

AI and Deep Learning

Linear Regression & Back-propagation

Jeju National University

Yungcheol Byun

Agenda

- Neuron and Regression
- Loss/Error/Cost Function
- Learning and Updating Weights
- Gradient/Slope
- Computation Graph
- Forward Propagation
- Backpropagation

“

After spending most of the **ocean** life, **salmons** go back to their home(**river**) where they were born.



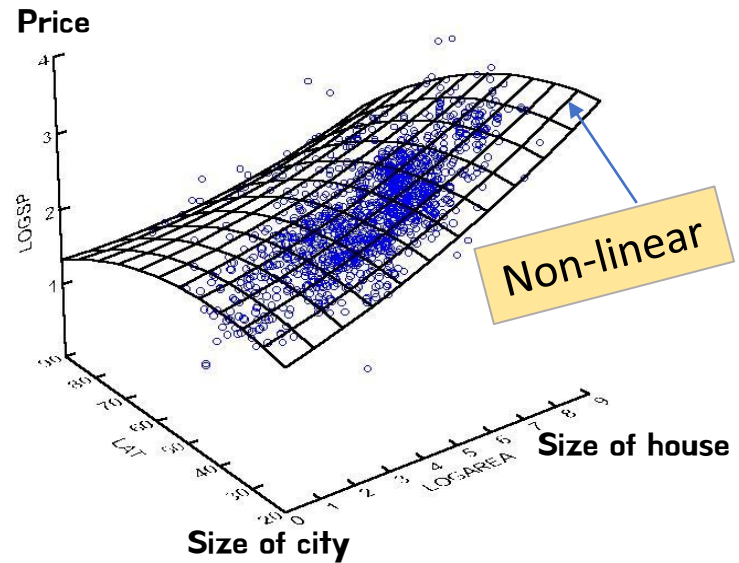
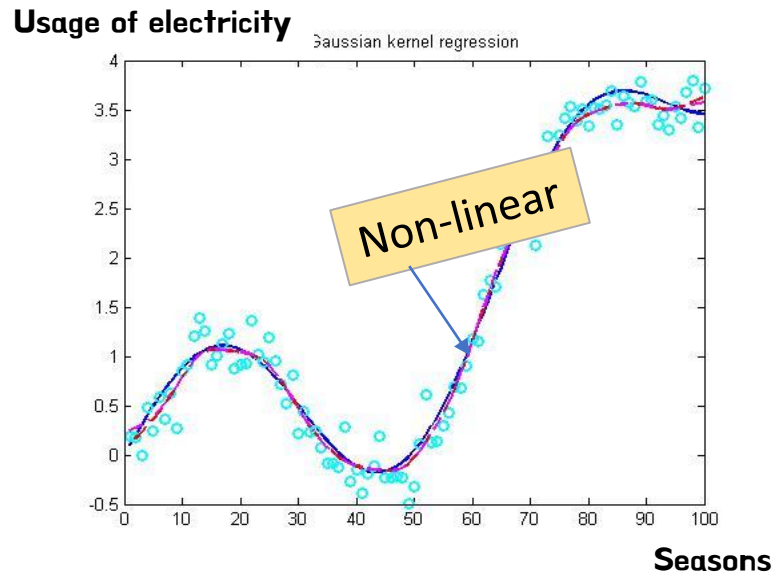
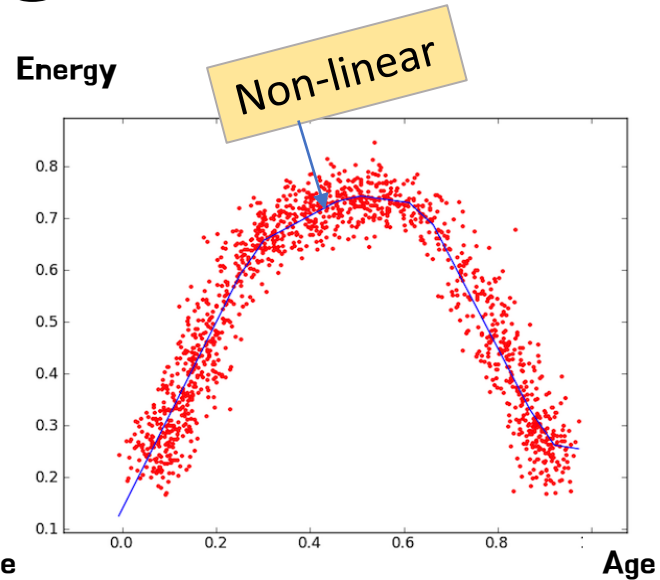
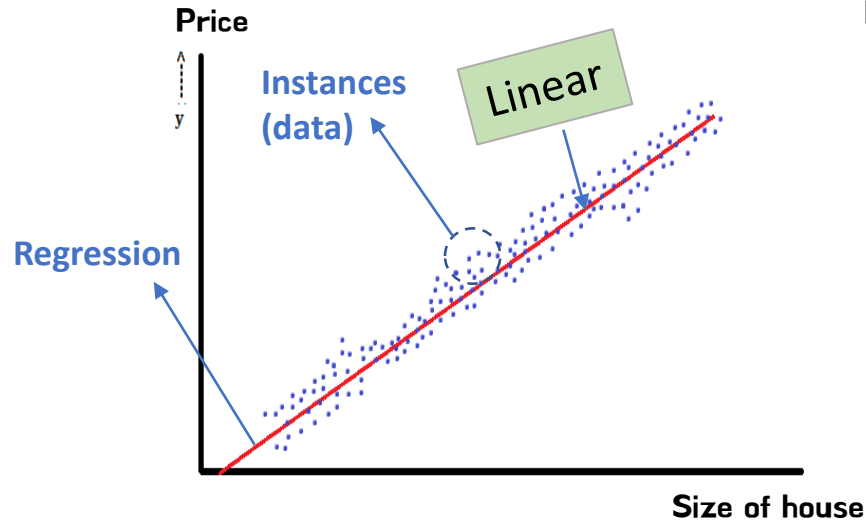
Regression (회귀)

- Go back
- To describe a natural phenomena
- A term frequently used in anthropology(인류학) to present a natural tendency

Regression (회귀)

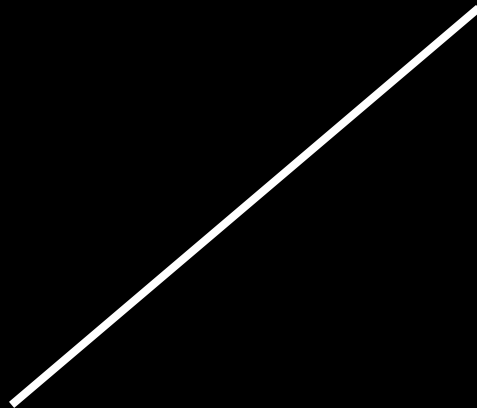
- Statistical measure to determine **the relationship** between one dependent variable (usually denoted by Y , 종속변수) and a series of other independent variables X 독립변수 .

Examples of Regression



Linear Regression

The relationship forms **linear** shape.
ex) wage/hour, price/size of house



Lab

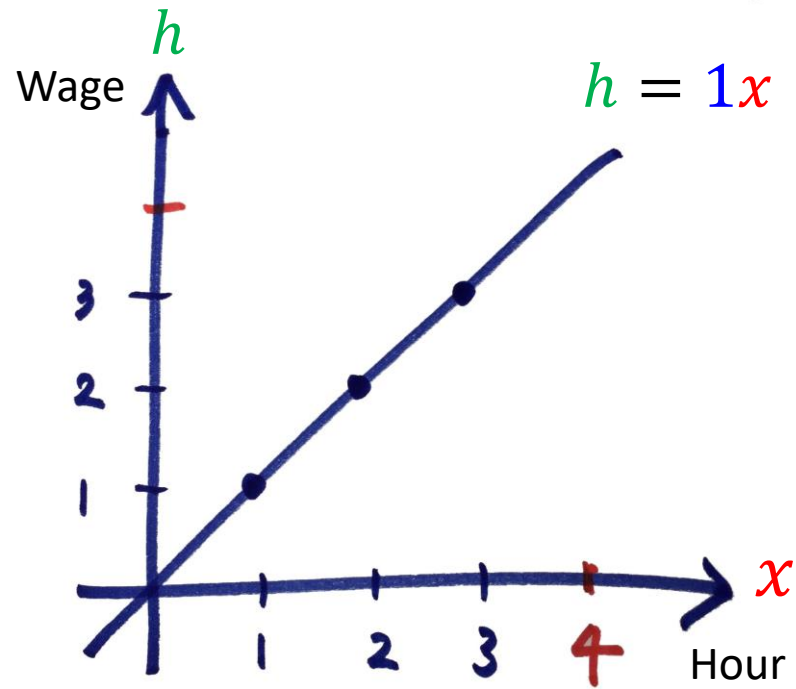
Linear Regression

using  desmos

www.desmos.com

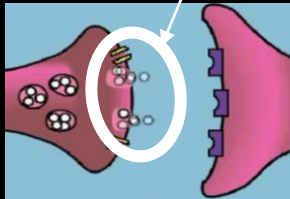
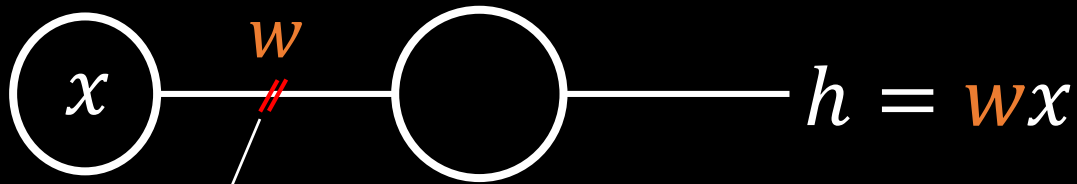
1. Draw a point(data) (1, 1)
2. Add (2, 2), (-1, -1), (-2, -2)
3. $h = x$
4. $h = 2x$
5. $h = wx$ (**rotation**)
6. Move all of the points by adding 1 to y
7. $h = wx + 1$ (**shifting**)
8. $h = wx + b$ (**rotation** and **shifting**)

www.desmos.com



$$h = wx$$

Neuron and regression



- w : Neuro-transmitter
- if large / if small / if not exists (rotation)
- A neuron represents
a linear regression

Hypothesis

$$h = wx$$

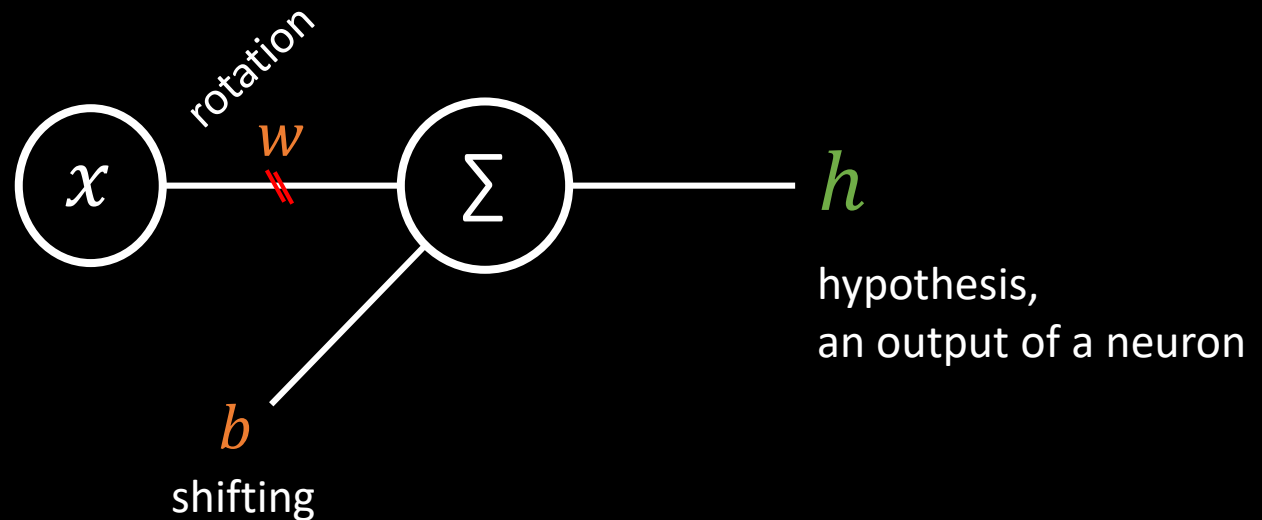
$$h = wx + b$$

- An answer by a neuron



- h ypothesis : a proposed explanation for a phenomenon (a regression).
- Not proved yet, but it can represents the regression after updating w .
- b ? for better linear regression

The role of w and b



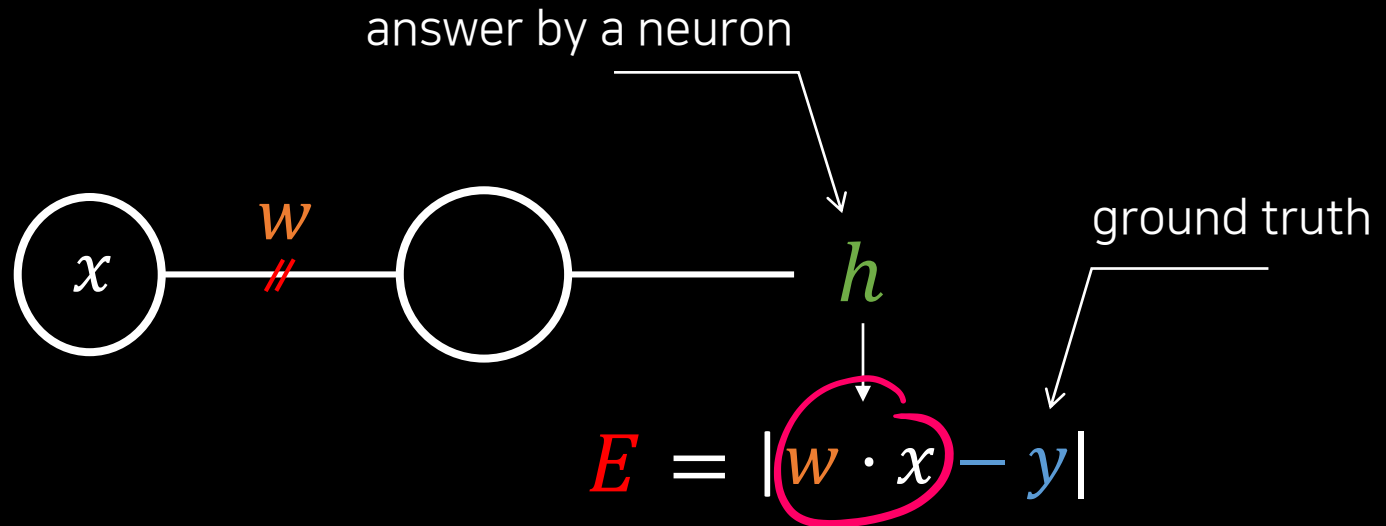
$$h = wx + b$$

How to learn (update w)

- Scolding or blaming the neuron if it is wrong
- The neuron gets stress and automatically updates w to answer well next time so that the error(difference) decreases.
- How can we calculate the error?

Error function

loss function
difference function



Why absolute?

