

Deep Learning Tutorial

李宏毅

Hung-yi Lee

Outline

Lecture I: Introduction of Deep Learning



Lecture II: Tips for Training Deep Neural Network



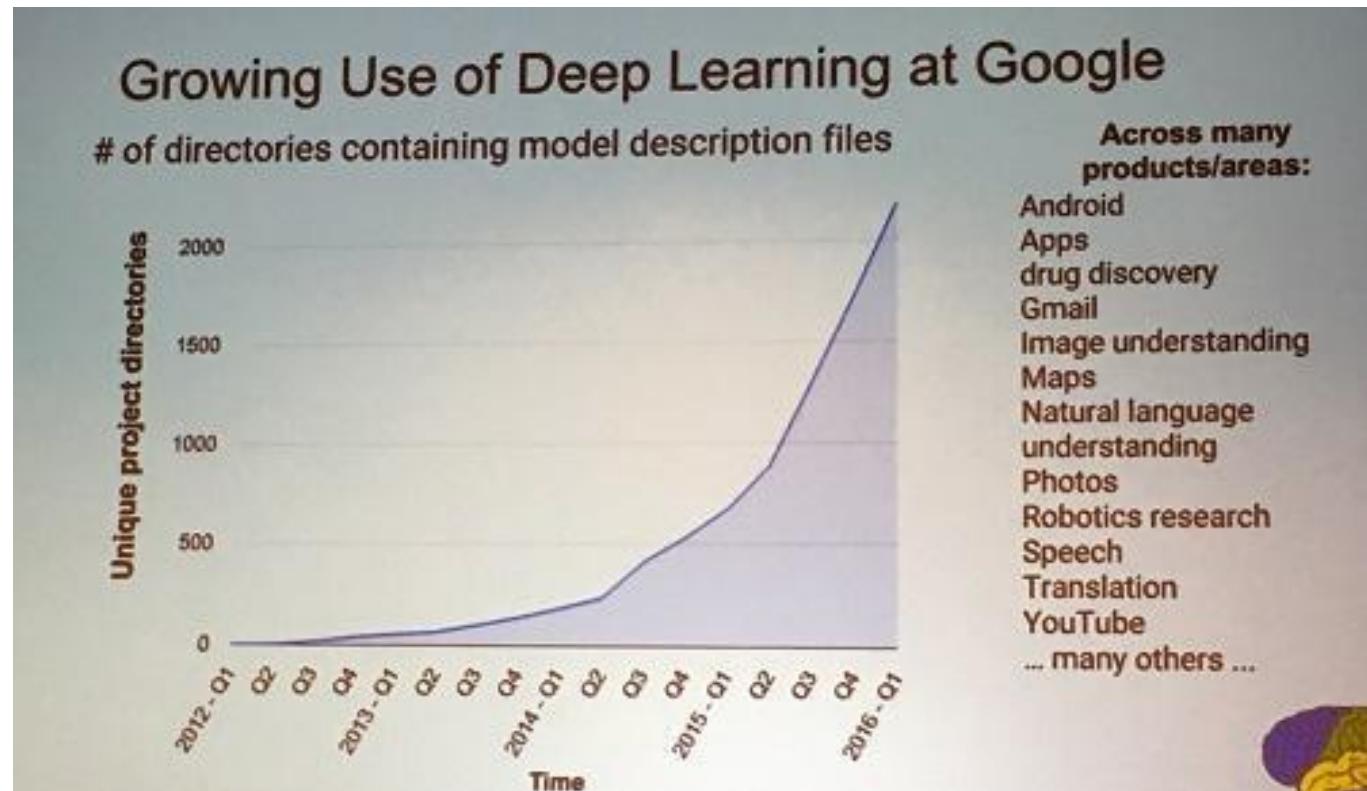
Lecture III: Variants of Neural Network



Lecture IV: Next Wave

Deep learning attracts lots of attention.

- I believe you have seen lots of exciting results before.



Deep learning trends at Google. Source: SIGMOD/Jeff Dean

This talk focuses on the basic techniques.

Lecture I: Introduction of Deep Learning

Outline of Lecture I

Introduction of Deep Learning

Let's start with general
machine learning.

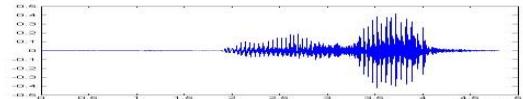
Why Deep?

“Hello World” for Deep Learning

Machine Learning ≈ Looking for a Function

- Speech Recognition

$$f($$



) = “How are you”

- Image Recognition

$$f($$



) = “Cat”

- Playing Go

$$f($$



) = “5-5”
(next move)

- Dialogue System

$$f($$

“Hi”

(what the user said)

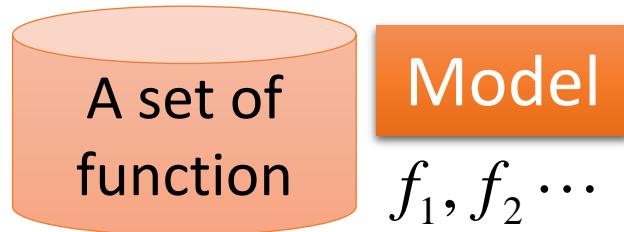
) = “Hello”

(system response)

Framework

Image Recognition:

$$f(\text{ }) = \text{ "cat"}$$

$$f_1(\text{ }) = \text{ "cat"}$$


$$f_2(\text{ }) = \text{ "money"}$$


$$f_1(\text{ }) = \text{ "dog"}$$


$$f_2(\text{ }) = \text{ "snake"}$$


Framework

A set of function

Model
 $f_1, f_2 \dots$

Goodness of function f

Training Data

Image Recognition:

$$f\left(\begin{array}{c} \text{Image of a cat} \end{array} \right) = \text{"cat"}$$

$$\begin{array}{ll} f_1\left(\begin{array}{c} \text{Image of a cat} \end{array} \right) = \text{"cat"} & f_2\left(\begin{array}{c} \text{Image of a cat} \end{array} \right) = \text{"money"} \\ f_1\left(\begin{array}{c} \text{Image of a dog} \end{array} \right) = \text{"dog"} & f_2\left(\begin{array}{c} \text{Image of a dog} \end{array} \right) = \text{"snake"} \end{array}$$

Better!

Supervised Learning

function input:

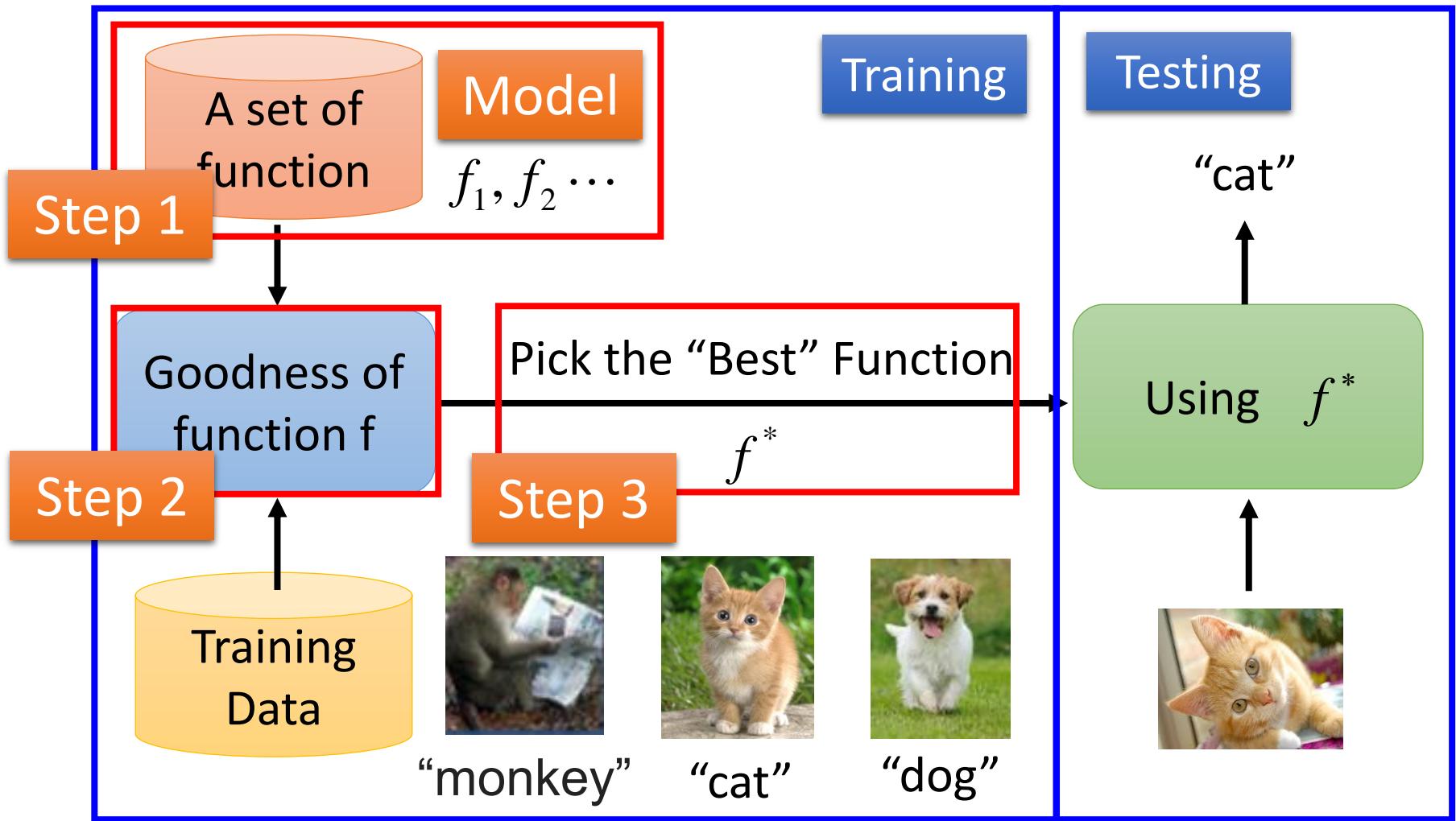


function output: "monkey" "cat" "dog"

Framework

Image Recognition:

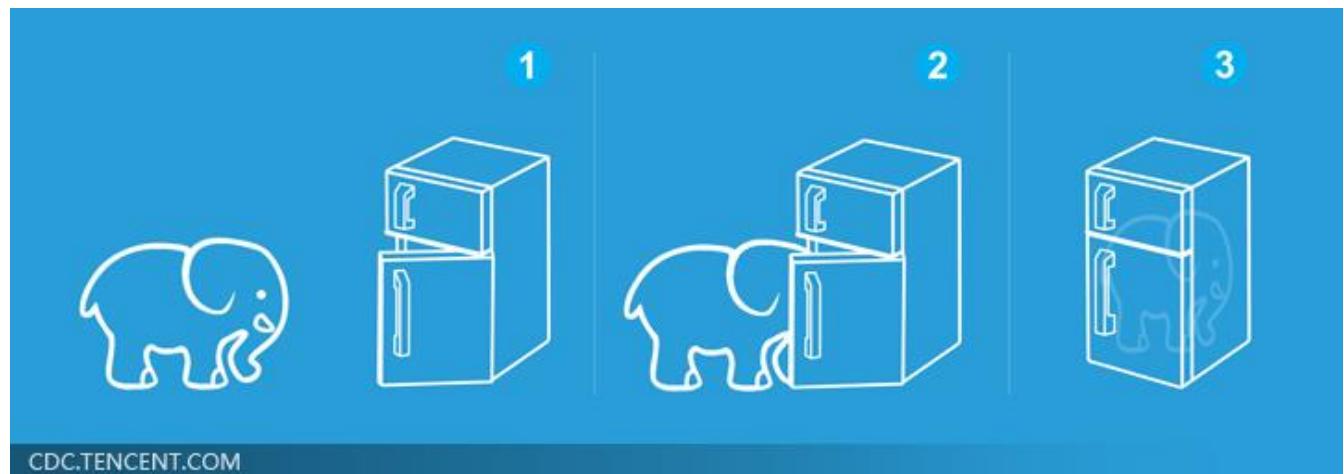
$$f(\text{cat image}) = \text{"cat"}$$



Three Steps for Deep Learning



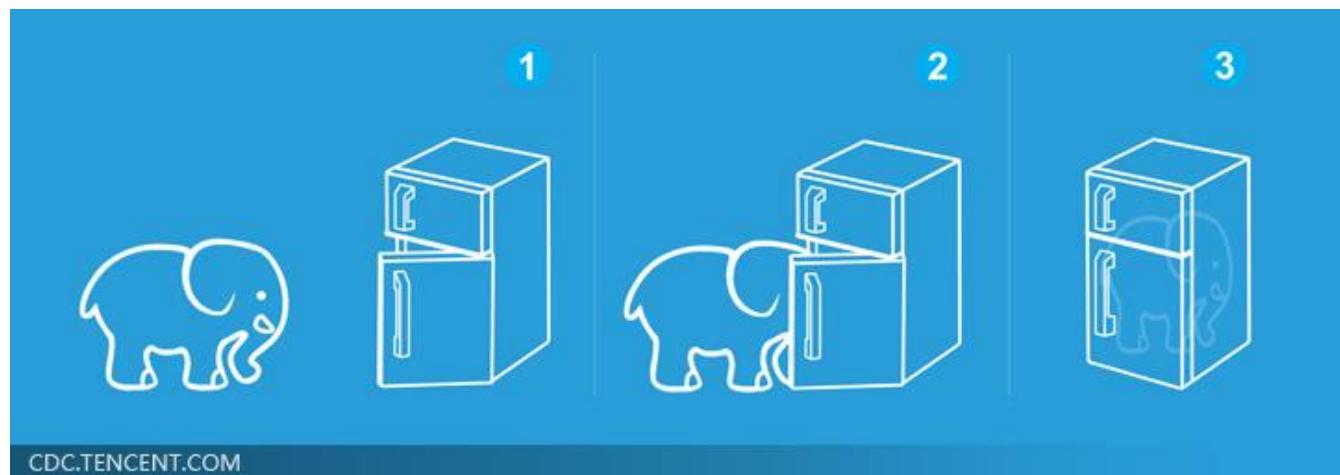
Deep Learning is so simple



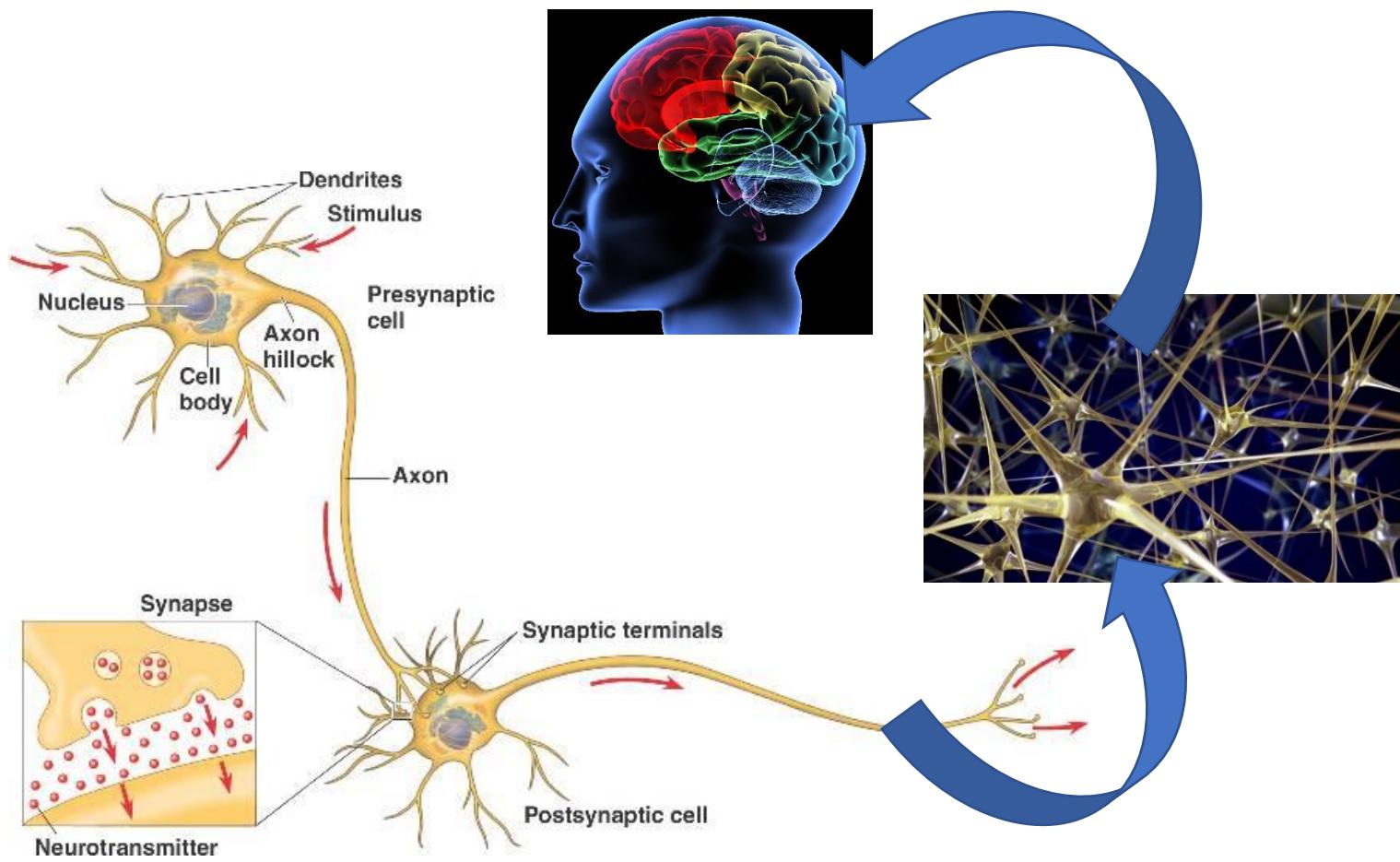
Three Steps for Deep Learning



Deep Learning is so simple



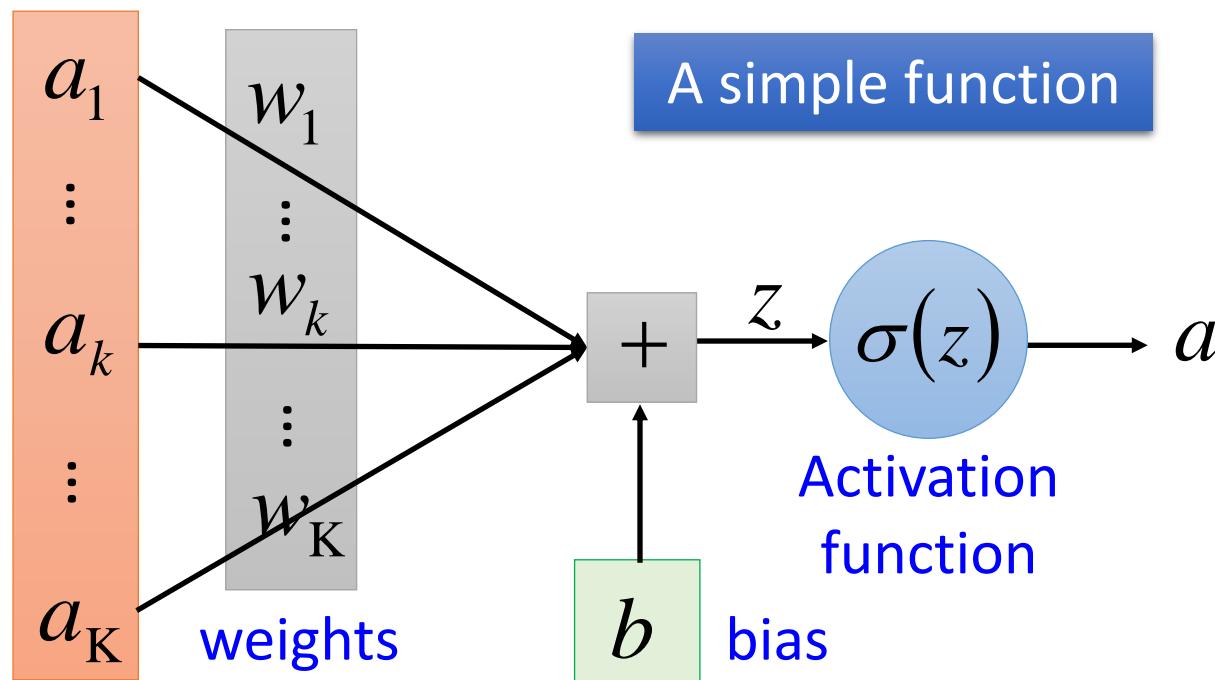
Human Brains



Neural Network

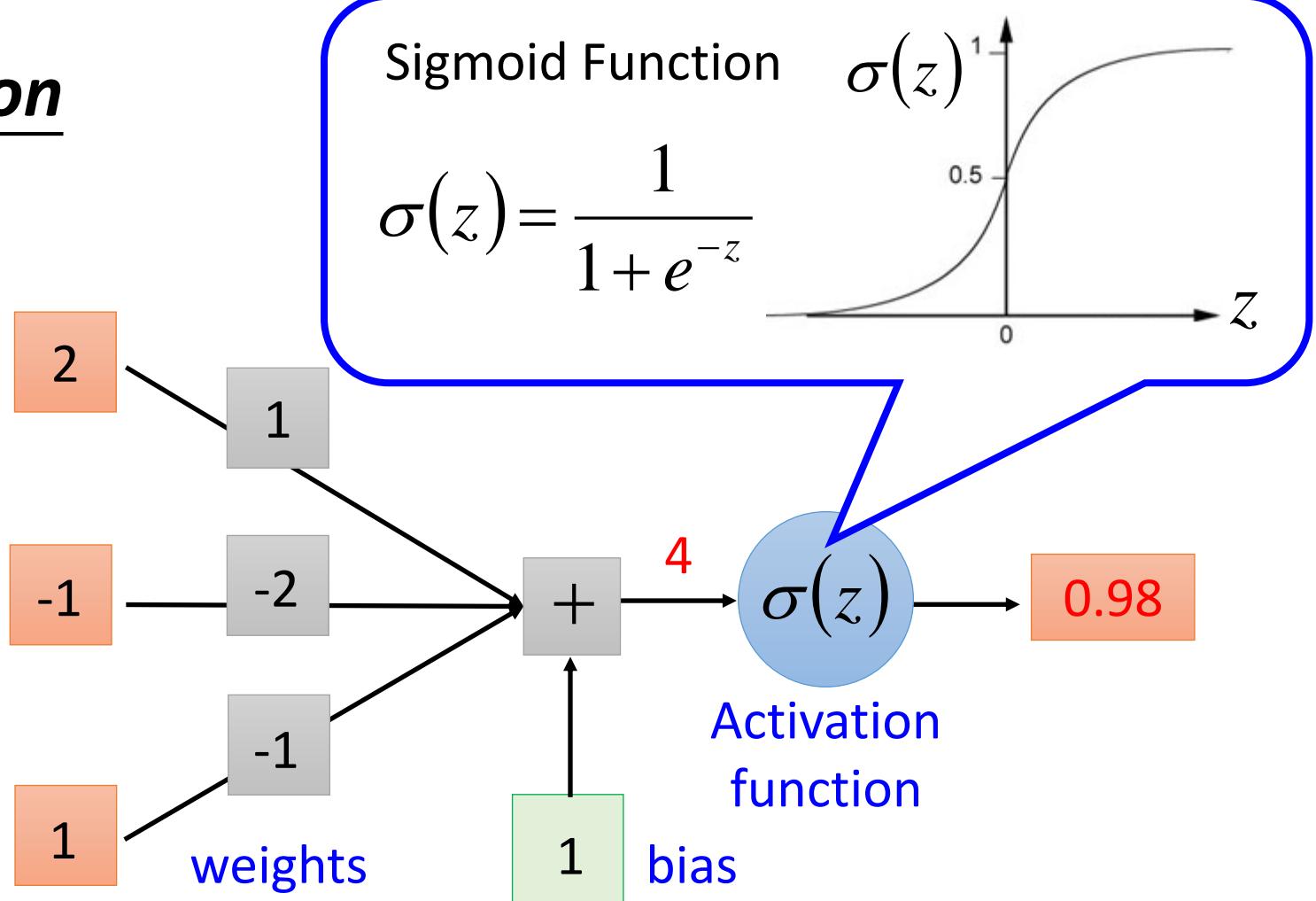
Neuron

$$z = a_1 w_1 + \dots + a_k w_k + \dots + a_K w_K + b$$



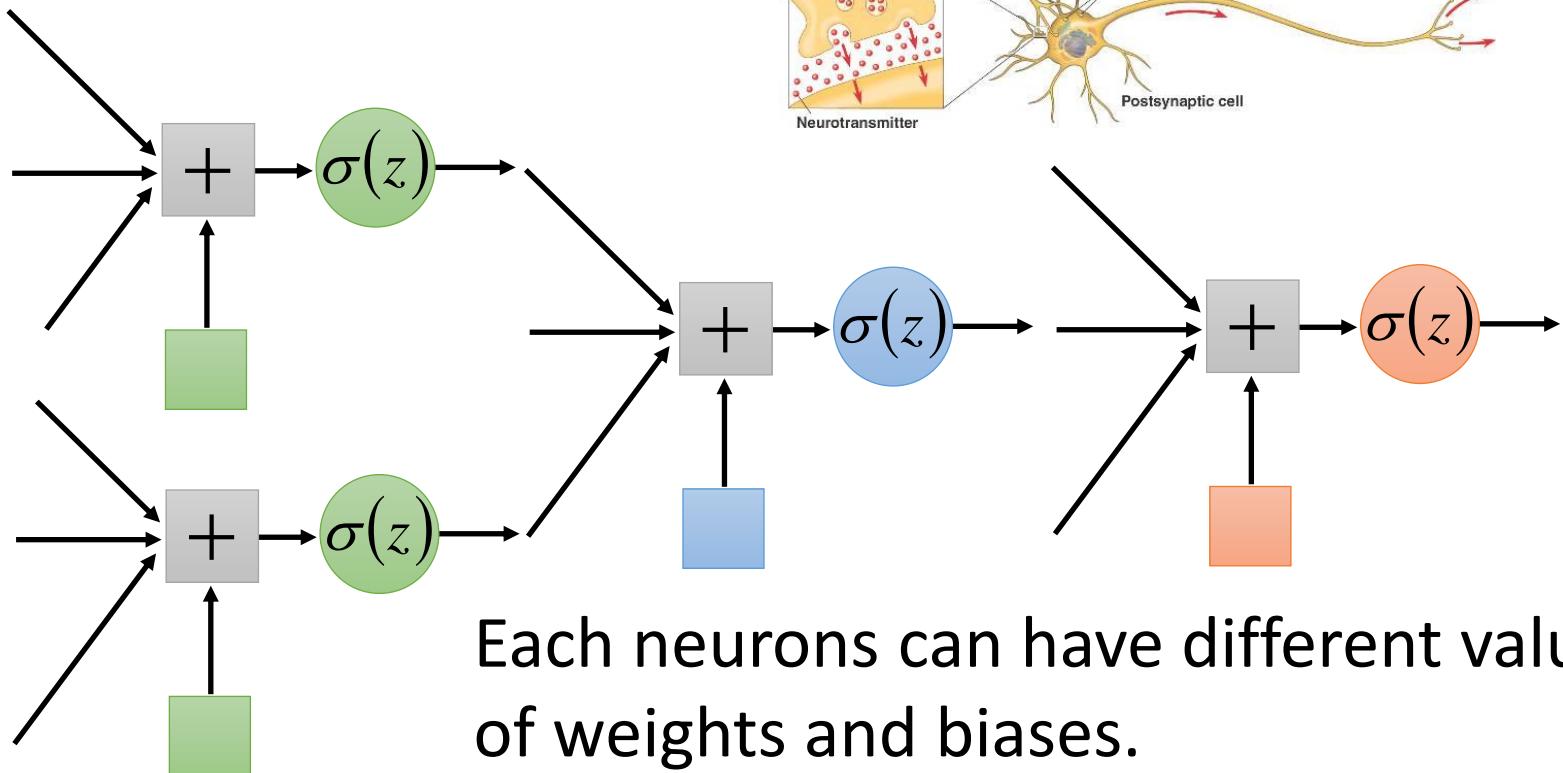
Neural Network

Neuron



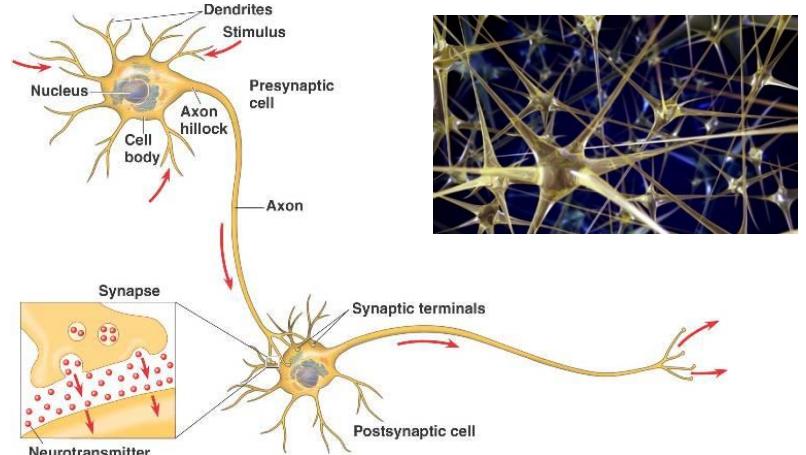
Neural Network

Different connections leads to different network structure

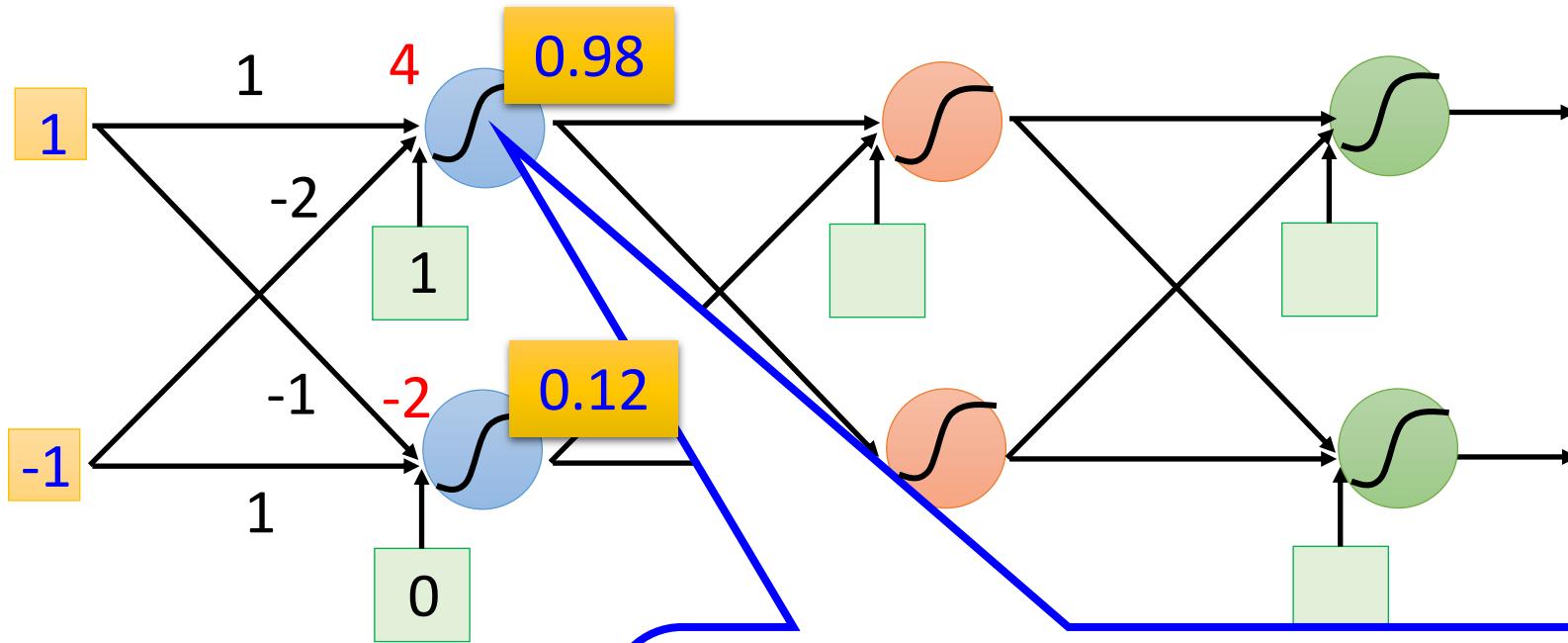


Each neurons can have different values of weights and biases.

Weights and biases are network parameters θ

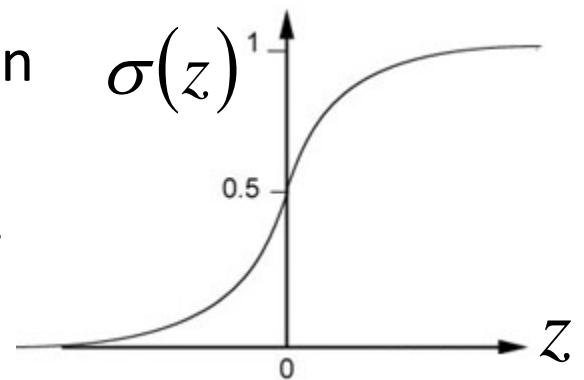


Fully Connect Feedforward Network

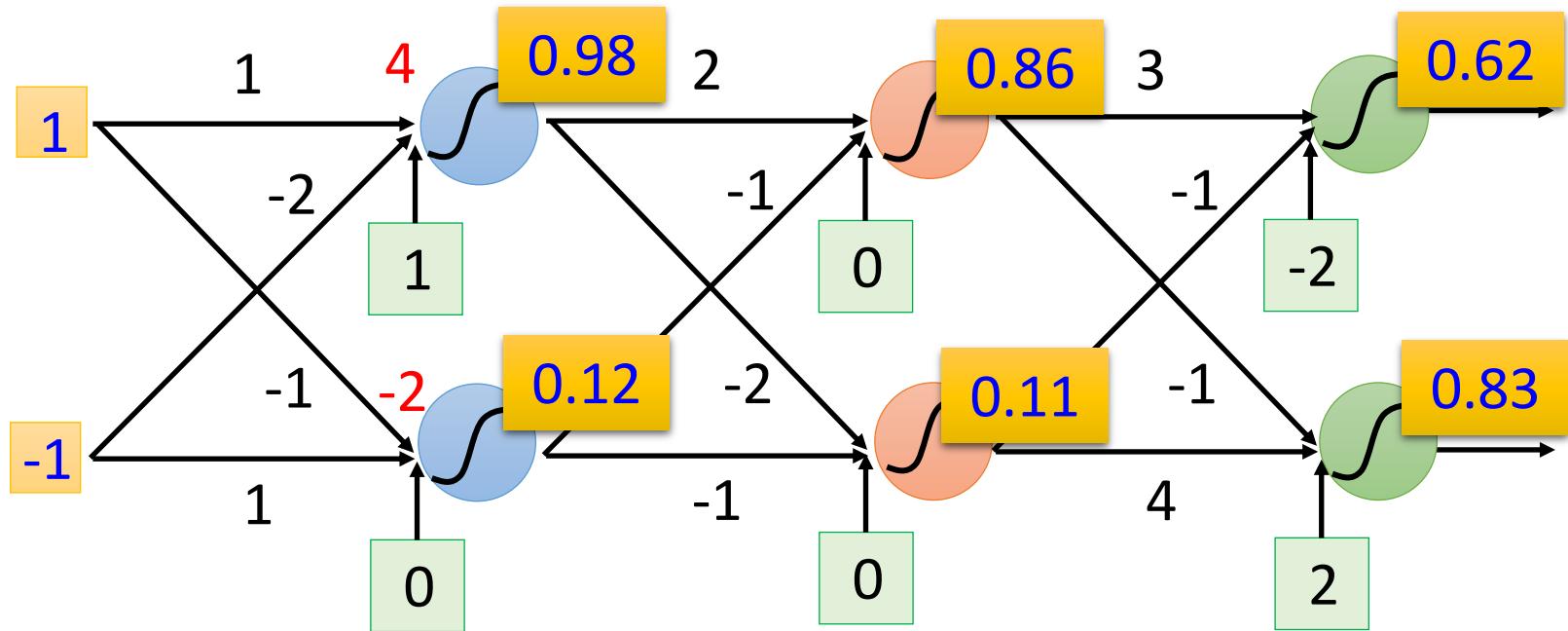


Sigmoid Function

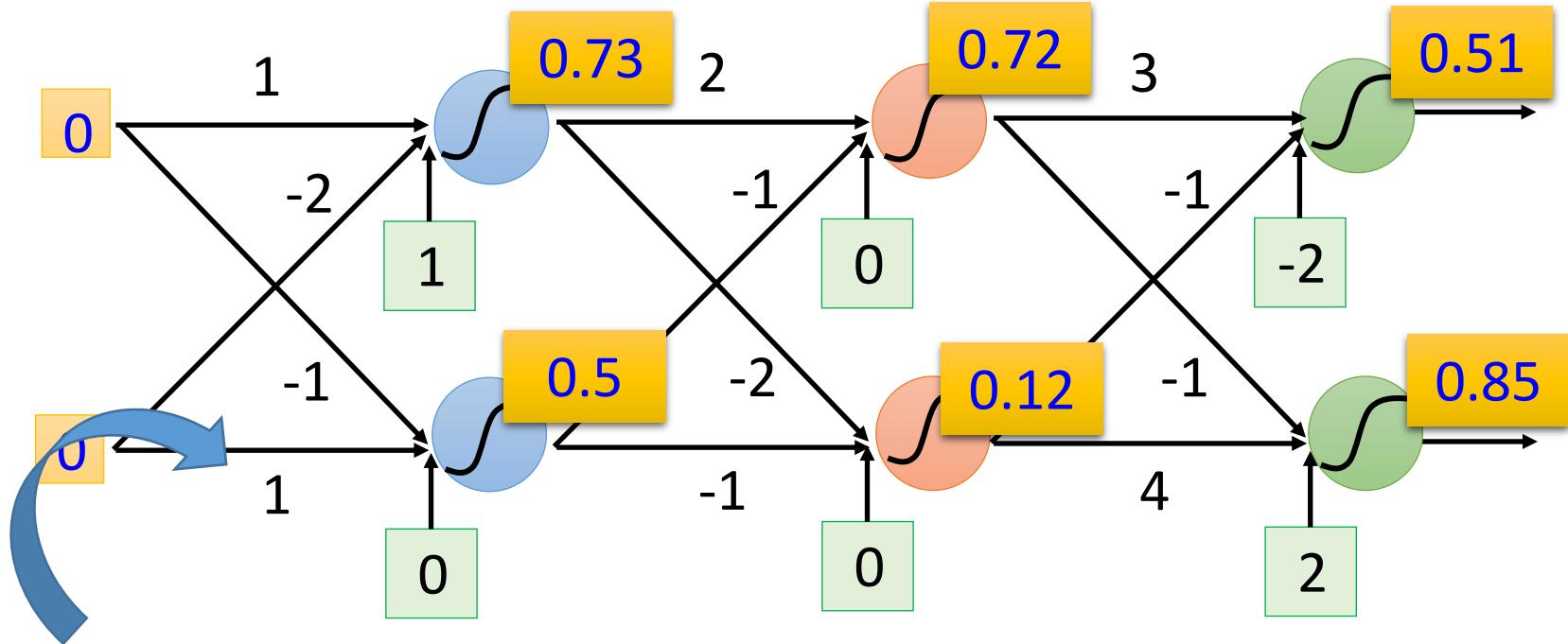
$$\sigma(z) = \frac{1}{1 + e^{-z}}$$



Fully Connect Feedforward Network



Fully Connect Feedforward Network



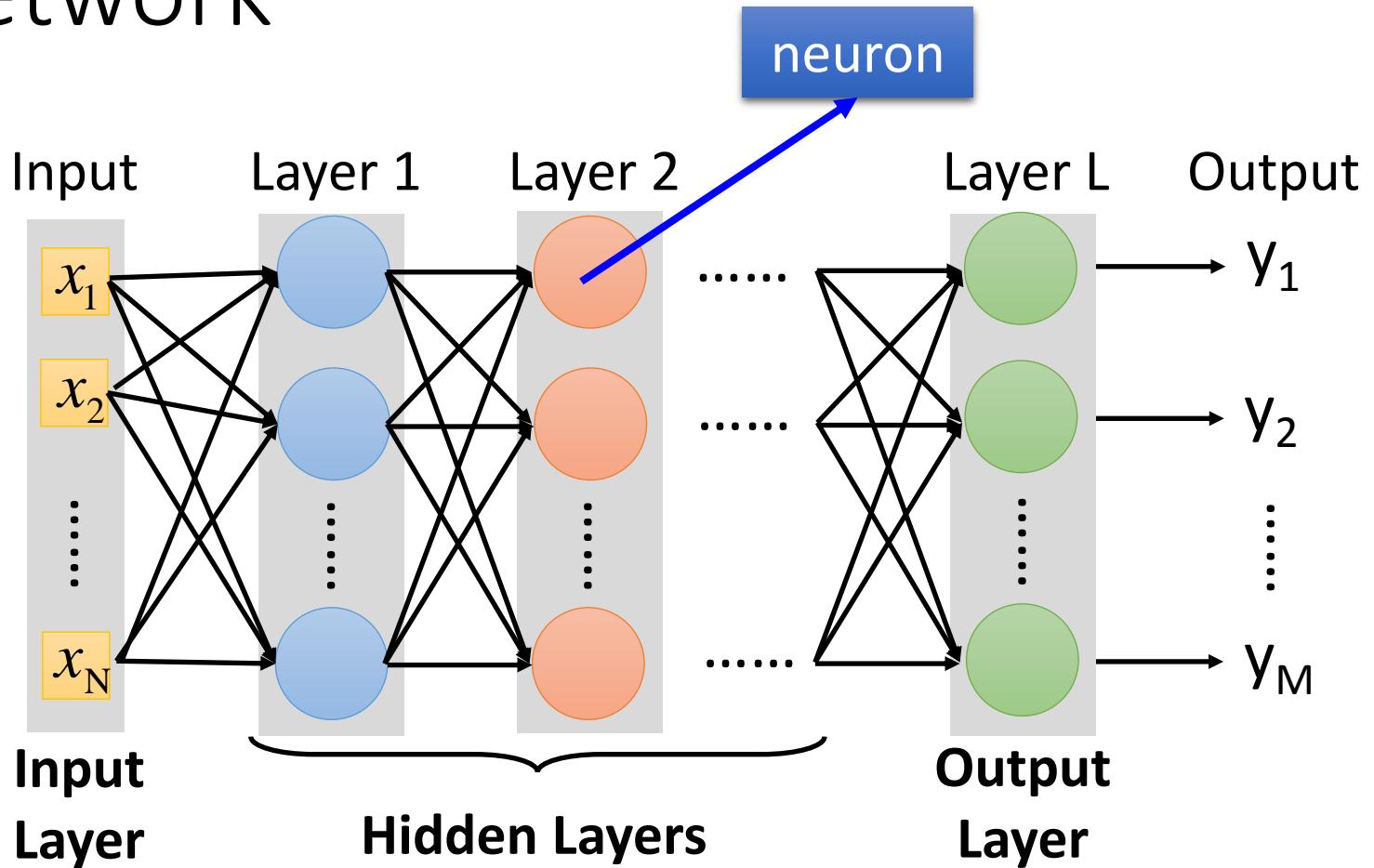
This is a function.
Input vector, output vector

$$f \left(\begin{bmatrix} 1 \\ -1 \end{bmatrix} \right) = \begin{bmatrix} 0.62 \\ 0.83 \end{bmatrix} \quad f \left(\begin{bmatrix} 0 \\ 2 \end{bmatrix} \right) = \begin{bmatrix} 0.51 \\ 0.85 \end{bmatrix}$$

Given parameters θ , define a function

Given network structure, define a function set

Fully Connect Feedforward Network



Deep means many hidden layers

Output Layer (Option)

- Softmax layer as the output layer

Ordinary Layer

$$z_1 \rightarrow \sigma \rightarrow y_1 = \sigma(z_1)$$

$$z_2 \rightarrow \sigma \rightarrow y_2 = \sigma(z_2)$$

$$z_3 \rightarrow \sigma \rightarrow y_3 = \sigma(z_3)$$

In general, the output of network can be any value.

May not be easy to interpret

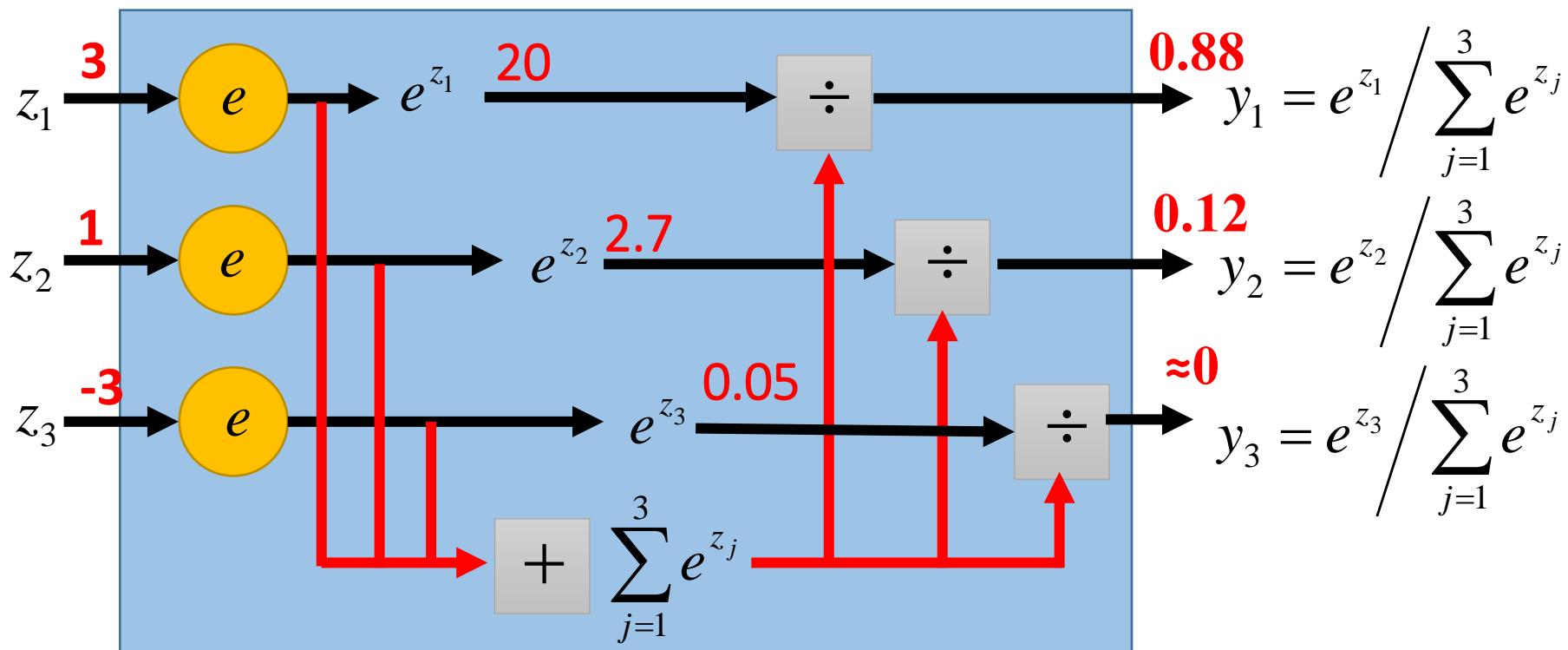
Output Layer (Option)

- Softmax layer as the output layer

Probability:

- $1 > y_i > 0$
- $\sum_i y_i = 1$

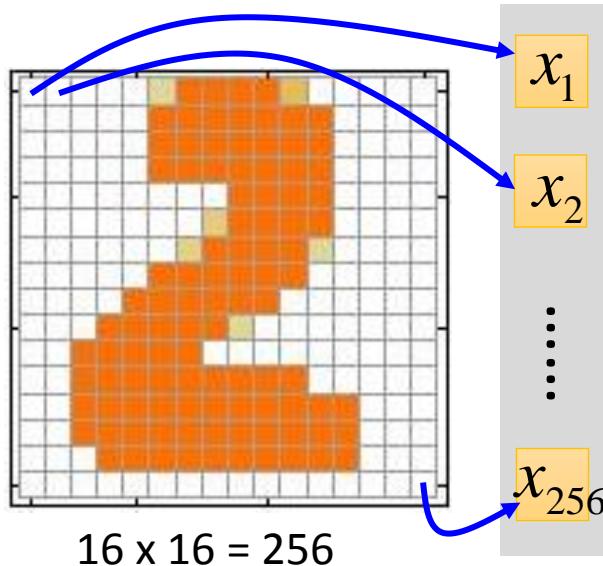
Softmax Layer



Example Application



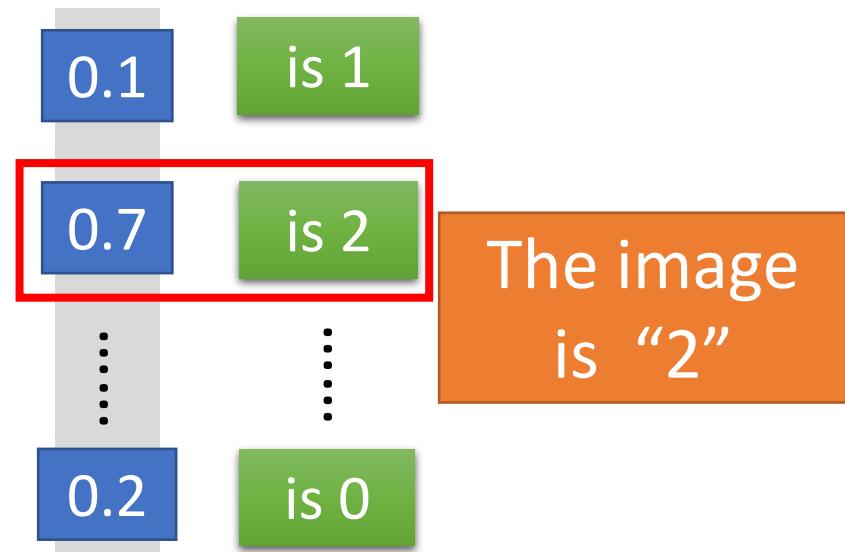
Input



Ink $\rightarrow 1$

No ink $\rightarrow 0$

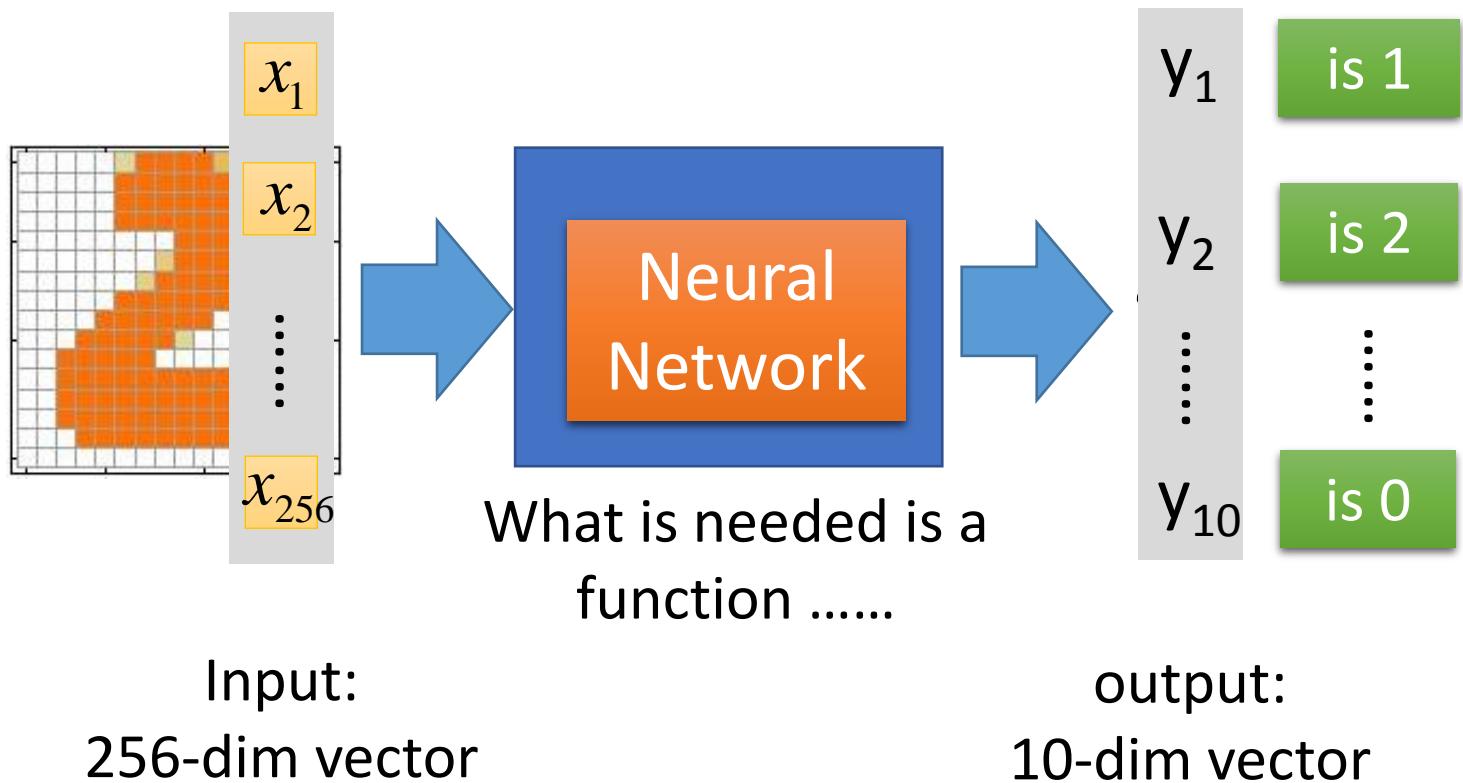
Output



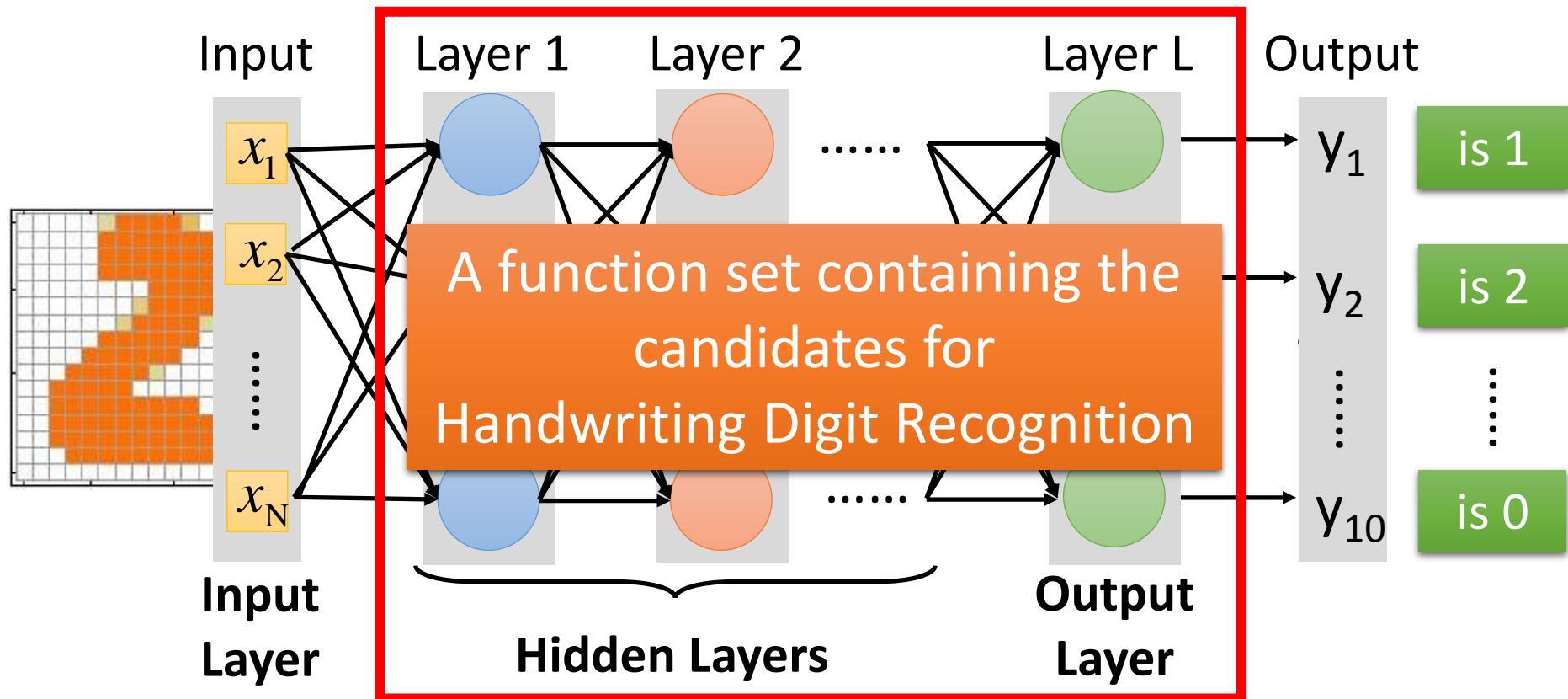
Each dimension represents the confidence of a digit.

Example Application

- Handwriting Digit Recognition

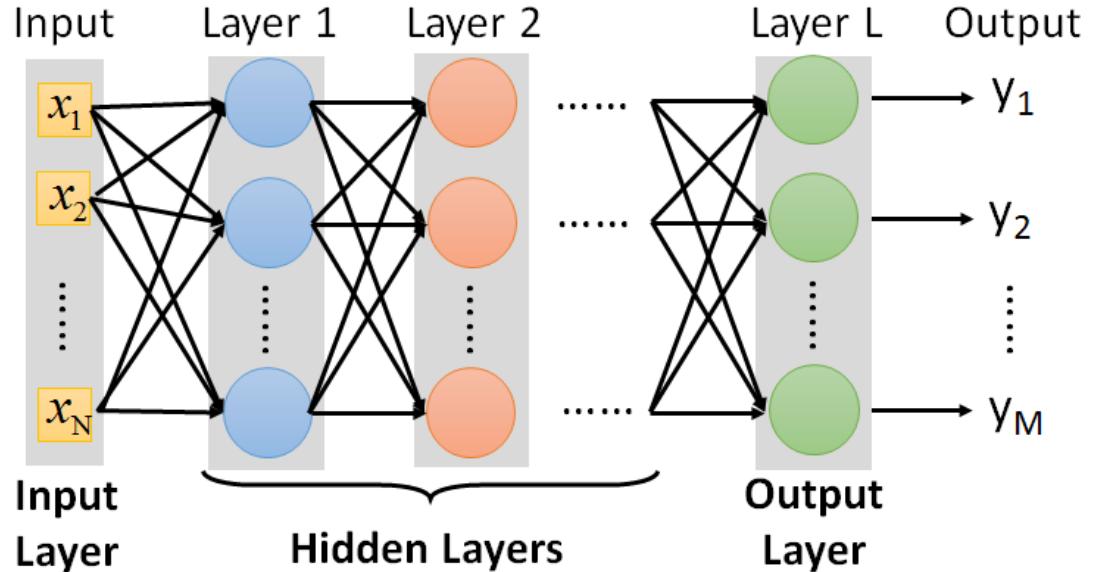


Example Application



You need to decide the network structure to let a good function in your function set.

FAQ



- Q: How many layers? How many neurons for each layer?

Trial and Error

+

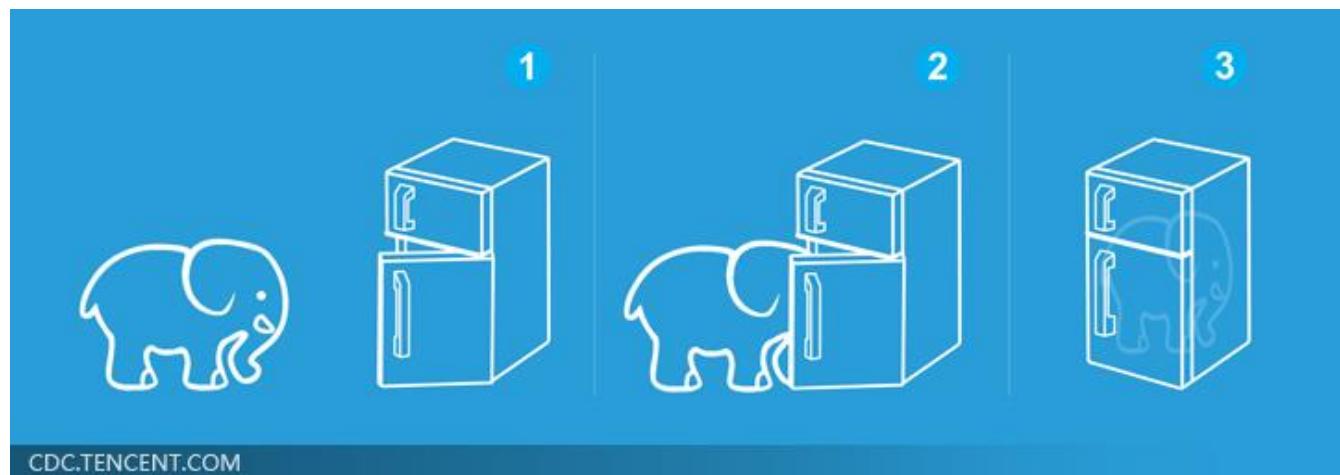
Intuition

- Q: Can the structure be automatically determined?

Three Steps for Deep Learning



Deep Learning is so simple



Training Data

- Preparing training data: images and their labels



“5”



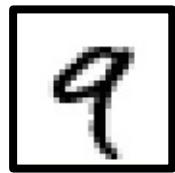
“0”



“4”



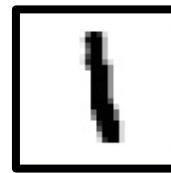
“1”



“9”



“2”



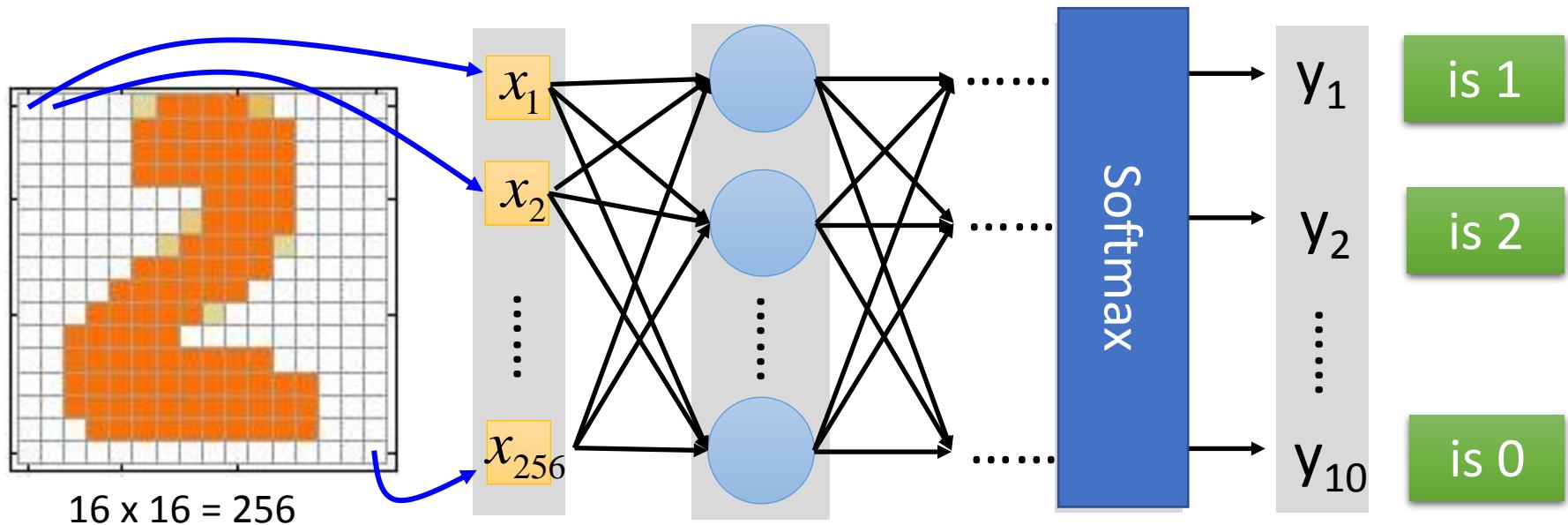
“1”



“3”

The learning target is defined on
the training data.

Learning Target



Ink $\rightarrow 1$

No ink $\rightarrow 0$

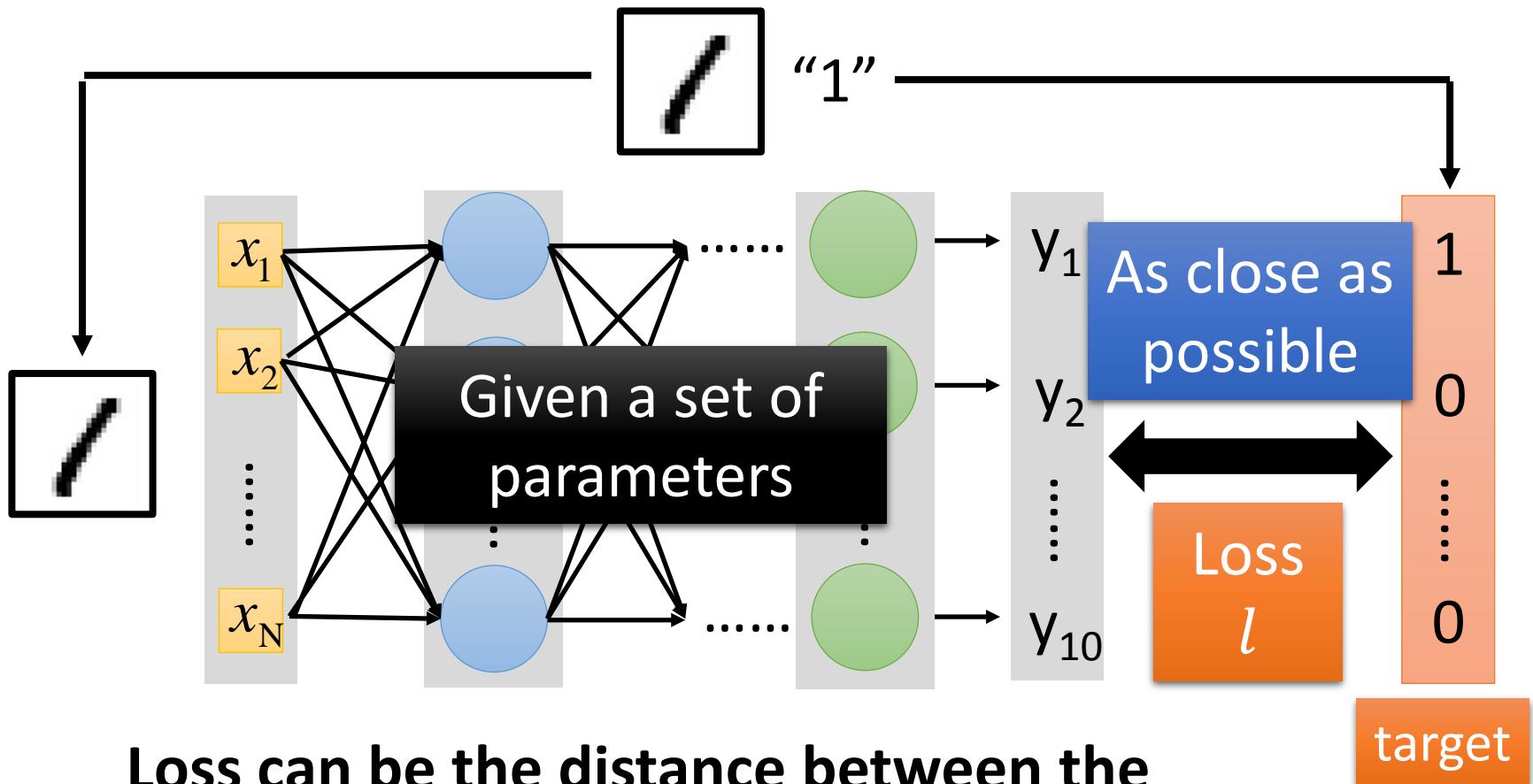
The learning target is

Input: $\rightarrow y_1$ has the maximum value

Input: $\rightarrow y_2$ has the maximum value

LOSS

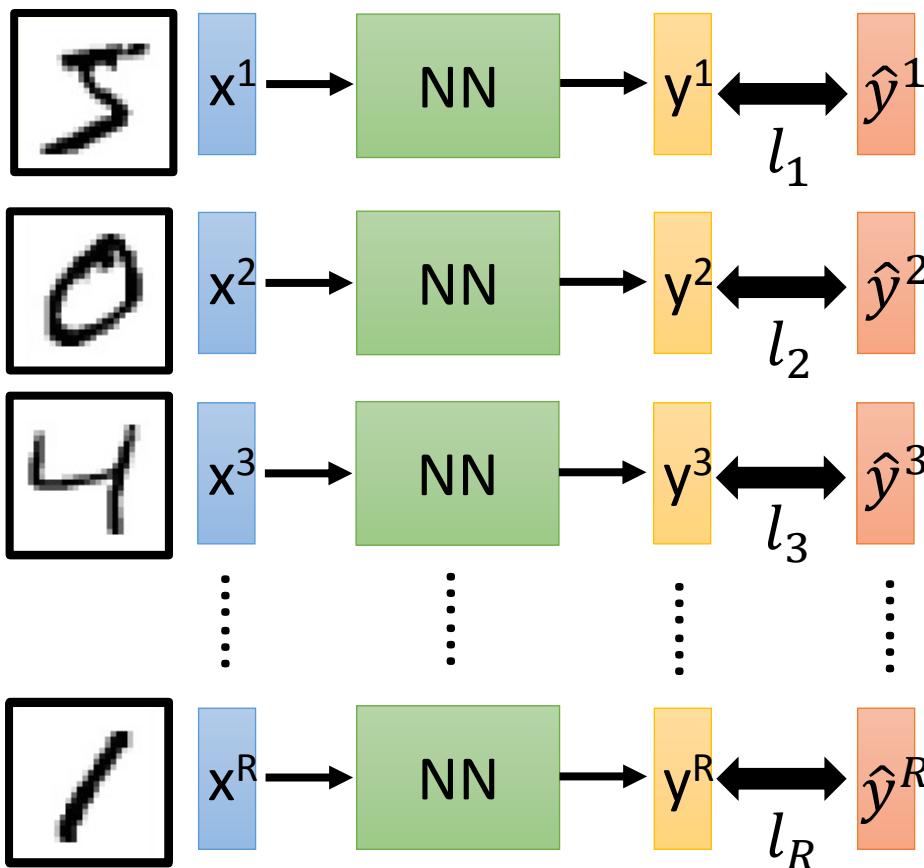
A good function should make the loss of all examples as small as possible.



Loss can be the distance between the network output and target

Total Loss

For all training data ...



Total Loss:

$$L = \sum_{r=1}^R l_r$$

As small as possible

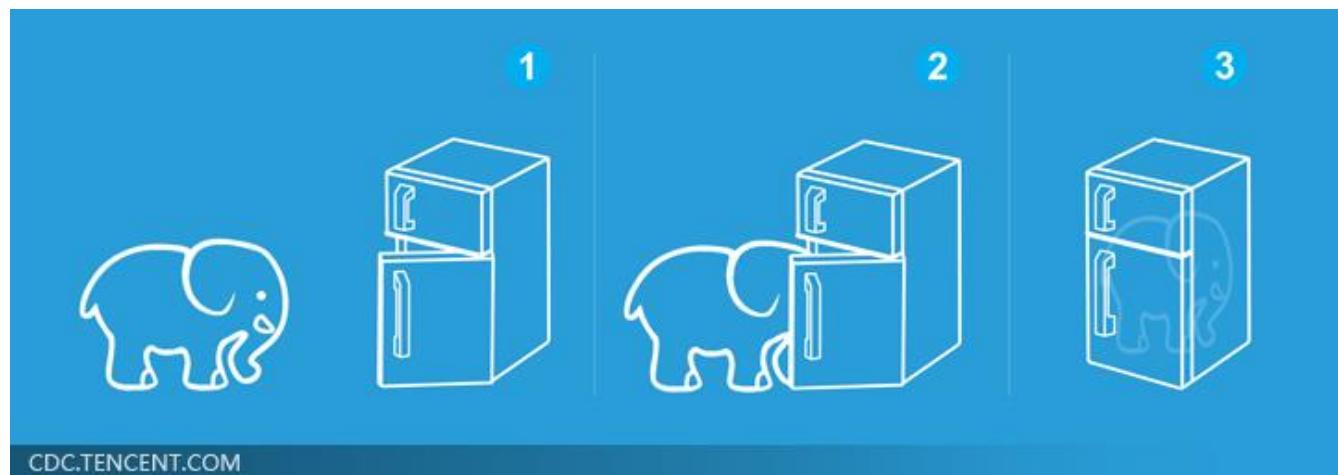
Find a function in function set that minimizes total loss L

Find the network parameters θ^* that minimize total loss L

Three Steps for Deep Learning



Deep Learning is so simple



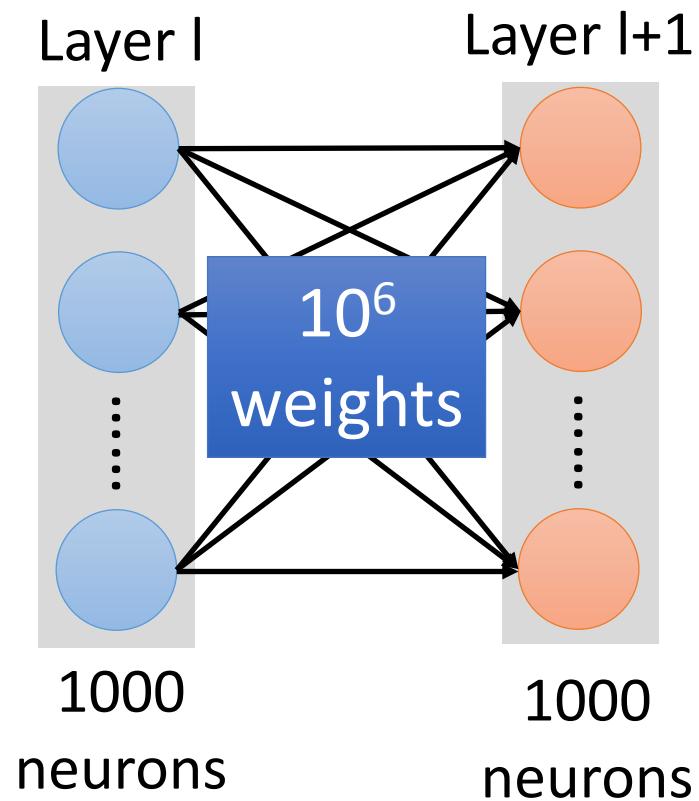
How to pick the best function

Find network parameters θ^* that minimize total loss L

Enumerate all possible values

Network parameters
 $\theta = \{w_1, w_2, w_3, \dots, b_1, b_2, b_3, \dots\}$
Millions of parameters

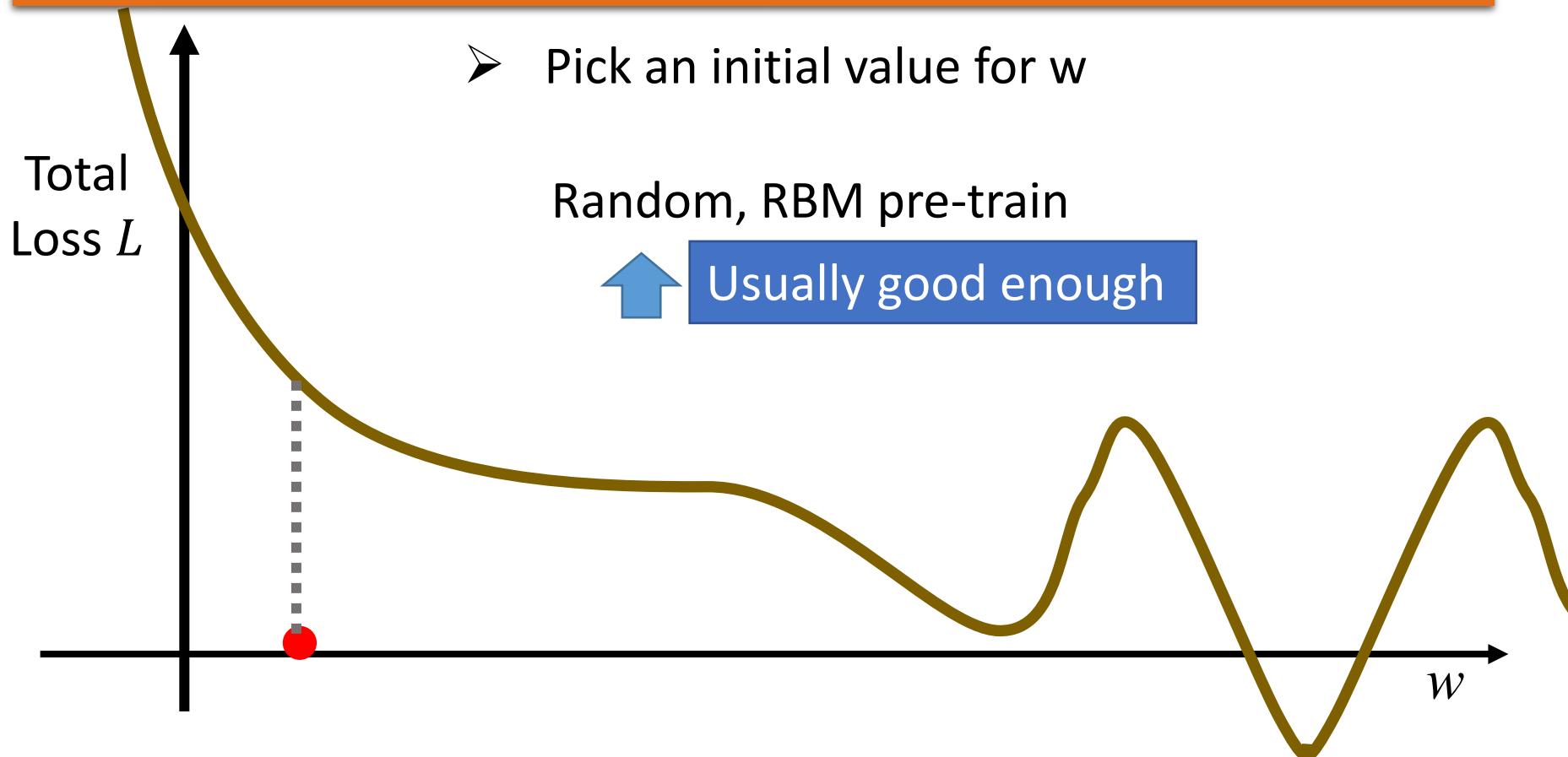
E.g. speech recognition: 8 layers and
1000 neurons each layer



Gradient Descent

Network parameters
 $\theta = \{w_1, w_2, \dots, b_1, b_2, \dots\}$

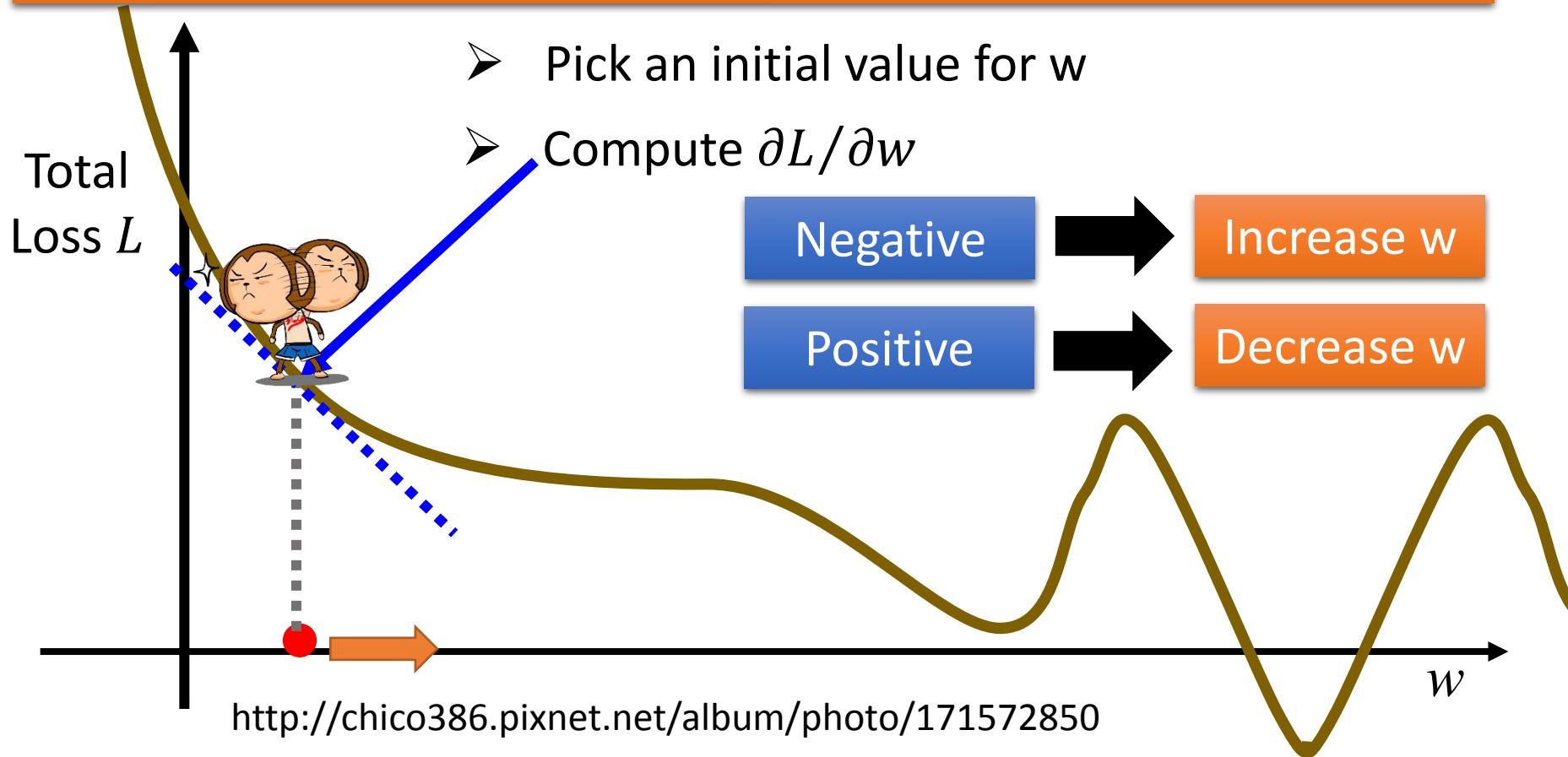
Find network parameters θ^* that minimize total loss L



Gradient Descent

Network parameters
 $\theta = \{w_1, w_2, \dots, b_1, b_2, \dots\}$

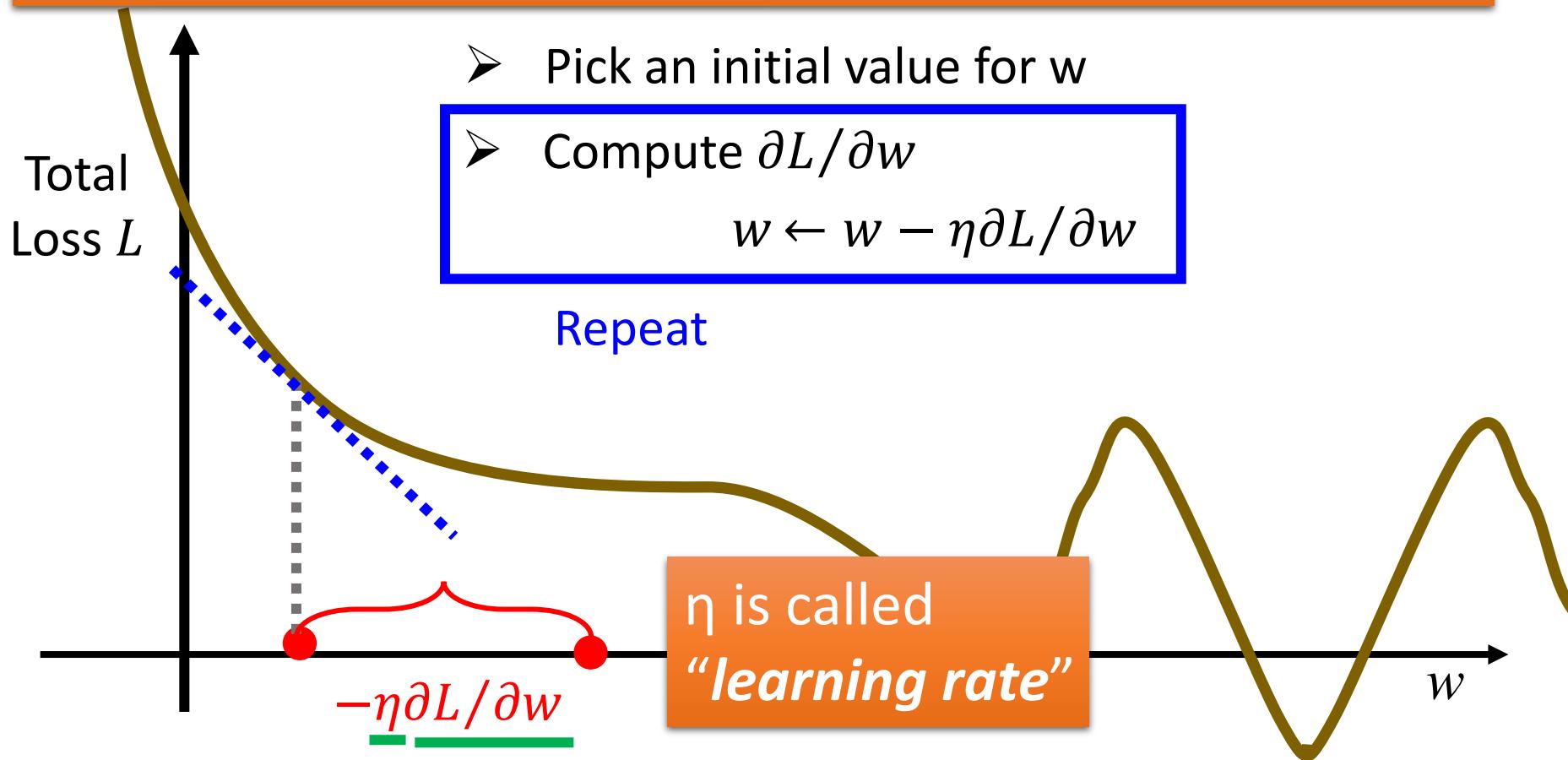
Find network parameters θ^* that minimize total loss L



