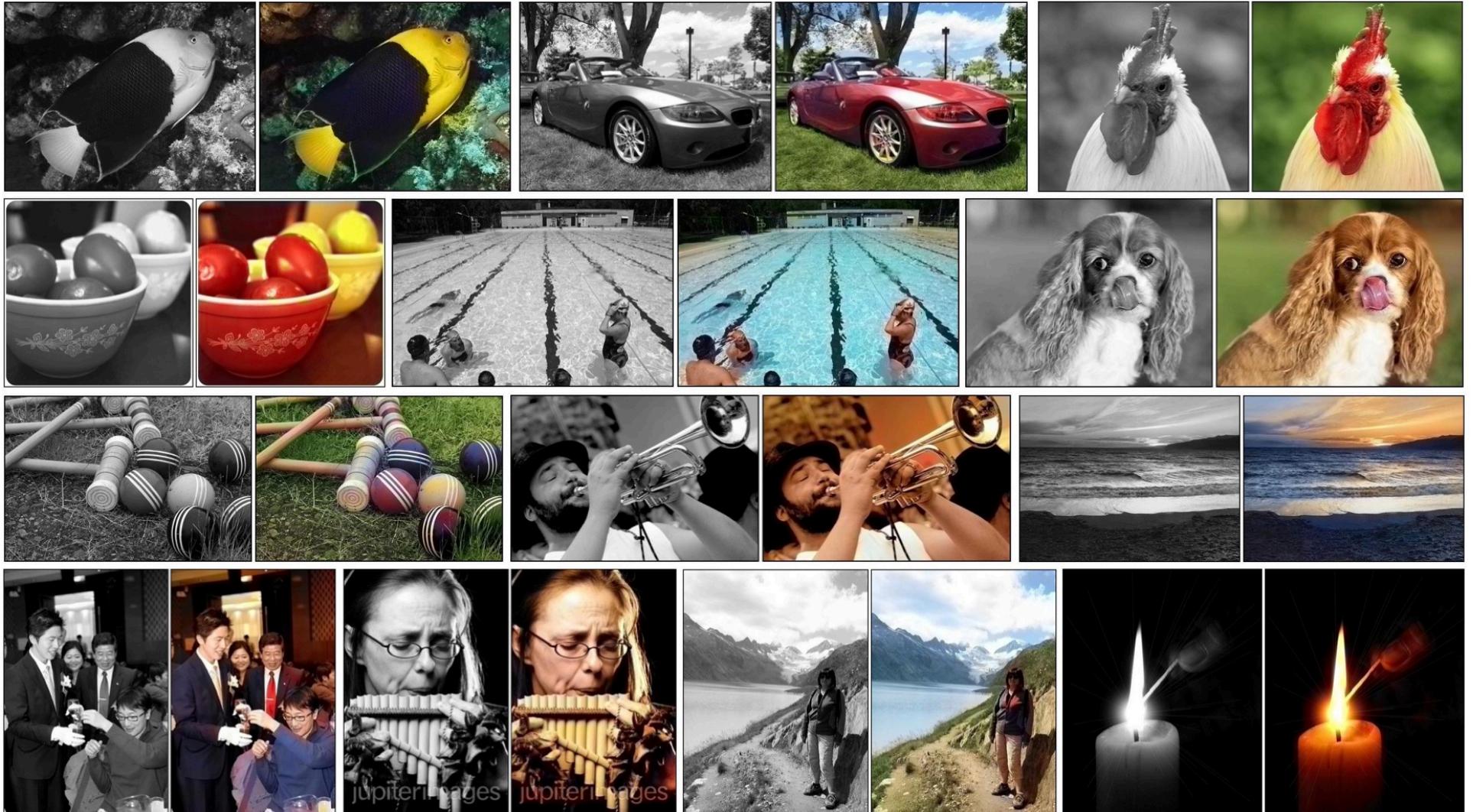
Step by step ANN

- Perceptron
- Backpropagation

Real world example

- Sklearn example

# Application: Colourization



<http://whattogive.com/videoColourization/>