Error function

The error is the difference between a neuron's answer and its ground truth.

$$E = |h_{\text{hypothesis}} - y|$$

$$E = |w \cdot x - y|$$

'1 hour, then 1 USD'

x_i	y_i
1	1

$$E = |w \cdot 1 - 1|$$

Supervised Learning

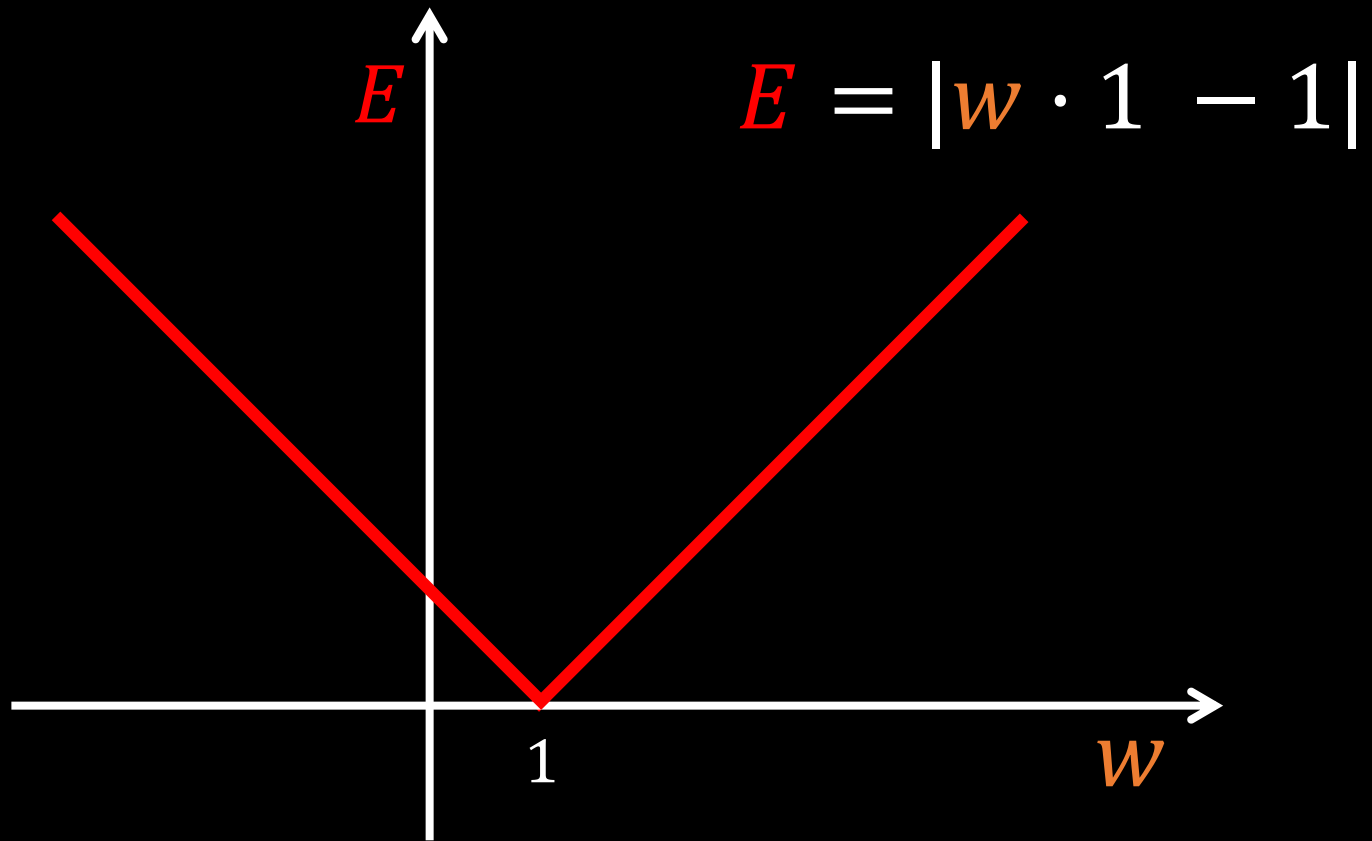
지도학습

www.desmos.com

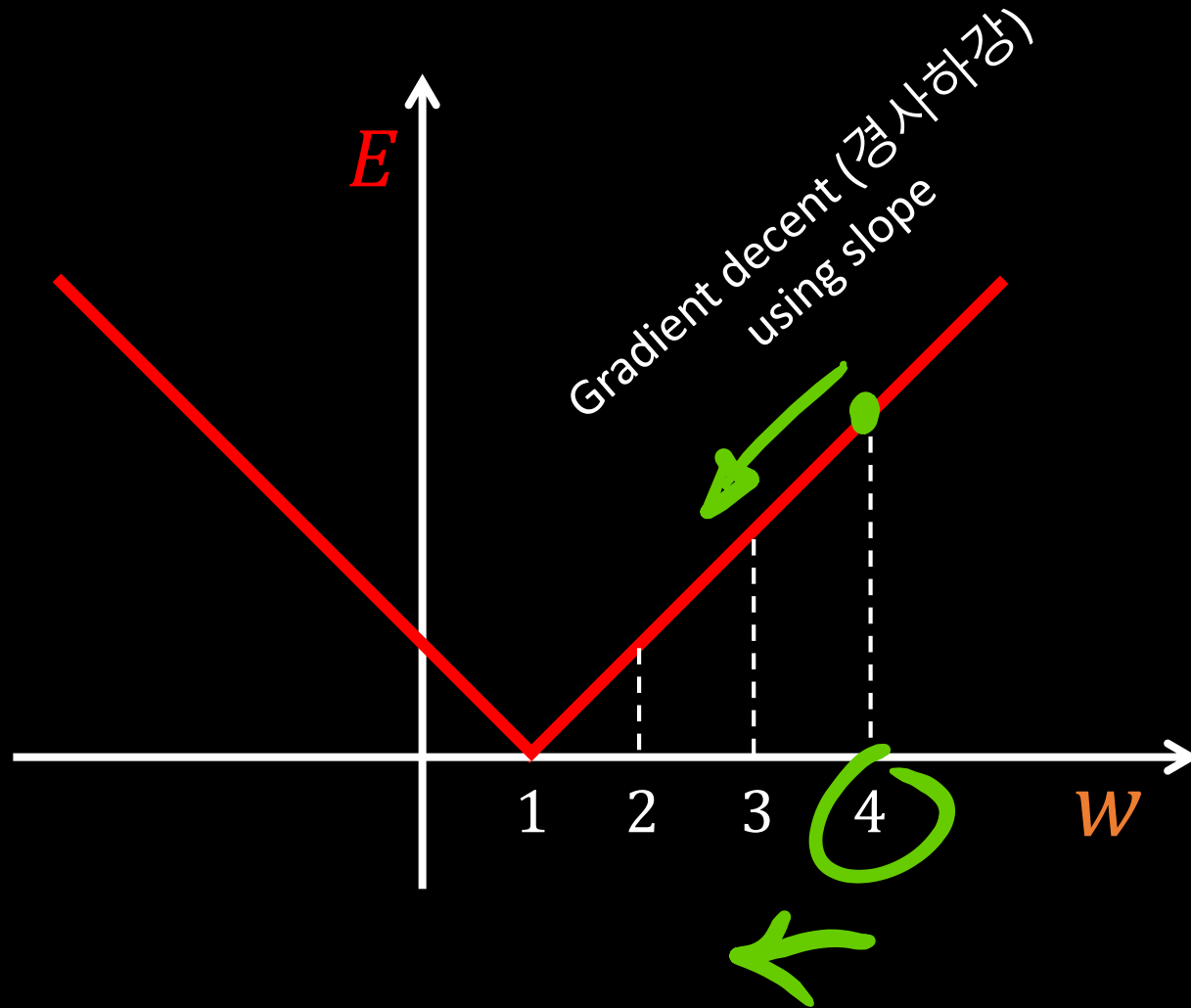
1. Mark $(1, 1)$
2. $h = w \cdot x$
3. $E = w \cdot 1 - 1$
4. $E = |w \cdot 1 - 1|$
5. (w, E)



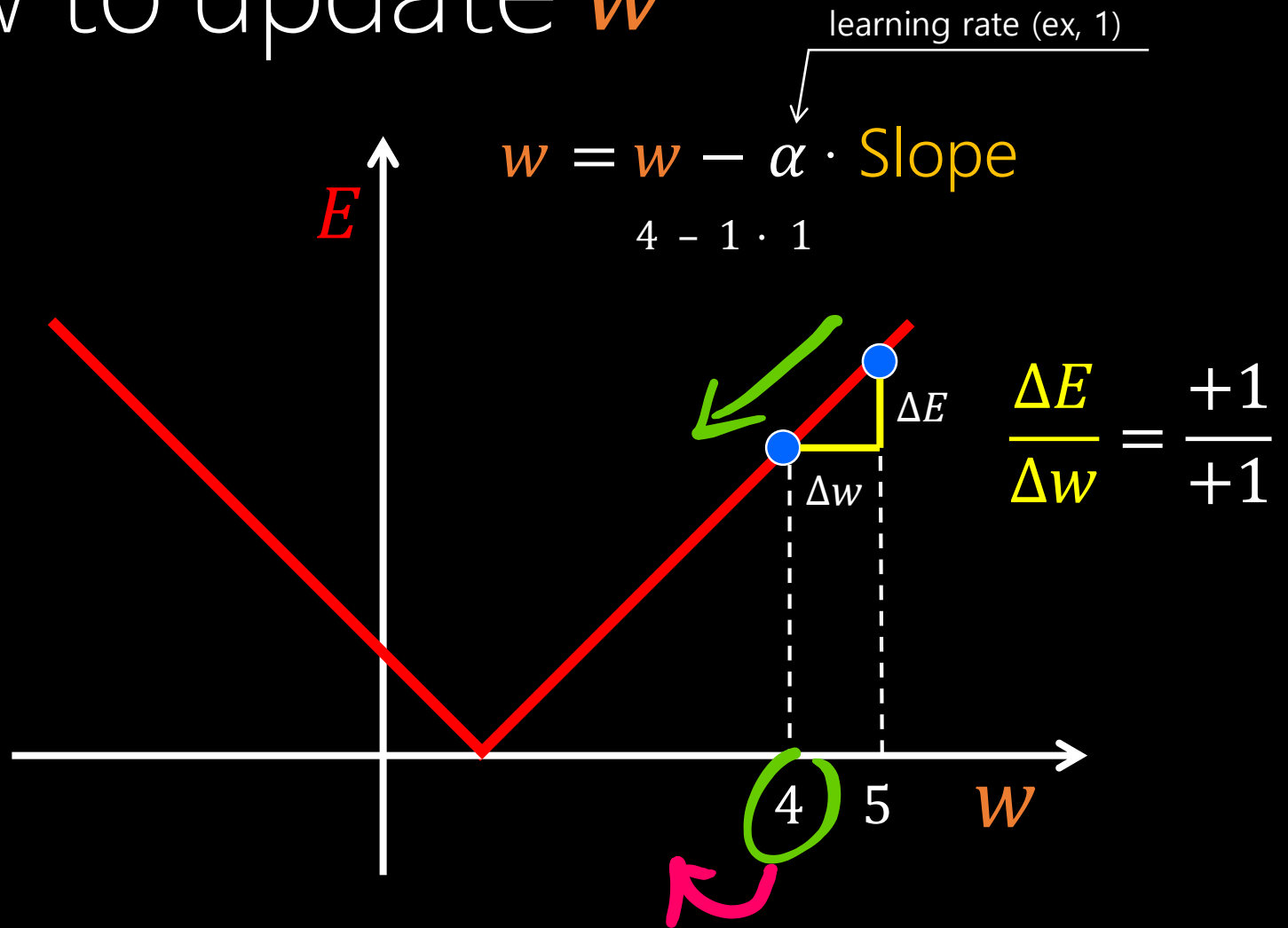
Error Function of w



How to update w



How to update w

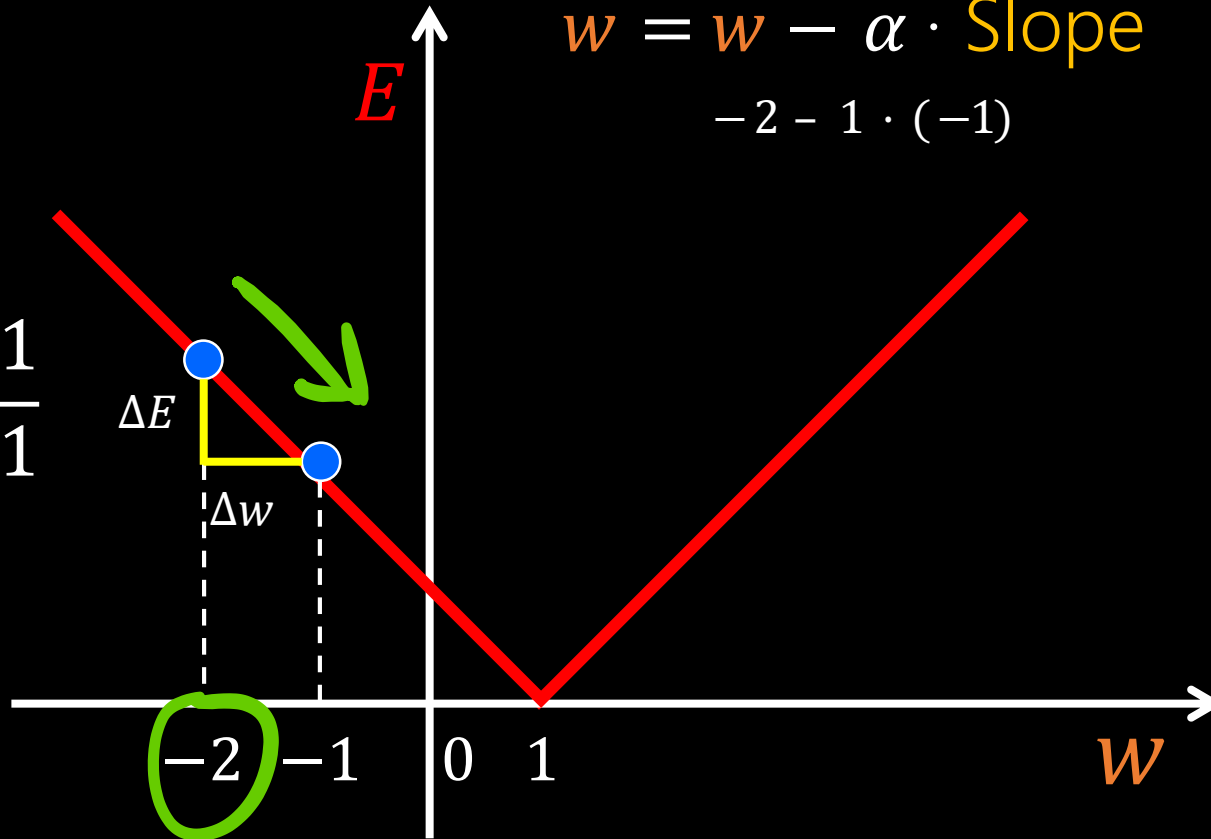


How to update w

learning rate (ex, 1)

$$w = w - \alpha \cdot \text{Slope}$$
$$-2 - 1 \cdot (-1)$$

$$\frac{\Delta E}{\Delta w} = \frac{-1}{+1}$$



$$w = 4, \alpha = 1, \text{Slope} = 1$$

$$w = w - \alpha \cdot \text{Slope}$$

$$4 - 1 \cdot 1 \longrightarrow 3 \quad \text{Error } E = 2$$

$$3 - 1 \cdot 1 \longrightarrow 2 \quad \text{Error } E = 1$$

$$2 - 1 \cdot 1 \longrightarrow 1 \quad \text{Error } E = 0$$

$$w = -2, \alpha = 1, \text{Slope} = -1$$

$$w = w - \alpha \cdot \text{Slope}$$

$$-2 - 1 \cdot (-1) \rightarrow -1 \quad \text{Error } E = 2$$

$$-1 - 1 \cdot (-1) \rightarrow 0 \quad \text{Error } E = 1$$

$$0 - 1 \cdot (-1) \rightarrow 1 \quad \text{Error } E = 0$$

$$w = -2, \alpha = 2, \text{Slope} = -1$$

$$w = w - \alpha \cdot \text{Slope}$$

$$-2 - 2 \cdot (-1) \rightarrow 0 \quad \text{Error } E = 1$$

$$0 - 2 \cdot (-1) \rightarrow 2 \quad \text{Error } E = 1$$

$$2 - 2 \cdot (1) \rightarrow 0 \quad \text{Error } E = 1$$

$$0 - 2 \cdot (-1) \rightarrow 2 \quad \text{Error } E = 1$$

$$2 - 2 \cdot (1) \rightarrow 0 \quad \text{Error } E = 1$$

Absolute Error

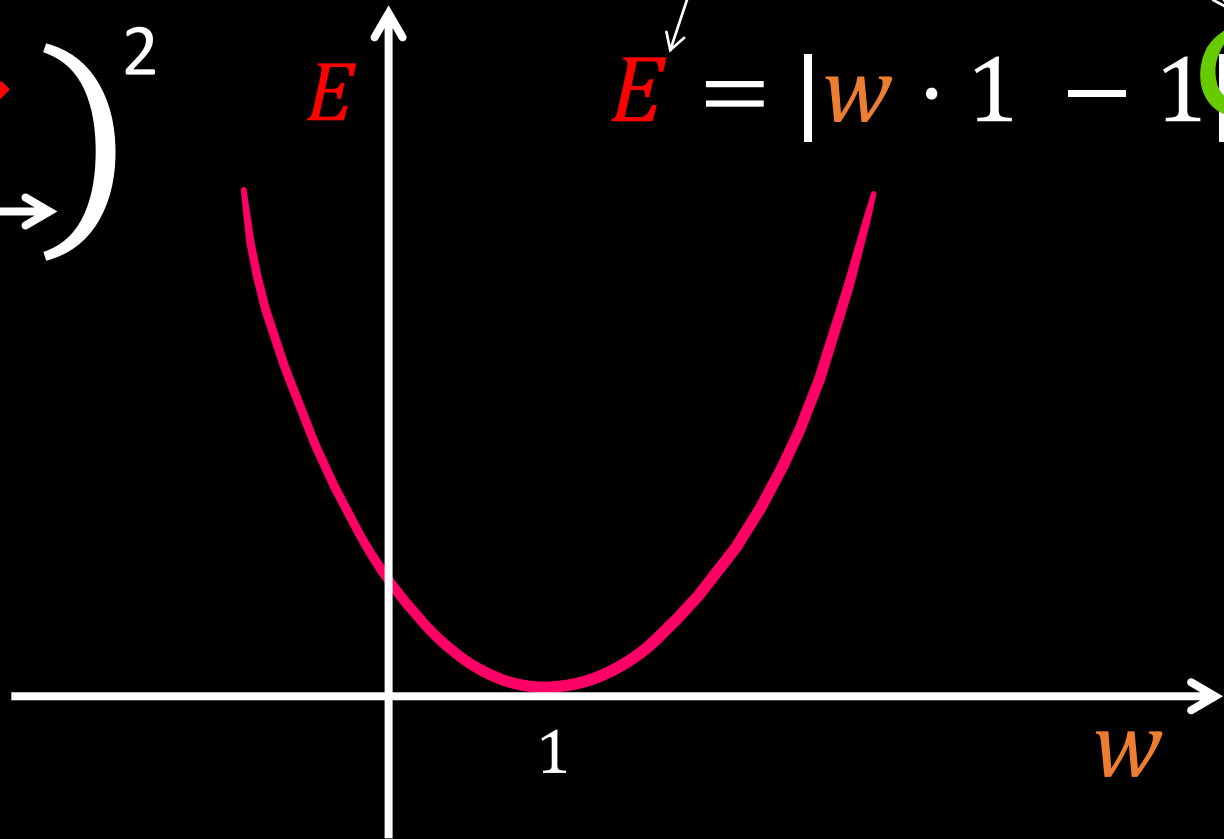
L1 Loss function

Issues in the absolute error

- Always **the same slope** in the error graph regardless of the value of w
- Therefore, **the same speed** in movement
- Not guarantee to get the proper value of w which gives 0 or almost 0 error.