Gradient Descent

Network parameters
 $\theta = \{w_1, w_2, \dots, b_1, b_2, \dots\}$

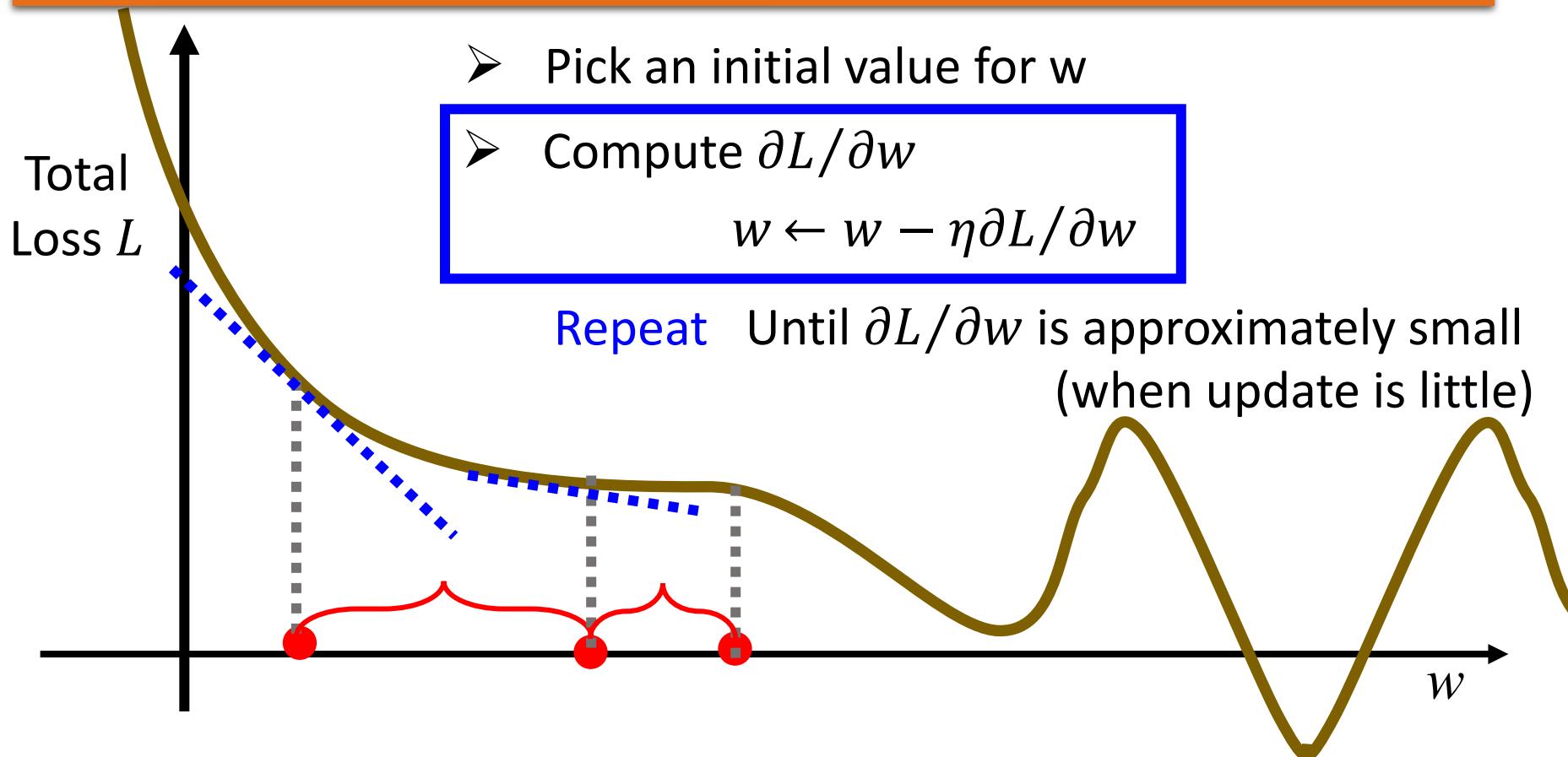
Find network parameters θ^* that minimize total loss L



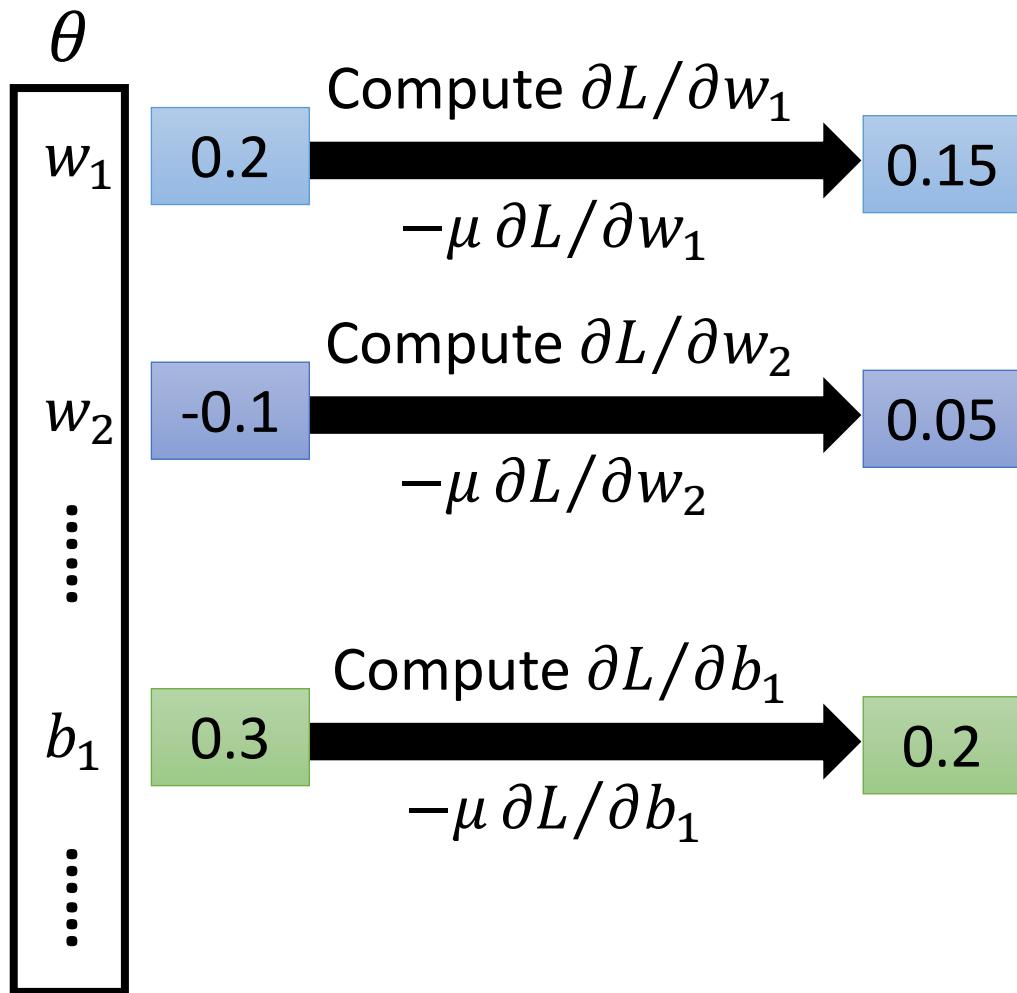
Gradient Descent

Network parameters
 $\theta = \{w_1, w_2, \dots, b_1, b_2, \dots\}$

Find network parameters θ^* that minimize total loss L



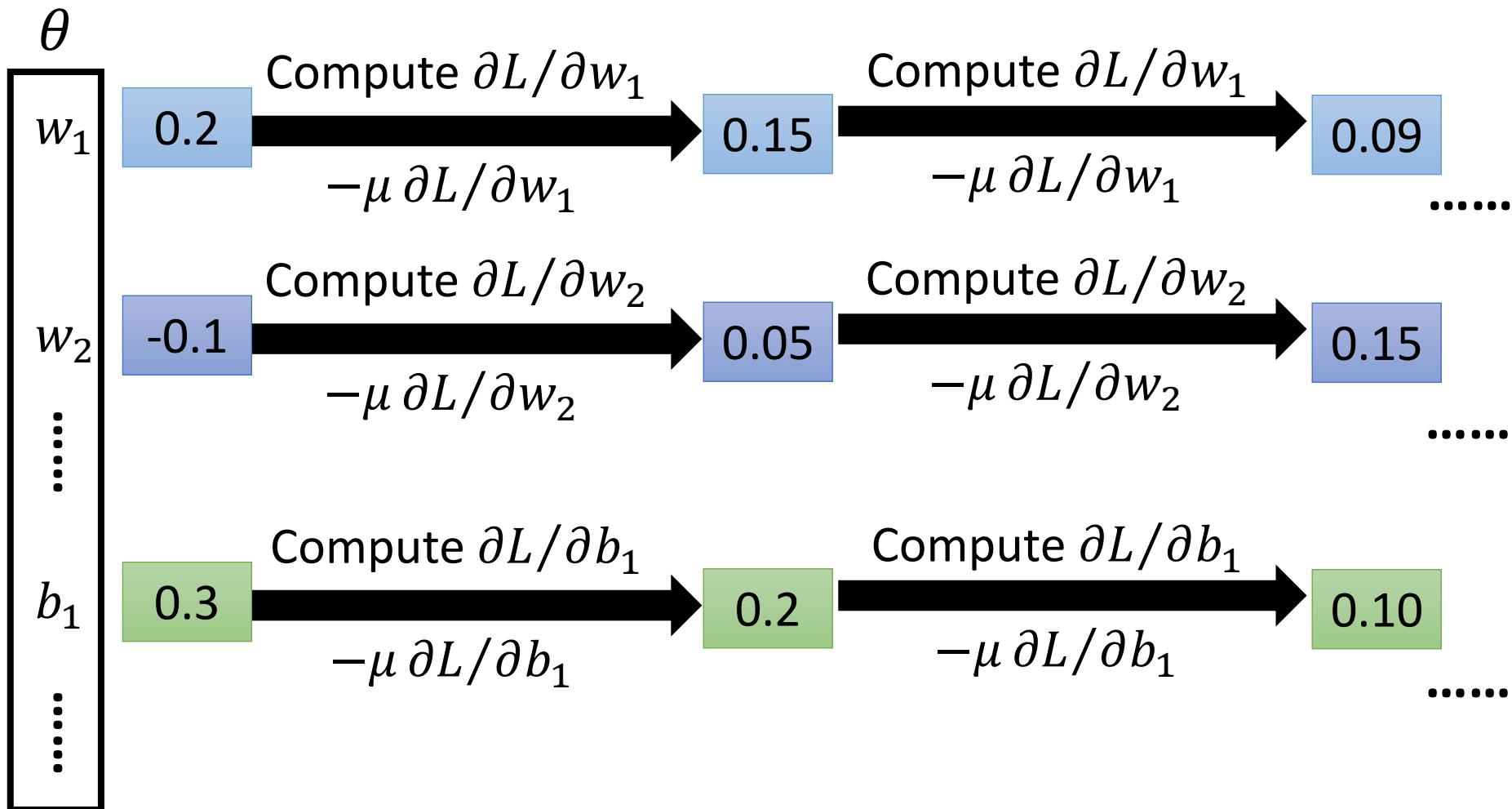
Gradient Descent



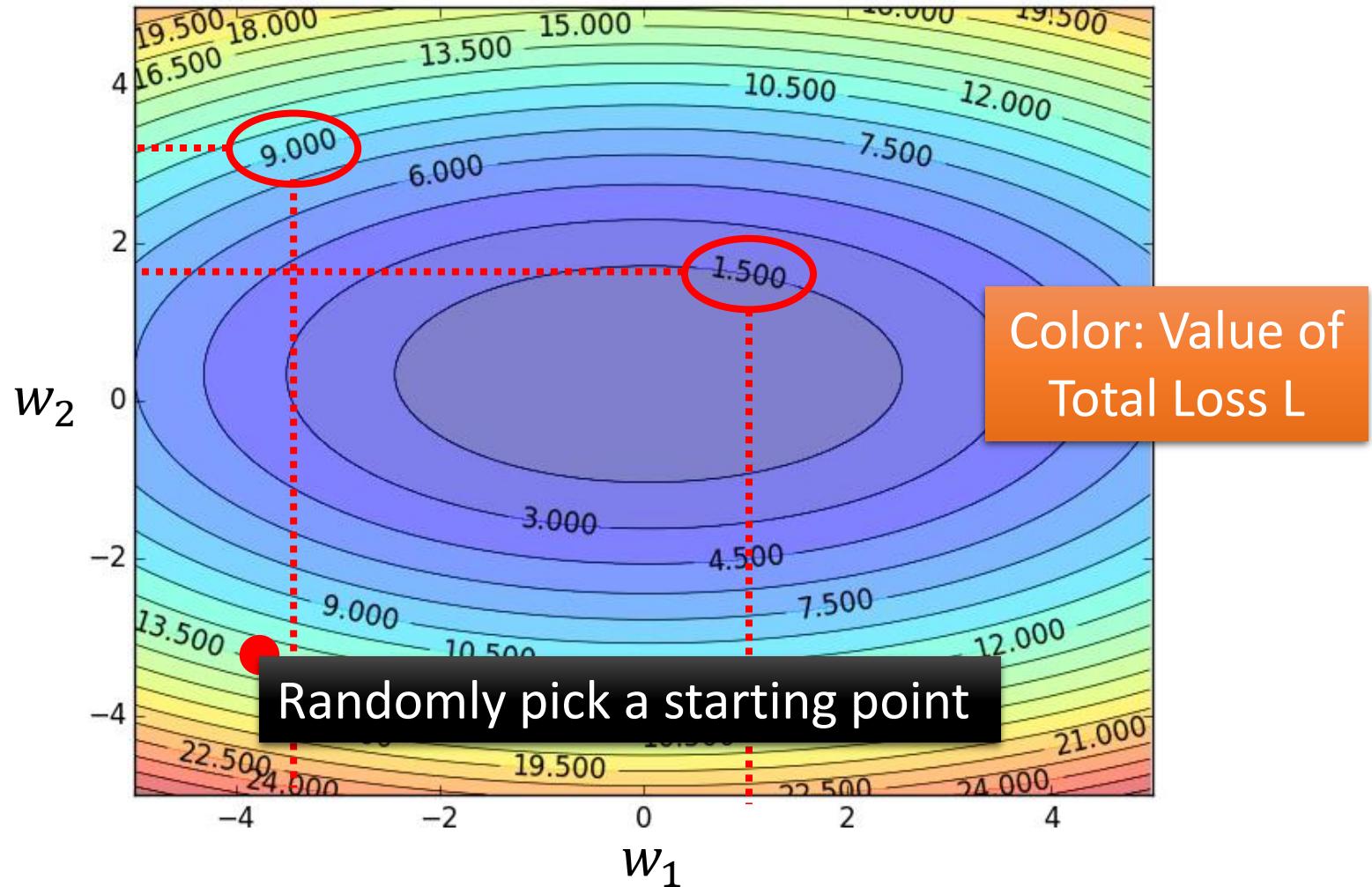
$$\nabla L = \begin{bmatrix} \frac{\partial L}{\partial w_1} \\ \frac{\partial L}{\partial w_2} \\ \vdots \\ \frac{\partial L}{\partial b_1} \\ \vdots \end{bmatrix}$$

gradient

Gradient Descent

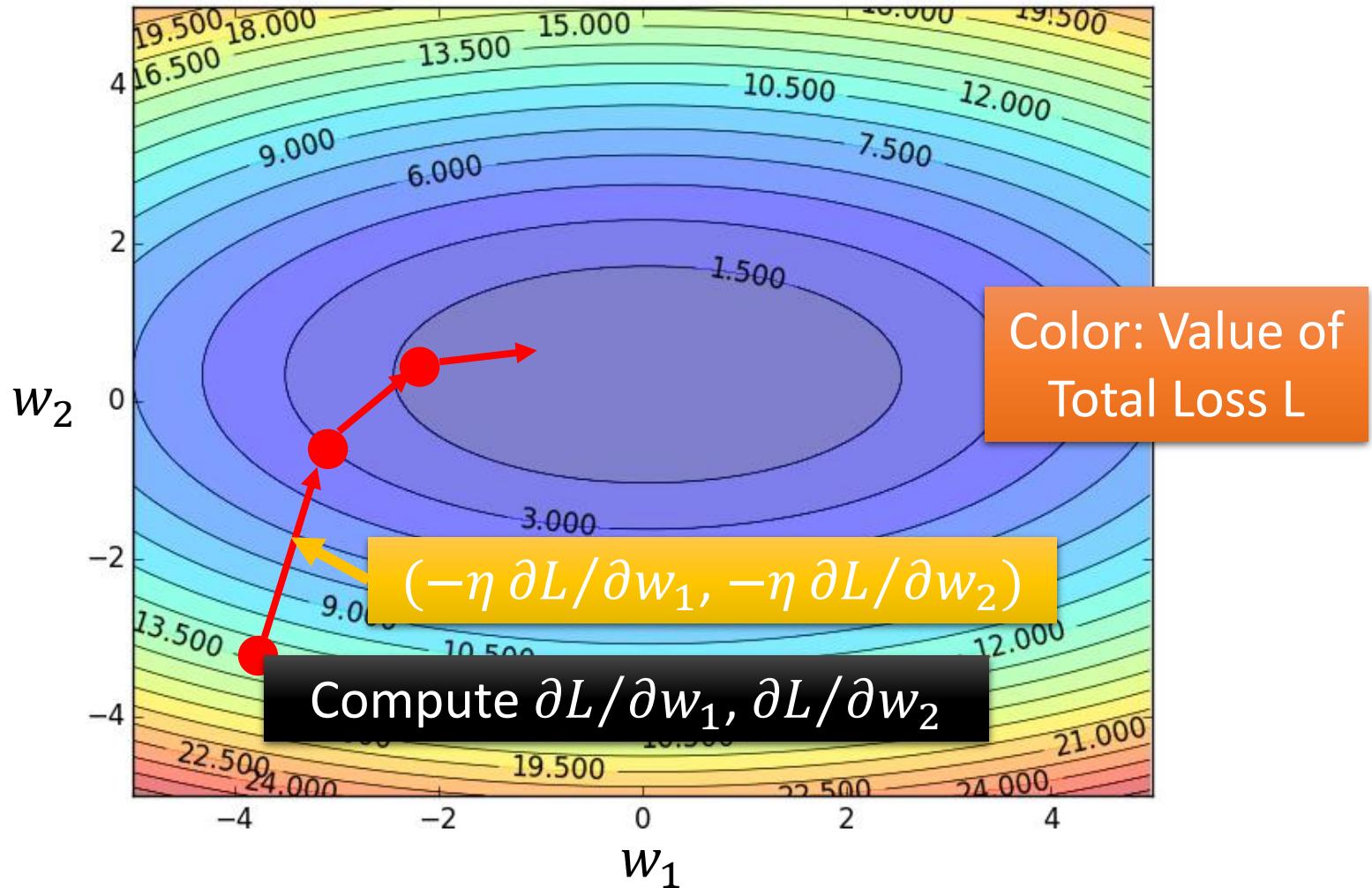


Gradient Descent



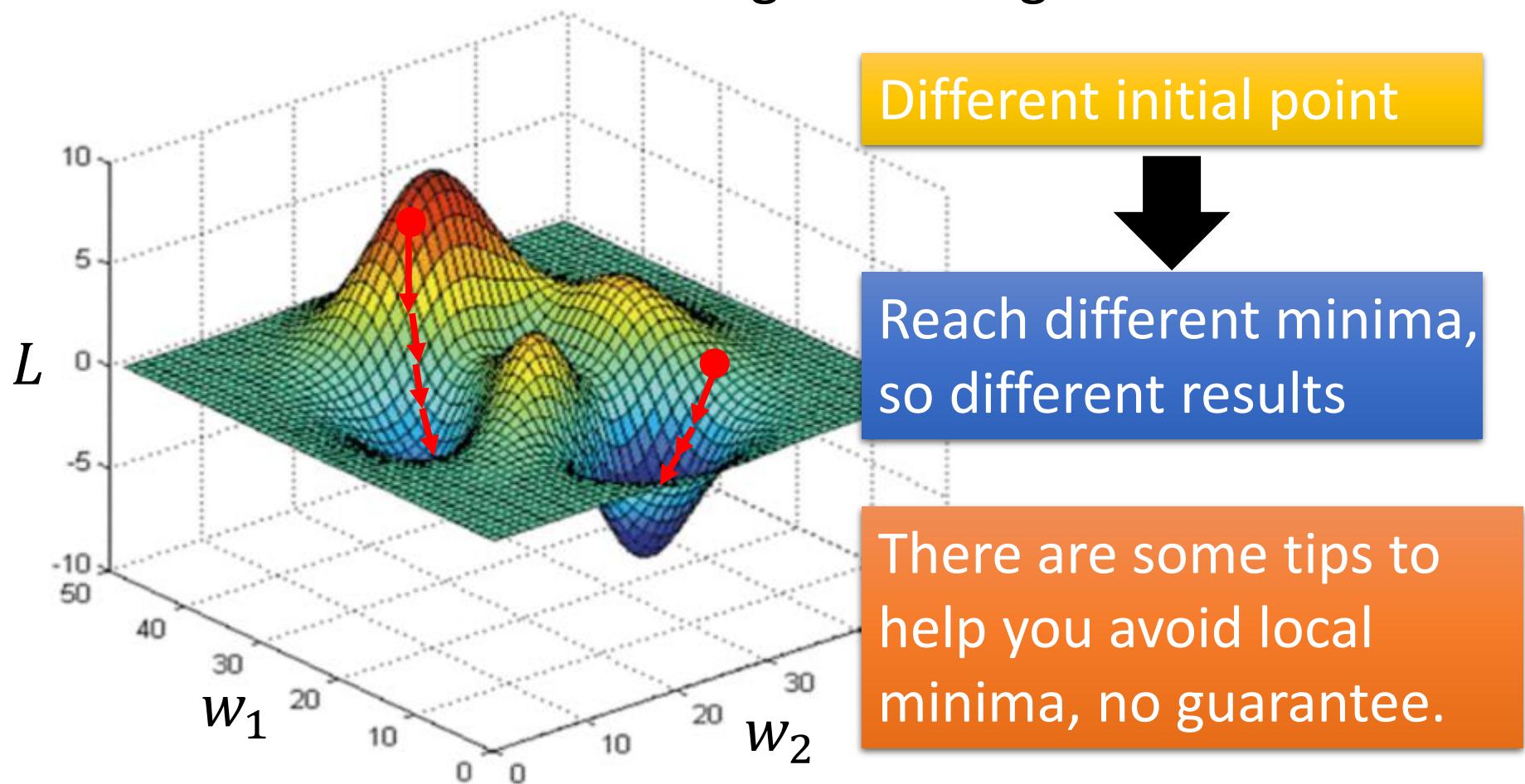
Gradient Descent

Hopfully, we would reach
a minima



Gradient Descent - Difficulty

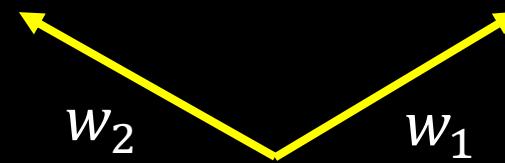
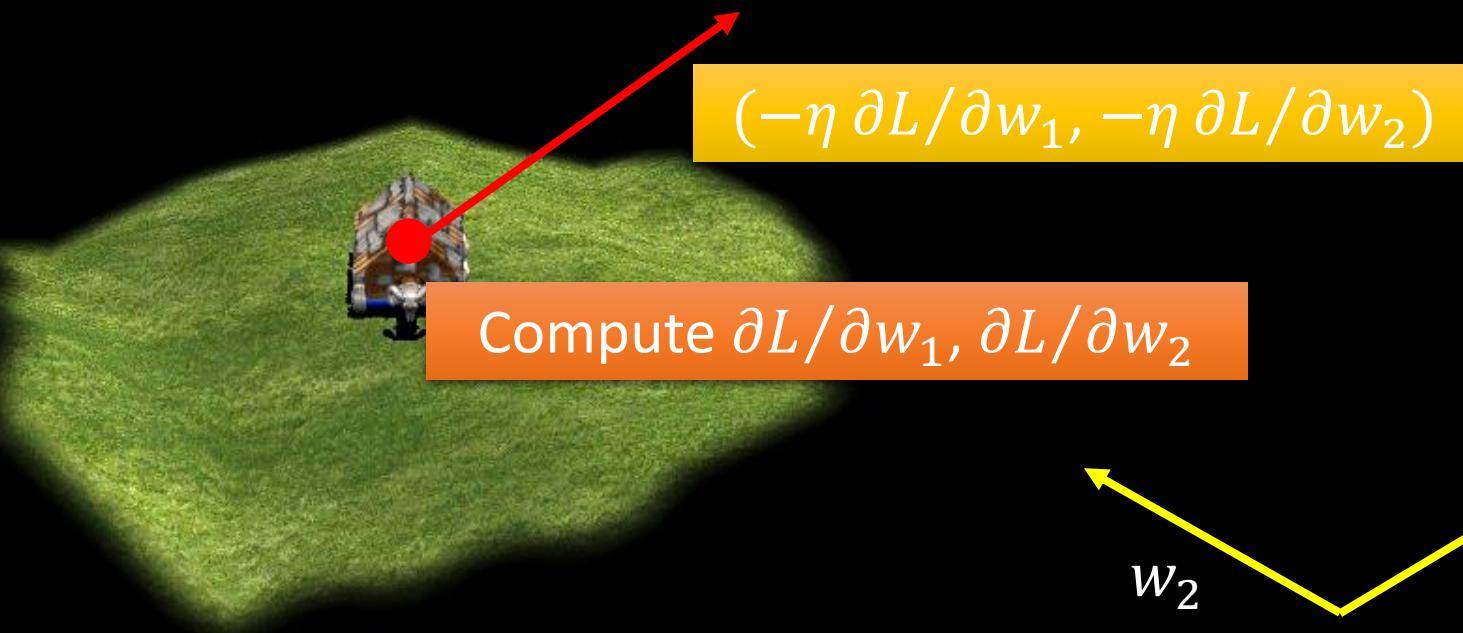
- Gradient descent never guarantee global minima





You are playing Age of Empires ...

You cannot see the whole map.

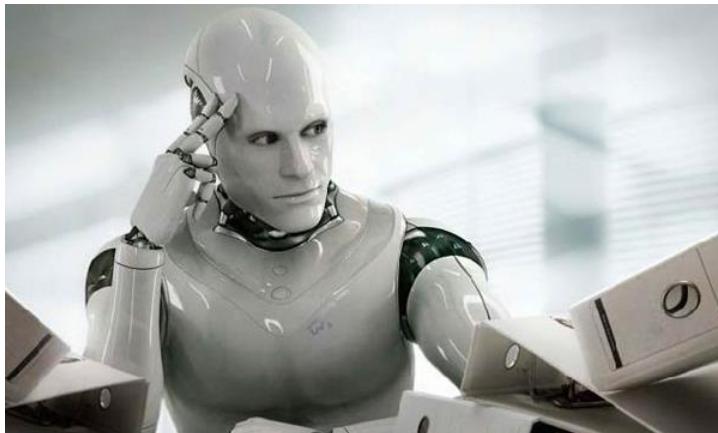


Gradient Descent

This is the “learning” of machines in deep learning

→ Even alpha go using this approach.

People image



Actually



I hope you are not too disappointed :p

Backpropagation

- Backpropagation: an efficient way to compute $\partial L / \partial w$
 - Ref:
http://speech.ee.ntu.edu.tw/~tlkagk/courses/MLDS_2015_2/Lecture/DNN%20backprop.ecm.mp4/index.html



theano

libdnn
台大周伯威
同學開發

Caffe

Microsoft
CNTK



mxnet

Don't worry about $\partial L / \partial w$, the toolkits will handle it.

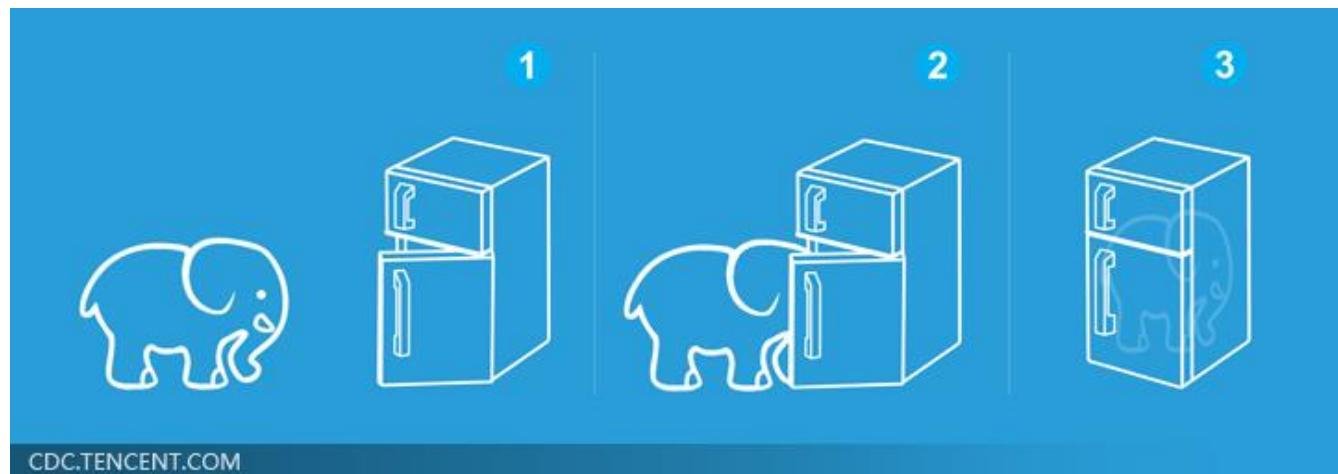
Concluding Remarks

Step 1:
define a set
of function

Step 2:
goodness of
function

Step 3: pick
the best
function

Deep Learning is so simple



Outline of Lecture I

Introduction of Deep Learning

Why Deep?

“Hello World” for Deep Learning

Deeper is Better?

Layer X Size	Word Error Rate (%)
1 X 2k	24.2
2 X 2k	20.4
3 X 2k	18.4
4 X 2k	17.8
5 X 2k	17.2
7 X 2k	17.1

Not surprised, more parameters, better performance

Seide, Frank, Gang Li, and Dong Yu. "Conversational Speech Transcription Using Context-Dependent Deep Neural Networks." *Interspeech*. 2011.

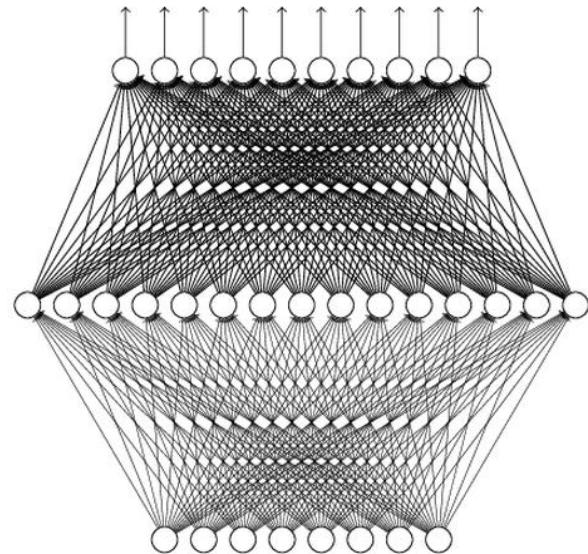
Universality Theorem

Any continuous function f

$$f : R^N \rightarrow R^M$$

Can be realized by a network
with one hidden layer

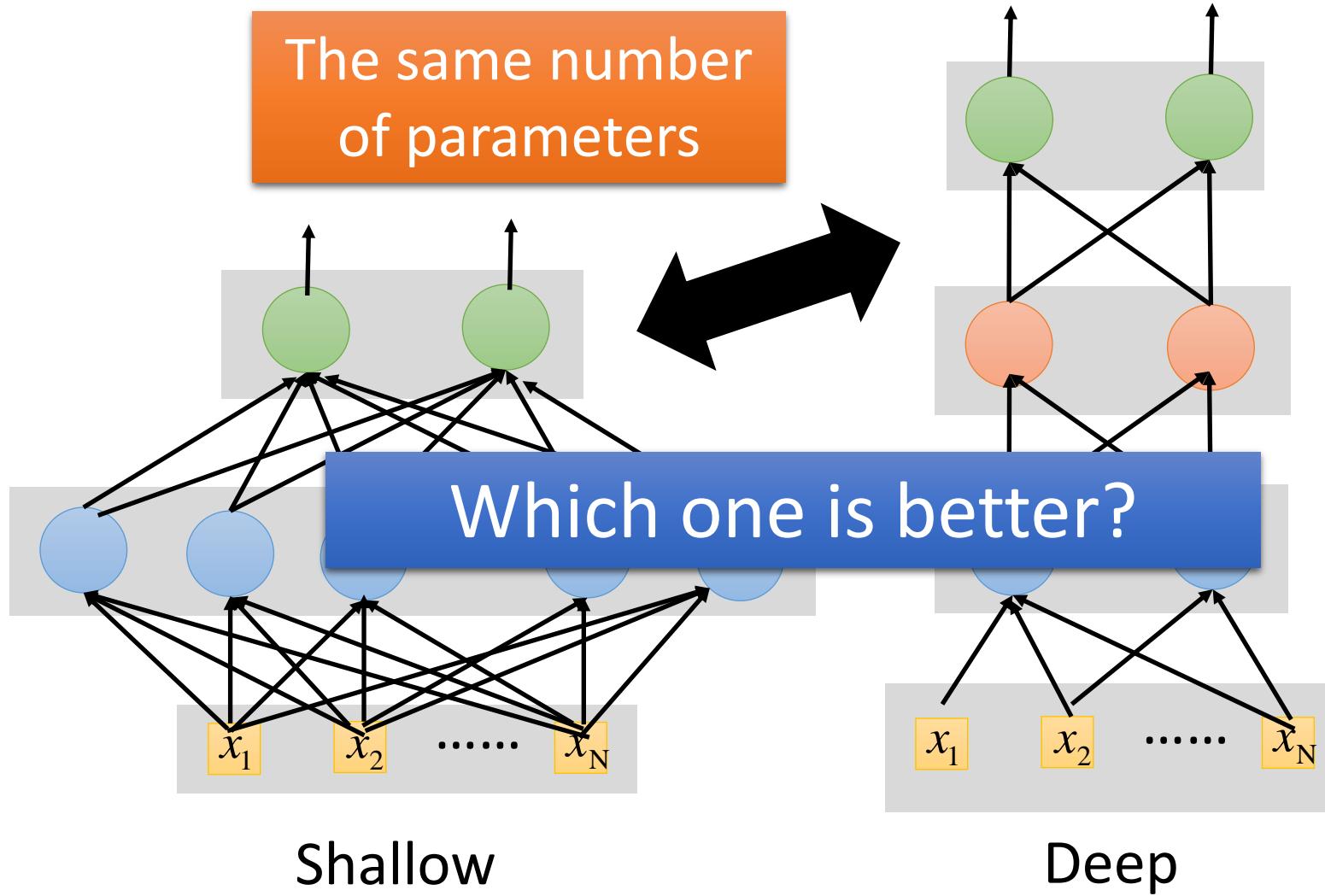
(given **enough** hidden
neurons)



Reference for the reason:
<http://neuralnetworksanddeeplearning.com/chap4.html>

Why “Deep” neural network not “Fat” neural network?

Fat + Short v.s. Thin + Tall



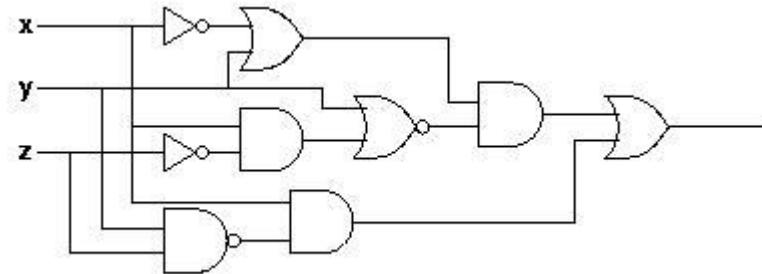
Fat + Short v.s. Thin + Tall

Layer X Size	Word Error Rate (%)	Layer X Size	Word Error Rate (%)
1 X 2k	24.2		
2 X 2k	20.4		
3 X 2k	18.4		
4 X 2k	17.8		
5 X 2k	17.2	1 X 3772	22.5
7 X 2k	17.1	1 X 4634	22.6
		1 X 16k	22.1

Why?

Seide, Frank, Gang Li, and Dong Yu. "Conversational Speech Transcription Using Context-Dependent Deep Neural Networks." *Interspeech*. 2011.

Analogy



Logic circuits

- Logic circuits consists of **gates**
- **A two layers of logic gates** can represent **any Boolean function.**
- Using multiple layers of logic gates to build some functions are much simpler



less gates needed



- Neural network consists of **neurons**
- **A hidden layer network** can represent **any continuous function.**
- Using multiple layers of neurons to represent some functions are much simpler



less parameters

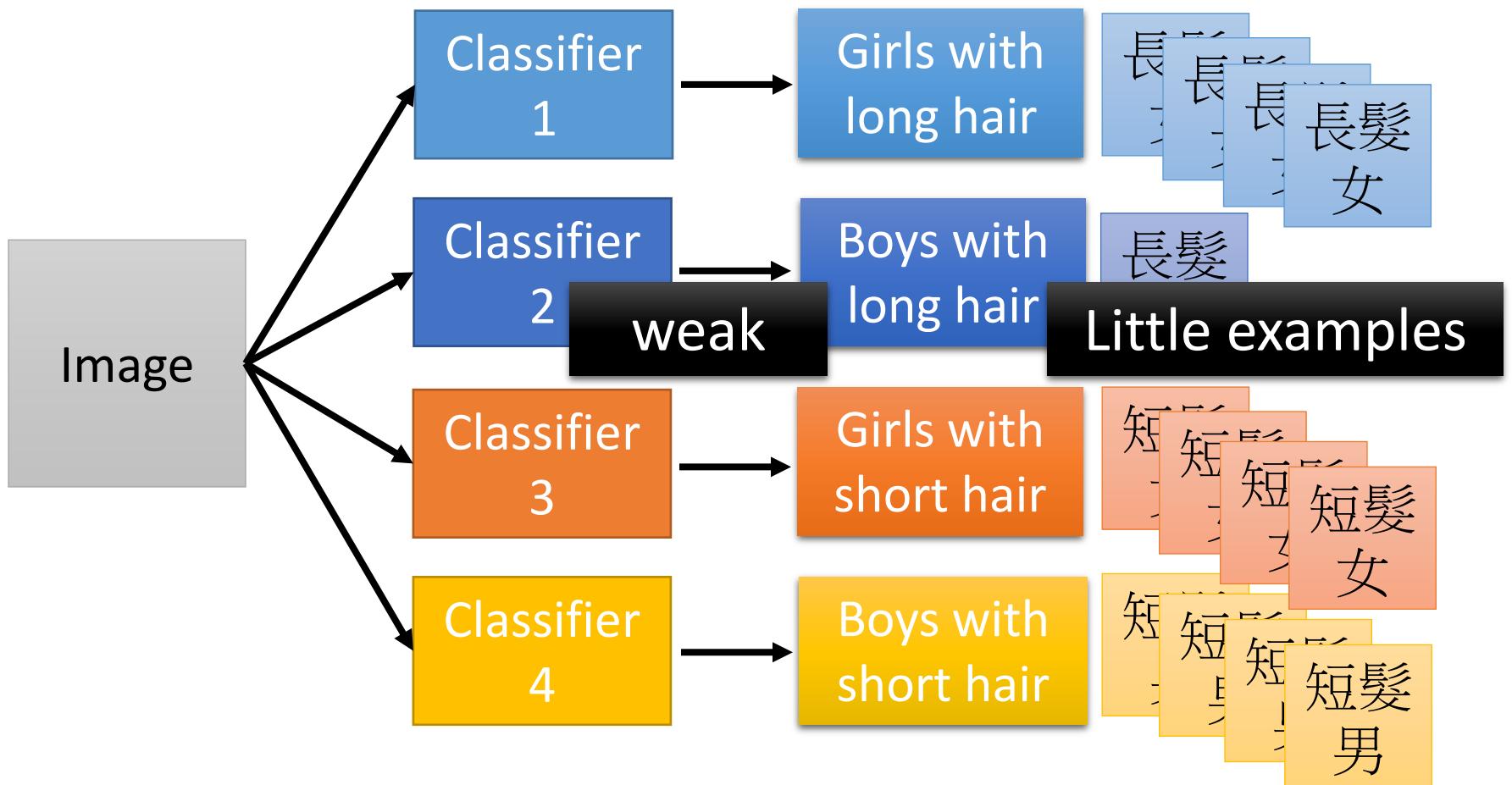


less data?

This page is for EE background.

Modularization

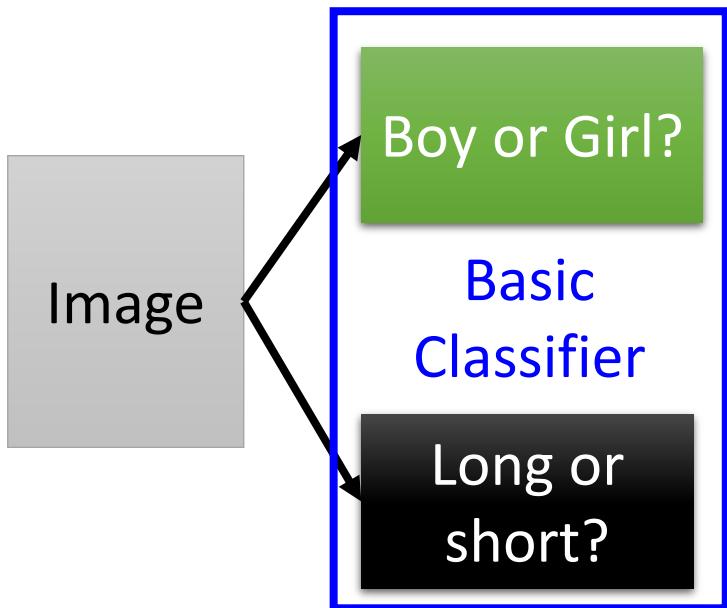
- Deep → Modularization



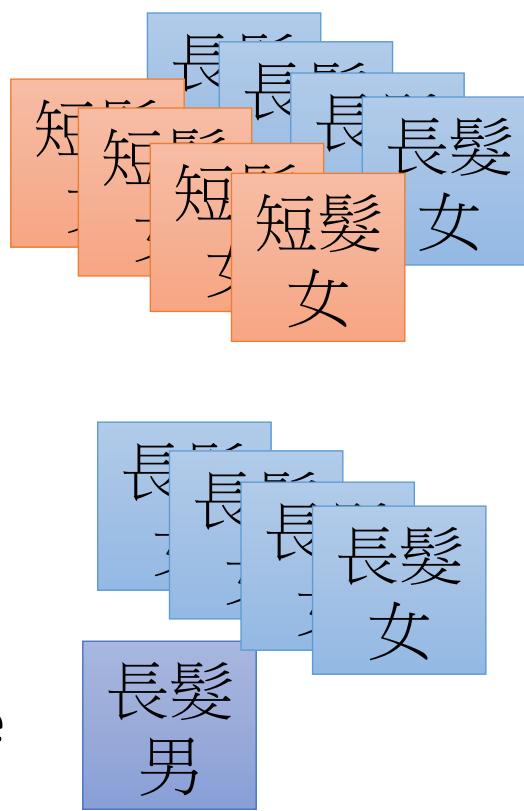
Modularization

Each basic classifier can have sufficient training examples.

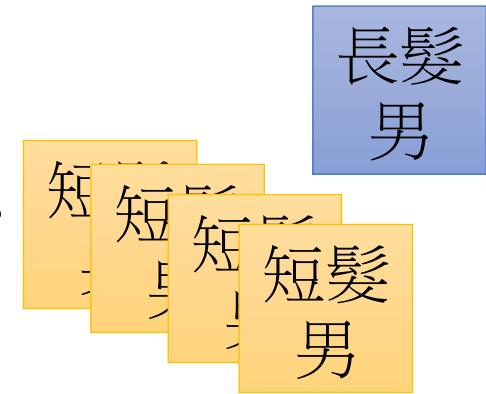
- Deep → Modularization



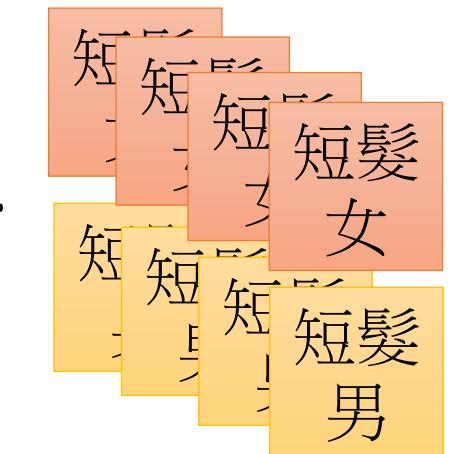
Classifiers for the
attributes



v.s.



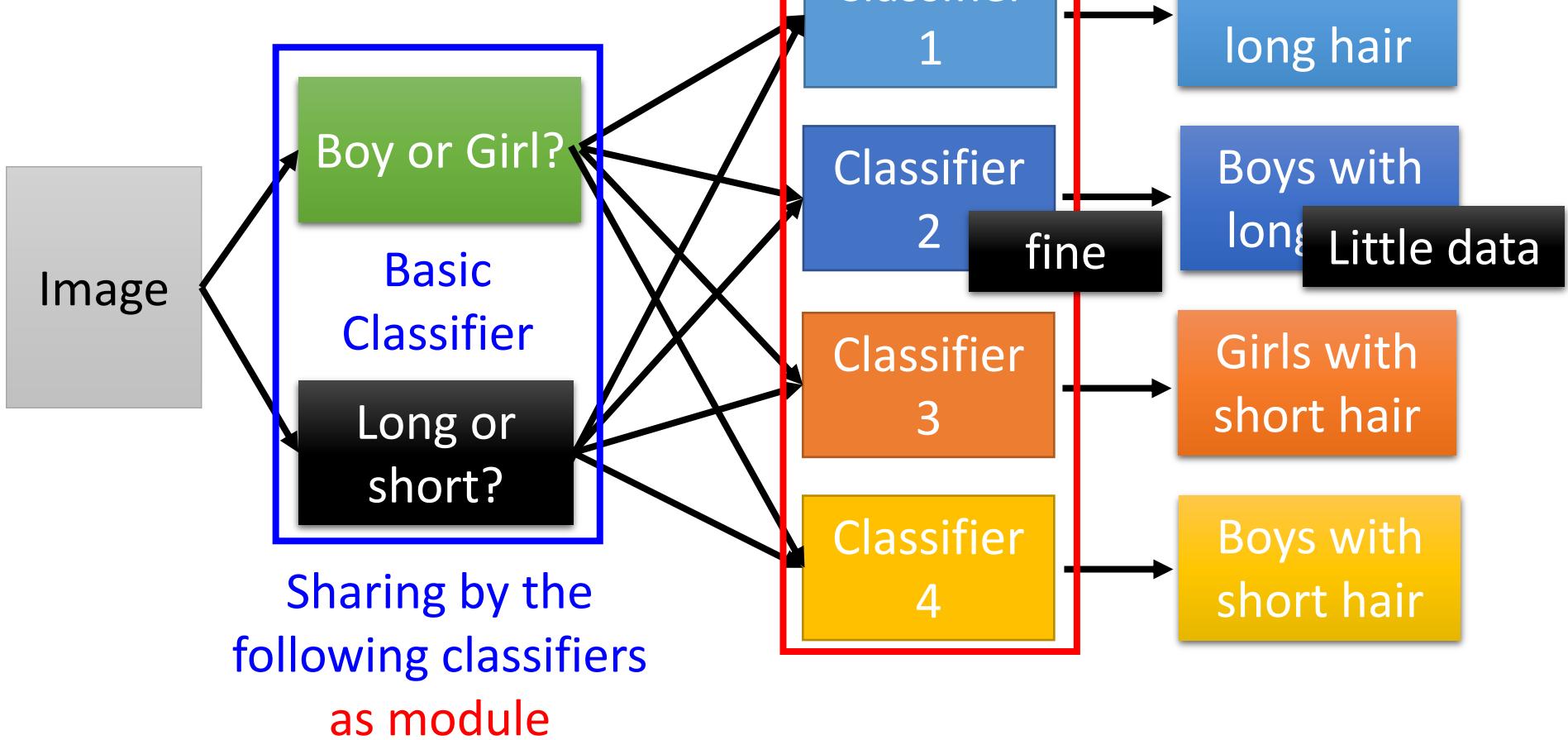
v.s.



Modularization

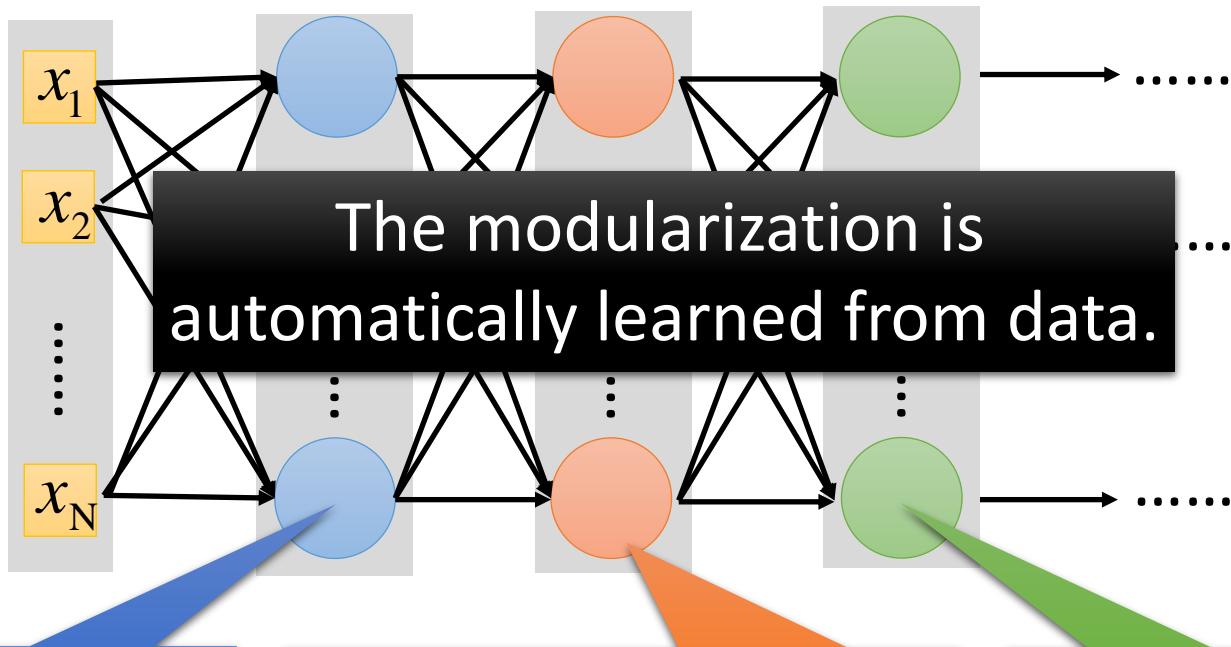
can be trained by little data

- Deep → Modularization



Modularization

- Deep \rightarrow Modularization → Less training data?



The most basic
classifiers

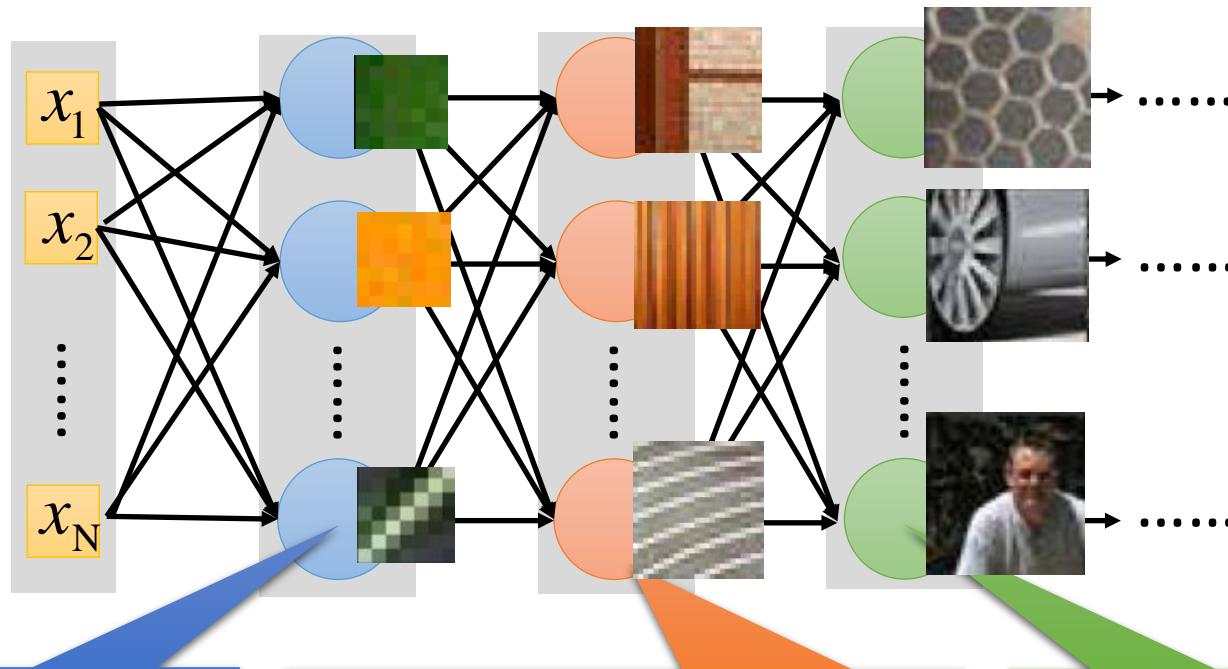
Use 1st layer as module
to build classifiers

Use 2nd layer as
module

Modularization

Reference: Zeiler, M. D., & Fergus, R. (2014). Visualizing and understanding convolutional networks. In *Computer Vision–ECCV 2014* (pp. 818-833)

- Deep → Modularization



The most basic
classifiers

Use 1st layer as module
to build classifiers

Use 2nd layer as
module

Outline of Lecture I

Introduction of Deep Learning

Why Deep?

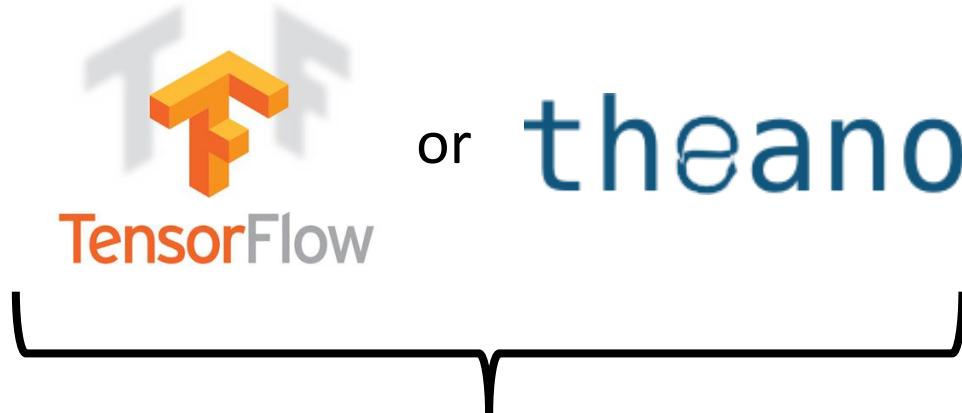
“Hello World” for Deep Learning

Keras

If you want to learn theano:

http://speech.ee.ntu.edu.tw/~tlkagk/courses/MLDS_2015_2/Lecture/Theano%20DNN.ecm.mp4/index.html

[http://speech.ee.ntu.edu.tw/~tlkagk/courses/MLDS_2015_2/Lecture/RNN%20training%20\(v6\).ecm.mp4/index.html](http://speech.ee.ntu.edu.tw/~tlkagk/courses/MLDS_2015_2/Lecture/RNN%20training%20(v6).ecm.mp4/index.html)



Interface of
TensorFlow or
Theano

Very flexible
Need some
effort to learn

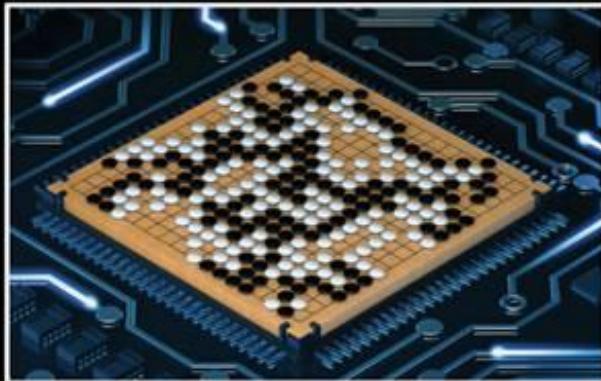
Easy to learn and use
(still have some flexibility)
You can modify it if you can write
TensorFlow or Theano

Keras

- François Chollet is the author of Keras.
 - He currently works for Google as a deep learning engineer and researcher.
- Keras means *horn* in Greek
- Documentation: <http://keras.io/>
- Example:
<https://github.com/fchollet/keras/tree/master/examples>

使用 Keras 心得

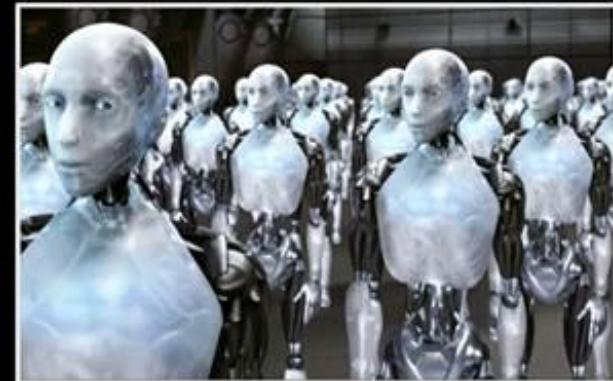
Deep Learning研究生



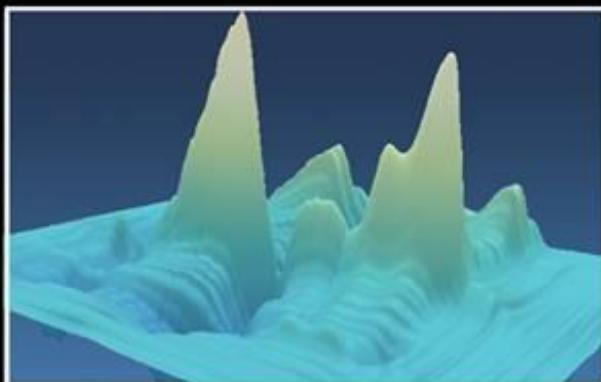
朋友覺得我在



我媽覺得我在



大眾覺得我在



指導教授覺得我在



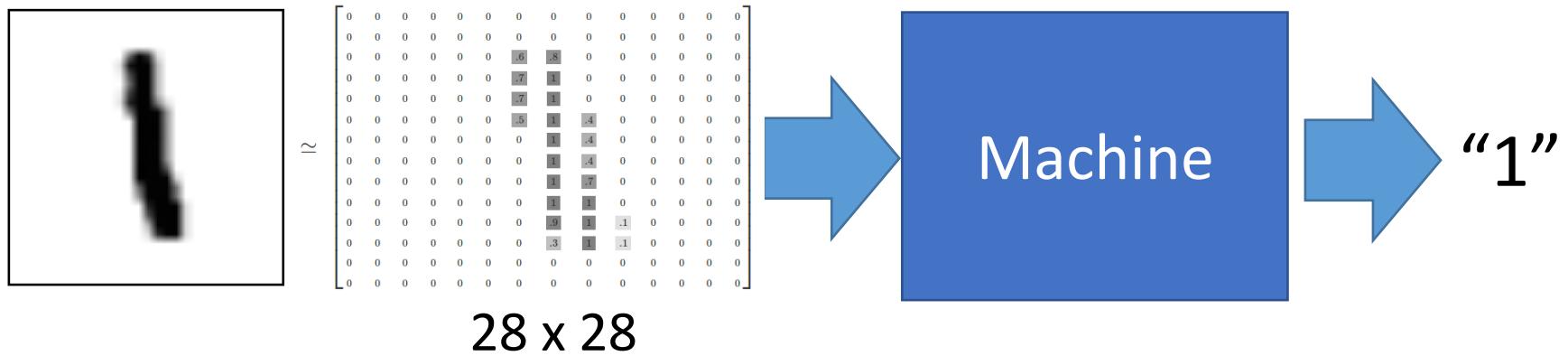
我以為我在



事實上我在

Example Application

- Handwriting Digit Recognition



MNIST Data: <http://yann.lecun.com/exdb/mnist/>
“Hello world” for deep learning

Keras provides data sets loading function: <http://keras.io/datasets/>

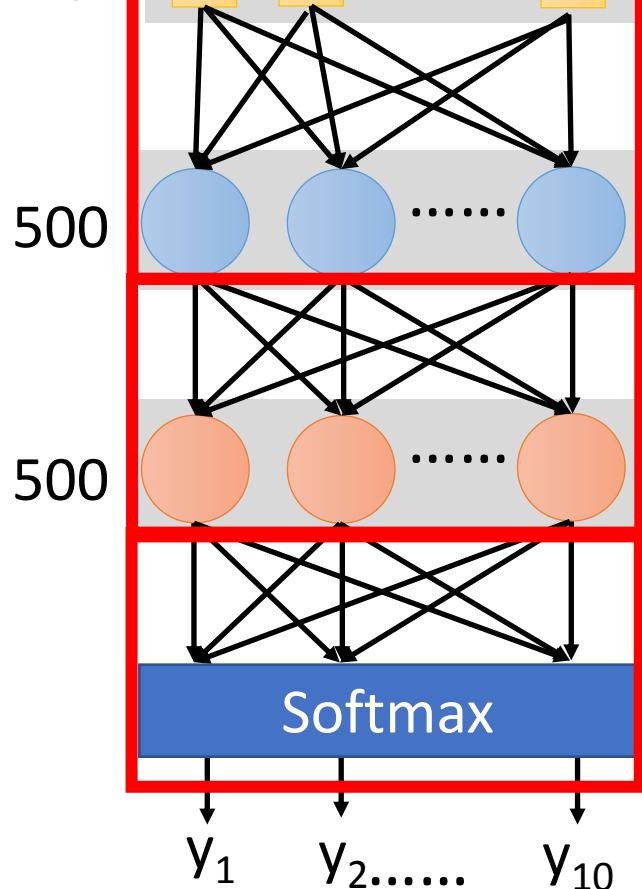
Keras

Step 1:
define a set
of function

Step 2:
goodness of
function

Step 3: pick
the best
function

28x28



```
model = Sequential()
```

```
model.add( Dense( input_dim=28*28,  
                  output_dim=500 ) )  
model.add( Activation('sigmoid') )
```

```
model.add( Dense( output_dim=500 ) )  
model.add( Activation('sigmoid') )
```

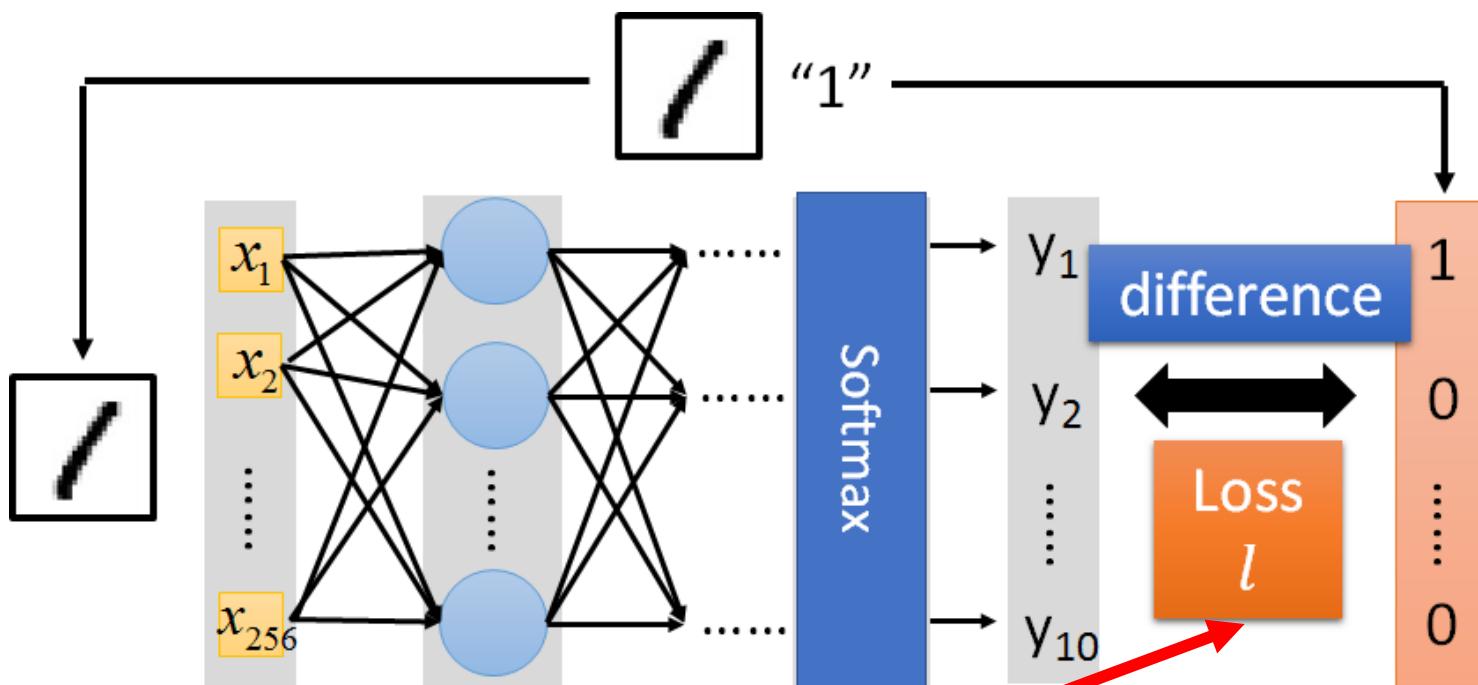
```
model.add( Dense( output_dim=10 ) )  
model.add( Activation('softmax') )
```

Keras

Step 1:
define a set
of function

Step 2:
goodness of
function

Step 3: pick
the best
function



```
model.compile(loss='mse',  
              optimizer=SGD(lr=0.1),  
              metrics=['accuracy'])
```

Keras

Step 1:
define a set
of function

Step 2:
goodness of
function

Step 3: pick
the best
function

Step 3.1: Configuration

```
model.compile(loss='mse',  
               optimizer=SGD(lr=0.1),  
               metrics=['accuracy'])
```

$$w \leftarrow w - \eta \partial L / \partial w$$

0.1

Step 3.2: Find the optimal network parameters

```
model.fit(x_train, y_train, batch_size=100, nb_epoch=20)
```

Training data
(Images)

Labels
(digits)

Next lecture

Keras

Step 1:
define a set
of function

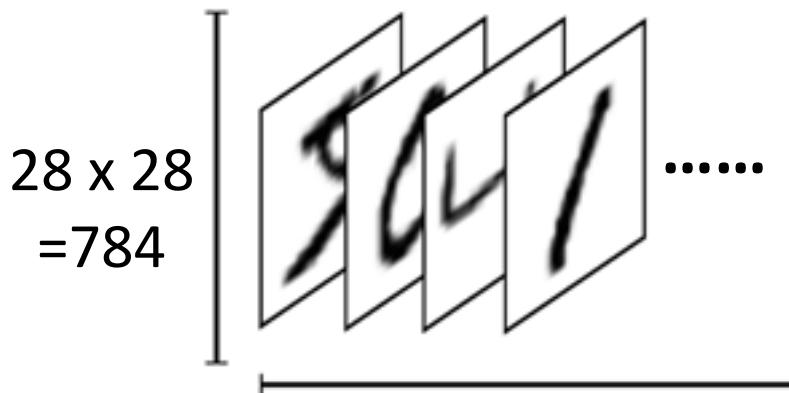
Step 2:
goodness of
function

Step 3: pick
the best
function

Step 3.2: Find the optimal network parameters

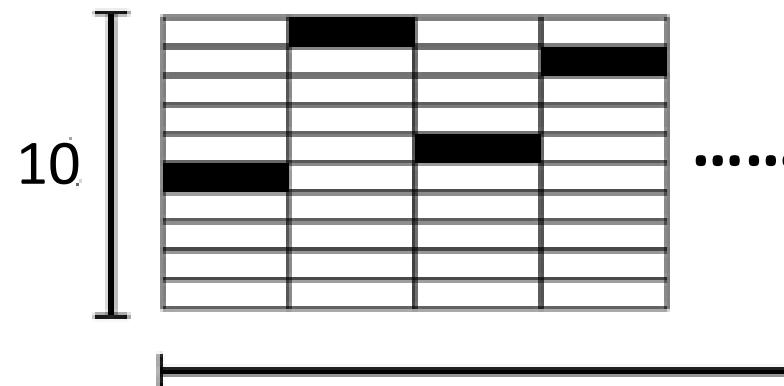
```
model.fit(x_train, y_train, batch_size=100, nb_epoch=20)
```

numpy array



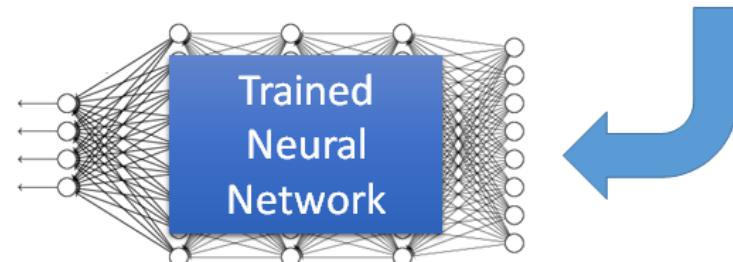
Number of training examples

numpy array



Number of training examples

Keras



Save and load models

<http://keras.io/getting-started/faq/#how-can-i-save-a-keras-model>

How to use the neural network (testing):

```
score = model.evaluate(x_test, y_test)
case 1: print('Total loss on Testing Set:', score[0])
          print('Accuracy of Testing Set:', score[1])
```

```
case 2: result = model.predict(x_test)
```

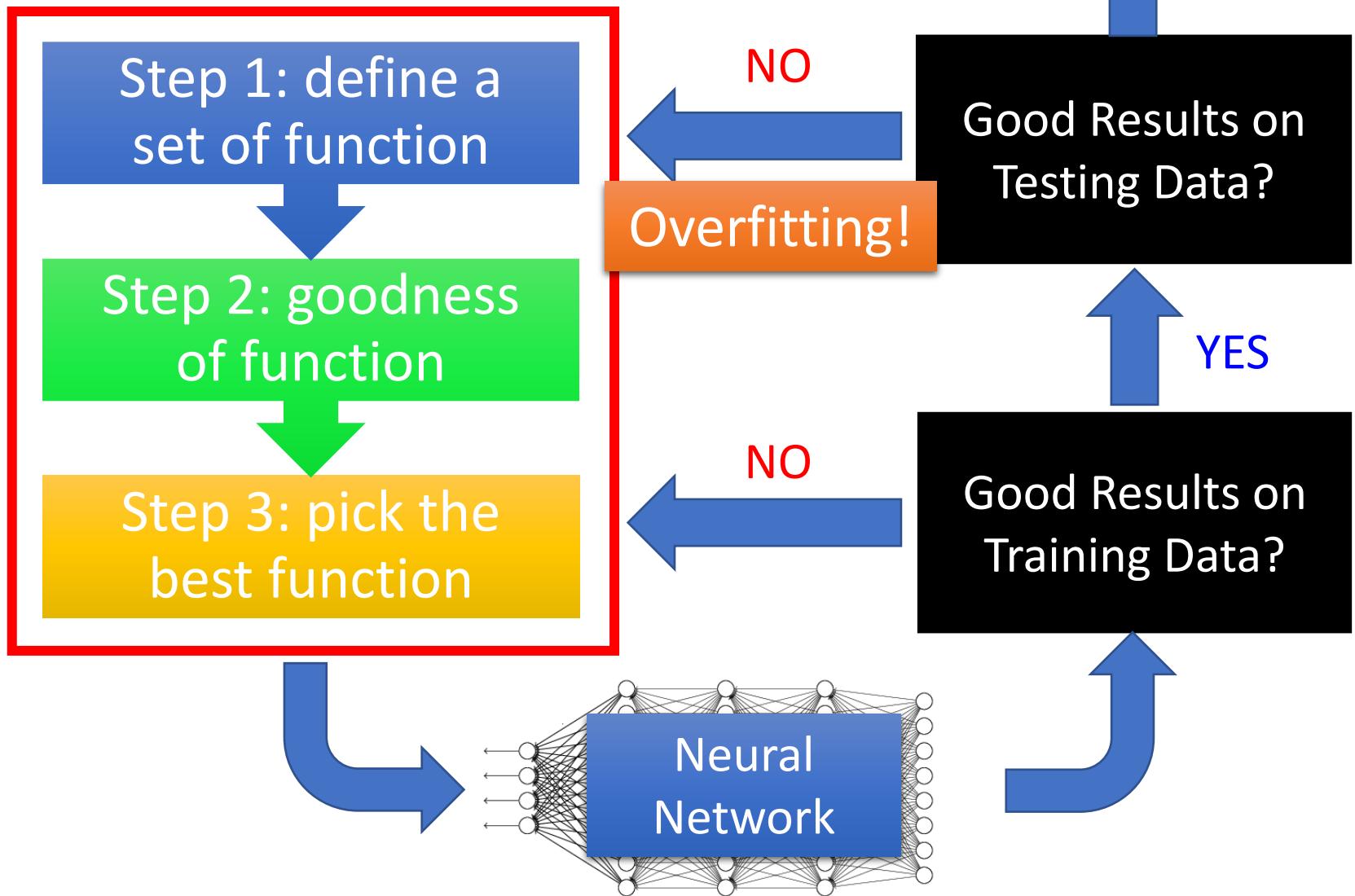
Keras

- Using GPU to speed training
 - Way 1
 - THEANO_FLAGS=device=gpu0 python YourCode.py
 - Way 2 (in your code)
 - import os
 - os.environ["THEANO_FLAGS"] = "device=gpu0"

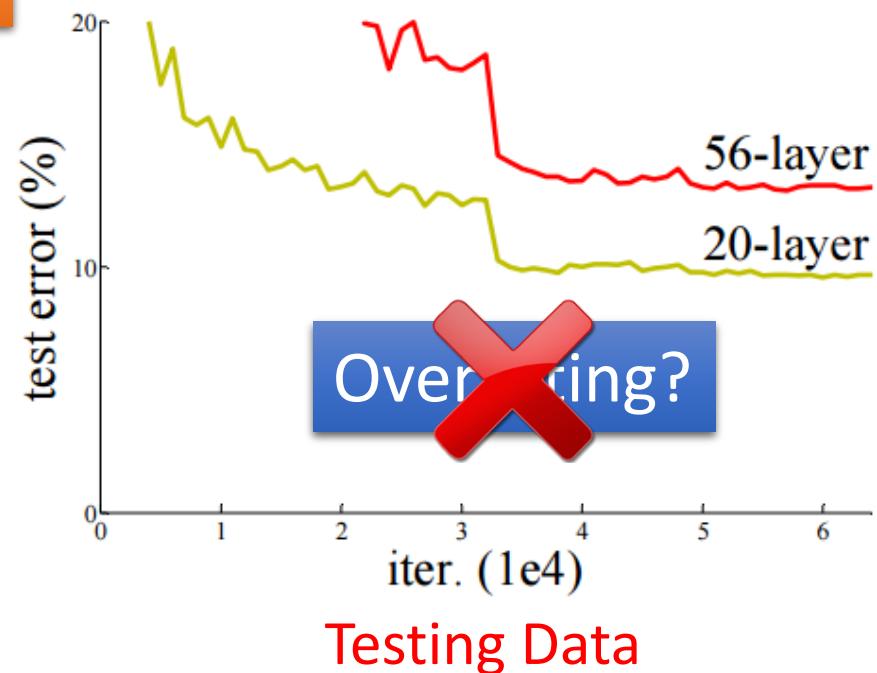
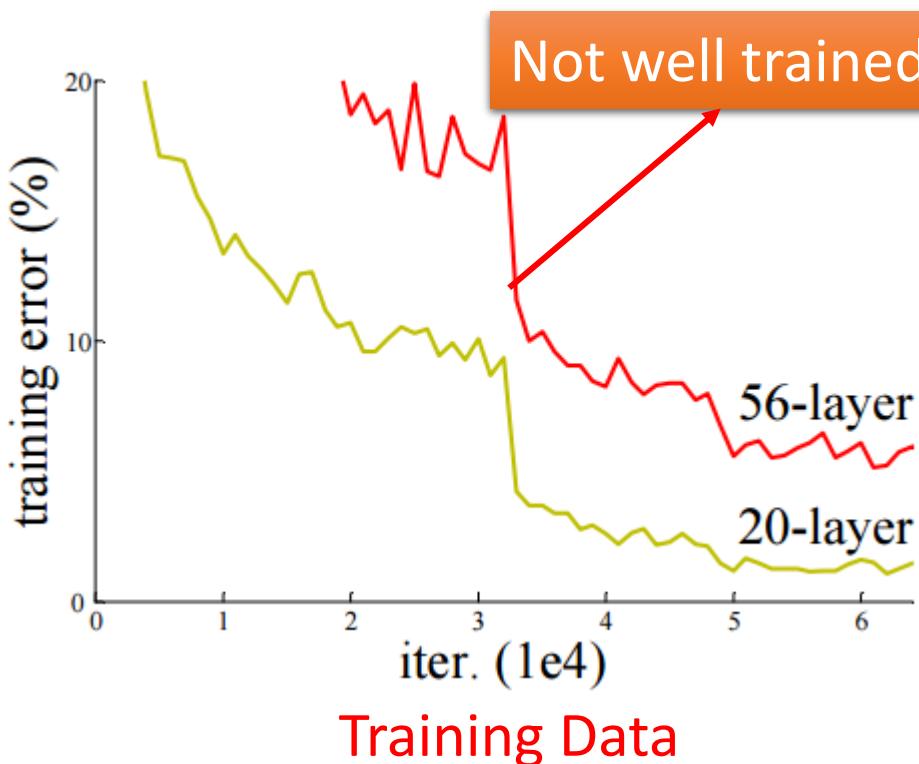
Live Demo

Lecture II: Tips for Training DNN

Recipe of Deep Learning



Do not always blame Overfitting

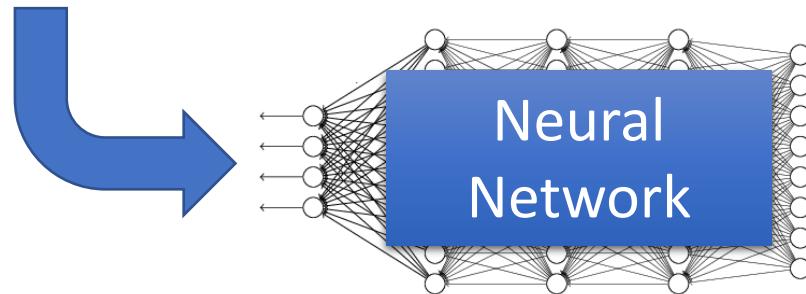


Deep Residual Learning for Image Recognition
<http://arxiv.org/abs/1512.03385>

Recipe of Deep Learning

Different approaches for different problems.

e.g. dropout for good results on testing data

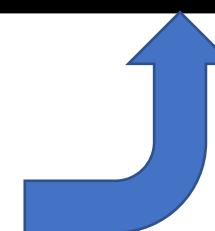


Good Results on Testing Data?

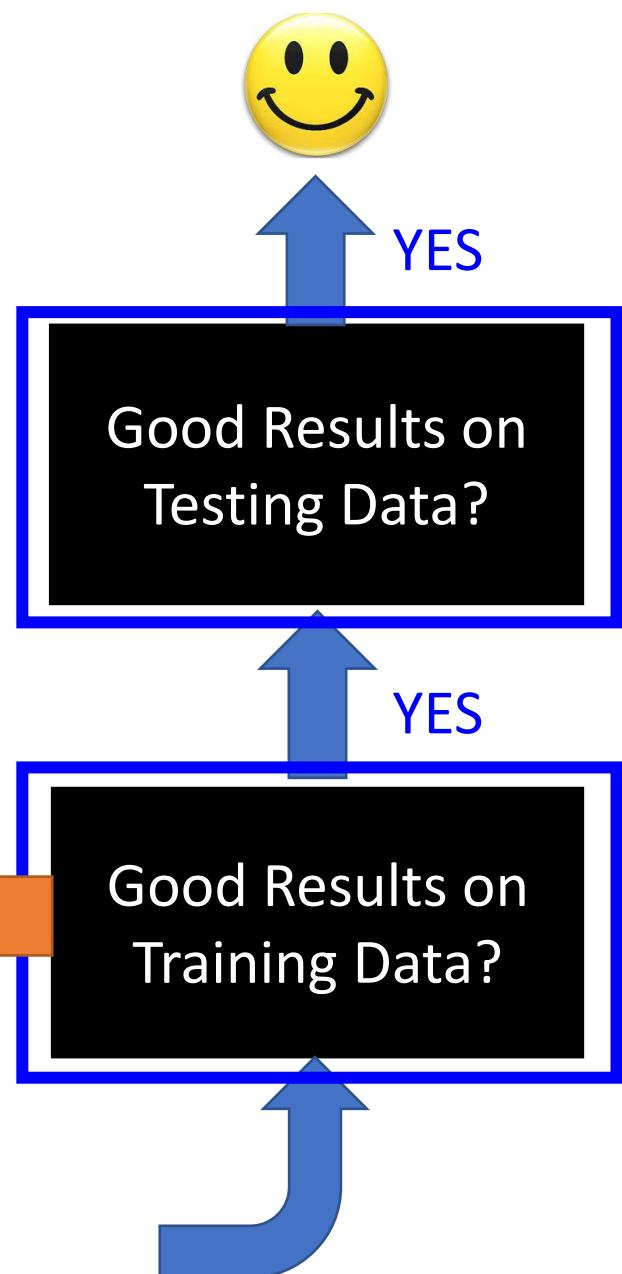
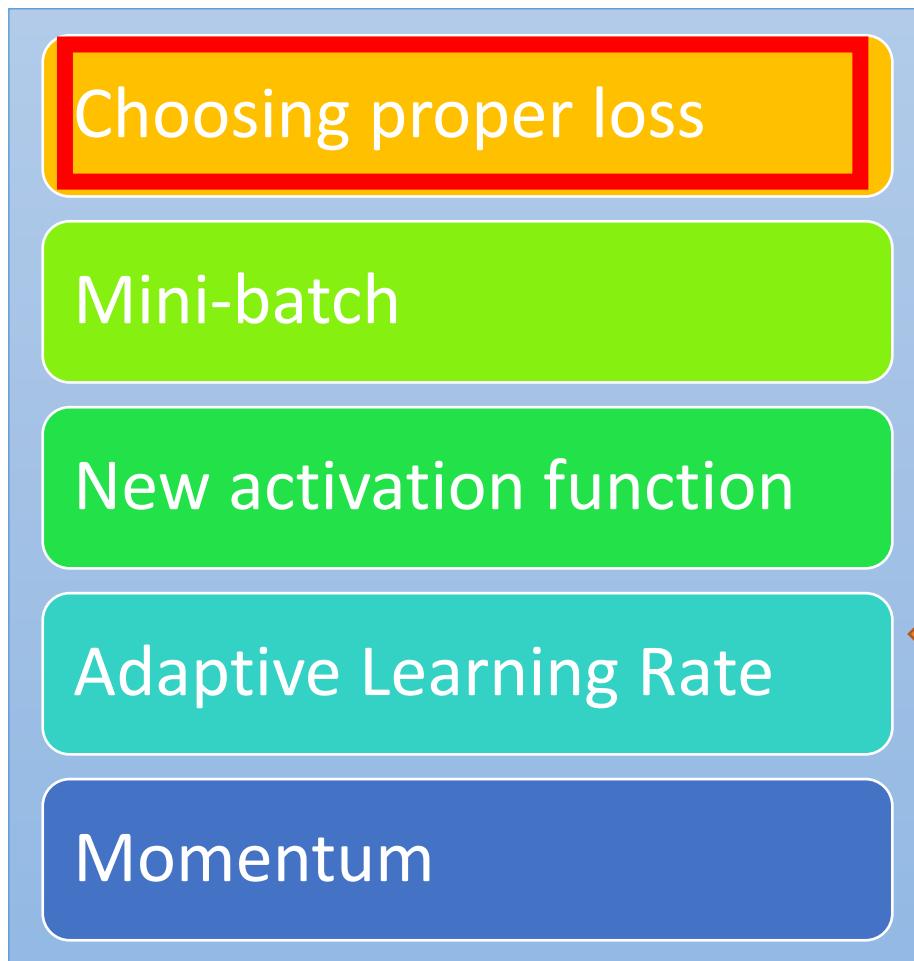
Good Results on Training Data?