<http://richzhang.github.io/colorization/>

11

NEIL A. ARMSTRONG  
JANET S. ARMSTRONG

2214

12/15

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420

PAY TO THE ORDER OF Coyne's Valley Christian Academy \$ 50 00

Fifty One &/100

DOLLARS



THE FIFTH THIRD BANK

CINCINNATI, OHIO 45201

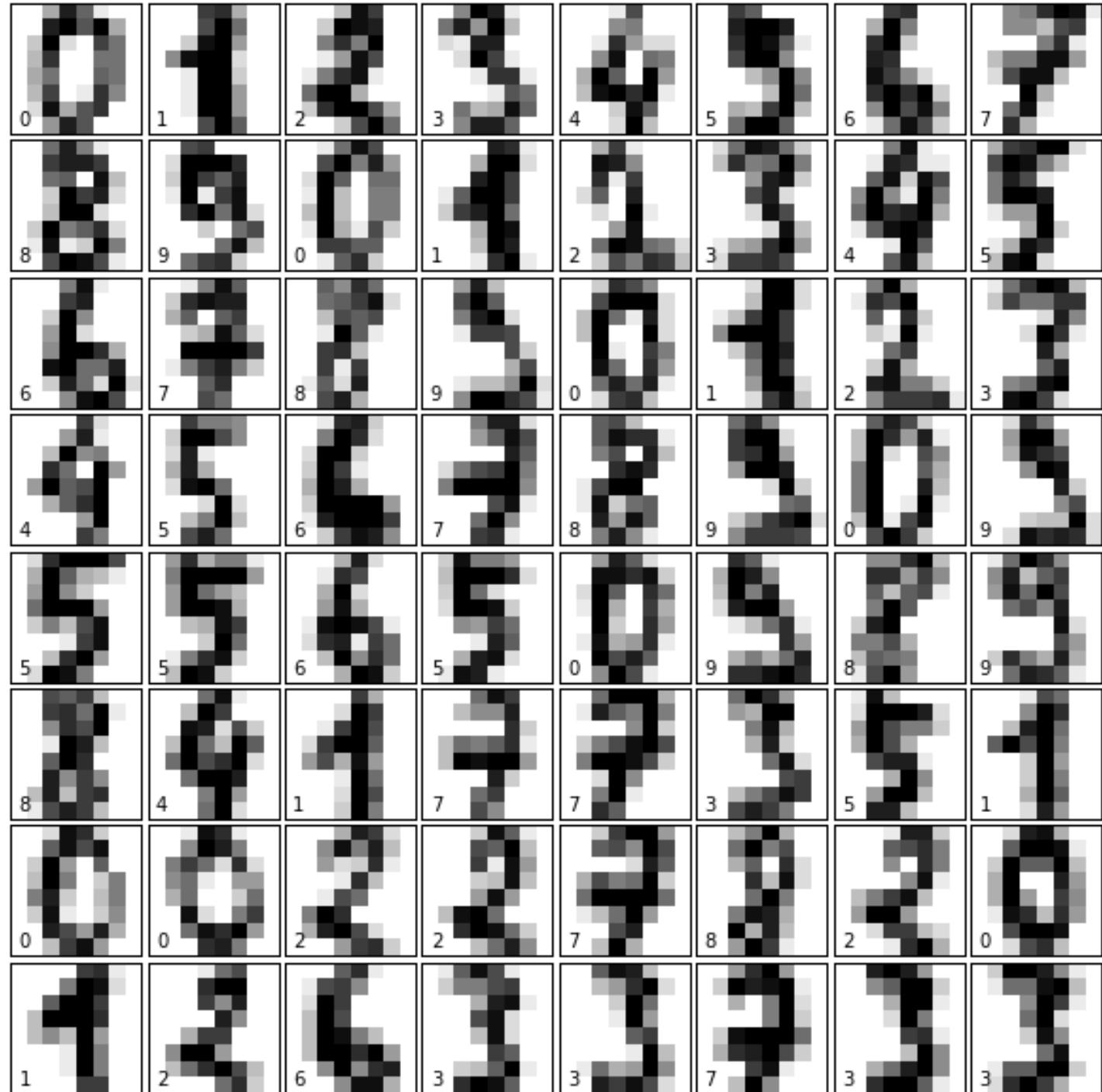
FIFTH THIRD CENTER  
38 FOUNTAIN SQUARE PLAZA, CINCINNATI, OH 45263

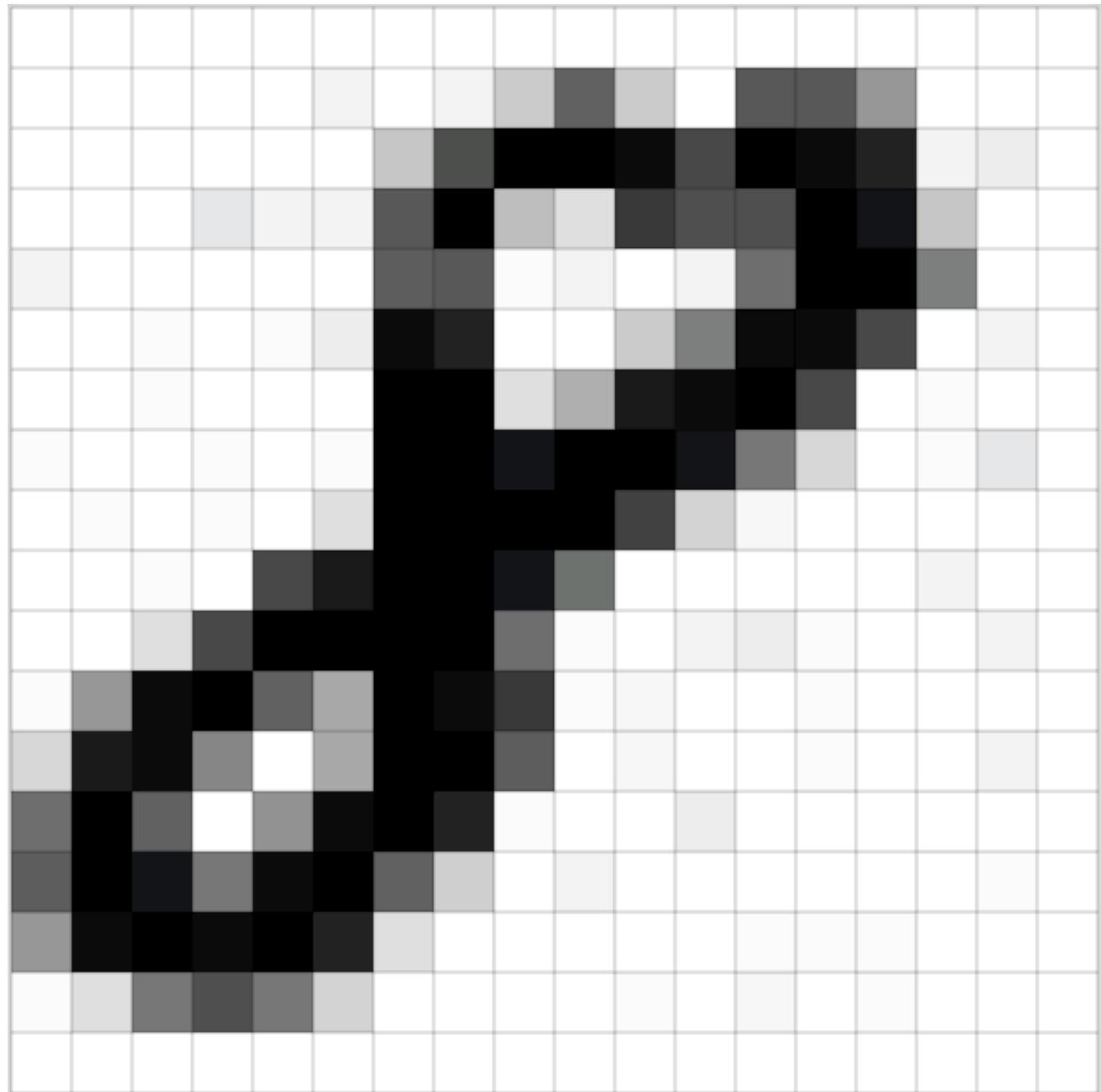
FOR RMB