Square Error

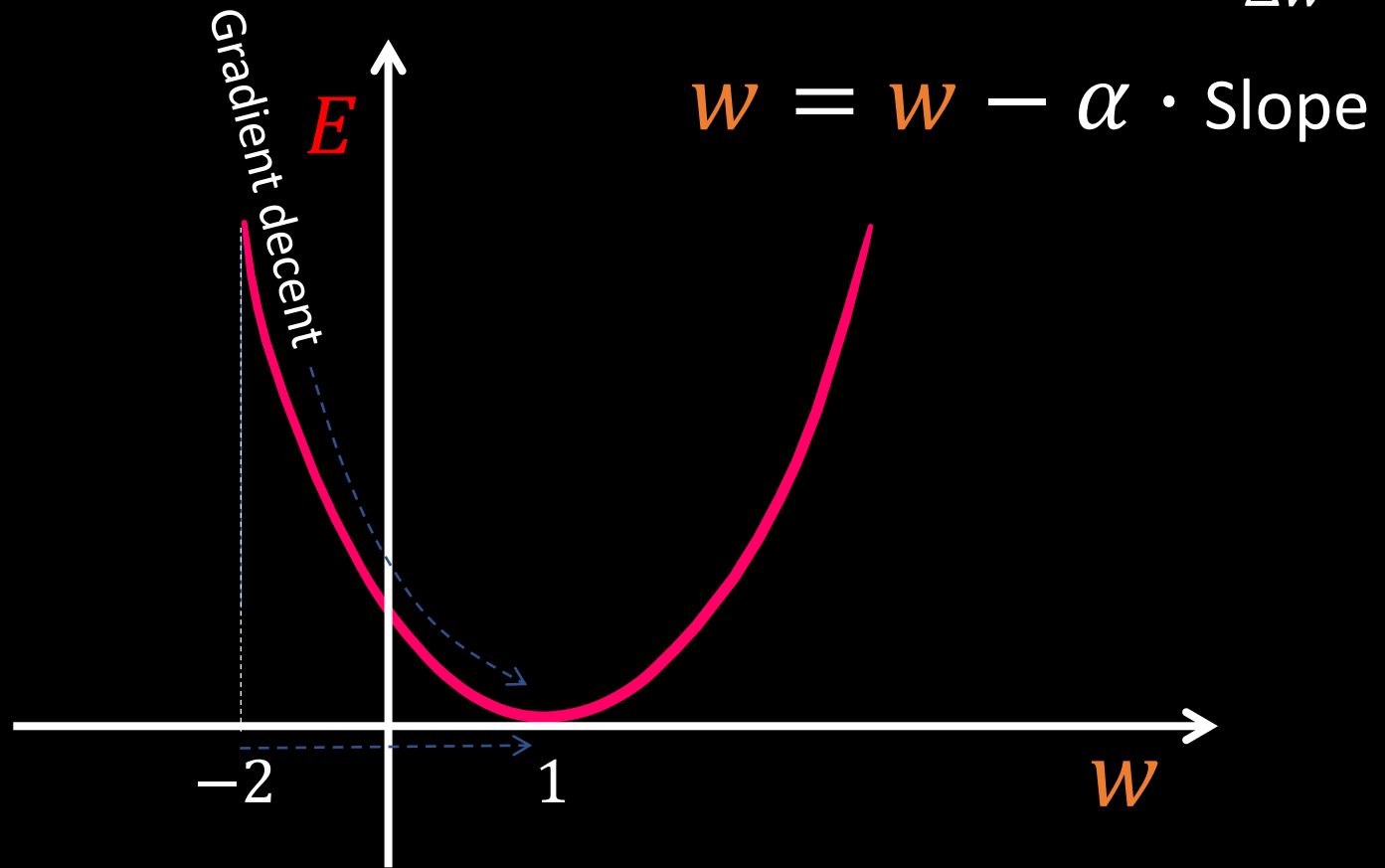
$$\left(\begin{array}{c} \text{red V-shape} \\ \text{on a coordinate system} \end{array} \right)^2$$



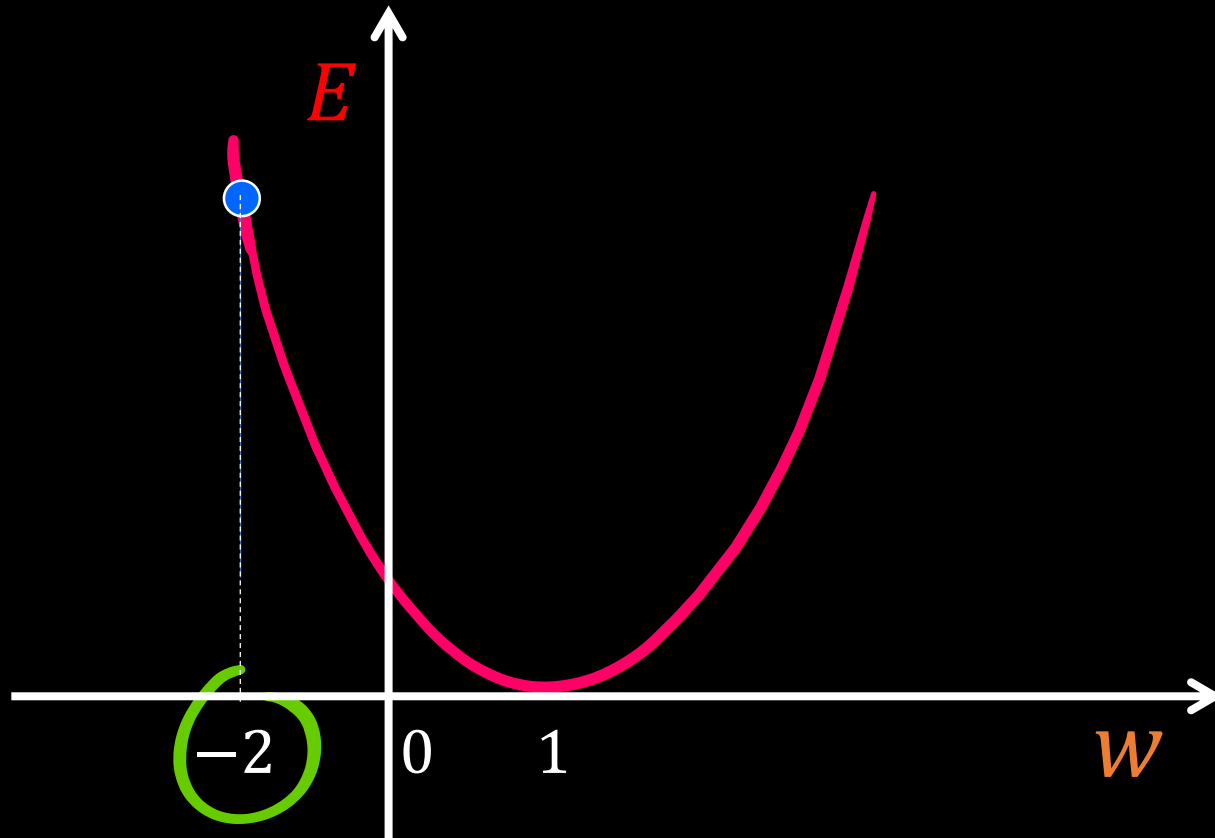
$$\overset{\text{error}}{E} = | \overset{\text{square (제곱)}}{w \cdot 1 - 1} |^2$$