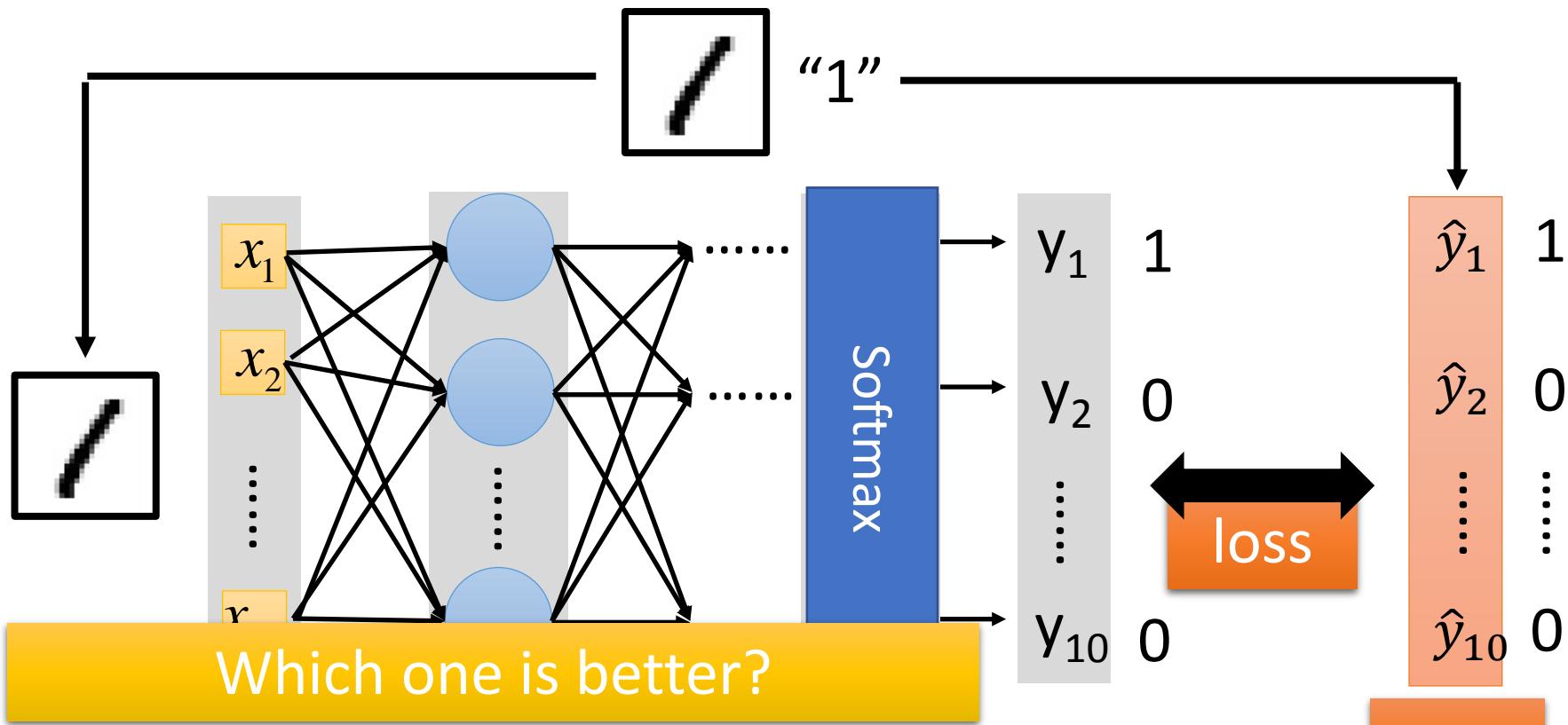
YES



Recipe of Deep Learning



Choosing Proper Loss



Square
Error

$$\sum_{i=1}^{10} (y_i - \hat{y}_i)^2 = 0$$

Cross
Entropy

$$-\sum_{i=1}^{10} \hat{y}_i \ln y_i = 0$$

target

Let's try it

Square Error

```
model.compile(loss='mse',  
              optimizer=SGD(lr=0.1),  
              metrics=['accuracy'])
```

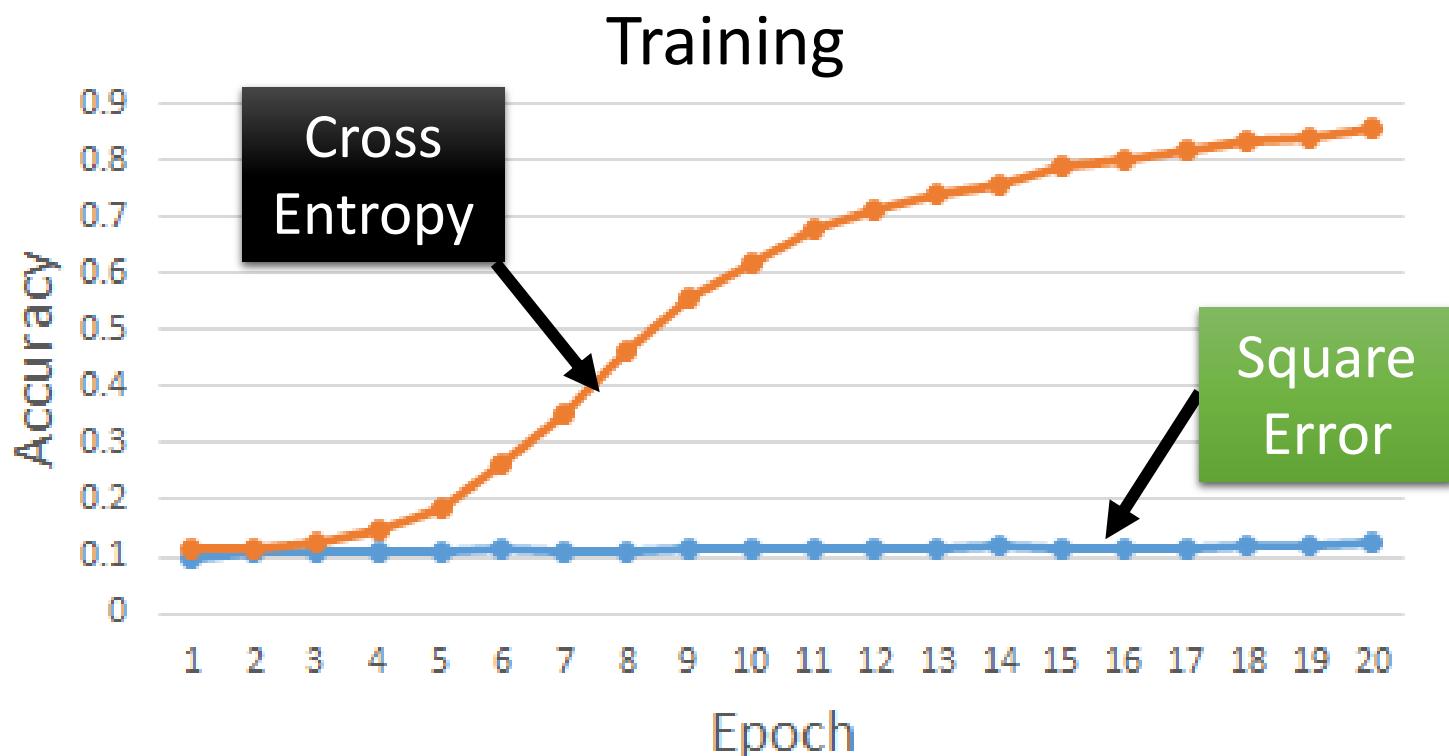
Cross Entropy

```
model.compile(loss='categorical_crossentropy',  
              optimizer=SGD(lr=0.1),  
              metrics=['accuracy'])
```

Let's try it

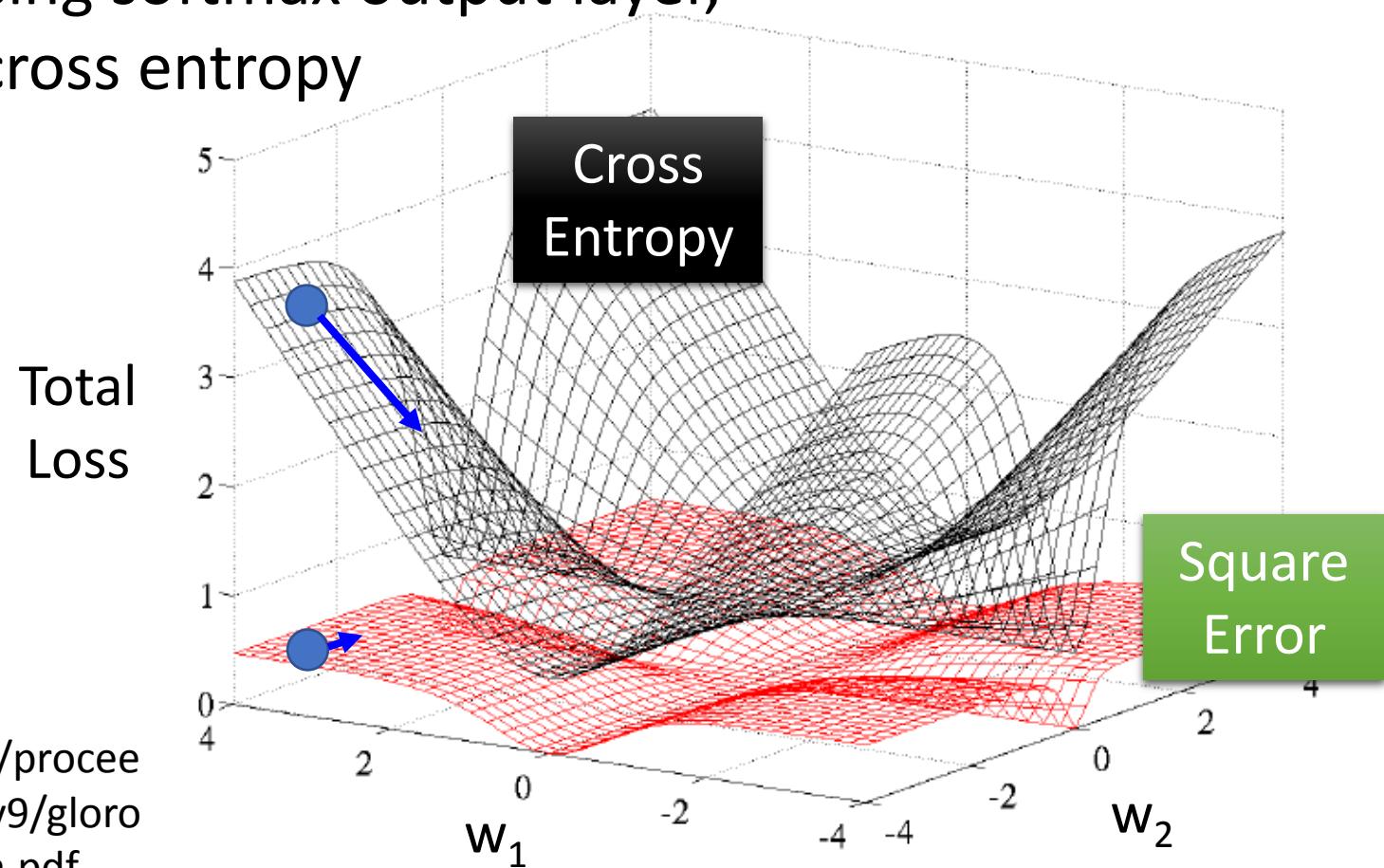
Testing:

	Accuracy
Square Error	0.11
Cross Entropy	0.84

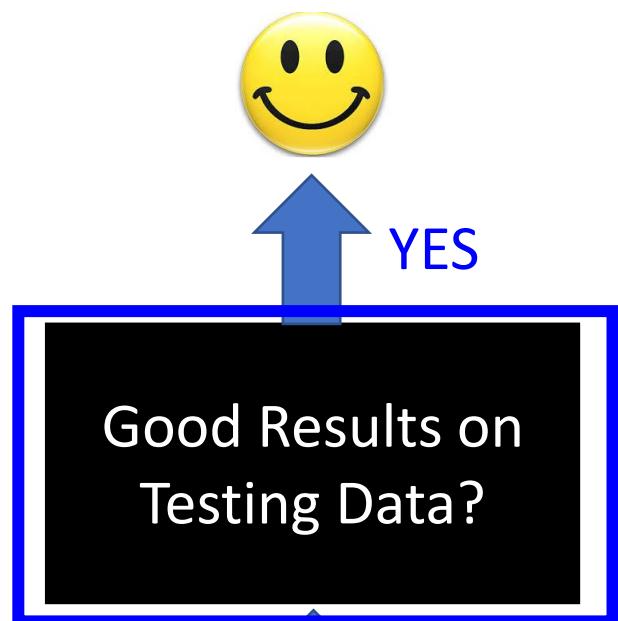
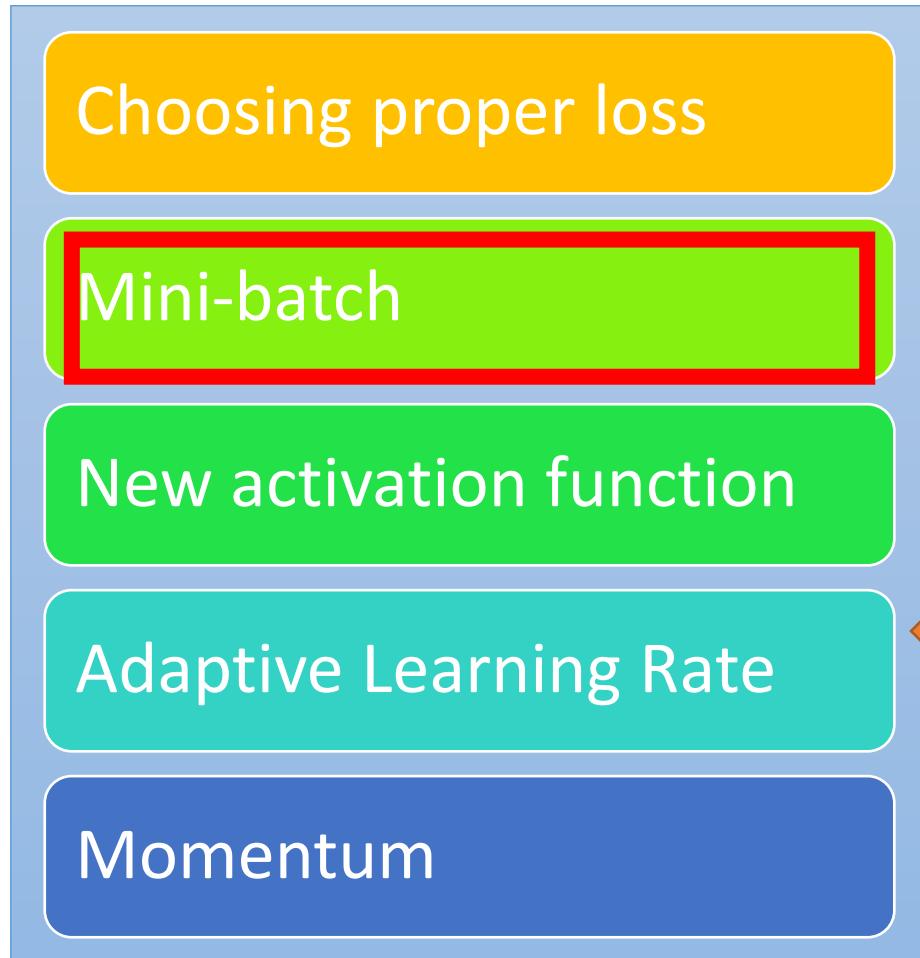


Choosing Proper Loss

When using softmax output layer,
choose cross entropy



Recipe of Deep Learning

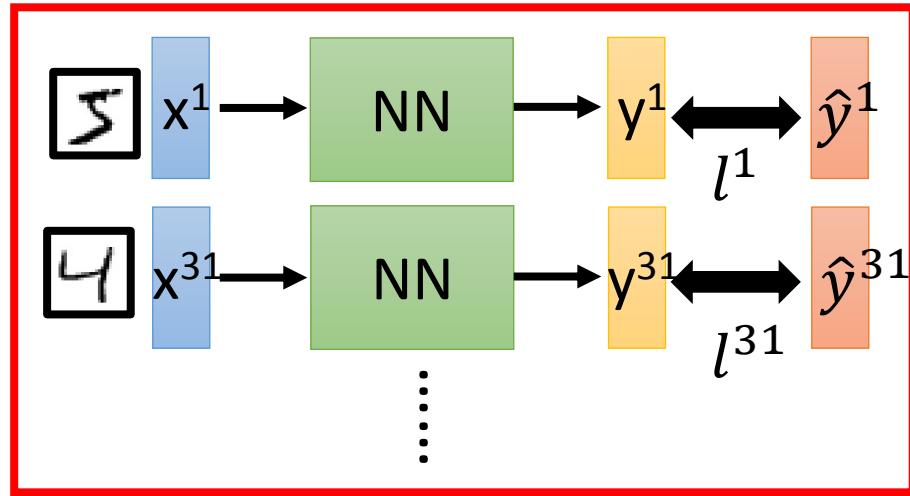


```
model.fit(x_train, y_train, batch_size=100, nb_epoch=20)
```

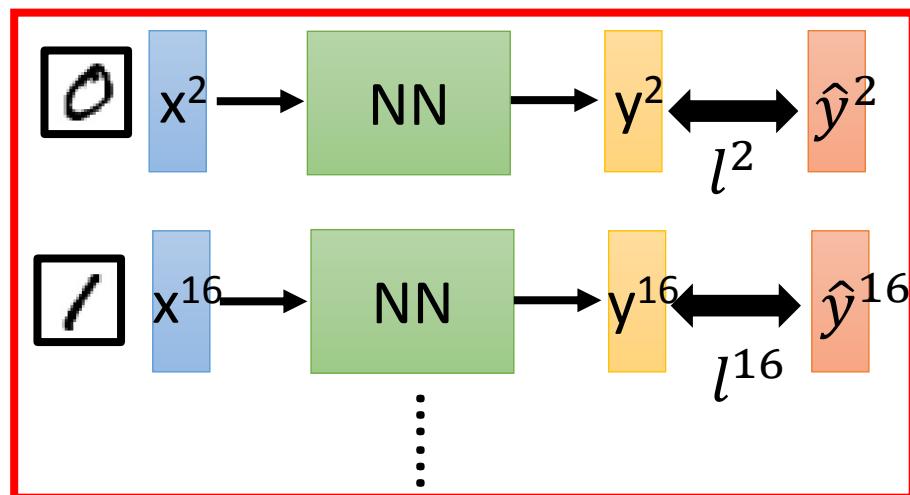
We do not really minimize total loss!

Mini-batch

Mini-batch



Mini-batch



- Randomly initialize network parameters

- Pick the 1st batch
 $L' = l^1 + l^{31} + \dots$
Update parameters once
- Pick the 2nd batch
 $L'' = l^2 + l^{16} + \dots$
Update parameters once
- ⋮
- Until all mini-batches have been picked

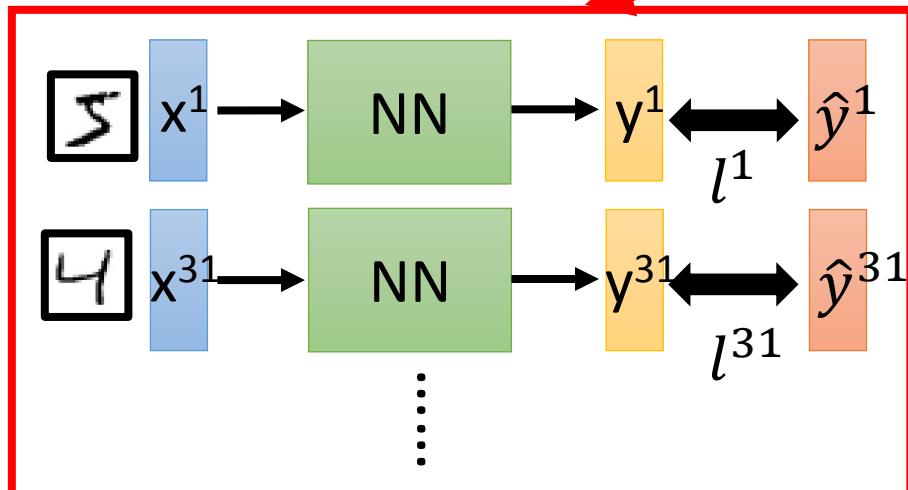
one epoch

Repeat the above process

Mini-batch

```
model.fit(x_train, y_train, batch_size=100, nb_epoch=20)
```

Mini-batch



100 examples in a mini-batch

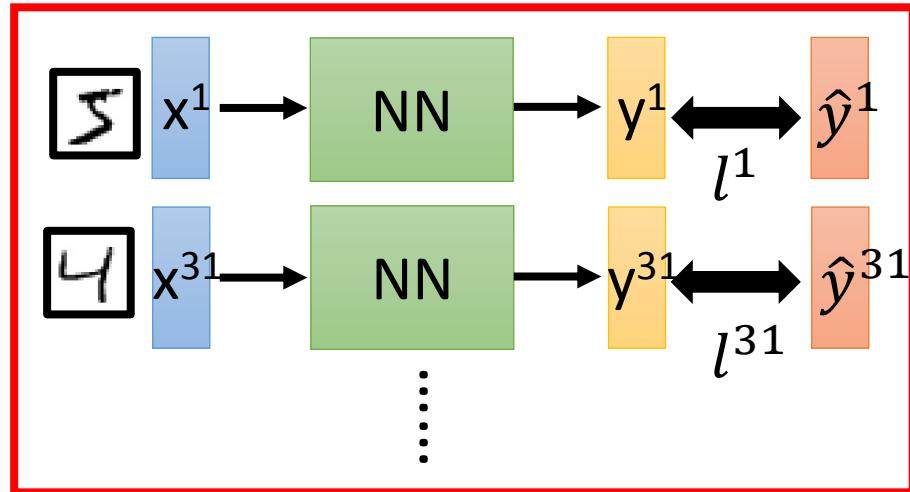
Repeat 20 times

- Pick the 1st batch
 $L' = l^1 + l^{31} + \dots$
Update parameters once
 - Pick the 2nd batch
 $L'' = l^2 + l^{16} + \dots$
Update parameters once
⋮
 - Until all mini-batches have been picked
- one epoch

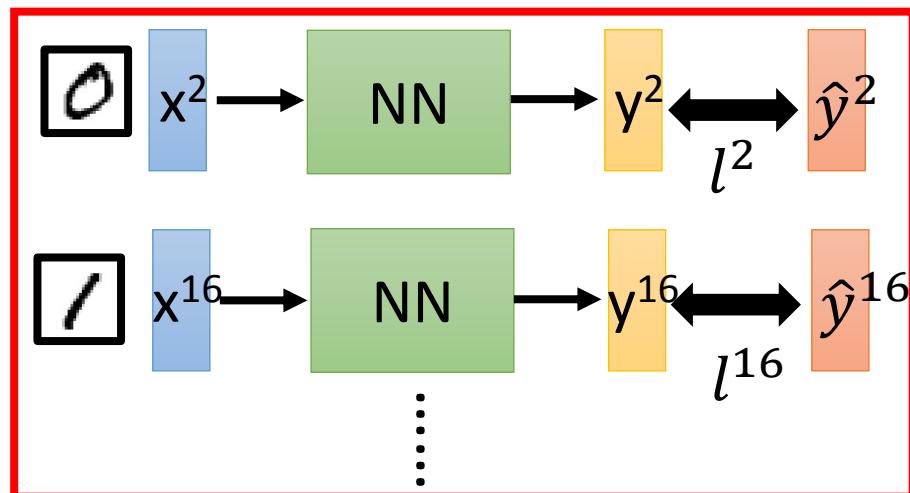
We do not really minimize total loss!

Mini-batch

Mini-batch



Mini-batch

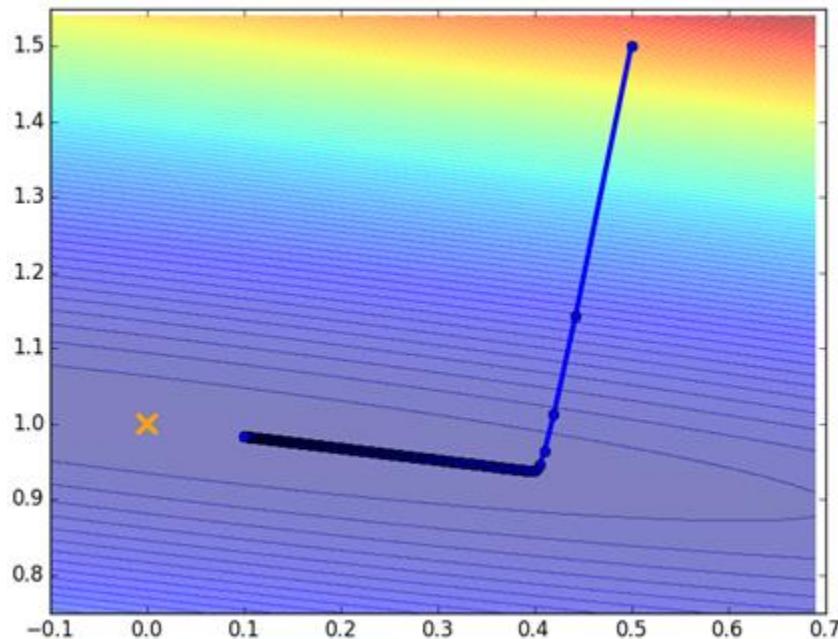


- Randomly initialize network parameters
- Pick the 1st batch
 $L' = l^1 + l^{31} + \dots$
Update parameters once
- Pick the 2nd batch
 $L'' = l^2 + l^{16} + \dots$
Update parameters once
⋮

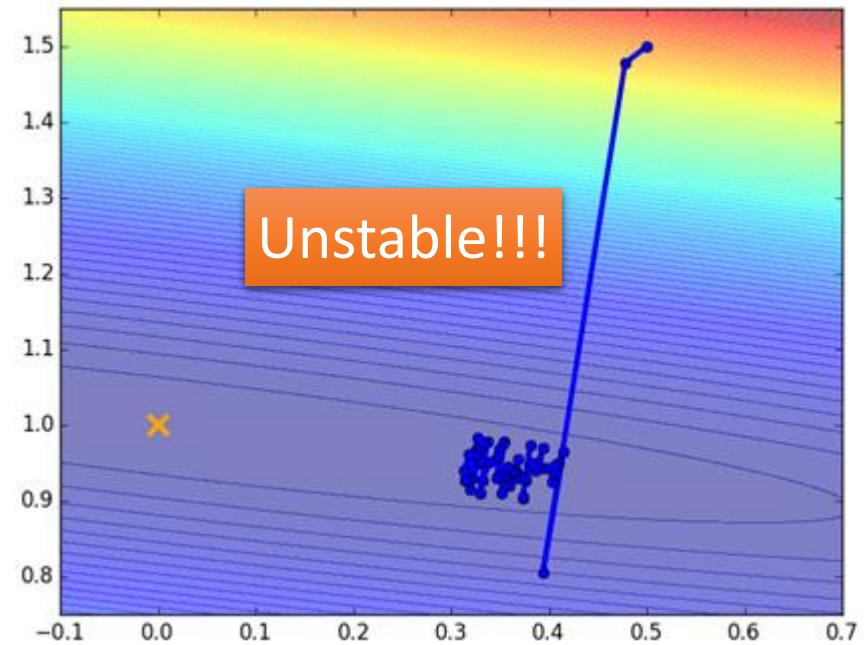
L is different each time when we update parameters!

Mini-batch

Original Gradient Descent



With Mini-batch



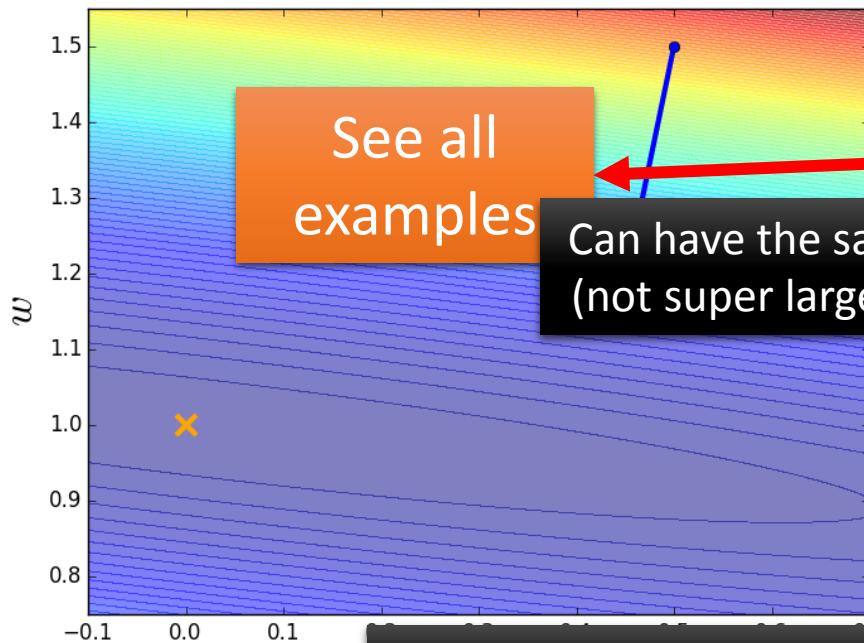
The colors represent the total loss.

Mini-batch is Faster

Not always true with parallel computing.

Original Gradient Descent

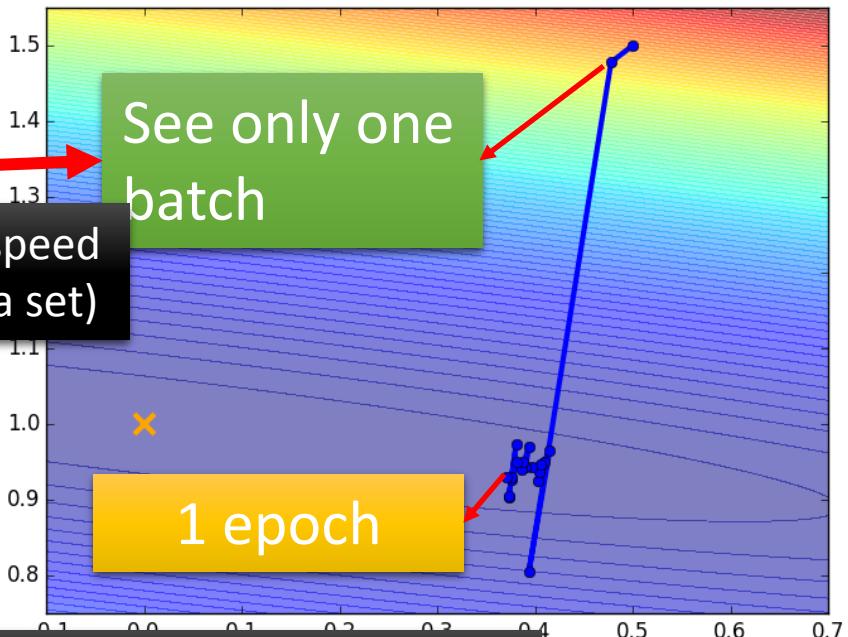
Update after seeing all examples



Mini-batch has better performance!

With Mini-batch

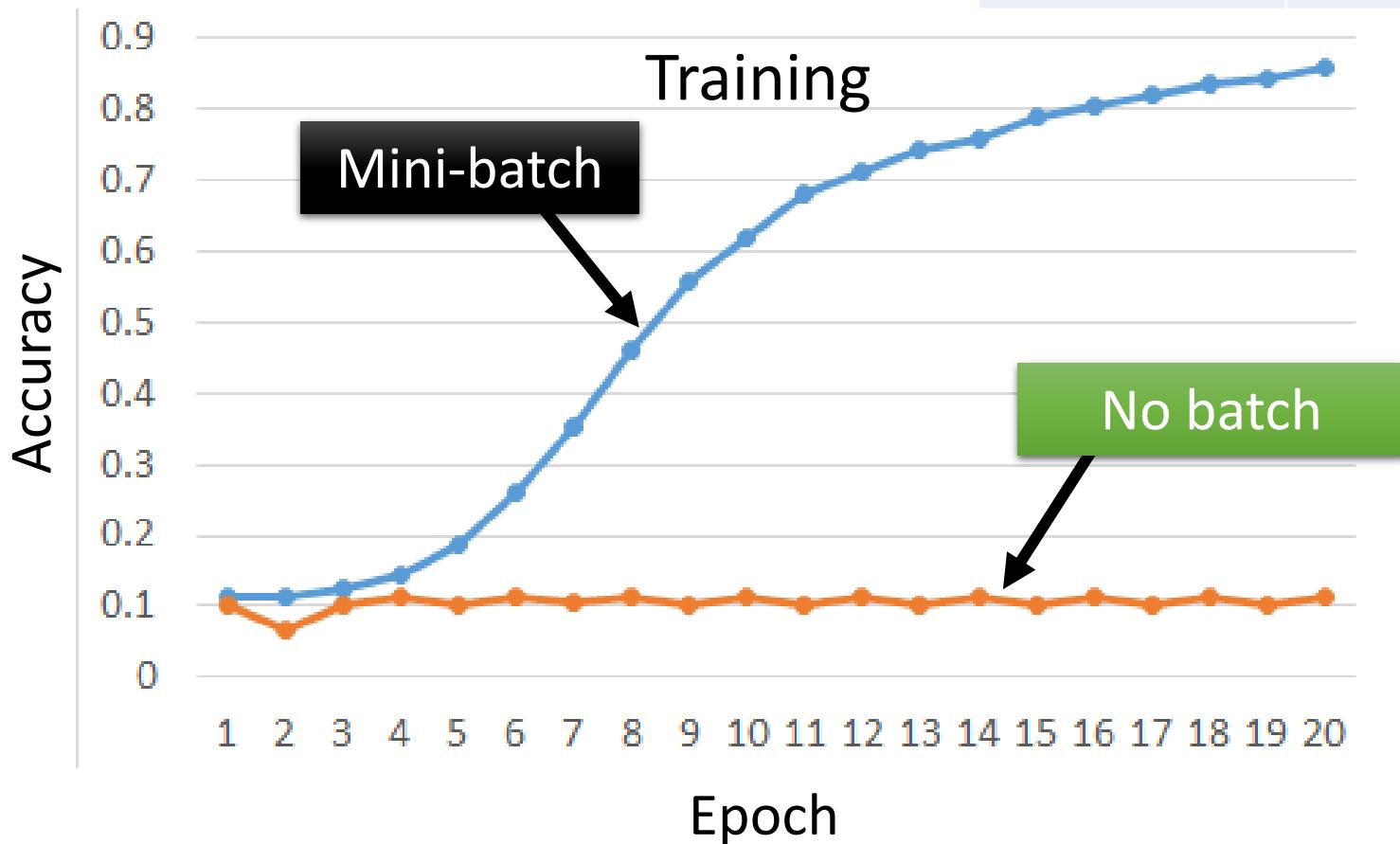
If there are 20 batches, update 20 times in one epoch.



Testing:

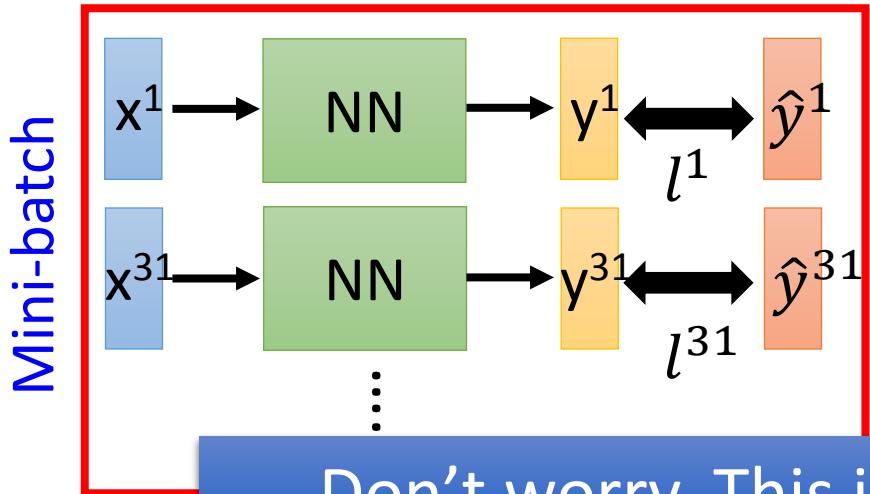
Mini-batch is Better!

	Accuracy
Mini-batch	0.84
No batch	0.12

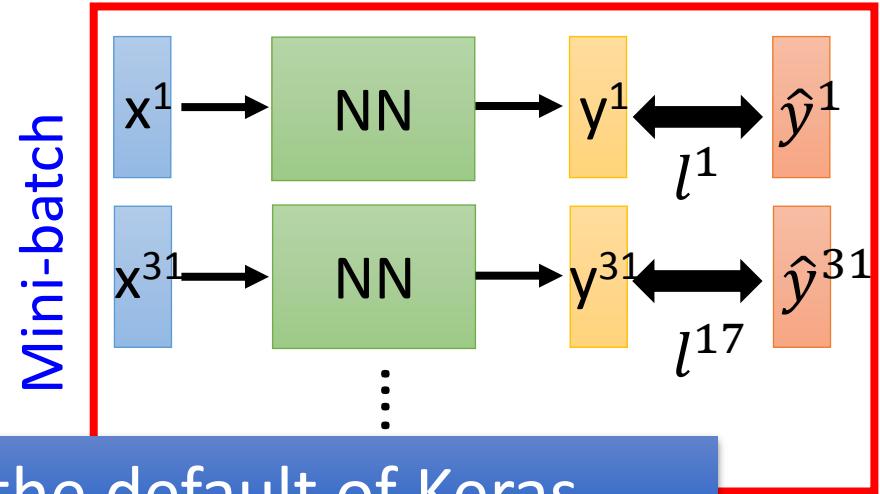


Shuffle the training examples for each epoch

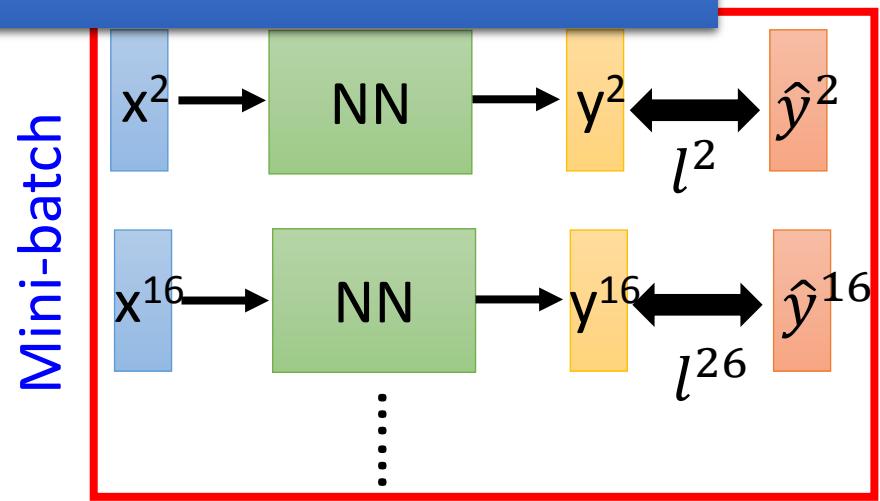
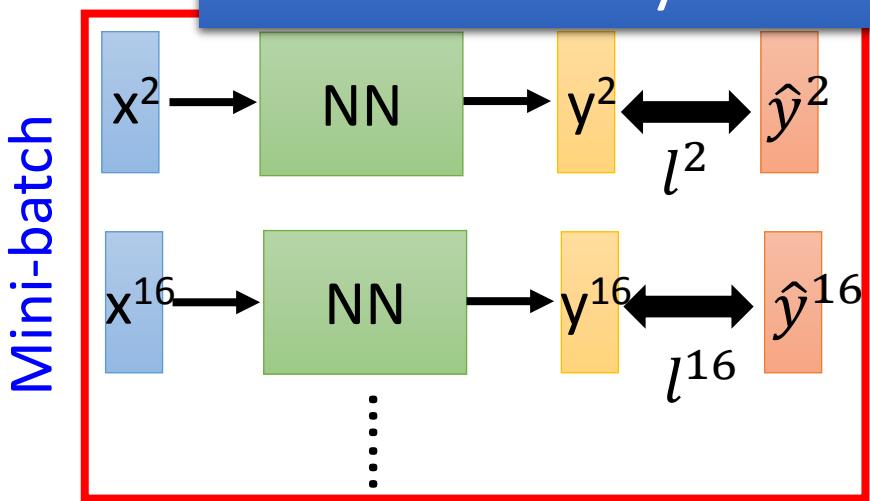
Epoch 1



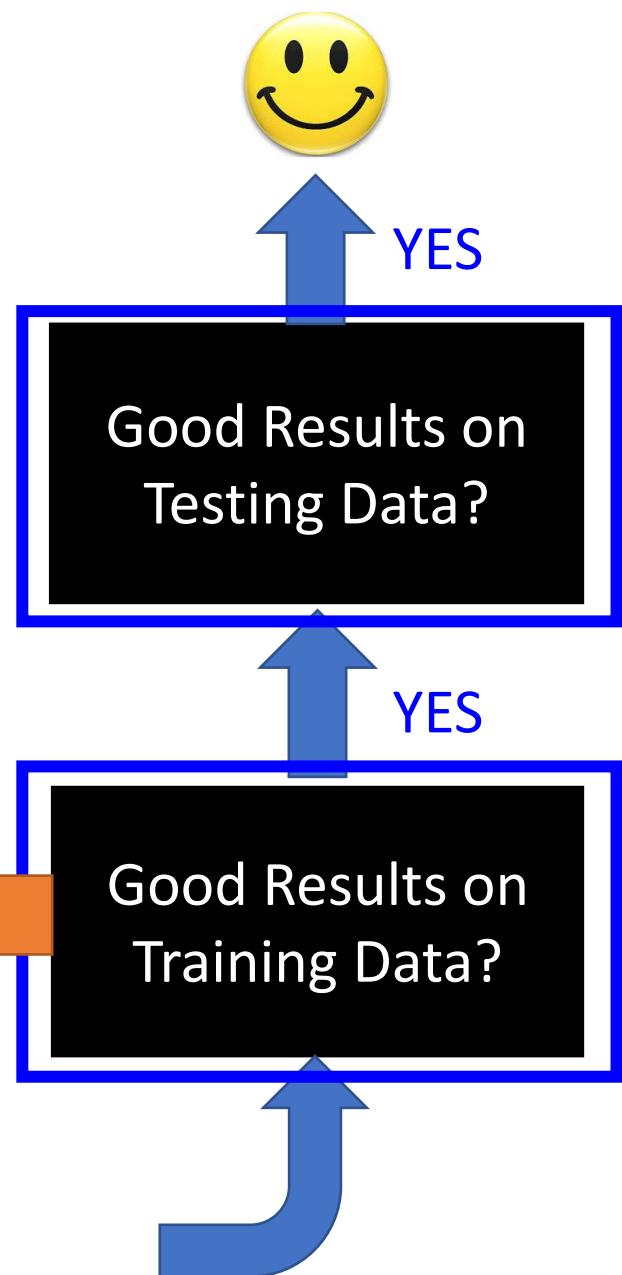
Epoch 2



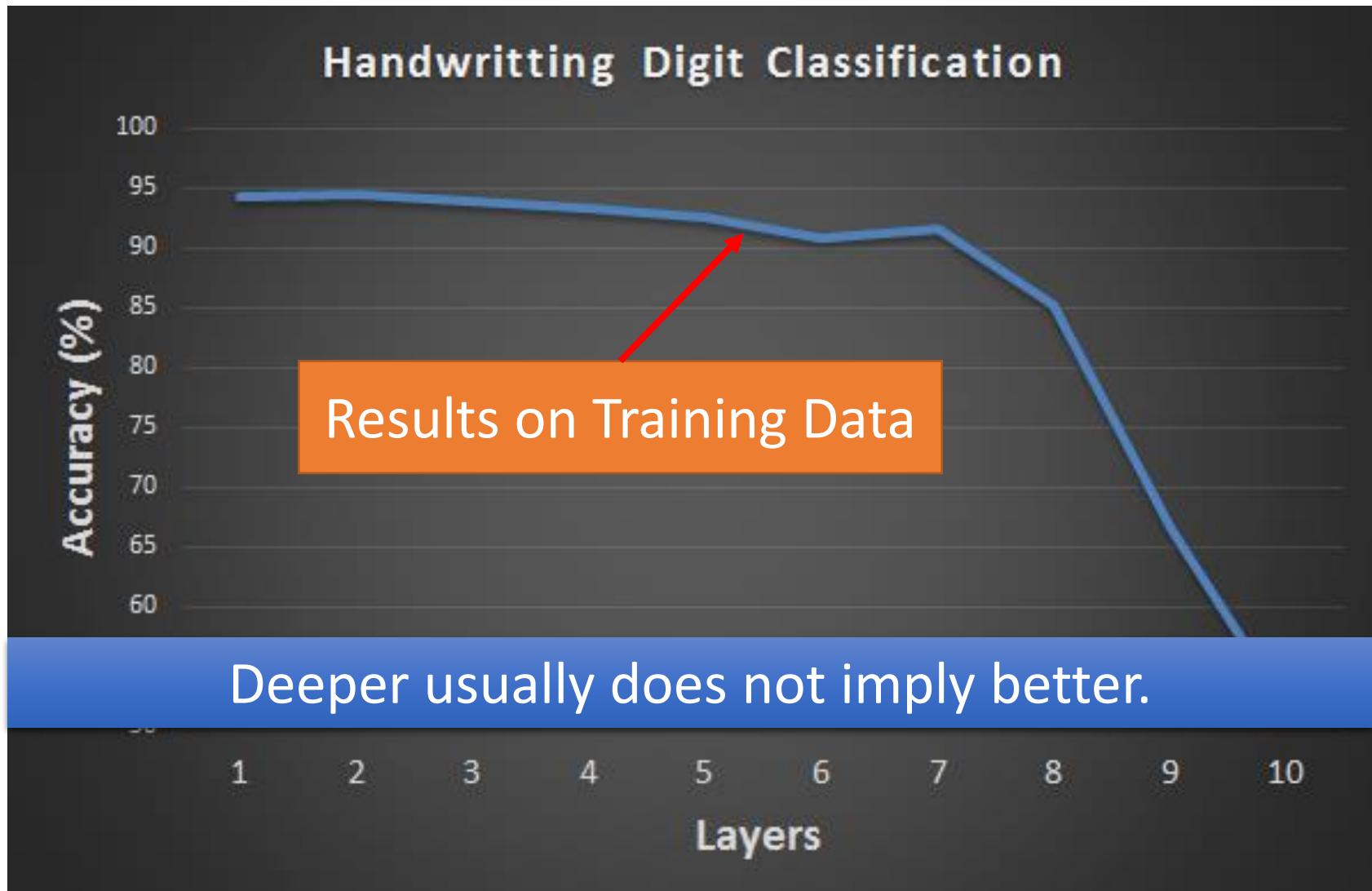
Don't worry. This is the default of Keras.



Recipe of Deep Learning



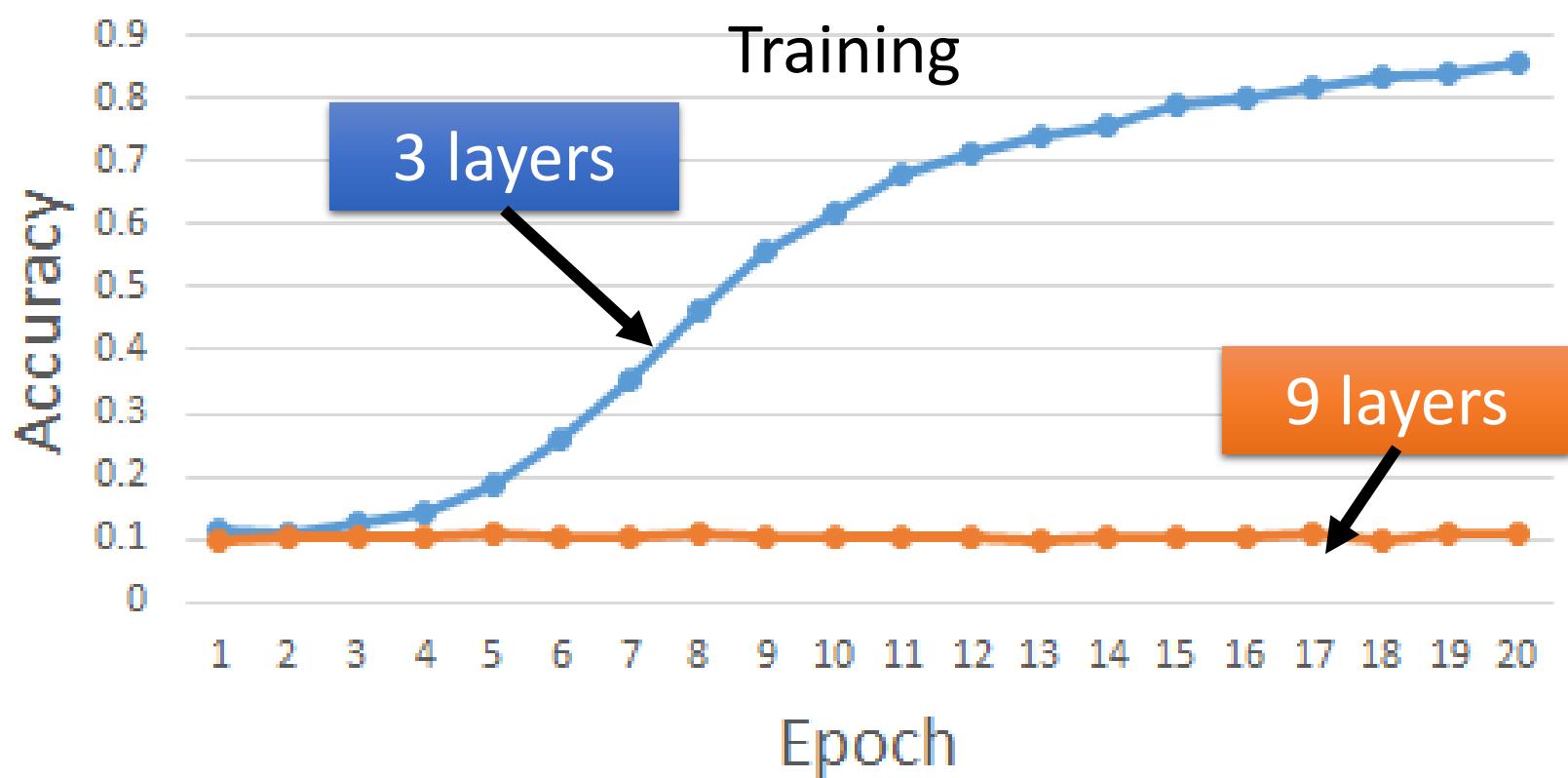
Hard to get the power of Deep ...



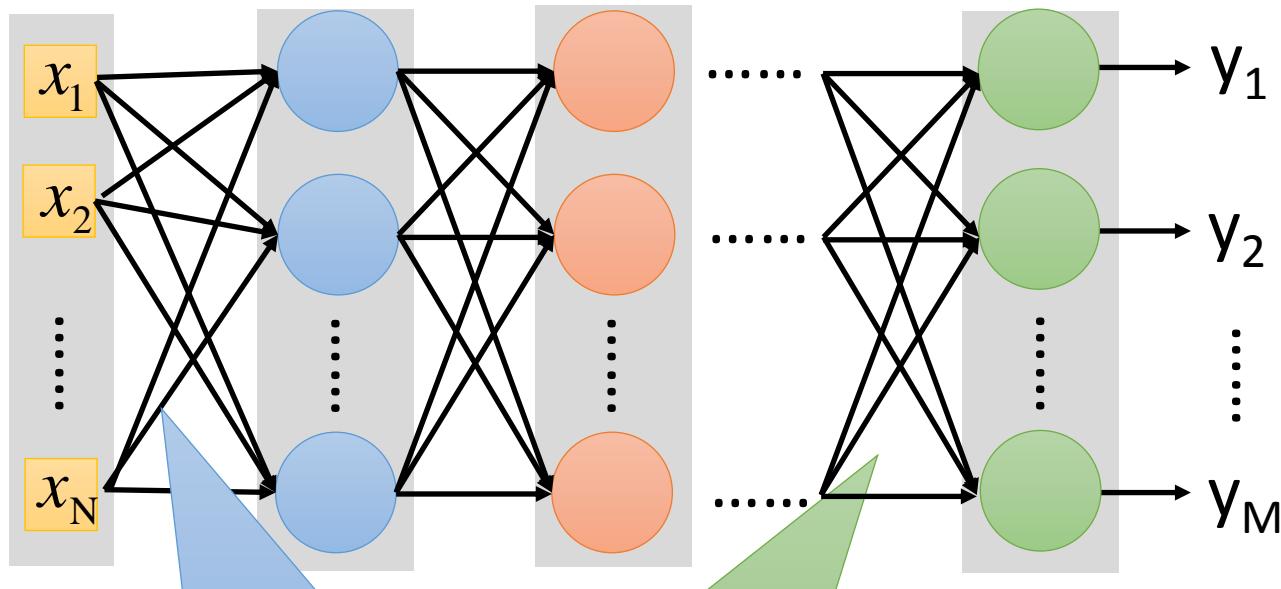
Let's try it

Testing:

	Accuracy
3 layers	0.84
9 layers	0.11



Vanishing Gradient Problem



Smaller gradients

Learn very slow

Almost random

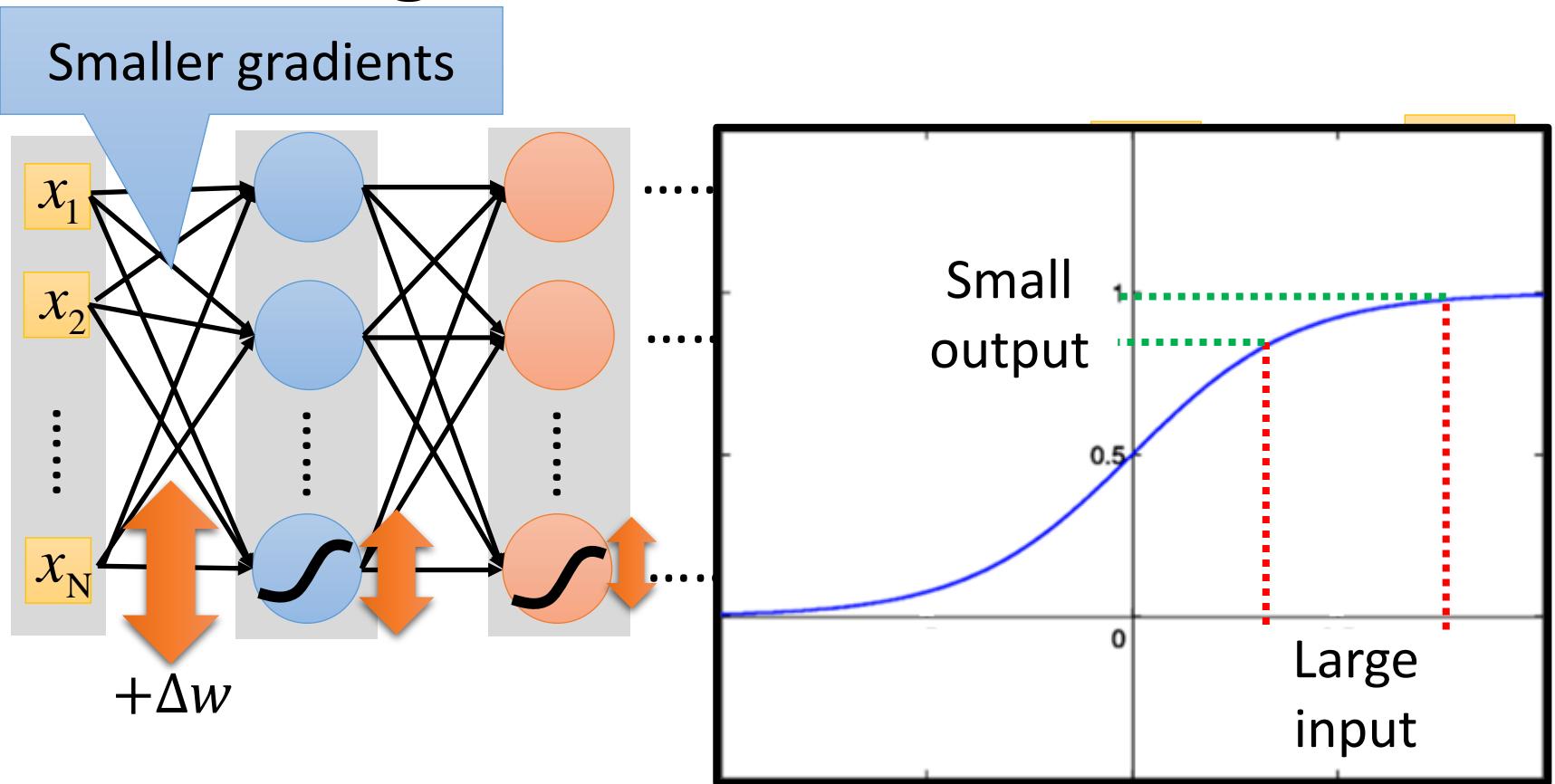
Larger gradients

Learn very fast

Already converge

based on random!?

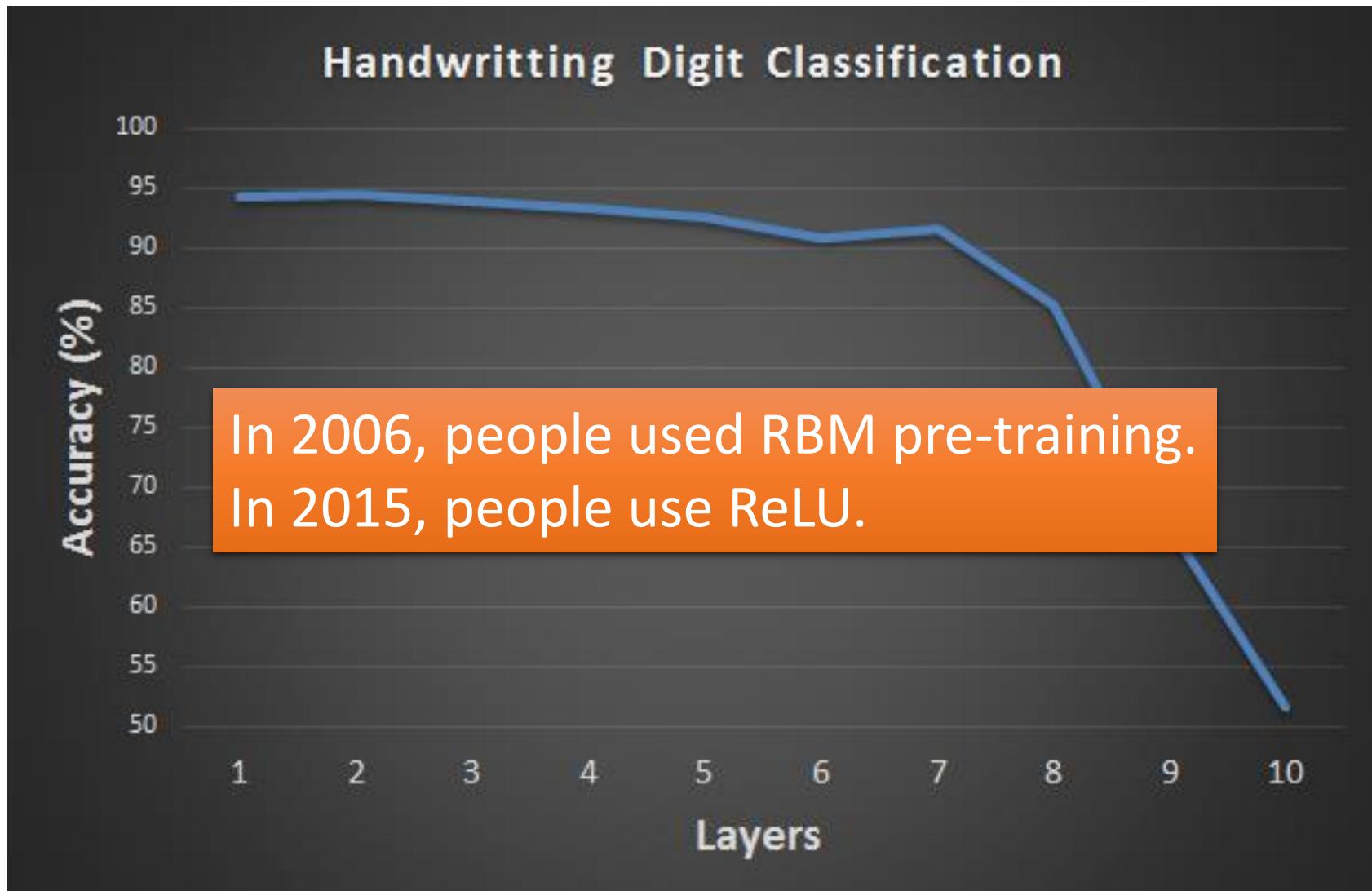
Vanishing Gradient Problem



Intuitive way to compute the derivatives ...

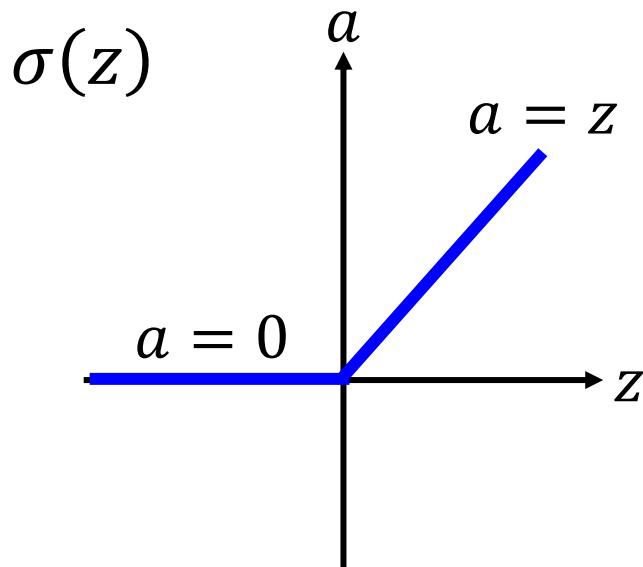
$$\frac{\partial l}{\partial w} = ? \quad \frac{\Delta l}{\Delta w}$$

Hard to get the power of Deep ...



ReLU

- Rectified Linear Unit (ReLU)

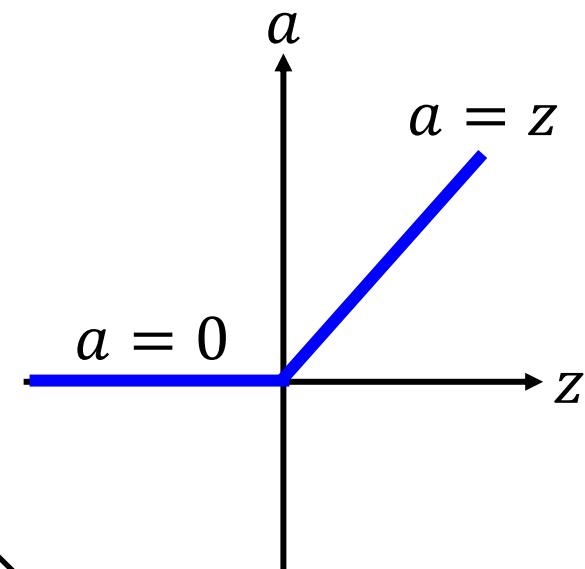
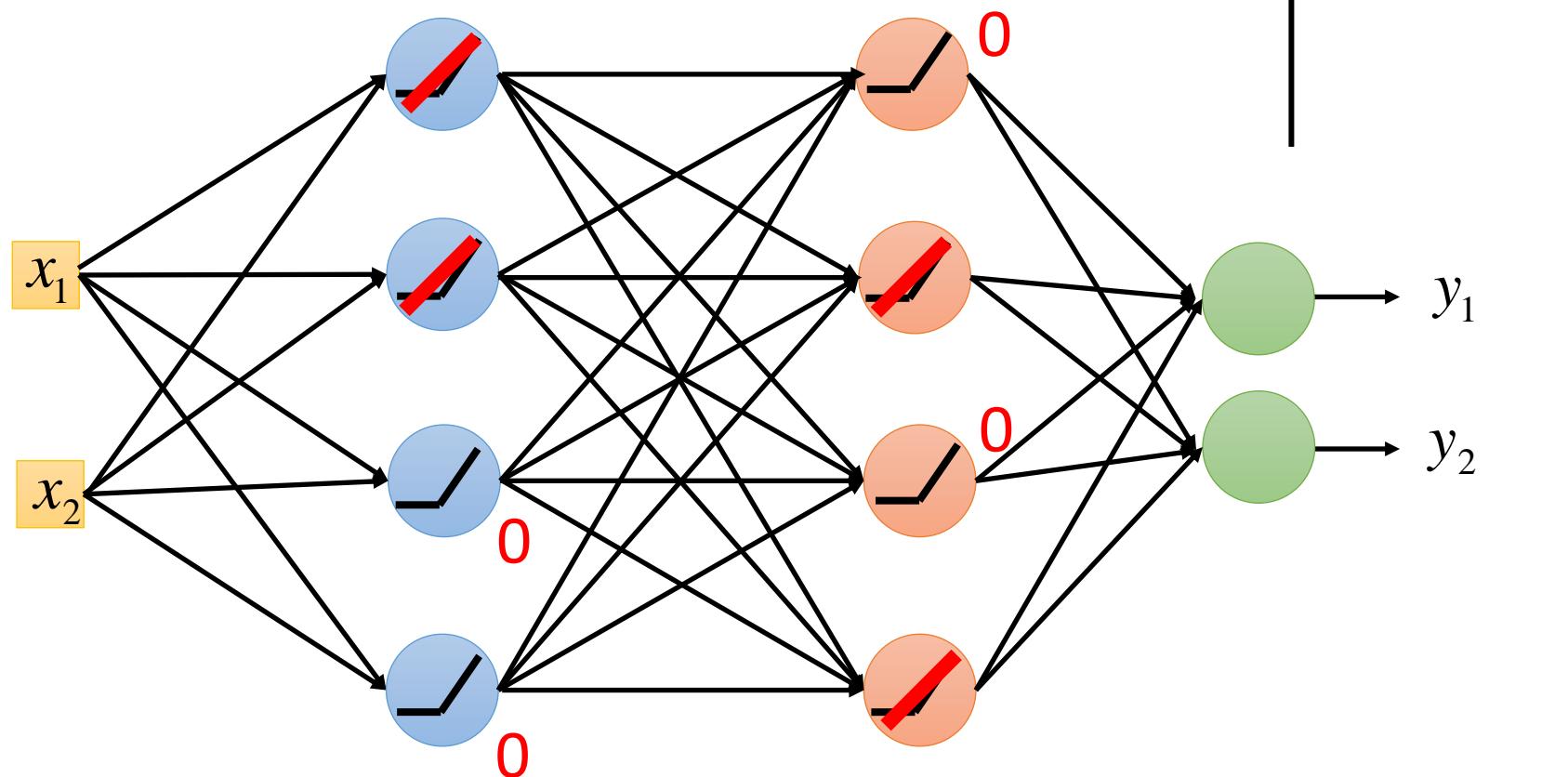


[Xavier Glorot, AISTATS'11]
[Andrew L. Maas, ICML'13]
[Kaiming He, arXiv'15]

Reason:

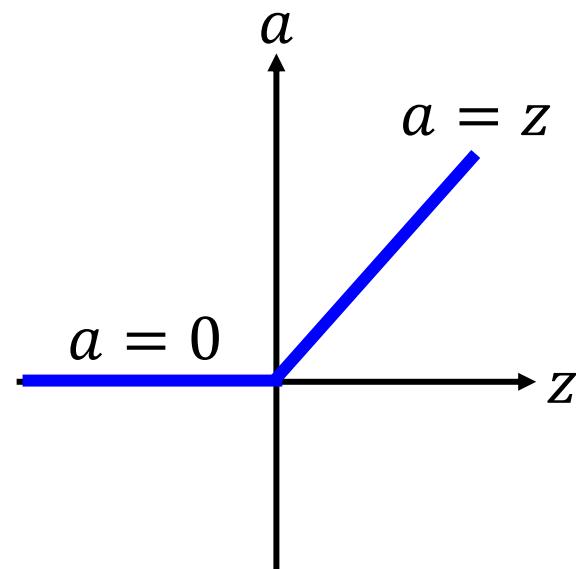
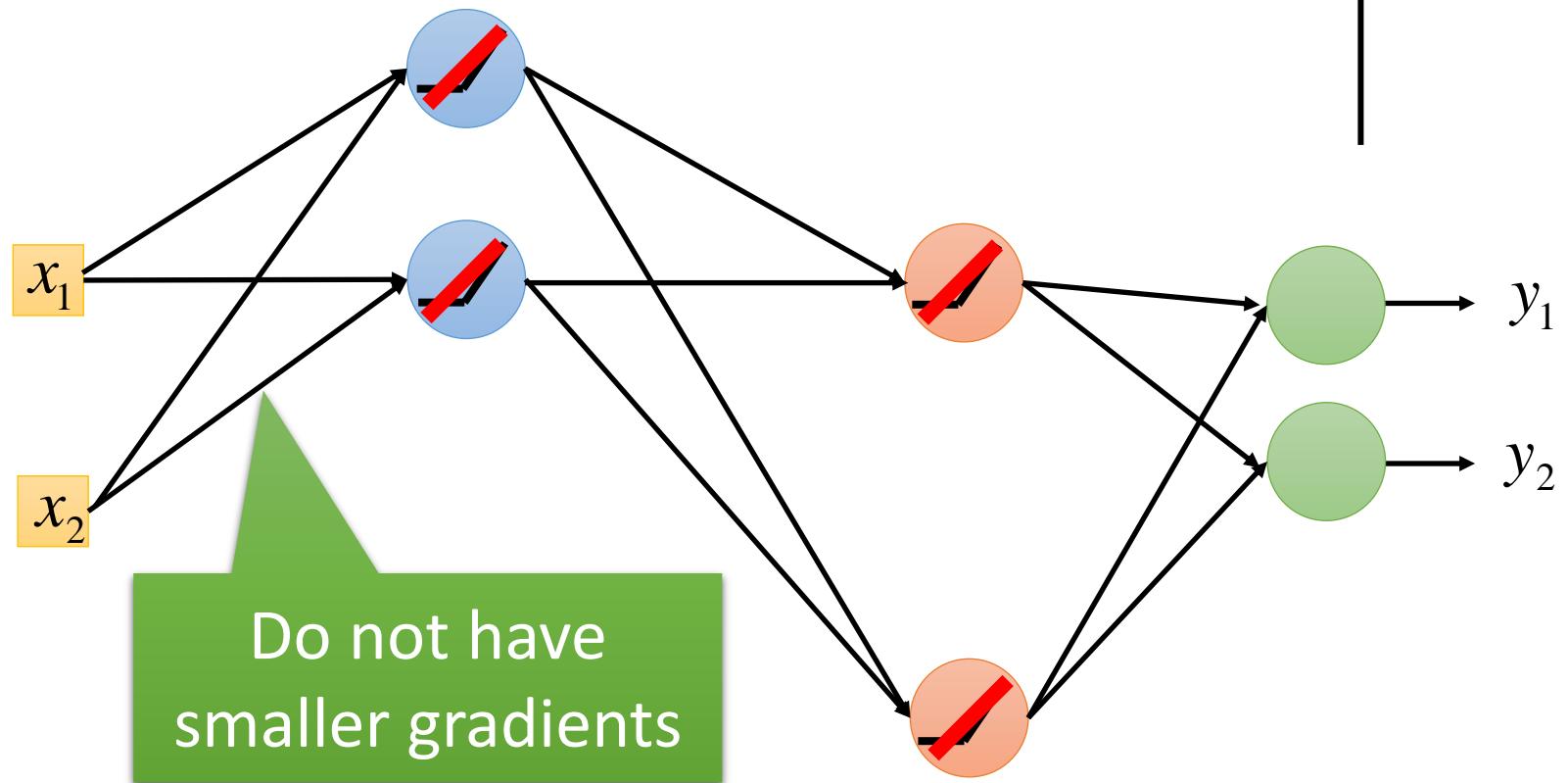
1. Fast to compute
2. Biological reason
3. Infinite sigmoid with different biases
4. Vanishing gradient problem

ReLU



ReLU

A Thinner linear network



Let's try it

```
model.add( Activation('sigmoid') )
```



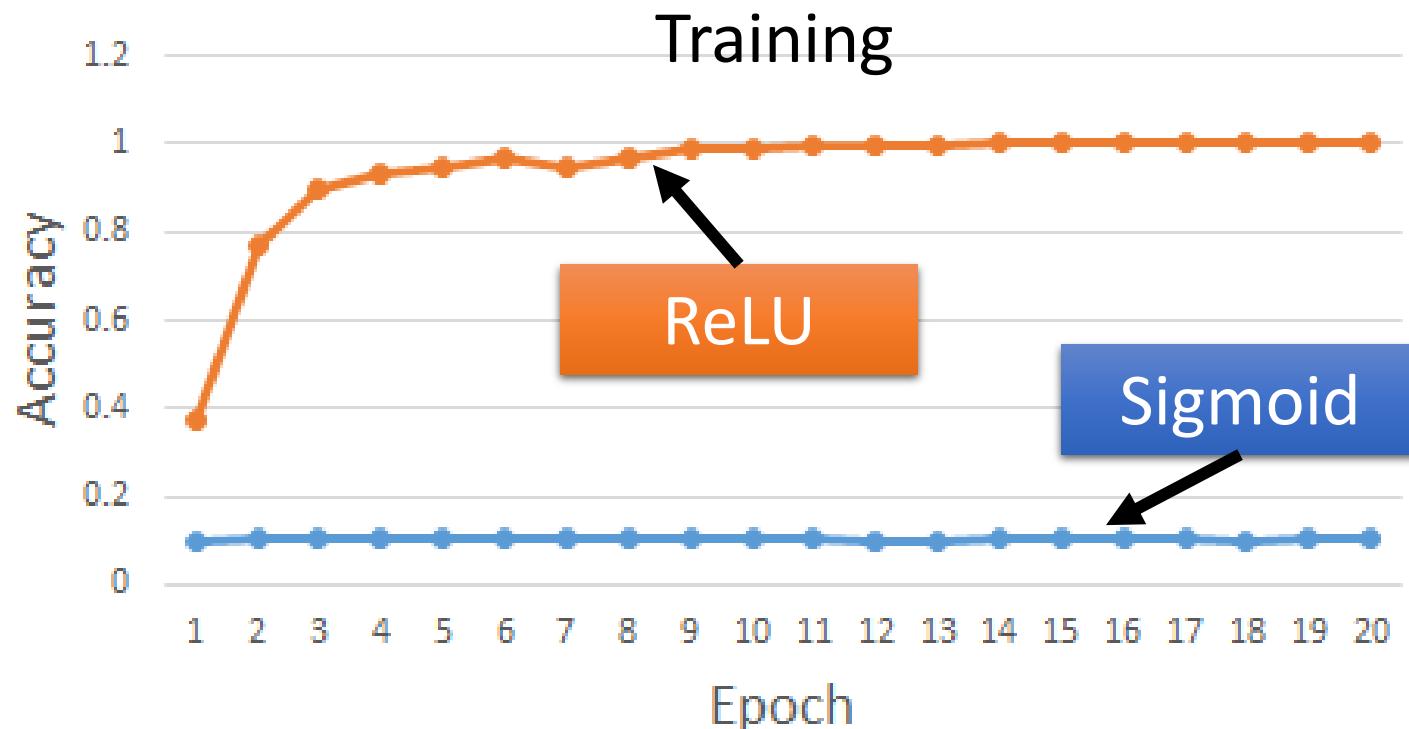
```
model.add( Activation('relu') )
```

Let's try it

- 9 layers

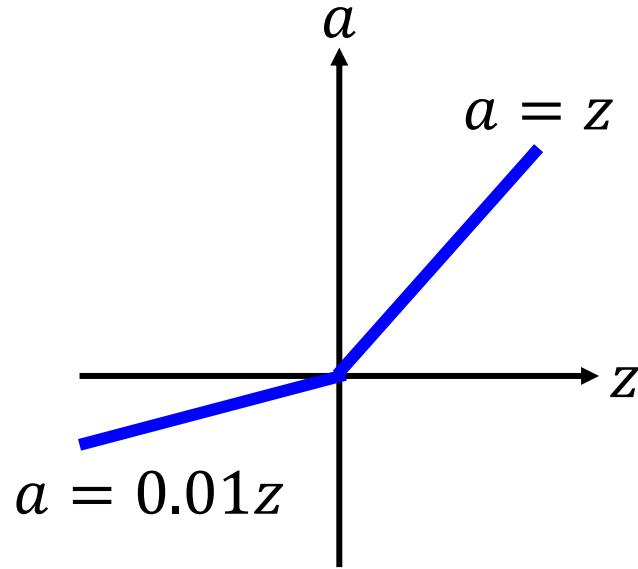
Testing:

9 layers	Accuracy
Sigmoid	0.11
ReLU	0.96

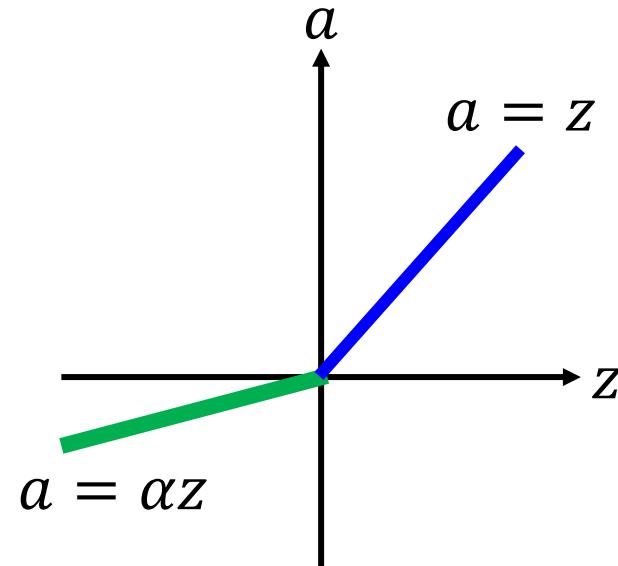


ReLU - variant

Leaky ReLU



Parametric ReLU

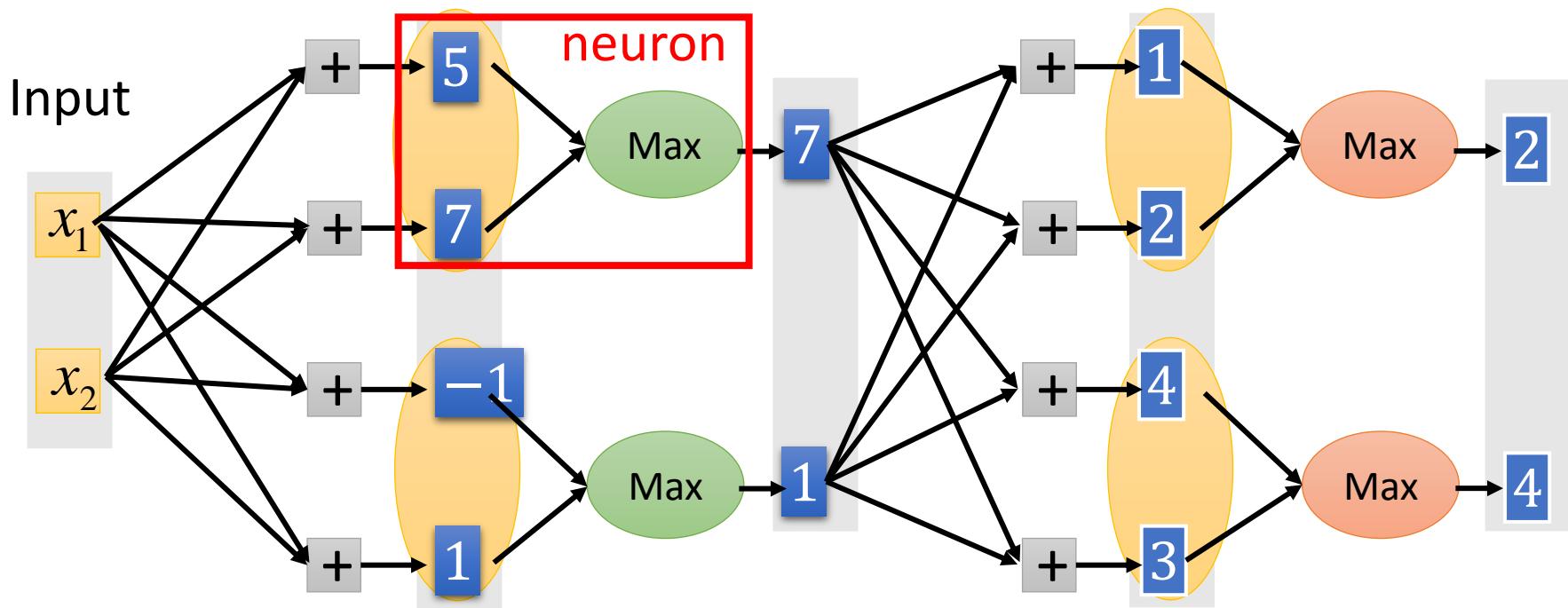


α also learned by
gradient descent

Maxout

ReLU is a special cases of Maxout

- Learnable activation function [Ian J. Goodfellow, ICML'13]



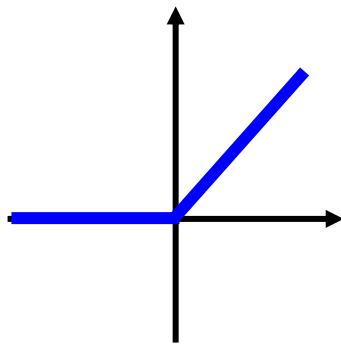
You can have more than 2 elements in a group.

Maxout

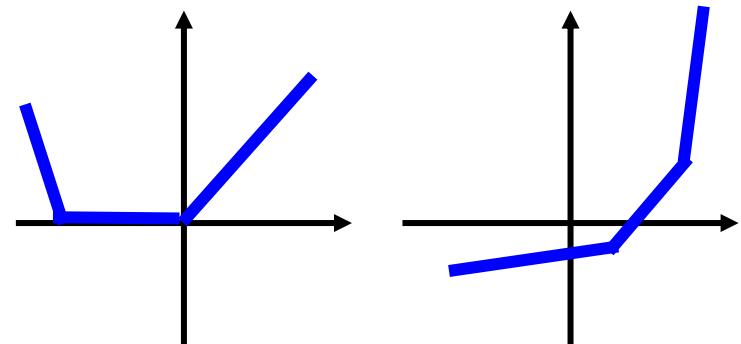
ReLU is a special cases of Maxout

- Learnable activation function [Ian J. Goodfellow, ICML'13]
 - Activation function in maxout network can be any piecewise linear convex function
 - How many pieces depending on how many elements in a group

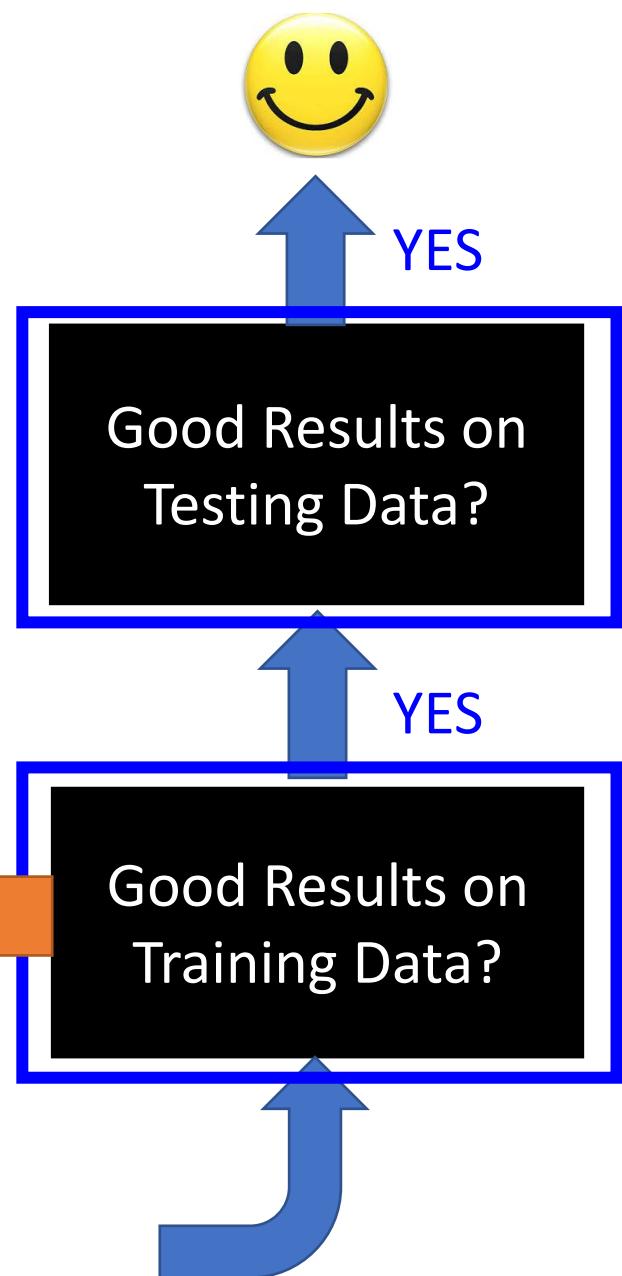
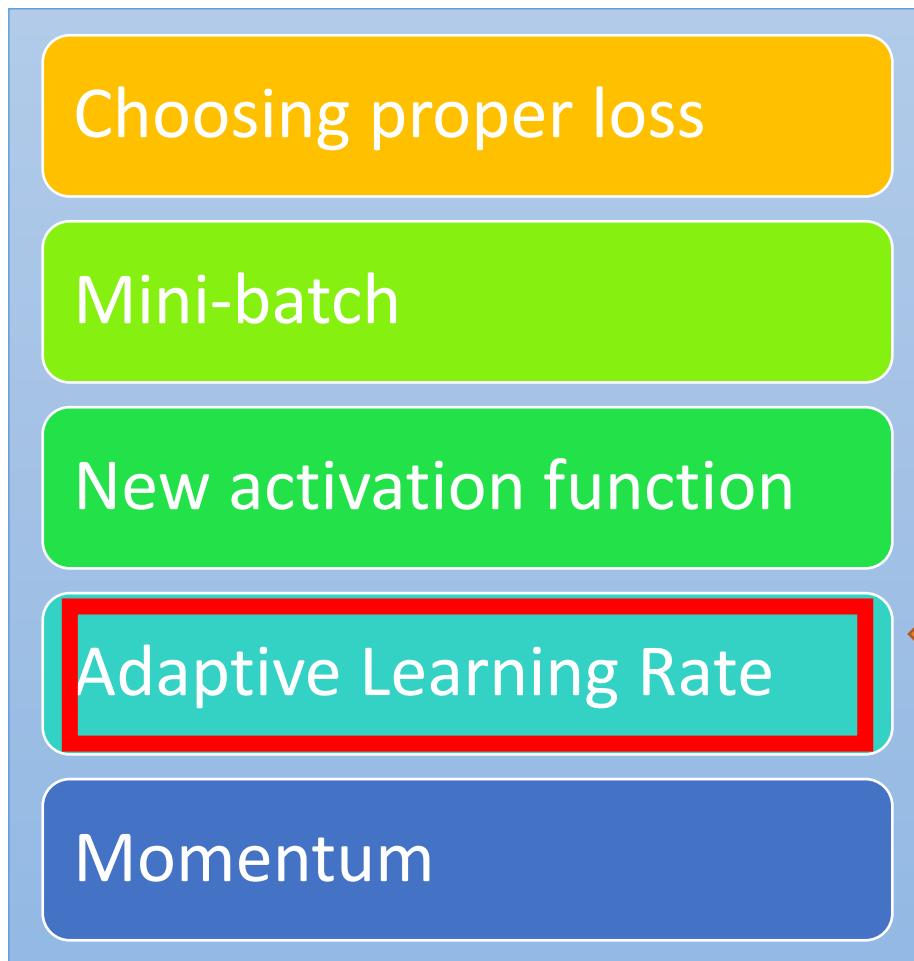
2 elements in a group



3 elements in a group

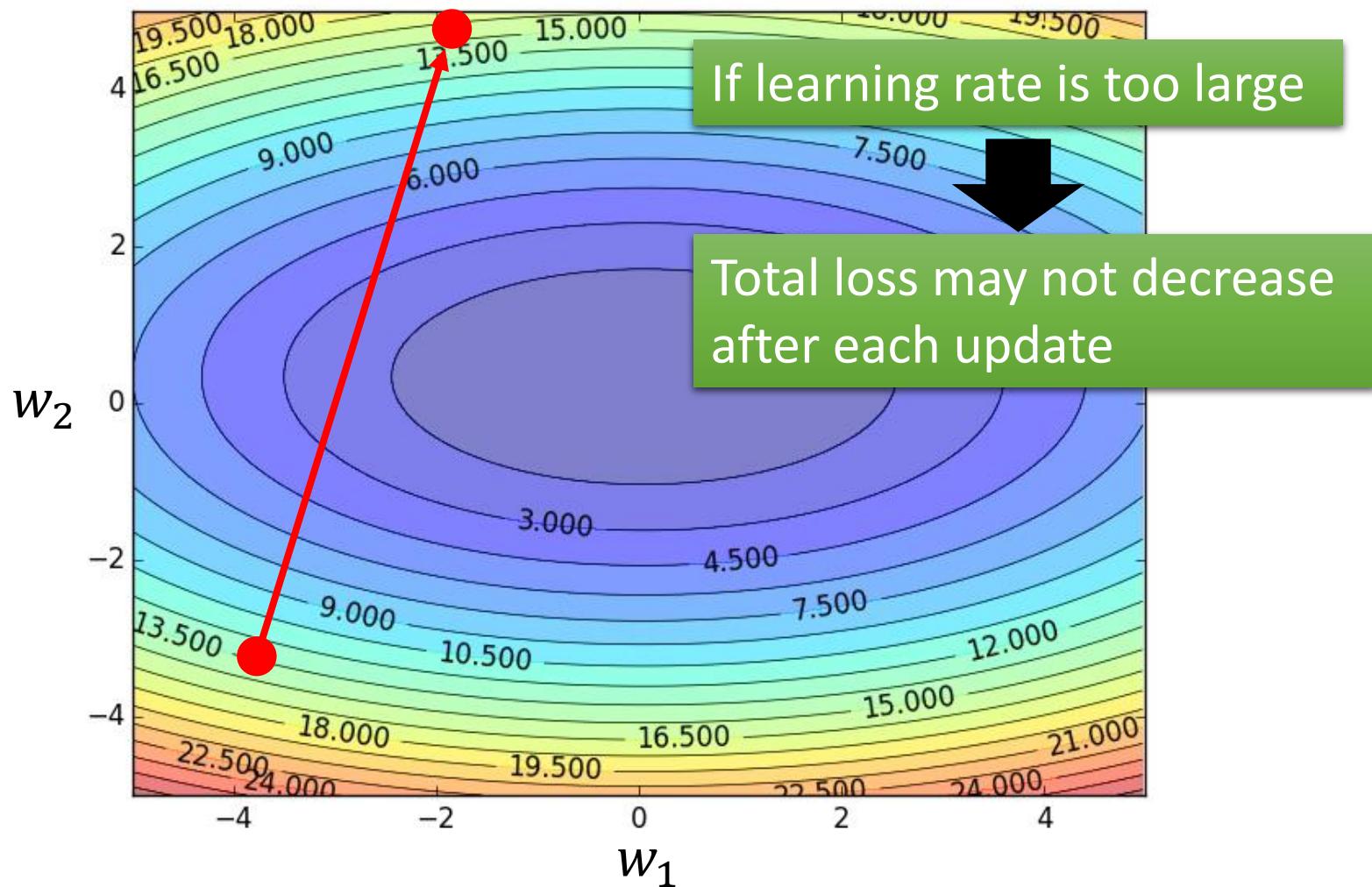


Recipe of Deep Learning



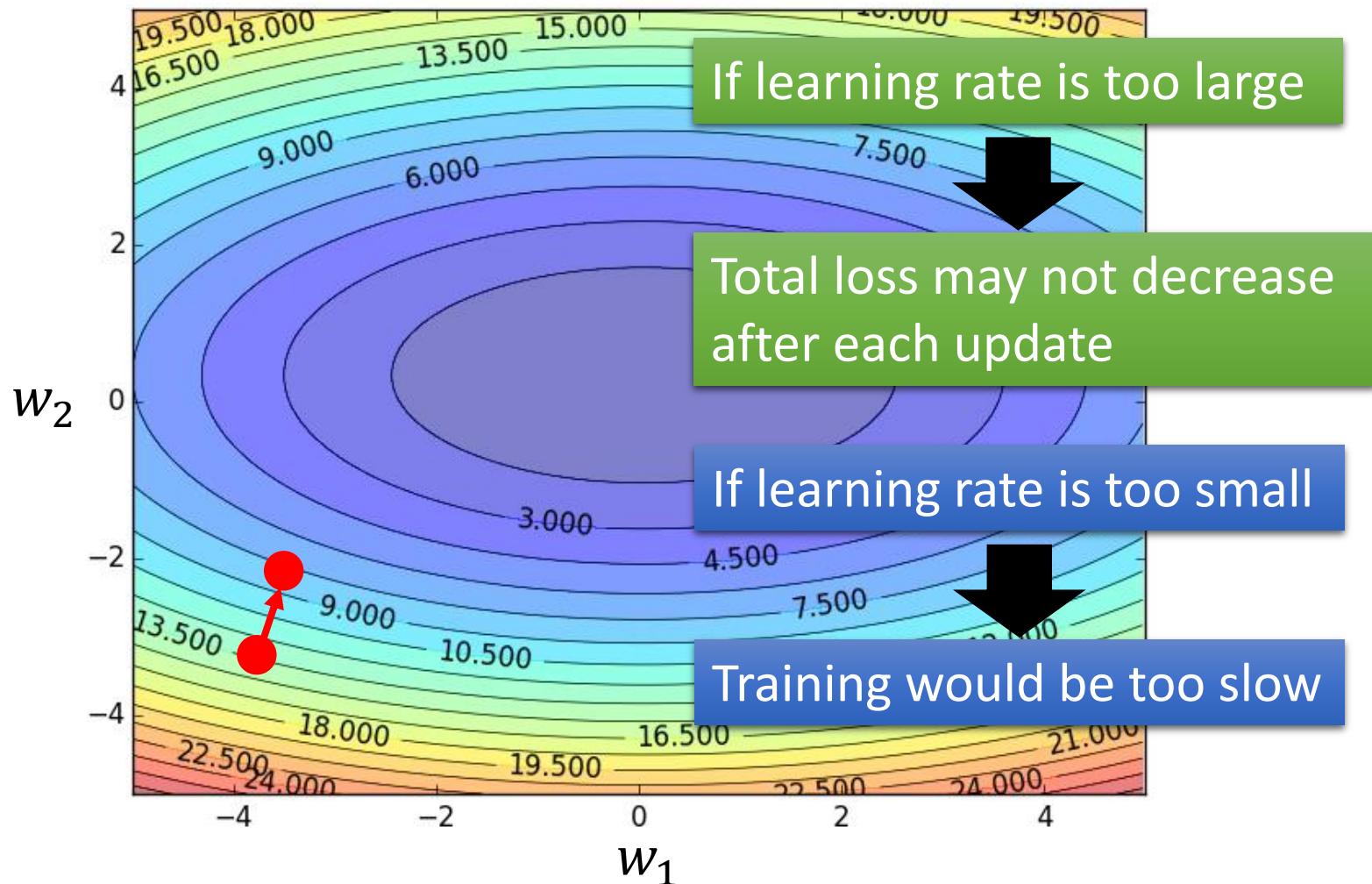
Learning Rates

Set the learning
rate η carefully



Learning Rates

Set the learning rate η carefully



Learning Rates

- Popular & Simple Idea: Reduce the learning rate by some factor every few epochs.
 - At the beginning, we are far from the destination, so we use larger learning rate
 - After several epochs, we are close to the destination, so we reduce the learning rate
 - E.g. 1/t decay: $\eta^t = \eta / \sqrt{t + 1}$
- Learning rate cannot be one-size-fits-all
 - Giving different parameters different learning rates

Adagrad

Original: $w \leftarrow w - \eta \partial L / \partial w$

Adagrad: $w \leftarrow w - \boxed{\eta_w} \partial L / \partial w$

Parameter dependent learning rate

$$\eta_w = \frac{\eta}{\sqrt{\sum_{i=0}^t (g^i)^2}}$$

η → constant

$\sum_{i=0}^t (g^i)^2$ → g^i is $\partial L / \partial w$ obtained at the i-th update

Summation of the square of the previous derivatives

Adagrad

$$\eta_w = \frac{\eta}{\sqrt{\sum_{i=0}^t (g^i)^2}}$$

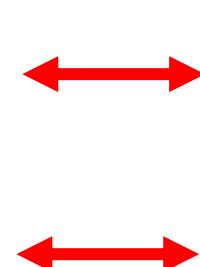
w_1	\mathbf{g}^0
	0.1

Learning rate:

$$\frac{\eta}{\sqrt{0.1^2}}$$

$$= \frac{\eta}{0.1}$$

$$\frac{\eta}{\sqrt{0.1^2 + 0.2^2}} = \frac{\eta}{\sqrt{0.01 + 0.04}} = \frac{\eta}{\sqrt{0.05}} = \frac{\eta}{\sqrt{0.05}} = \frac{\eta}{0.22}$$



w_2	\mathbf{g}^0
	20.0

Learning rate:

$$\frac{\eta}{\sqrt{20^2}}$$

$$= \frac{\eta}{20}$$

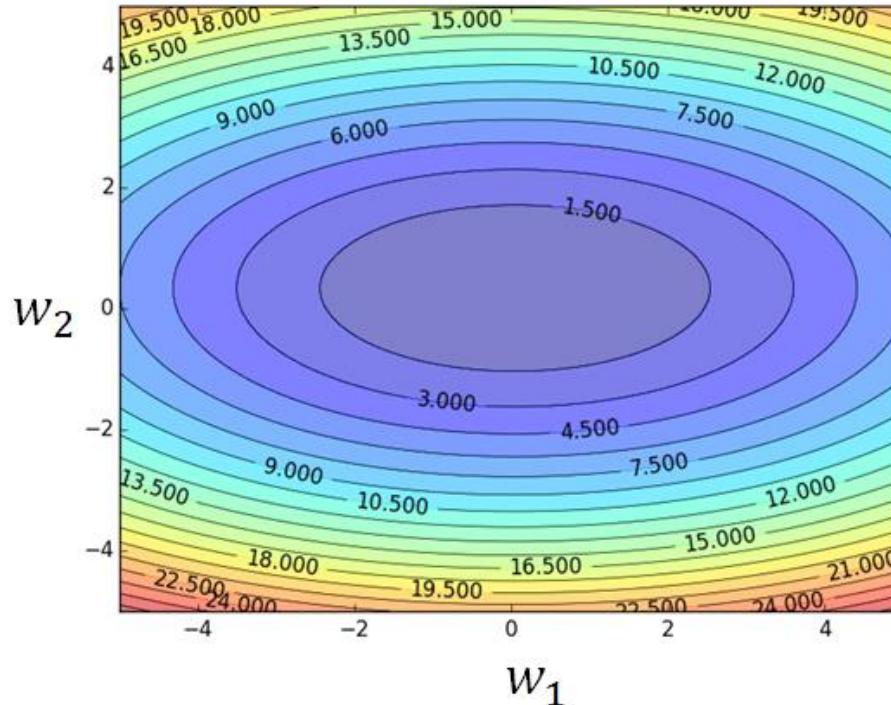
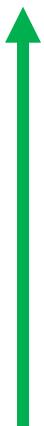
$$\frac{\eta}{\sqrt{20^2 + 10^2}} = \frac{\eta}{\sqrt{400 + 100}} = \frac{\eta}{\sqrt{500}} = \frac{\eta}{\sqrt{25 \cdot 20}} = \frac{\eta}{5\sqrt{20}} = \frac{\eta}{22}$$

- Observation:**
1. Learning rate is smaller and smaller for all parameters
 2. Smaller derivatives, larger learning rate, and vice versa

Why?