1042000341 2214 590 536090

00000005000.00

N. A. Armstrong





Go to notebook 03

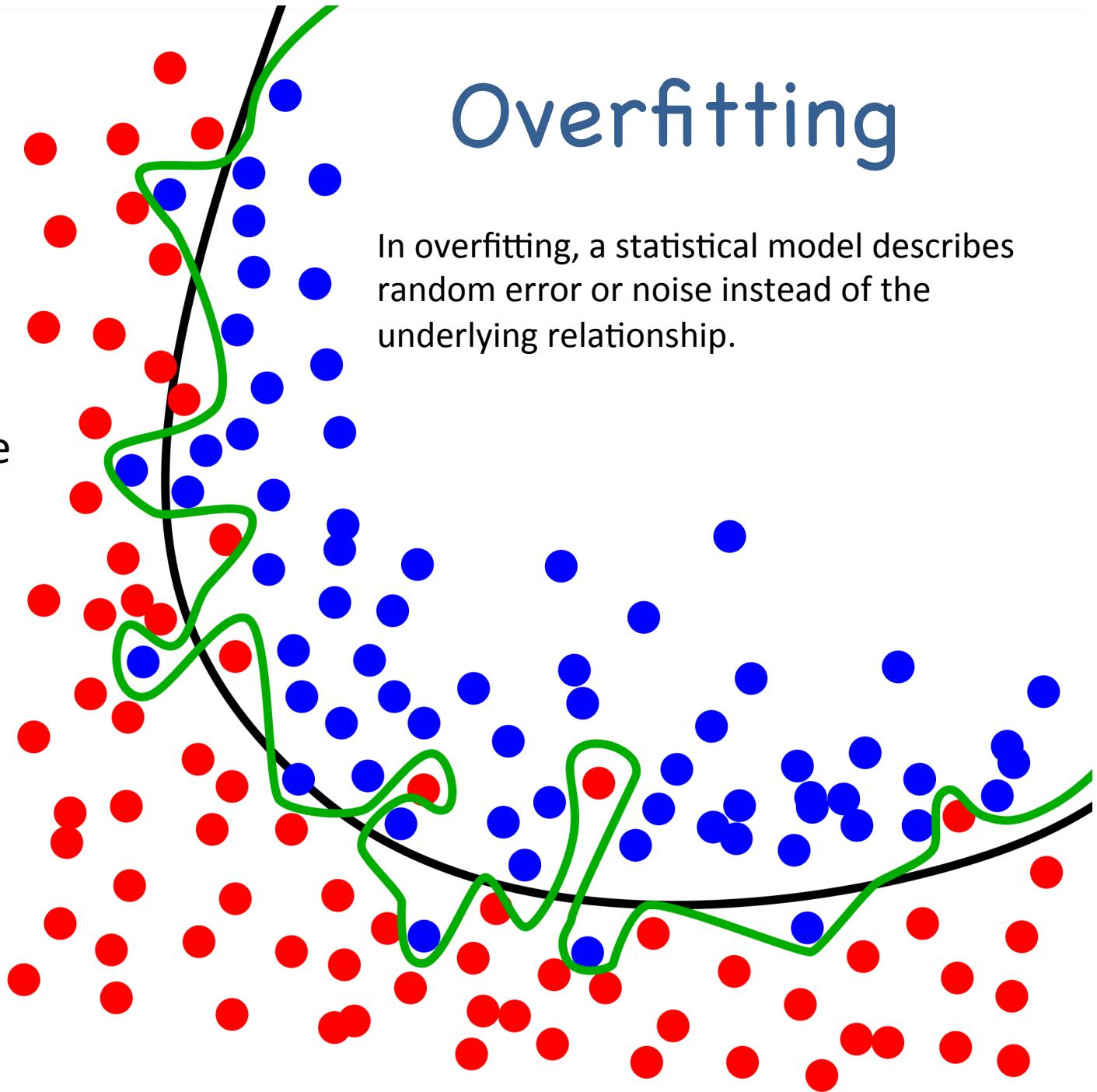
More on ANN



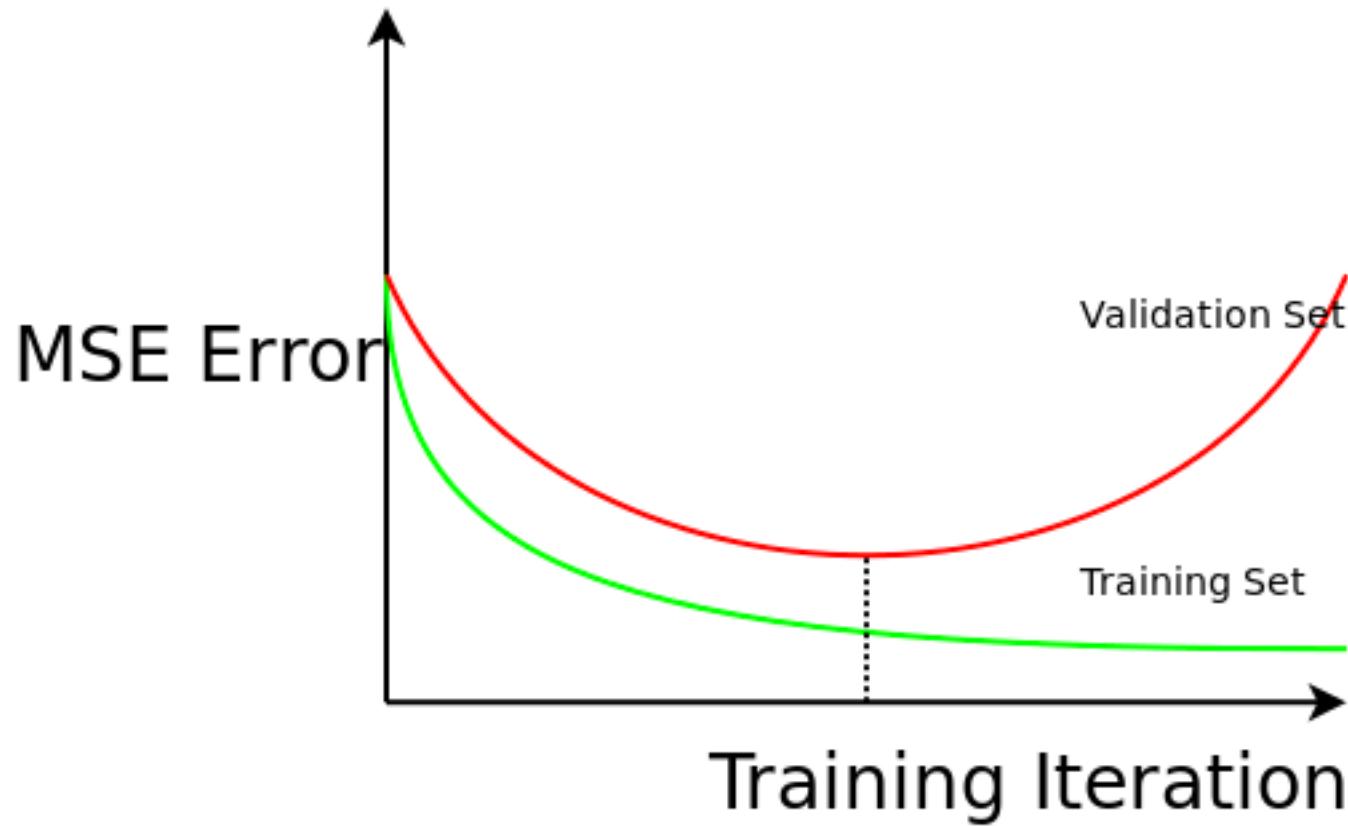
# Overfitting

Overfitting occurs when a model is excessively complex, such as having too many parameters relative to the number of observations.

In overfitting, a statistical model describes random error or noise instead of the underlying relationship.