How to update w

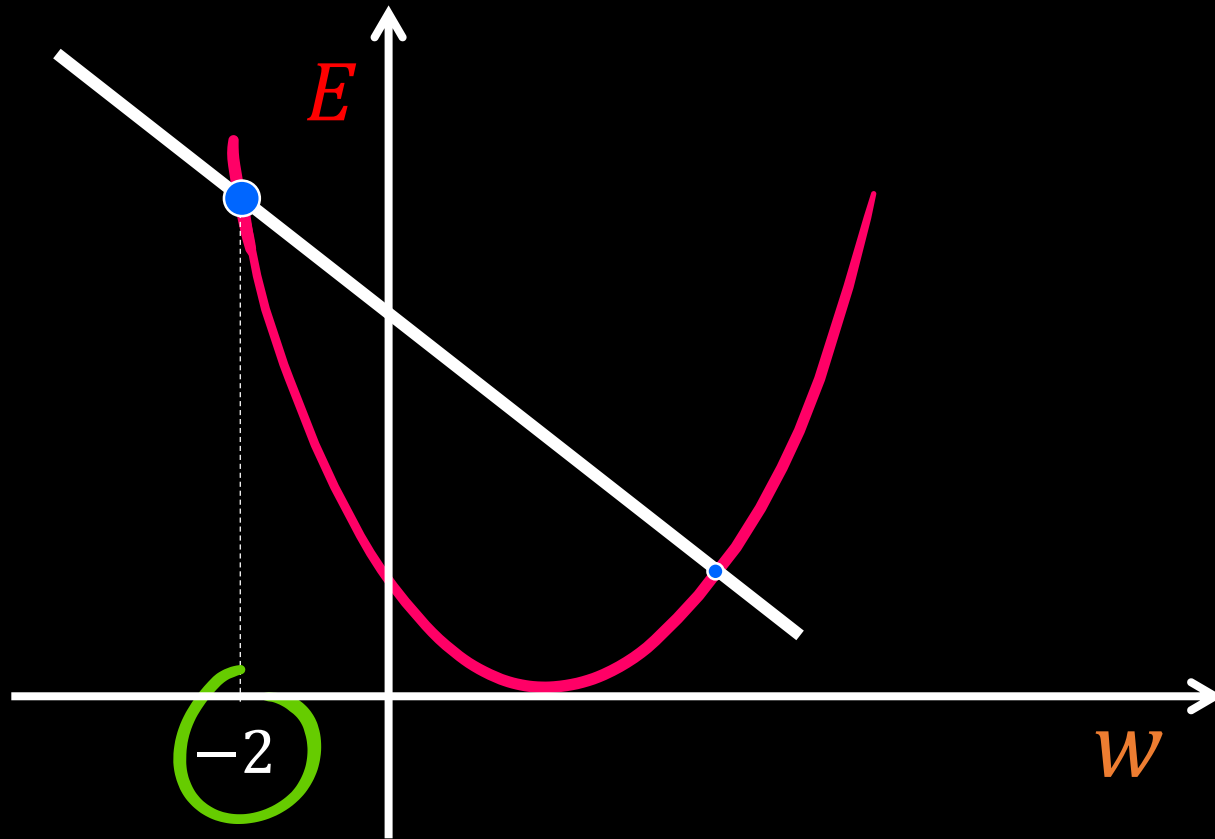
$$\frac{\Delta E}{\Delta w}$$



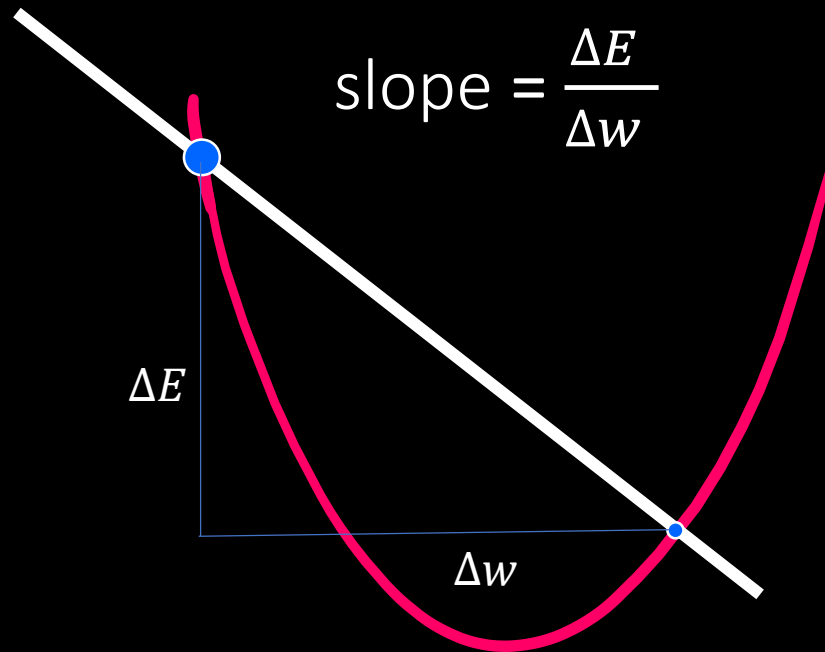
How to update w



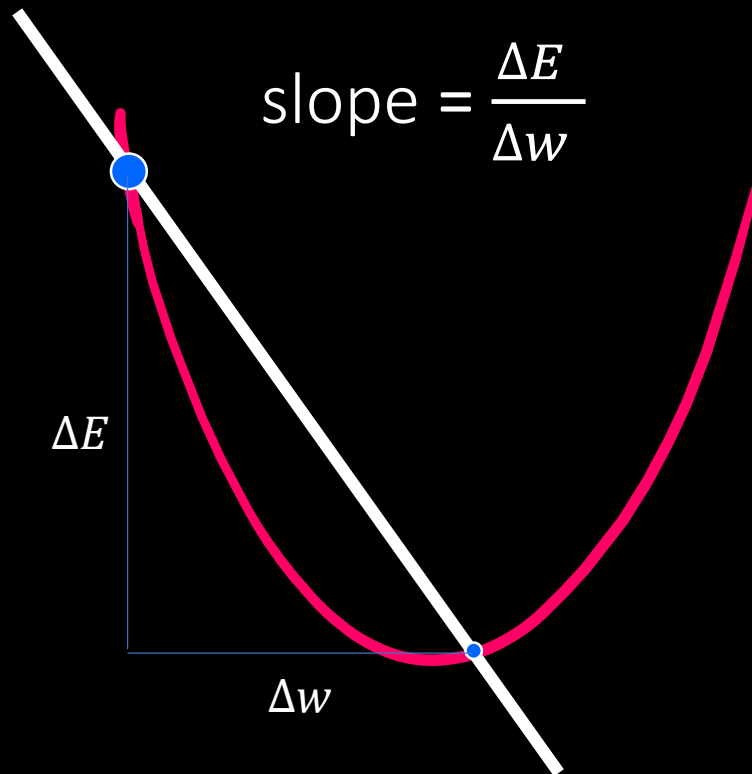
How to update w



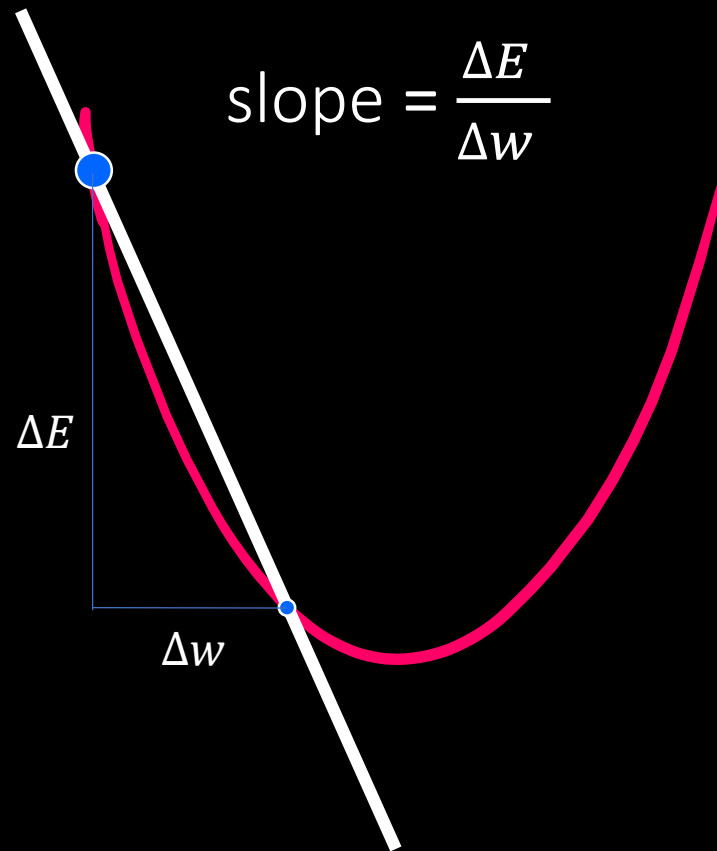
How to update w



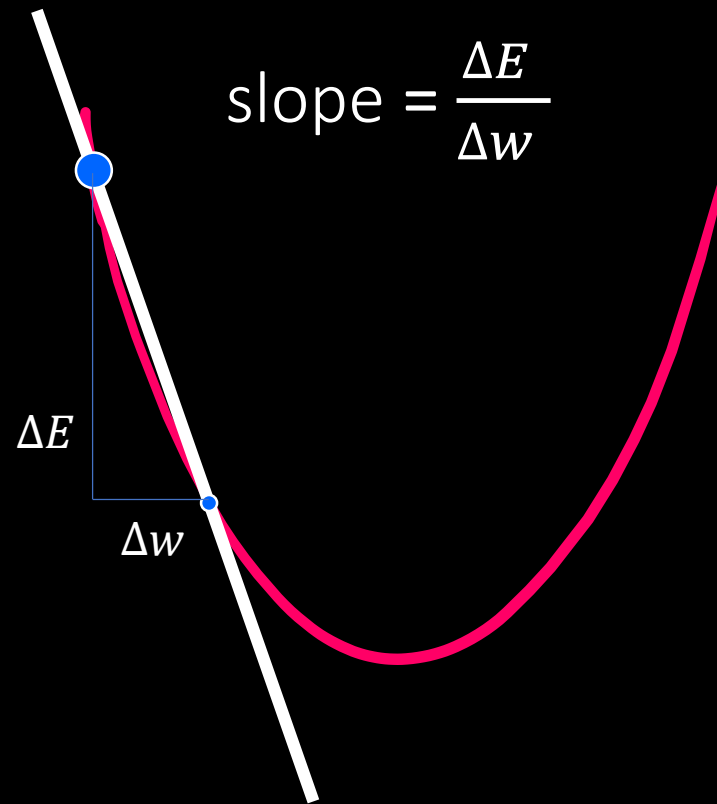
How to update w



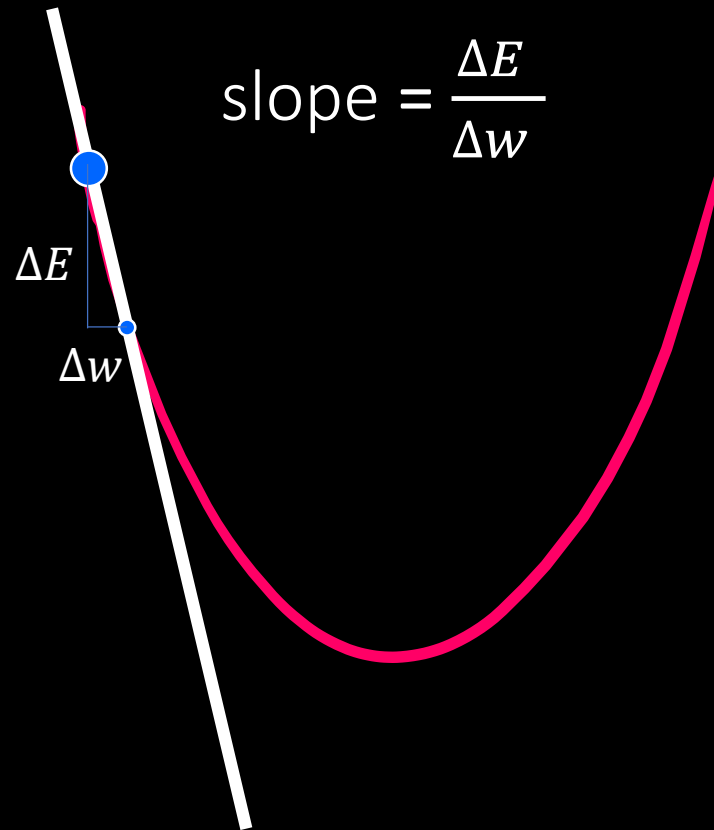
How to update w



How to update w

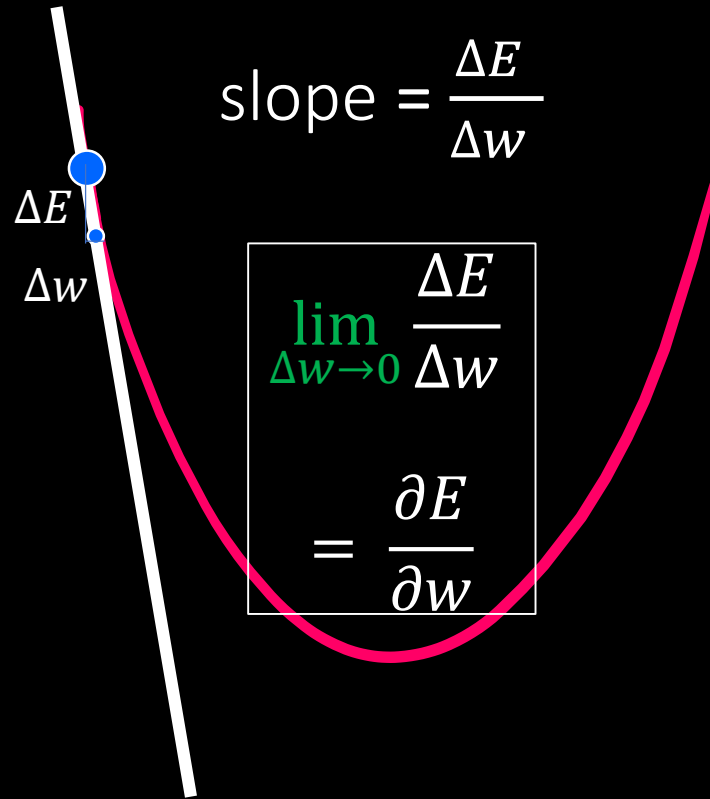


How to update w

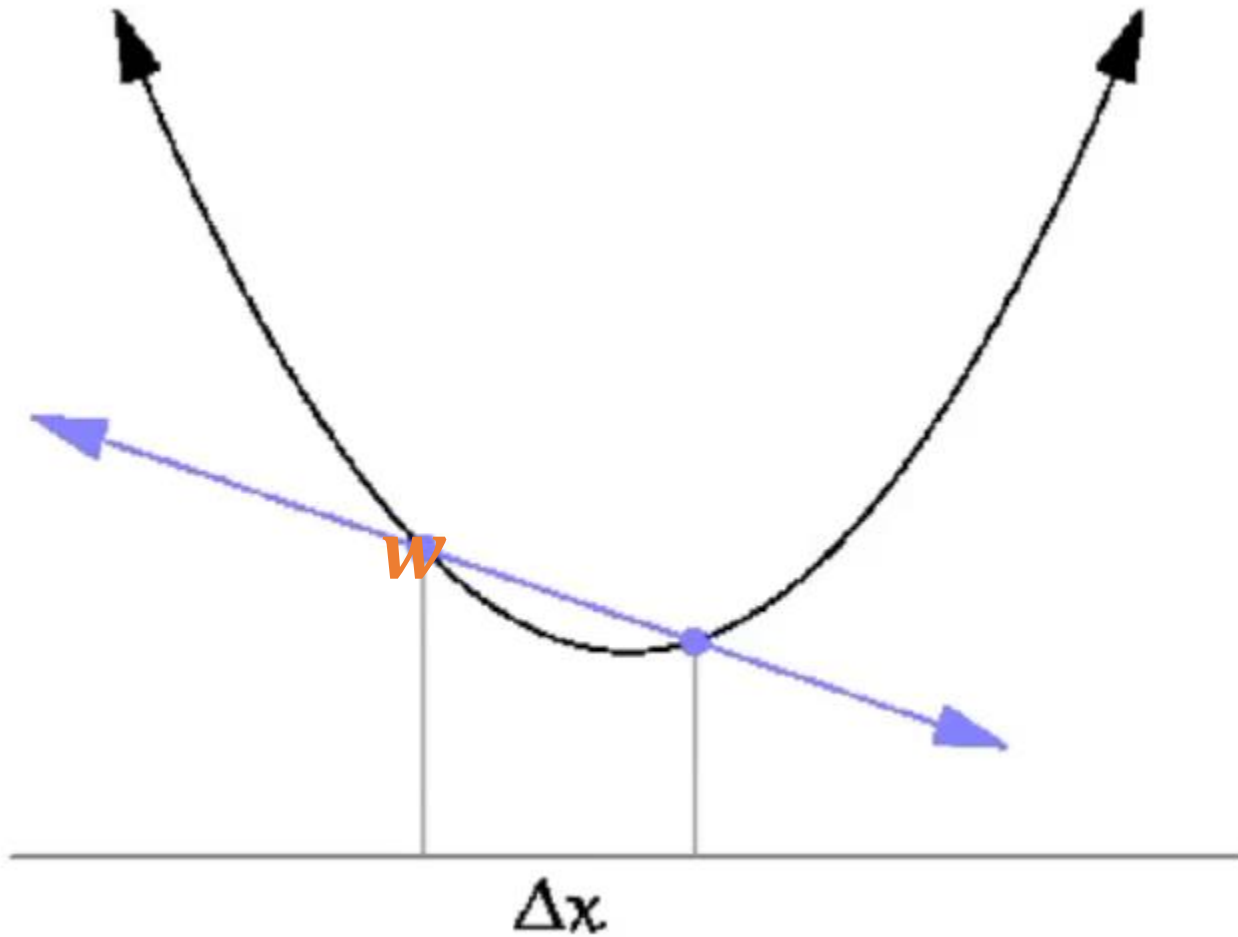


How to update w

접선·Tangent line



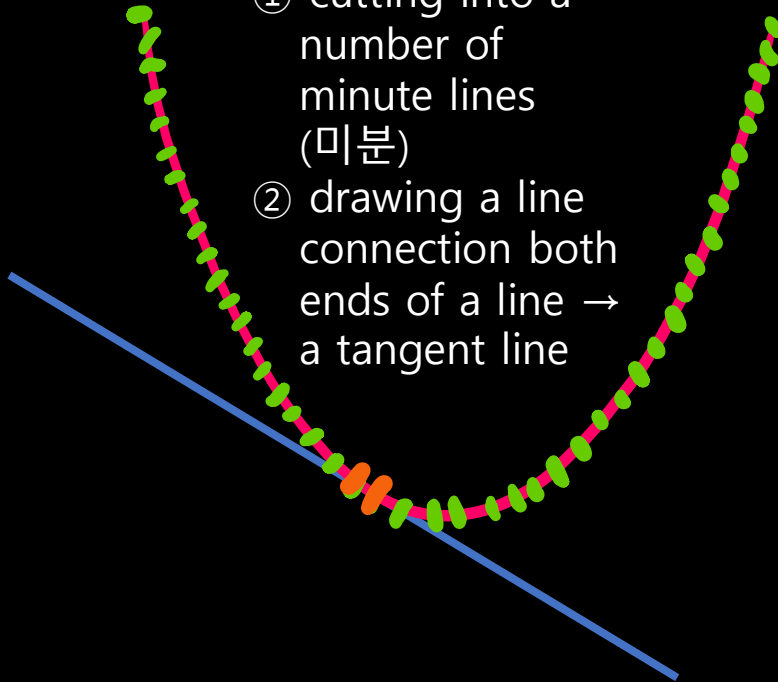
How to update w



How to update w

Numerical differentiation

- ① cutting into a number of minute lines (미분)
- ② drawing a line connection both ends of a line \rightarrow a tangent line



$$\lim_{\Delta w \rightarrow 0} \frac{\Delta E}{\Delta w}$$

$$= \frac{\partial E}{\partial w}$$

$$= \text{미분}$$

How to update w

$$w = w - \alpha * \text{Slope}$$

$$w = w - \alpha \frac{\partial E}{\partial w}$$

$$\alpha = \text{learning rate (ex, 0.1)}$$

Squared Error

L2 Loss function

Advantages

- Fast movement from both sides and fine tuning at the valley(center) area
- Different slope/gradient according to the value of w
- Steep slope means that the error is big and w is far from the optimal area.
- We can get the slope(gradient) at any place(differentiable).

In case of AE

- Always the same slope in the error graph regardless of the value of w
- Therefore, the same speed in the movement
- Not sure to get the w value which gives 0 error or almost 0
- No way to guess the current value of w
- Not differentiable when w is 1

Multiple Data

For 3 instances of data

x_i	y_i
1	1
2	2
3	3

$$E = \frac{1}{3} \sum_{i=1}^3 (wx_i - y_i)^2$$



Add (2, 2), (3, 3)

$$E = \frac{1}{3} \sum_{i=1}^3 (wx_i - y_i)^2$$

Draw (w , E)

Multiple Data

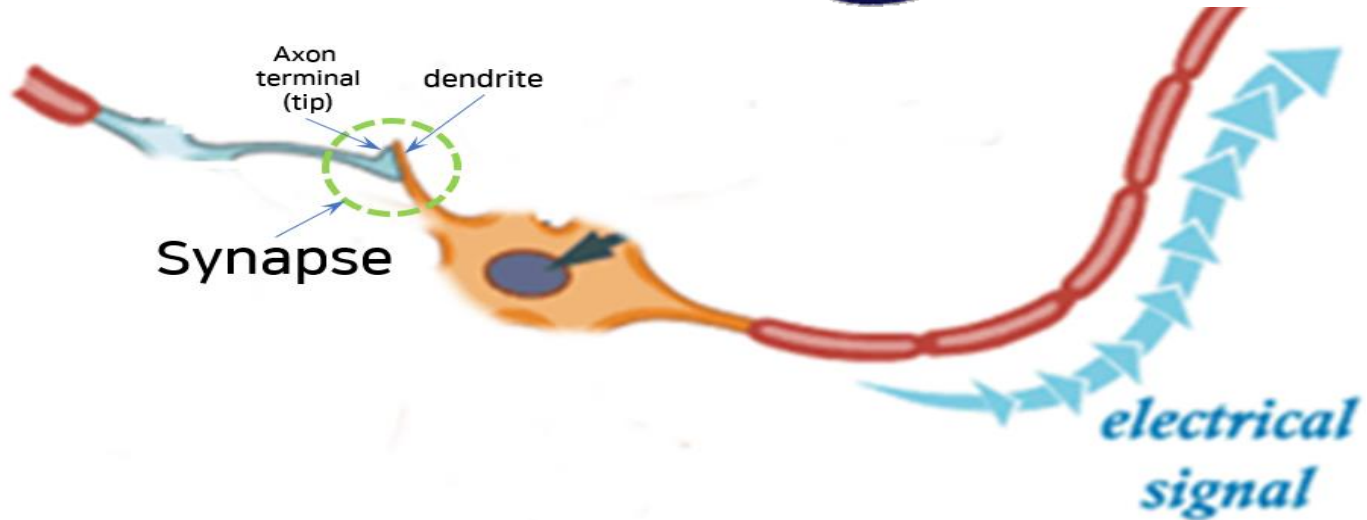
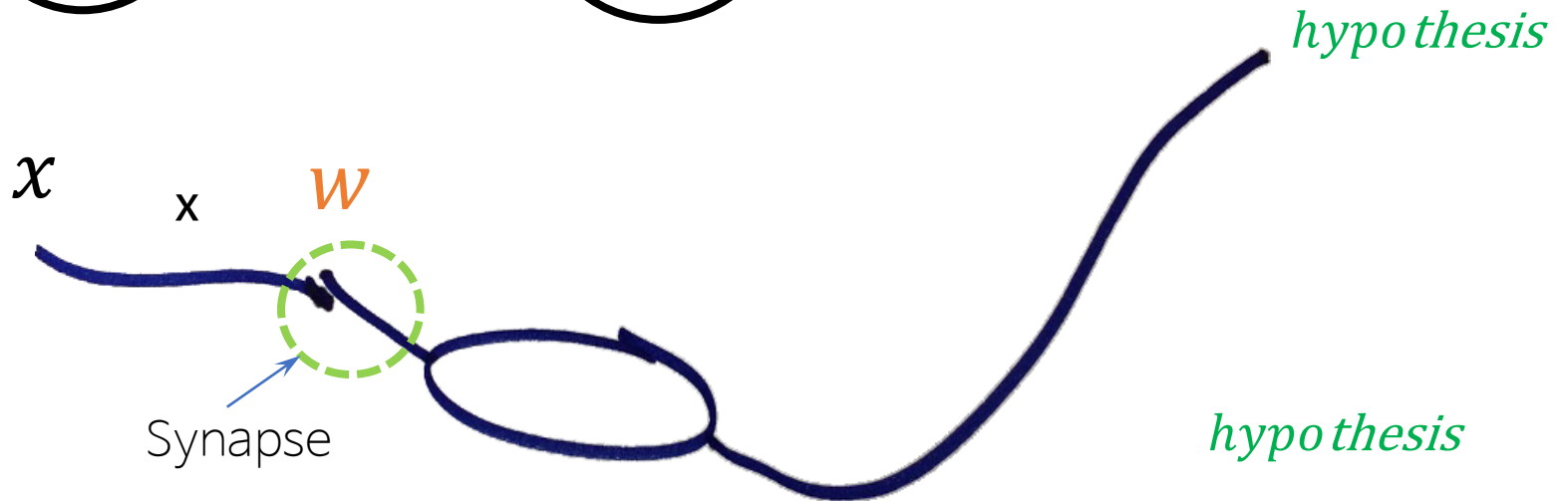
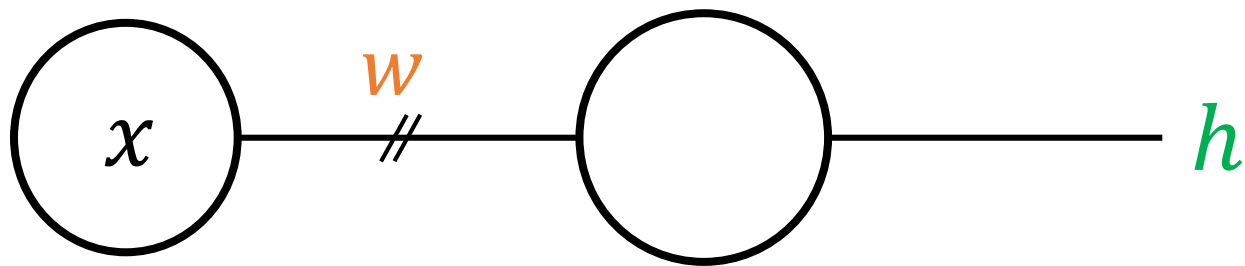
In case of m instances,

Mean Square
Error

$$E = \frac{1}{m} \sum_{i=1}^m (\mathbf{w}x_i - y_i)^2$$

An answer by a neuron

Ground truth



The meaning of slope

Steep slope $\frac{\Delta E}{\Delta w}$ $\frac{8}{1}$

The error E will change drastically when we change w .