Larger derivatives

Smaller Learning Rate



Smaller Derivatives



Larger Learning Rate

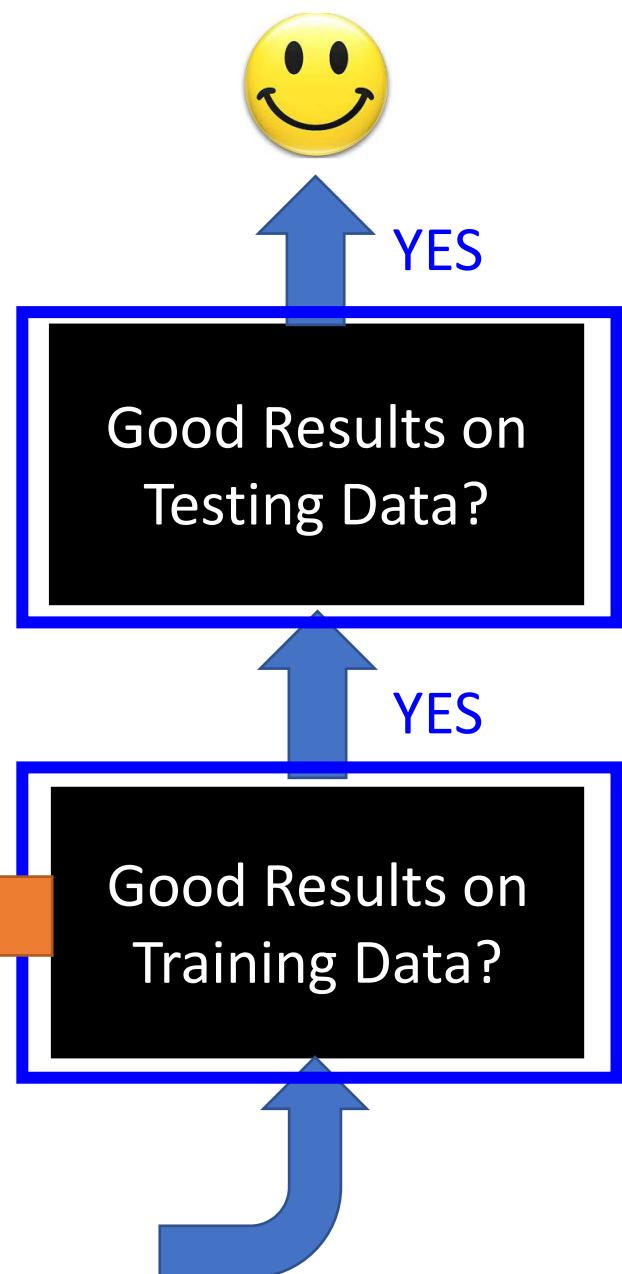
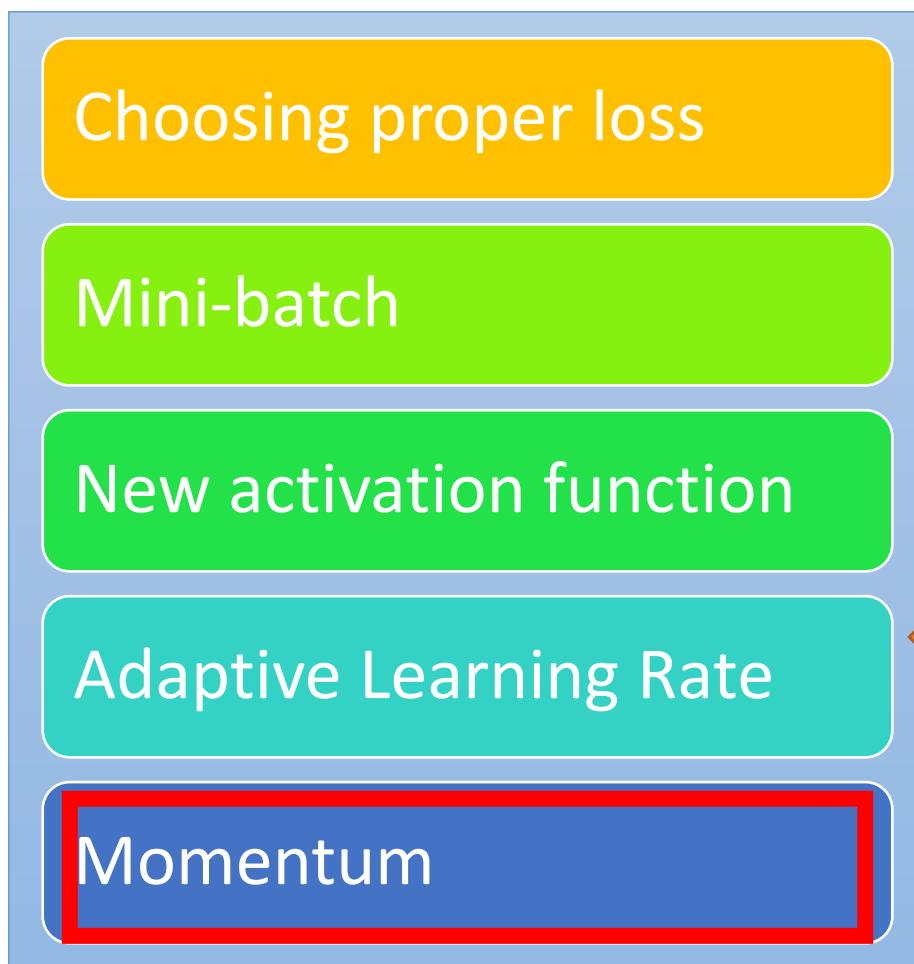
2. Smaller derivatives, larger learning rate, and vice versa

Why?

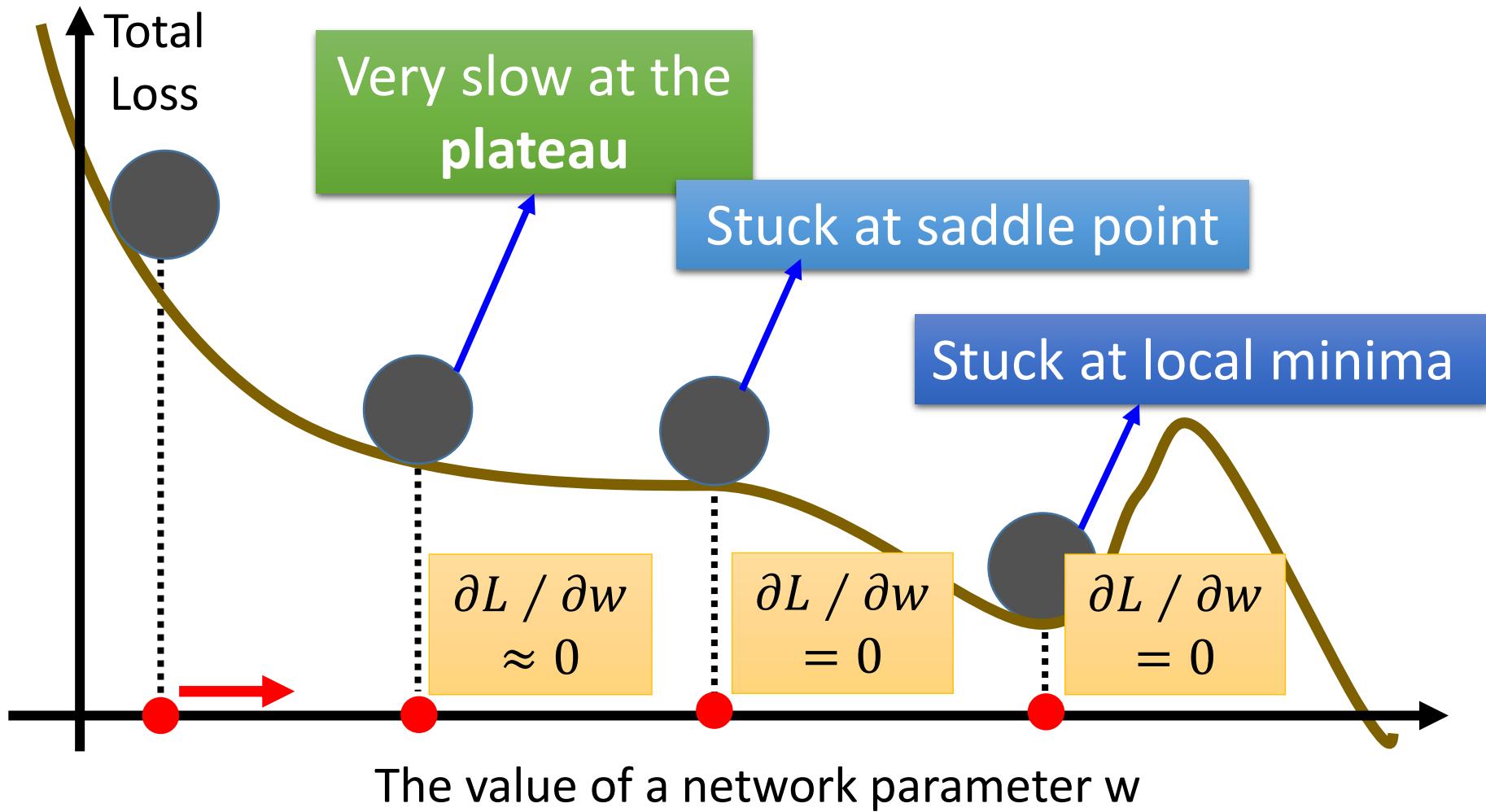
Not the whole story

- Adagrad [John Duchi, JMLR'11]
- RMSprop
 - <https://www.youtube.com/watch?v=O3sxAc4hxZU>
- Adadelta [Matthew D. Zeiler, arXiv'12]
- “No more pesky learning rates” [Tom Schaul, arXiv'12]
- AdaSecant [Caglar Gulcehre, arXiv'14]
- Adam [Diederik P. Kingma, ICLR'15]
- Nadam
 - http://cs229.stanford.edu/proj2015/054_report.pdf

Recipe of Deep Learning

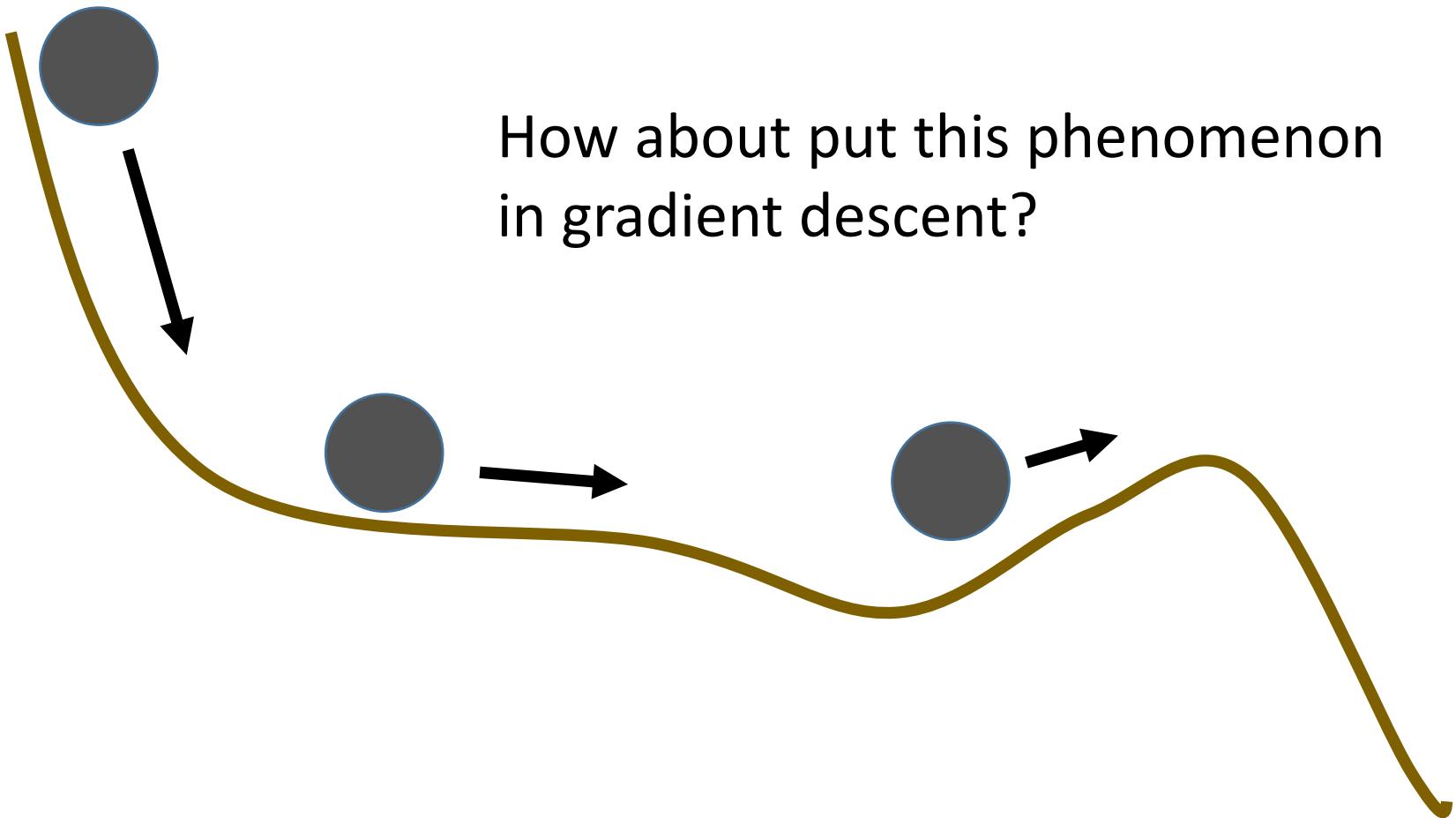


Hard to find optimal network parameters



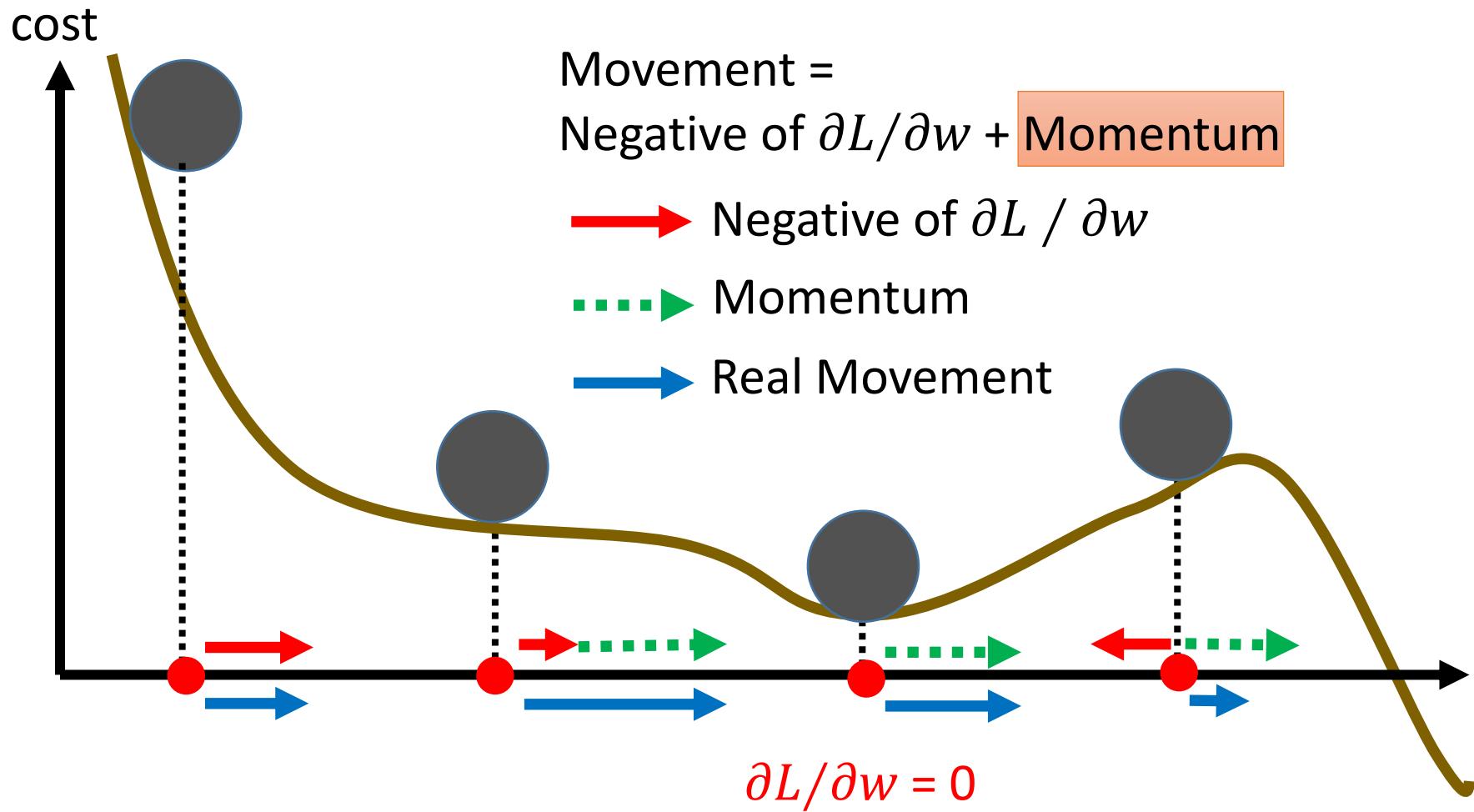
In physical world

- Momentum



Momentum

Still not guarantee reaching global minima, but give some hope



Adam

RMSProp (Advanced Adagrad) + Momentum

```
model.compile(loss='categorical_crossentropy',
               optimizer=SGD(lr=0.1),
               metrics=['accuracy'])
```

```
model.compile(loss='categorical_crossentropy',
               optimizer=Adam(),
               metrics=['accuracy'])
```

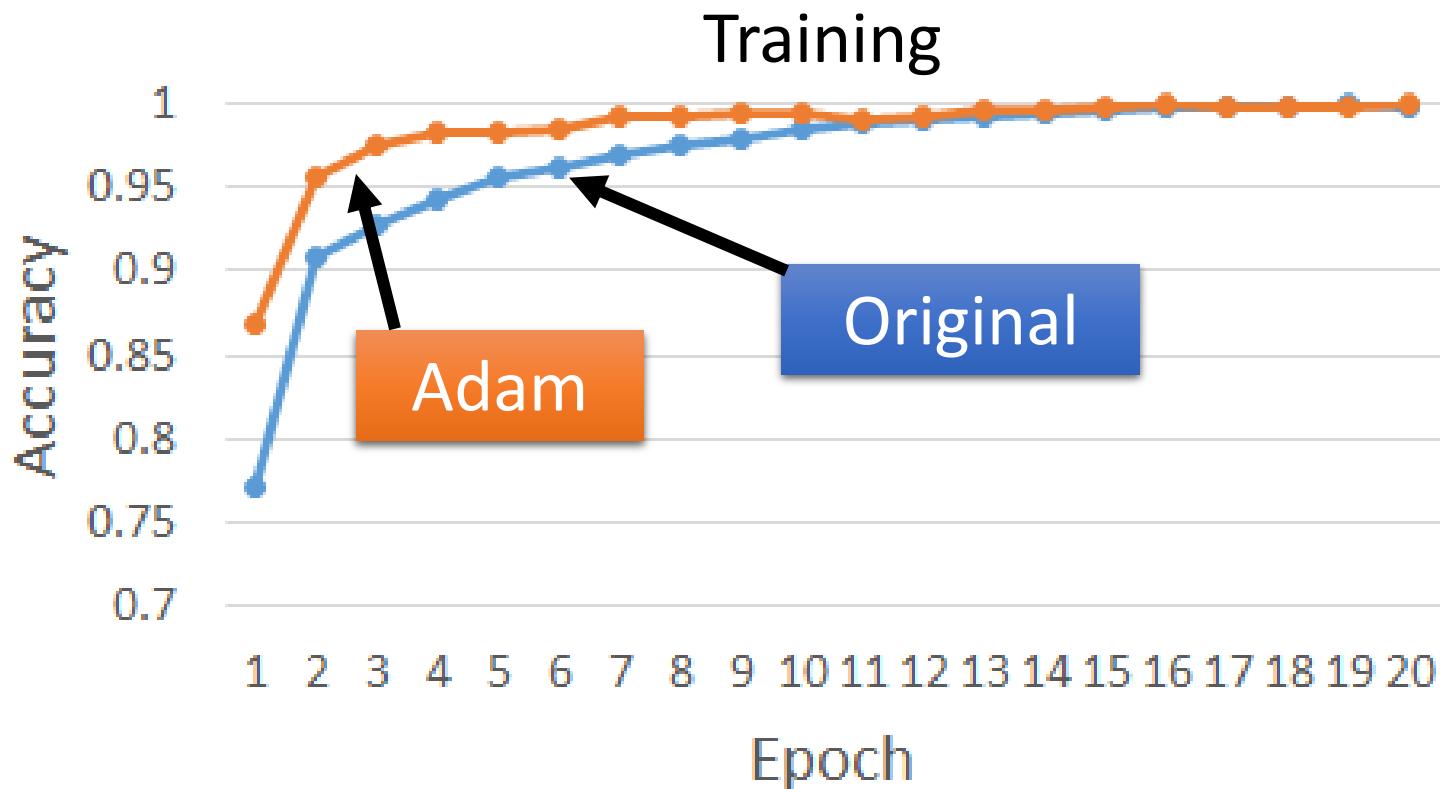
Algorithm 1: *Adam*, our proposed algorithm for stochastic optimization. See section 2 for details, and for a slightly more efficient (but less clear) order of computation. g_t^2 indicates the elementwise square $g_t \odot g_t$. Good default settings for the tested machine learning problems are $\alpha = 0.001$, $\beta_1 = 0.9$, $\beta_2 = 0.999$ and $\epsilon = 10^{-8}$. All operations on vectors are element-wise. With β_1^t and β_2^t we denote β_1 and β_2 to the power t .

Require: α : Stepsize
Require: $\beta_1, \beta_2 \in [0, 1]$: Exponential decay rates for the moment estimates
Require: $f(\theta)$: Stochastic objective function with parameters θ
Require: θ_0 : Initial parameter vector
 $m_0 \leftarrow 0$ (Initialize 1st moment vector)
 $v_0 \leftarrow 0$ (Initialize 2nd moment vector)
 $t \leftarrow 0$ (Initialize timestep)
while θ_t not converged **do**
 $t \leftarrow t + 1$
 $g_t \leftarrow \nabla_{\theta} f_t(\theta_{t-1})$ (Get gradients w.r.t. stochastic objective at timestep t)
 $m_t \leftarrow \beta_1 \cdot m_{t-1} + (1 - \beta_1) \cdot g_t$ (Update biased first moment estimate)
 $v_t \leftarrow \beta_2 \cdot v_{t-1} + (1 - \beta_2) \cdot g_t^2$ (Update biased second raw moment estimate)
 $\hat{m}_t \leftarrow m_t / (1 - \beta_1^t)$ (Compute bias-corrected first moment estimate)
 $\hat{v}_t \leftarrow v_t / (1 - \beta_2^t)$ (Compute bias-corrected second raw moment estimate)
 $\theta_t \leftarrow \theta_{t-1} - \alpha \cdot \hat{m}_t / (\sqrt{\hat{v}_t} + \epsilon)$ (Update parameters)
end while
return θ_t (Resulting parameters)

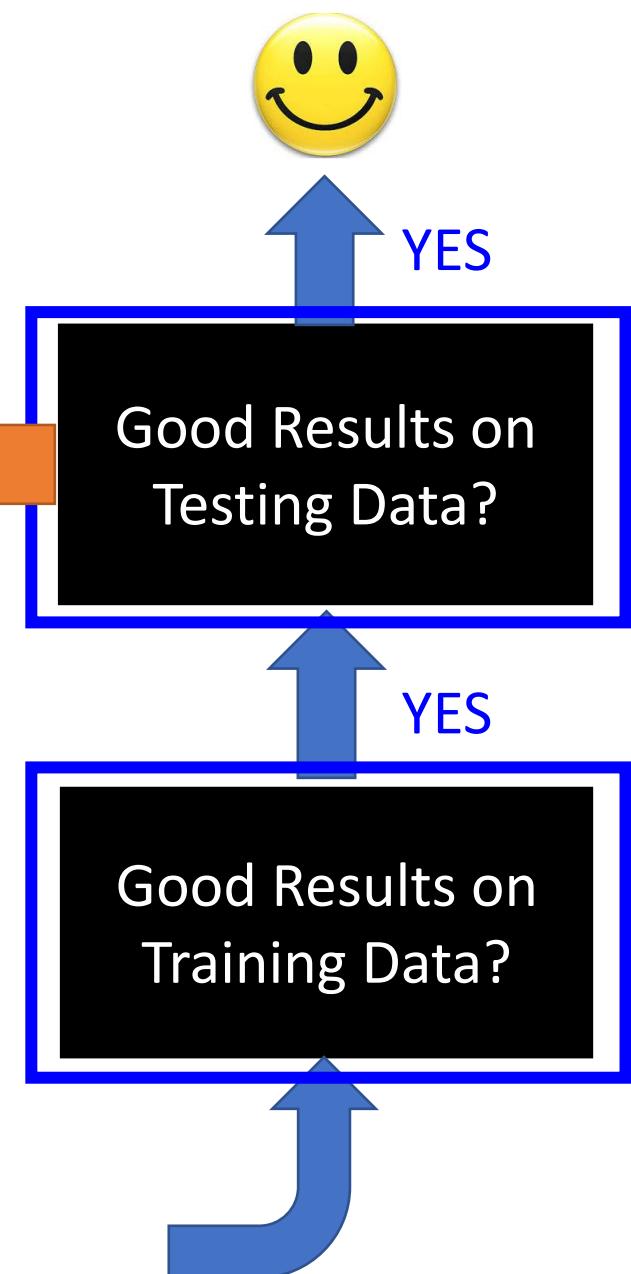
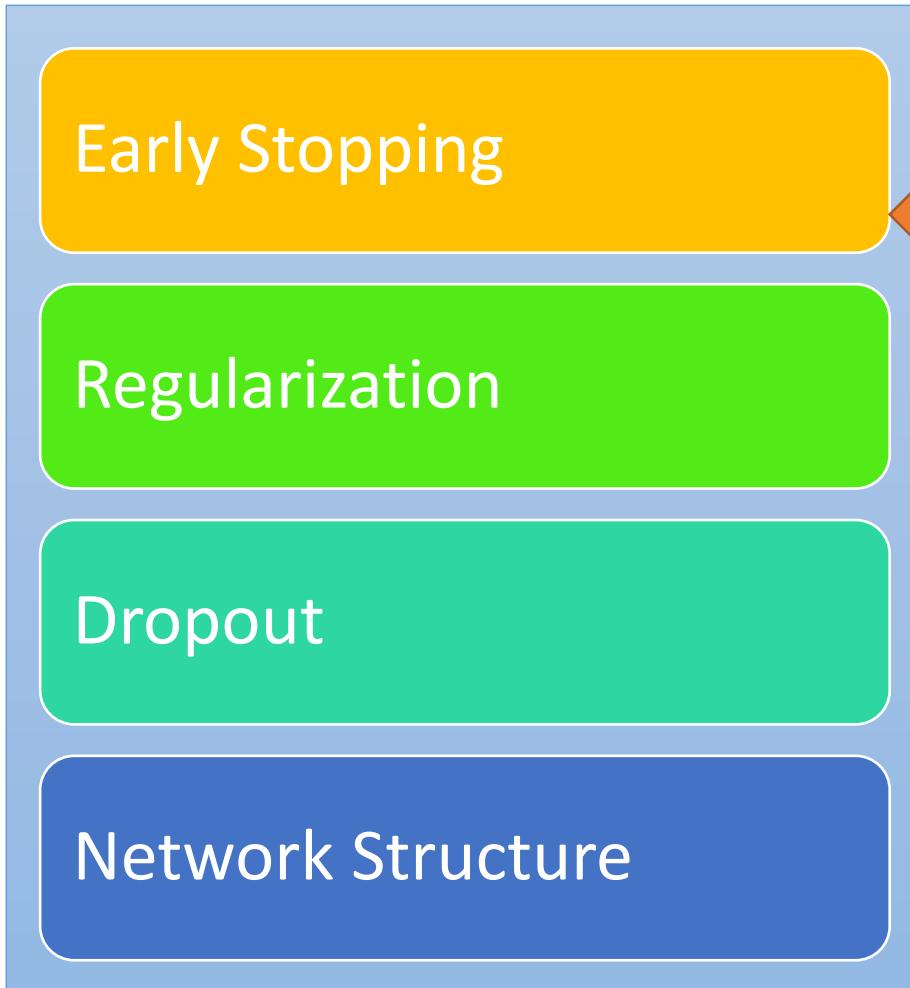
Let's try it

- ReLU, 3 layer

	Accuracy
Original	0.96
Adam	0.97



Recipe of Deep Learning



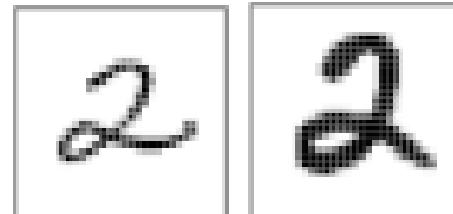
Why Overfitting?

- Training data and testing data can be different.

Training Data:



Testing Data:



Learning target is defined by the training data.

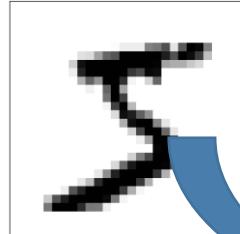
The parameters achieving the learning target do not necessarily have good results on the testing data.

Panacea for Overfitting

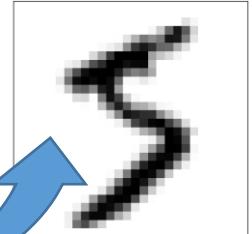
- Have more training data
- *Create* more training data (?)

Handwriting recognition:

Original
Training Data:



Created
Training Data:



Shift 15 °

Why Overfitting?

- For experiments, we added some noises to the testing data

```
-1.36230370e-01, 1.03749340e-01, 1.15432226e-01,  
2.58670464e-01, 1.48774333e+00, 1.92885328e+00,  
1.70038673e+00, 2.46242981e+00, 1.21244572e+00,  
-9.28660713e-01, 3.63209761e-01, -1.81327713e+00,  
-1.97910760e-01, 4.32874592e-01, -5.40565788e-01,  
2.95630655e-01, 2.07984424e+00, -1.84243292e+00,  
-5.11166017e-01, -5.80935128e-01, 1.06273647e+00,  
1.80551097e-02, 2.27983997e-02, -1.67979148e+00,  
8.12423001e-01, -6.25888706e-01, -1.25027082e+00,  
6.15135458e-01, -1.21394611e-01, -1.28089527e+00,  
3.24609806e-01, 6.70569391e-01, 1.49161323e-01,  
8.01573609e-01, 6.43116741e-01, -9.37629233e-02,  
1.74677366e+00, 6.80996008e-01, -7.03717611e-01,  
1.02079749e-01, 1.19505614e+00, -2.77959386e-01,  
-5.21652916e-02, 3.53683601e-01, -4.08310762e-01,  
-1.81042967e+00, -9.03308062e-01, 1.05404509e+00,  
-9.80876877e-01, 3.52078891e-01, 6.65981840e-01,  
1.06550150e+00, -2.28433613e-01, 3.64483904e-01,  
-1.51484666e+00, -7.52612872e-02, -2.97058082e-01,  
-7.27414382e-01, -2.45875340e-01, -1.27948942e-01,  
-3.69310620e-01, -2.62300428e+00, 2.11585073e+00,  
6.85561585e-01, -1.57443985e-01, 1.38128777e+00,  
6.84265587e-02, 3.12536292e-01, 4.54253185e-01,  
-7.88471875e-01, -6.58403343e-02, -1.41847985e+00,  
-1.39753340e-01, -5.55354856e-01, -5.01917779e-01,  
6.93118522e-01, -2.45360497e-01, -1.26943186e+00,  
-2.62323855e-01])  
n [3]: x test[0]
```

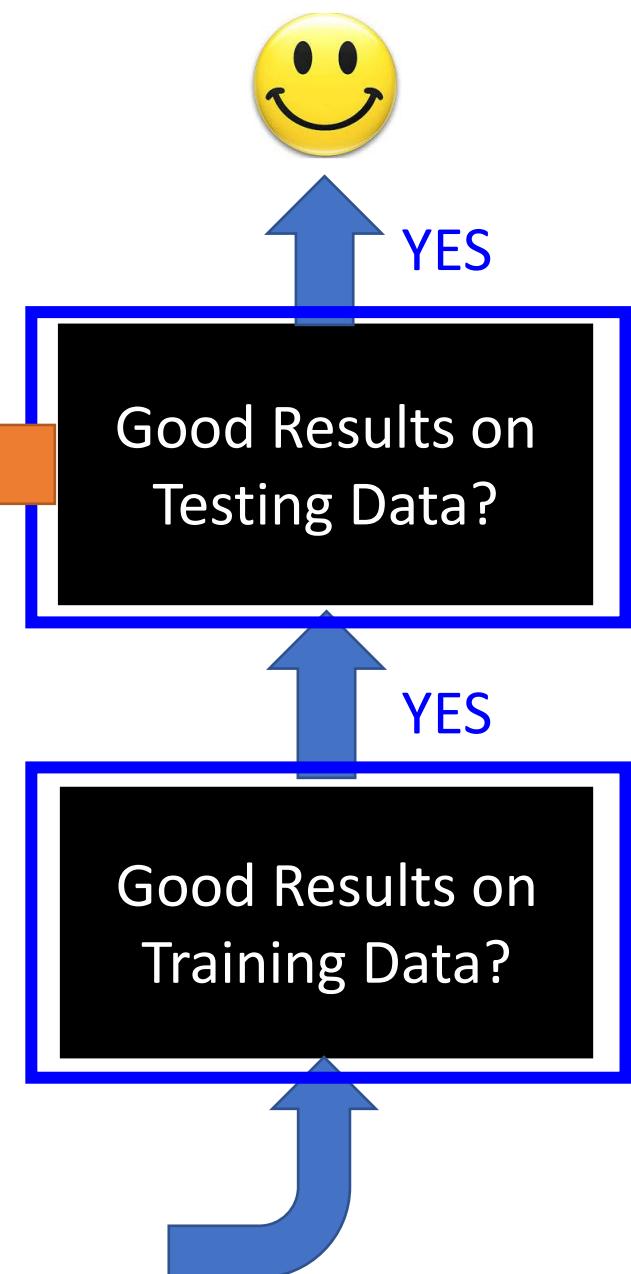
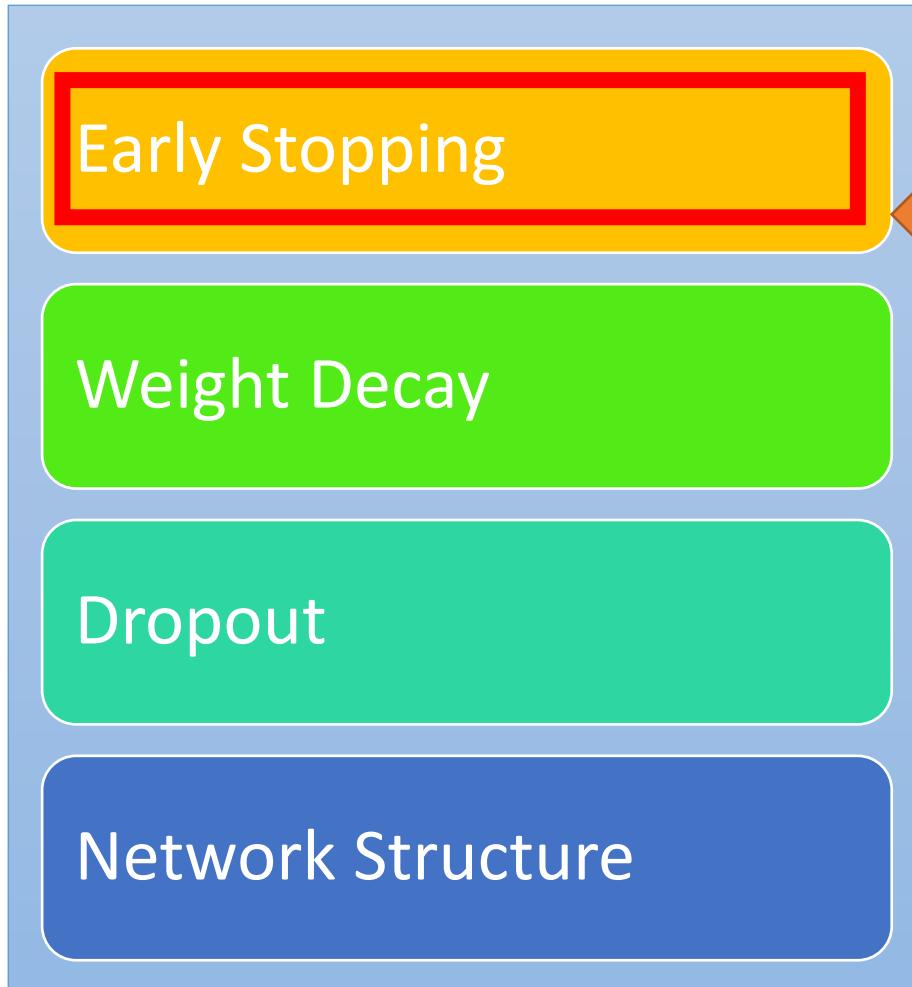
Why Overfitting?

- For experiments, we added some noises to the testing data

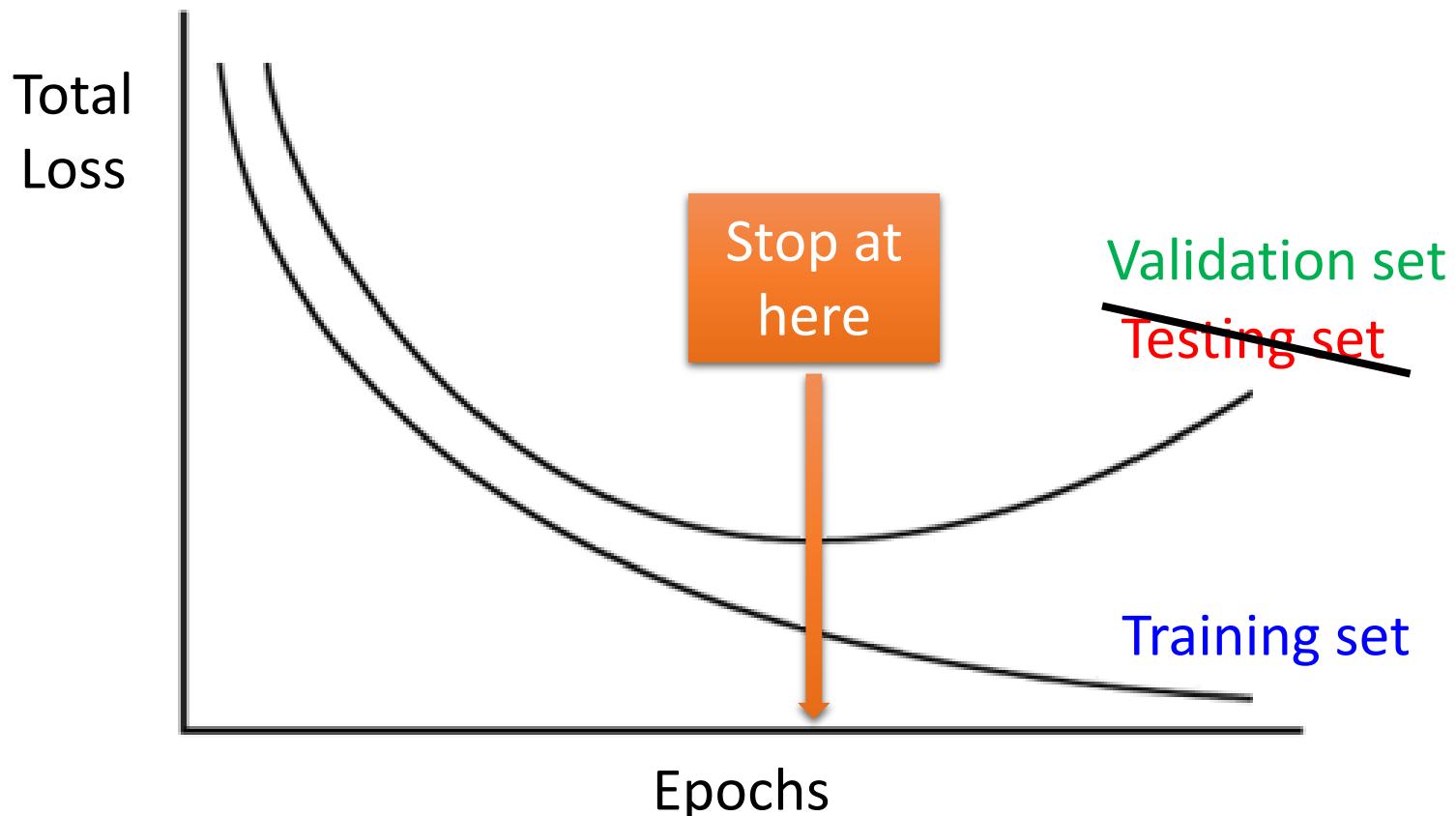
Testing:	Accuracy
Clean	0.97
Noisy	0.50

Training is not influenced.

Recipe of Deep Learning

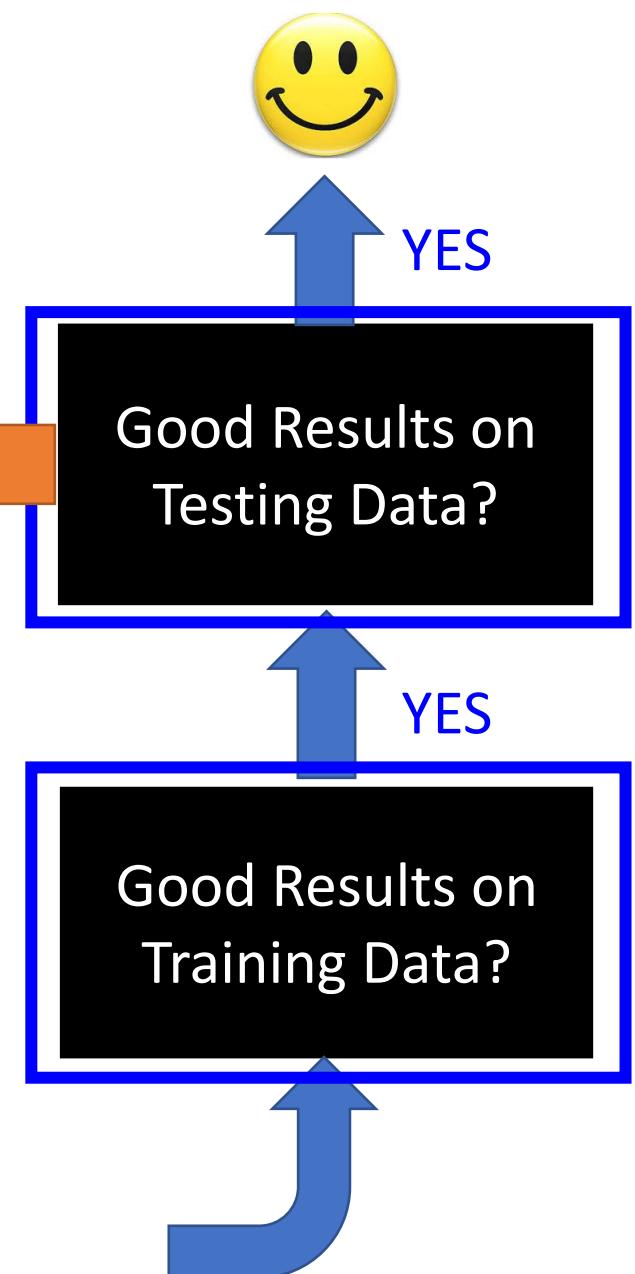
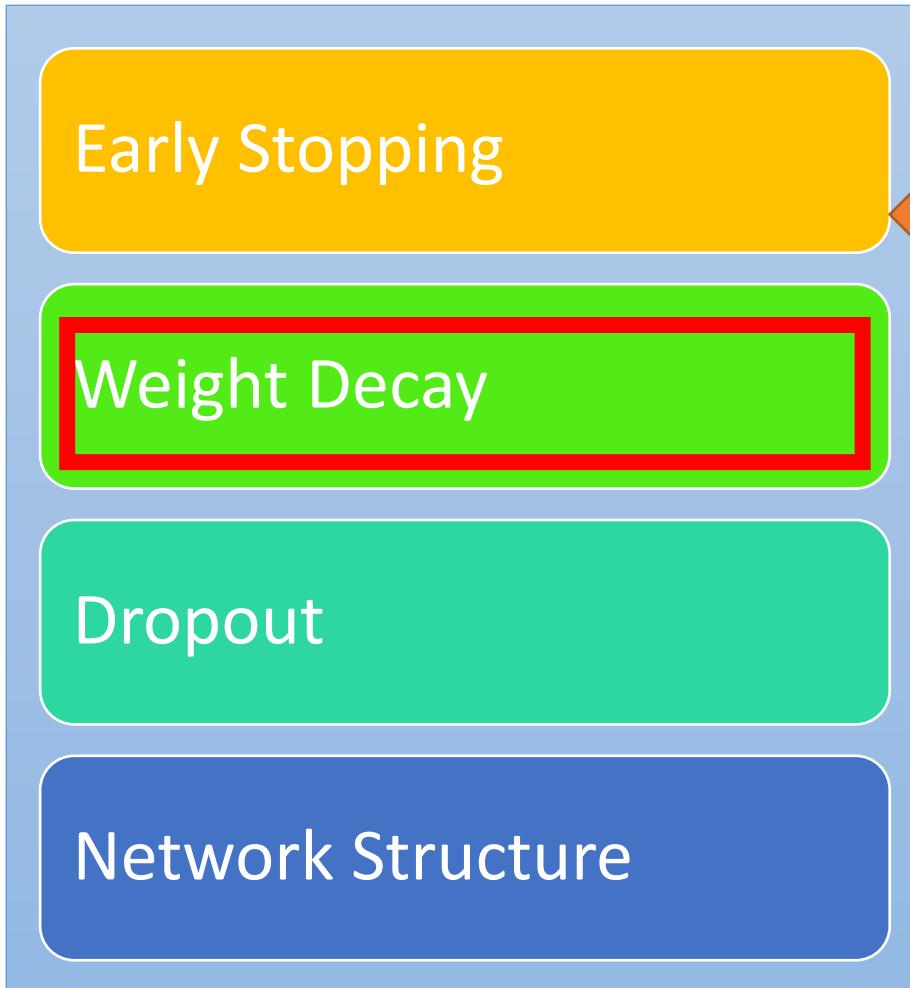


Early Stopping



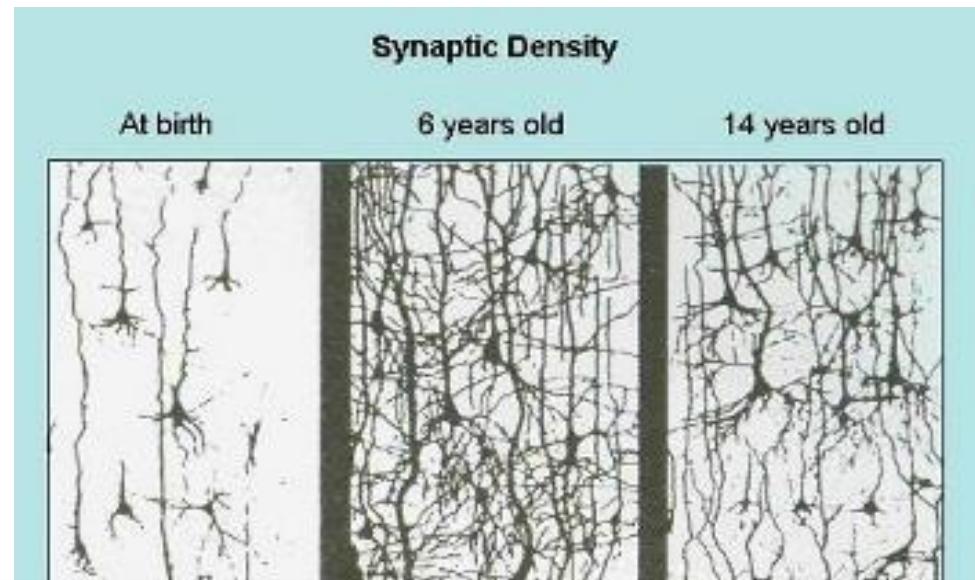
Keras: <http://keras.io/getting-started/faq/#how-can-i-interrupt-training-when-the-validation-loss-isnt-decreasing-anymore>

Recipe of Deep Learning

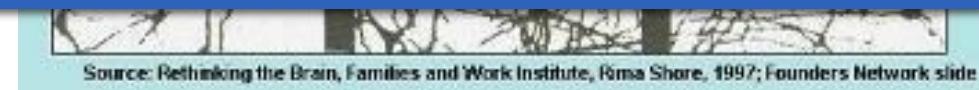


Weight Decay

- Our brain prunes out the useless link between neurons.

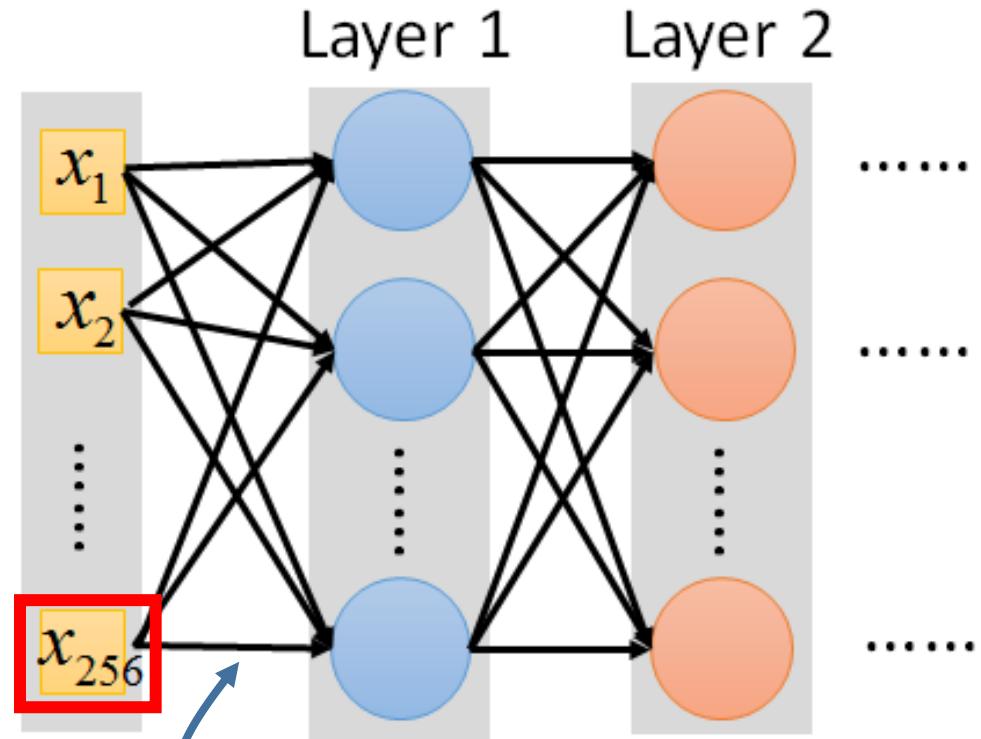
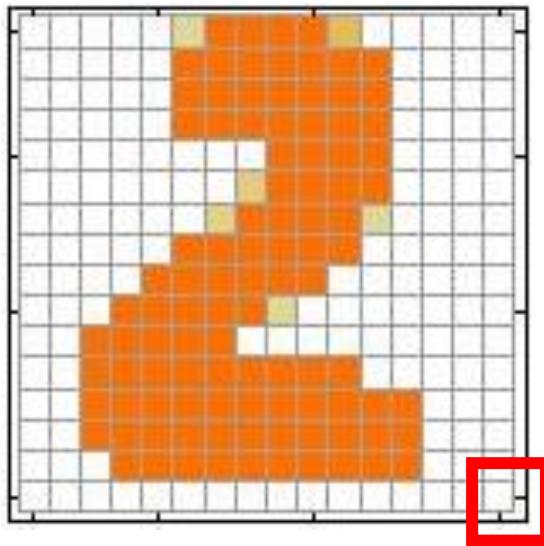


Doing the same thing to machine's brain improves the performance.



Source: Rethinking the Brain, Families and Work Institute, Rima Shore, 1997; Founders Network slide

Weight Decay



Weight decay is one kind of regularization

Useless

Close to zero (萎缩了)

Weight Decay

- Implementation

$$\text{Original: } w \leftarrow w - \eta \frac{\partial L}{\partial w}$$

$$\lambda = 0.01$$

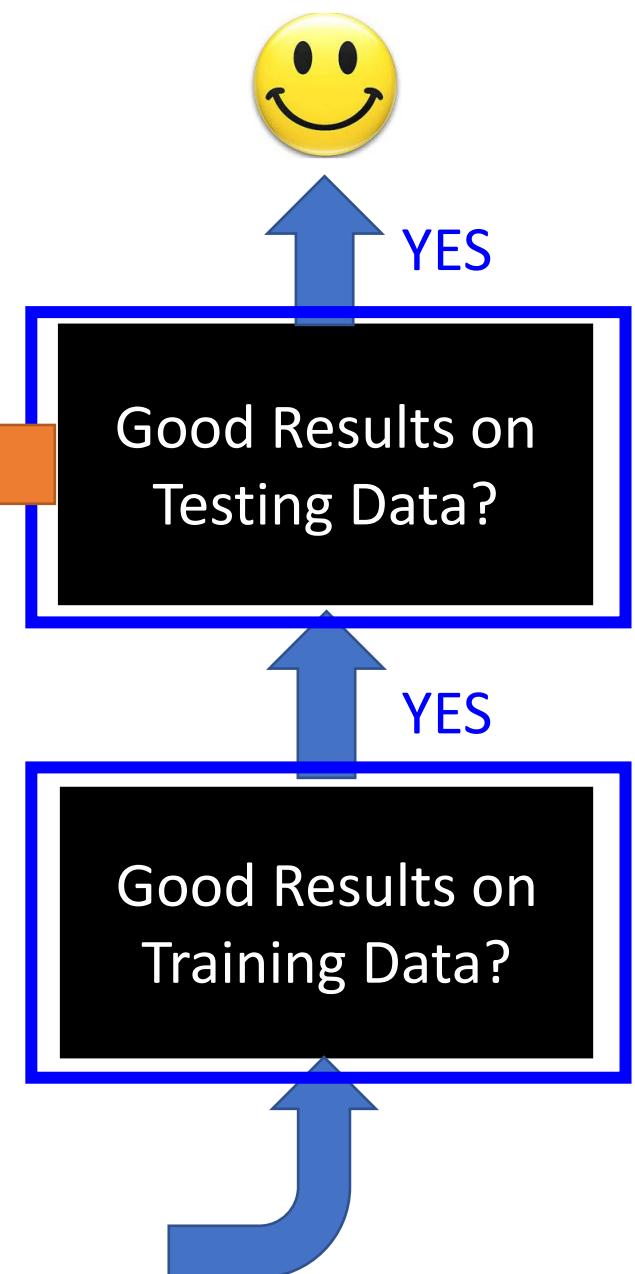
Weight Decay:

$$w \leftarrow \underbrace{0.99}_{\downarrow} w - \eta \frac{\partial L}{\partial w}$$

Smaller and smaller

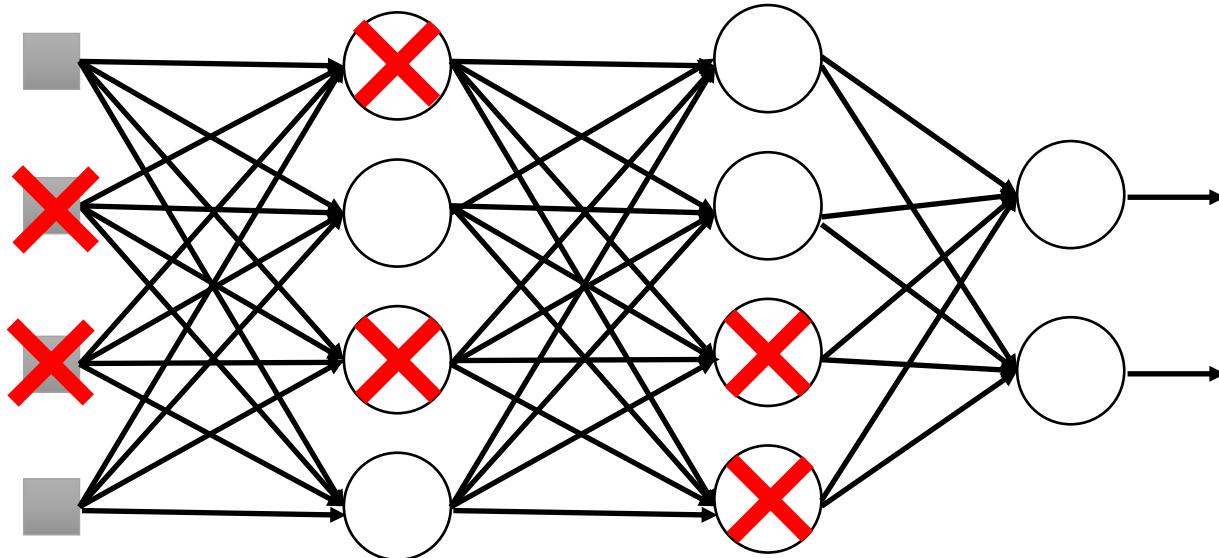
Keras: <http://keras.io/regularizers/>

Recipe of Deep Learning



Dropout

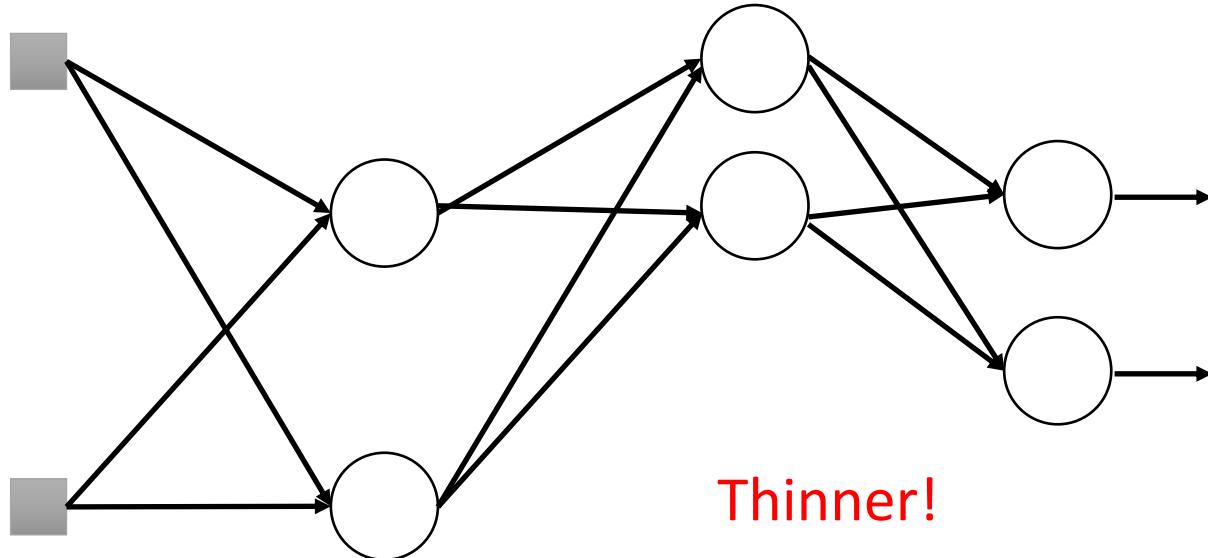
Training:



- **Each time before updating the parameters**
 - Each neuron has $p\%$ to dropout

Dropout

Training:

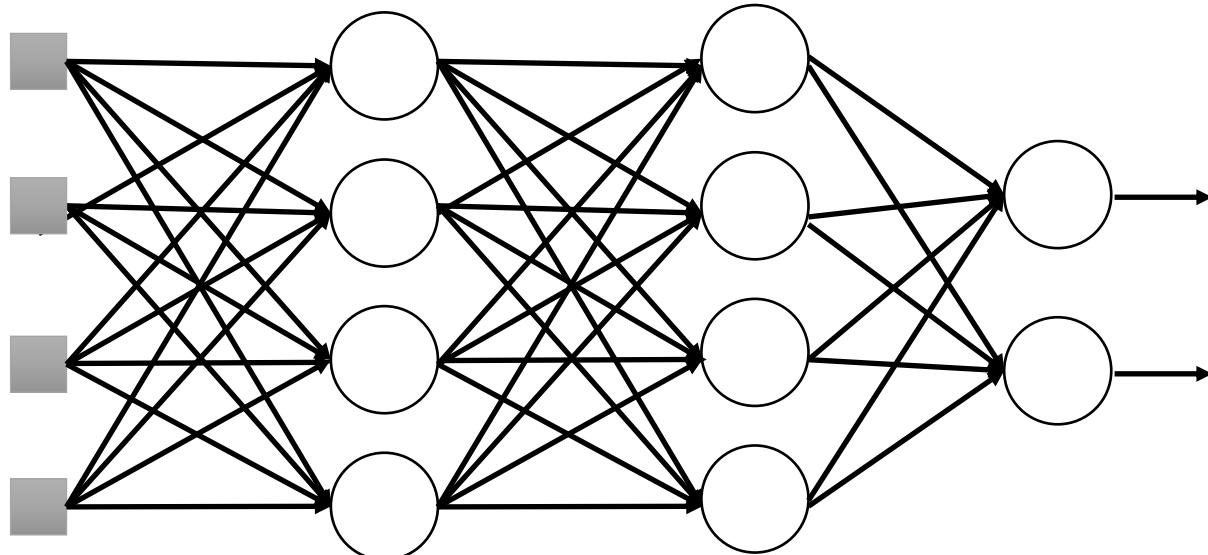


- **Each time before updating the parameters**
 - Each neuron has $p\%$ to dropout
 - ➡ **The structure of the network is changed.**
 - Using the new network for training

For each mini-batch, we resample the dropout neurons

Dropout

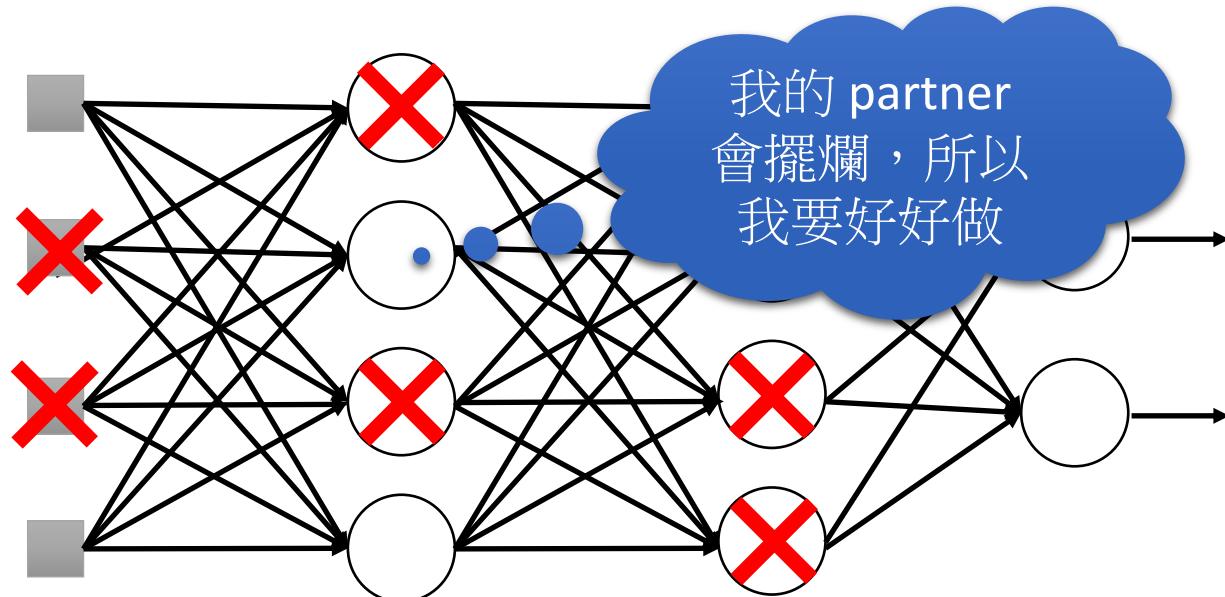
Testing:



➤ No dropout

- If the dropout rate at training is $p\%$,
all the weights times $(1-p)\%$
- Assume that the dropout rate is 50%.
If a weight $w = 1$ by training, set $w = 0.5$ for testing.

Dropout - Intuitive Reason



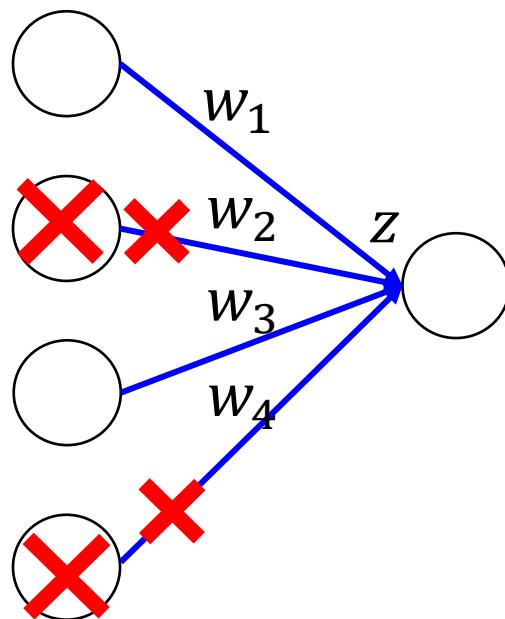
- When teams up, if everyone expect the partner will do the work, nothing will be done finally.
- However, if you know your partner will dropout, you will do better.
- When testing, no one dropout actually, so obtaining good results eventually.

Dropout - Intuitive Reason

- Why the weights should multiply $(1-p)\%$ (dropout rate) when testing?

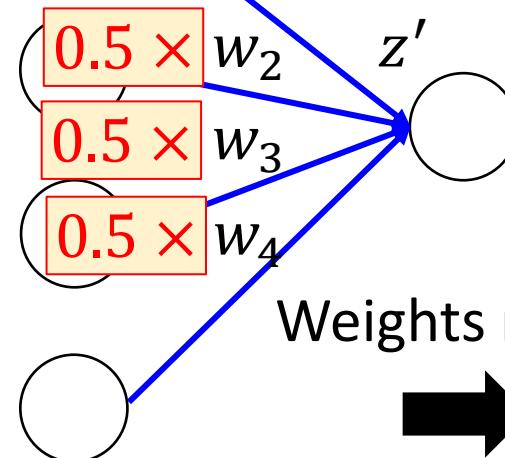
Training of Dropout

Assume dropout rate is 50%



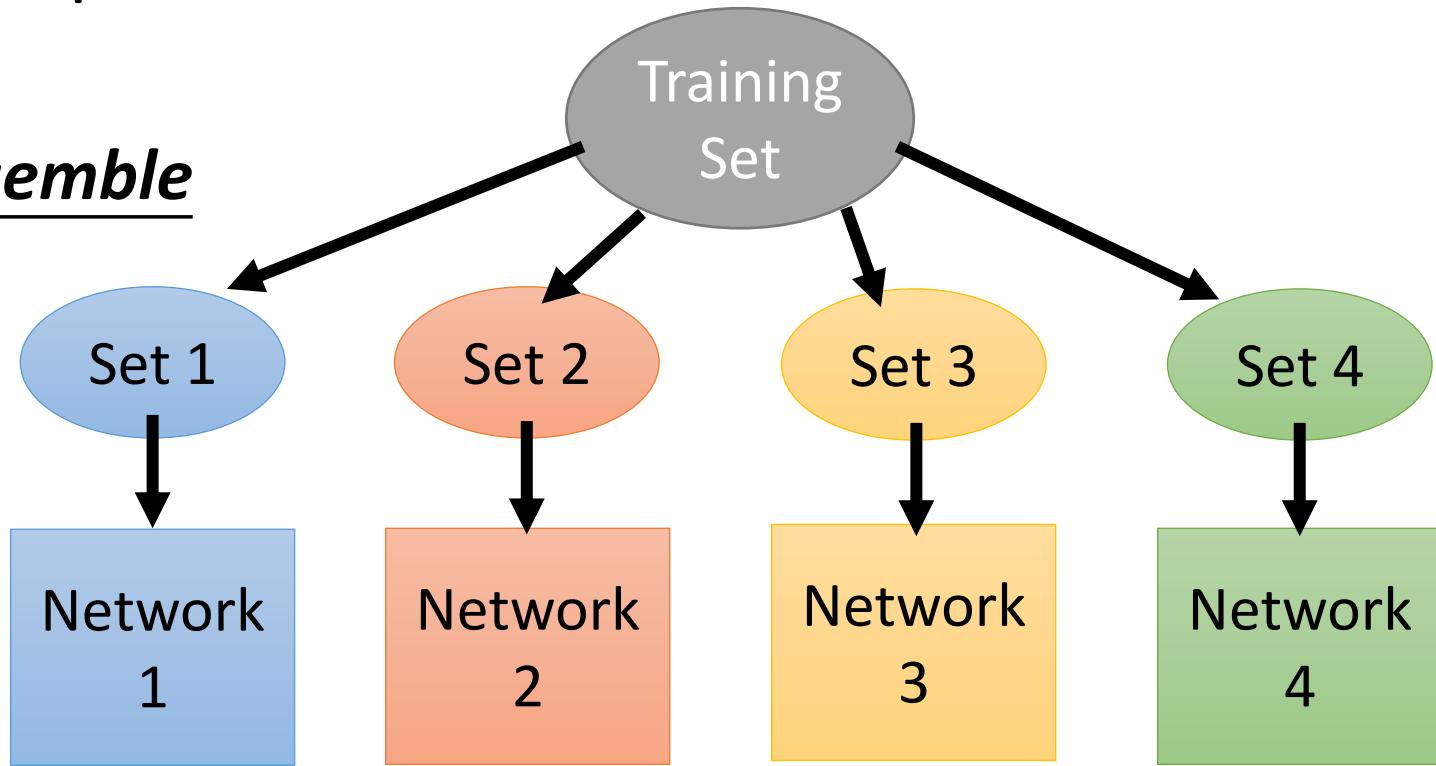
Testing of Dropout

No dropout



Dropout is a kind of ensemble.

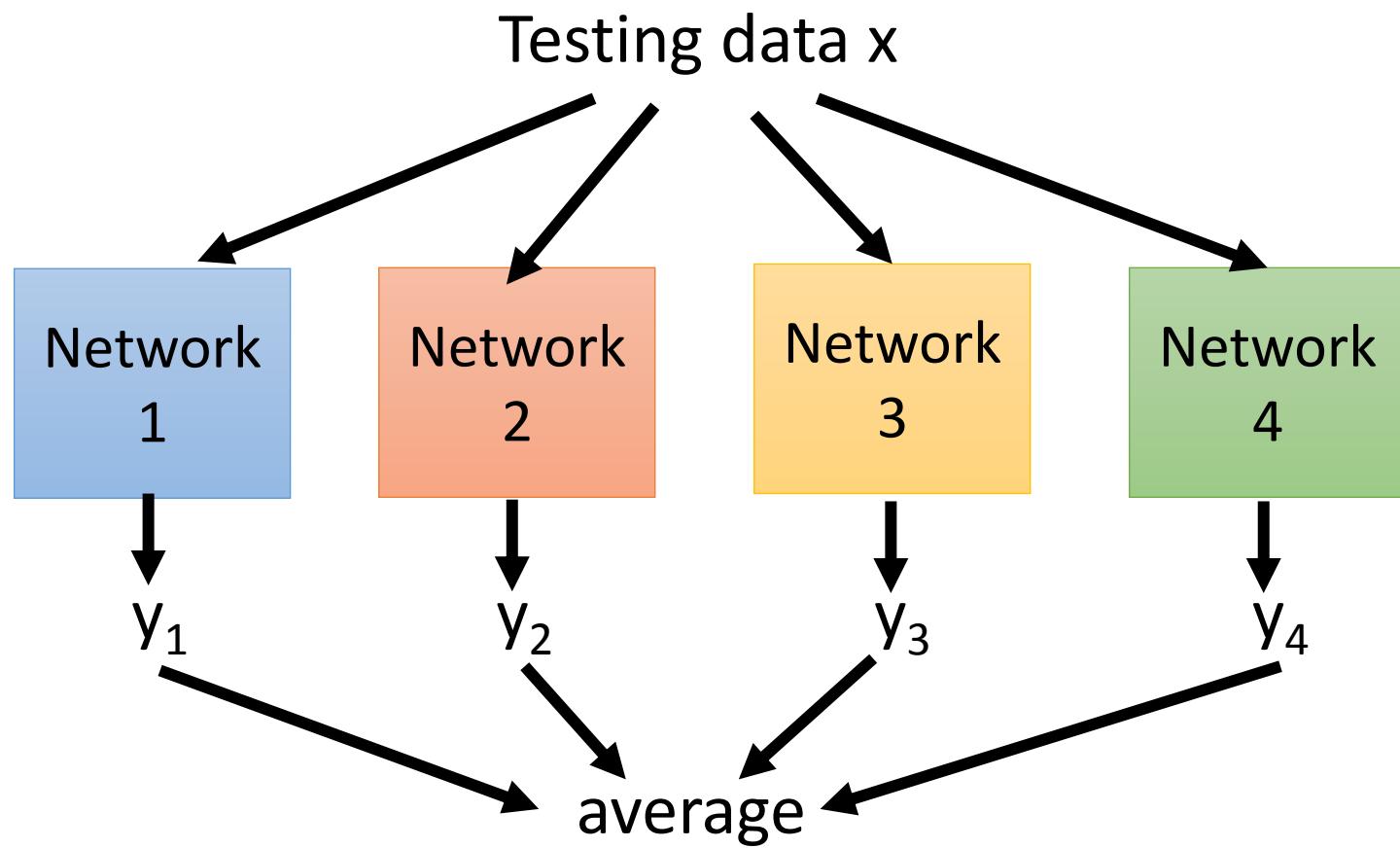
Ensemble



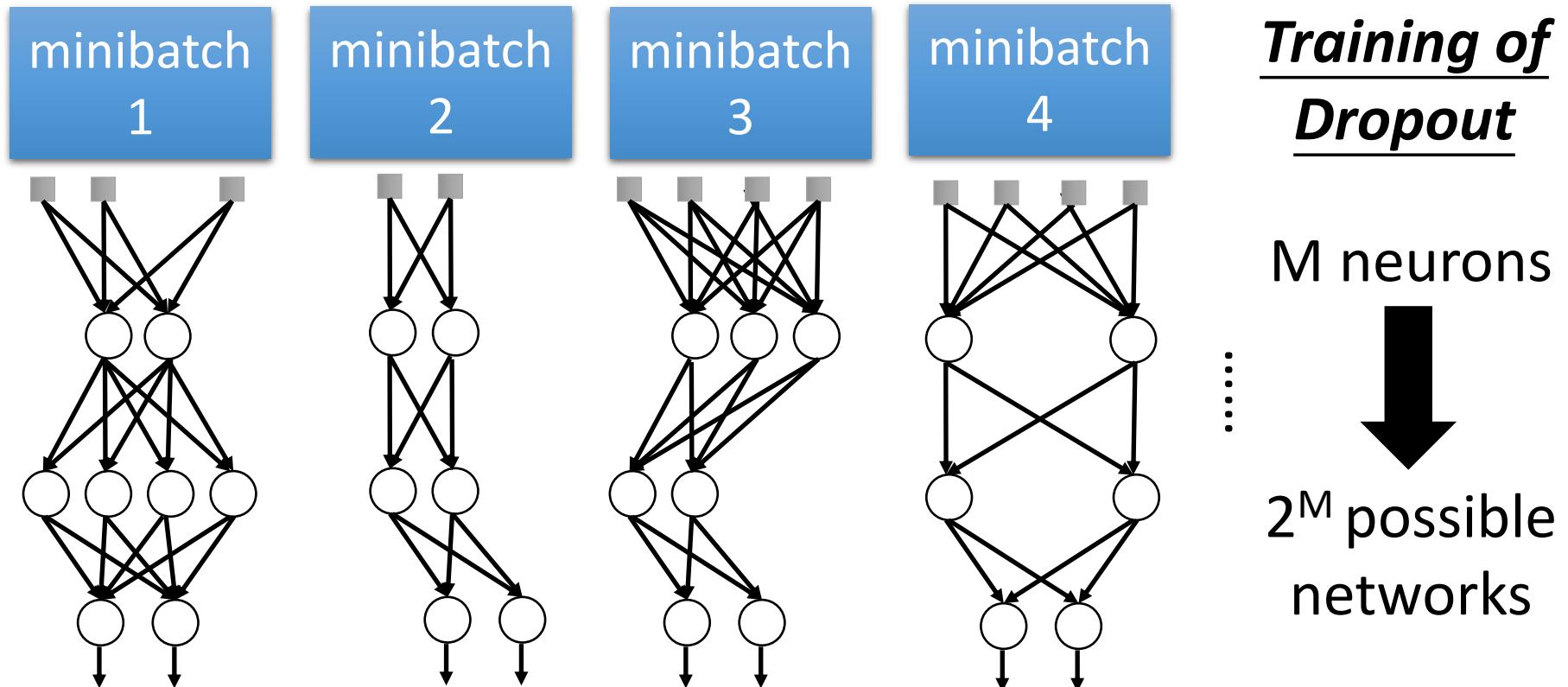
Train a bunch of networks with different structures

Dropout is a kind of ensemble.