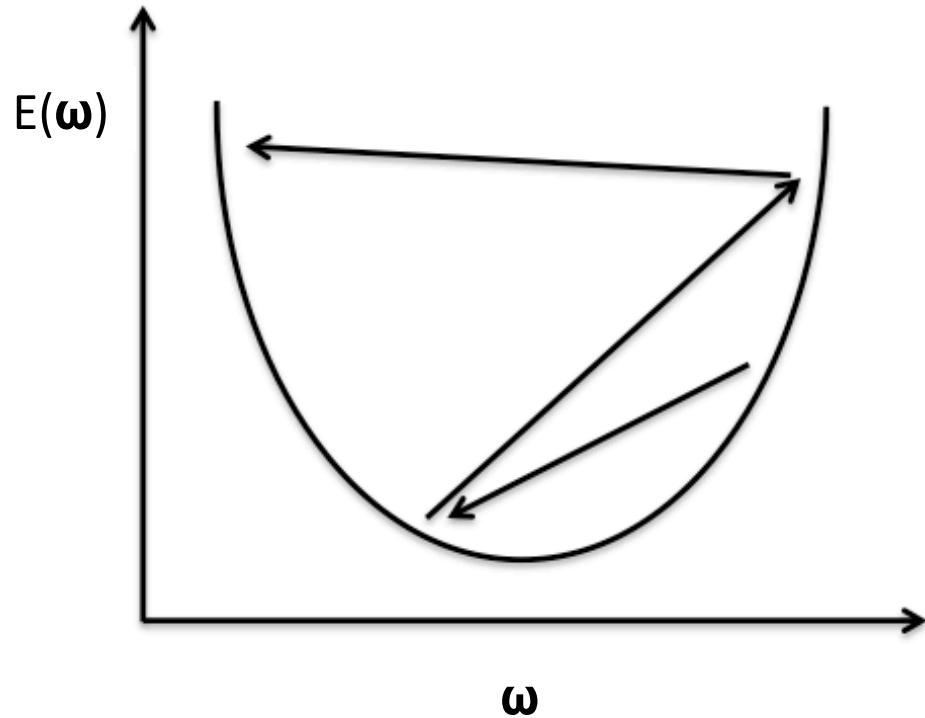
# When to stop



**Training error** is the error that you get when you run the trained model back on the training data.

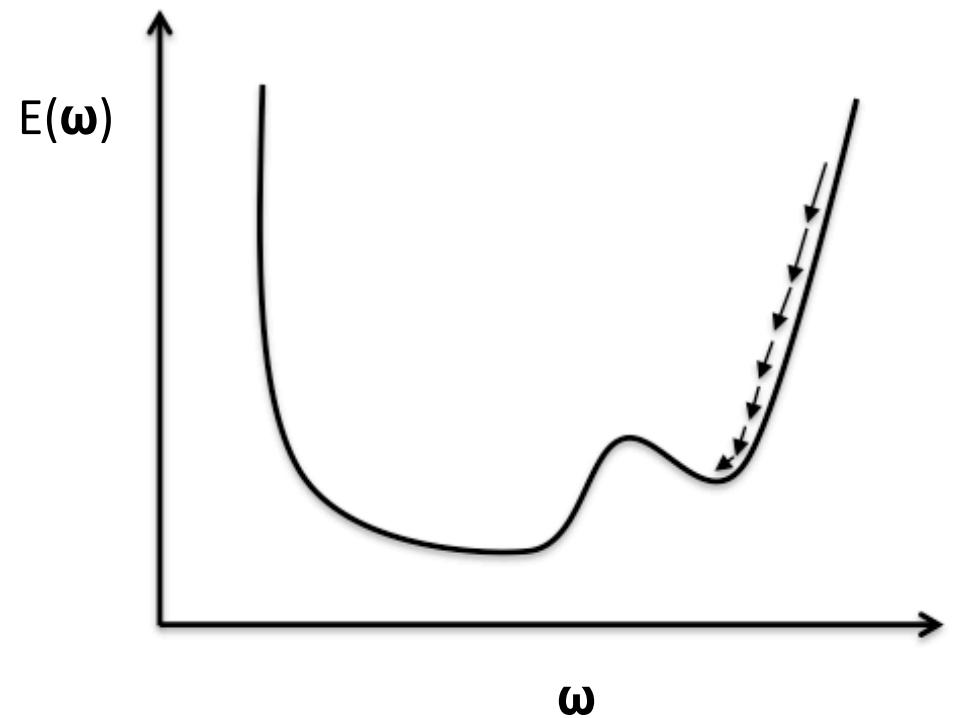
**Validation error** is the error when you get when you run the trained model on a set of data that it has previously never been exposed to.