.....

Gentle slope $\frac{\Delta E}{\Delta w}$ $\frac{1}{10}$

The error E changes just a little bit when we change w .

Therefore,

$$\lim_{\Delta w \rightarrow 0} \frac{\Delta E}{\Delta w} \rightarrow \frac{\partial E}{\partial w}$$

Slope/Gradient

means the influence of w
change on error E .

(Q) Compute the influence

$$E = (wx - y)^2$$

Let's assume that data (x, y) is $(1, 1)$,
then compute the influence of w change
on E when the current w is equal to 3.

Method1 numerical gradient

$$E = (w \cdot 1 - 1)^2$$

w : 3 -> E : 4

w : 3.00001 -> E : 4.00004

$\Delta w = 0.00001$

$\Delta E = 0.00004$

Slope =
Influence of w change = 4

$$\frac{\Delta E}{\Delta w} = \frac{0.00004}{0.00001} = 4$$

Method2 derivative, differential equation

$$E = (w \cdot 1 - 1)^2$$

$$\begin{aligned} \lim_{\Delta w \rightarrow 0} \frac{\Delta E}{\Delta w} &= \frac{\partial E}{\partial w} = \frac{\partial}{\partial w} (w \cdot 1 - 1)^2 \\ &= 2(w \cdot 1 - 1) \end{aligned}$$

Therefore, when $w = 3$,
the gradient is $2(3 - 1) = 4$

How to update w (Learning)

1. Initialize w with a random value (ex, 4)

2. Get influence(slope) of w on E

Loop

3. To decrease the error, update w using below eq:

Parameter Tuning

$$W = W - \alpha * \text{slope}$$

4. Go to step 2

TensorFlow



- Machine learning framework by Google
- Tuning parameters including w automatically instead of us
- Define w inside of TensorFlow to be tuned (managed) by it
- Hypothesis and cost_function(E)

Linear Regression using TF

③

`w = tf.Variable(tf.random_normal([1]))`

`hypo = w * x`

h

④

`y = [1]`

②

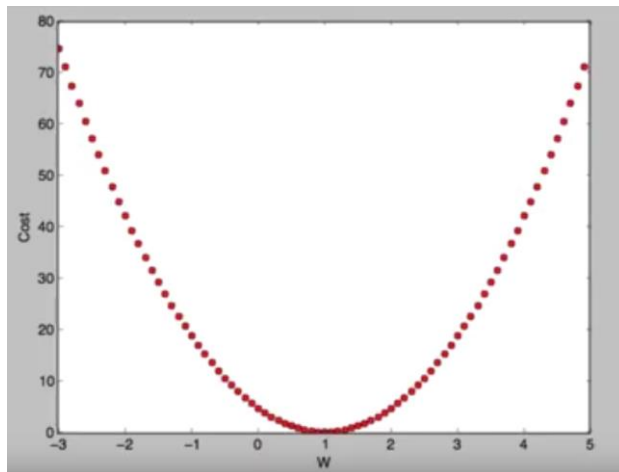
x

x

w

①

`x = [1]`



`cost_function = (hypo - y) ** 2`

⑤

$$E = (\text{hypo} - y)^2$$

Download myml.git

<https://github.com/yungbyun/myml.git>

- 1) Run DOS prompt
- 2) git clone <https://github.com/yungbyun/myml.git>
- 3) Open using PyCharm (File | Open...)

Lab 01.py

Finding w in
linear regression

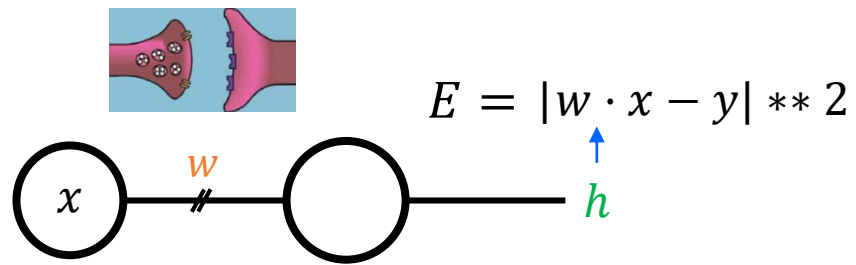
```
import tensorflow as tf
```

```
#----- training data  
x_data = [1]  
y_data = [1]
```

```
#----- a neuron / neural network  
w = tf.Variable(tf.random_normal([1]))  
hypo = w * x_data
```

```
#----- learning  
cost = (hypo - y_data) ** 2  
  
train = tf.train.GradientDescentOptimizer(learning_rate=0.01).minimize(cost)  
  
sess = tf.Session()  
sess.run(tf.global_variables_initializer())  
  
for i in range(1001):  
    sess.run(train) #1-run, 1-update of w -> 1001 updates  
  
    if i % 100 == 0:  
        print('w:', sess.run(w), 'cost:', sess.run(cost))
```

```
#----- testing(prediction)  
x_data = [2]  
print(sess.run(x_data * w))
```



train operation to
update w to minimize
error(E)

```
sess.run(train)
```

How to update w in
TensorFlow

Computation Graph

Loss/error function

$$E = (wx - y)^2$$

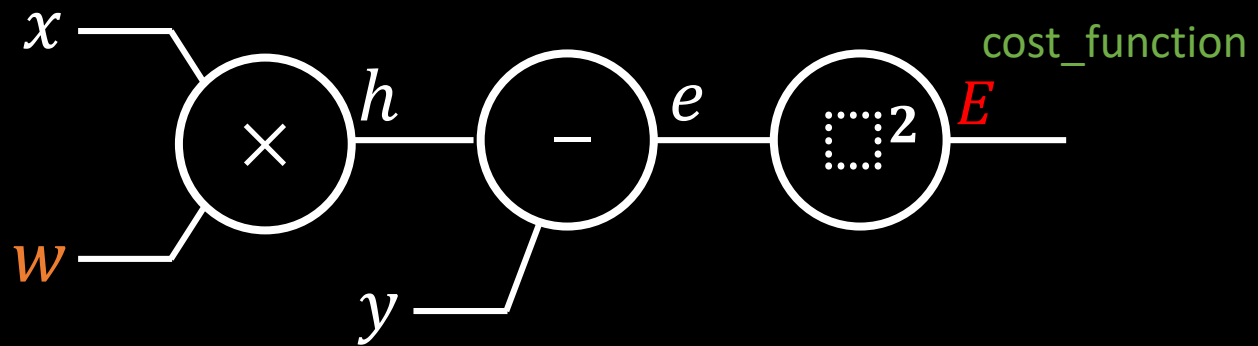
- The part representing a neuron
- Where is a synapse?
- Which one is an input data?
- The output of a neuron
- Find a correct answer or ground truth.
- Find hypothesis.
- Imagine E having many inputs.