Ensemble



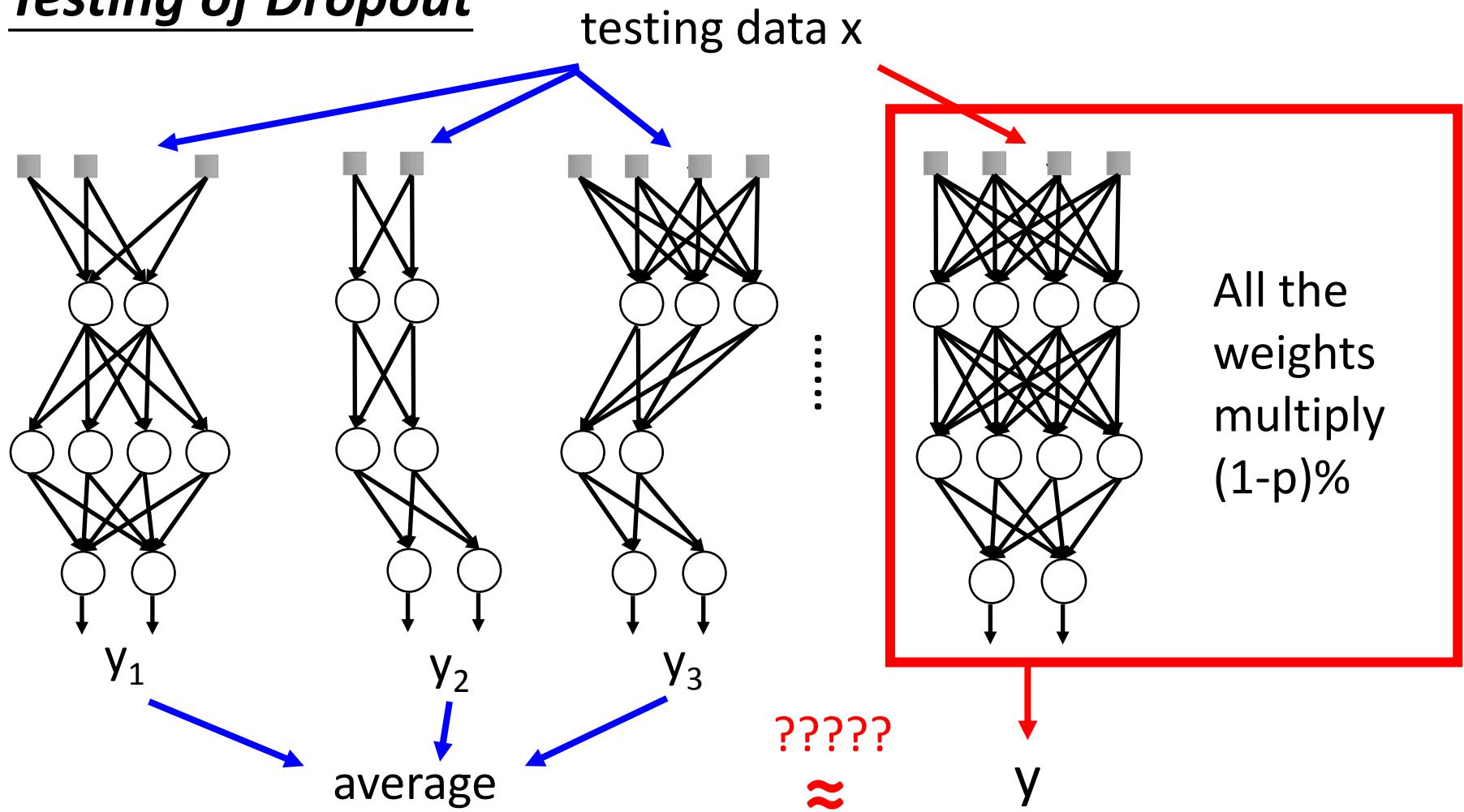
Dropout is a kind of ensemble.



- Using one mini-batch to train one network
- Some parameters in the network are shared

Dropout is a kind of ensemble.

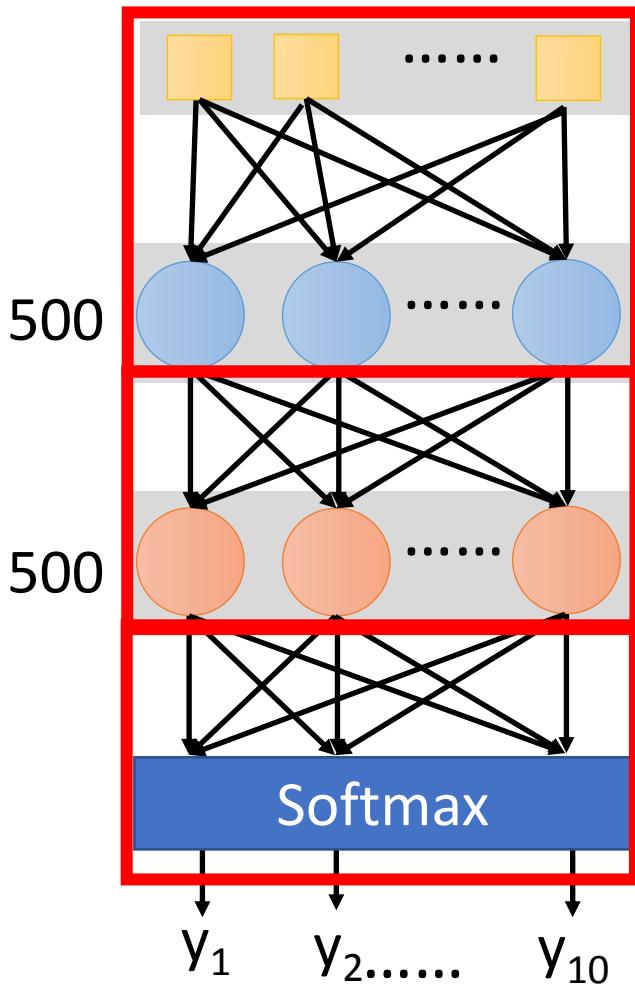
Testing of Dropout



More about dropout

- More reference for dropout [Nitish Srivastava, JMLR'14] [Pierre Baldi, NIPS'13][Geoffrey E. Hinton, arXiv'12]
- Dropout works better with Maxout [Ian J. Goodfellow, ICML'13]
- Dropconnect [Li Wan, ICML'13]
 - Dropout delete neurons
 - Dropconnect deletes the connection between neurons
- Annealed dropout [S.J. Rennie, SLT'14]
 - Dropout rate decreases by epochs
- Standout [J. Ba, NISP'13]
 - Each neural has different dropout rate

Let's try it



```
model = Sequential()
```

```
model.add( Dense( input_dim=28*28,  
                  output_dim=500 ) )  
model.add( Activation('sigmoid') )
```

model.add(dropout(0.8))

```
model.add( Dense( output_dim=500 ) )  
model.add( Activation('sigmoid') )
```

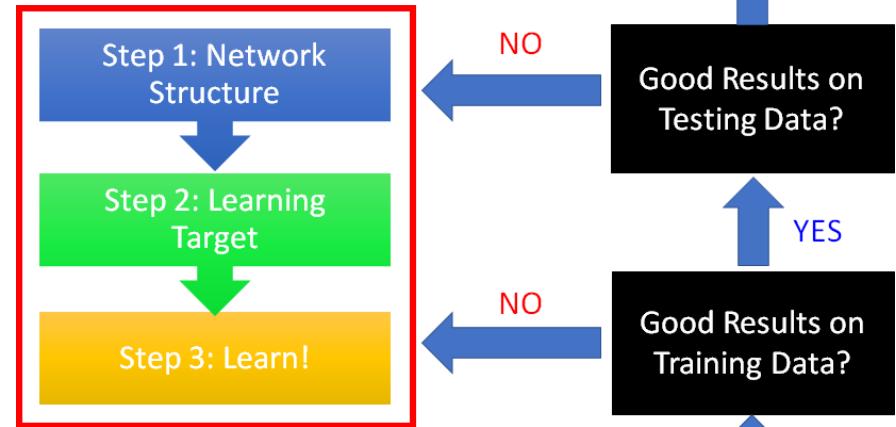
model.add(dropout(0.8))

```
model.add( Dense(output_dim=10) )  
model.add( Activation('softmax') )
```

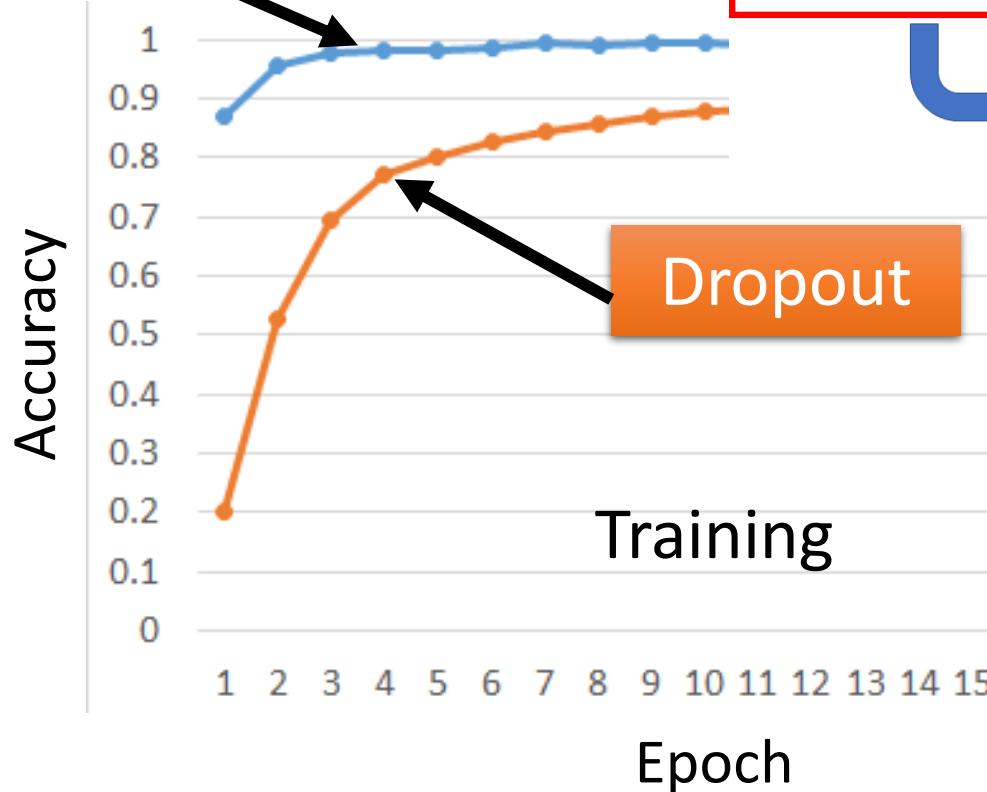


YES

Let's try it



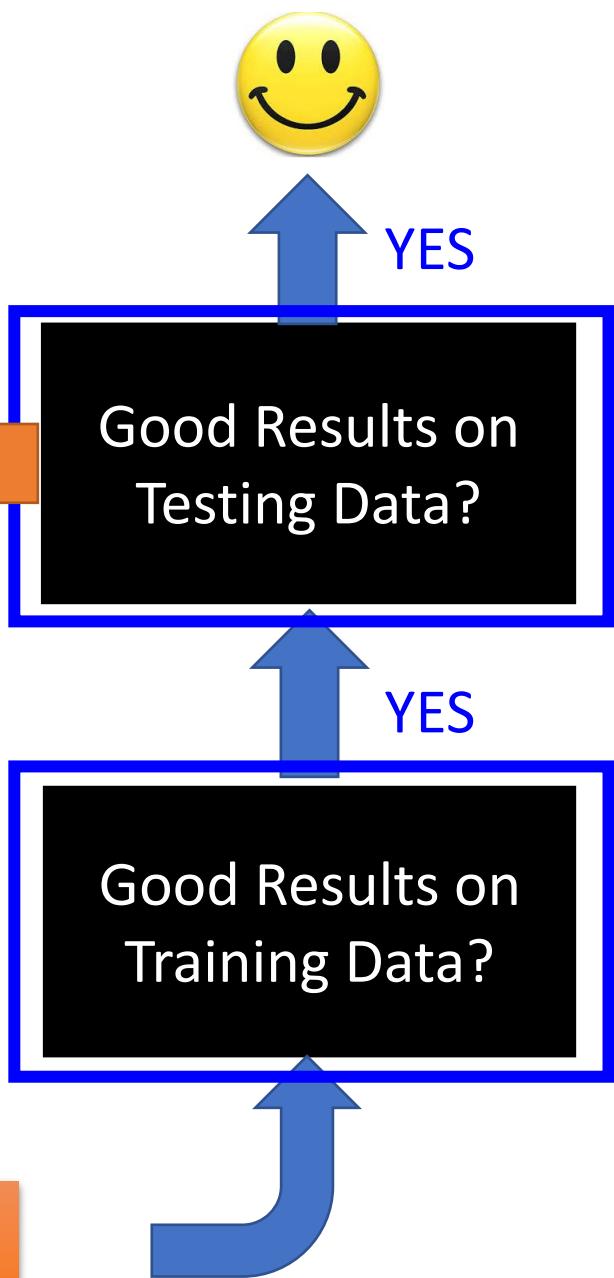
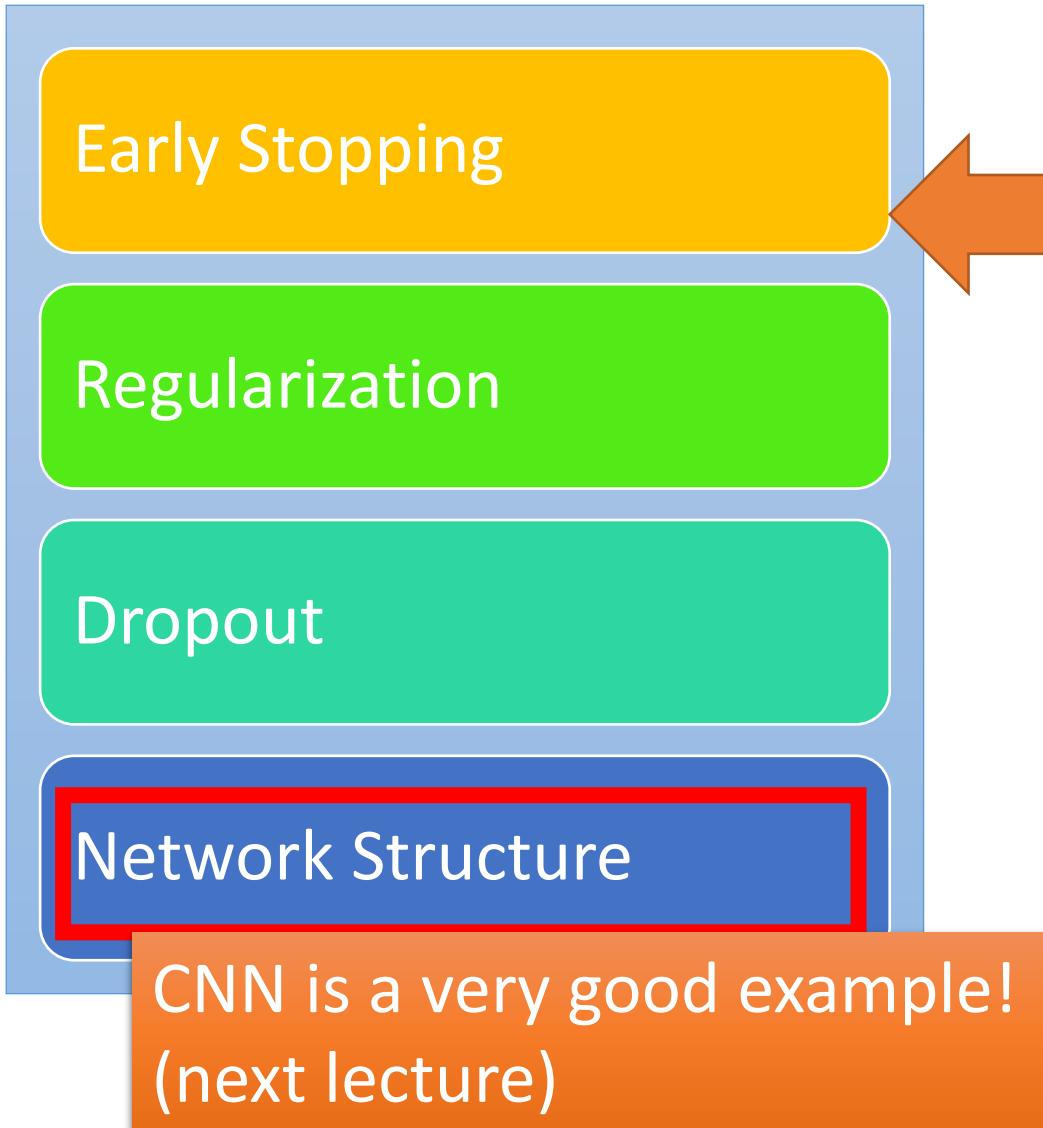
No Dropout



Testing:

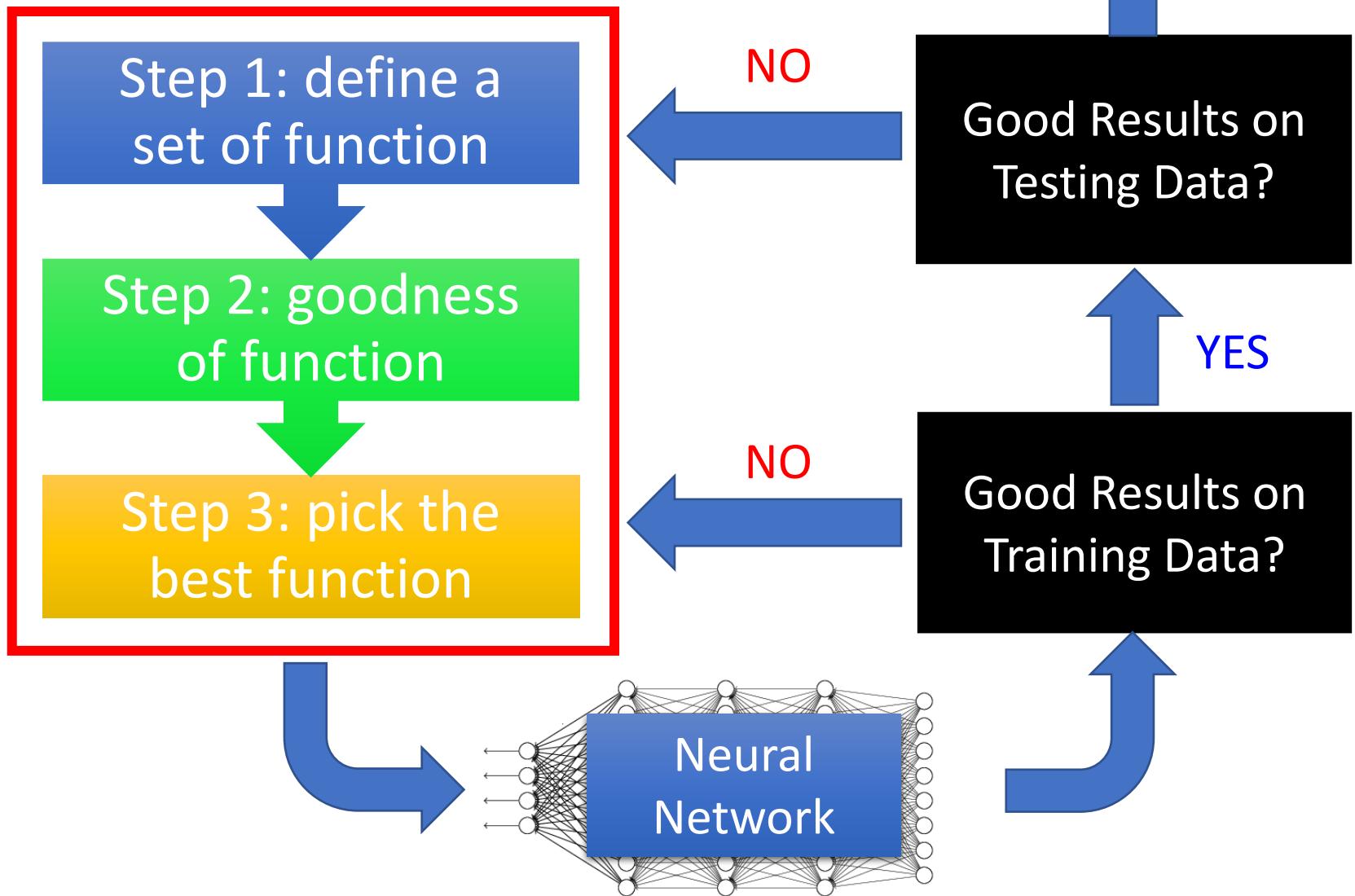
	Accuracy
Noisy	0.50
+ dropout	0.63

Recipe of Deep Learning



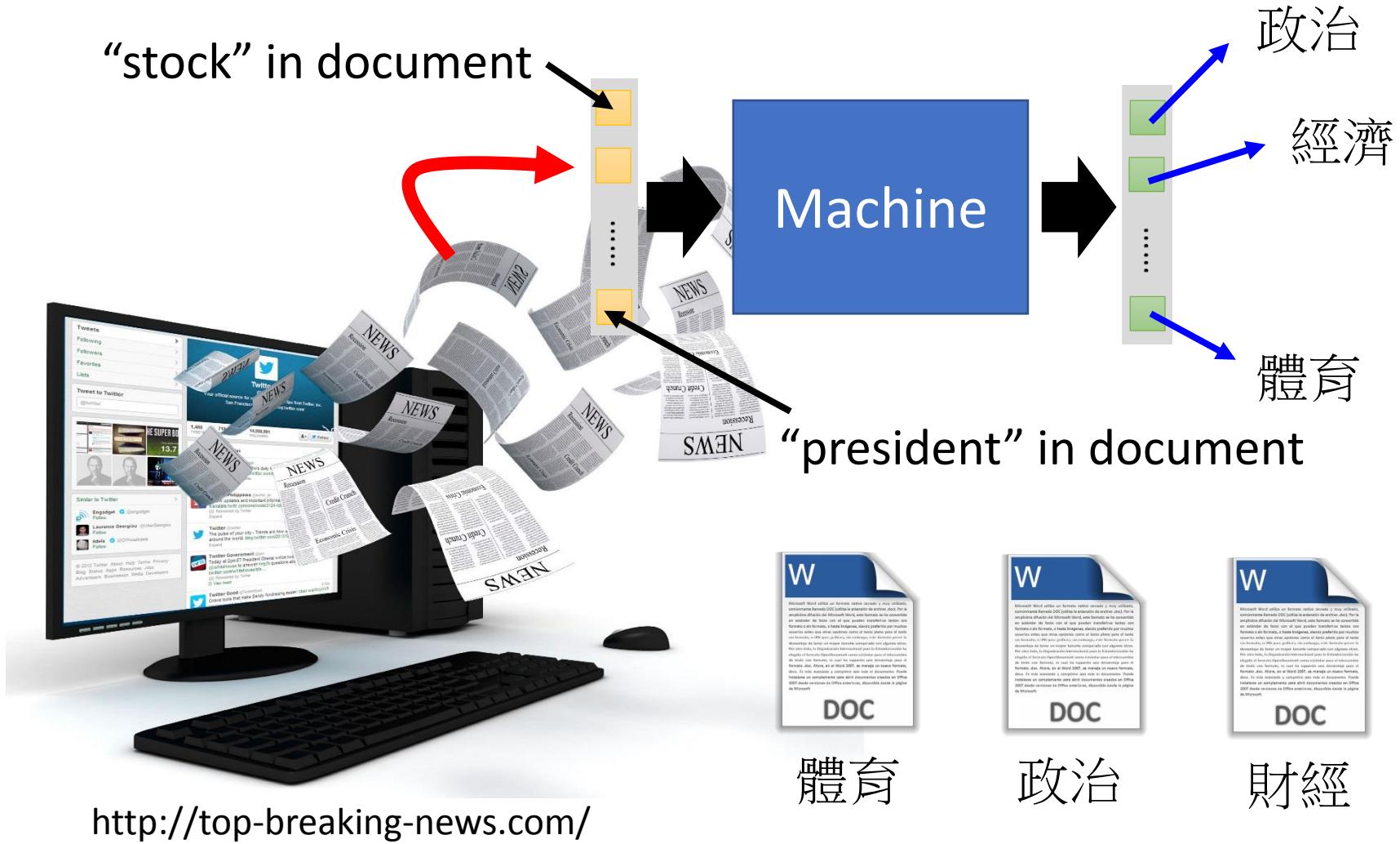
Concluding Remarks of Lecture II

Recipe of Deep Learning



Let's try another task

Document Classification



Data

```
In [8]: x_train.shape  
Out[8]: (8982, 1000)
```

```
In [9]: y_train.shape  
Out[9]: (8982, 46)
```

```
In [12]: x_train[0]
```

Out[12]:

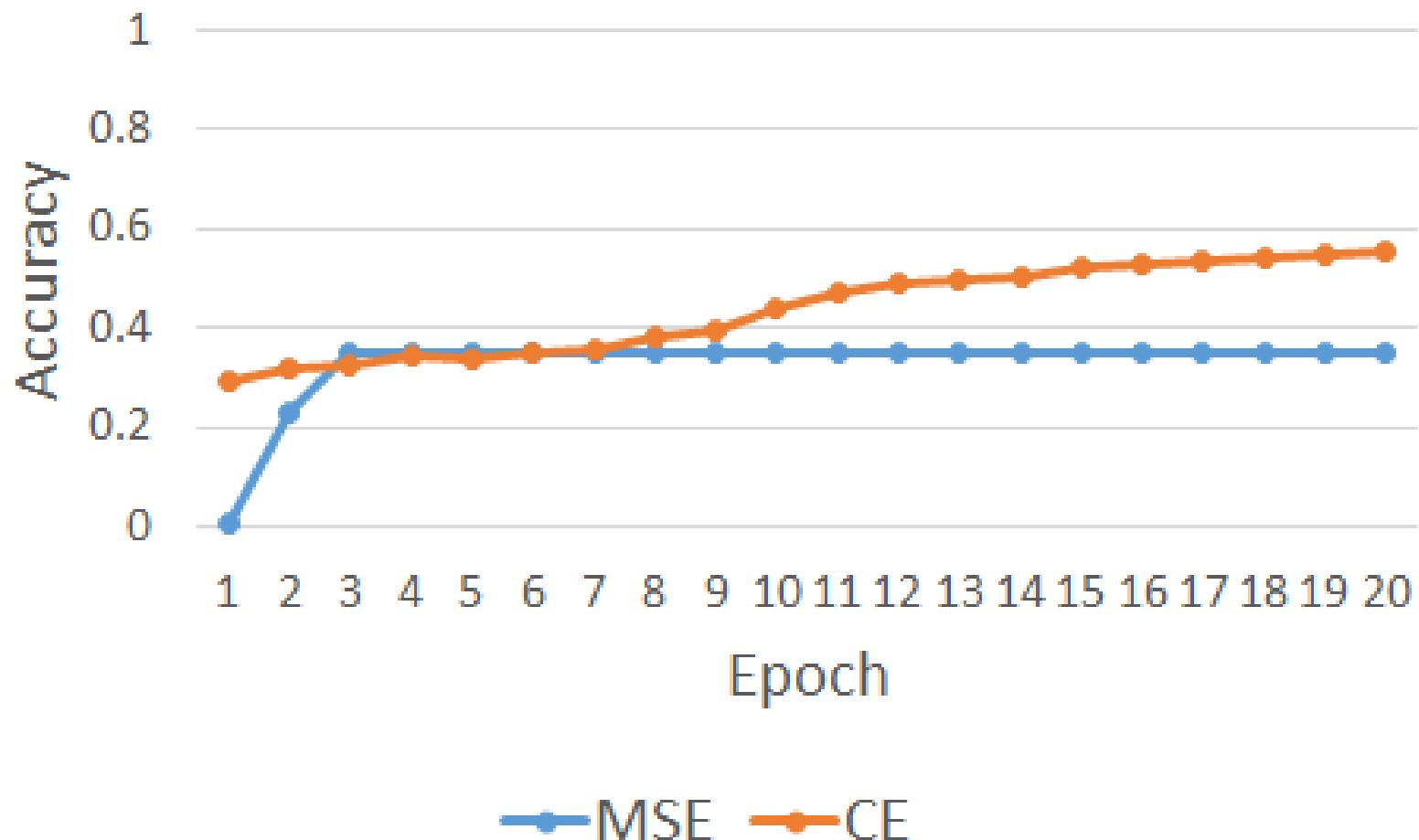
```
In [10]: x_test.shape
```

```
In [11]: y_test.shape  
Out[11]: (2246, 46)
```

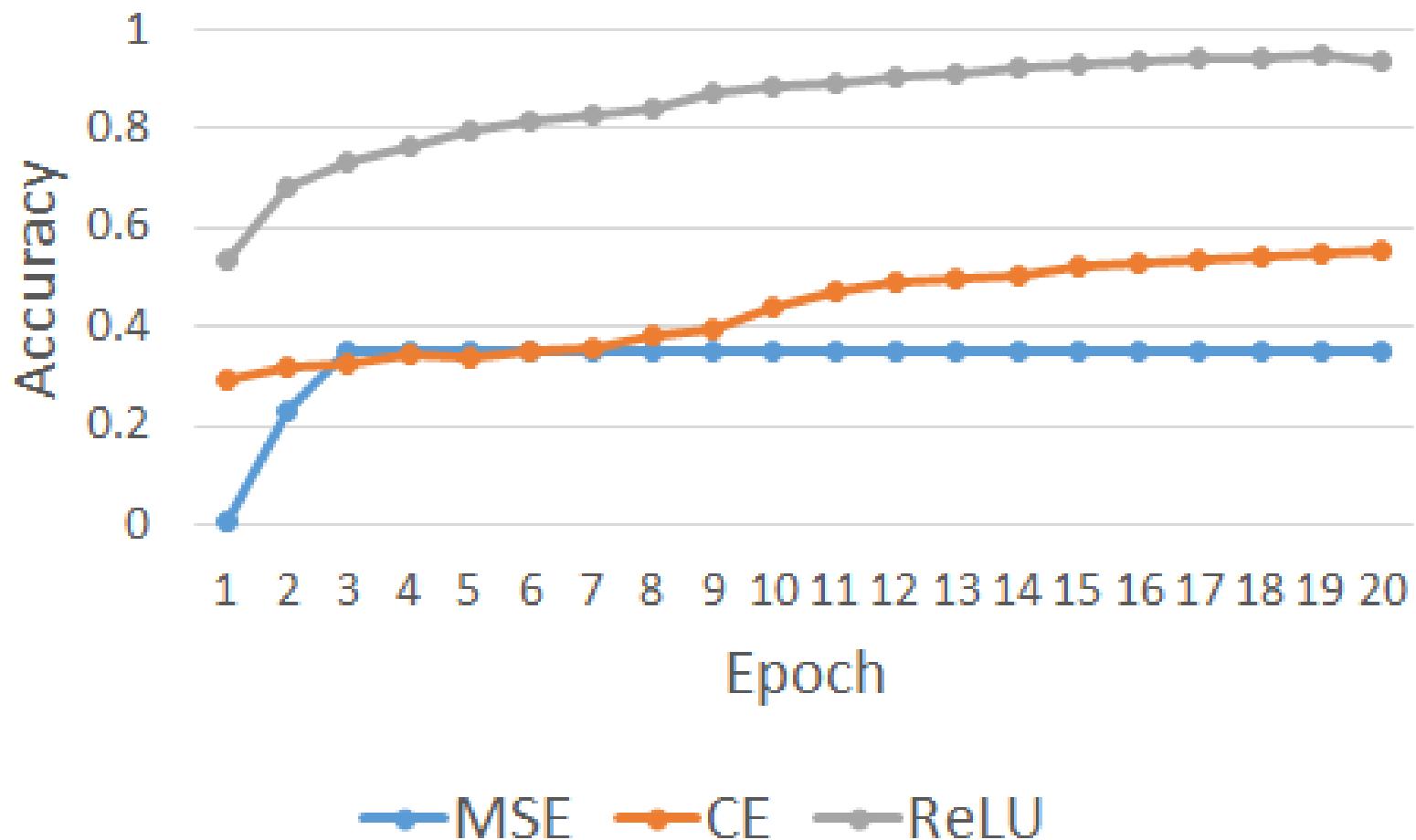
```
In [13]: y_train[0]
```

Out[13]:

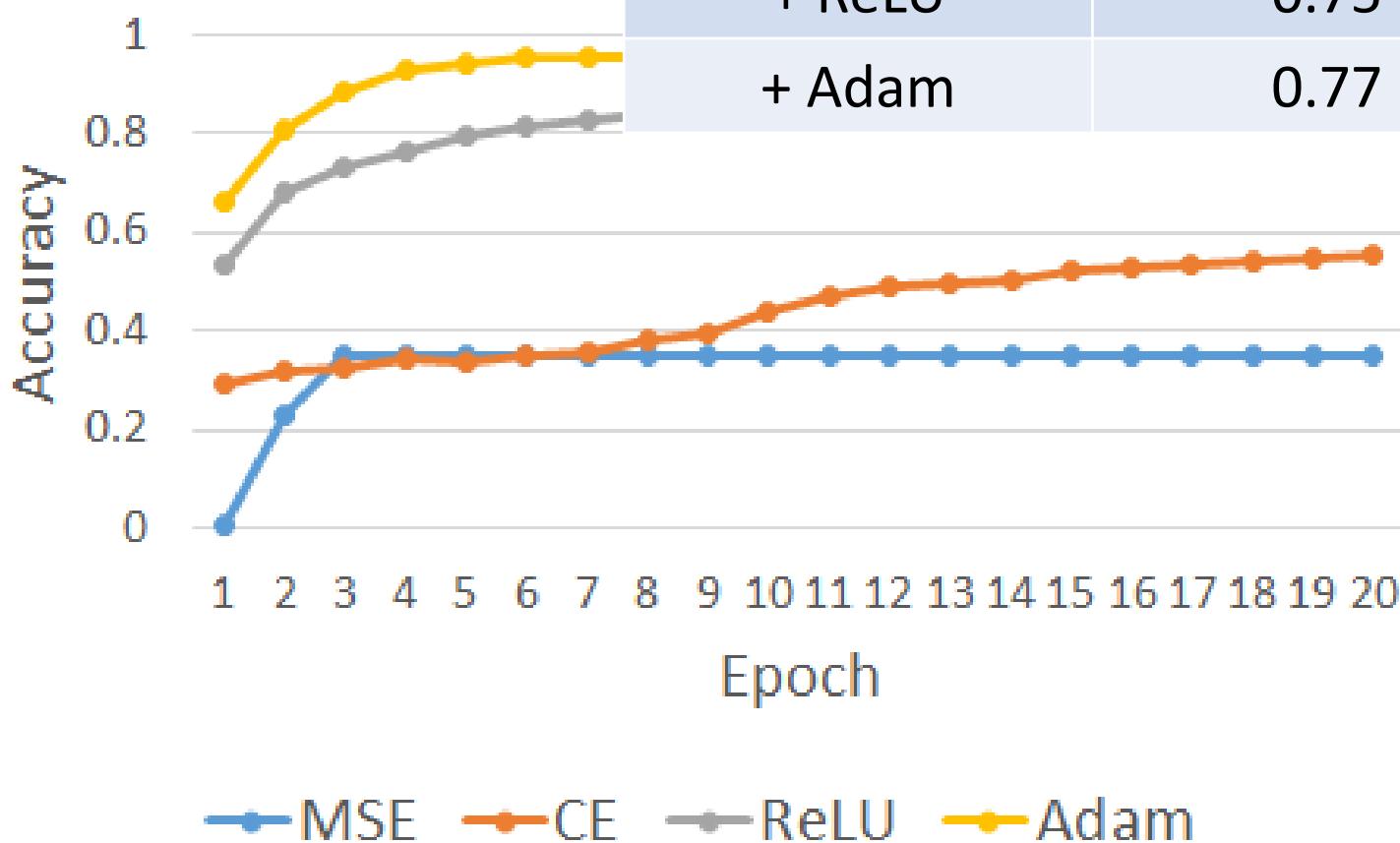
MSE



ReLU

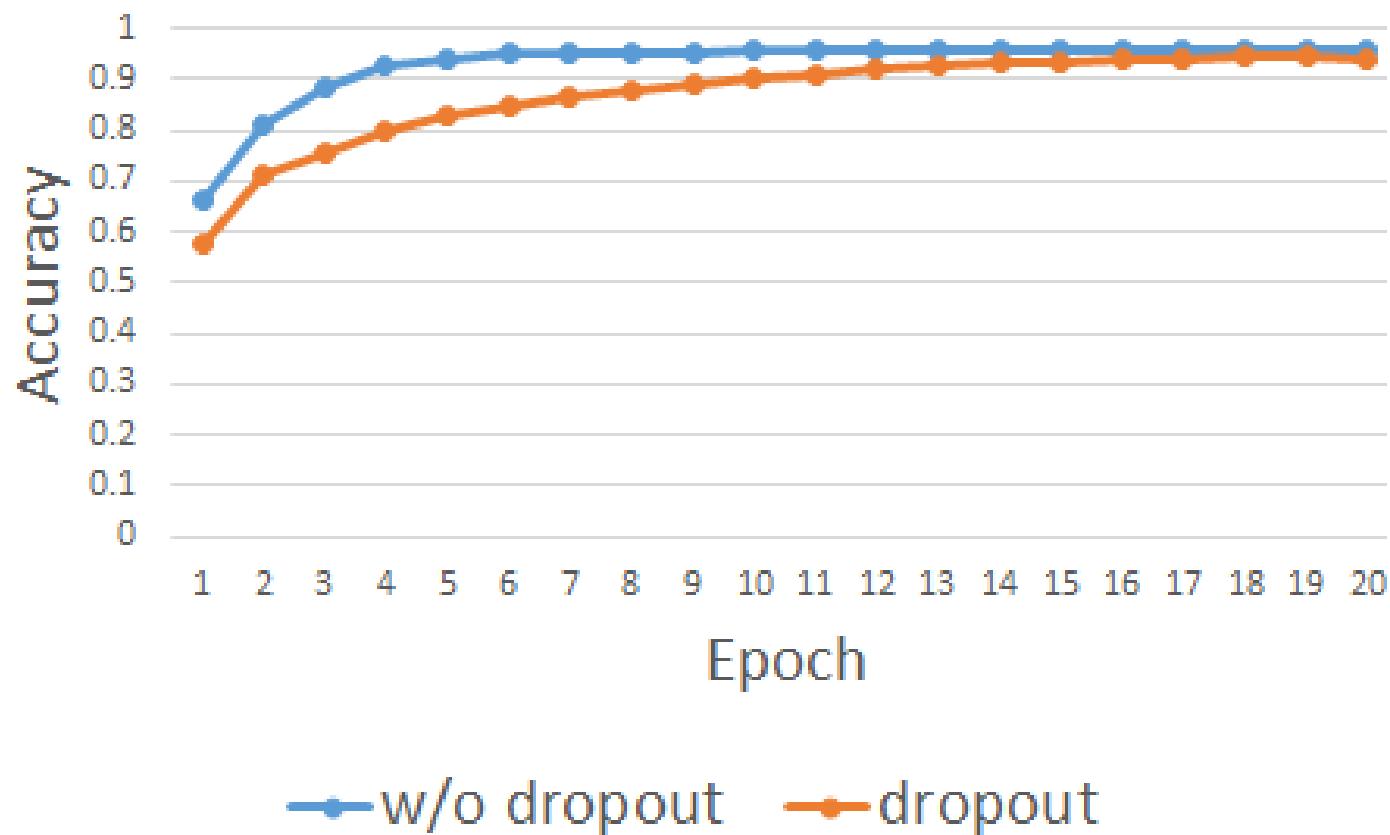


Adaptive Learn



Dropout

	Accuracy
Adam	0.77
+ dropout	0.79



Lecture III:

Variants of Neural Networks

Variants of Neural Networks

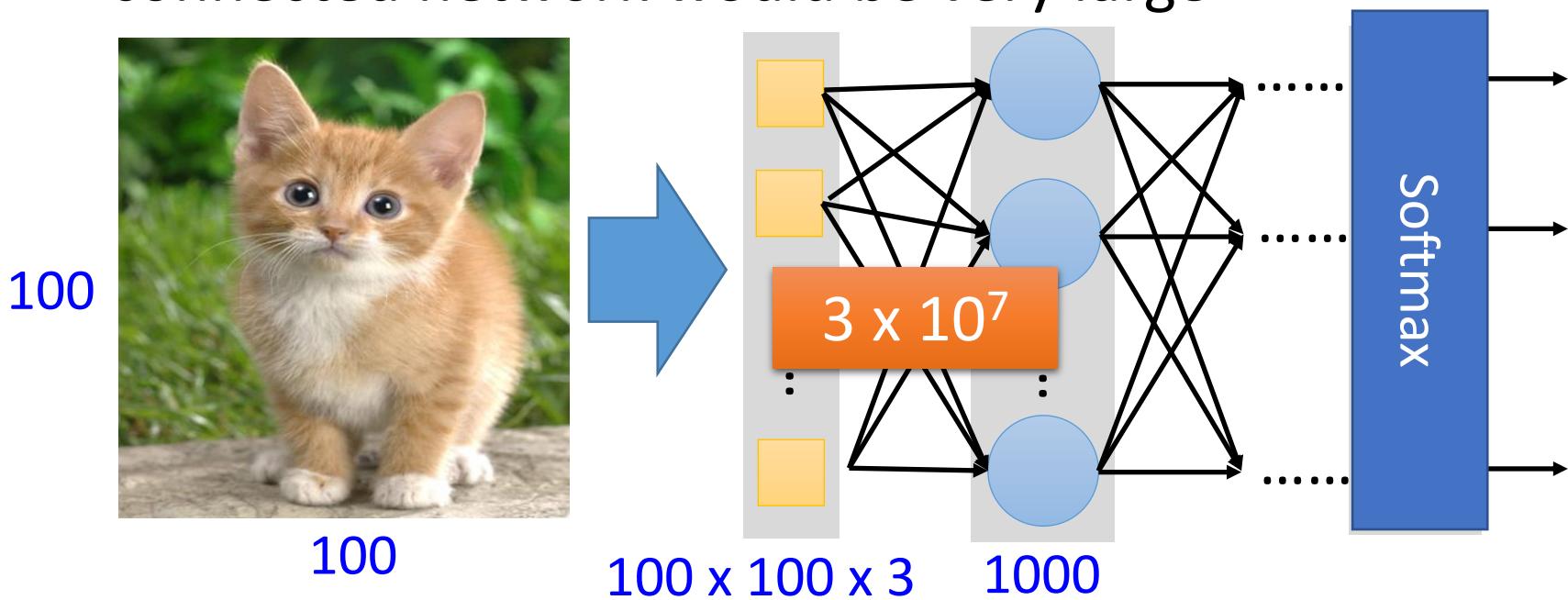
Convolutional Neural
Network (CNN)

Widely used in
image processing

Recurrent Neural Network
(RNN)

Why CNN for Image?

- When processing image, the first layer of fully connected network would be very large



Can the fully connected network be simplified by considering the properties of image recognition?

Why CNN for Image

- Some patterns are much smaller than the whole image

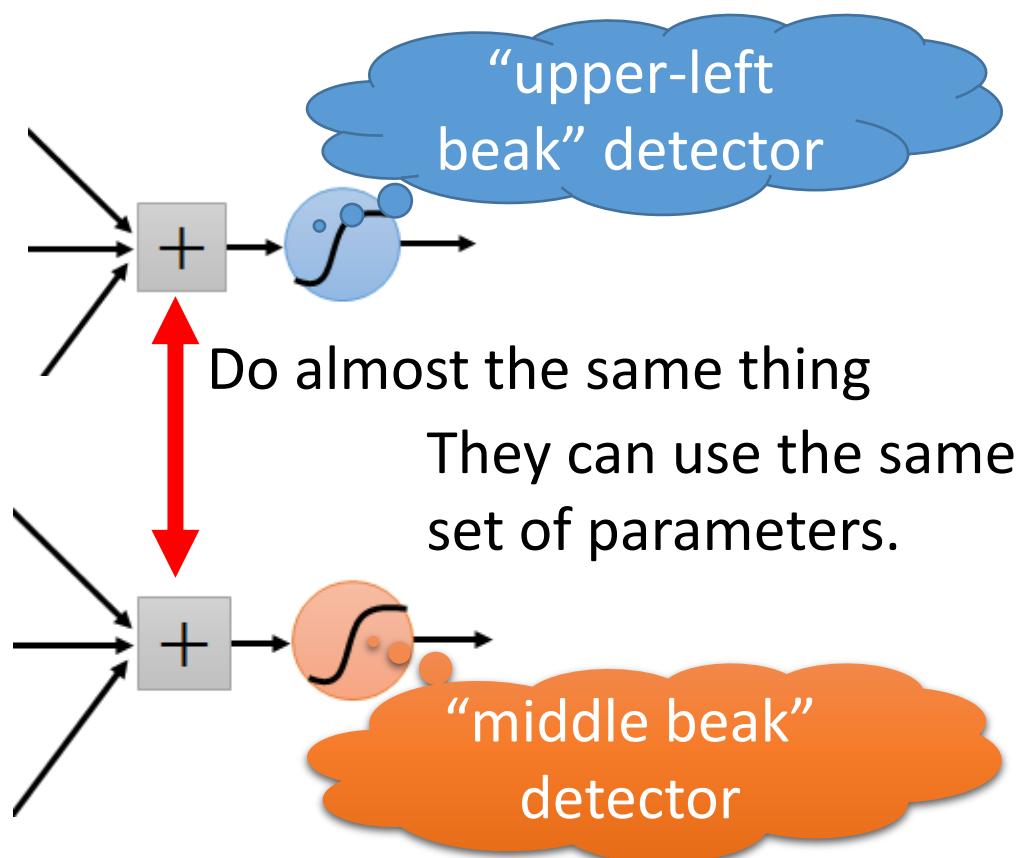
A neuron does not have to see the whole image to discover the pattern.

Connecting to small region with less parameters



Why CNN for Image

- The same patterns appear in different regions.



Why CNN for Image

- Subsampling the pixels will not change the object

bird



subsampling

bird



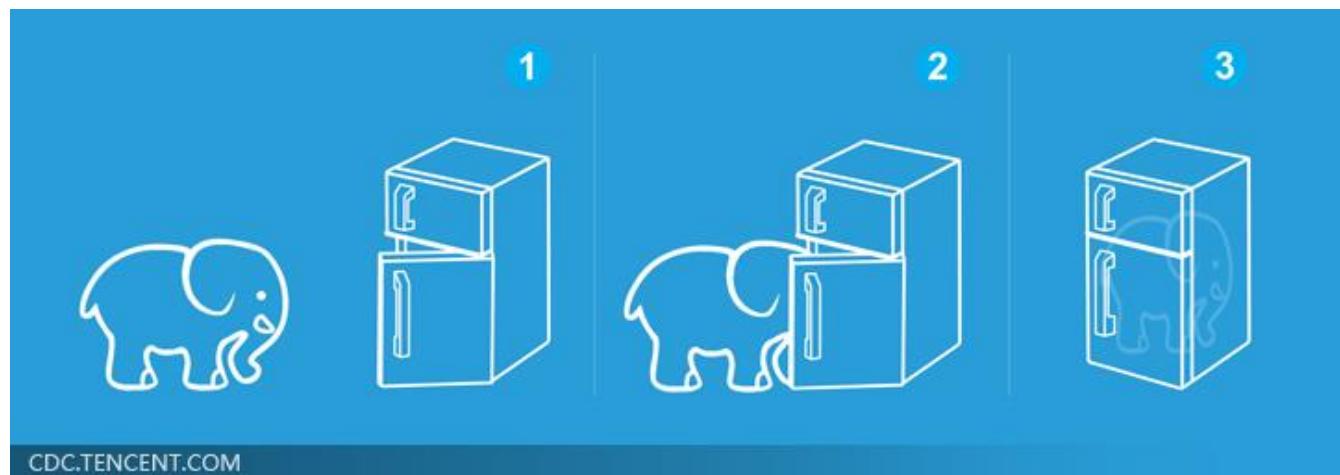
We can subsample the pixels to make image smaller

→ Less parameters for the network to process the image

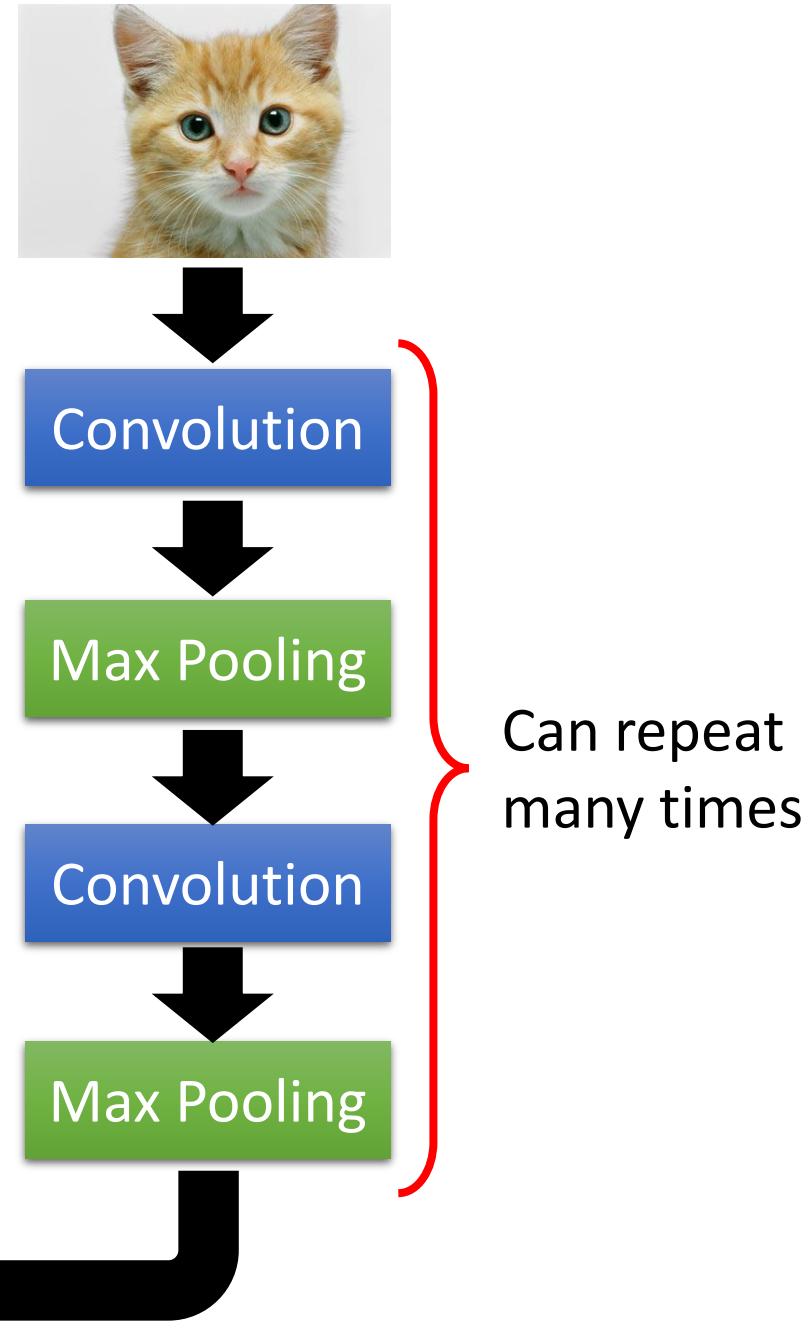
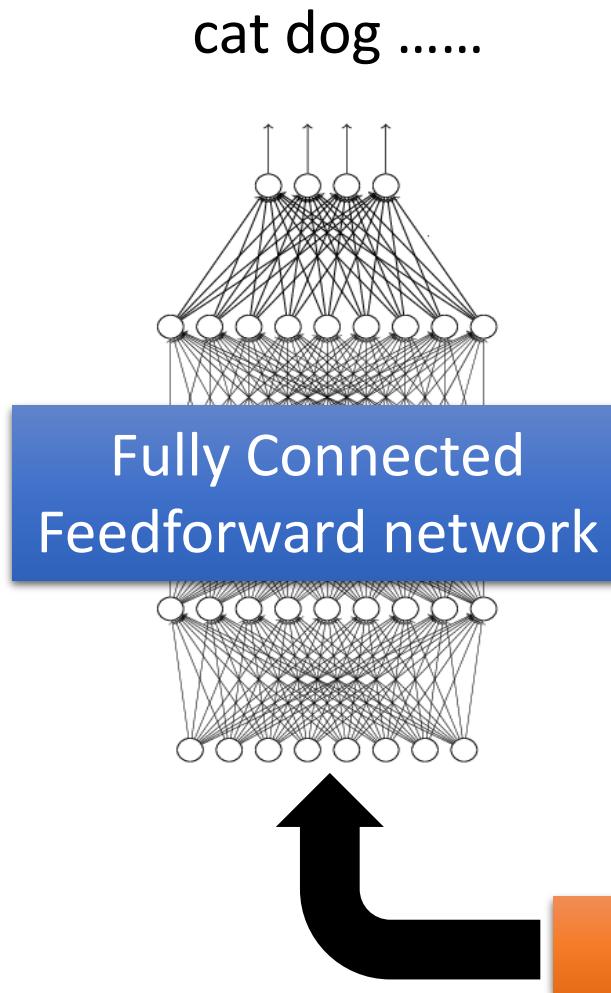
Three Steps for Deep Learning



Deep Learning is so simple



The whole CNN



The whole CNN

Property 1

- Some patterns are much smaller than the whole image

Property 2

- The same patterns appear in different regions.

Property 3

- Subsampling the pixels will not change the object



Convolution

Max Pooling

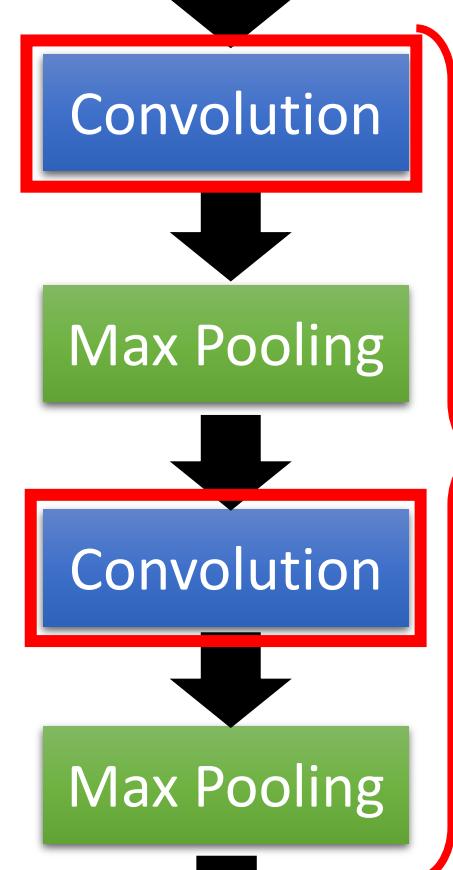
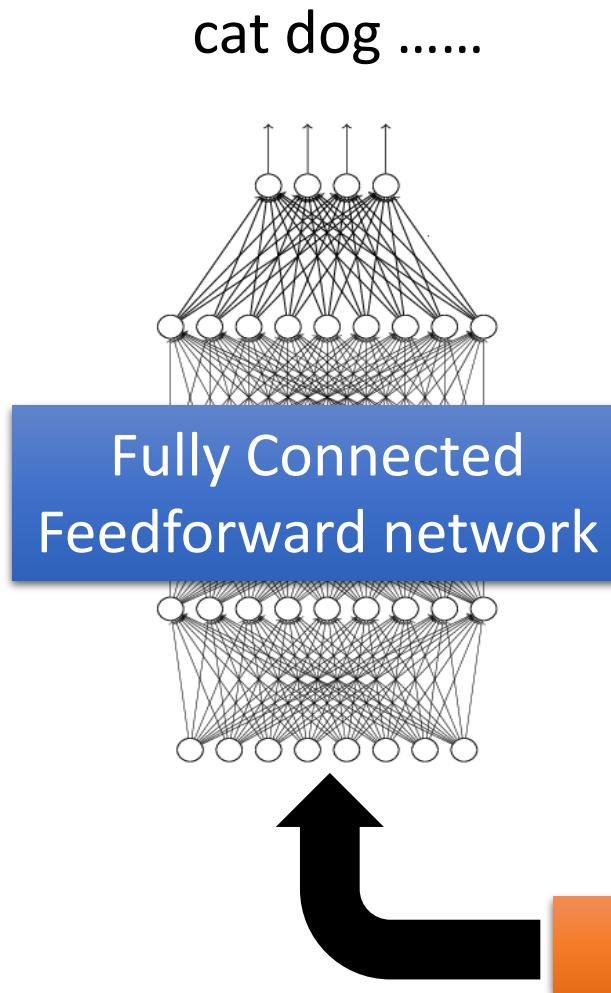
Convolution

Max Pooling

Flatten



The whole CNN



Can repeat
many times

Flatten

CNN – Convolution

Those are the network parameters to be learned.

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

6 x 6 image

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

Filter 1
Matrix

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

Filter 2
Matrix

⋮

Property 1

Each filter detects a small pattern (3 x 3).

CNN – Convolution

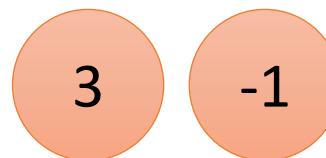
stride=1

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

6 x 6 image

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

Filter 1



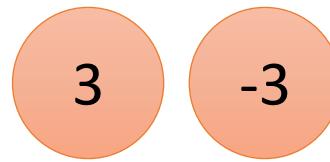
CNN – Convolution

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

Filter 1

If stride=2

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

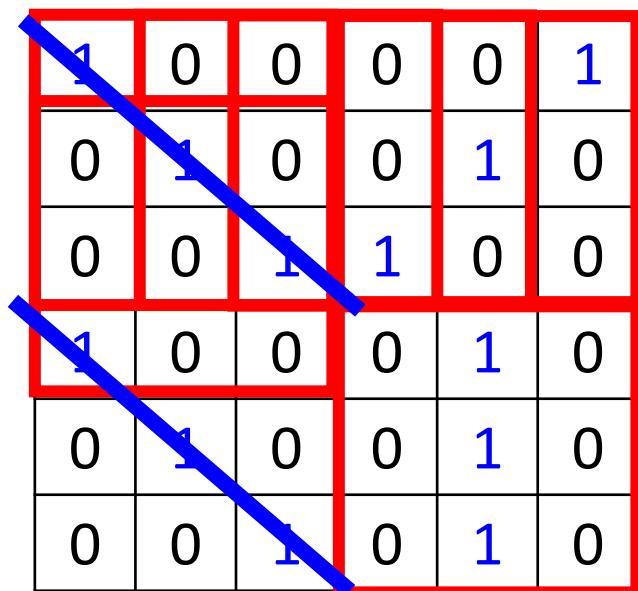


We set stride=1 below

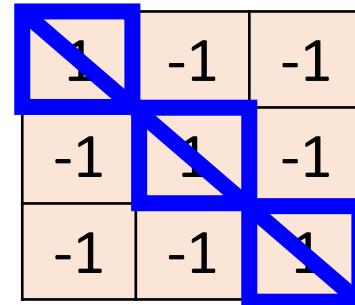
6 x 6 image

CNN – Convolution

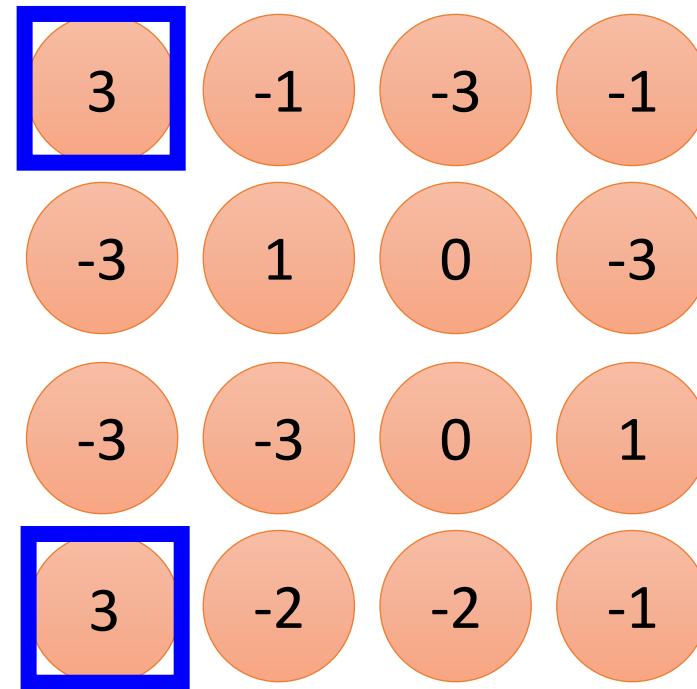
stride=1



6 x 6 image



Filter 1



Property 2

CNN – Convolution

stride=1

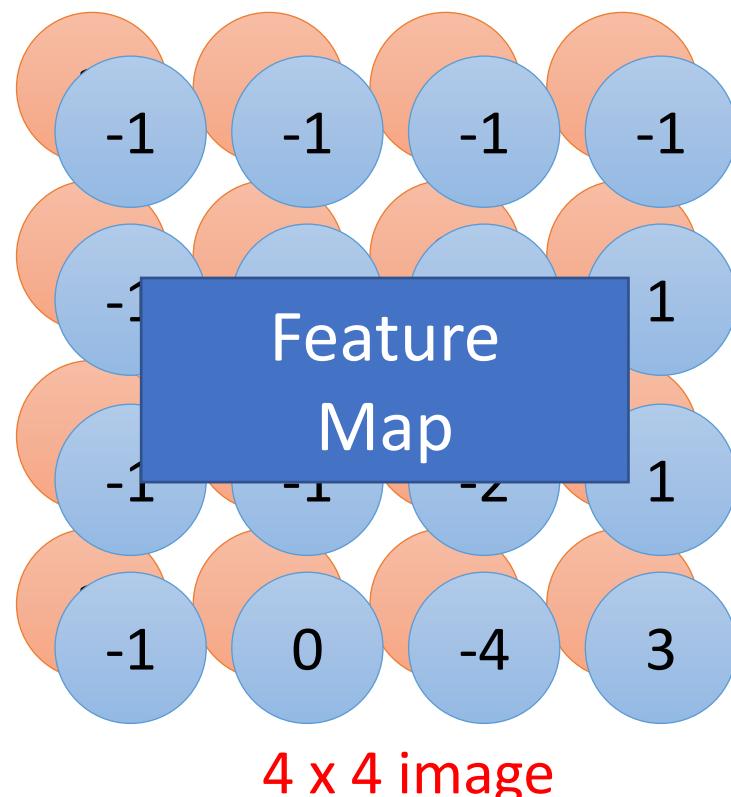
1	0	0	0	0	1
0	1	0	0	1	0
0	0	1	1	0	0
1	0	0	0	1	0
0	1	0	0	1	0
0	0	1	0	1	0

6 x 6 image

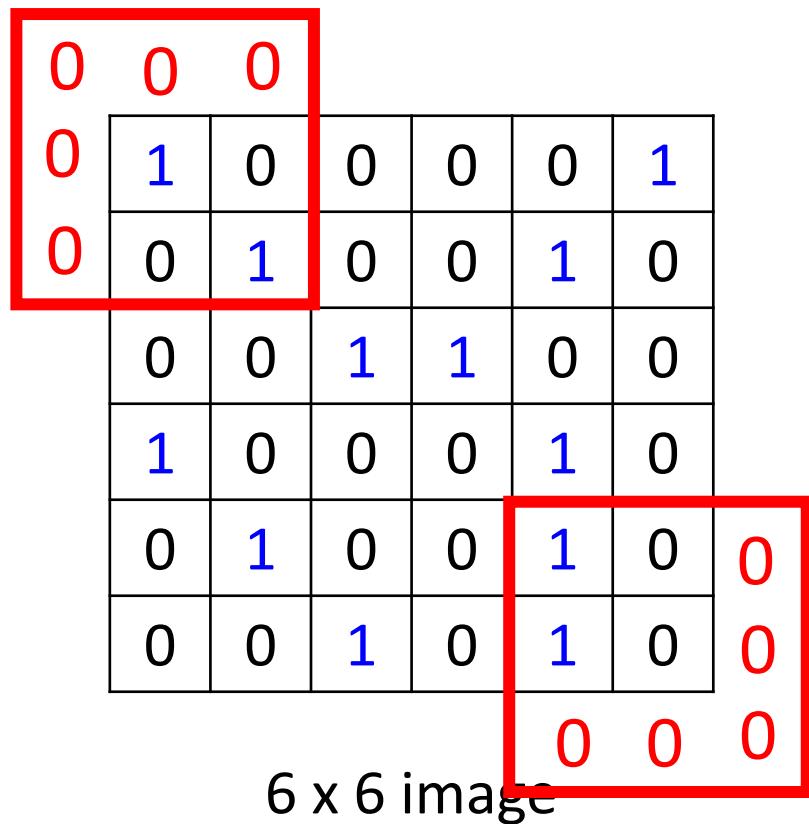
-1	1	-1
-1	1	-1
-1	1	-1

Filter 2

Do the same process for every filter



CNN – Zero Padding



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

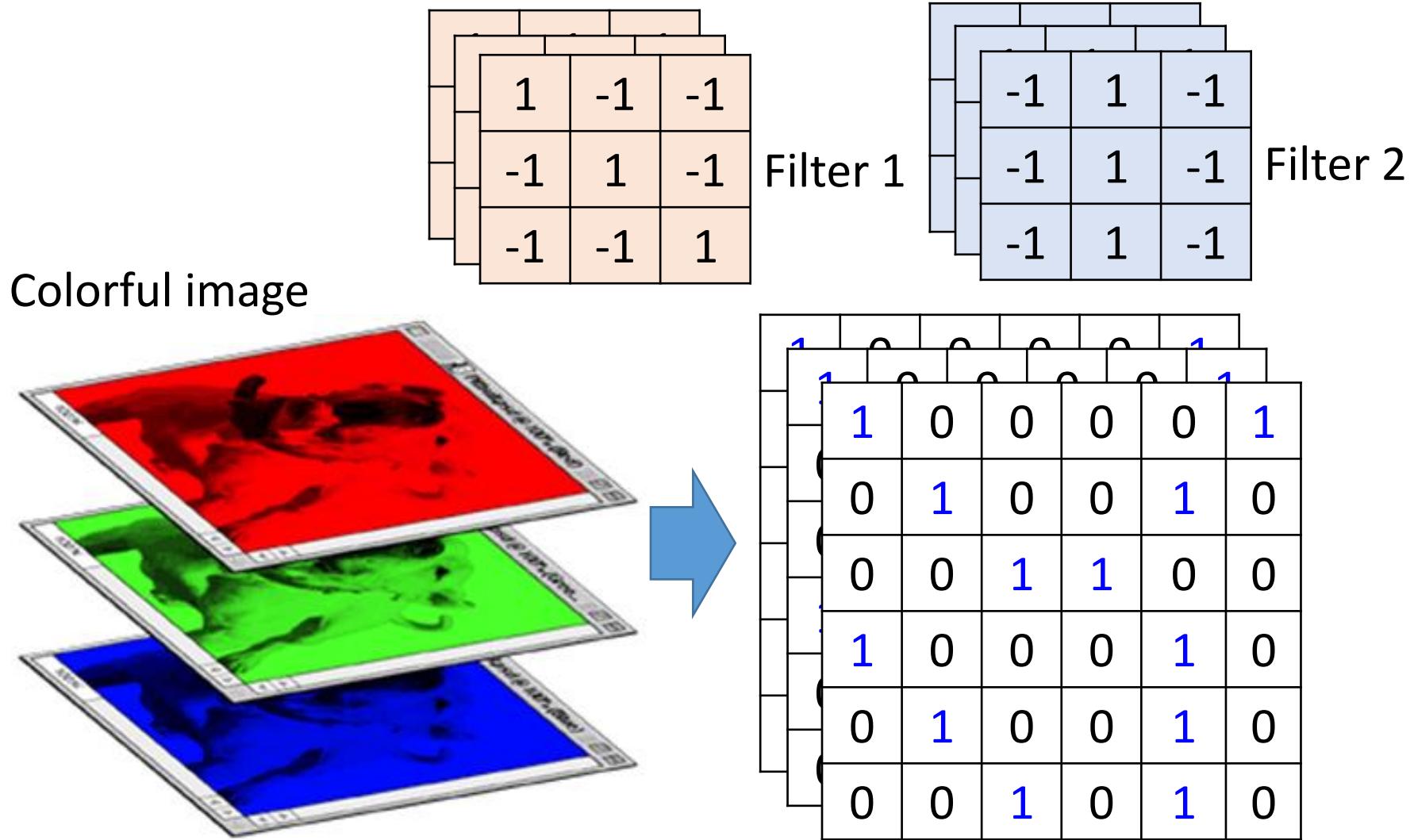
Filter 1

You will get another 6×6 images in this way

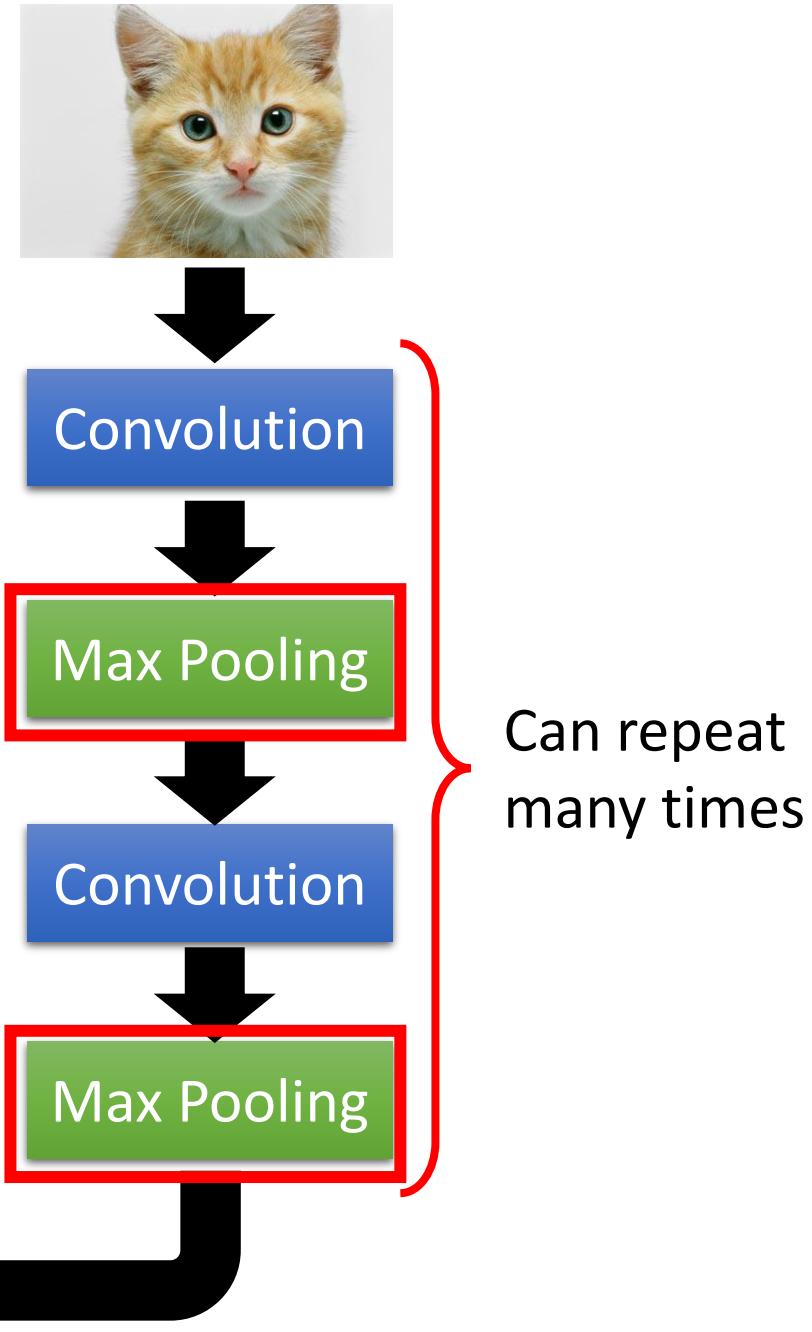
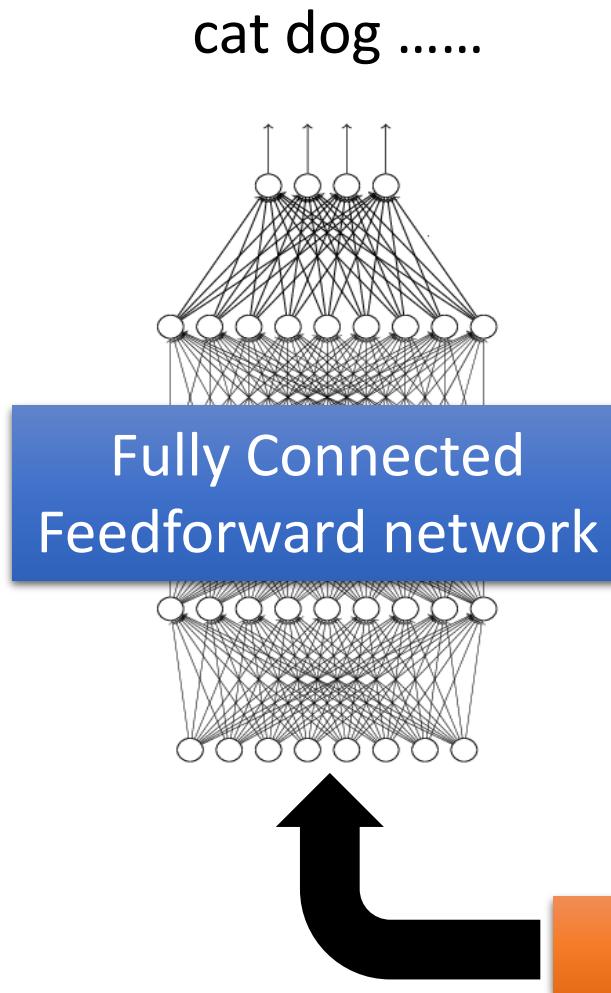


Zero padding

CNN – Colorful image



The whole CNN



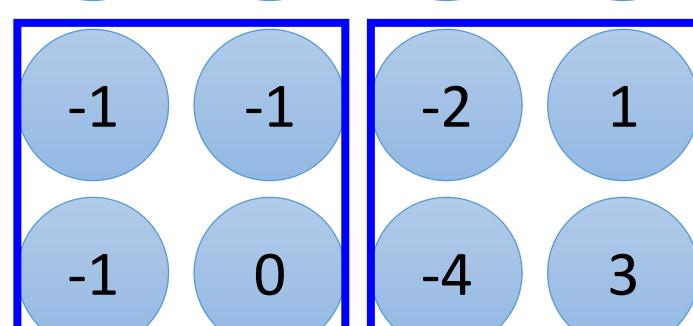
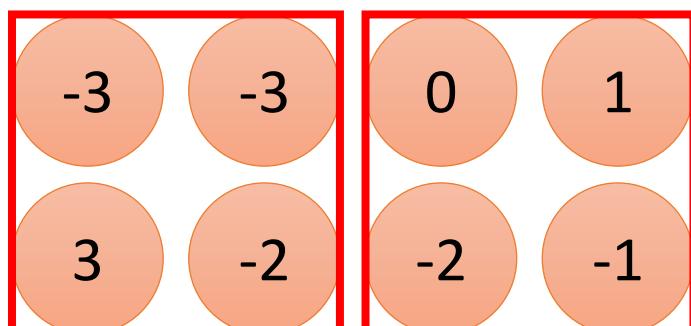
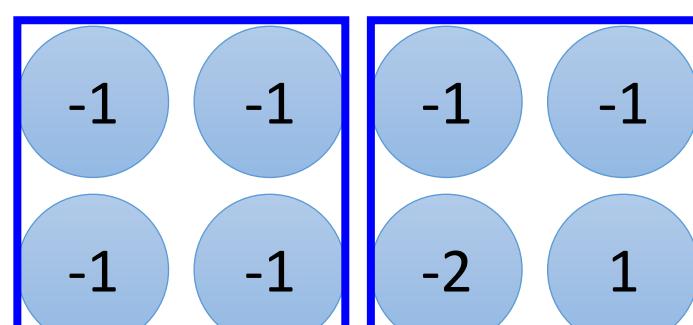
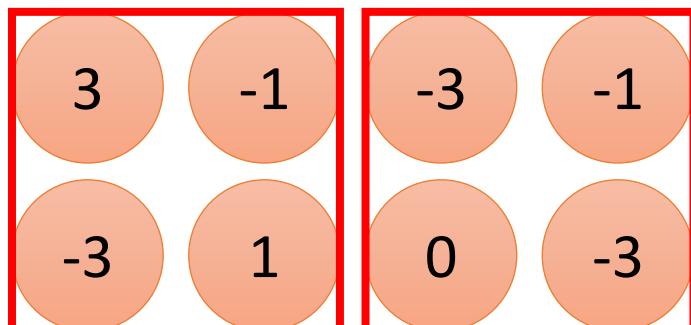
CNN – Max Pooling

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

Filter 1

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

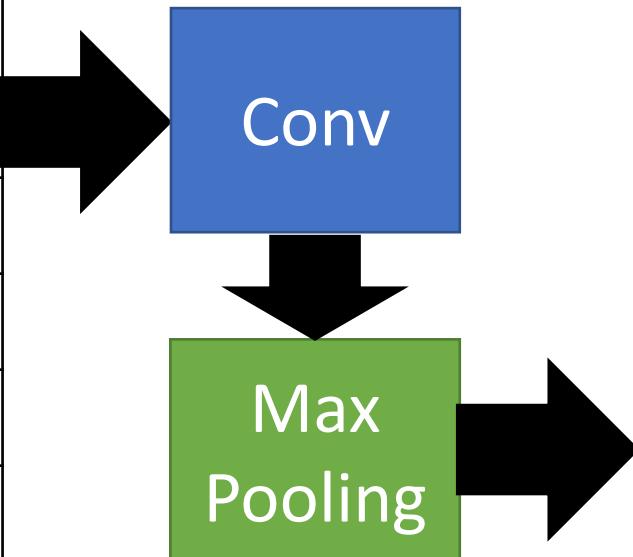
Filter 2



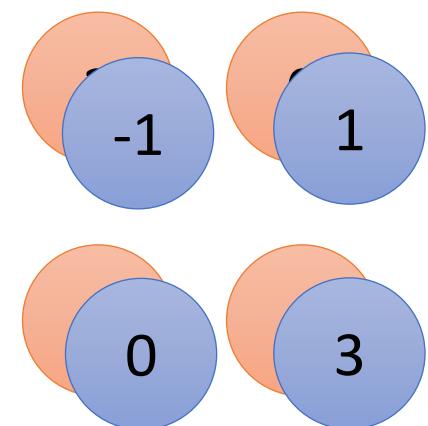
CNN – Max Pooling

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

6 x 6 image



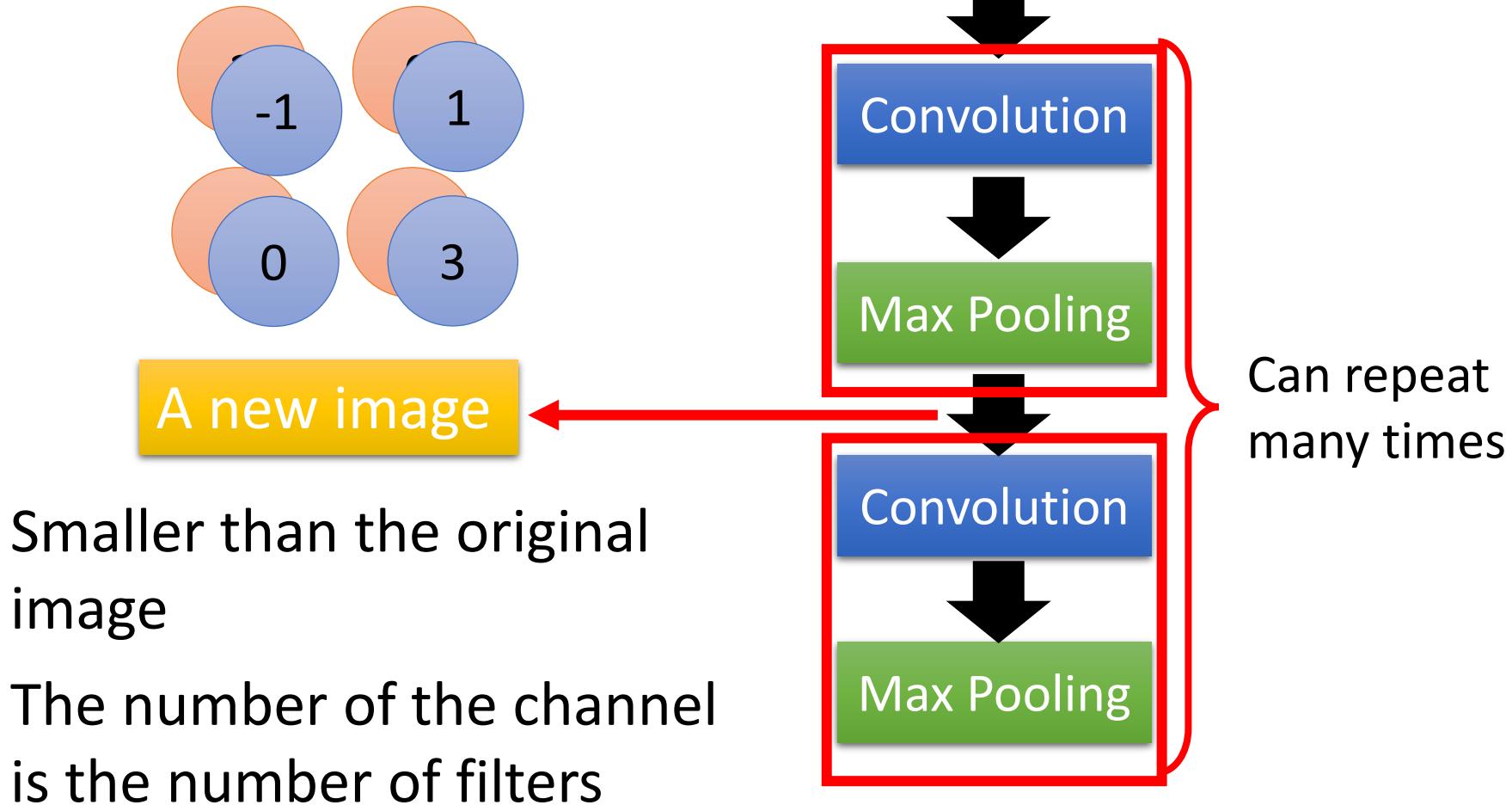
New image
but smaller



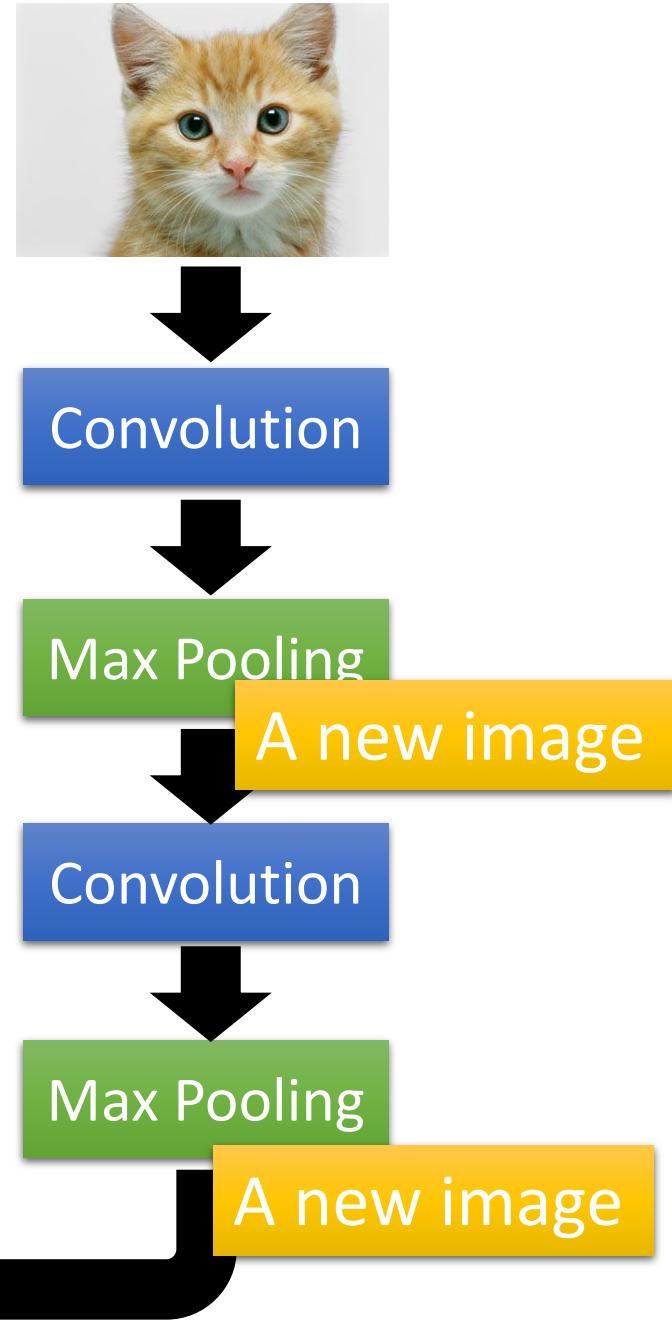
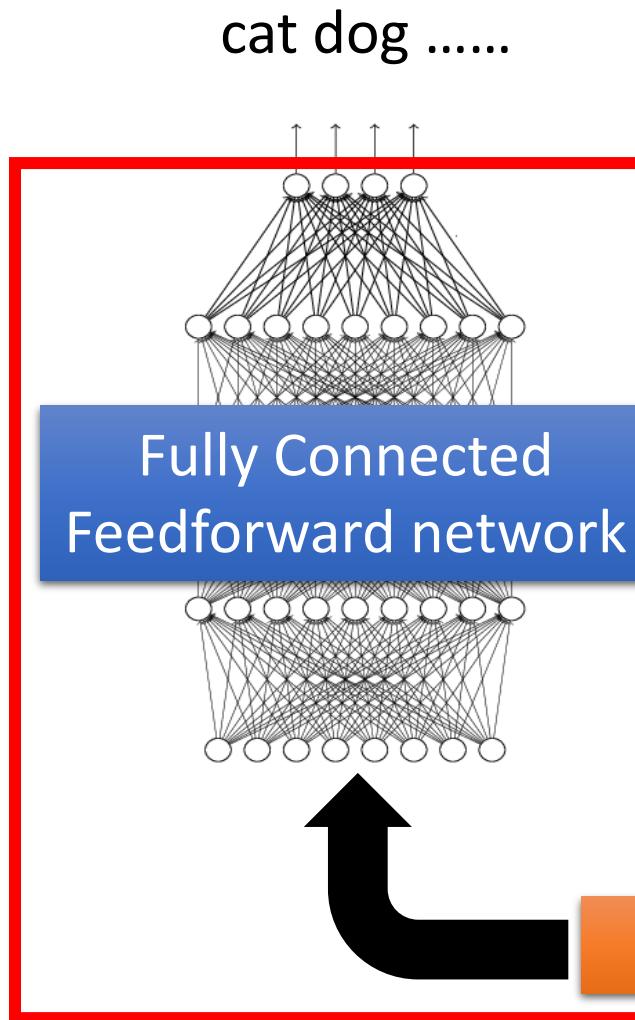
2 x 2 image

Each filter
is a channel

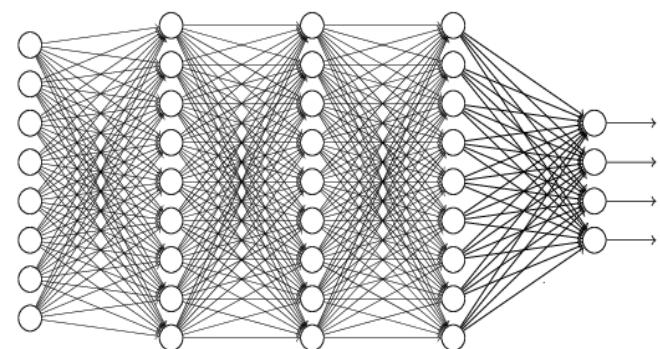
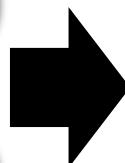
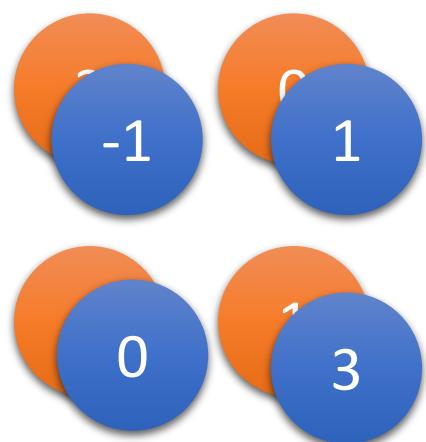
The whole CNN



The whole CNN

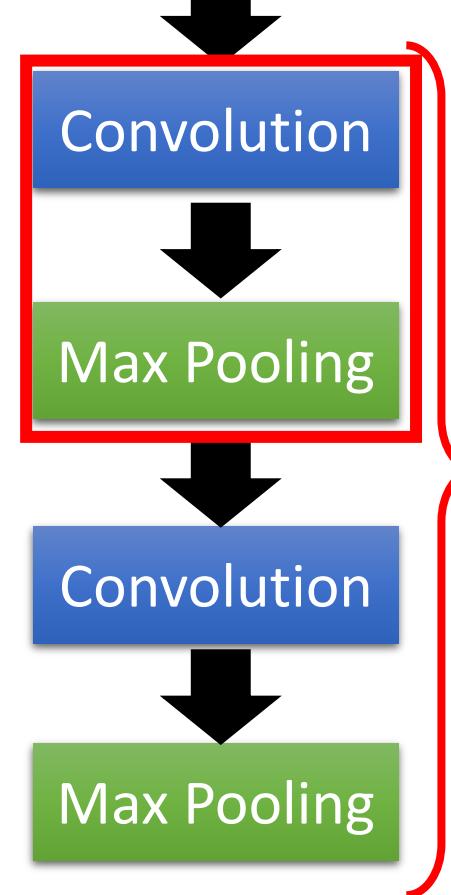
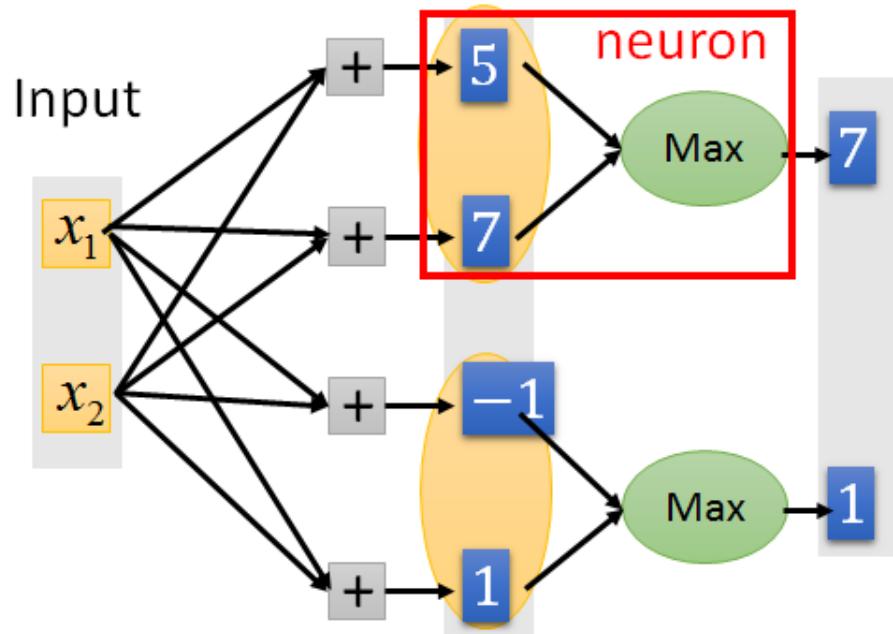


Flatten

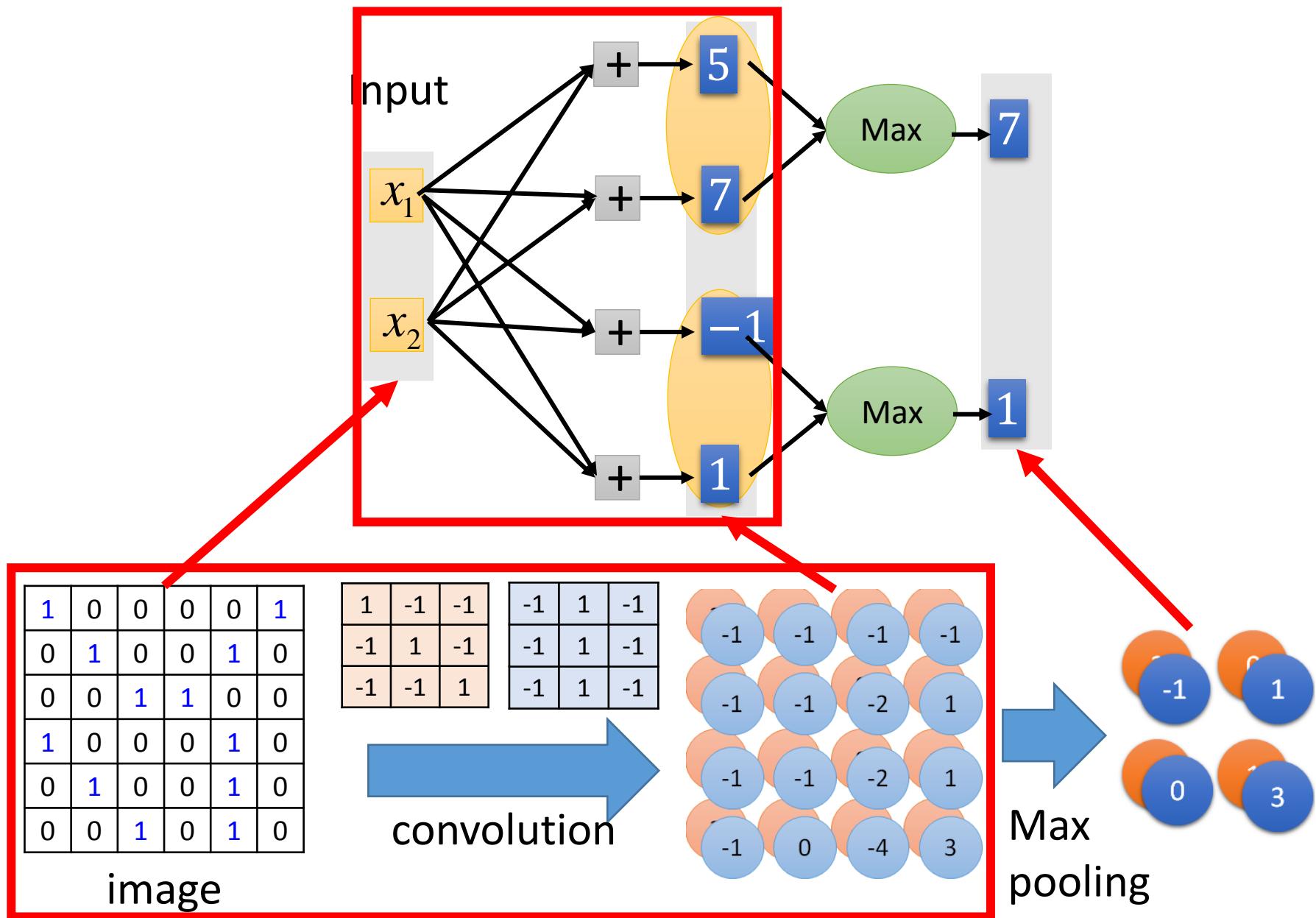


Fully Connected
Feedforward network

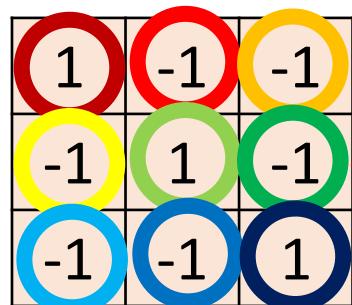
The whole CNN



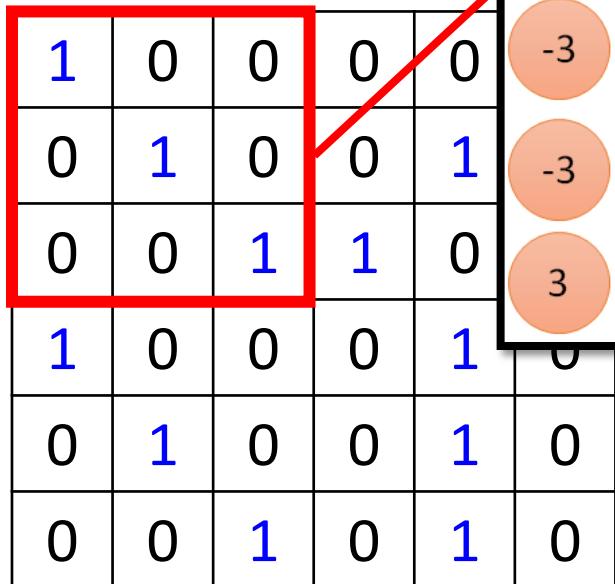
Can repeat
many times



(Ignoring the non-linear activation function after the convolution.)