# Learning rate



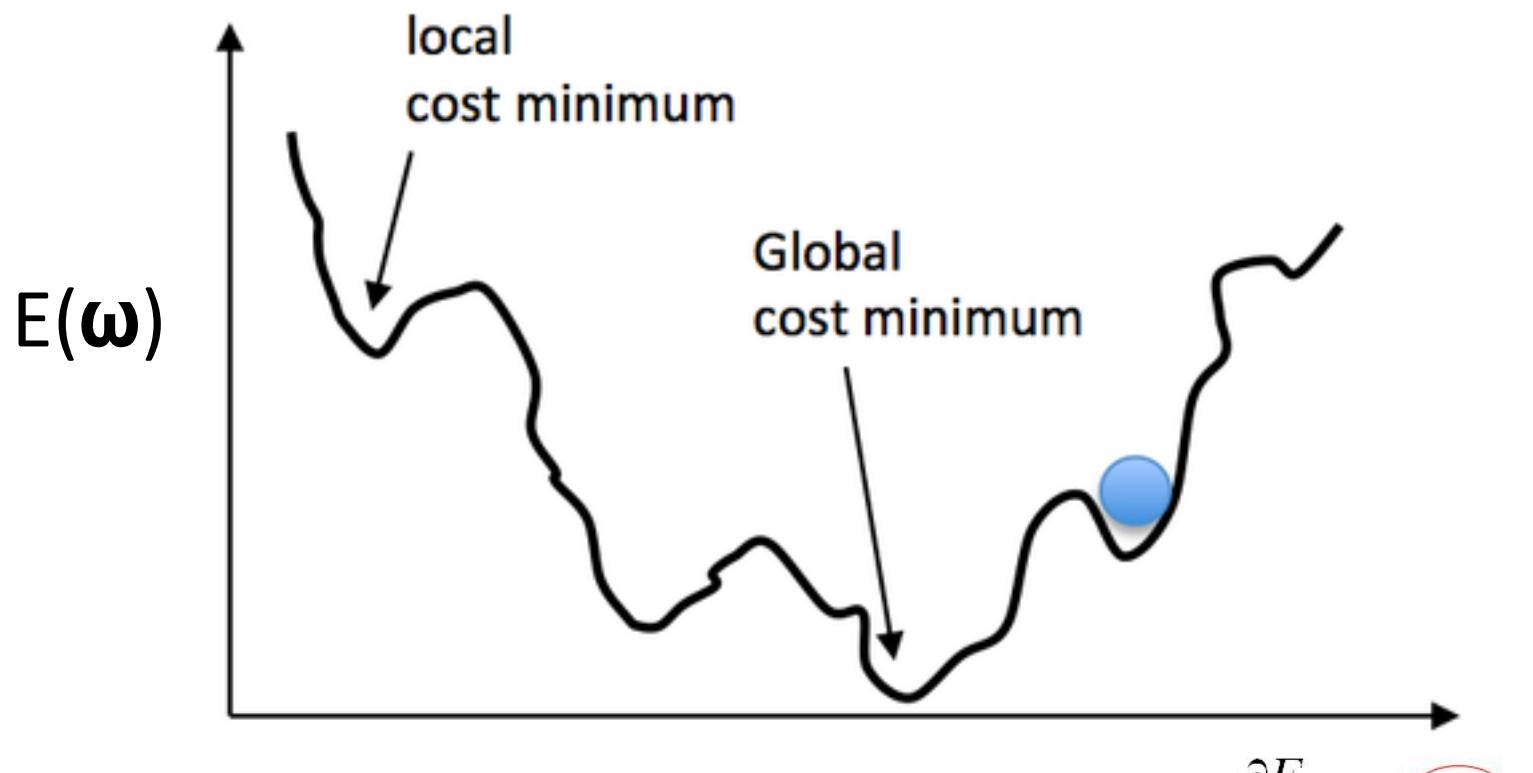
**Large learning rate: Overshooting.**

Learning rate controls step size of each iteration. Use an adaptive learning rate is better.



**Small learning rate: Many iterations until convergence and trapping in local minima.**

# Momentum



A simple way to avoid trapping into a local minimum. (Not guarantee to find the global minimum though)