Computation Graph

$$E = (w \cdot x - y)^2$$

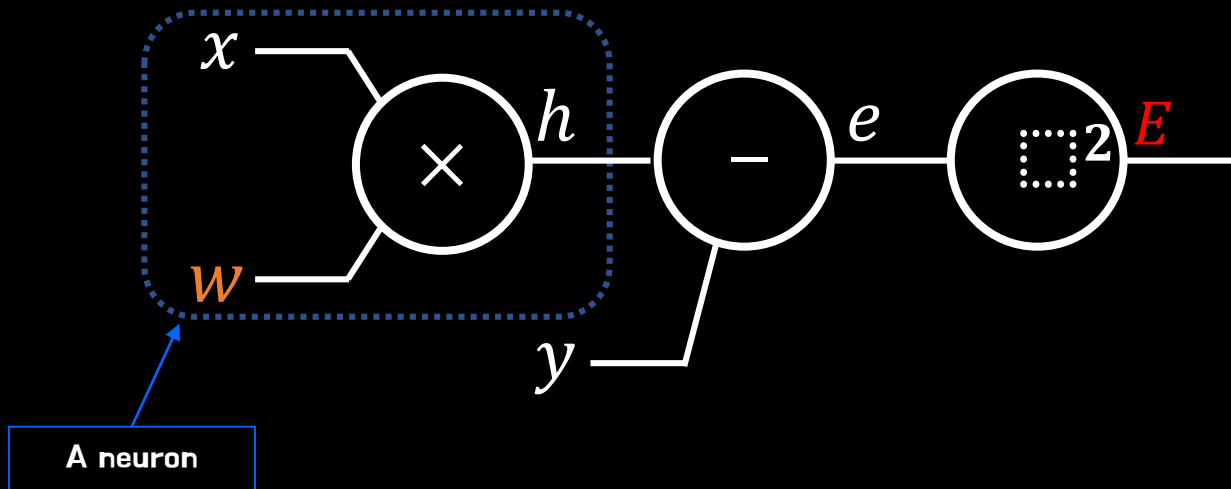
hypo = w * x

cost_function(E) = (hypo - y) ** 2



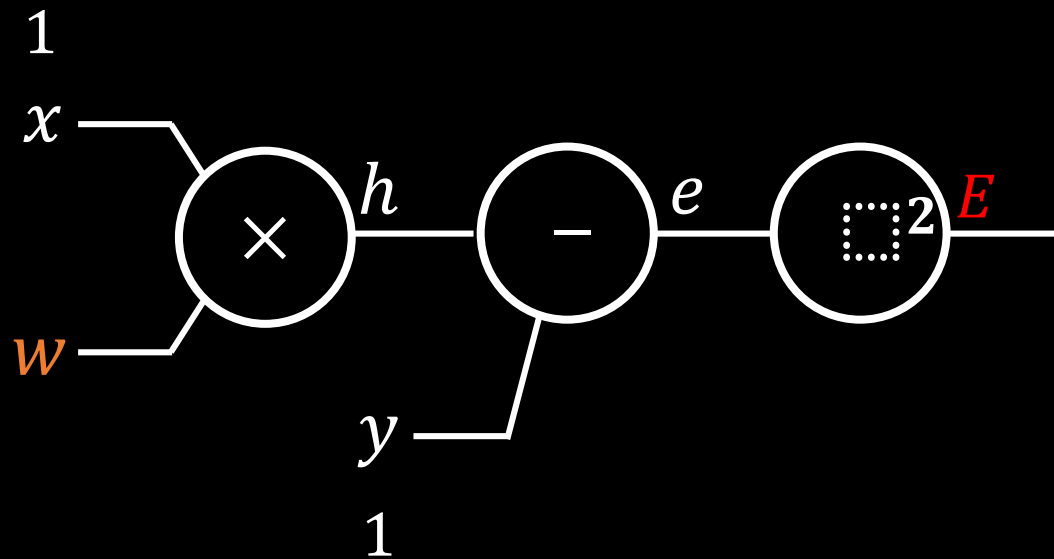
Computation Graph

$$E = (w \cdot x - y)^2$$

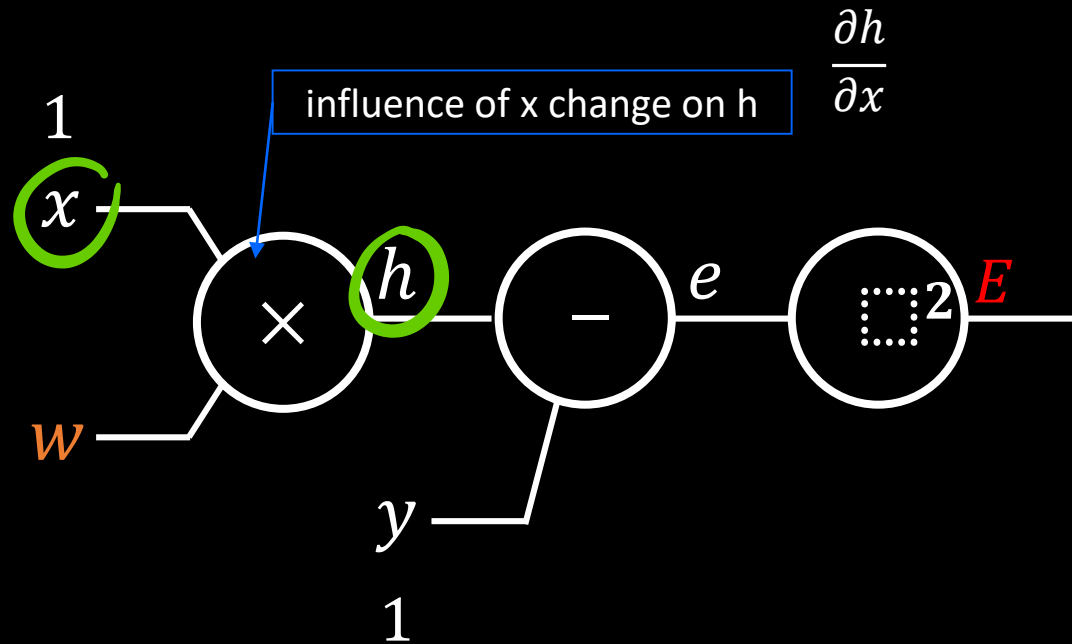


Computation Graph

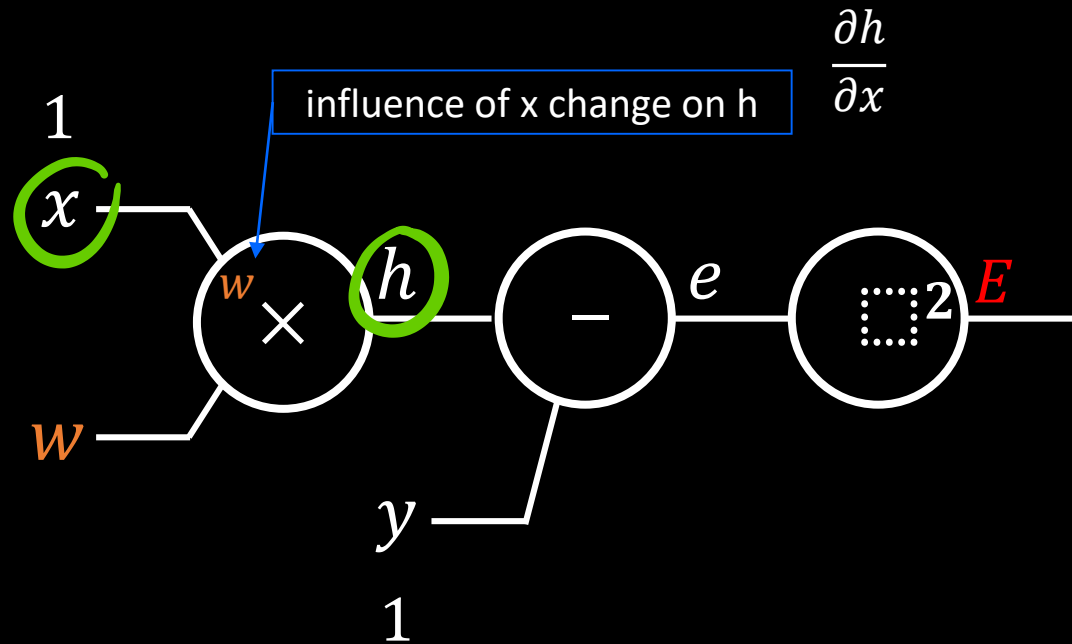
Data $(x, y) \rightarrow (1, 1)$



Computation Graph

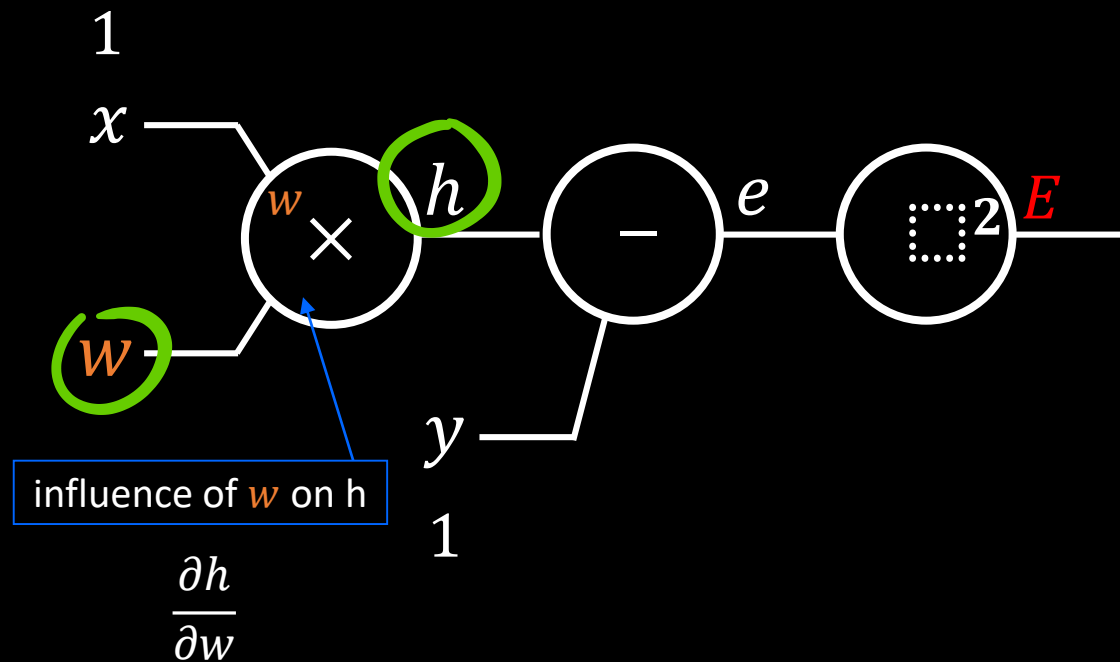


Computation Graph

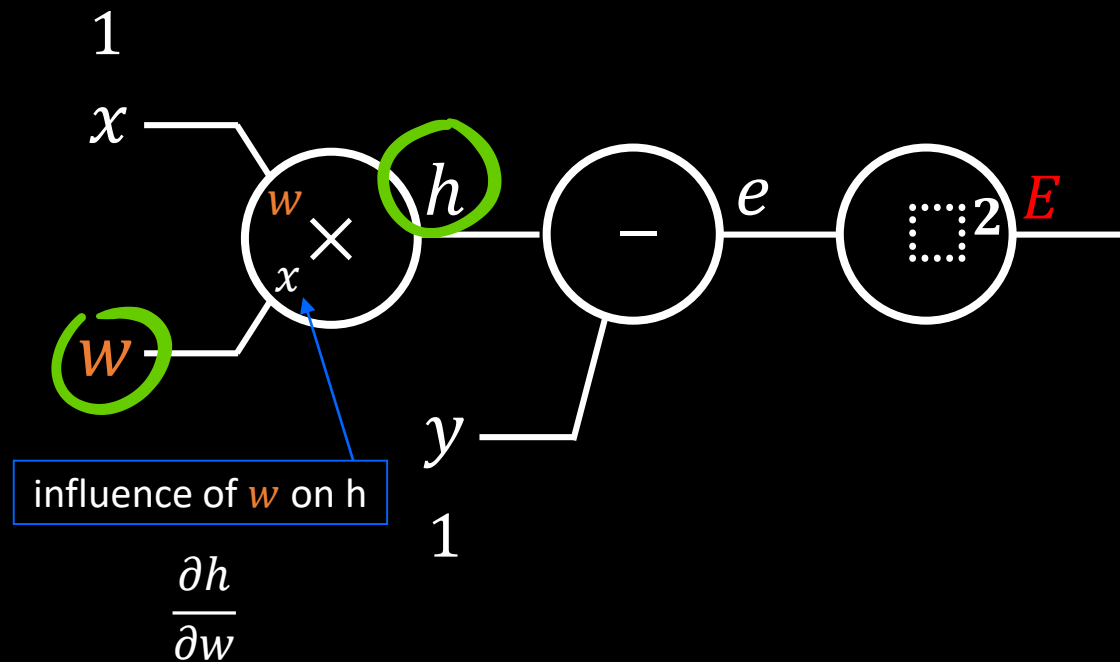


Local gradient

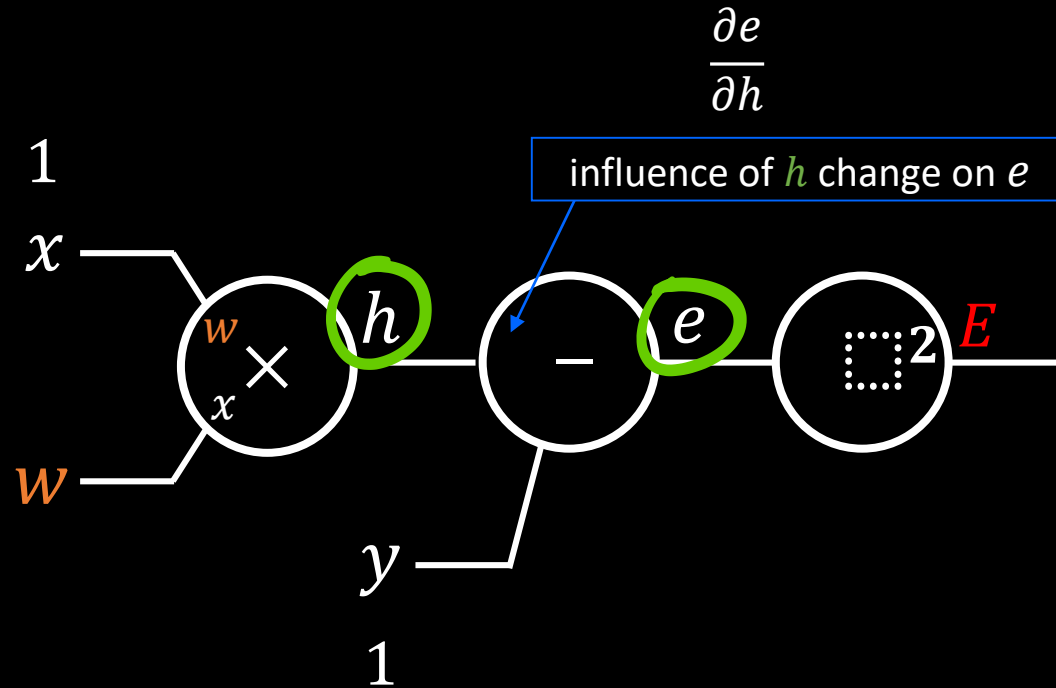
Computation Graph



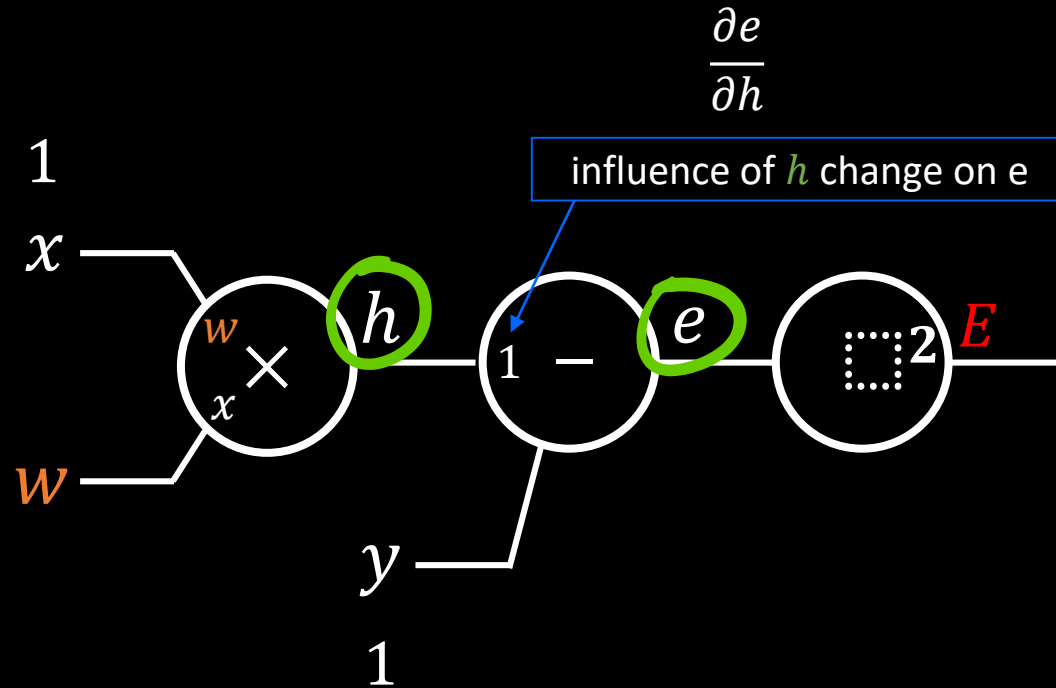
Computation Graph



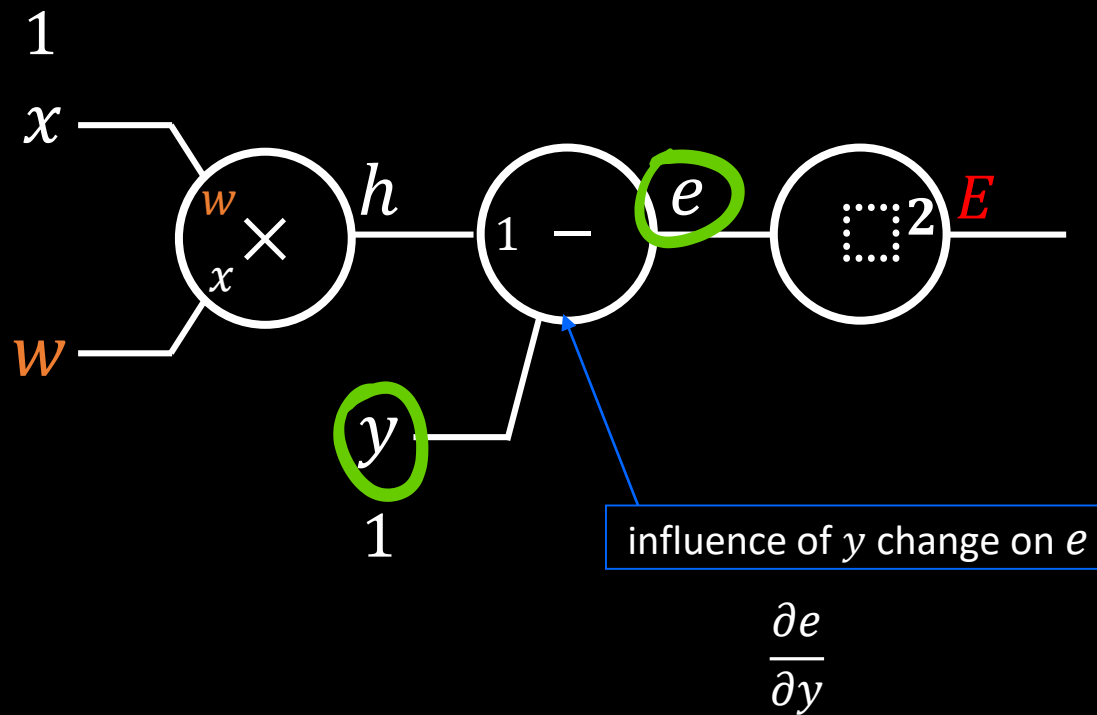
Computation Graph



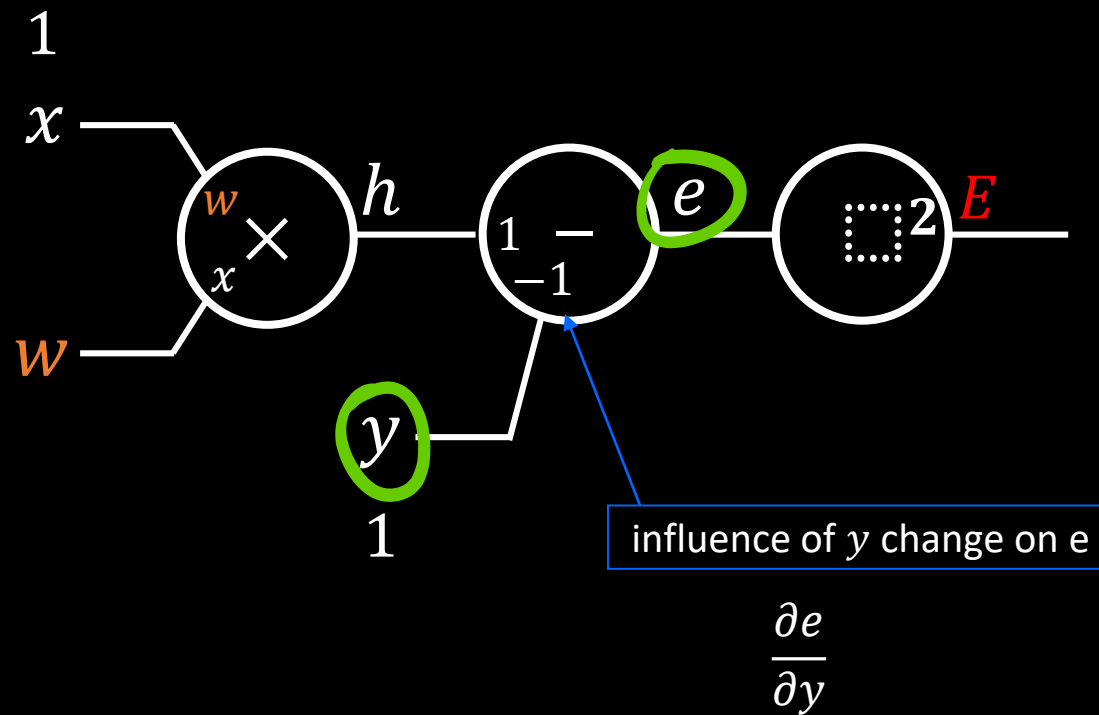
Computation Graph



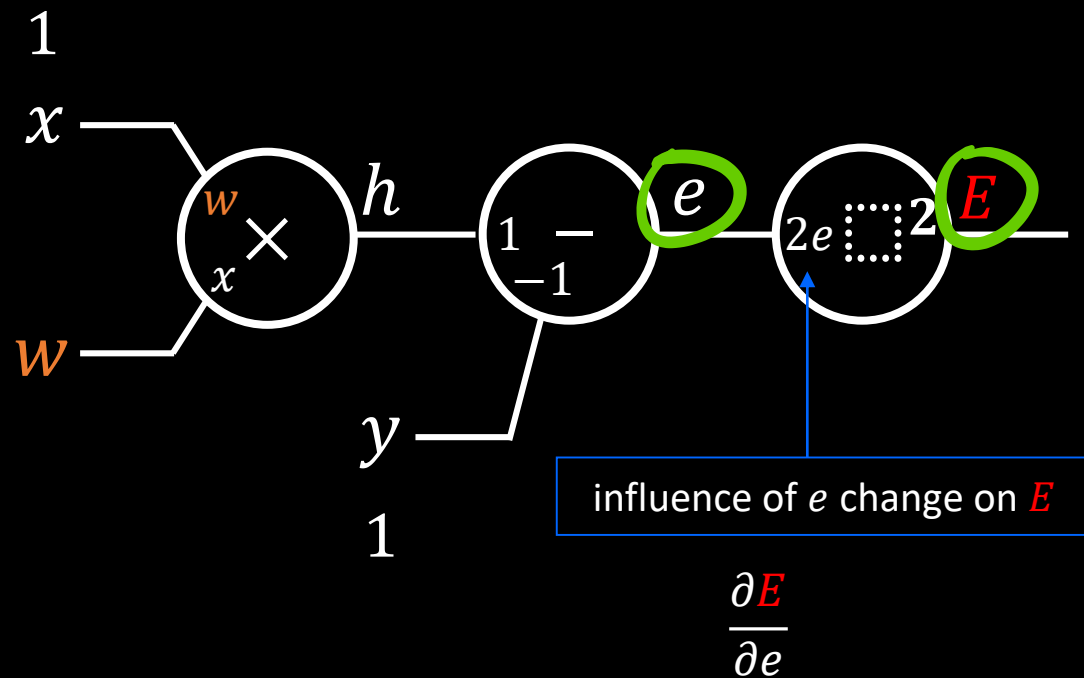
Computation Graph