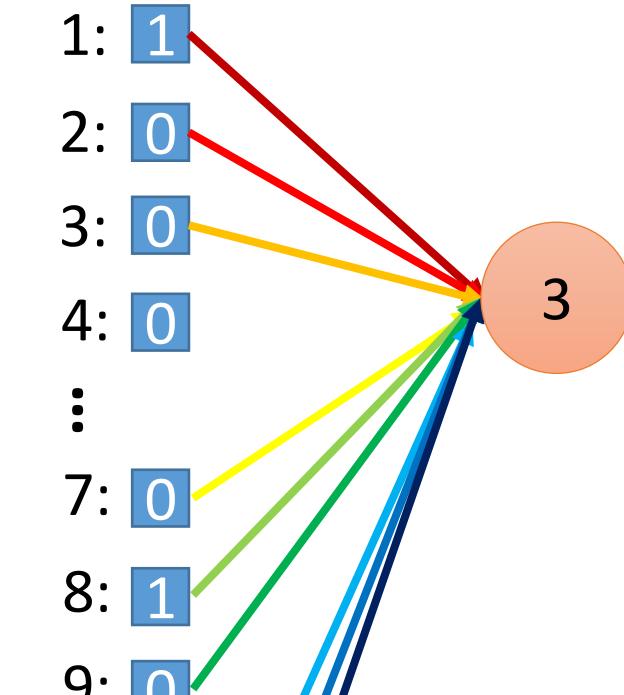
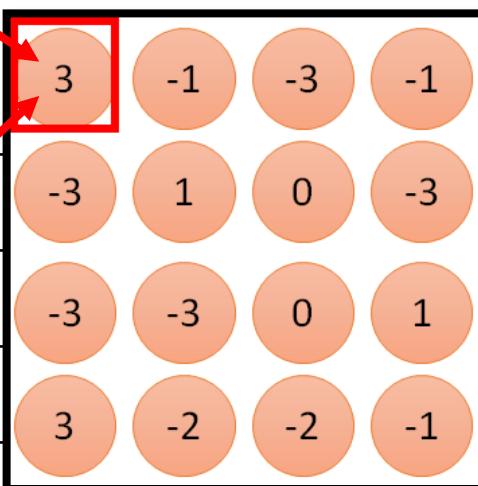


Filter 1

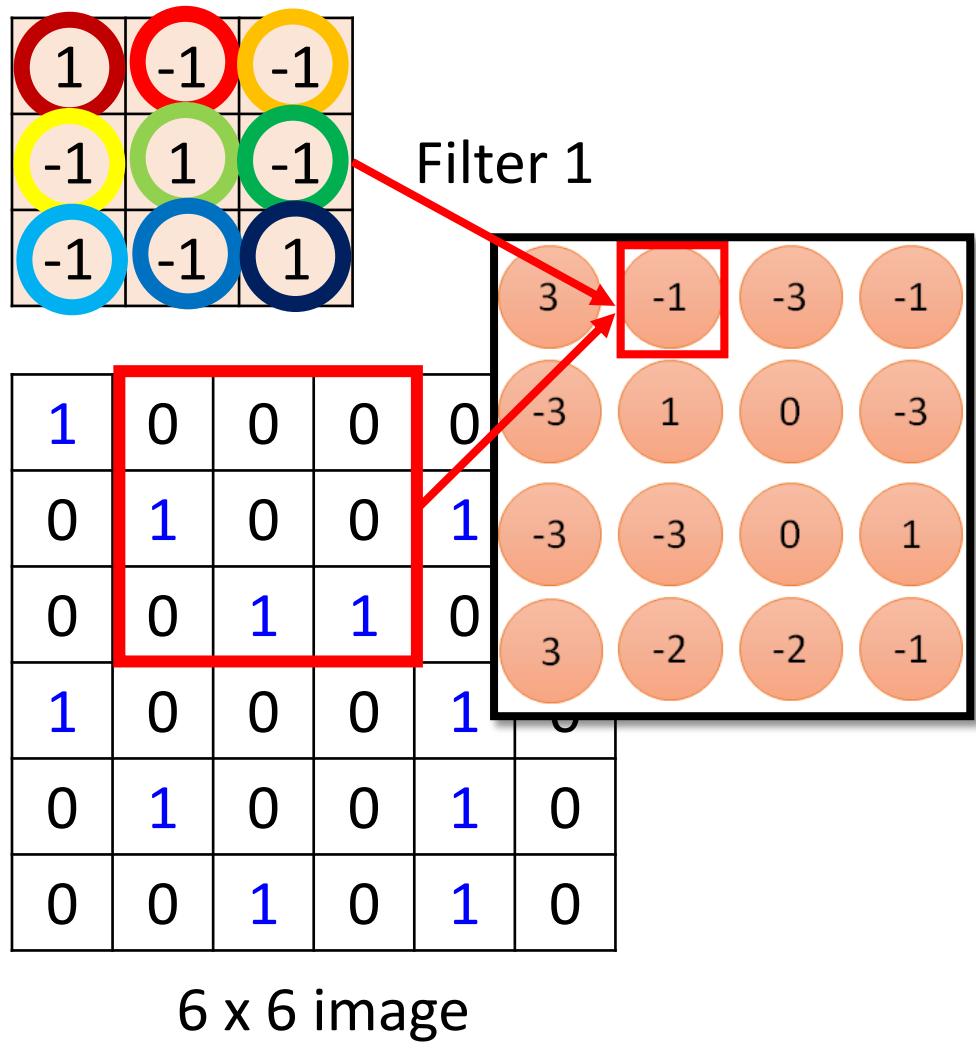


6 x 6 image

Less parameters!

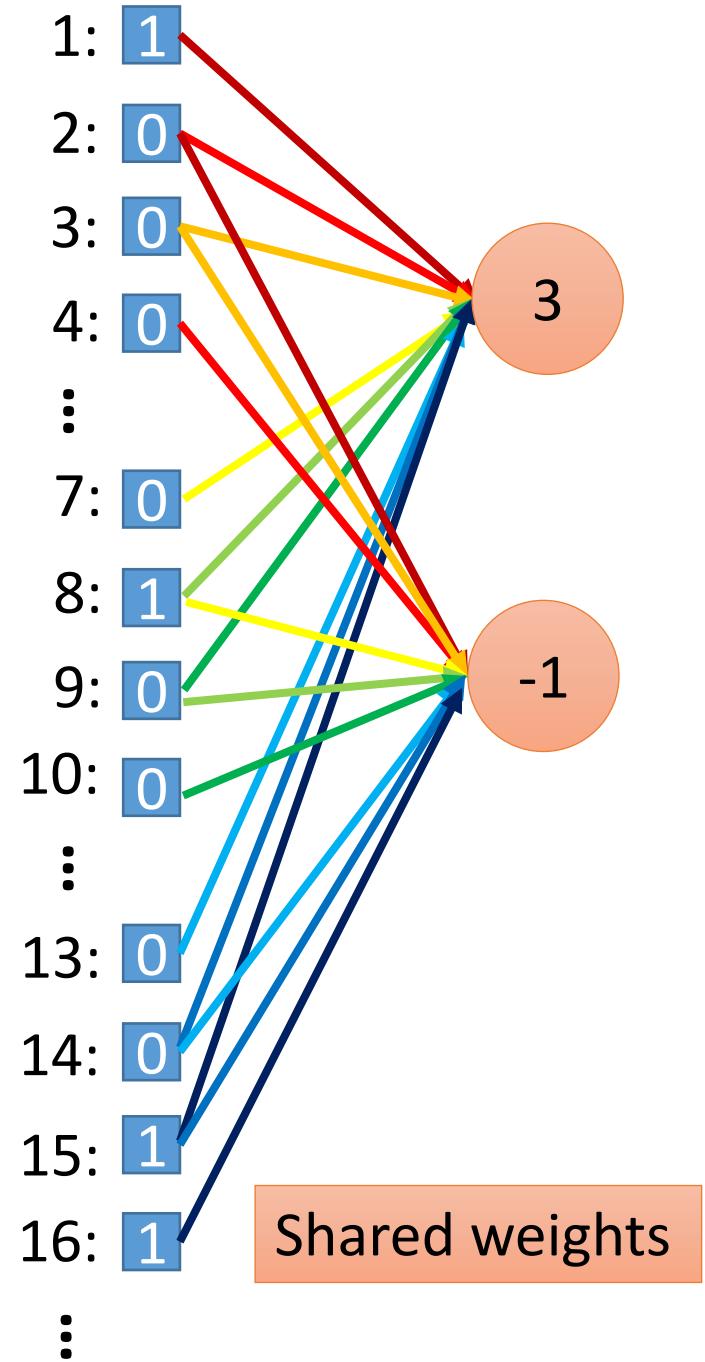


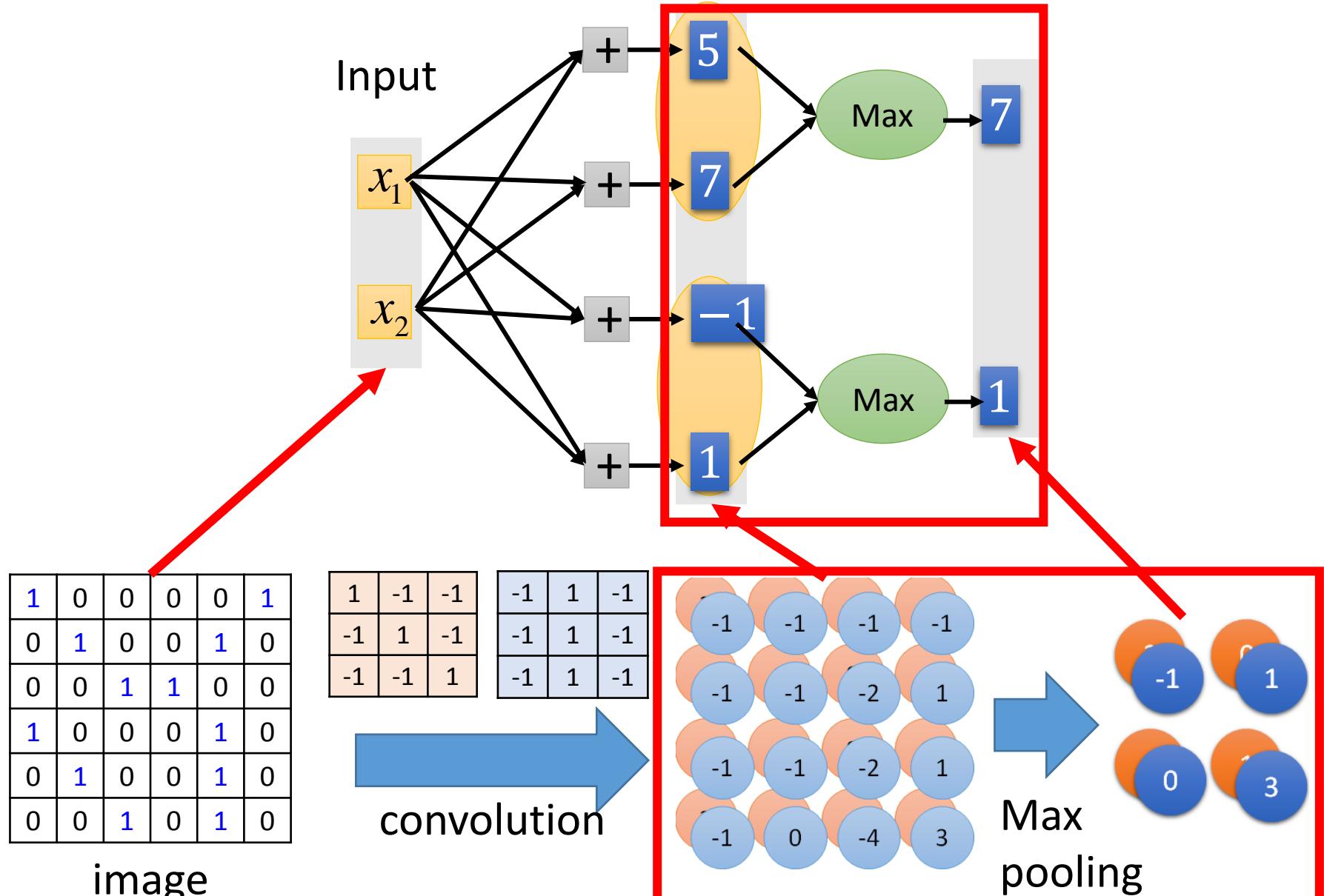
Only connect to 9
input, not fully
connected



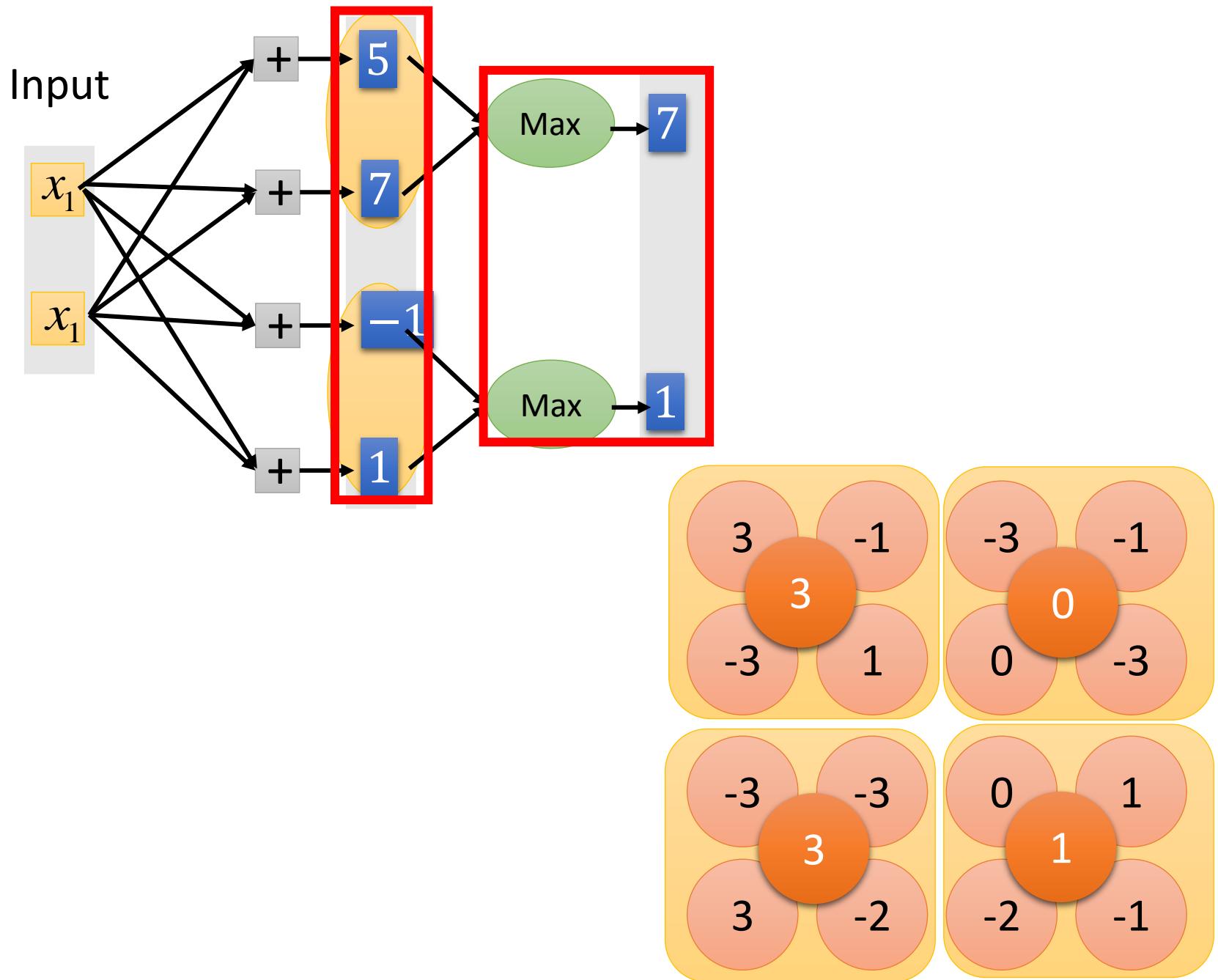
Less parameters!

Even less parameters!





(Ignoring the non-linear activation function after the convolution.)



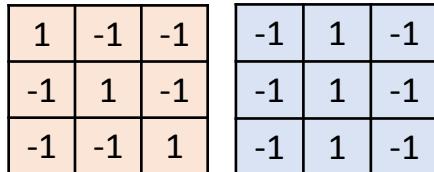
Dim = $6 \times 6 = 36$

parameters =
 $36 \times 32 = 1152$

Dim = $4 \times 4 \times 2$
 $= 32$

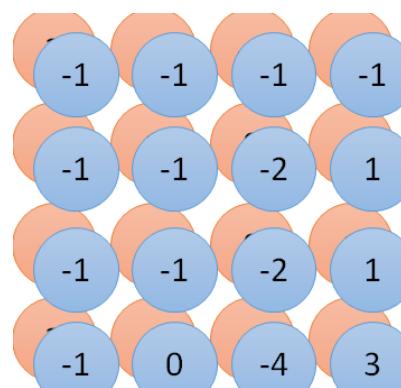
1	0	0	0	0	0	1
0	1	0	0	1	0	0
0	0	1	1	0	0	0
1	0	0	0	0	1	0
0	1	0	0	0	1	0
0	0	1	0	0	1	0

image

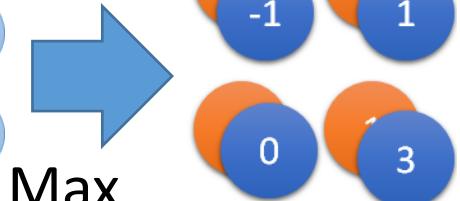


convolution

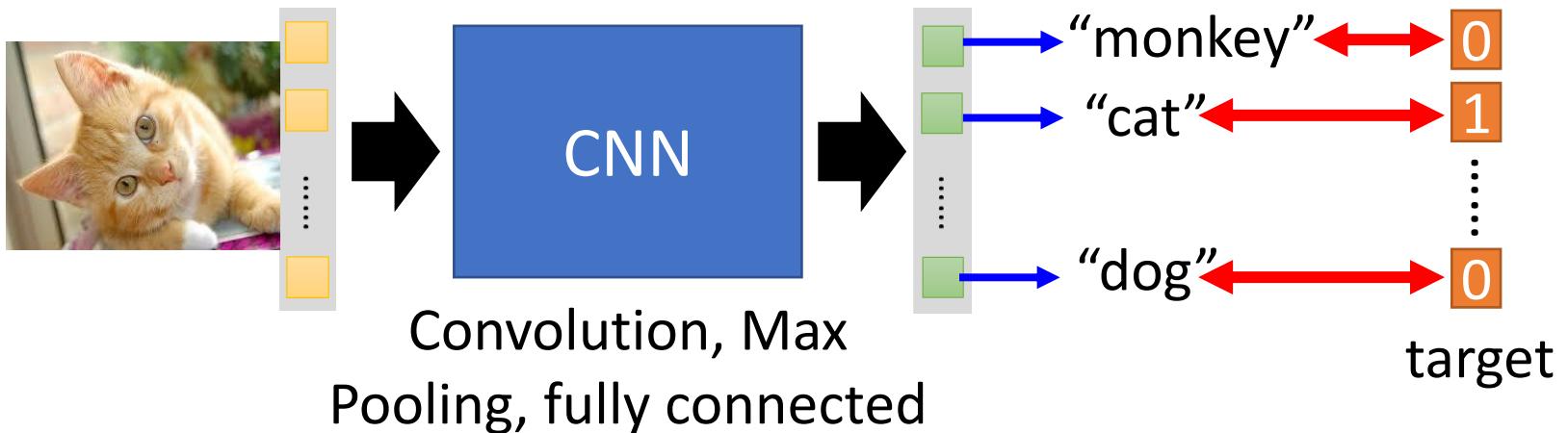
Only $9 \times 2 = 18$
parameters



Max
pooling

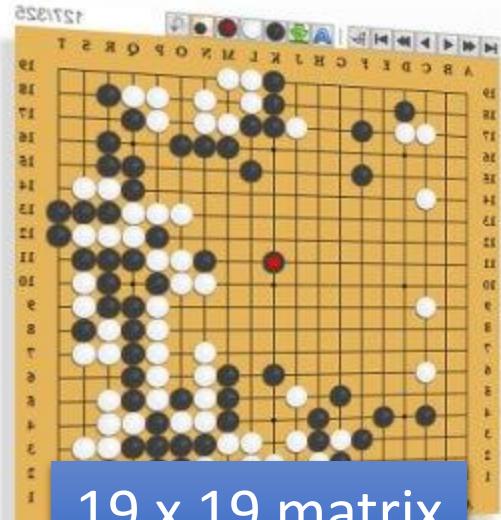


Convolutional Neural Network



Learning: Nothing special, just gradient descent

Playing Go

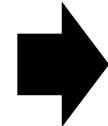


19 x 19 matrix
(image)

Black: 1
white: -1
none: 0



Network



Next move
(19 x 19
positions)

19 x 19 vector

Fully-connected feedword
network can be used

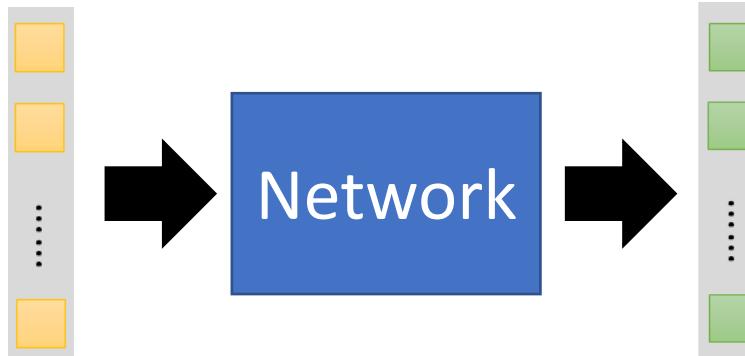
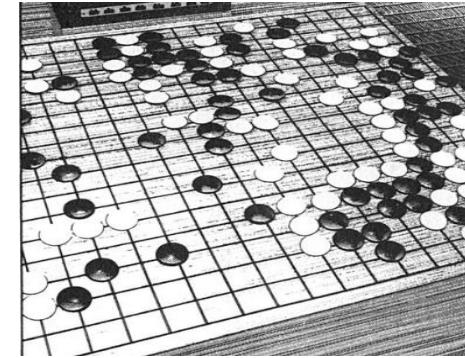
But CNN performs much better.

Playing Go

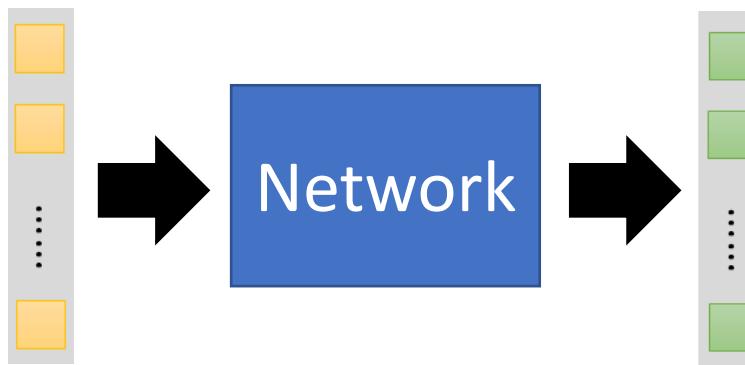
Training:



record of previous plays



Target:
“天元” = 1
else = 0



Target:
“五之五” = 1
else = 0

進藤光 v.s. 社清春

黒: 5之五

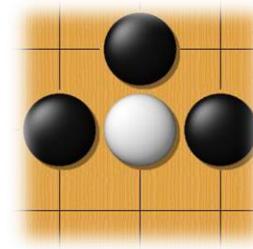
→ 白: 天元

→ 黑: 五之五

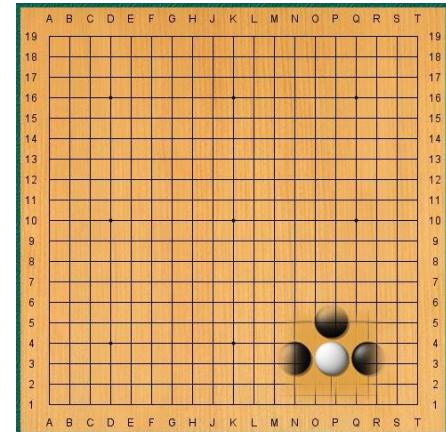
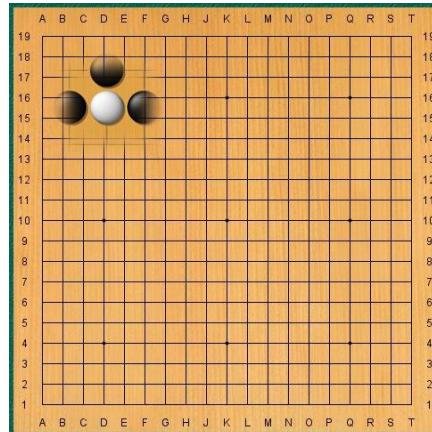
Why CNN for playing Go?

- Some patterns are much smaller than the whole image

Alpha Go uses 5 x 5 for first layer



- The same patterns appear in different regions.



Why CNN for playing Go?

- Subsampling the pixels will not change the object



Max Pooling

How to explain this???

Neural network architecture. The input to the policy network is a $19 \times 19 \times 48$ image stack consisting of 48 feature planes. The first hidden layer zero pads the input into a 23×23 image, then convolves k filters of kernel size 5×5 with stride 1 with the input image and applies a rectifier nonlinearity. Each of the subsequent hidden layers 2 to 12 zero pads the respective previous hidden layer into a 21×21 image, then convolves k filters of kernel size 3×3 with stride 1, again followed by a rectifier nonlinearity. The final layer convolves 1 filter of kernel size 1×1 with stride 1 with a different bias for each position, and applies a softmax function. The Alpha Go does not use Max Pooling Extended Data Table 3 additionally show the results of training with $k = 128, 256$ and 384 filters.

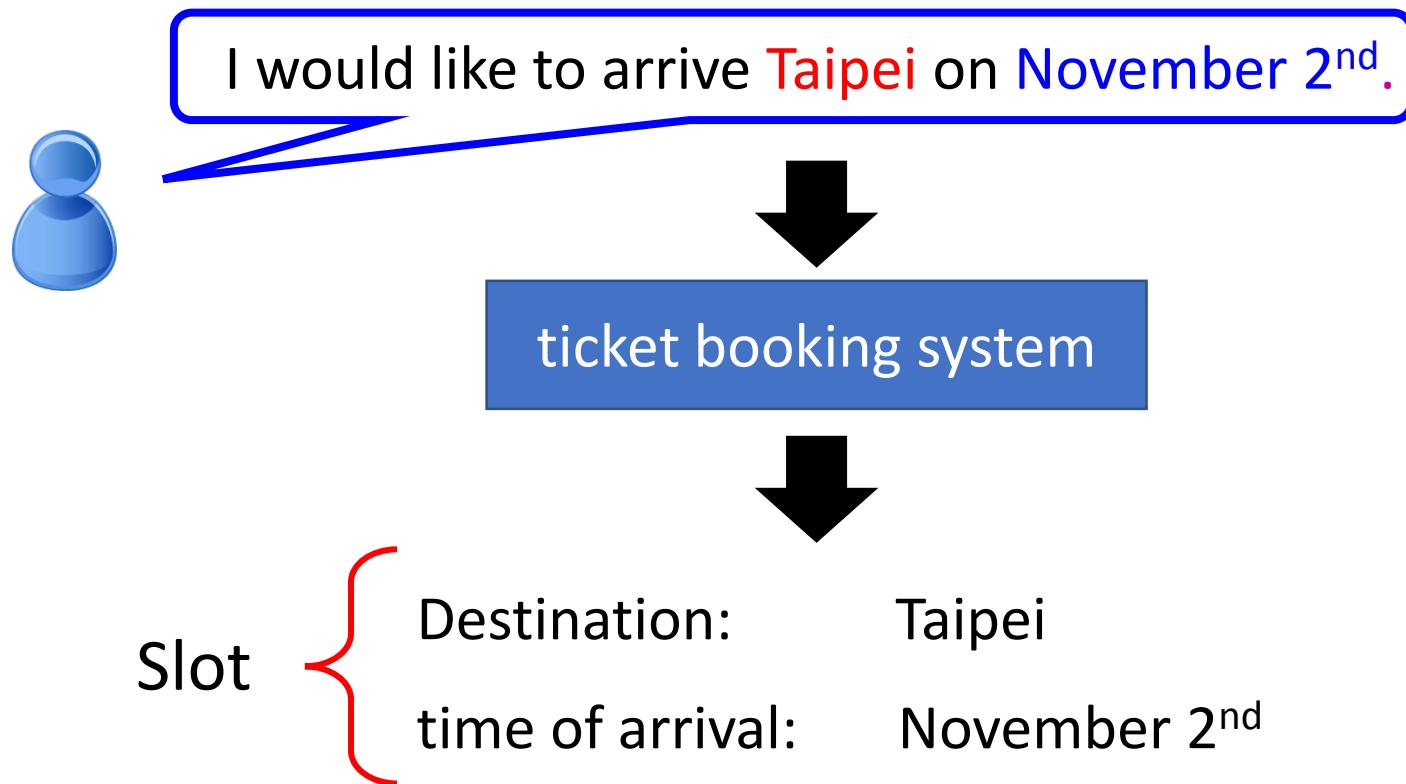
Variants of Neural Networks

Convolutional Neural
Network (CNN)

Recurrent Neural Network
(RNN) Neural Network with Memory

Example Application

- Slot Filling



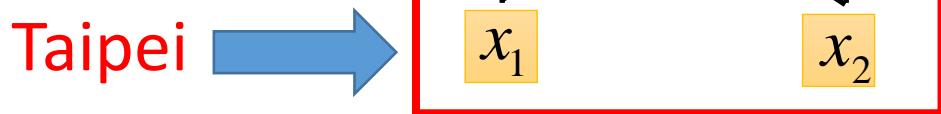
Example Application

Solving slot filling by
Feedforward network?

Input: a word

(Each word is represented
as a vector)

Taipei



1-of-N encoding

How to represent each word as a vector?

1-of-N Encoding lexicon = {apple, bag, cat, dog, elephant}

The vector is lexicon size.

$$\text{apple} = [1 \ 0 \ 0 \ 0 \ 0]$$

Each dimension corresponds
to a word in the lexicon

$$\text{bag} = [0 \ 1 \ 0 \ 0 \ 0]$$

The dimension for the word
is 1, and others are 0

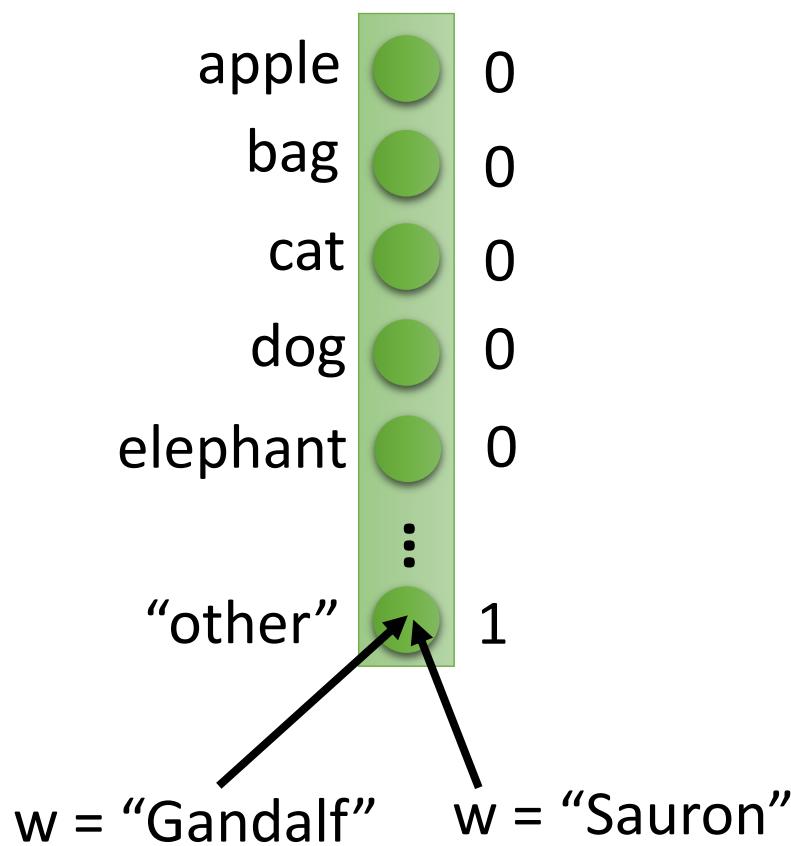
$$\text{cat} = [0 \ 0 \ 1 \ 0 \ 0]$$

$$\text{dog} = [0 \ 0 \ 0 \ 1 \ 0]$$

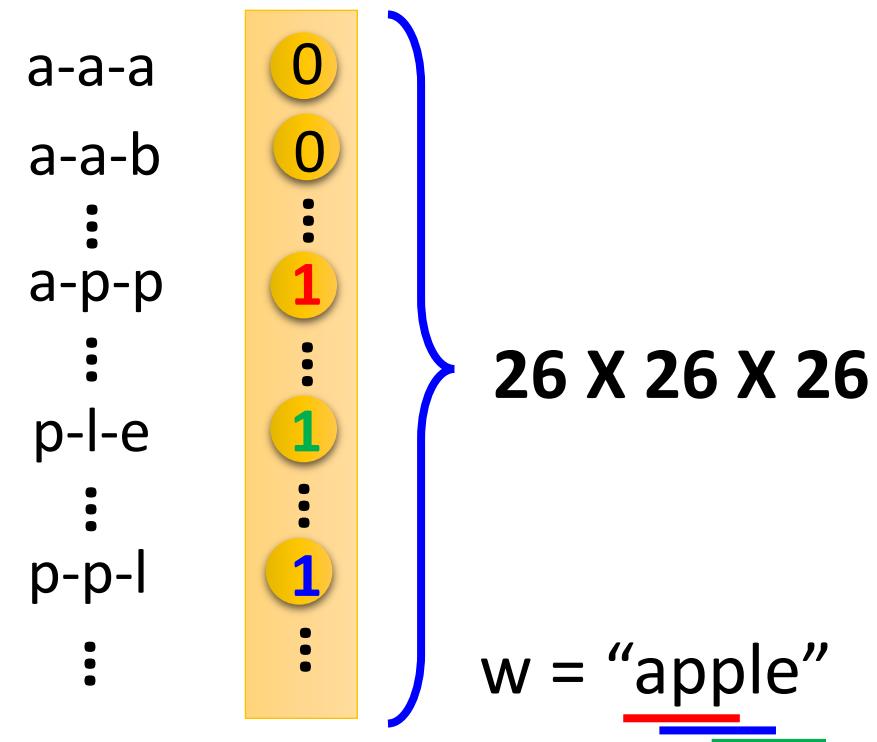
$$\text{elephant} = [0 \ 0 \ 0 \ 0 \ 1]$$

Beyond 1-of-N encoding

Dimension for “Other”



Word hashing



Example Application

Solving slot filling by
Feedforward network?

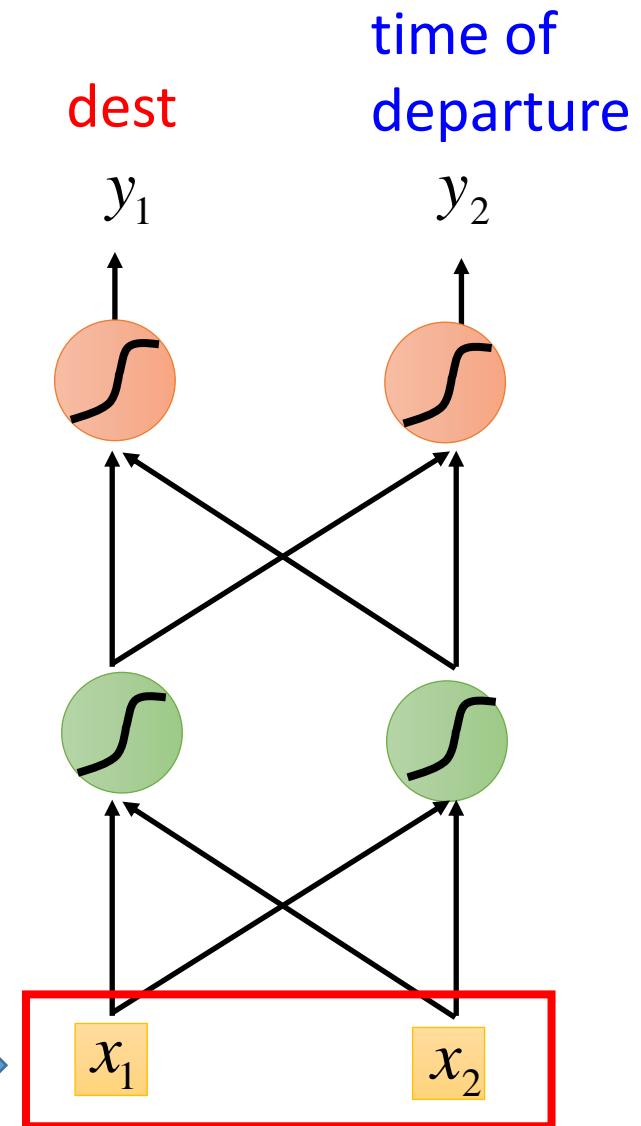
Input: a word

(Each word is represented
as a vector)

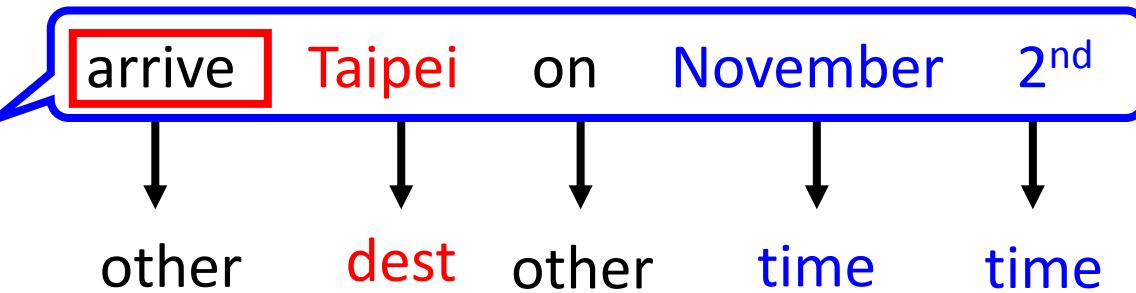
Output:

Probability distribution that
the input word belonging to
the slots

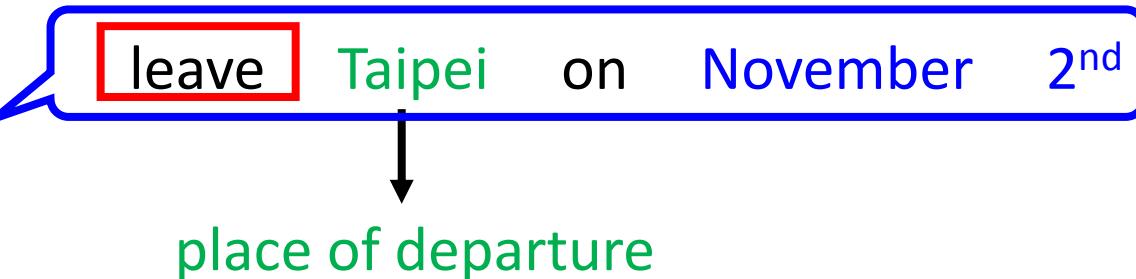
Taipei



Example Application



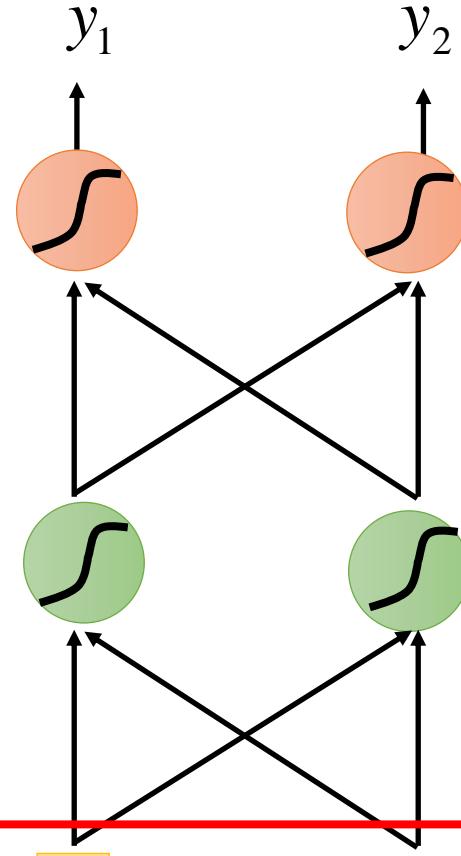
Problem?



Neural network
needs memory!

Taipei →

dest
time of
departure

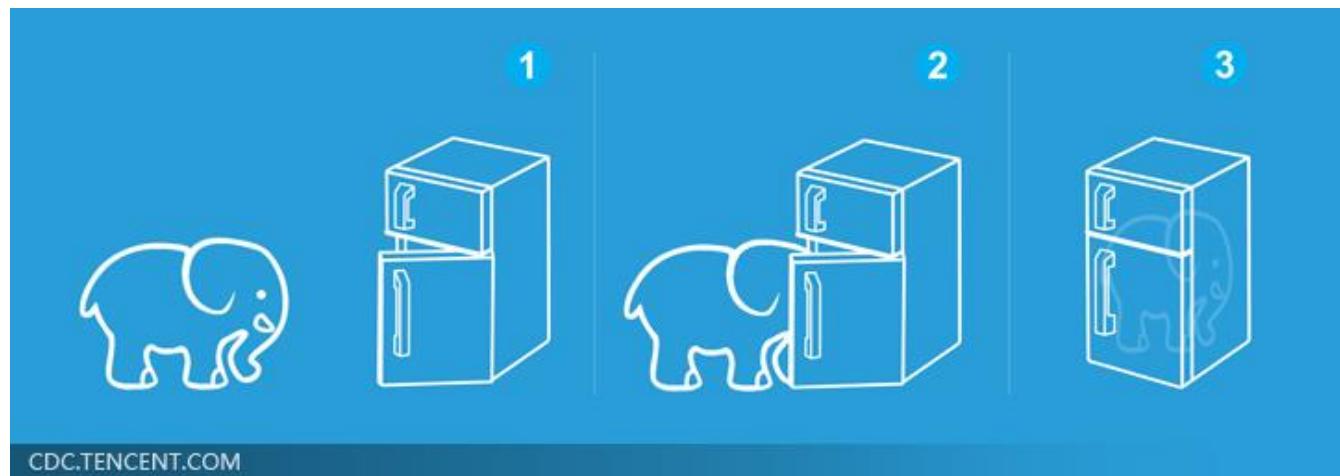


x_1 x_2

Three Steps for Deep Learning

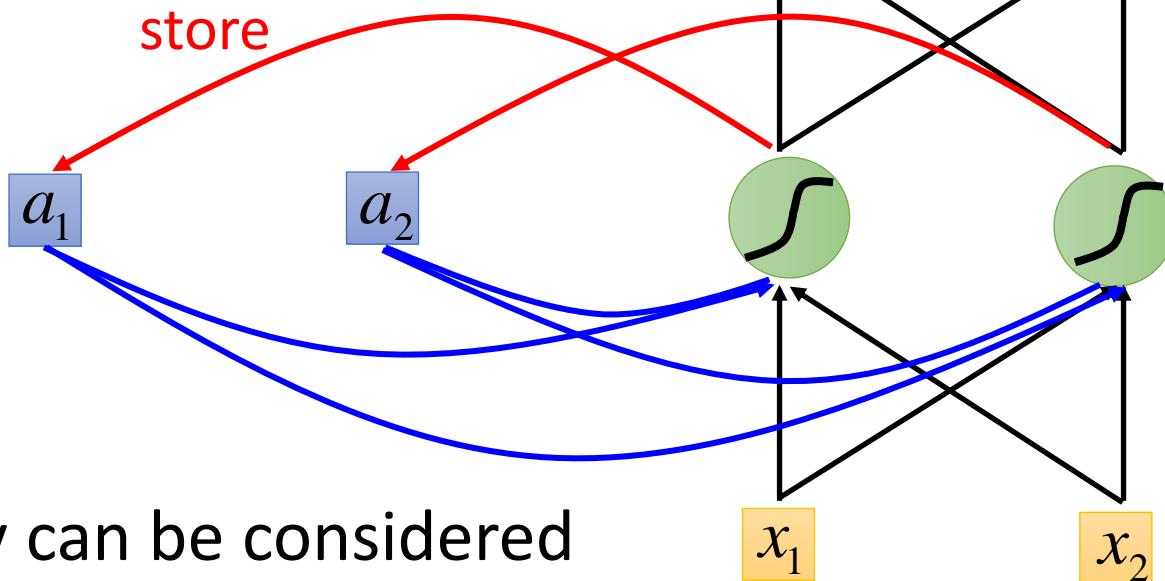


Deep Learning is so simple



Recurrent Neural Network (RNN)

The output of hidden layer
are stored in the memory.



Memory can be considered
as another input.

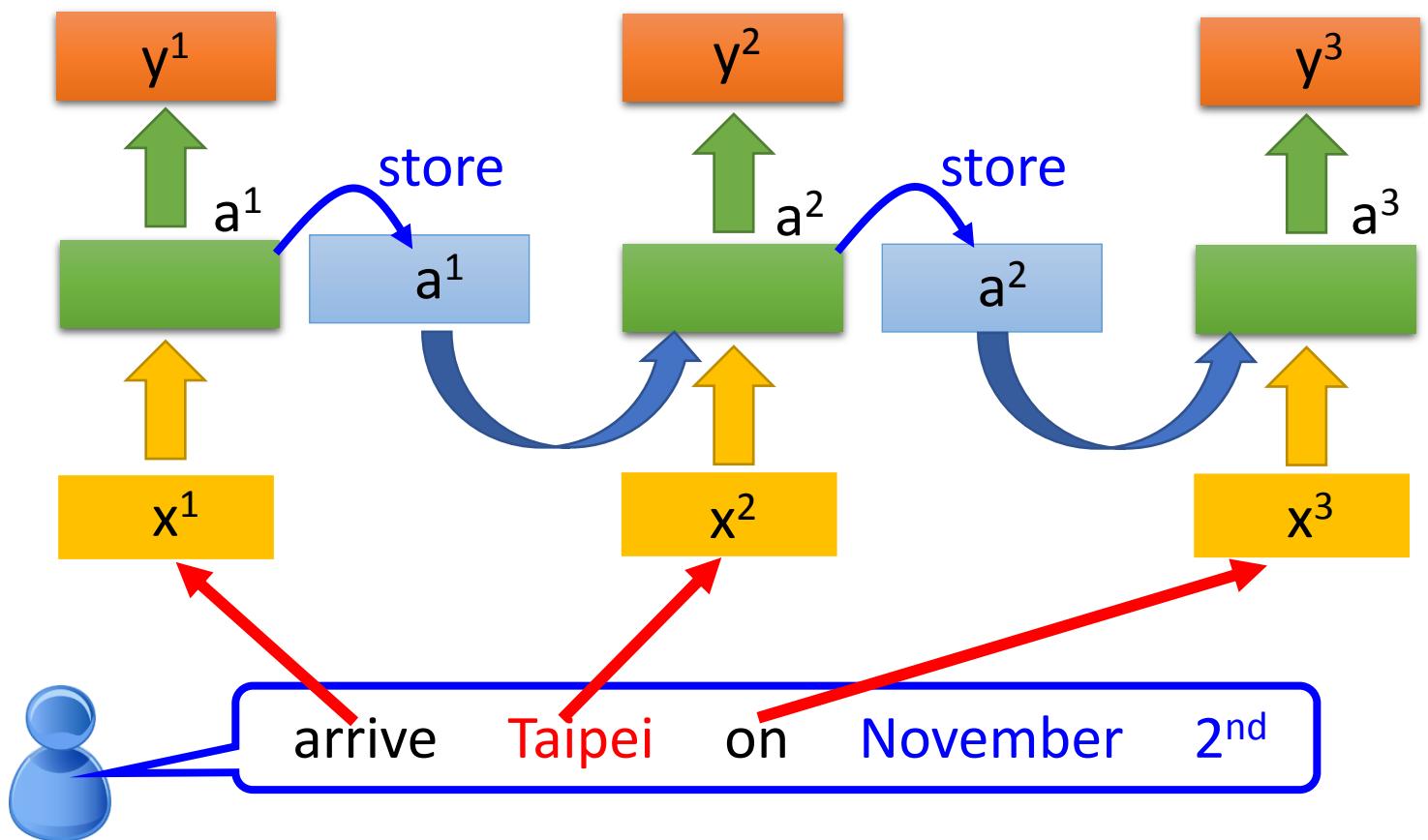
RNN

The same network is used again and again.

Probability of
“arrive” in each slot

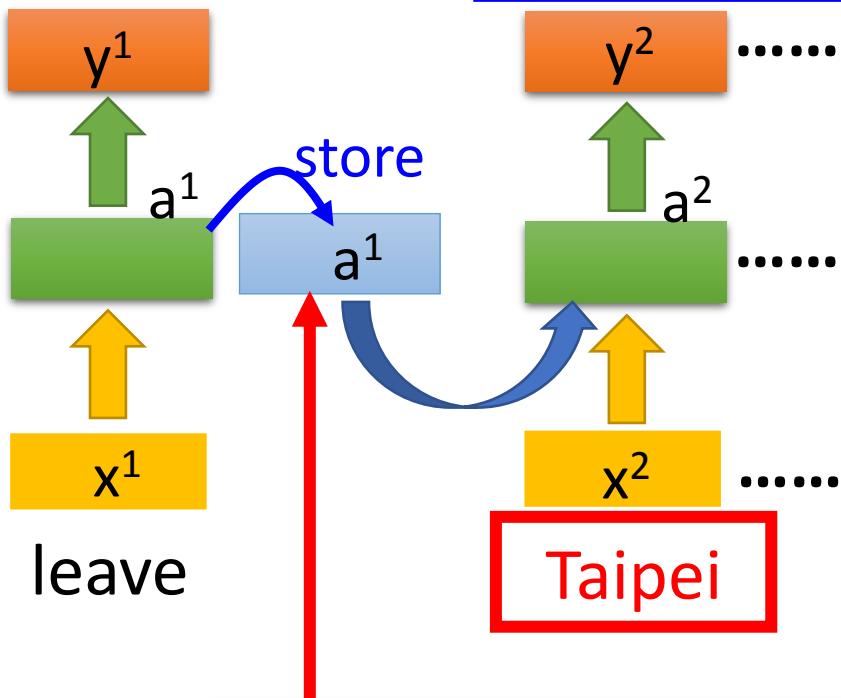
Probability of
“Taipei” in each slot

Probability of
“on” in each slot



RNN

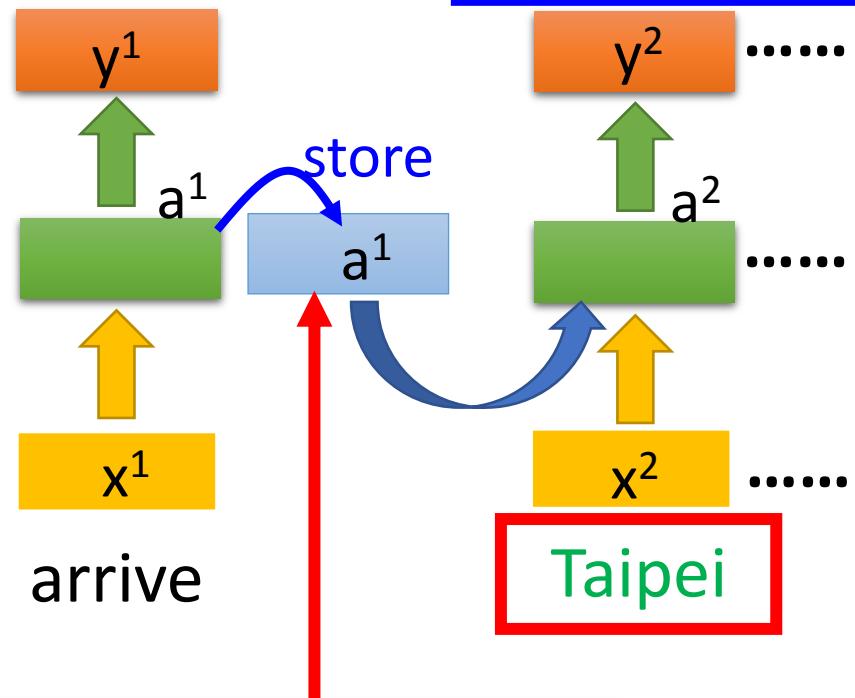
Prob of “leave”
in each slot



Prob of “Taipei”
in each slot

Different

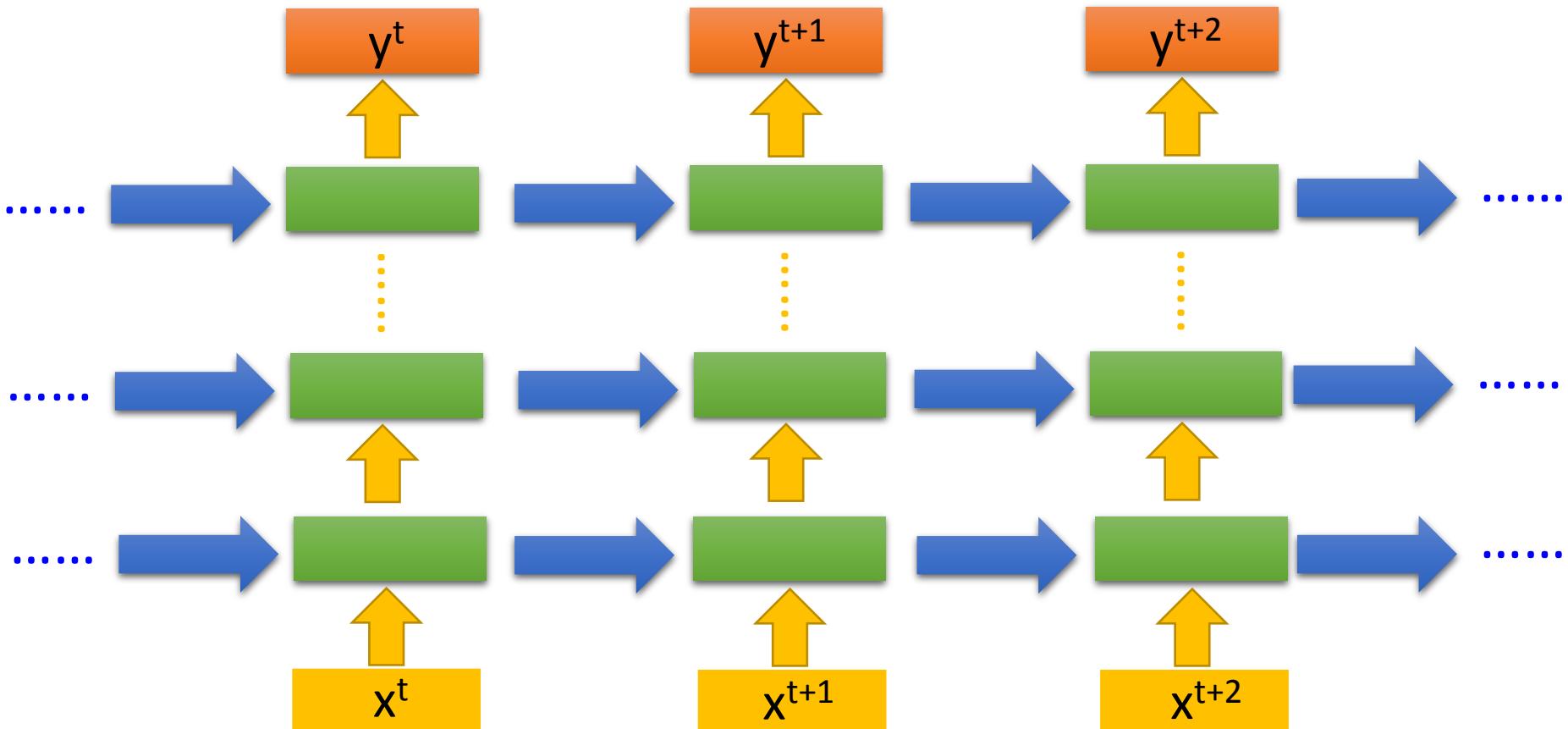
Prob of “arrive”
in each slot



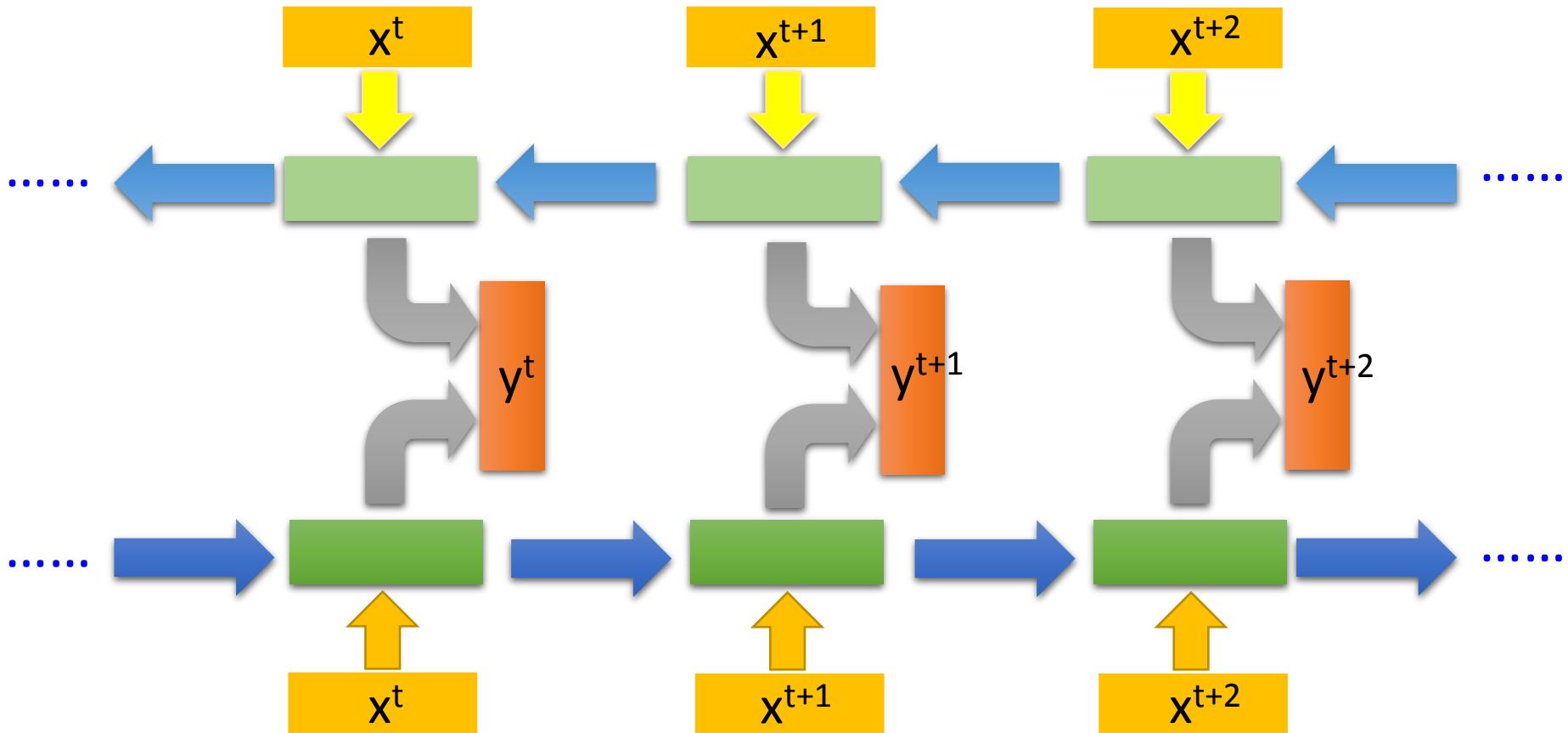
Prob of “Taipei”
in each slot

The values stored in the memory is different.

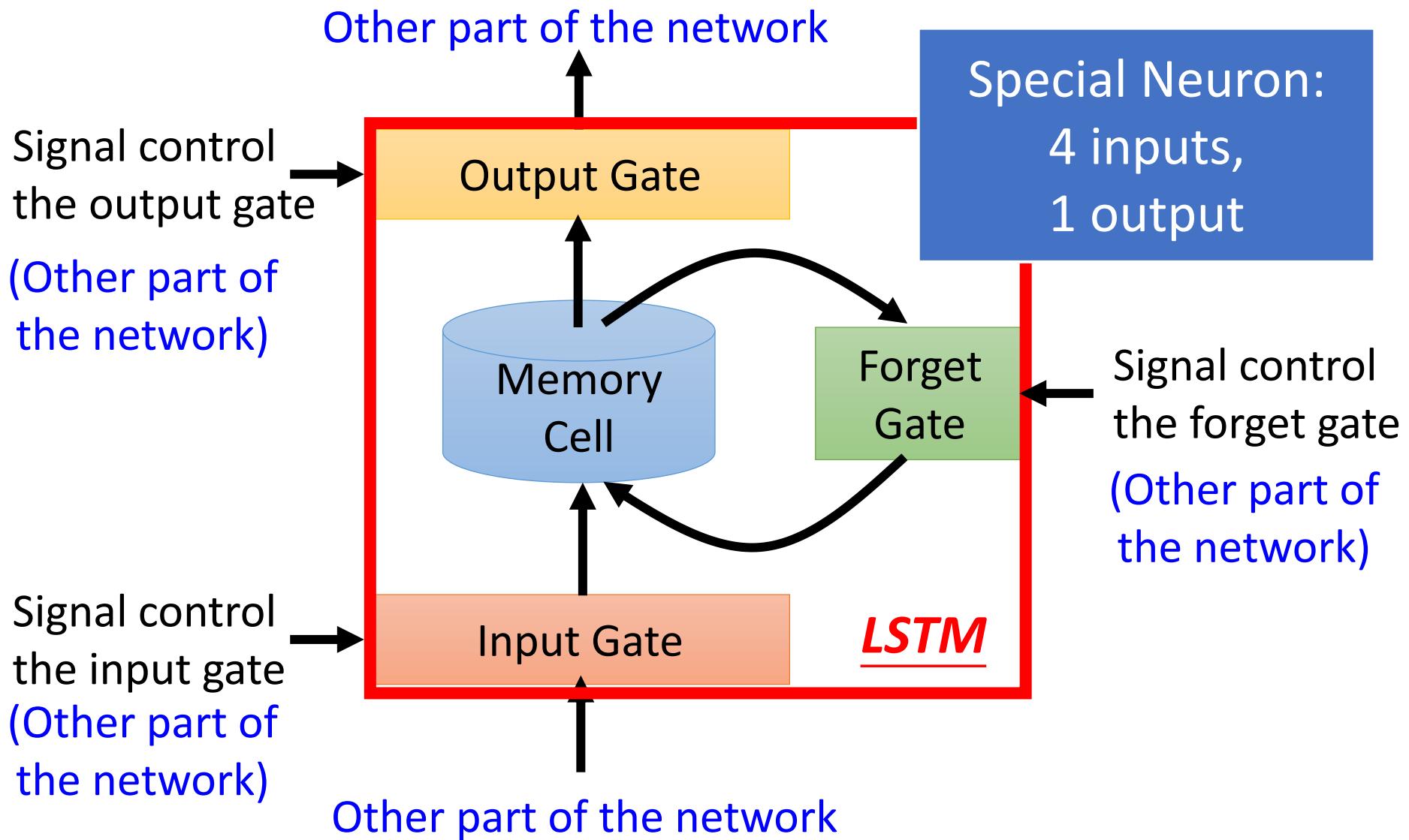
Of course it can be deep ...

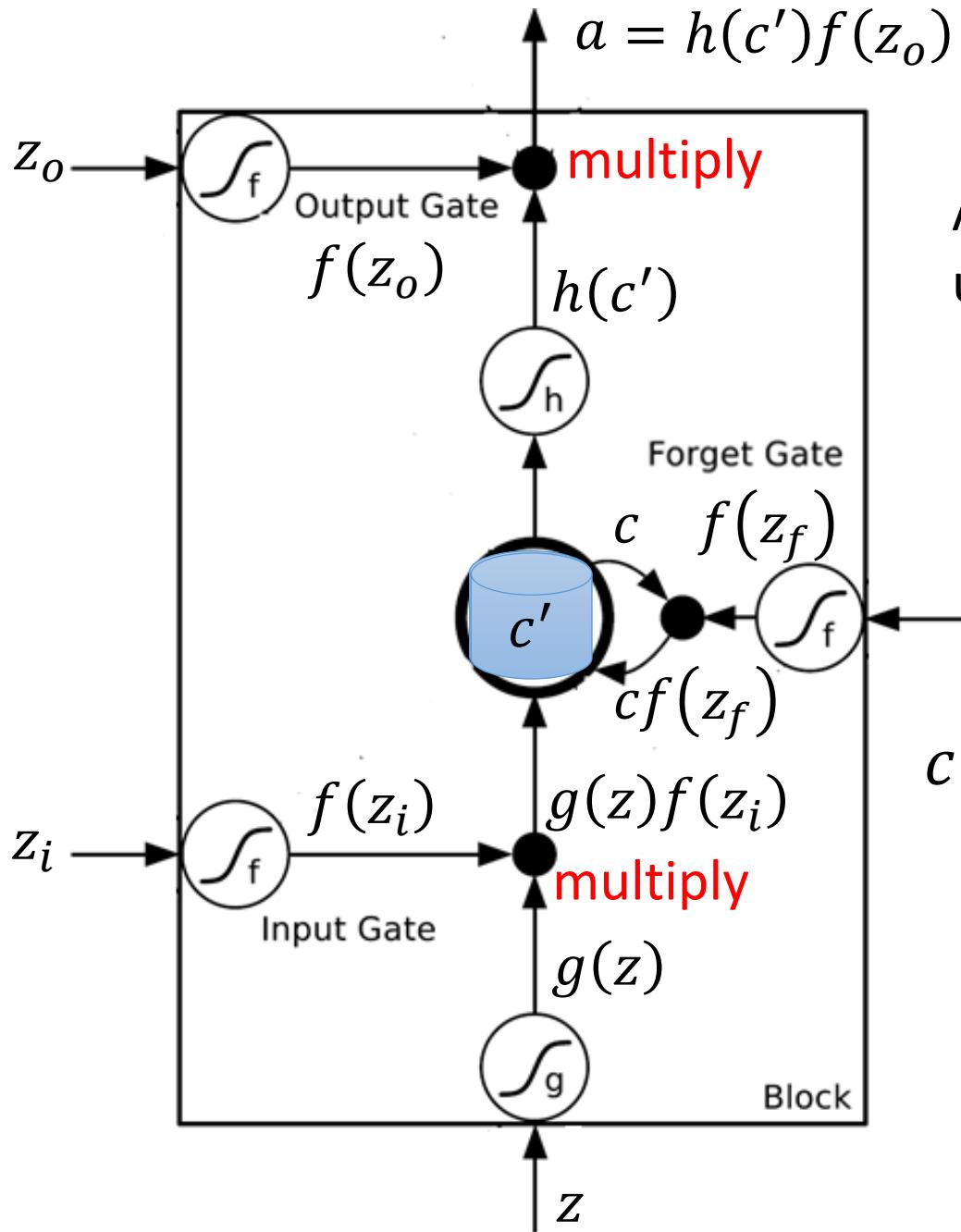


Bidirectional RNN



Long Short-term Memory (LSTM)



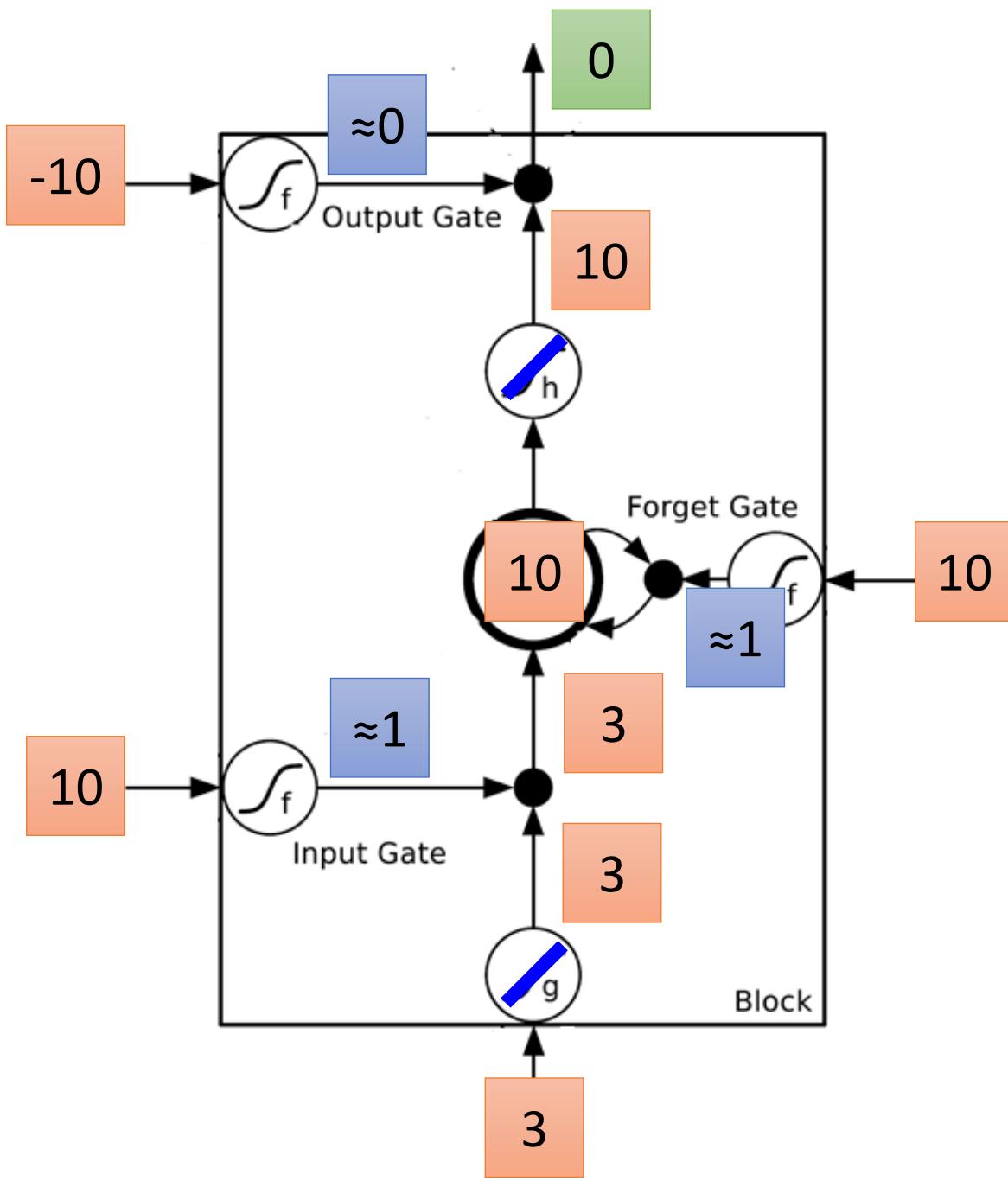


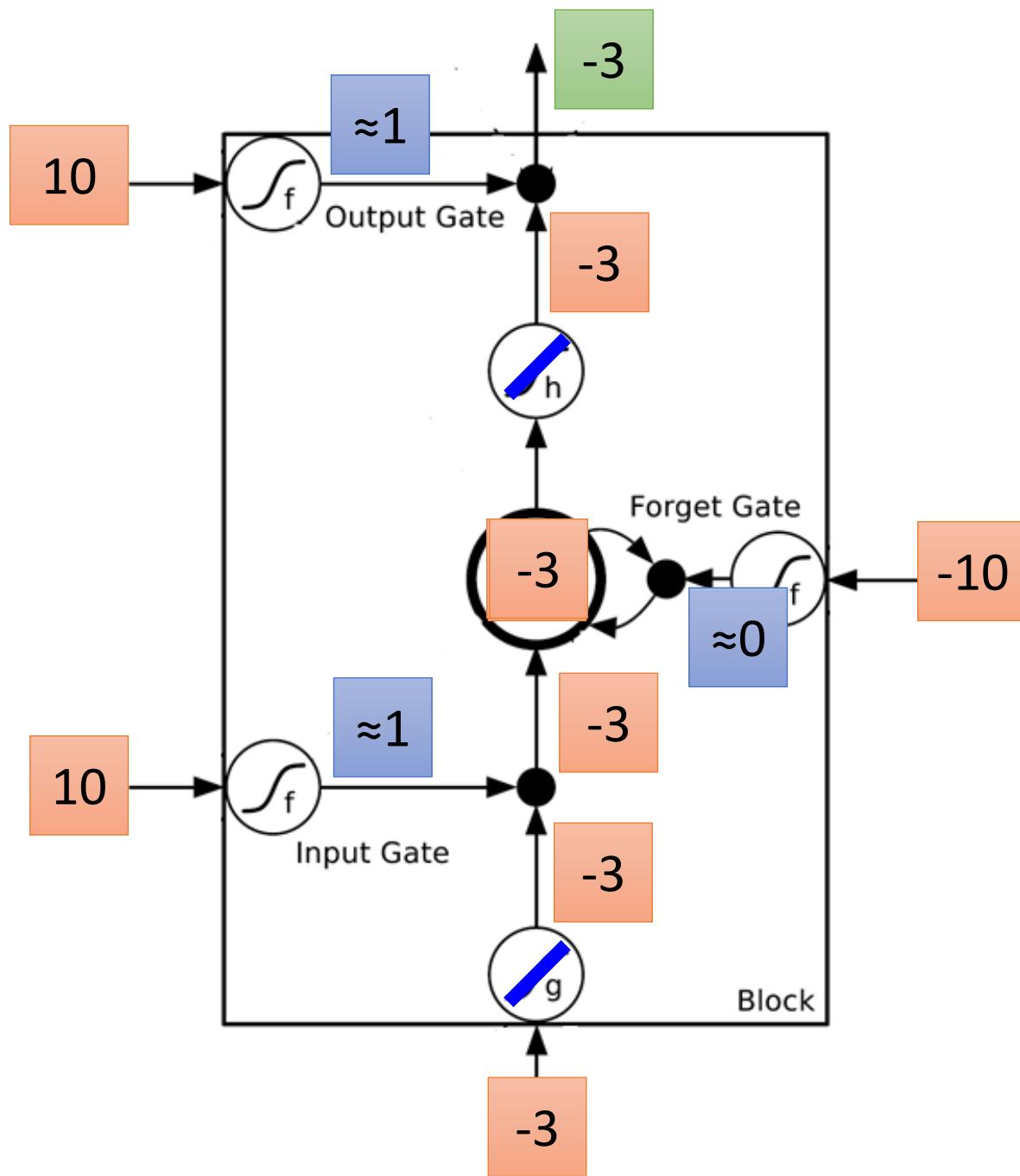
Activation function f is usually a sigmoid function

Between 0 and 1

Mimic open and close gate

$$c' = g(z)f(z_i) + cf(z_f)$$

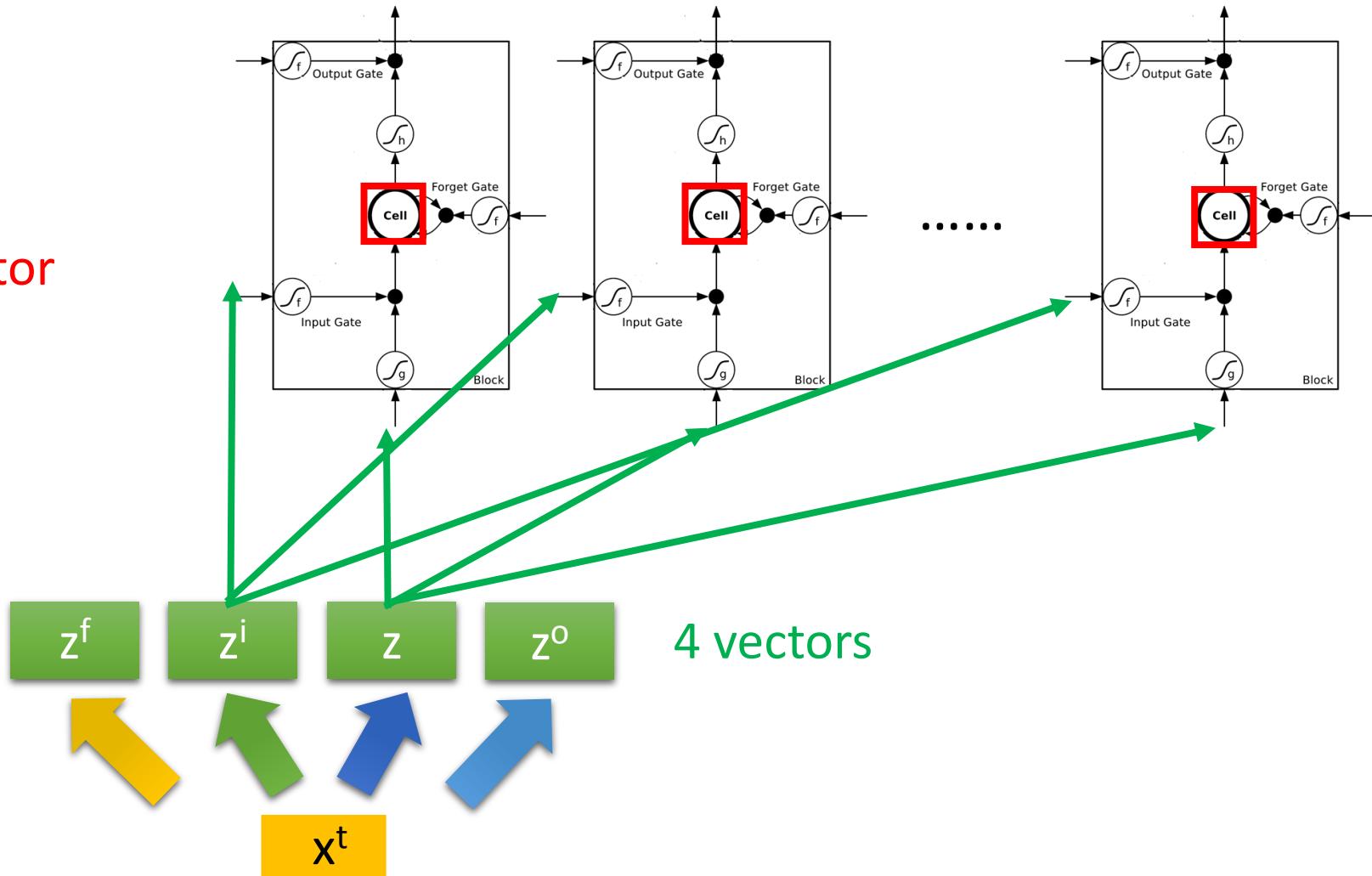




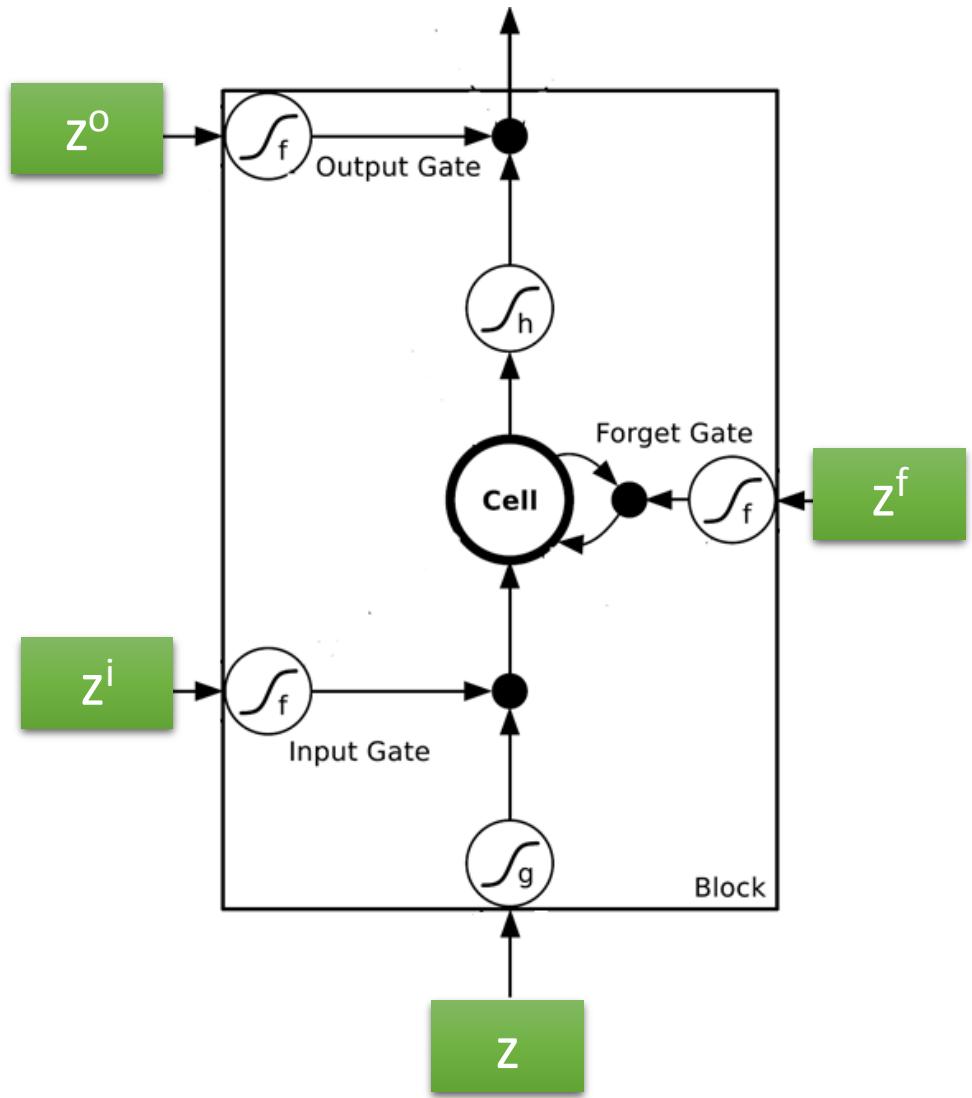
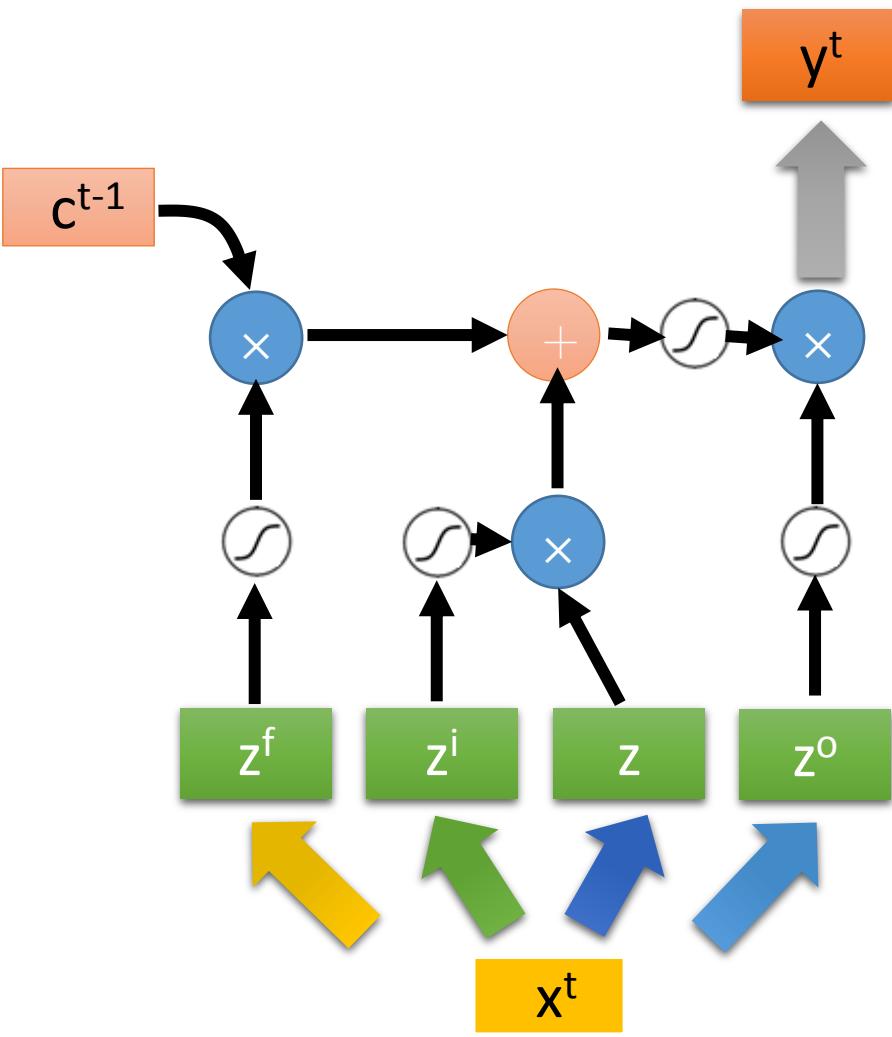
LSTM

C^{t-1}

vector

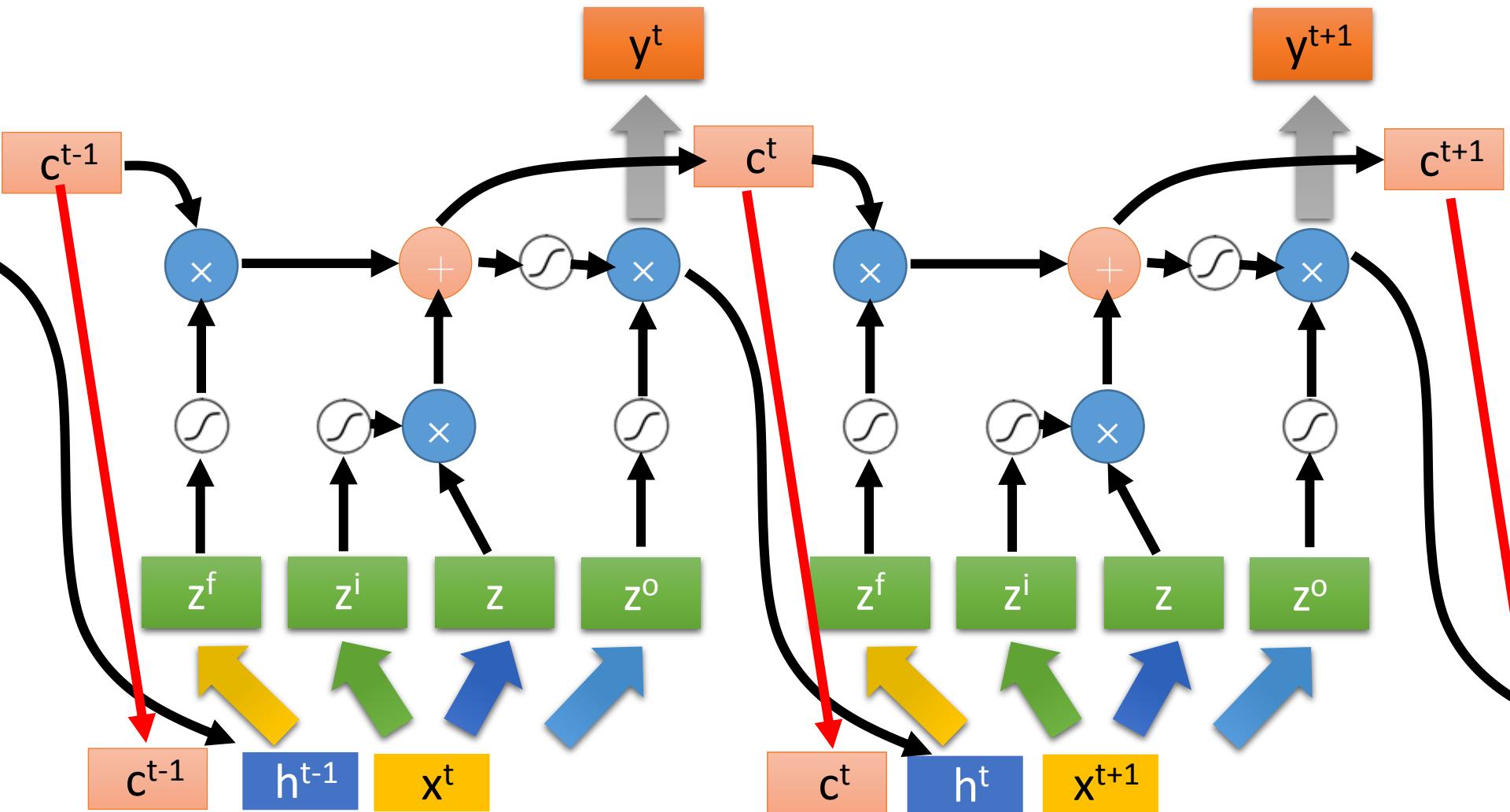


LSTM

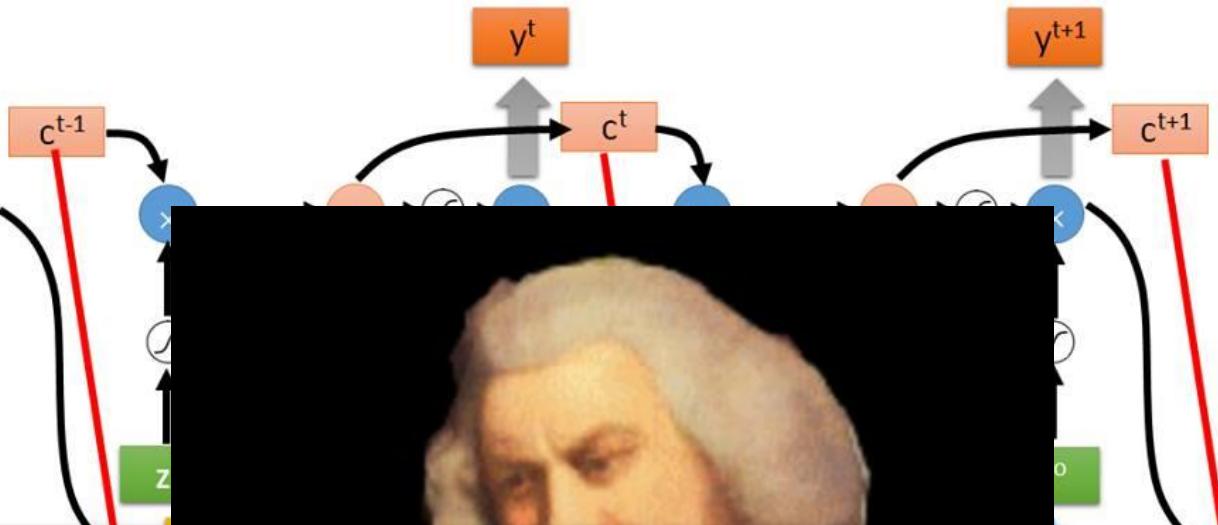


LSTM

Extension: “peephole”



Multiple-layer LSTM



Don't worry if you cannot understand this.
Keras can handle it.