$$\Delta w^t = -\eta \frac{\partial E}{\partial w} + \alpha \Delta w^{t-1}$$

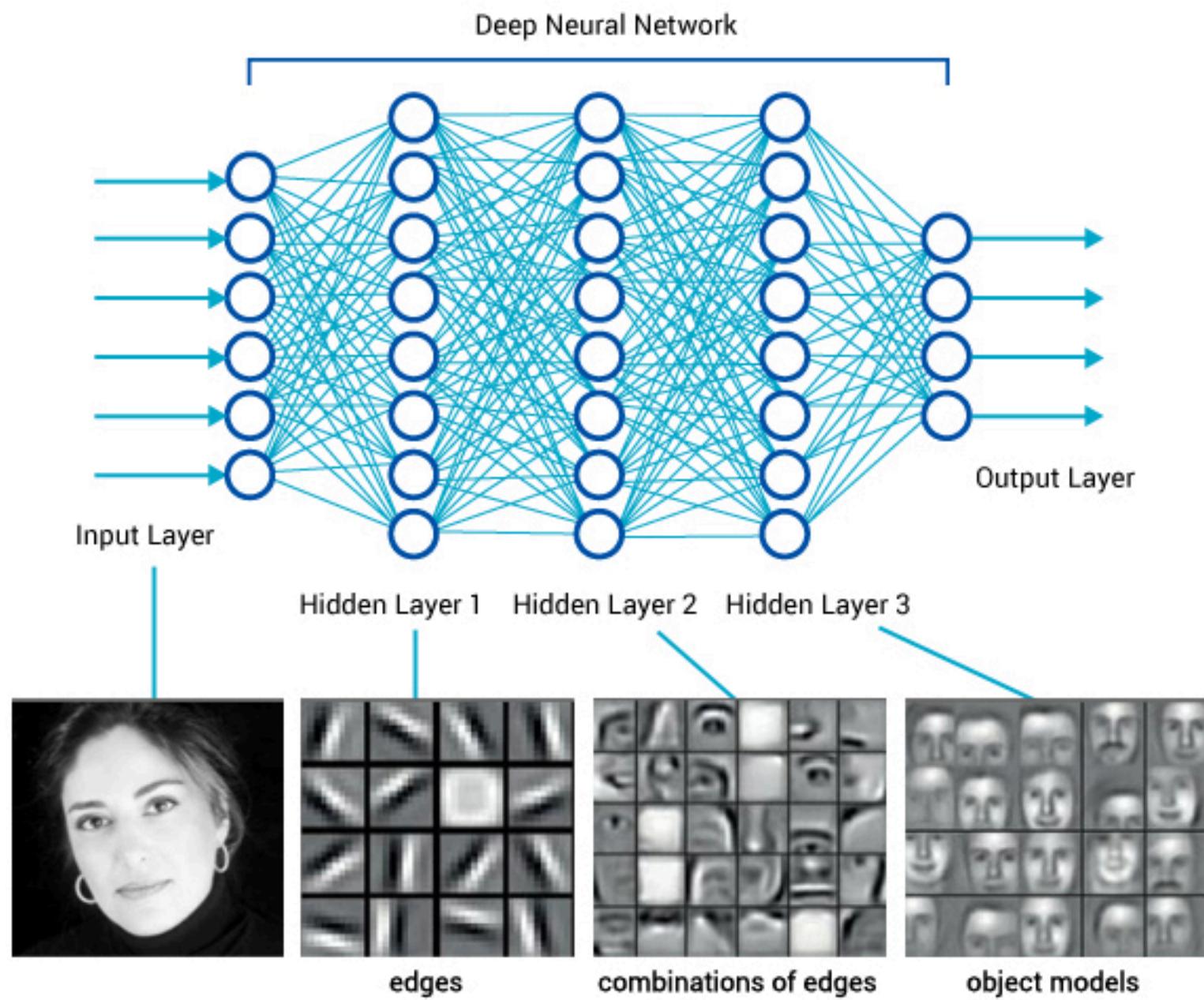
Diagram illustrating the momentum update rule:

- Momentum parameter 0.1-0.8*: Points to the coefficient  $\alpha$  in the equation.
- Momentum term*: Points to the term  $\alpha \Delta w^{t-1}$  in the equation.

A close-up shot from the movie Inception. Leonardo DiCaprio's character, Dom Cobb, is on the left, looking down with a serious expression. Another man's face is partially visible on the right, also looking down. The scene is dimly lit with warm, golden light.

WE NEED TO GO

DEEPER



If you want to learn more ...



# Some useful resources

- <http://iamtrask.github.io/2015/07/12/basic-python-network/>
- <https://seat.massey.ac.nz/personal/s.r.marsland/MLBook.html>
- [http://sebastianraschka.com/Articles/2015\\_singlelayer\\_neurons.html](http://sebastianraschka.com/Articles/2015_singlelayer_neurons.html)
- <http://www.emergentmind.com/neural-network>
- <http://neuralnetworksanddeeplearning.com/>
- <https://www.coursera.org/learn/neural-networks>

I thank all the authors of the above links, as well as a lot of the images I got from internet.