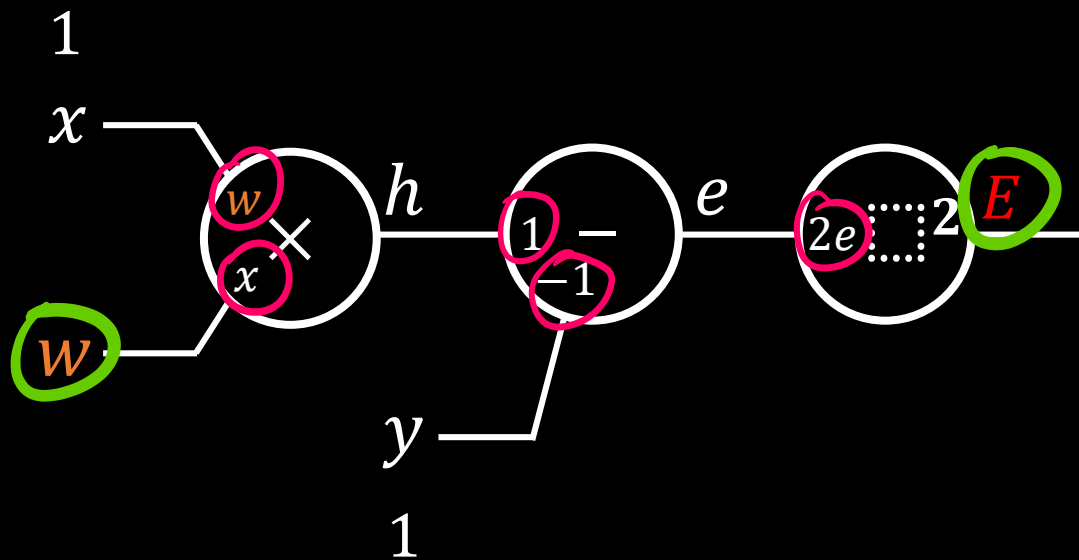
Computation Graph



Computation Graph

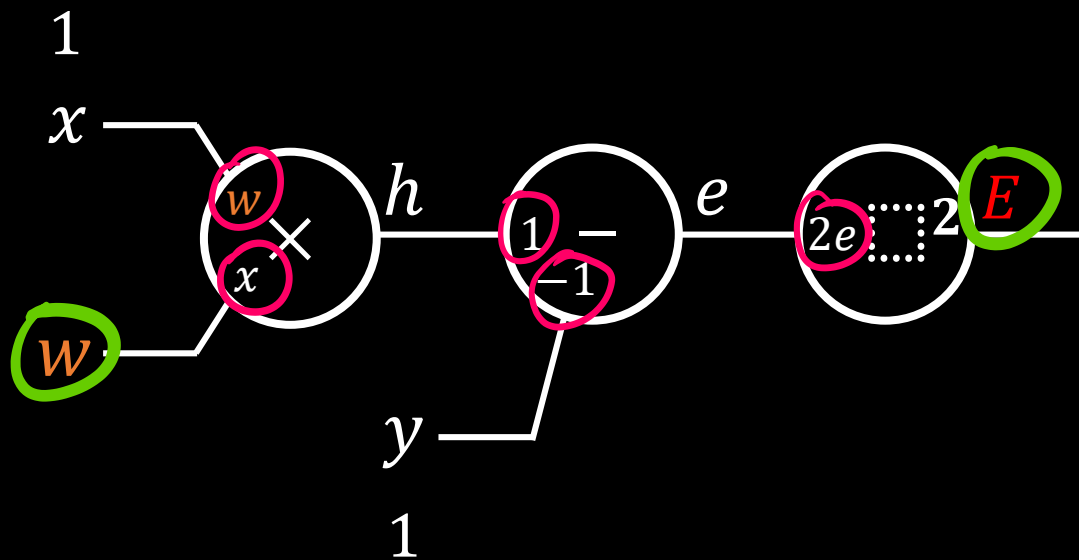


5 Local Gradients in gates

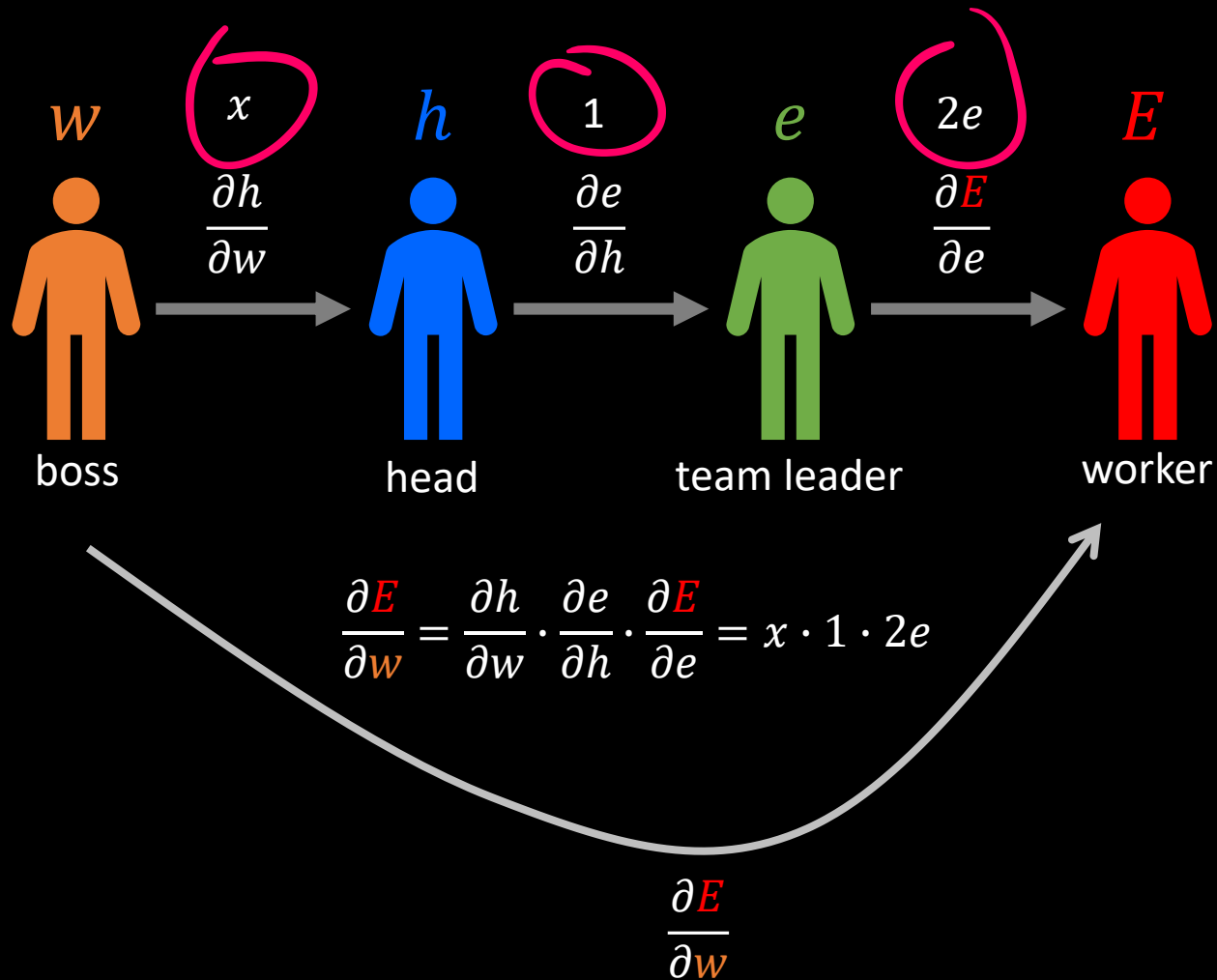


How can we get the influence
of w change on E ?

5 Local Gradients in gates



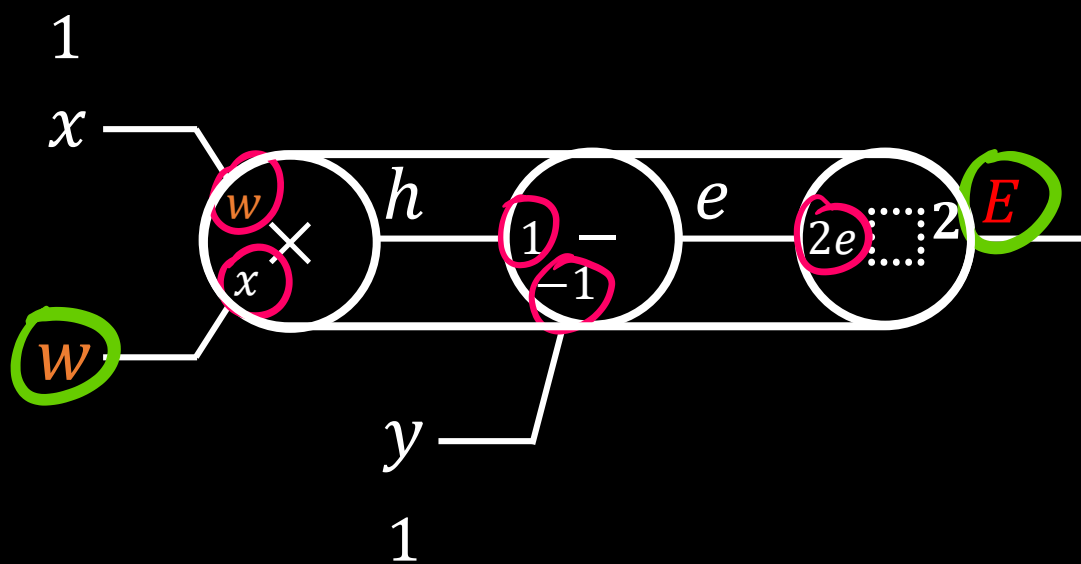
Influence between persons



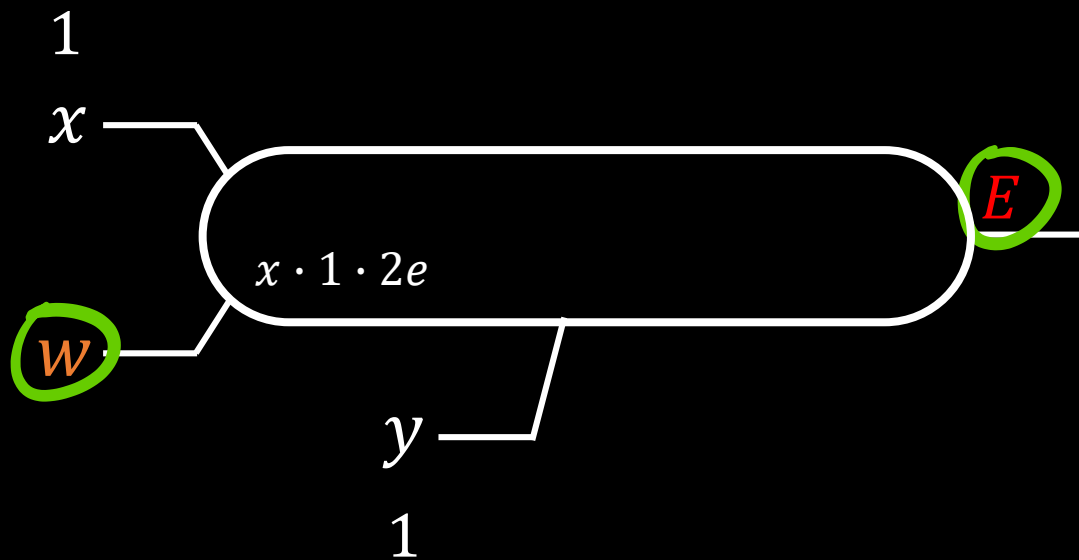
The influence of w change
on E

$$\frac{\partial E}{\partial w} = \frac{\partial h}{\partial w} \times \frac{\partial e}{\partial h} \times \frac{\partial E}{\partial e}$$

Chain rule!

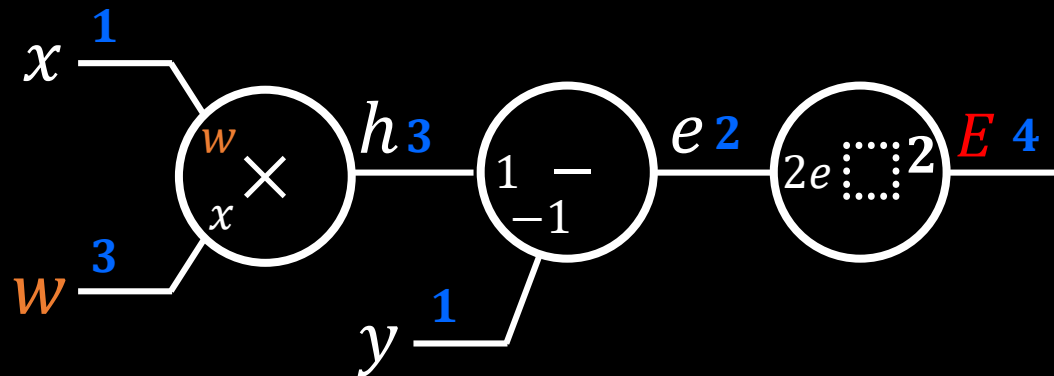


Composite Gate



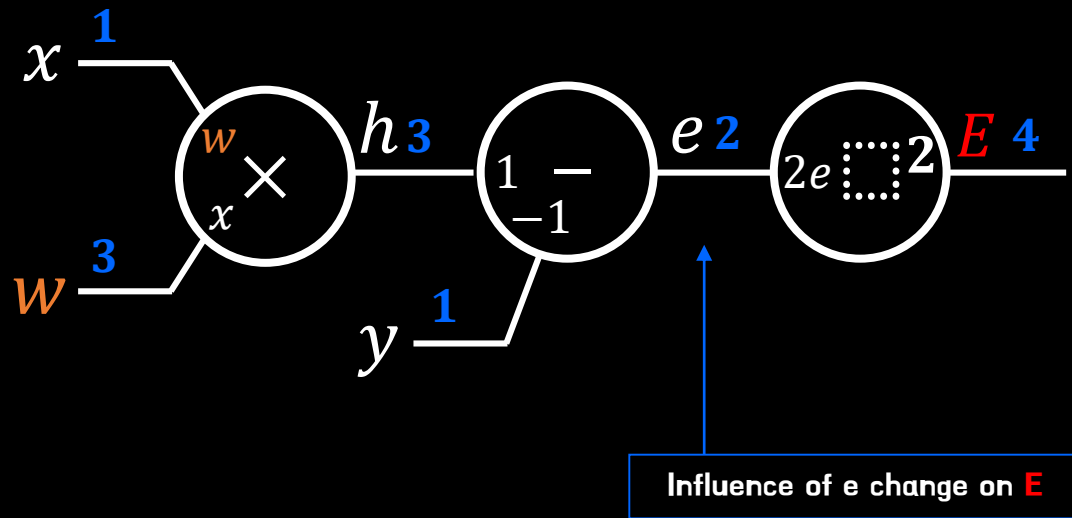
Forward propagation

Let $(x, y) = (1, 1)$ and $w = 3$, then compute E .

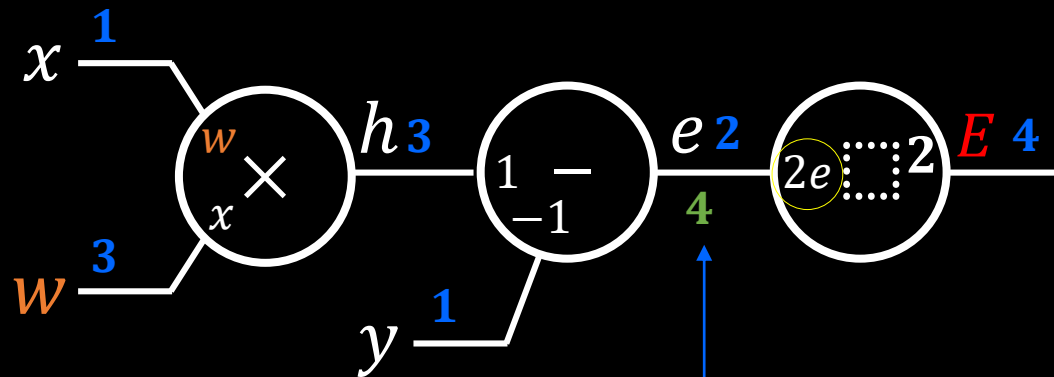


Error is big (4),
so let's update w
using back-propagation.