Keras supports
“LSTM”, “GRU”, “SimpleRNN” layers

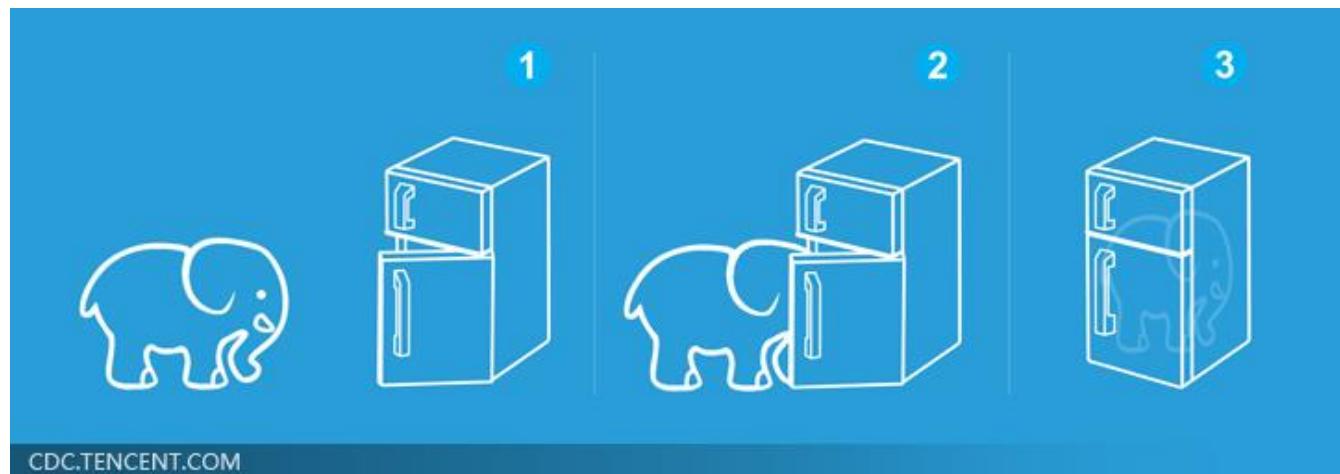
This is quite
standard now.



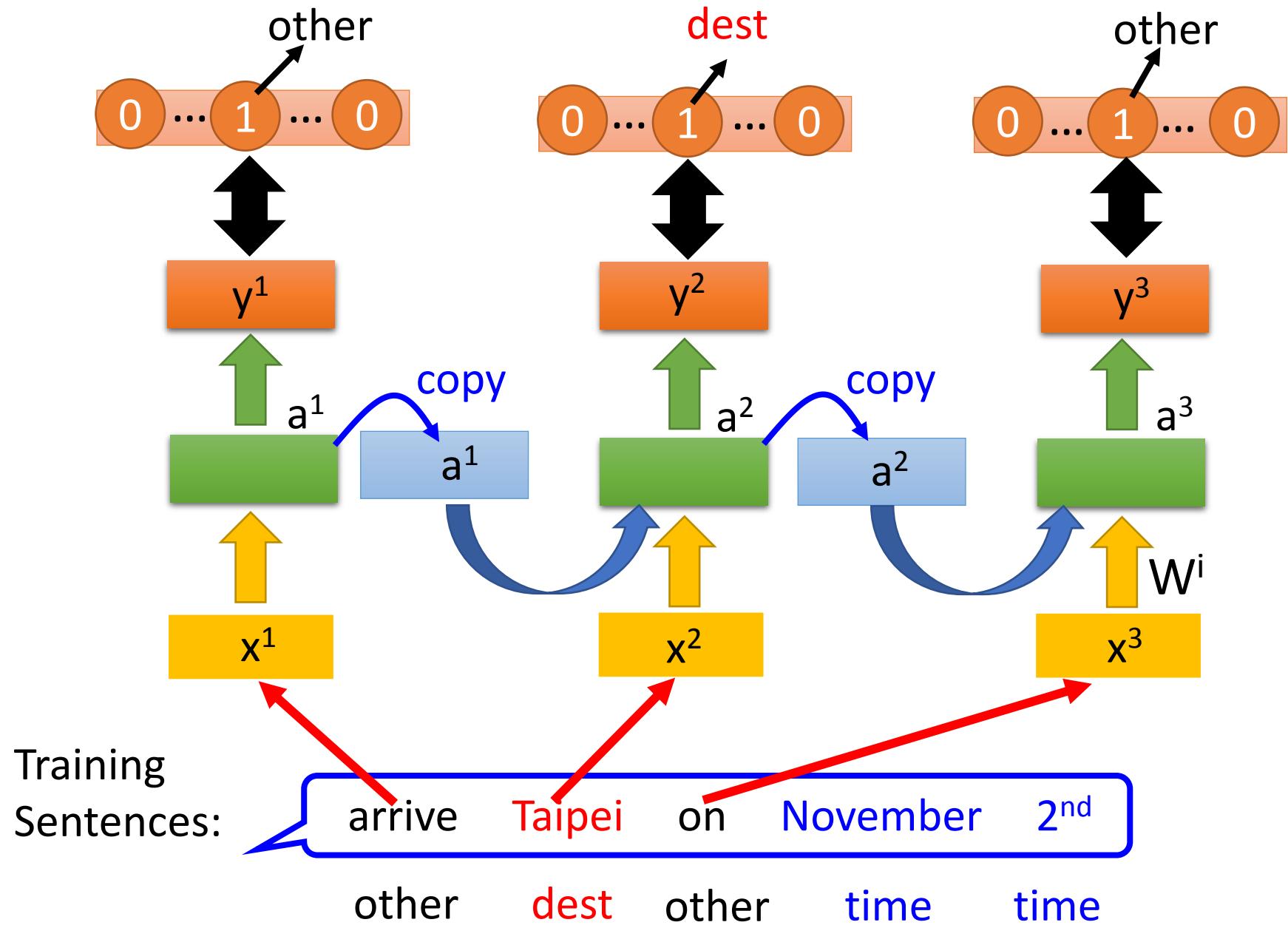
Three Steps for Deep Learning



Deep Learning is so simple



Learning Target



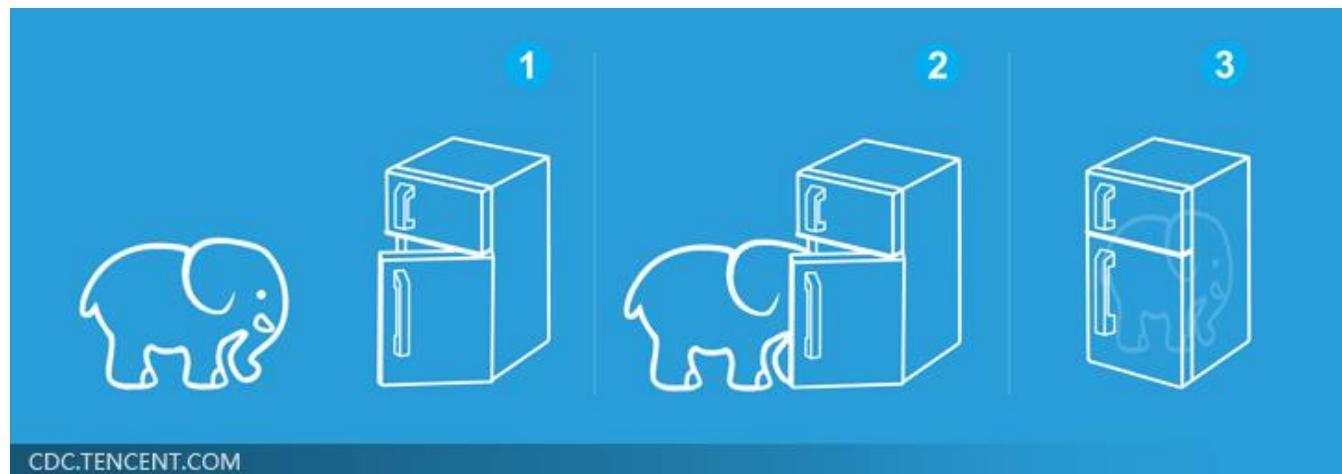
Three Steps for Deep Learning

Step 1:
define a set
of function

Step 2:
goodness of
function

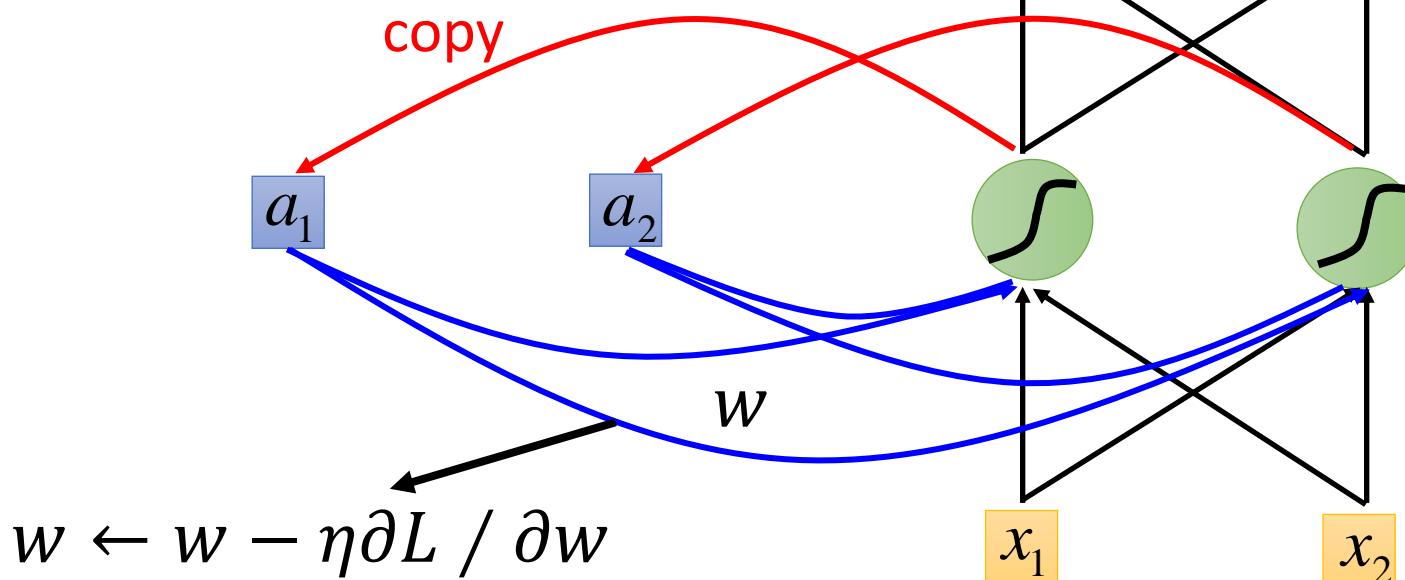
Step 3: pick
the best
function

Deep Learning is so simple



Learning

Backpropagation
through time (BPTT)

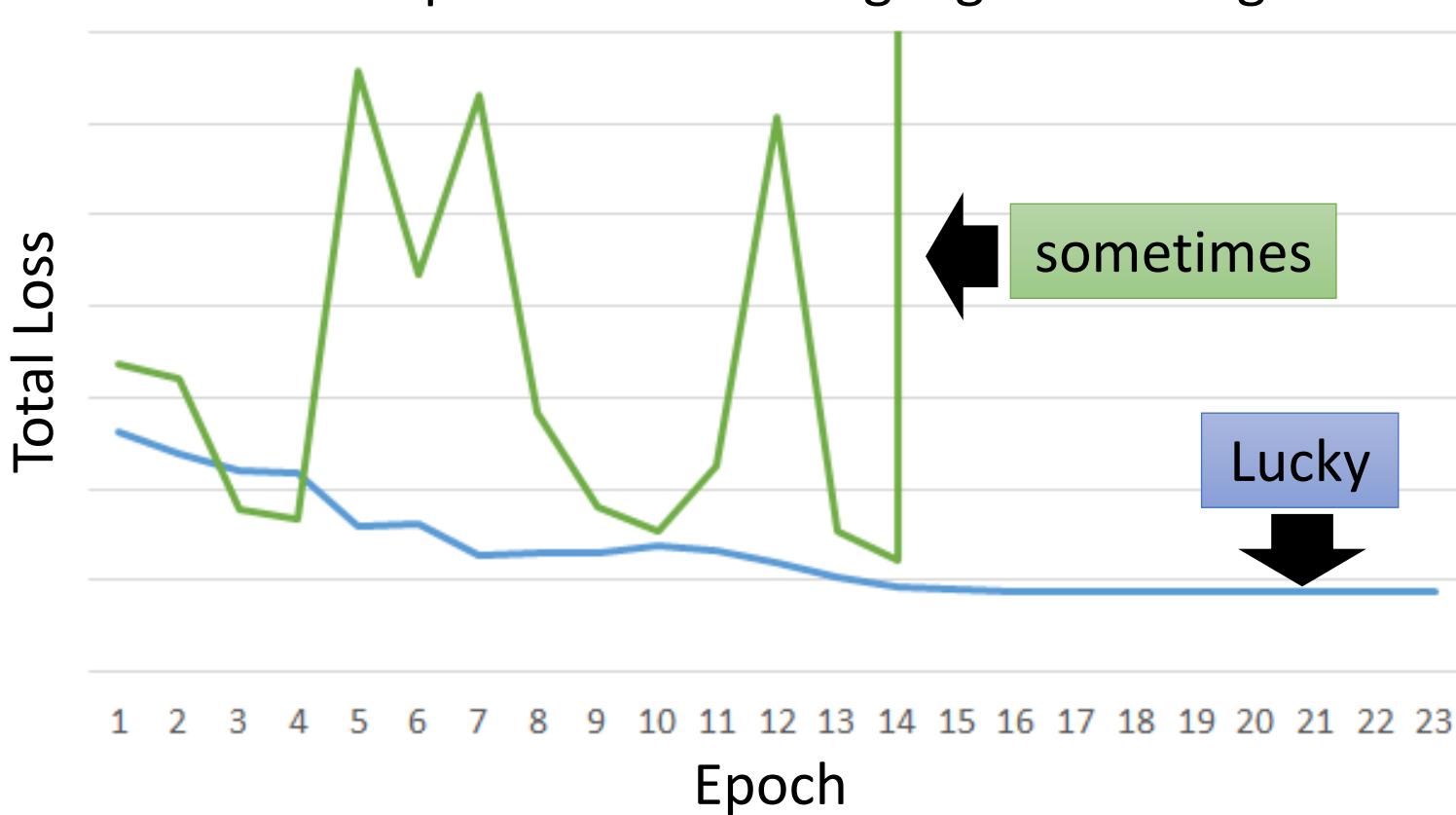


RNN Learning is very difficult in practice.

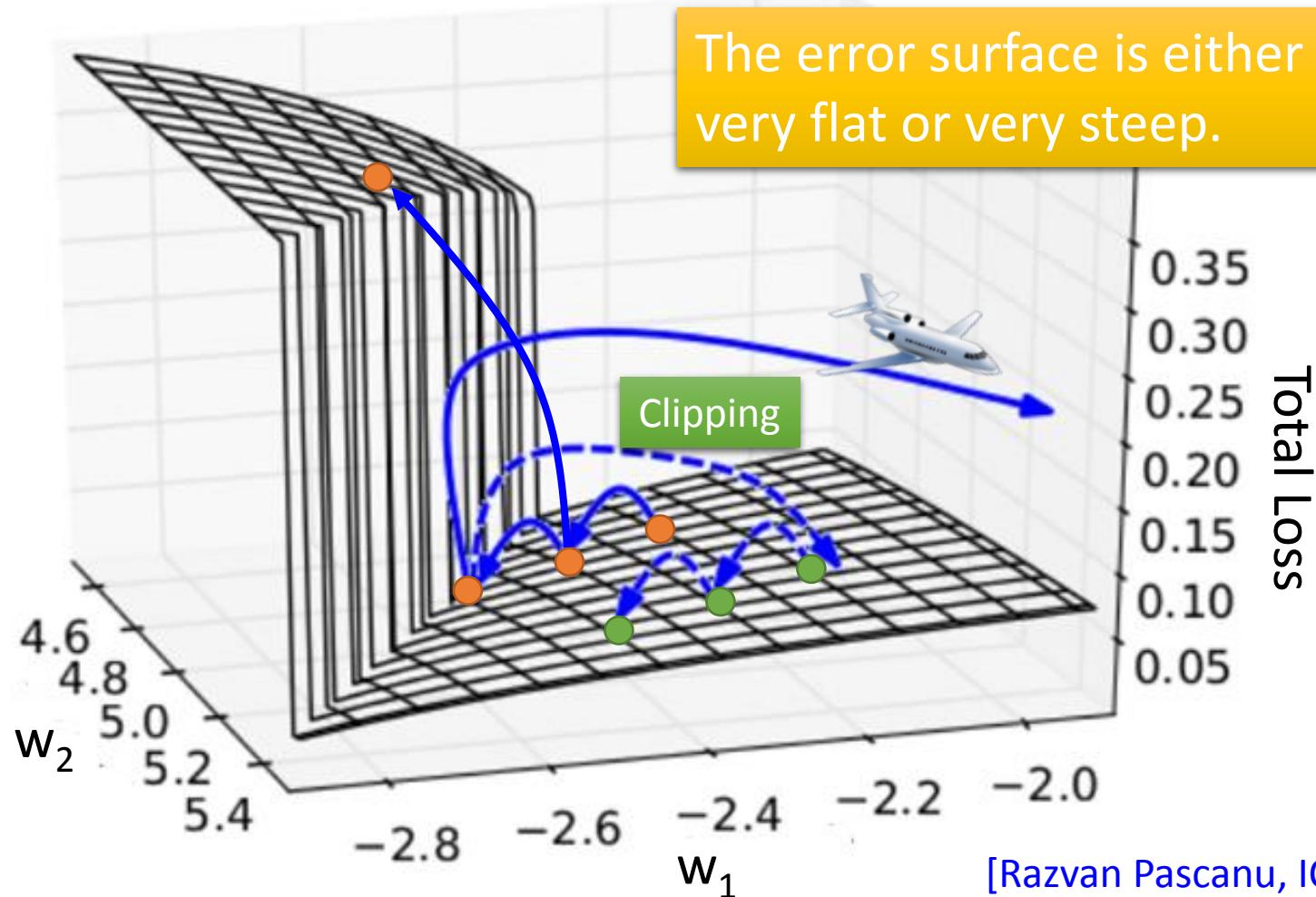
Unfortunately

- RNN-based network is not always easy to learn

Real experiments on Language modeling



The error surface is rough.



Why?

$$w = 1 \quad \rightarrow \quad y^{1000} = 1$$

$$w = 1.01 \quad \rightarrow \quad y^{1000} \approx 20000$$

$$w = 0.99 \quad \rightarrow \quad y^{1000} \approx 0$$

$$w = 0.01 \quad \rightarrow \quad y^{1000} \approx 0$$

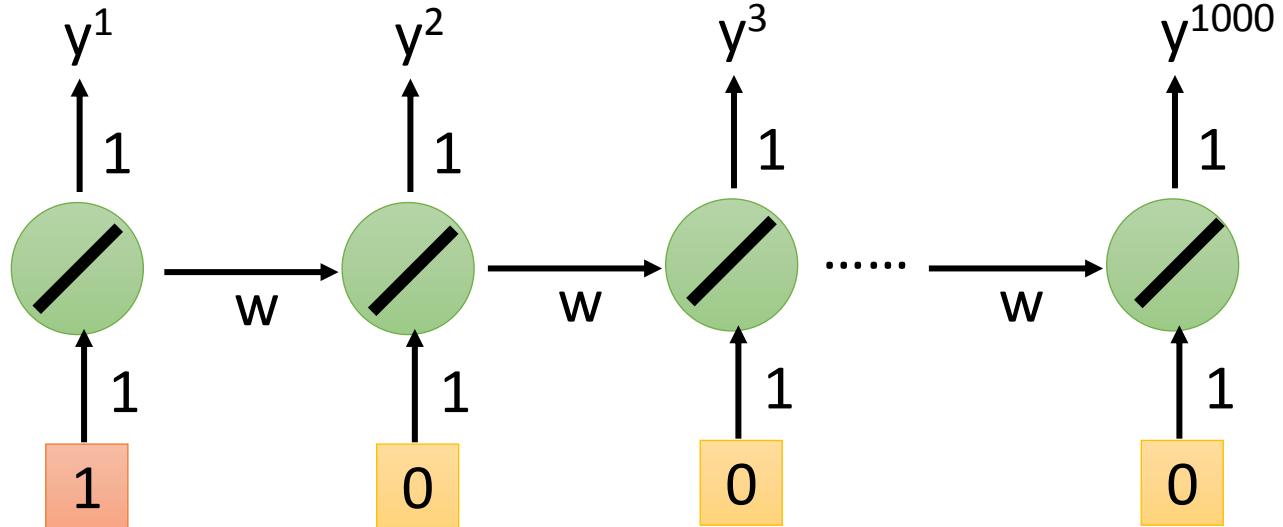
Large
 $\partial L / \partial w$

Small
Learning rate?

small
 $\partial L / \partial w$

Large
Learning rate?

Toy Example



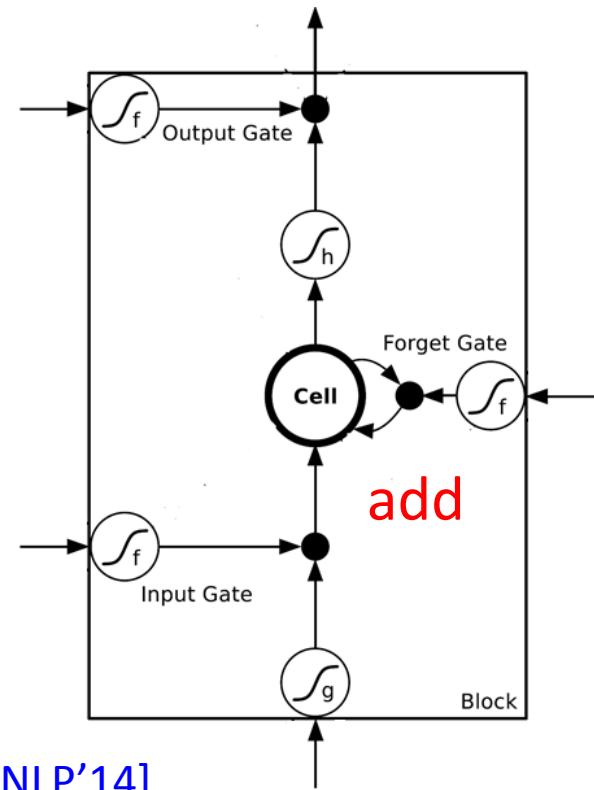
Helpful Techniques

• Long Short-term Memory (LSTM)

- Can deal with gradient vanishing (not gradient explode)
 - Memory and input are added
 - The influence never disappears unless forget gate is closed
- No Gradient vanishing
(If forget gate is opened.)

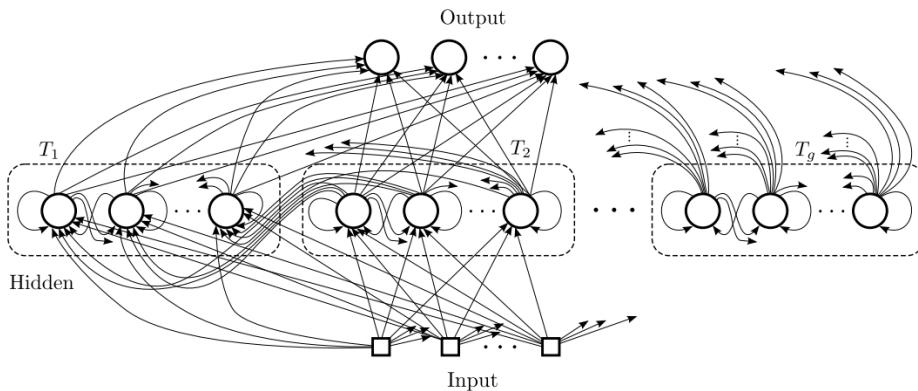
Gated Recurrent Unit (GRU):
simpler than LSTM

[Cho, EMNLP'14]



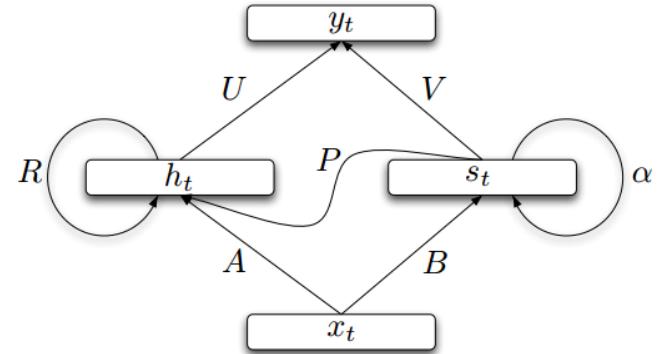
Helpful Techniques

Clockwise RNN



[Jan Koutnik, JMLR'14]

Structurally Constrained Recurrent Network (SCRN)



[Tomas Mikolov, ICLR'15]

Vanilla RNN Initialized with Identity matrix + ReLU activation function [Quoc V. Le, arXiv'15]

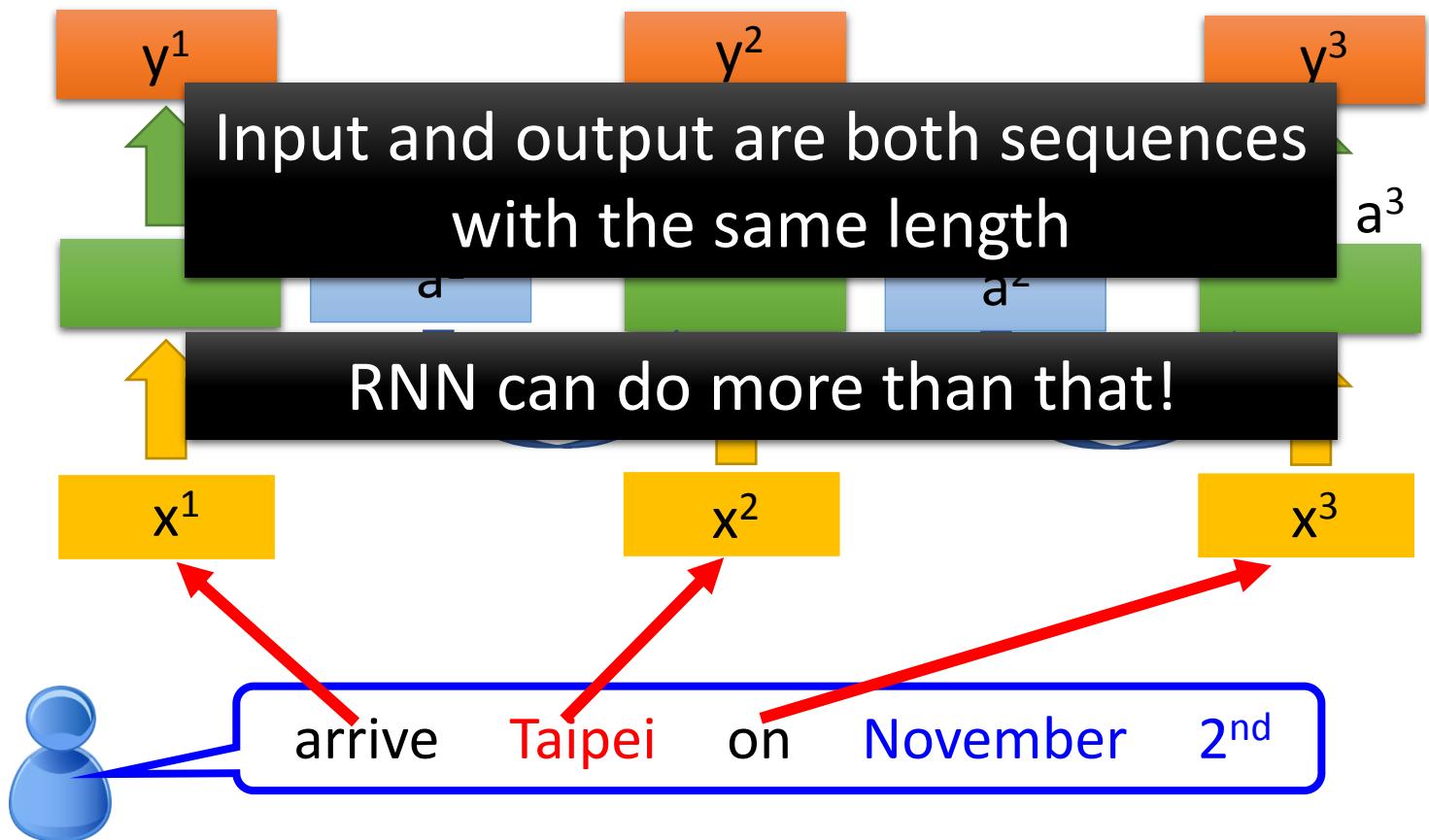
- Outperform or be comparable with LSTM in 4 different tasks

More Applications

Probability of
“arrive” in each slot

Probability of
“Taipei” in each slot

Probability of
“on” in each slot



Many to one

Keras Example:

https://github.com/fchollet/keras/blob/master/examples/imdb_lstm.py

- Input is a vector sequence, but output is only one vector

Sentiment Analysis

看了這部電影覺
得很高興

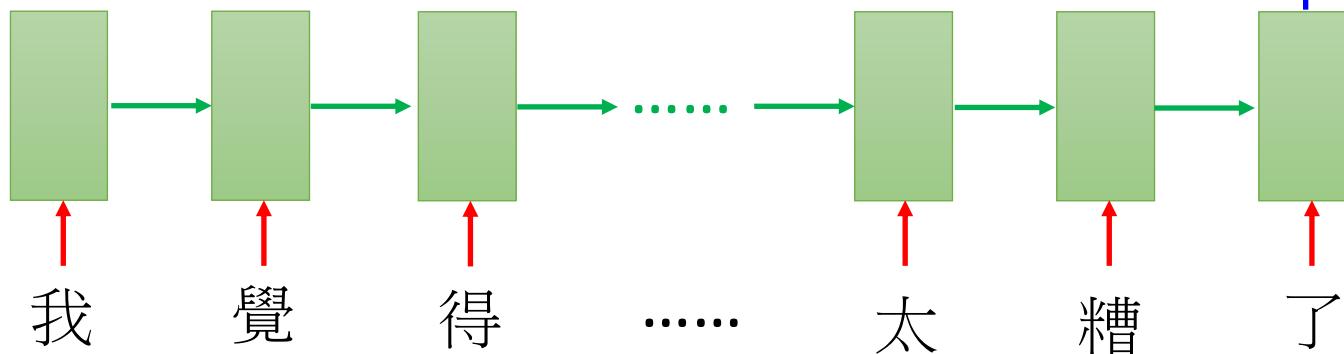
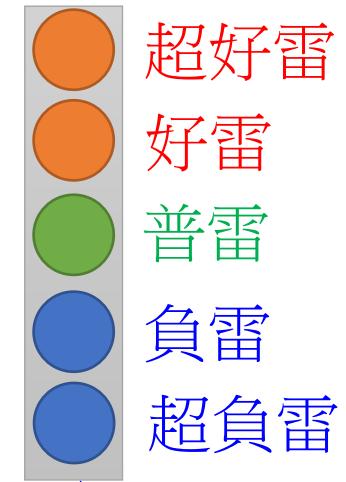
Positive (正雷)

這部電影太糟了
.....

Negative (負雷)

這部電影很
棒

Positive (正雷)



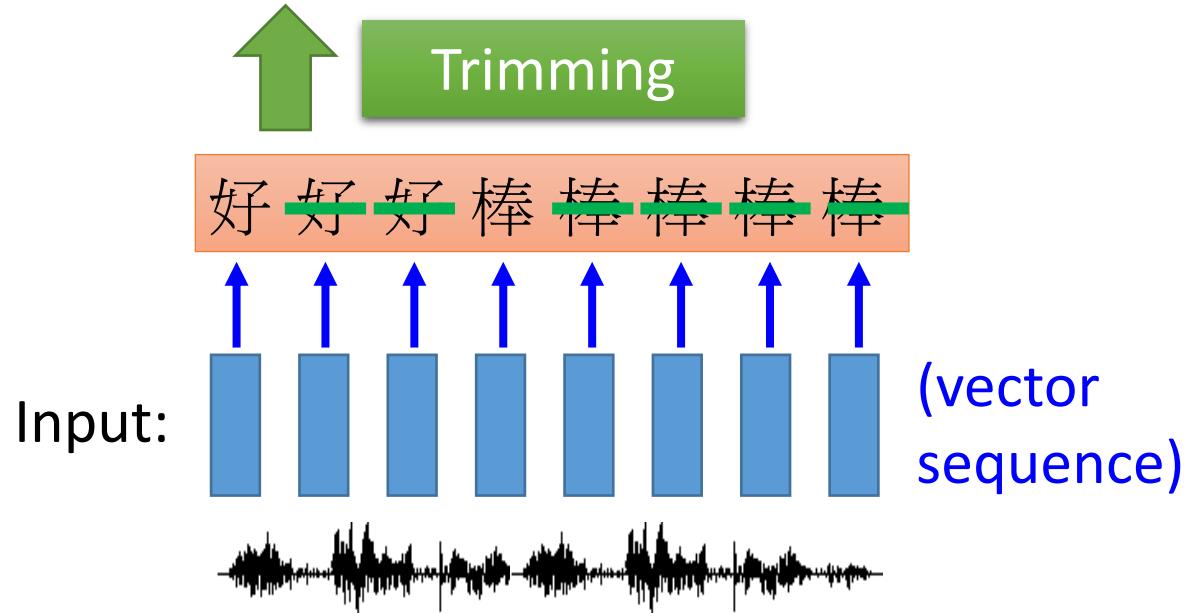
Many to Many (Output is shorter)

- Both input and output are both sequences, **but the output is shorter.**
 - E.g. **Speech Recognition**

Problem?

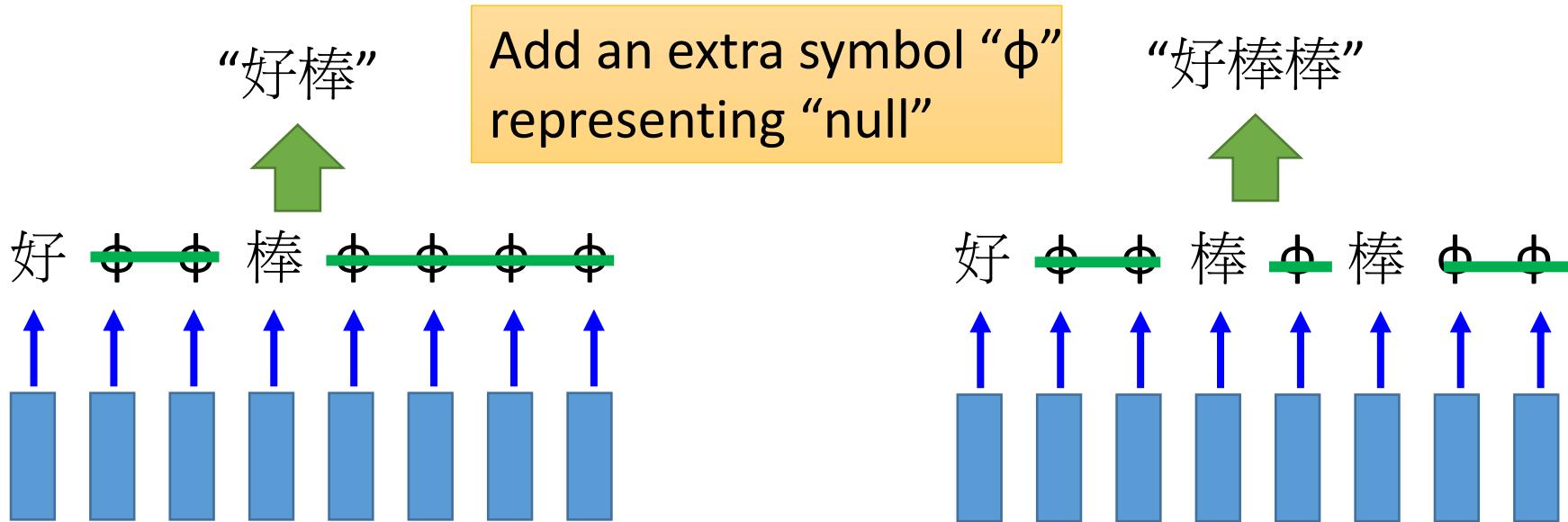
Why can't it be
“好棒棒”

Output: “好棒” (character sequence)



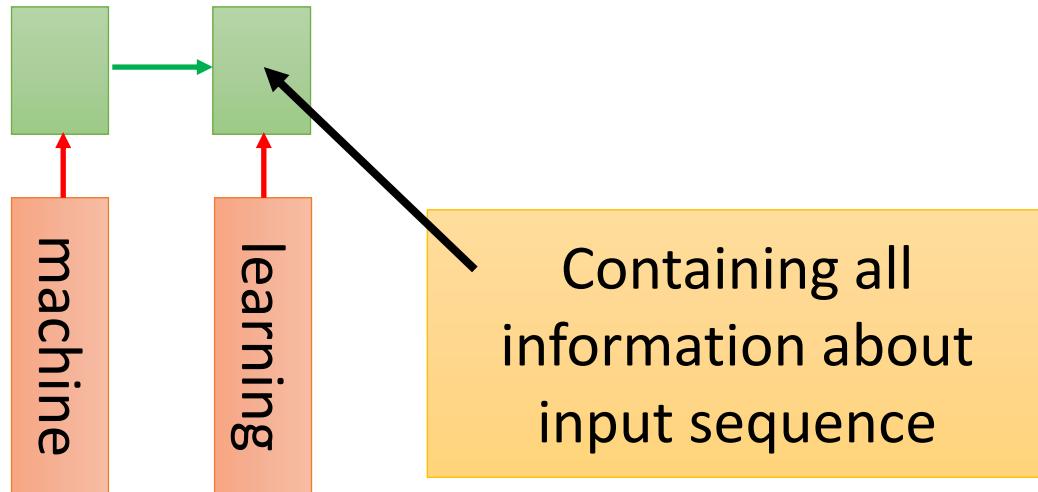
Many to Many (Output is shorter)

- Both input and output are both sequences, **but the output is shorter.**
- Connectionist Temporal Classification (CTC) [Alex Graves, ICML'06][Alex Graves, ICML'14][Hasim Sak, Interspeech'15][Jie Li, Interspeech'15][Andrew Senior, ASRU'15]



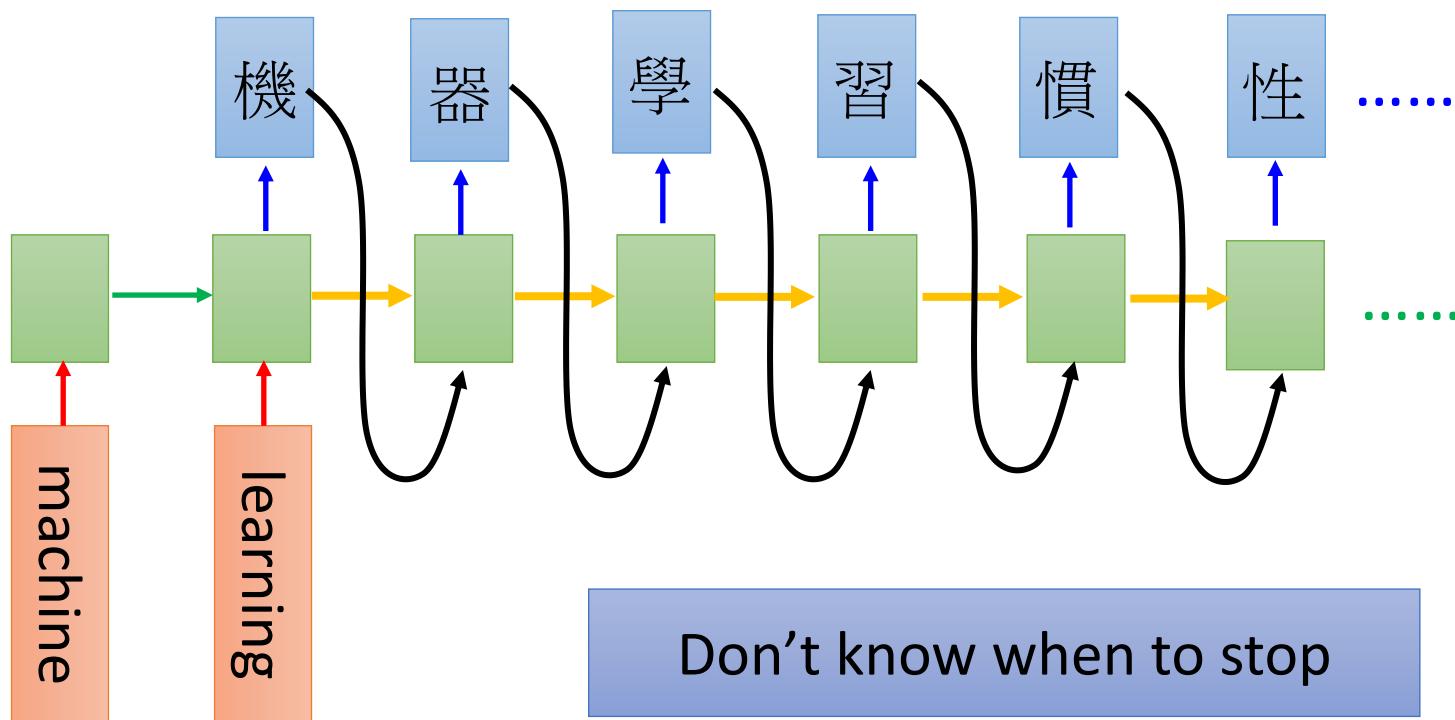
Many to Many (No Limitation)

- Both input and output are both sequences *with different lengths*. → *Sequence to sequence learning*
 - E.g. *Machine Translation* (machine learning → 機器學習)



Many to Many (No Limitation)

- Both input and output are both sequences with different lengths. → Sequence to sequence learning
 - E.g. Machine Translation (machine learning→機器學習)



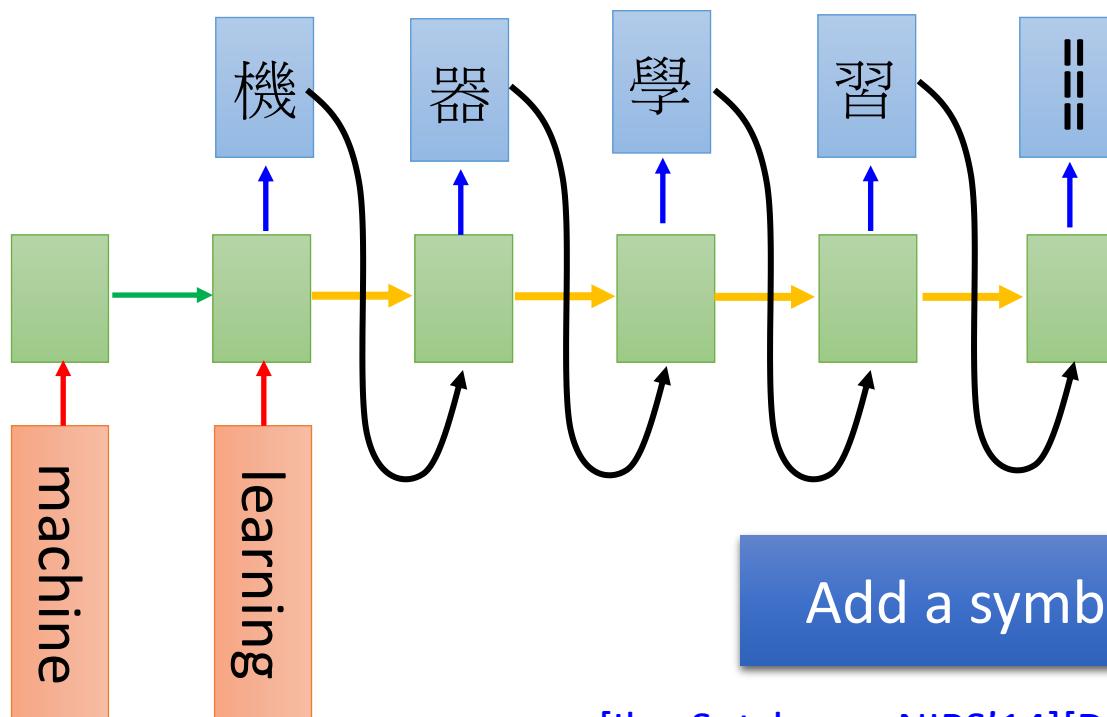
Many to Many (No Limitation)

推	1:	超	06/12 10:39
推	n:	人	06/12 10:40
推	tion:	正	06/12 10:41
→	host:	大	06/12 10:47
推	:	中	06/12 10:59
推	403:	天	06/12 11:11
推	:	外	06/12 11:13
推	527:	飛	06/12 11:17
→	990b:	仙	06/12 11:32
→	512:	草	06/12 12:15

推 tlkagk: =====斷=====

Many to Many (No Limitation)

- Both input and output are both sequences with different lengths. → Sequence to sequence learning
 - E.g. Machine Translation (machine learning→機器學習)



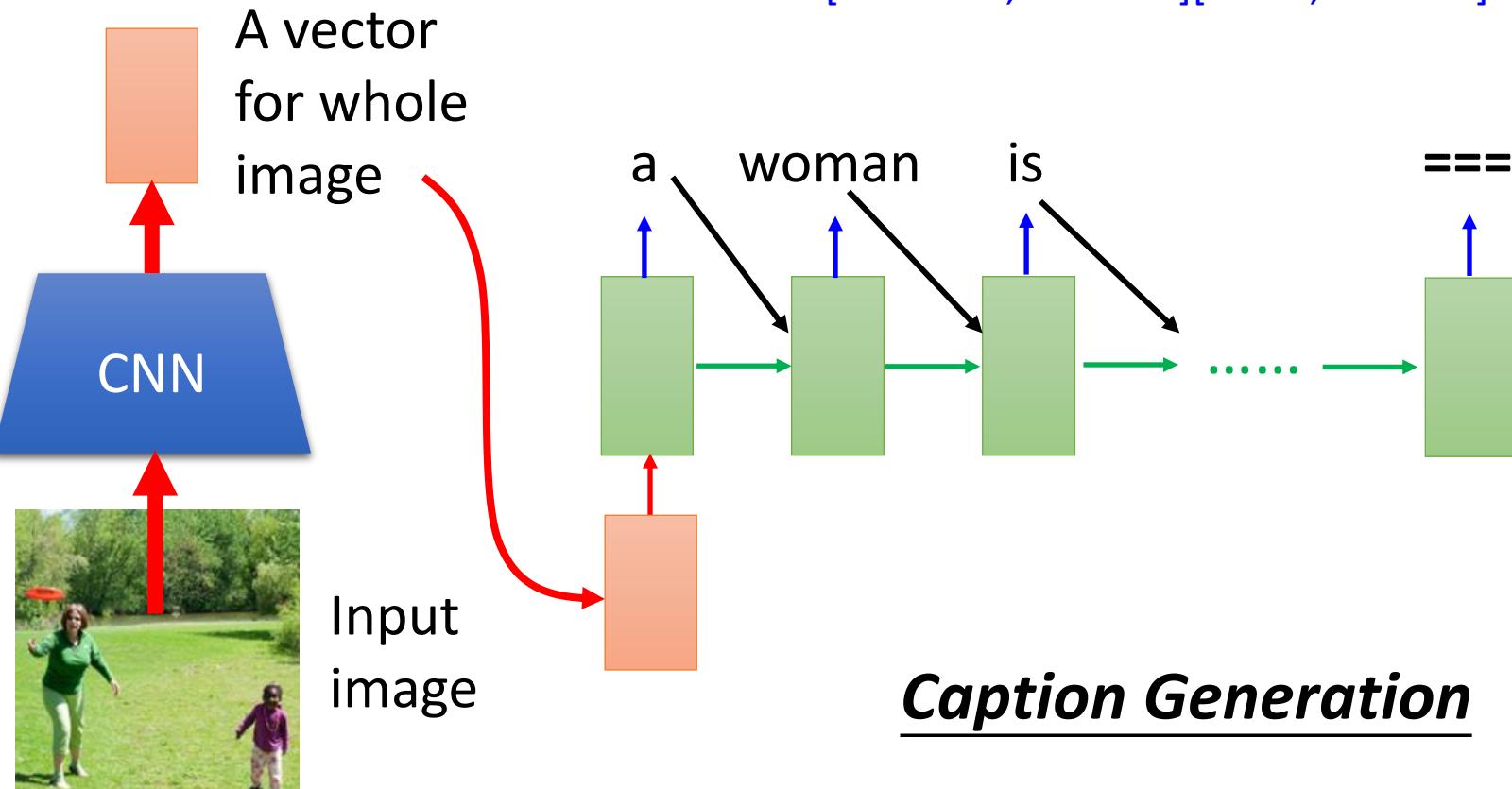
Add a symbol “==” (斷)

[Ilya Sutskever, NIPS'14][Dzmitry Bahdanau, arXiv'15]

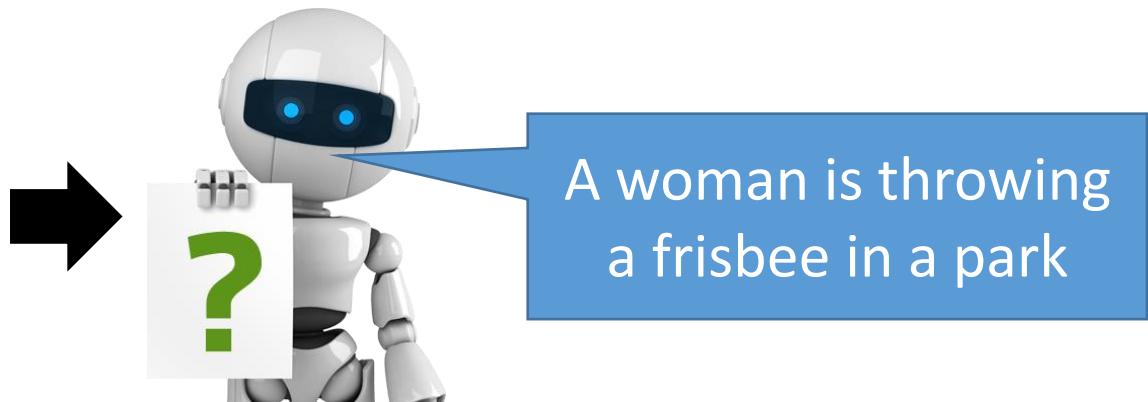
One to Many

- Input an image, but output a sequence of words

[Kelvin Xu, arXiv'15][Li Yao, ICCV'15]



Application: Image Caption Generation



The man at bat readies to swing at the pitch while the umpire looks on.



A large bus sitting next to a very tall building.



A horse carrying a large load of hay and two people sitting on it.



Bunk bed with a narrow shelf sitting underneath it.

Application: Image Caption Generation

- Can machine describe what it see from image?
- Demo:台大電機系 大四 林奕辰、蘇子睿、徐翊祥、陳奕安

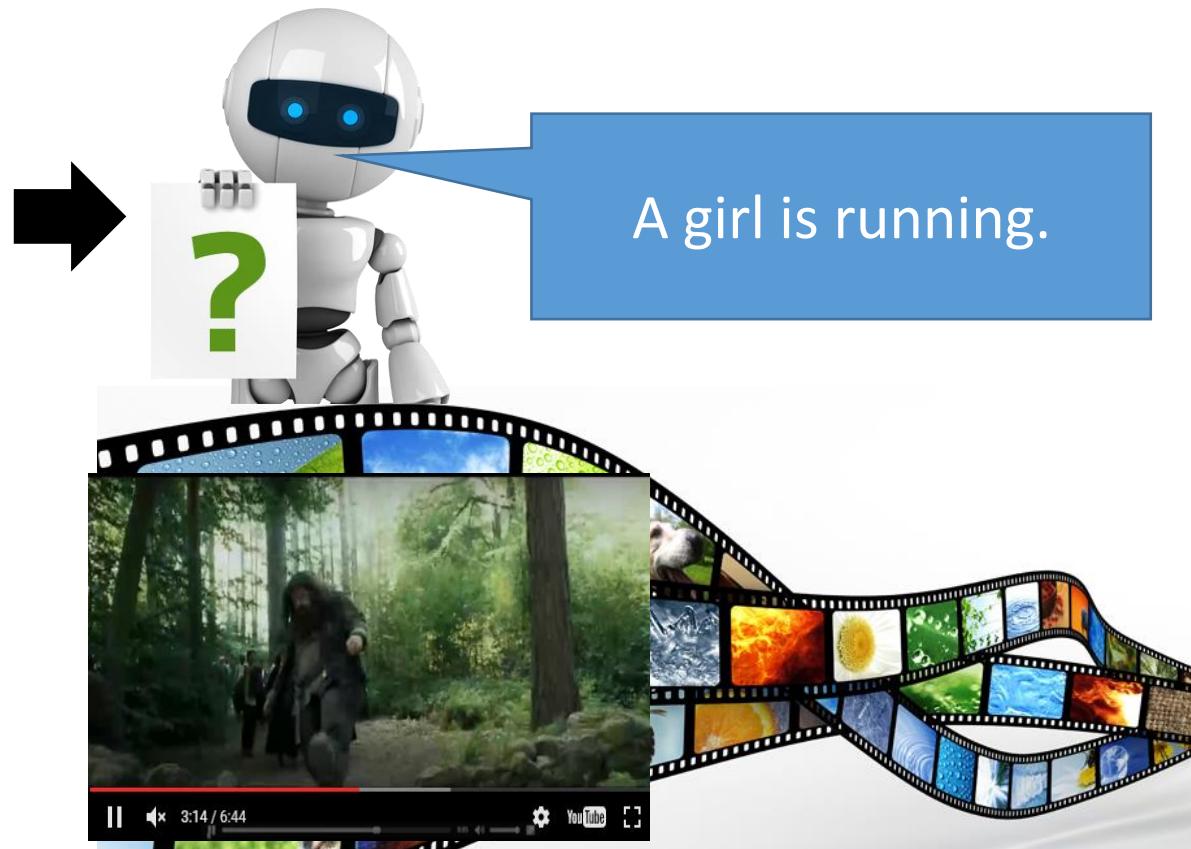
Application: Video Caption Generation



Video



A group of people is
knocked by a tree.



A group of people is
walking in the forest.

Video Caption Generation

- Can machine describe what it see from video?
- Demo: 曾柏翔、吳柏瑜、盧宏宗

Concluding Remarks

Convolutional Neural
Network (CNN)

Recurrent Neural Network
(RNN)

Lecture IV: Next Wave

Outline

Supervised Learning

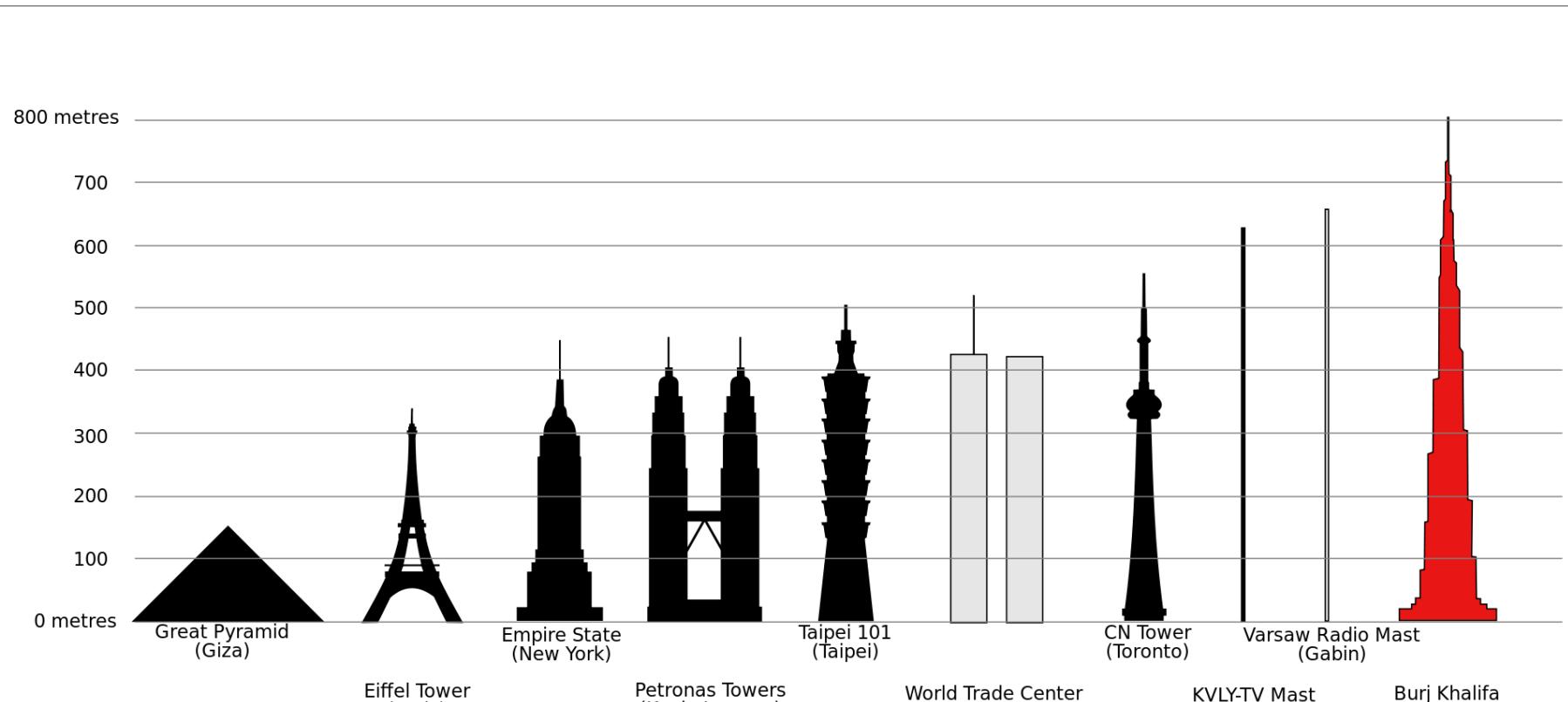
- Ultra Deep Network
 - Attention Model
- }
- New network structure

Reinforcement Learning

Unsupervised Learning

- Image: Realizing what the World Looks Like
- Text: Understanding the Meaning of Words
- Audio: Learning human language without supervision

Skyscraper

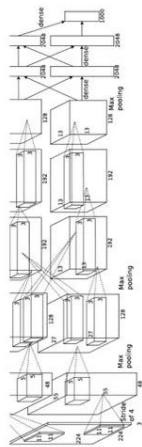


<https://zh.wikipedia.org/wiki/%E9%9B%99%E5%B3%B0%E5%A1%94#media/File:BurjDubaiHeight.svg>

Ultra Deep Network

http://cs231n.stanford.edu/slides/winter1516_lecuture8.pdf

16.4%



AlexNet (2012)

8 layers

7.3%



VGG (2014)

19 layers

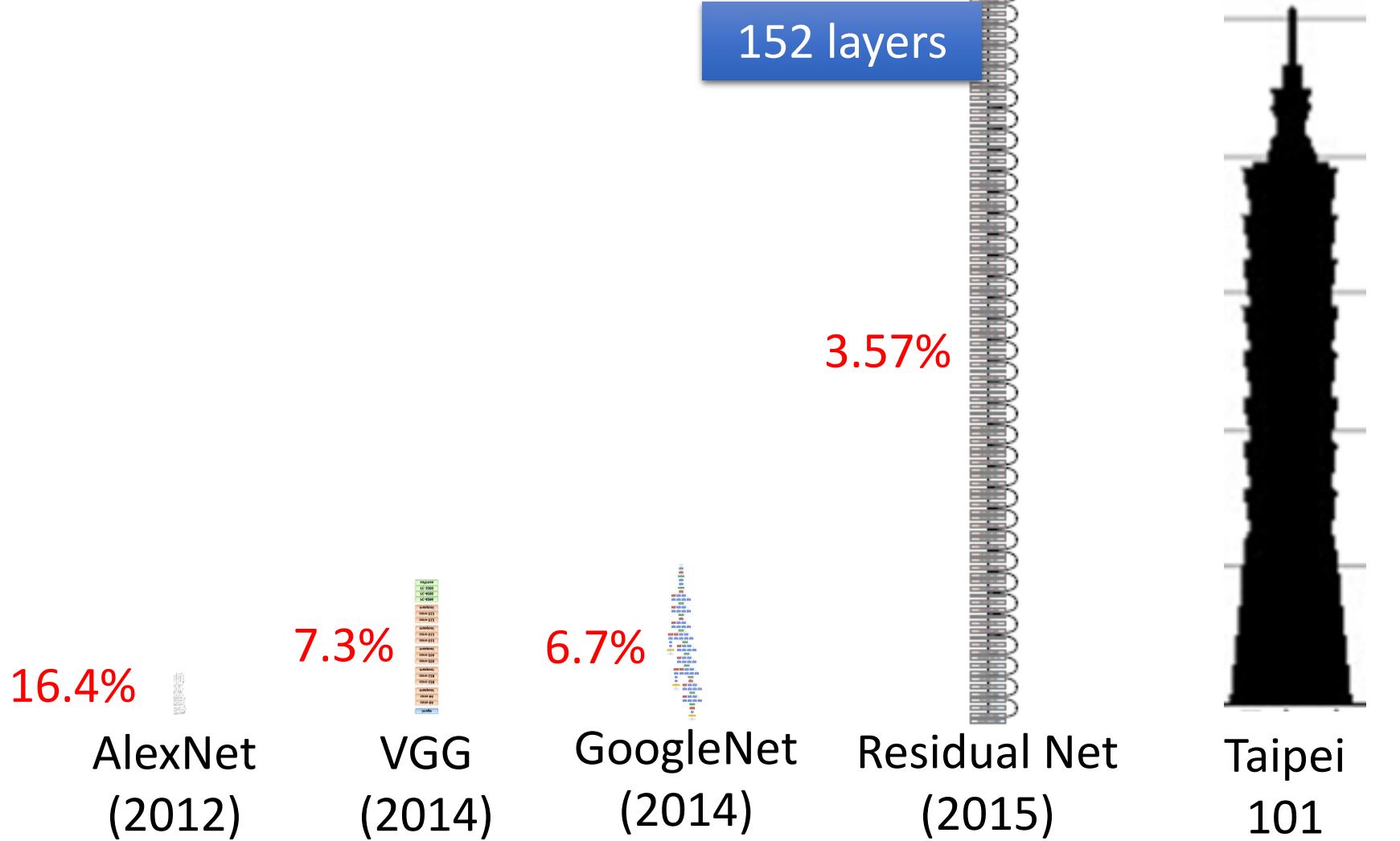
6.7%



GoogleNet (2014)

22 layers

Ultra Deep Network



Ultra Deep Network

Worry about overfitting?

152 layers

Worry about training
first!

This ultra deep network
have special structure.

3.57%

16.4%



AlexNet
(2012)

7.3%



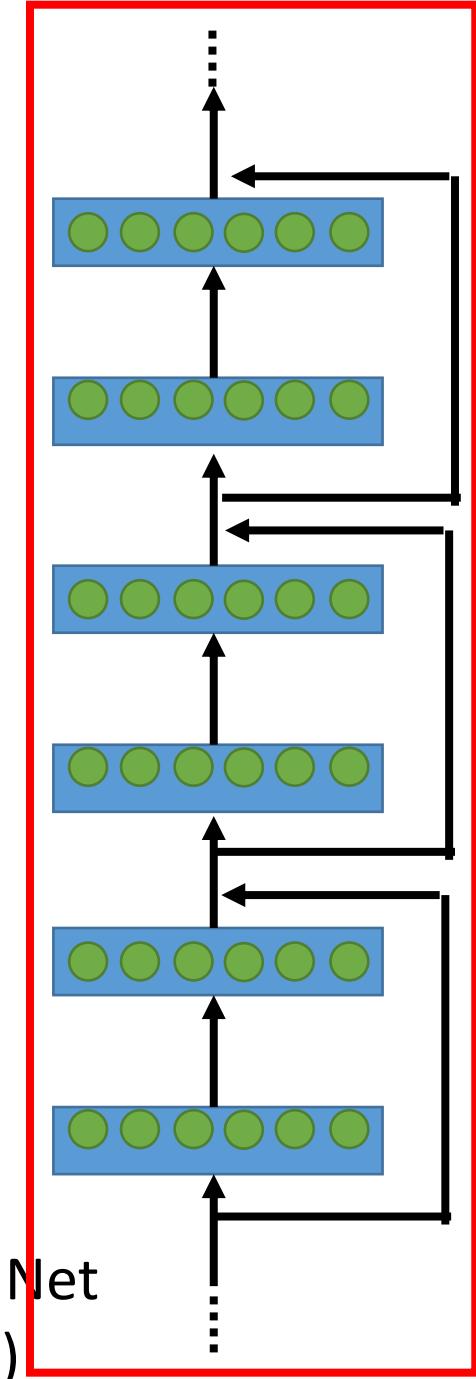
VGG
(2014)

6.7%



GoogleNet
(2014)

Residual Net
(2015)

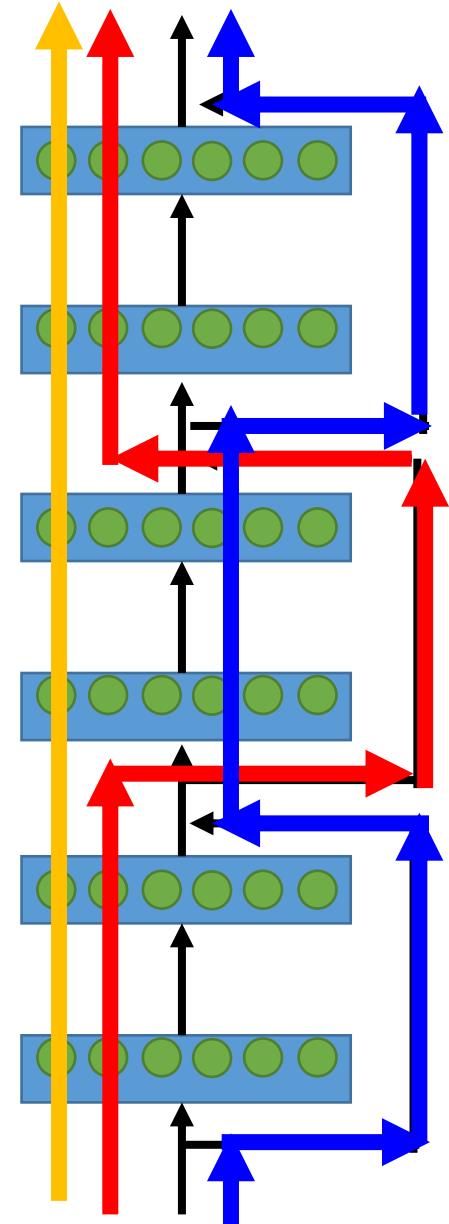


Ultra Deep Network

- Ultra deep network is the ensemble of many networks with different depth.

Ensemble {
 6 layers
 4 layers
 2 layers

Residual Networks are Exponential Ensembles
of Relatively Shallow Networks
<https://arxiv.org/abs/1605.06431>



Ultra Deep Network

- FractalNet

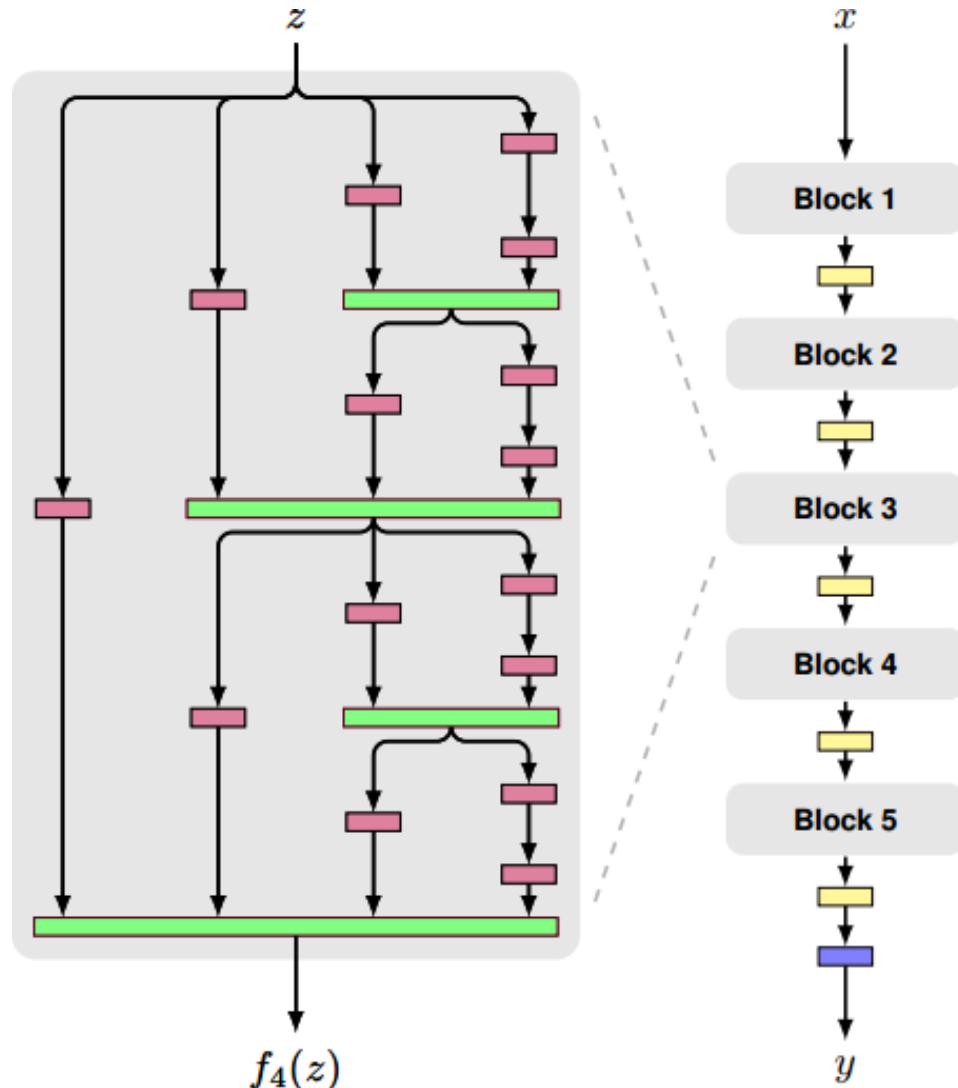
FractalNet: Ultra-Deep Neural Networks without Residuals
<https://arxiv.org/abs/1605.07648>

Resnet in Resnet

Resnet in Resnet: Generalizing Residual Architectures
<https://arxiv.org/abs/1603.08029>

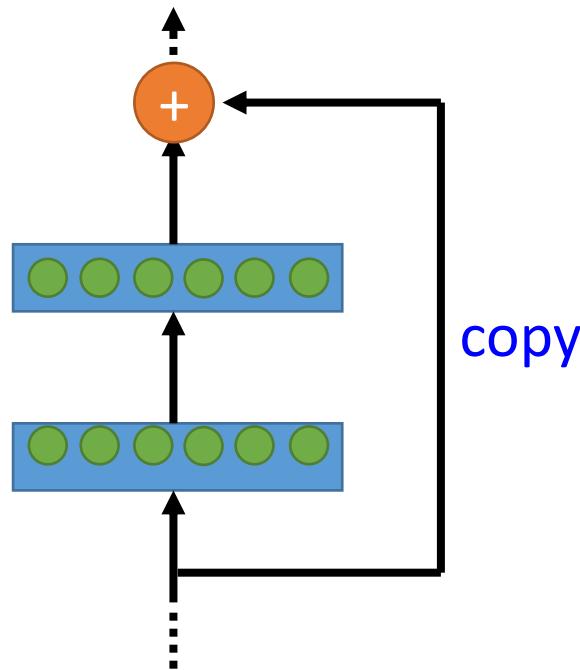
Good Initialization?

All you need is a good init
<http://arxiv.org/pdf/1511.06422v7.pdf>



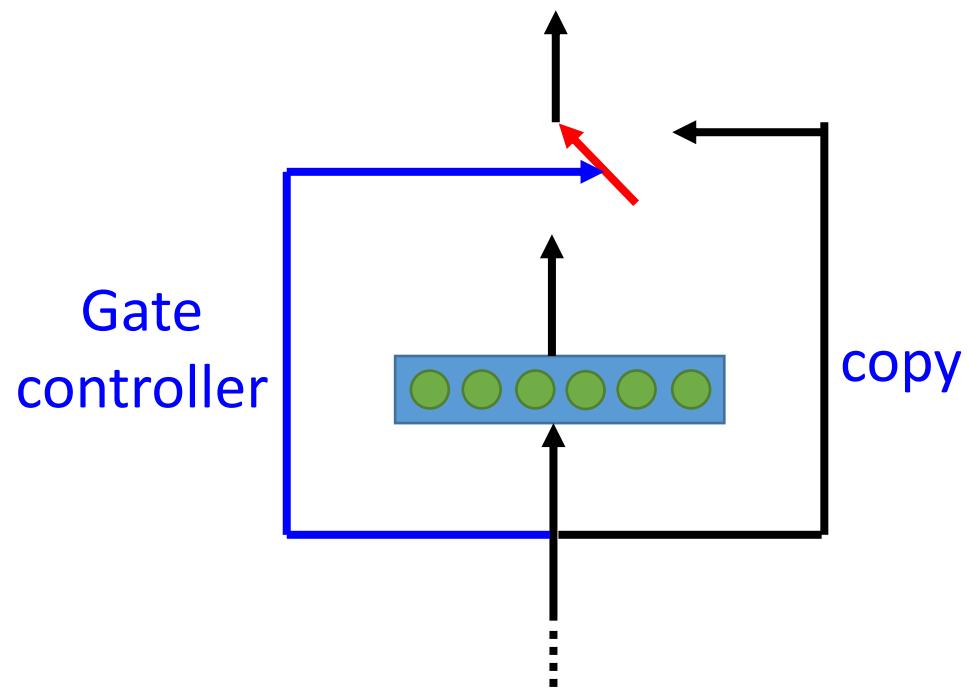
Ultra Deep Network

- Residual Network



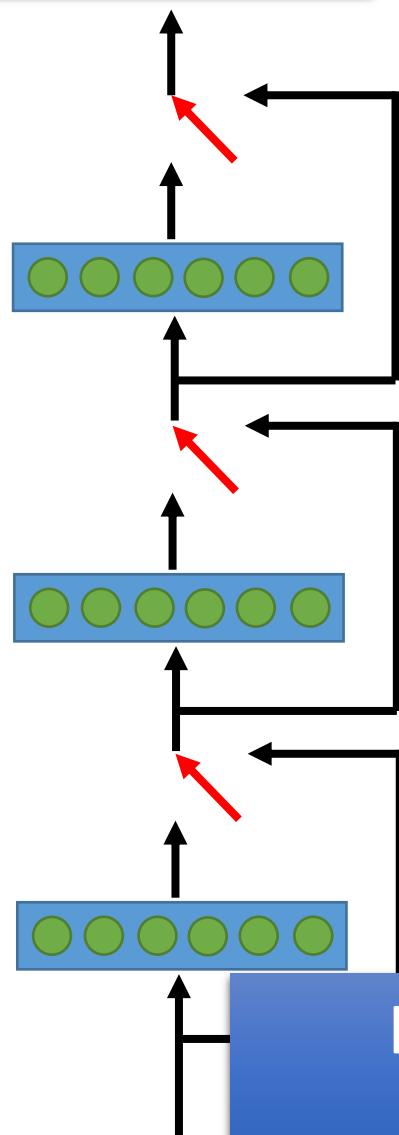
Deep Residual Learning for Image
Recognition
<http://arxiv.org/abs/1512.03385>

- Highway Network

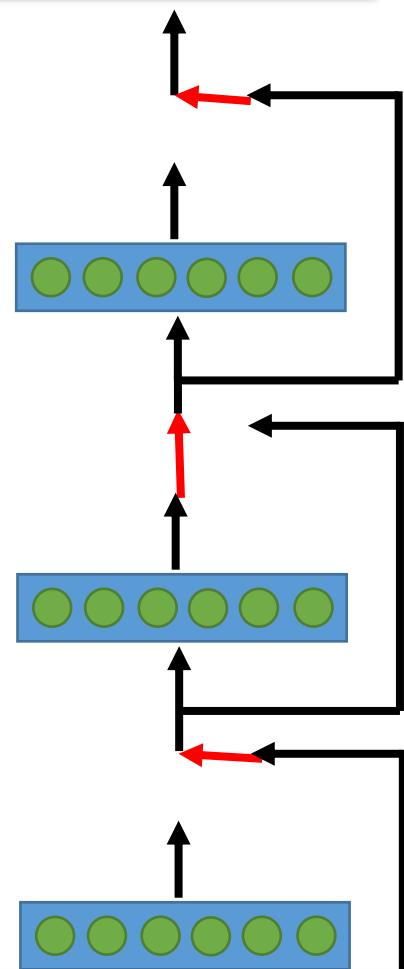


Training Very Deep Networks
<https://arxiv.org/pdf/1507.06228v2.pdf>

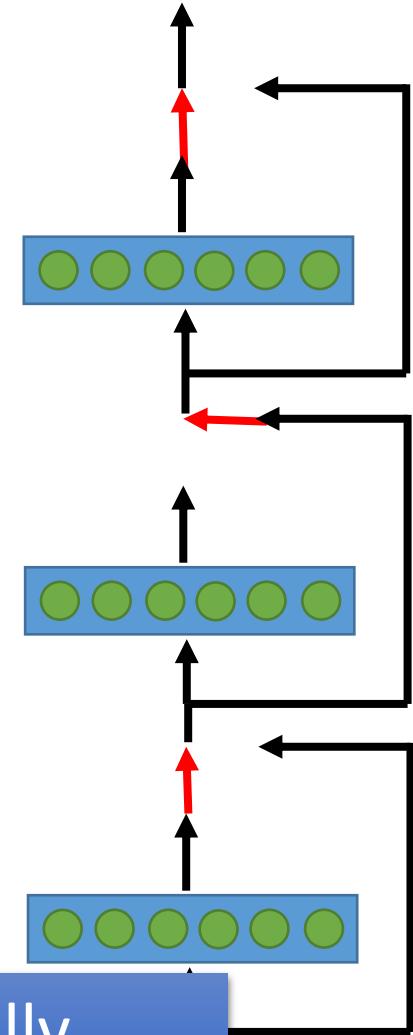
output layer



output layer



output layer



Highway Network automatically
determines the layers needed!