Back-propagation



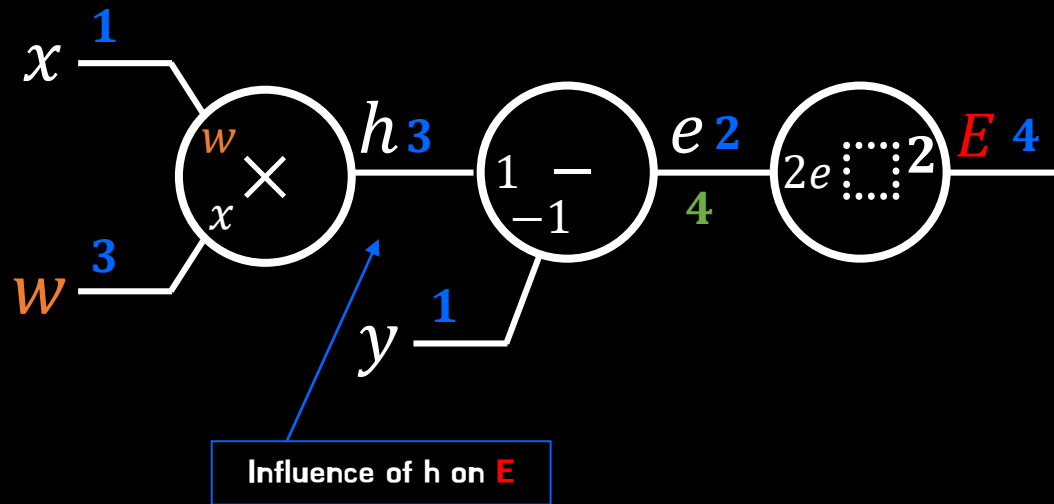
Back-propagation



Influence of e change on E

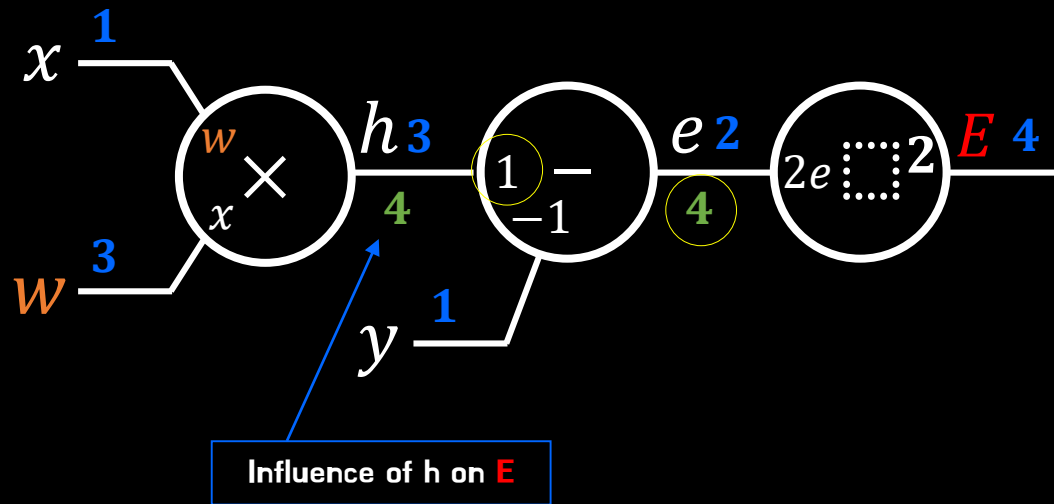
$$\frac{\partial E}{\partial e} = 2e$$

Back-propagation

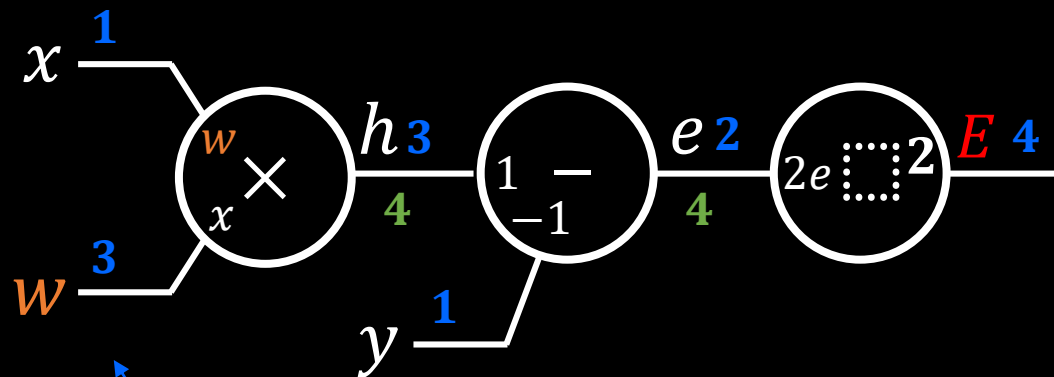


$$\frac{\partial E}{\partial h} = \frac{\partial e}{\partial h} \cdot \frac{\partial E}{\partial e} = 1 \cdot 4$$

Back-propagation

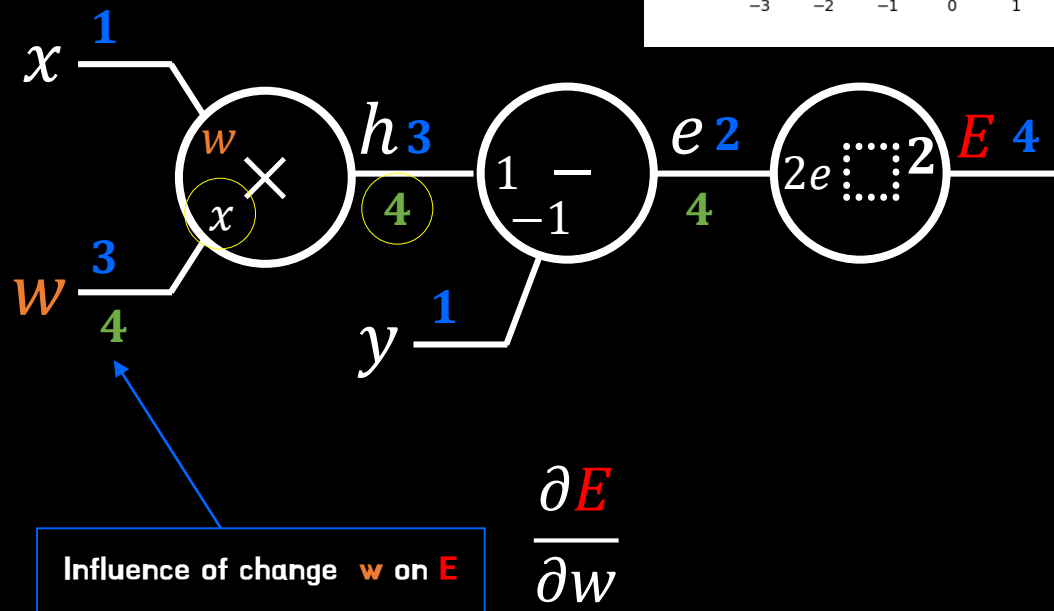
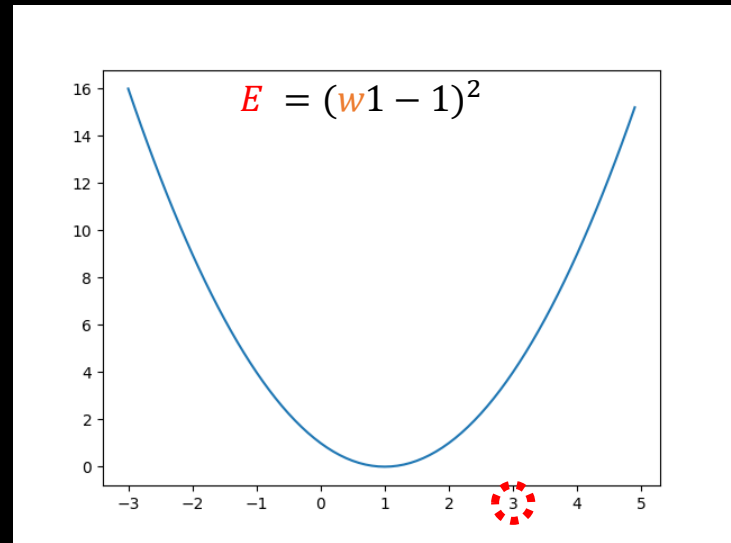


Back-propagation



Influence of change w on E

$$\frac{\partial E}{\partial w} = \frac{\partial h}{\partial w} \cdot \frac{\partial E}{\partial h} = 1 \cdot 1 \cdot 4$$




Back-propagation,
the process to **apply**
chain rules.

$$\frac{\partial E}{\partial w}$$

$$\frac{\partial E}{\partial w}$$

$$w = 3 - 0.1 * 4$$

$$w = 2.6$$



Tuned parameter after 1
step learning

After enough number of steps,
the parameter w will be optimized.

Backpropagation

by Paul Webros (1974, 1982) and
Geoffrey Hinton (1986)




Univ. of Toronto, Google Brain
Yann LeCun (post doc)

```
import tensorflow as tf
```

```
#----- training data  
x_data = [1]  
y_data = [1]
```

```
#----- a neuron / neural network  
w = tf.Variable(tf.random_normal([1]))  
hypo = w * x_data
```

train operation to
update w to
minimize cost(error)



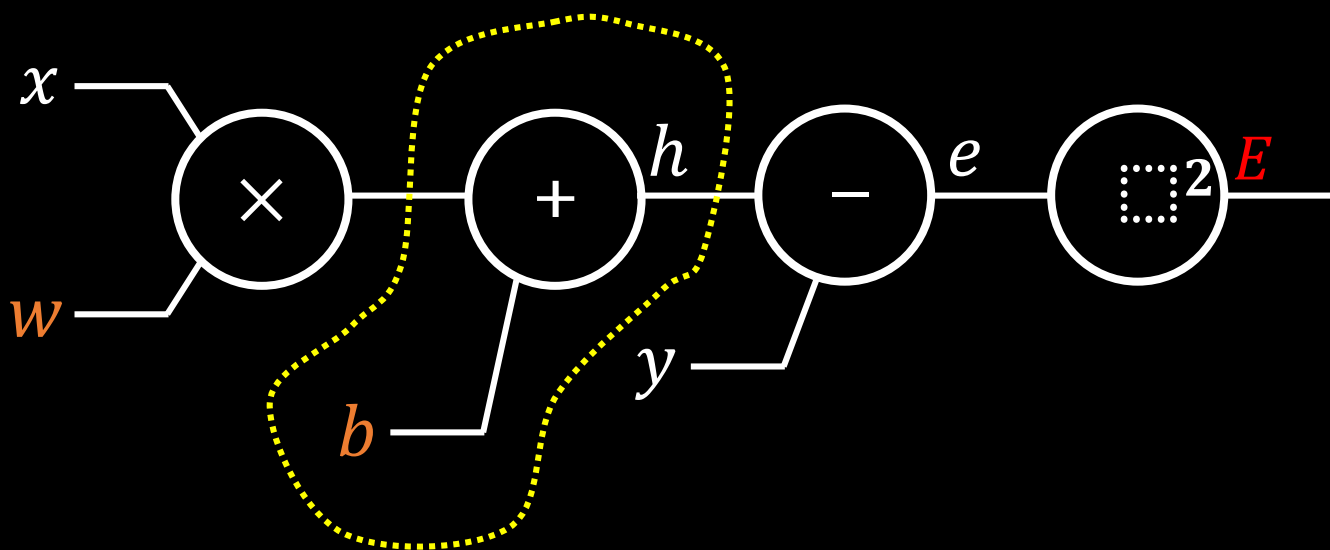
```
#----- learning  
cost = (hypo - y_data) ** 2  
  
train = tf.train.GradientDescentOptimizer(learning_rate=0.01).minimize(cost)  
  
sess = tf.Session()  
sess.run(tf.global_variables_initializer())  
  
for i in range(1001):  
    sess.run(train) # 1-run, 1-update of w -> 1001 updates  
  
    if i % 100 == 0:  
        print('w:', sess.run(w), 'cost:', sess.run(cost))
```

```
#----- testing(prediction)  
x_data = [2]  
print(sess.run(x_data * w))
```

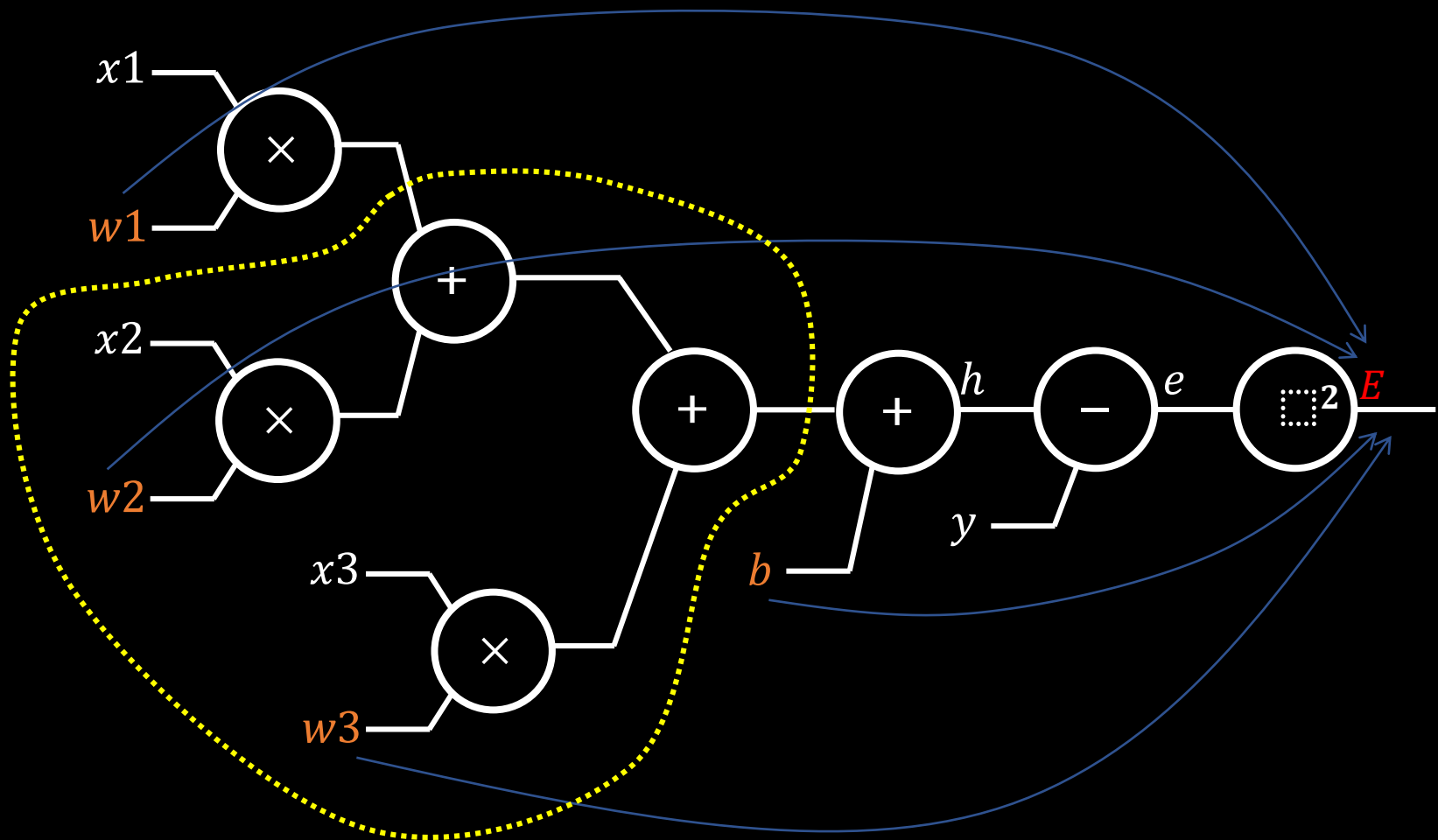
Extension of the Graph

- adding bias b (one more plus gate)
- a neuron with 3 inputs (2 more + gate)
- two neurons

$$E = ((wx + b) - y)^2$$



$$E = ((w_1x_1 + w_2x_2 + w_3x_3 + b) - y)^2$$

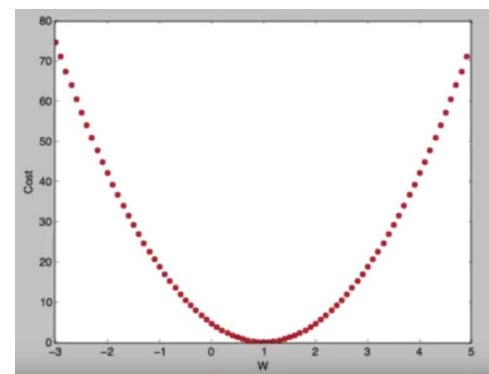
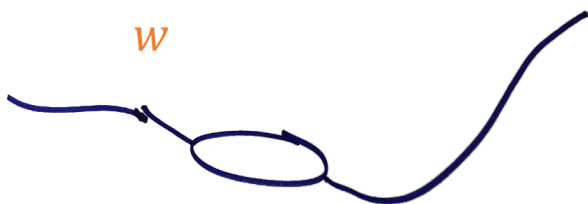


The background features two large, blue, organic, blob-like shapes on the left and right sides. In the center, there is a vertical column of approximately ten small, glowing yellow dots. The text "Learning, making the connection better" is centered over the image in a white, sans-serif font.

Learning, making the
connection better

Cost(Error) graph

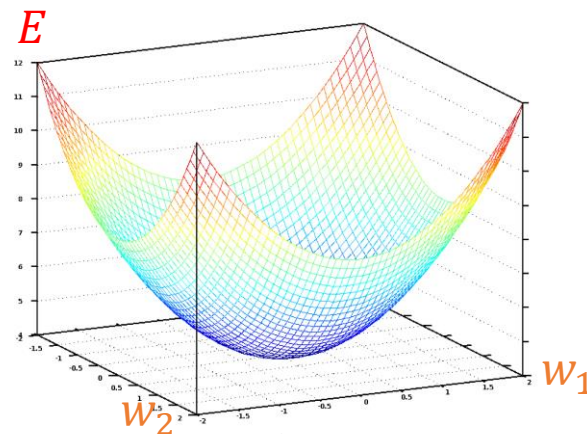
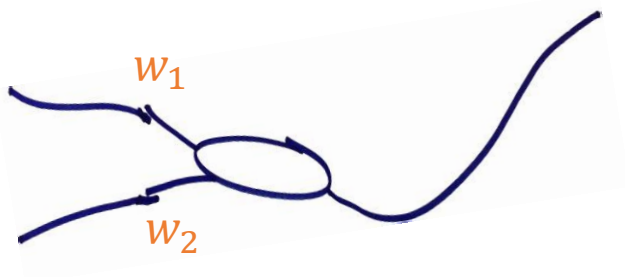
$$E = (w \cdot 1 - 1)^2$$



w

convex function

$$E = (w_1 \cdot 1 + w_2 \cdot 1 - 1)^2$$



convex function

Lab 02.with_bias.py

Parameter tuning
including bias

Lab 03.py

Using multiple
data

Lab 04.py

Training a neuron
having multiple
inputs