Input layer

Input layer

Input layer

Outline

Supervised Learning

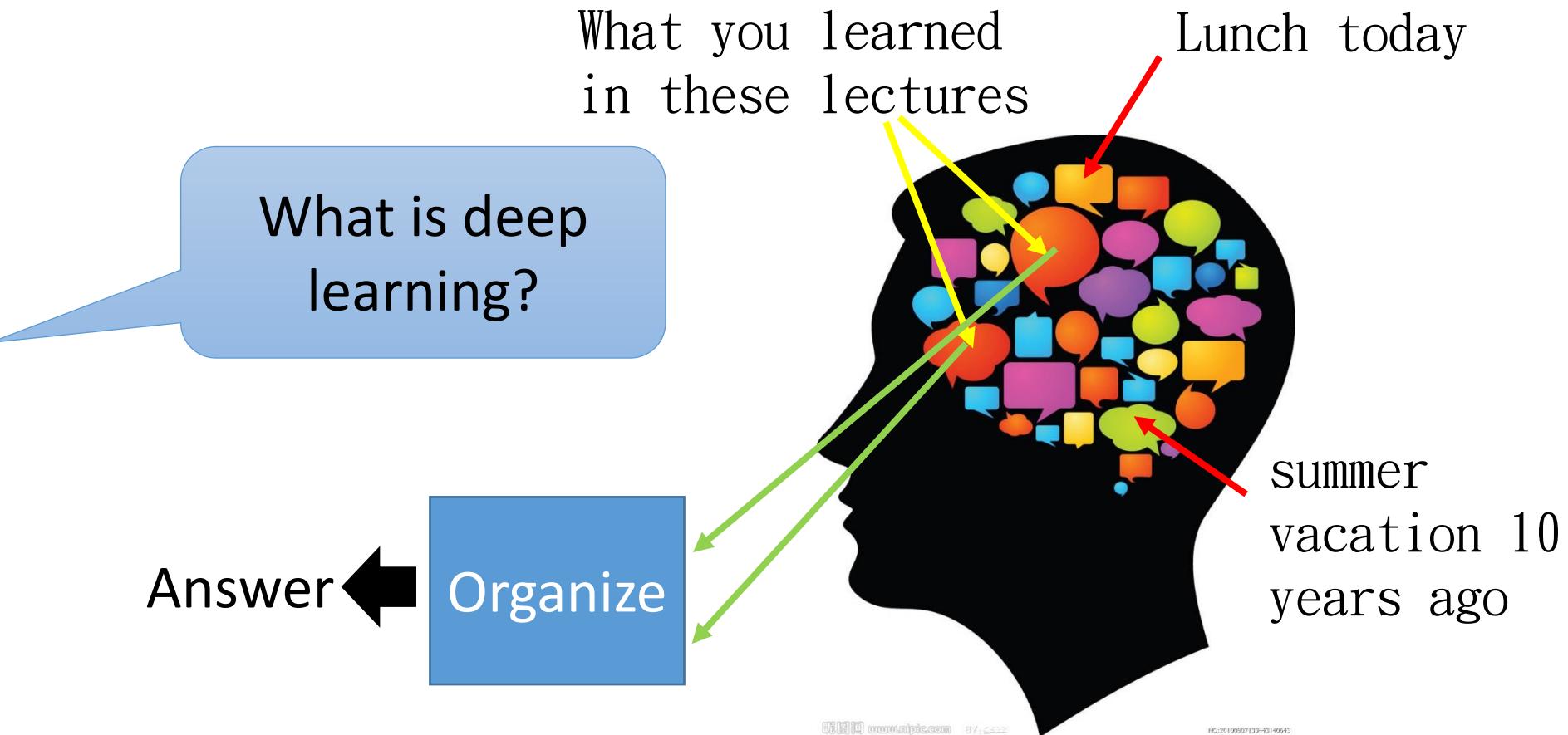
- Ultra Deep Network
 - Attention Model
- }
- New network structure

Reinforcement Learning

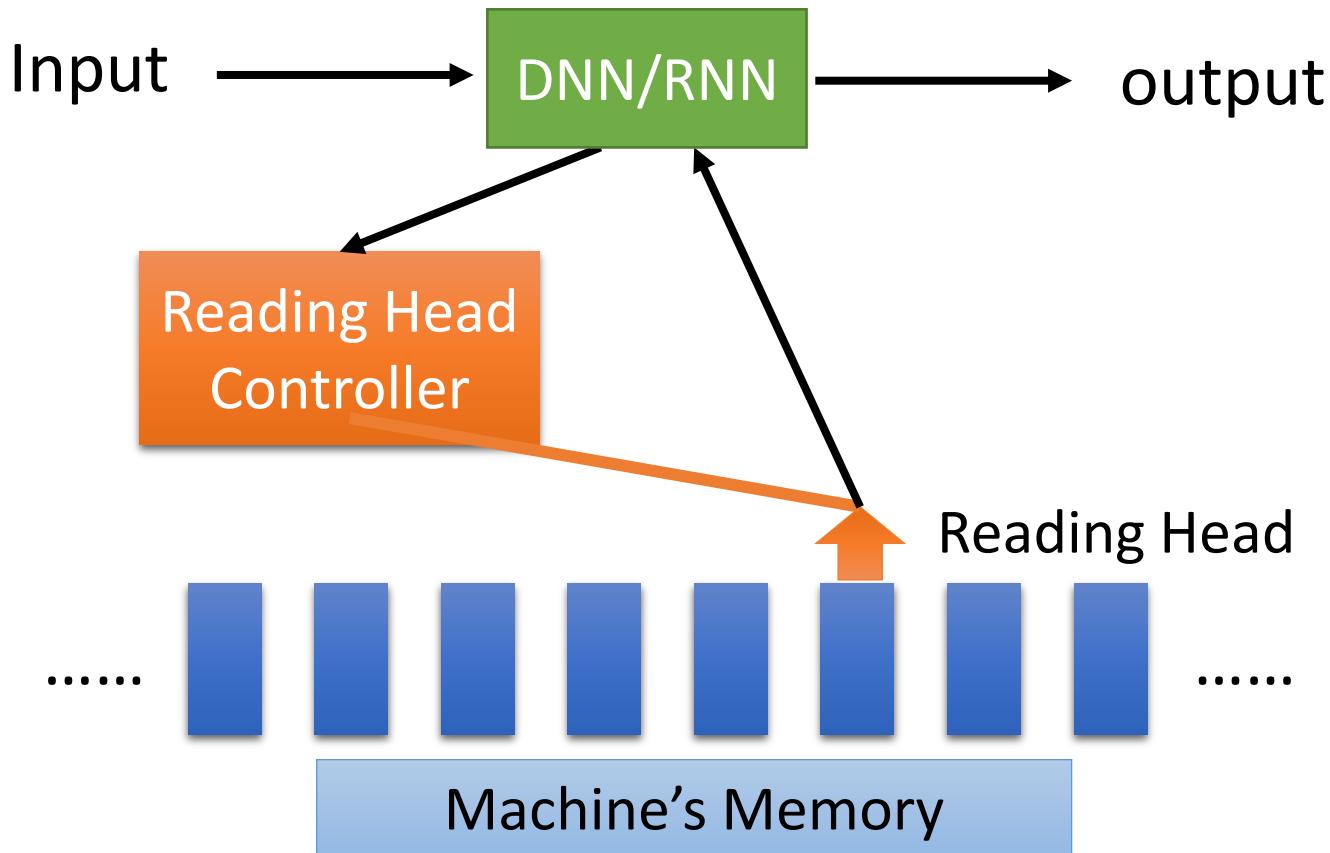
Unsupervised Learning

- Image: Realizing what the World Looks Like
- Text: Understanding the Meaning of Words
- Audio: Learning human language without supervision

Attention-based Model



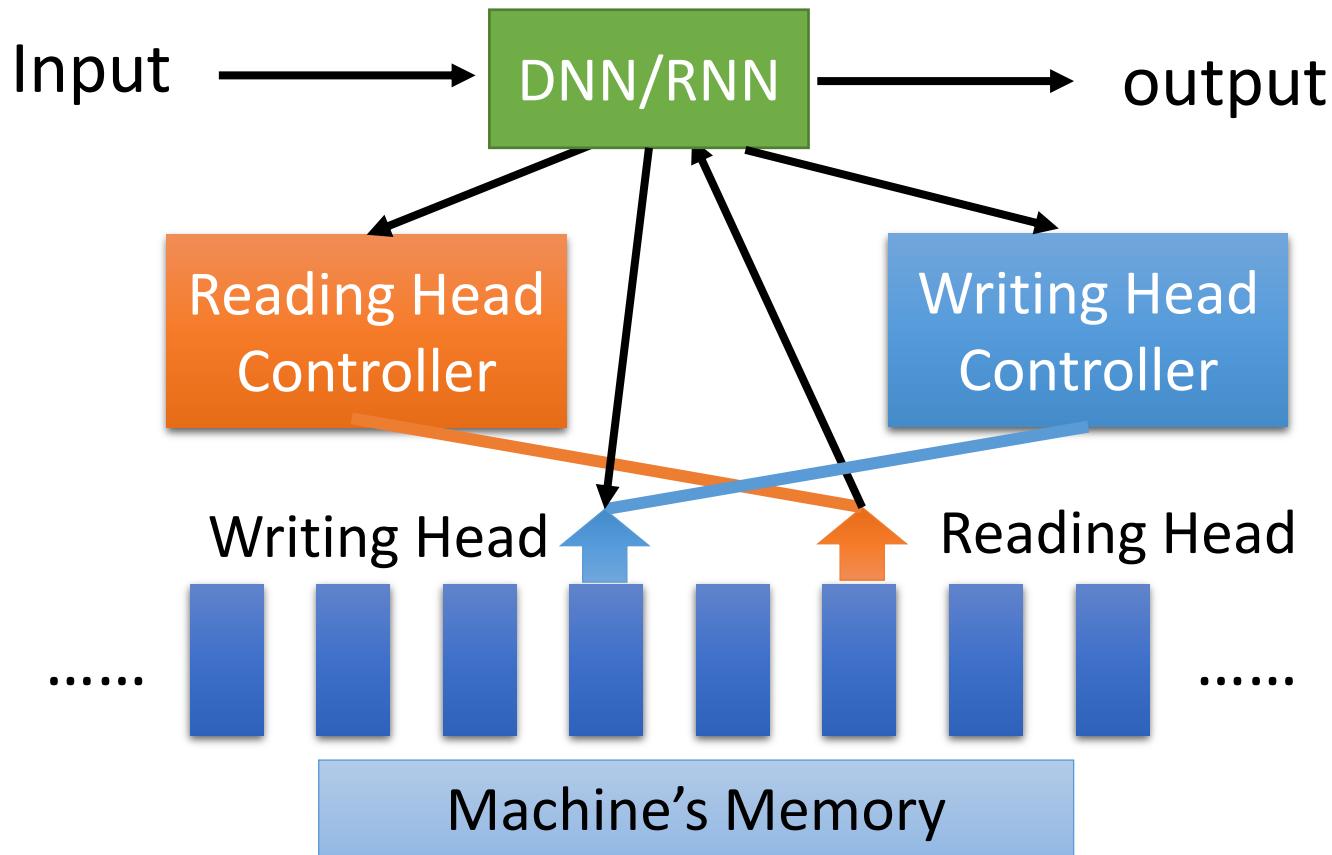
Attention-based Model



Ref:

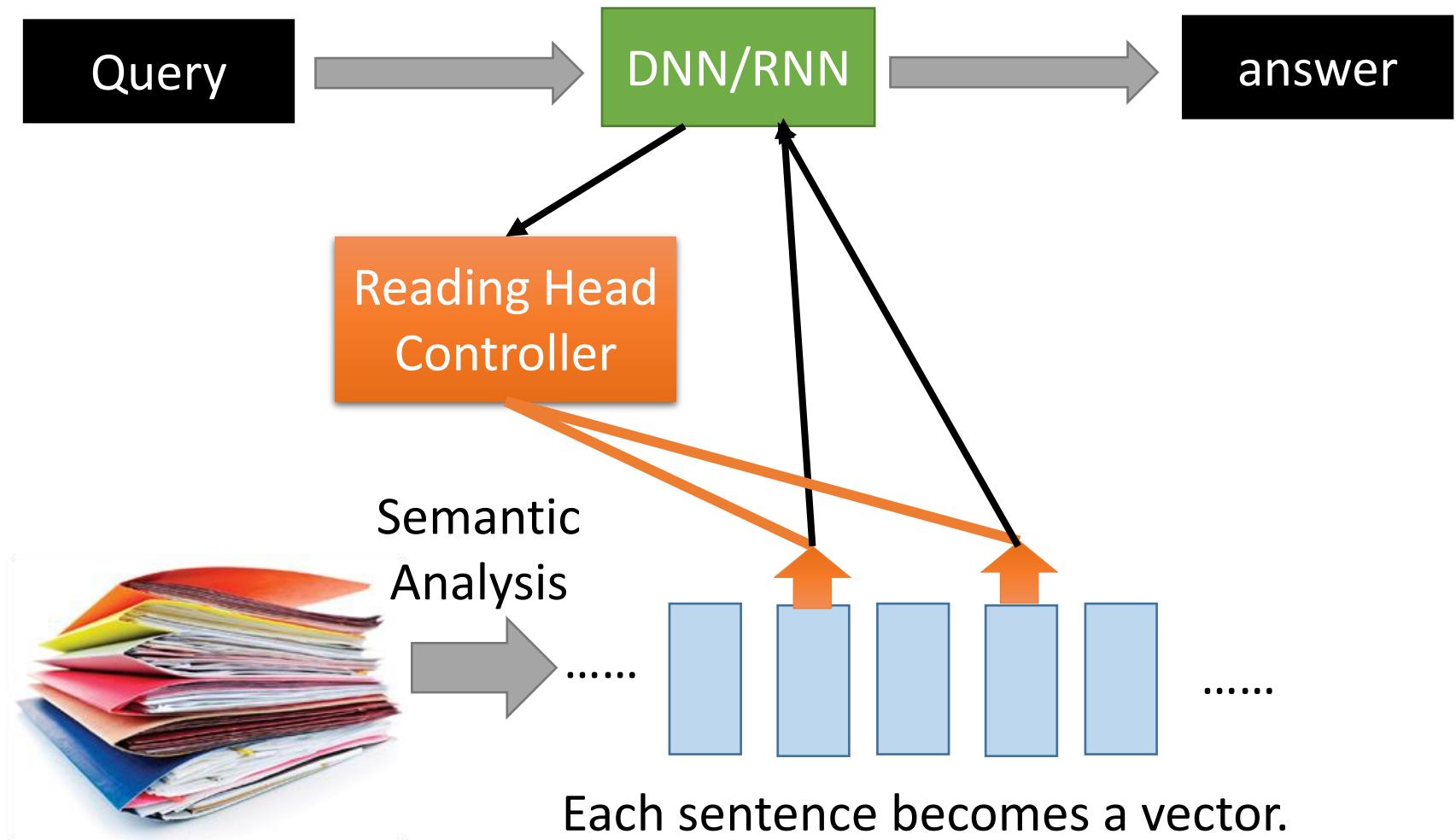
[http://speech.ee.ntu.edu.tw/~tlkagk/courses/MLDS_2015_2/Lecture/Attain%20\(v3\).ecm.mp4/index.html](http://speech.ee.ntu.edu.tw/~tlkagk/courses/MLDS_2015_2/Lecture/Attain%20(v3).ecm.mp4/index.html)

Attention-based Model v2



Neural Turing Machine

Reading Comprehension



Reading Comprehension

- End-To-End Memory Networks. S. Sukhbaatar, A. Szlam, J. Weston, R. Fergus. NIPS, 2015.

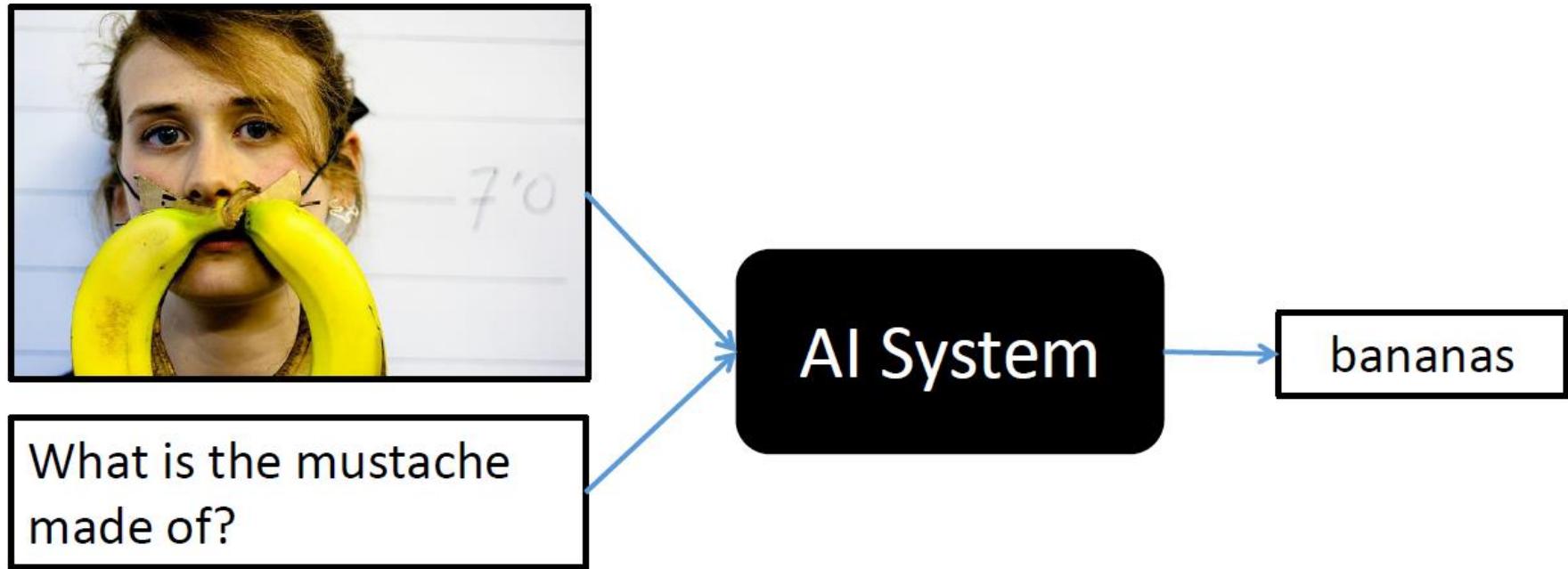
The position of reading head:

Story (16: basic induction)	Support	Hop 1	Hop 2	Hop 3
Brian is a frog.	yes	0.00	0.98	0.00
Lily is gray.		0.07	0.00	0.00
Brian is yellow.	yes	0.07	0.00	1.00
Julius is green.		0.06	0.00	0.00
Greg is a frog.	yes	0.76	0.02	0.00
What color is Greg? Answer: yellow		Prediction: yellow		

Keras has example:

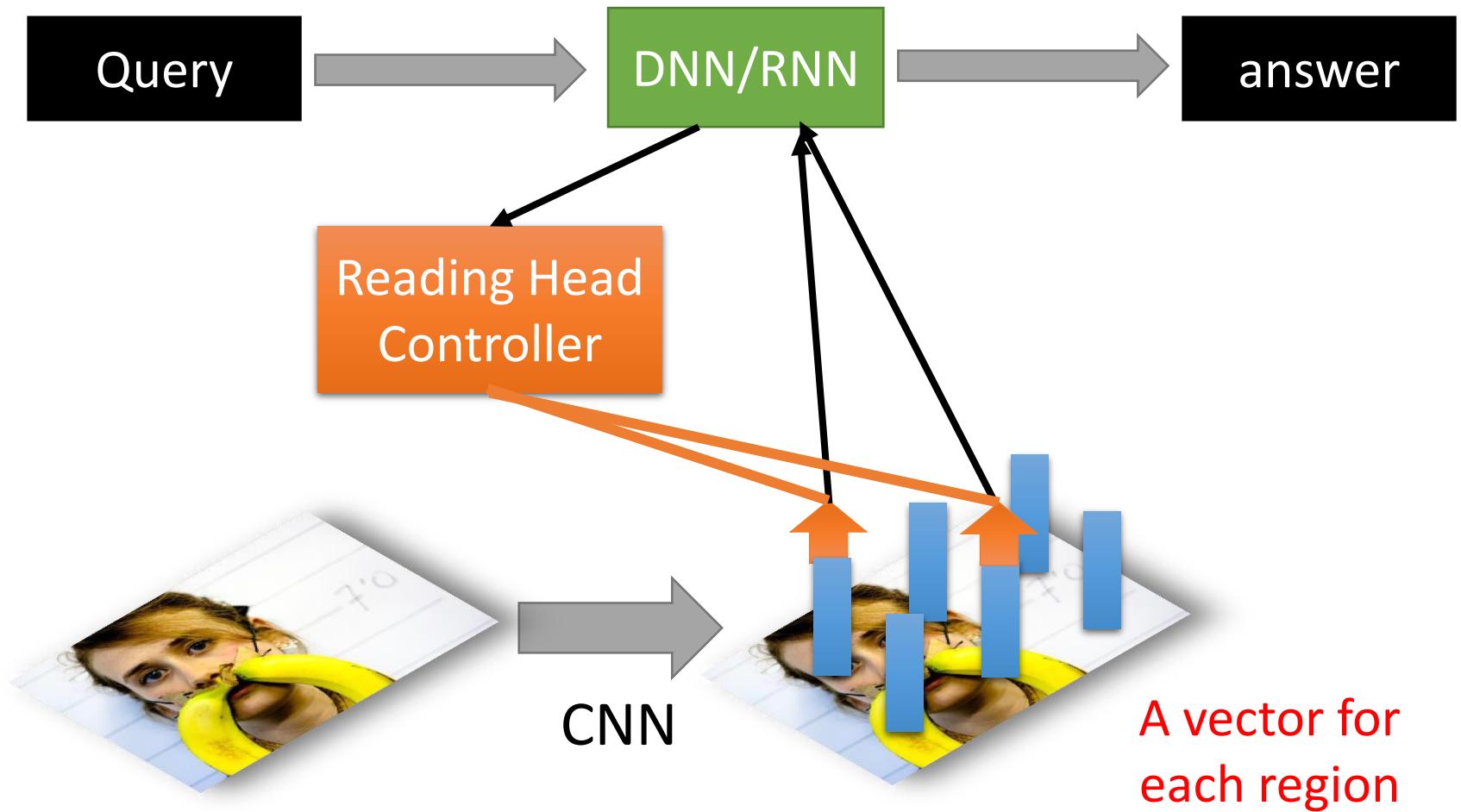
https://github.com/fchollet/keras/blob/master/examples/babi_memnn.py

Visual Question Answering



source: <http://visualqa.org/>

Visual Question Answering



Visual Question Answering

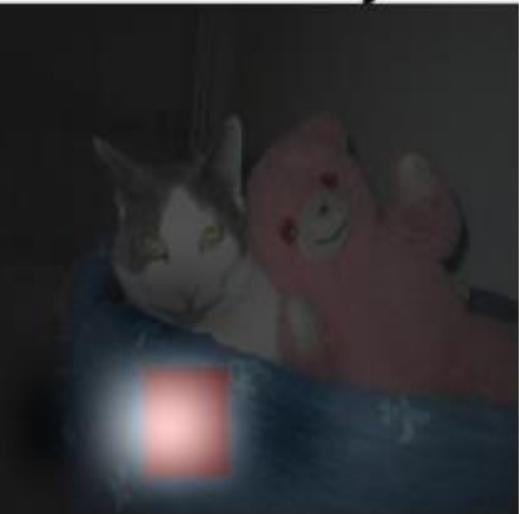
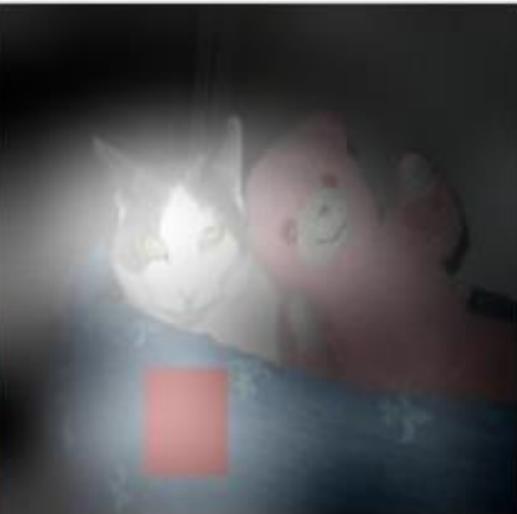
- Huijuan Xu, Kate Saenko. Ask, Attend and Answer: Exploring Question-Guided Spatial Attention for Visual Question Answering. arXiv Pre-Print, 2015

Is there a red square on the bottom of the cat?

GT: yes



Prediction: yes



Speech Question Answering

- **TOEFL Listening Comprehension Test by Machine**
- Example:

Audio Story:  (The original story is 5 min long.)

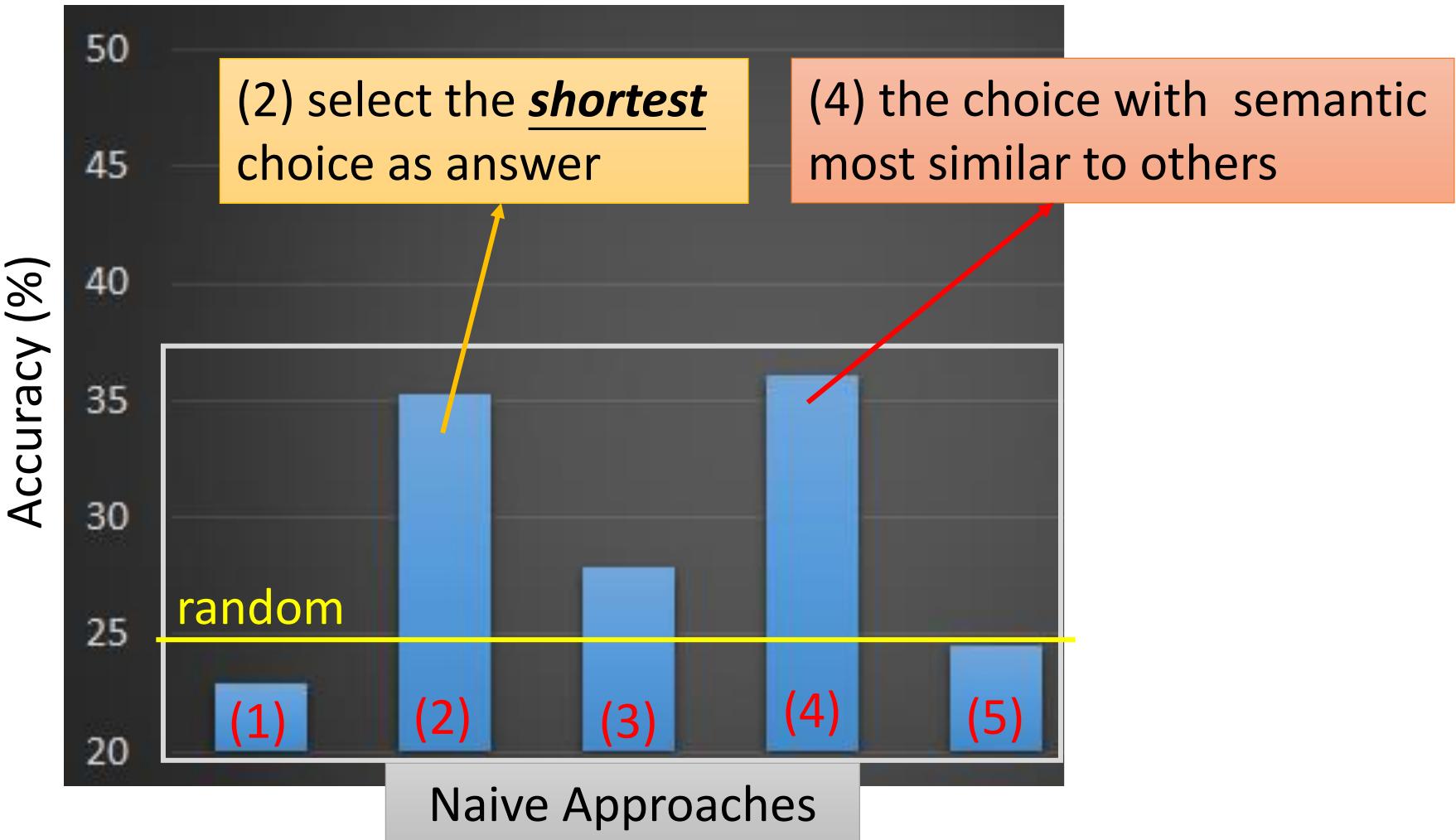
Question: “What is a possible origin of Venus’ clouds?”

Choices:

- (A) gases released as a result of volcanic activity
- (B) chemical reactions caused by high surface temperatures
- (C) bursts of radio energy from the planet's surface
- (D) strong winds that blow dust into the atmosphere

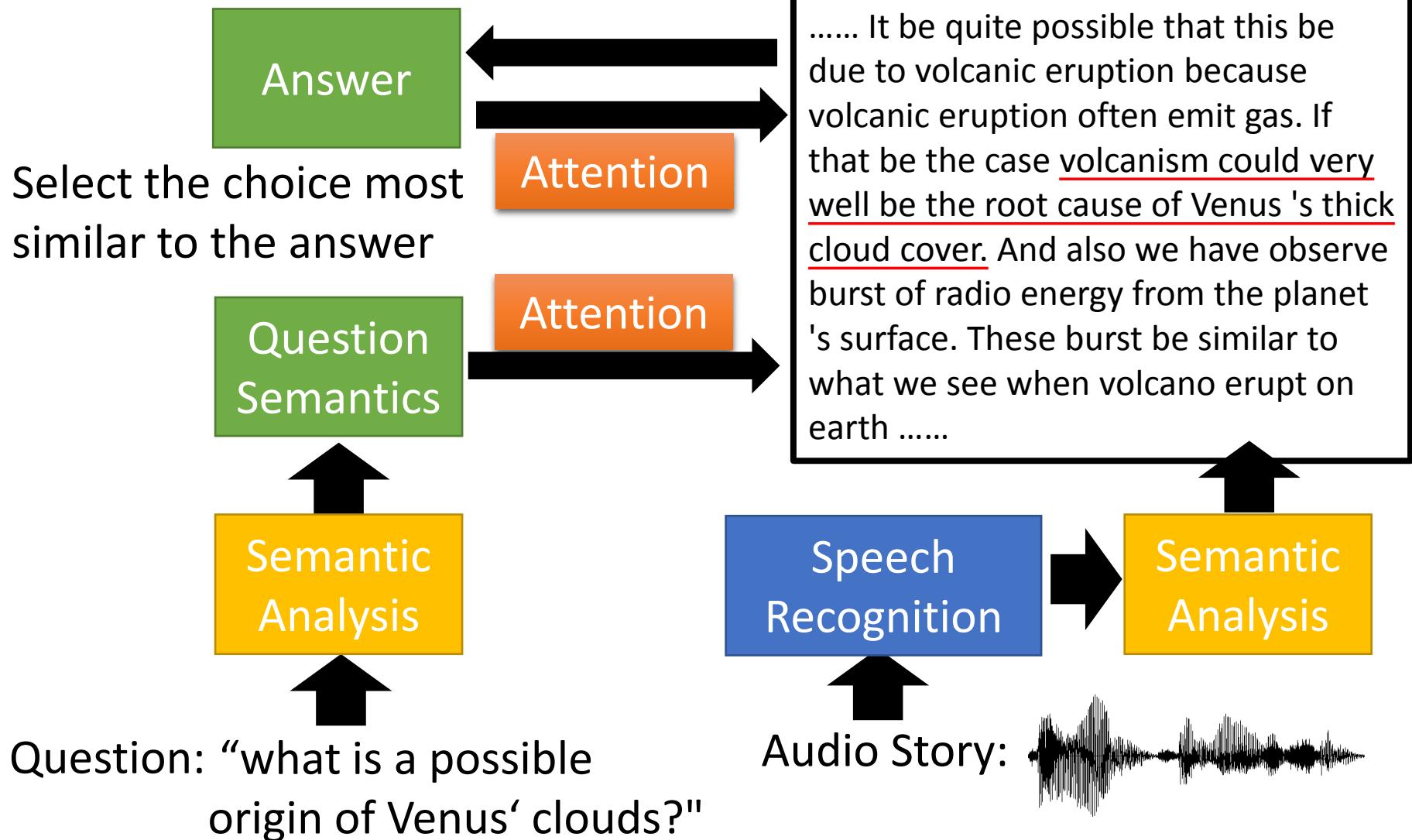
Simple Baselines

Experimental setup:
717 for training,
124 for validation, 122 for testing



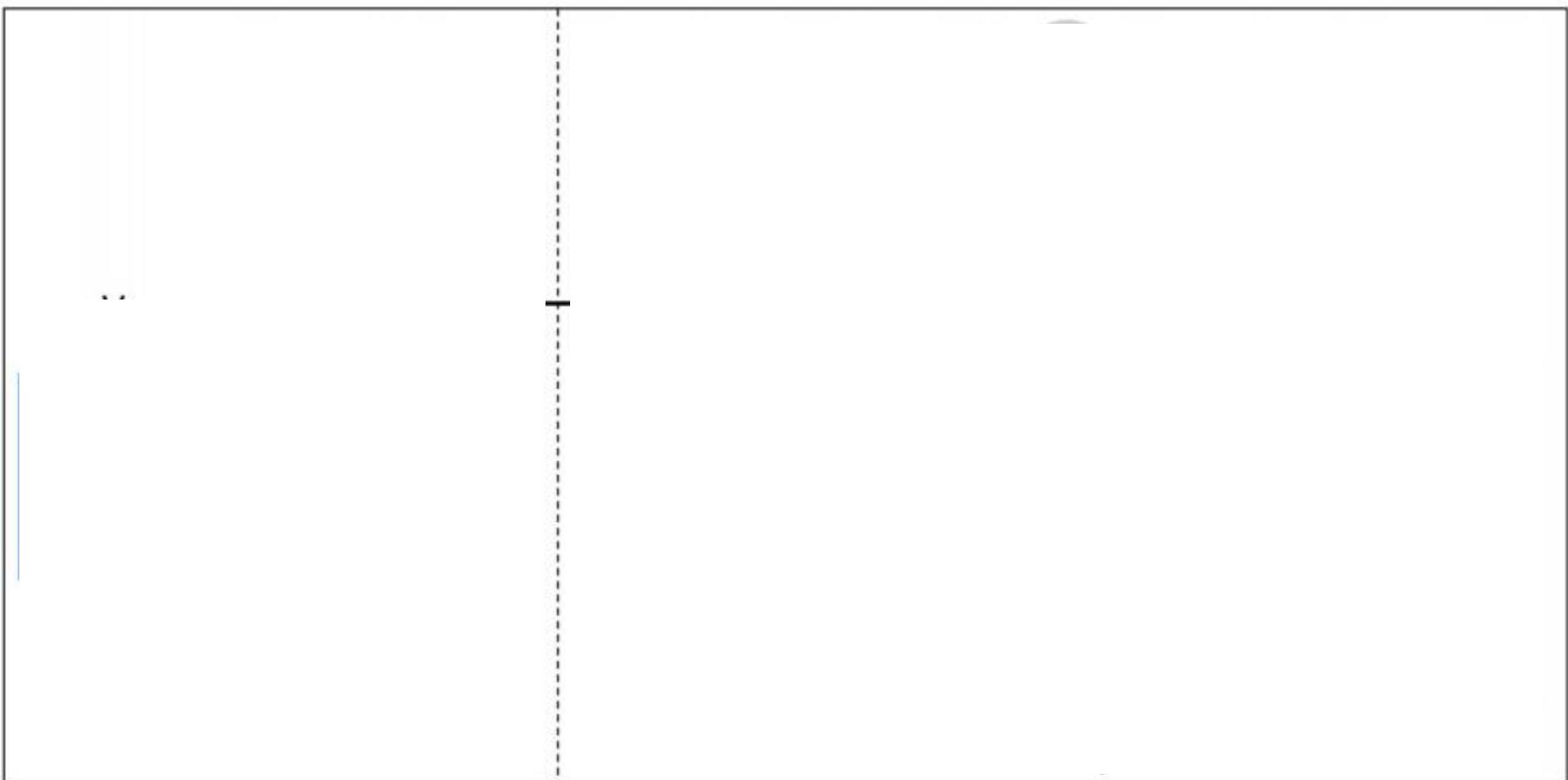
Model Architecture

Everything is learned from training examples



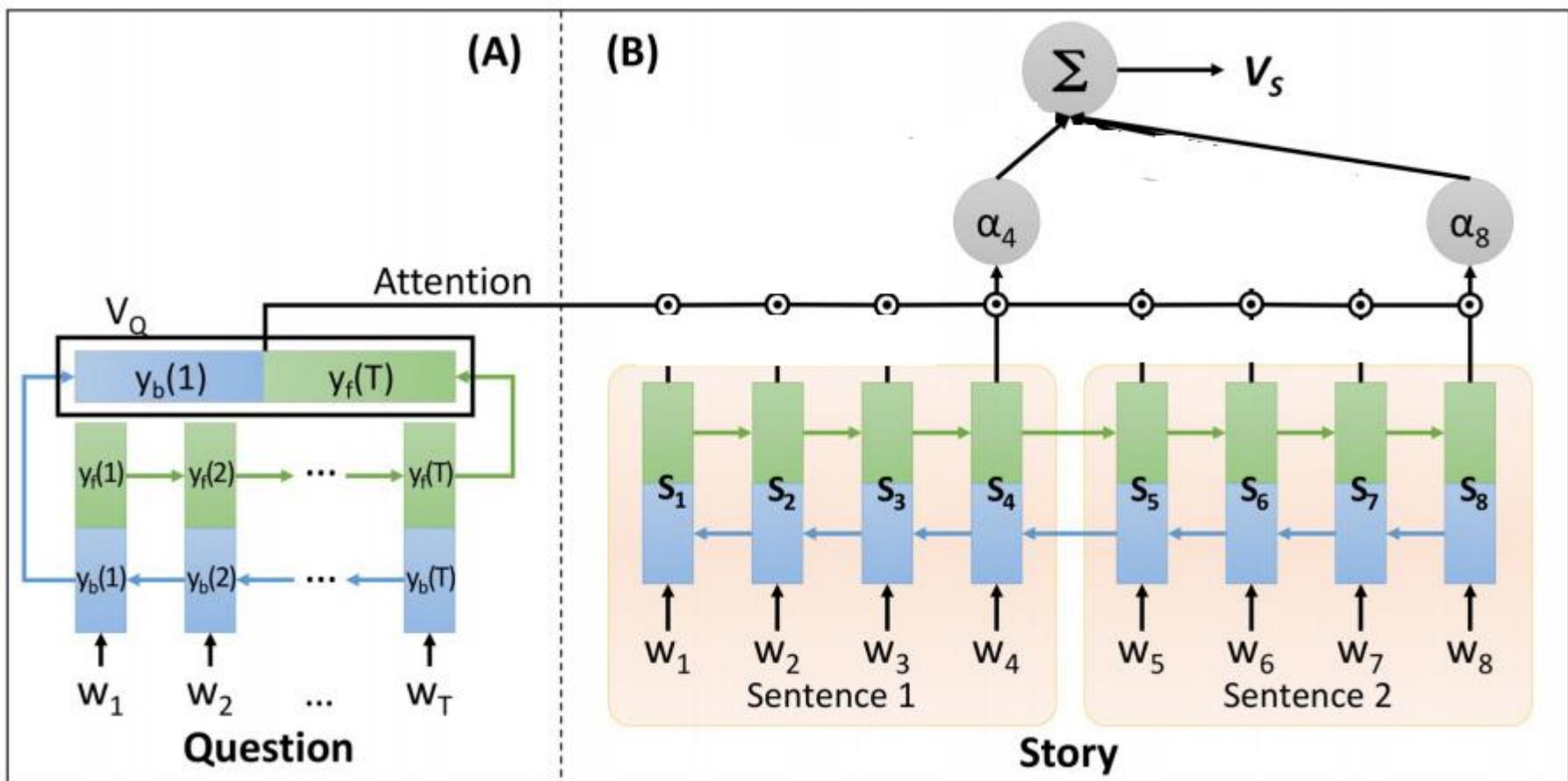
Model Architecture

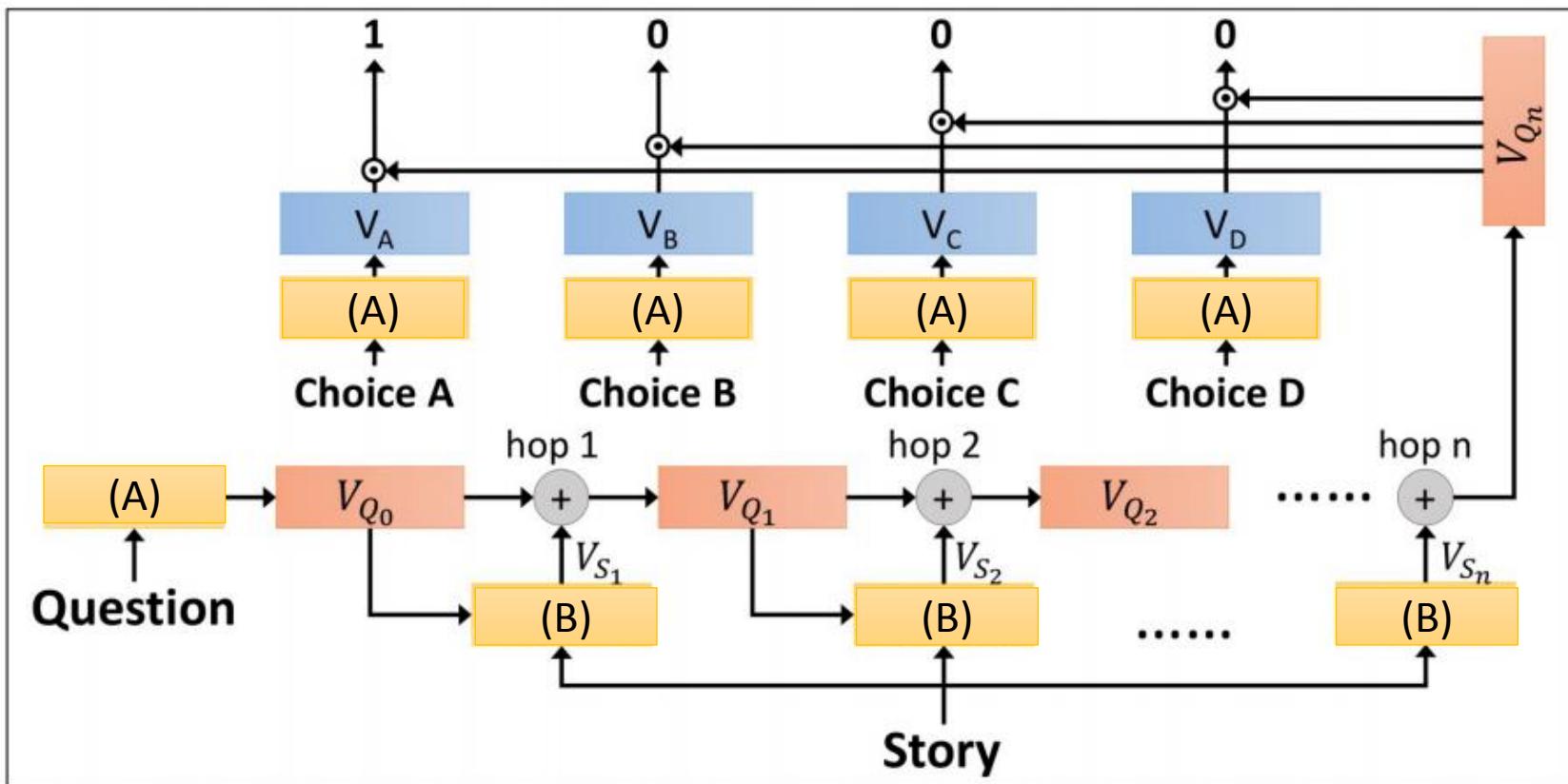
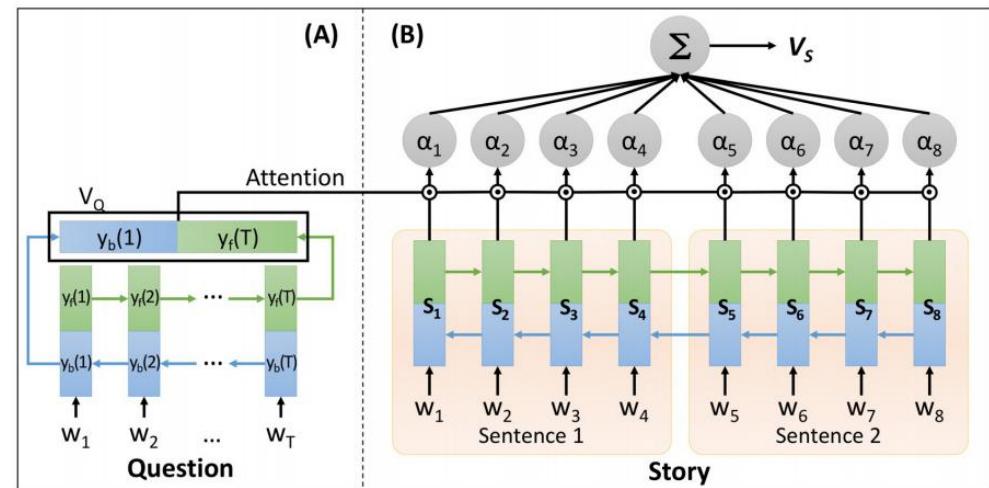
Word-based Attention



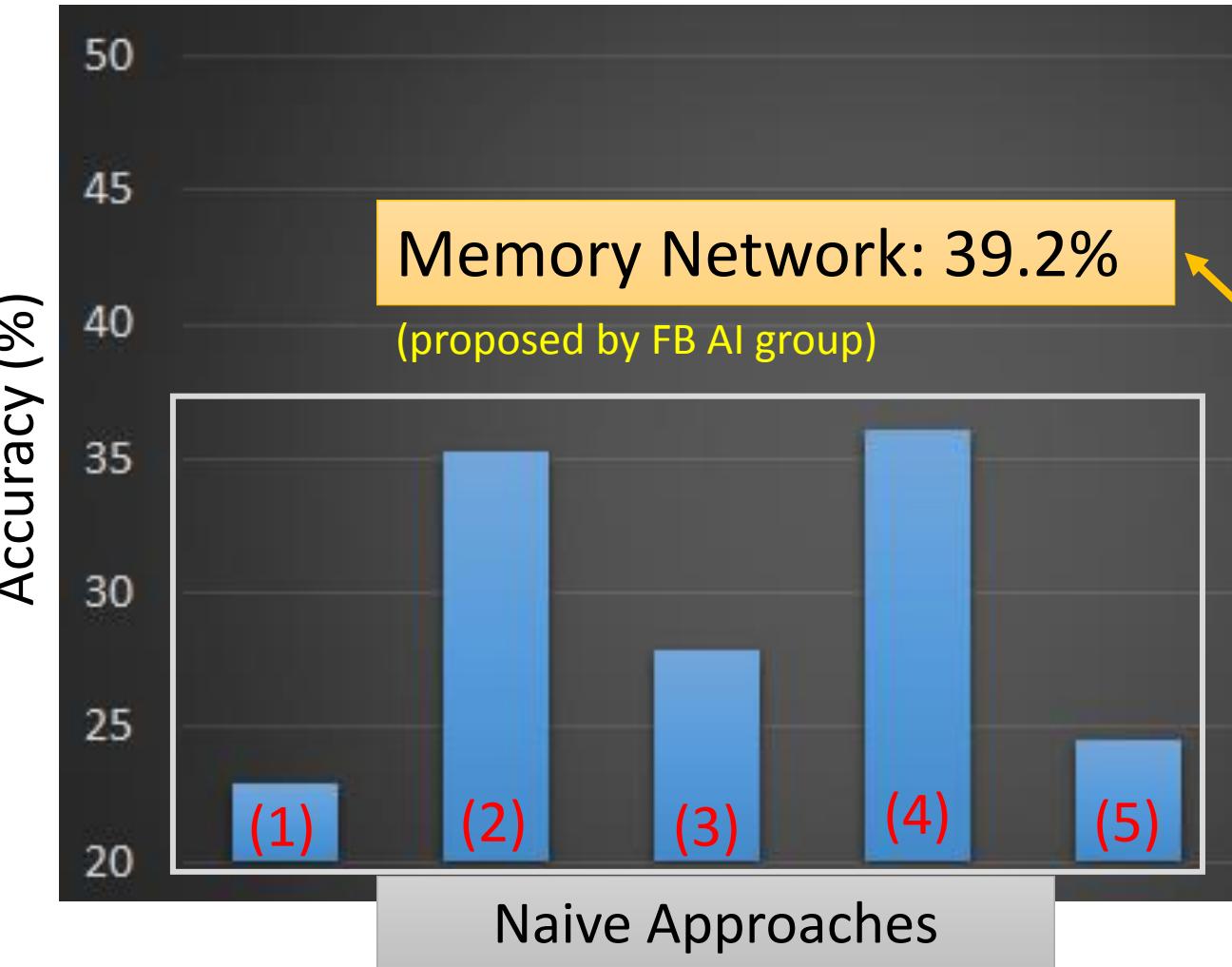
Model Architecture

Sentence-based Attention



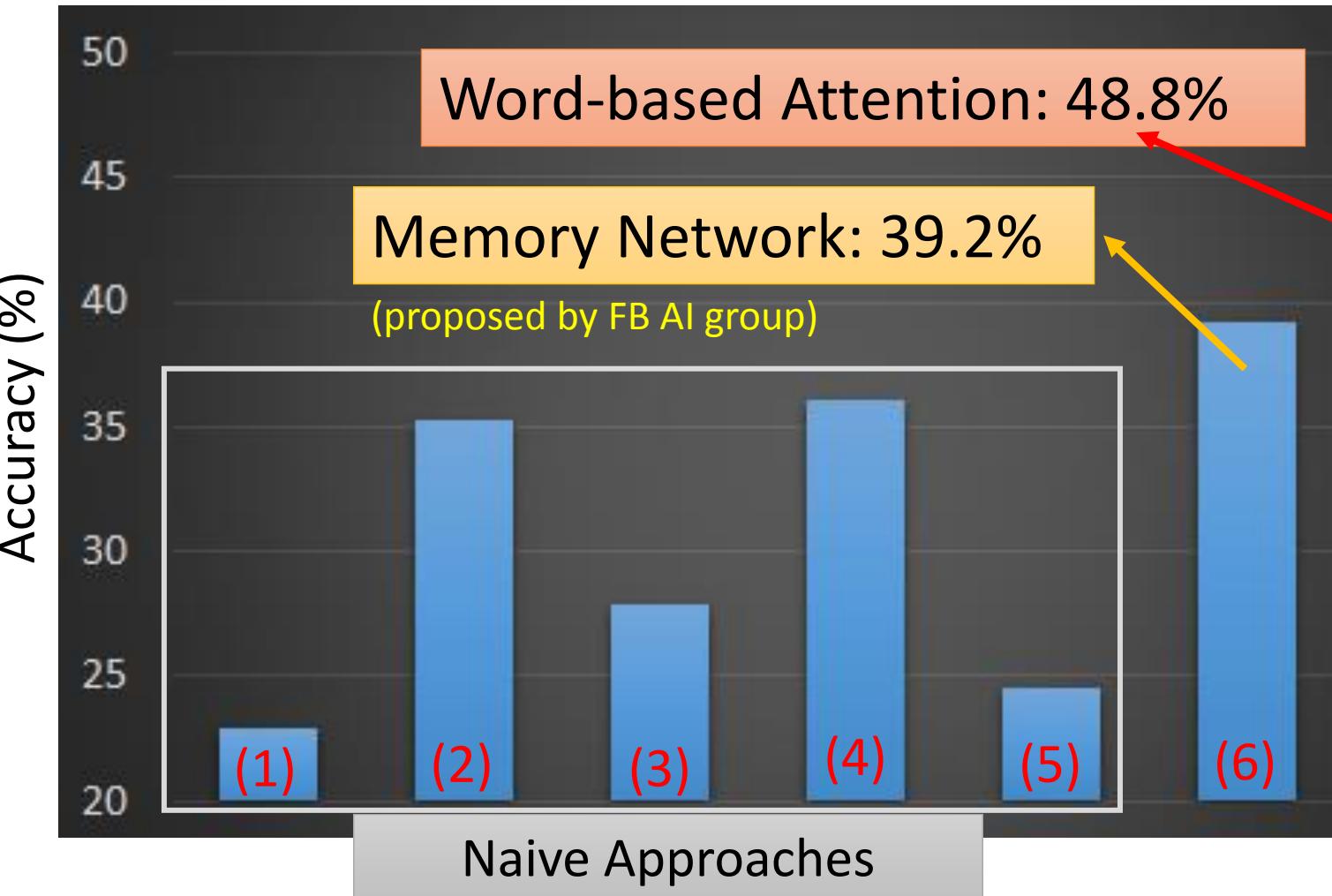


Supervised Learning



Supervised Learning

[Tseng & Lee, Interspeech 16]
[Fang & Hsu & Lee, SLT 16]



Outline

Supervised Learning

- Ultra Deep Network
 - Attention Model
- }
- New network structure

Reinforcement Learning

Unsupervised Learning

- Image: Realizing what the World Looks Like
- Text: Understanding the Meaning of Words
- Audio: Learning human language without supervision

Scenario of Reinforcement Learning



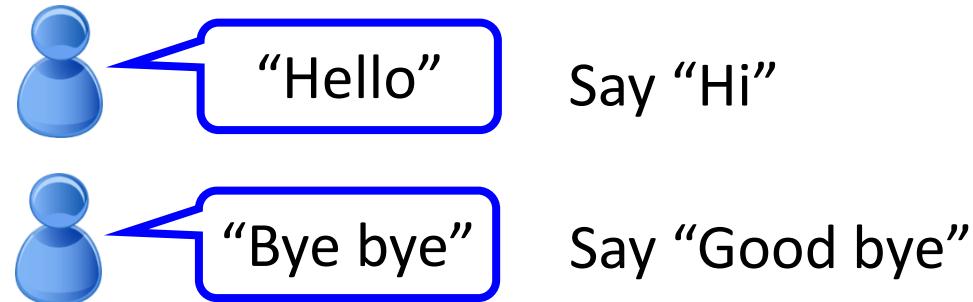
Scenario of Reinforcement Learning



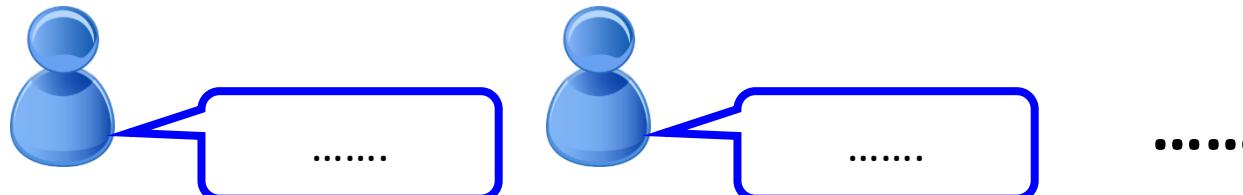
Supervised v.s. Reinforcement

- Supervised

Learning from teacher



- Reinforcement

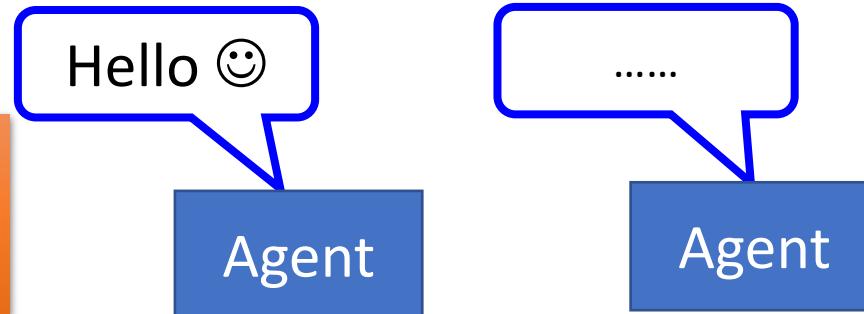


Bad

Learning from critics

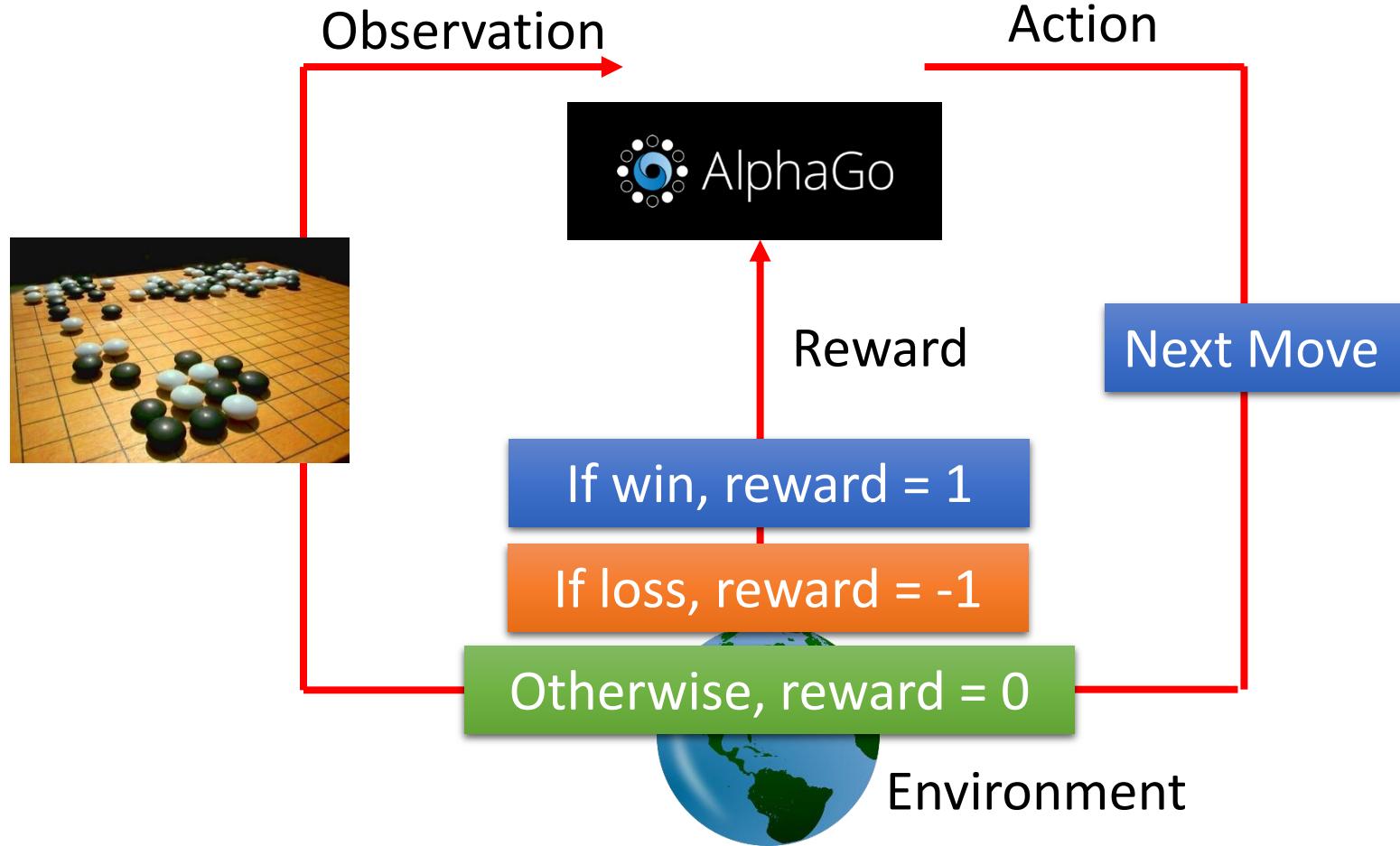
Agent

Agent



Scenario of Reinforcement Learning

Agent learns to take actions to maximize expected reward.



Supervised v.s. Reinforcement

- Supervised:



Next move:
“5-5”



Next move:
“3-3”

- Reinforcement Learning

First move → many moves → Win!

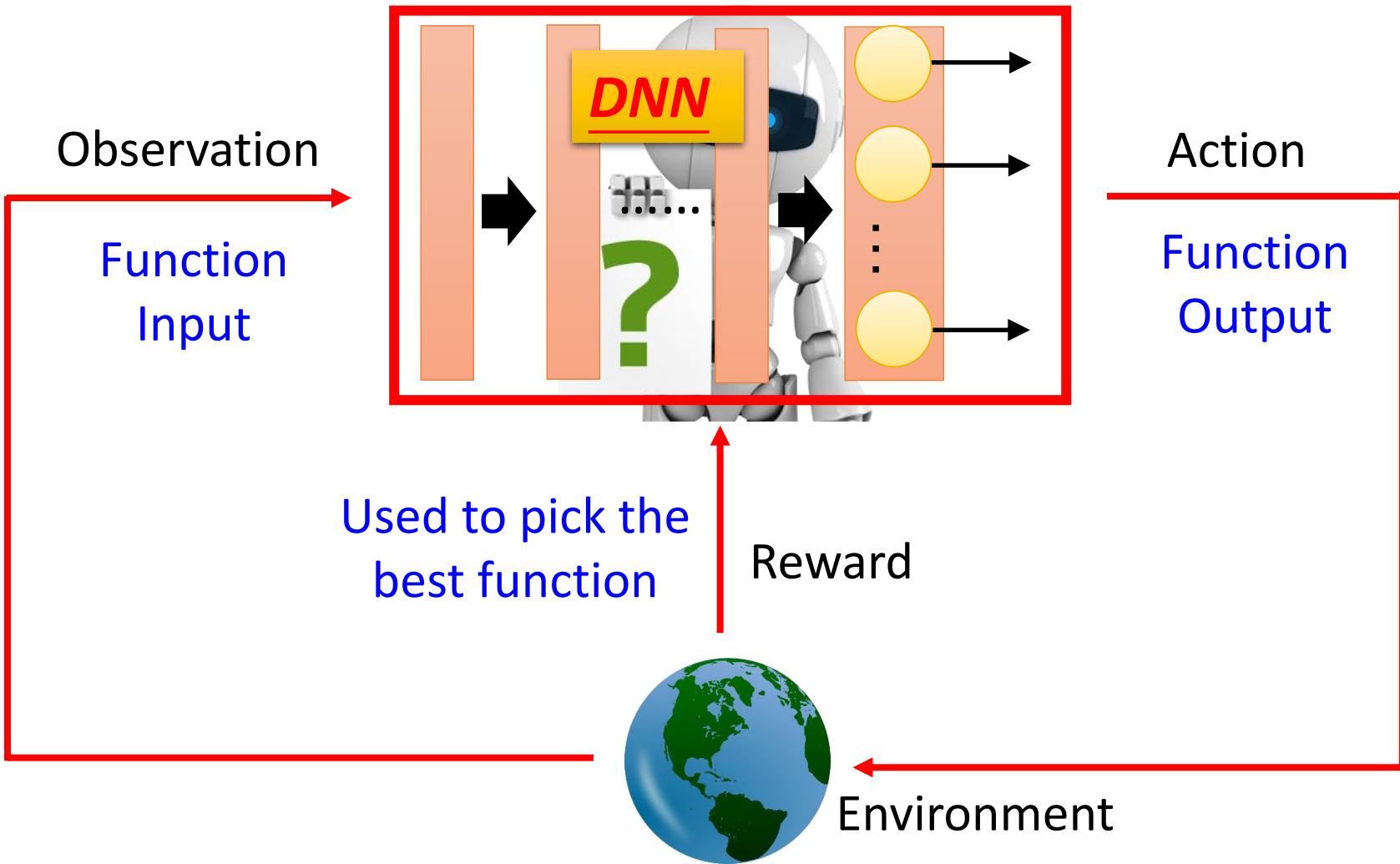
Alpha Go is supervised learning + reinforcement learning.

Difficulties of Reinforcement Learning

- It may be better to sacrifice immediate reward to gain more long-term reward
 - E.g. Playing Go
- Agent's actions affect the subsequent data it receives
 - E.g. Exploration



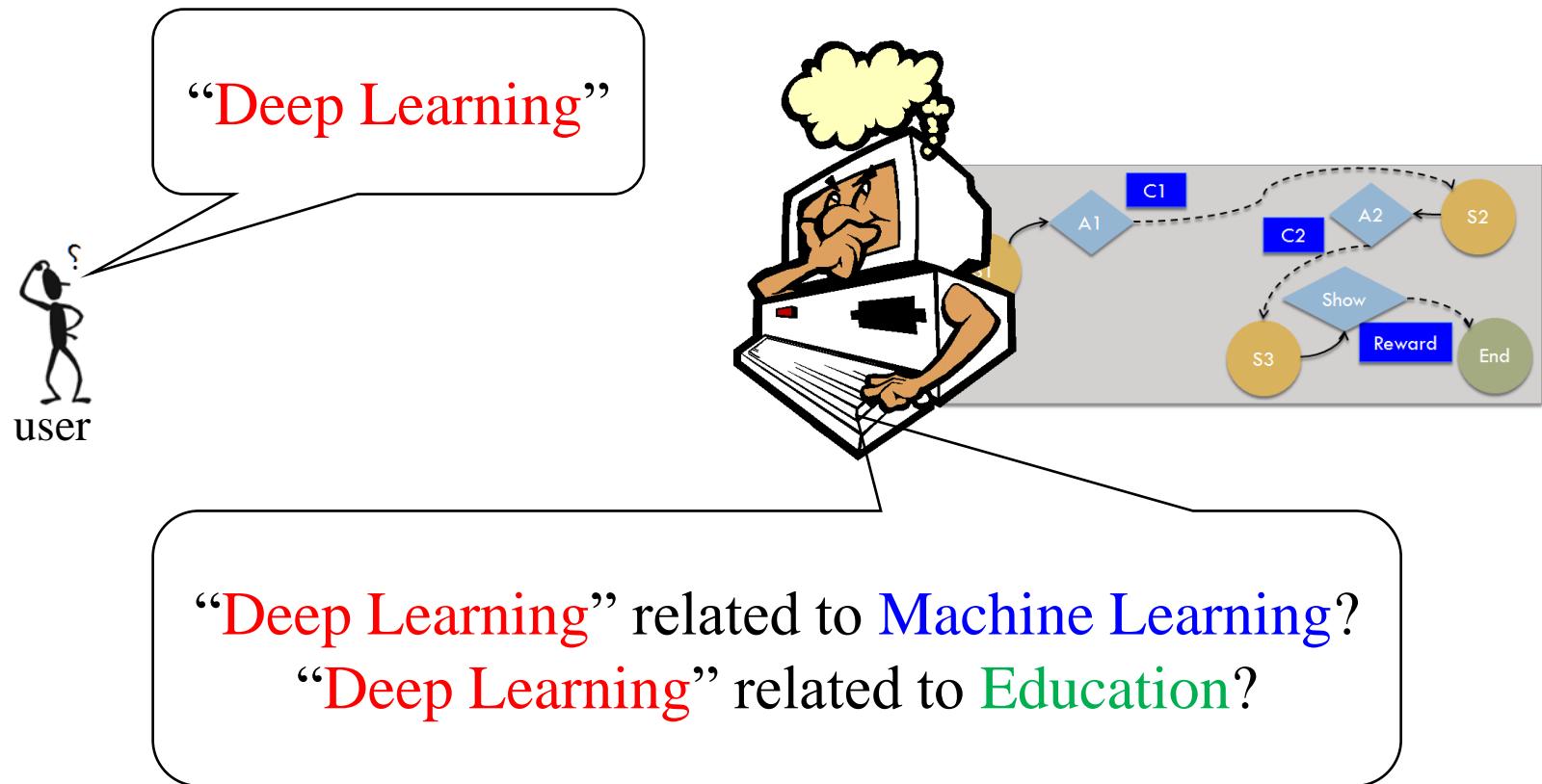
Deep Reinforcement Learning



Application: Interactive Retrieval

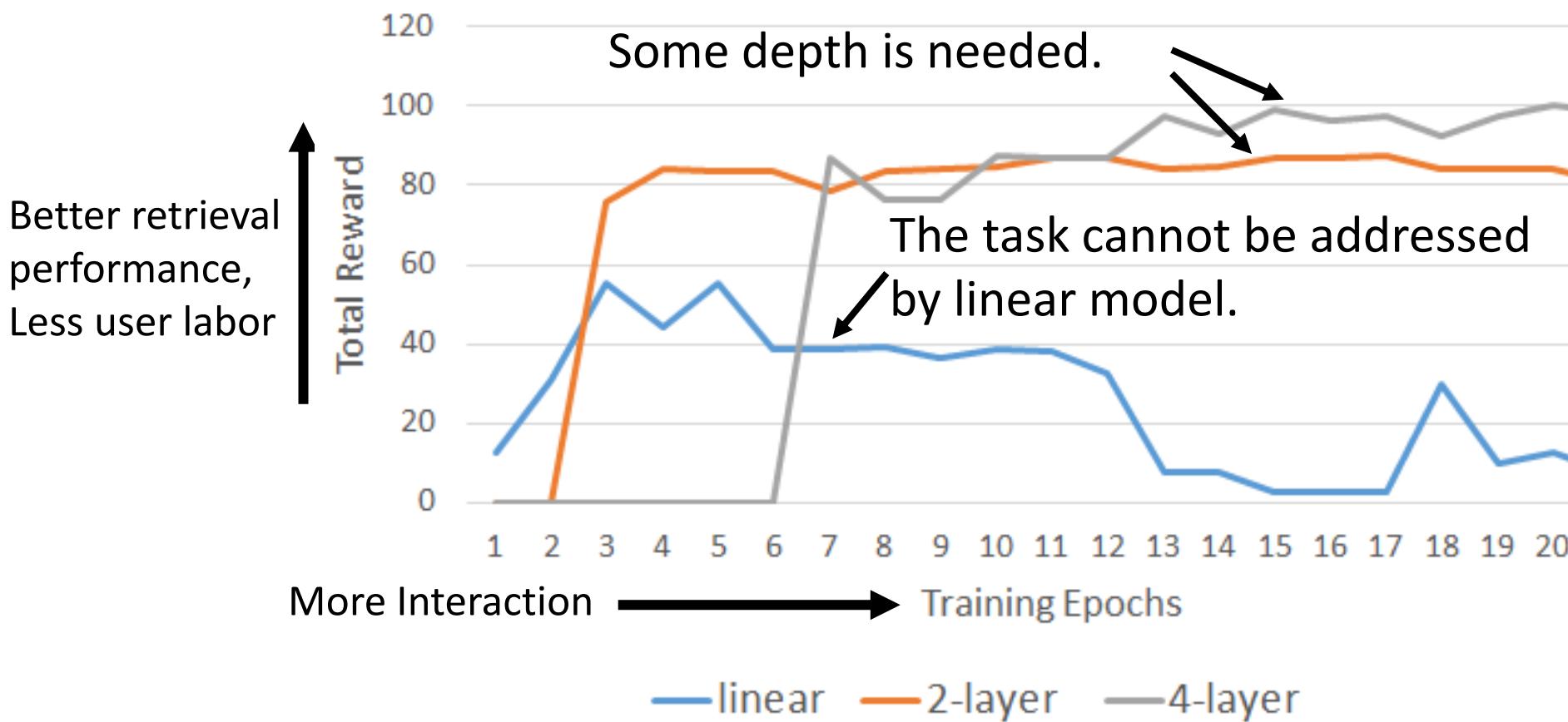
- Interactive retrieval is helpful.

[Wu & Lee, INTERSPEECH 16]



Deep Reinforcement Learning

- Different network depth



More applications

- Alpha Go, Playing Video Games, Dialogue
- Flying Helicopter
 - <https://www.youtube.com/watch?v=0JL04JJjocc>
- Driving
 - <https://www.youtube.com/watch?v=0xo1Ldx3L5Q>
- Google Cuts Its Giant Electricity Bill With DeepMind-Powered AI
 - <http://www.bloomberg.com/news/articles/2016-07-19/google-cuts-its-giant-electricity-bill-with-deepmind-powered-ai>

To learn deep reinforcement learning

- Lectures of David Silver
 - <http://www0.cs.ucl.ac.uk/staff/D.Silver/web/Teaching.html>
 - 10 lectures (1:30 each)
- Deep Reinforcement Learning
 - http://videolectures.net/rldm2015_silver_reinforcement_learning/

Outline

Supervised Learning

- Ultra Deep Network
 - Attention Model
- }
- New network structure

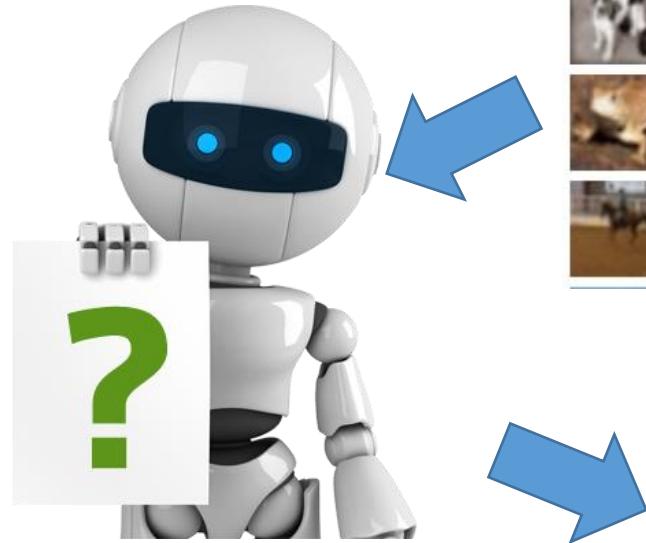
Reinforcement Learning

Unsupervised Learning

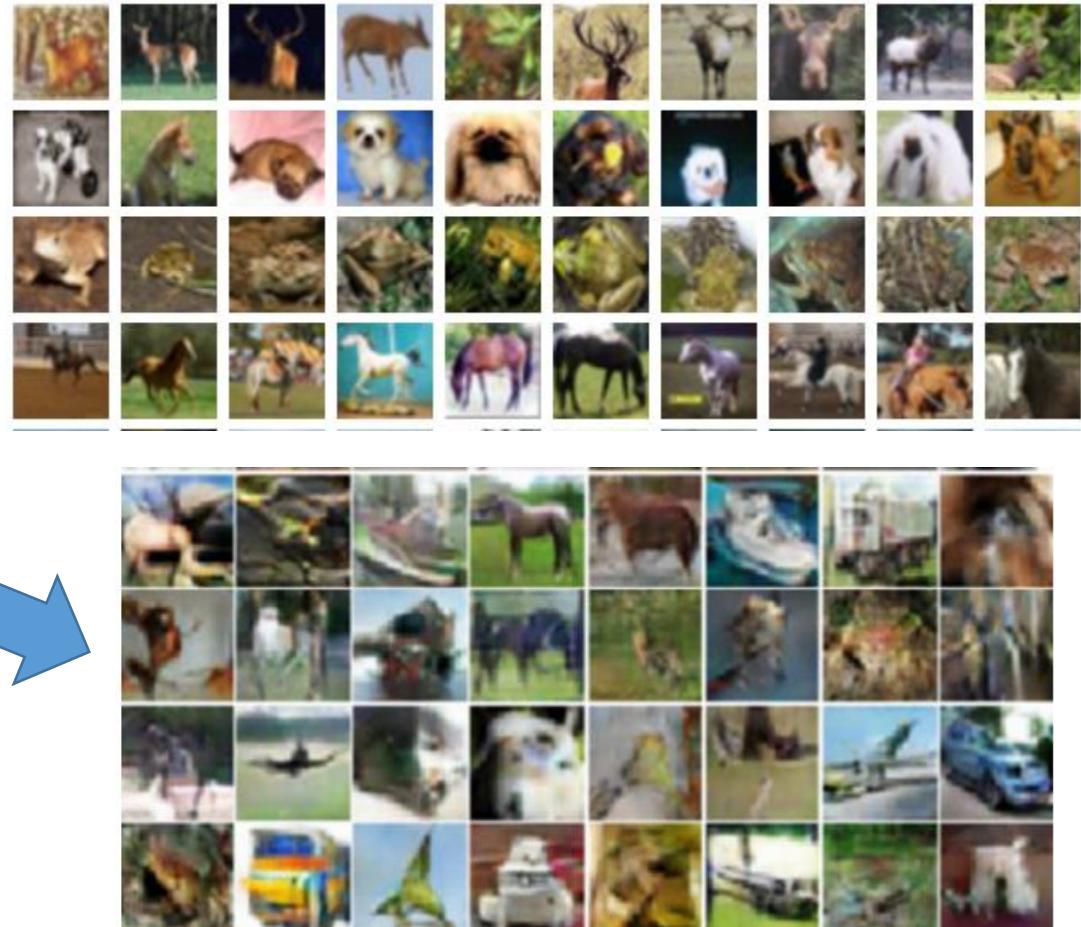
- Image: Realizing what the World Looks Like
- Text: Understanding the Meaning of Words
- Audio: Learning human language without supervision

Does machine know what the world look like?

Ref: <https://openai.com/blog/generative-models/>



Draw something!



Deep Dream

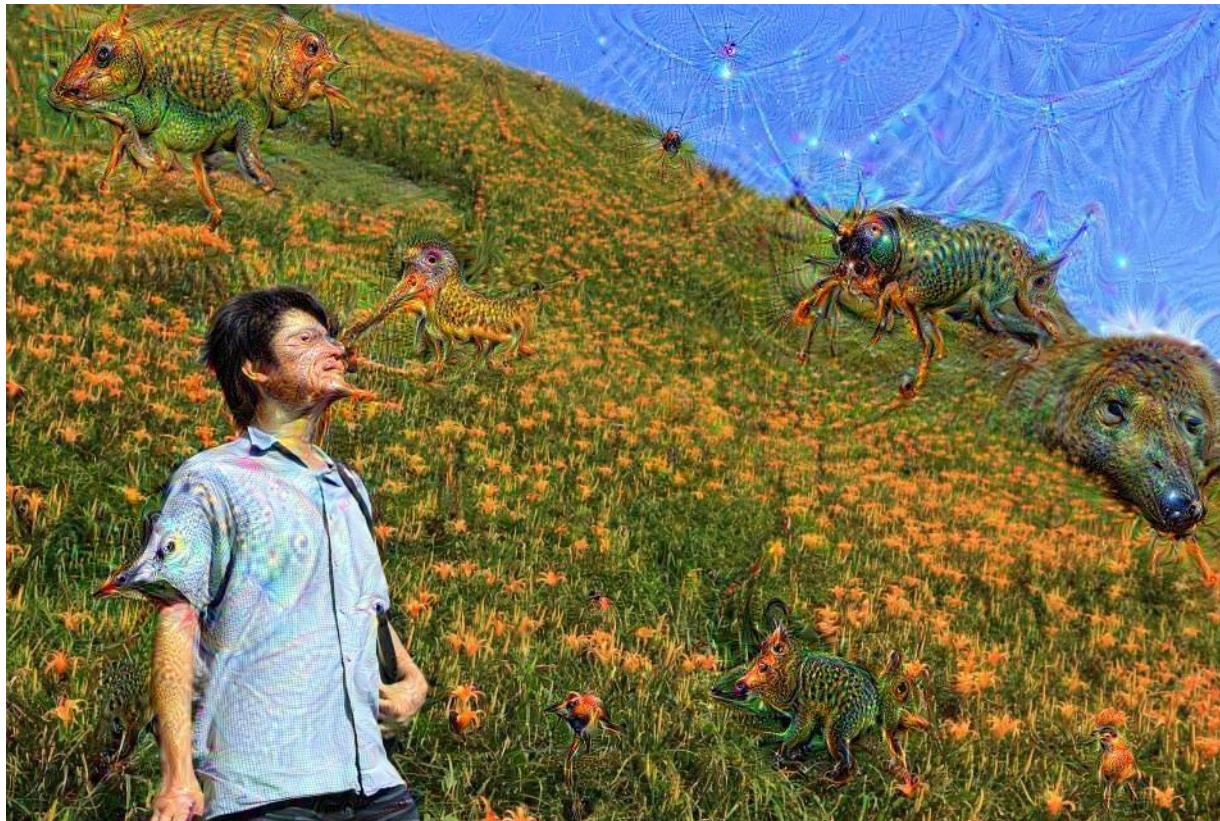
- Given a photo, machine adds what it sees



<http://deepdreamgenerator.com/>

Deep Dream

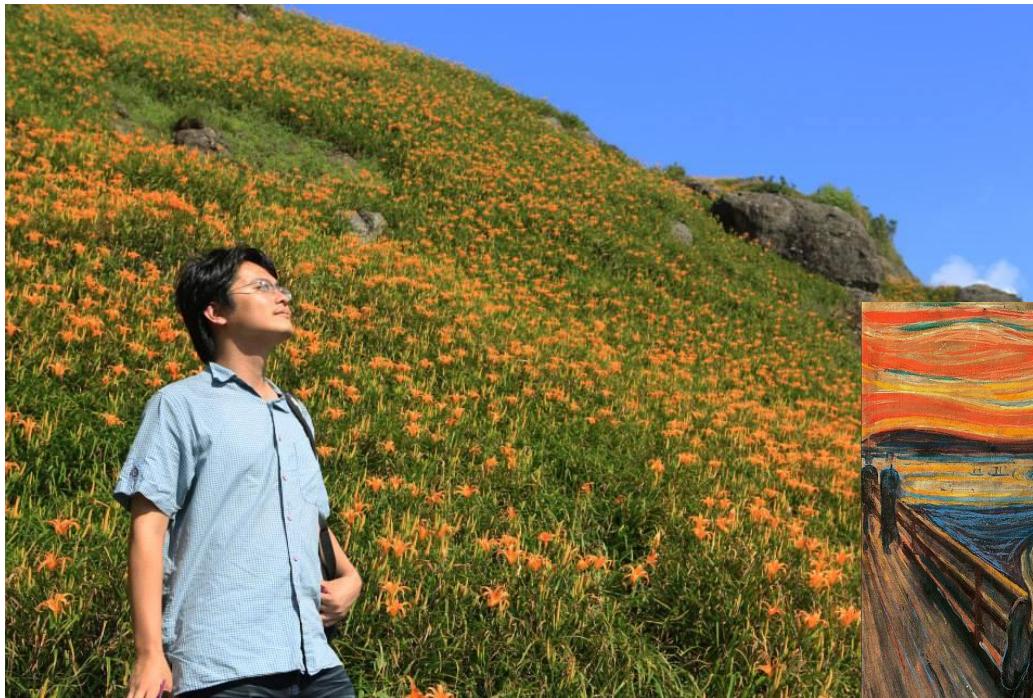
- Given a photo, machine adds what it sees



<http://deepdreamgenerator.com/>

Deep Style

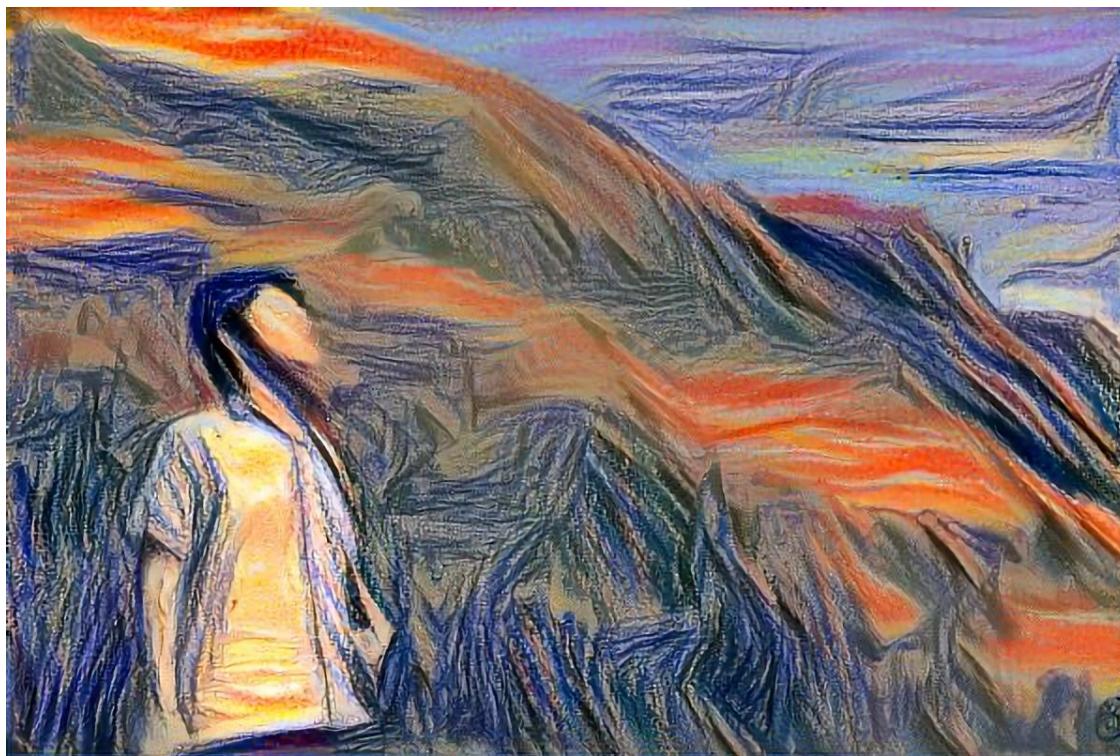
- Given a photo, make its style like famous paintings



<https://dreamscopeapp.com/>

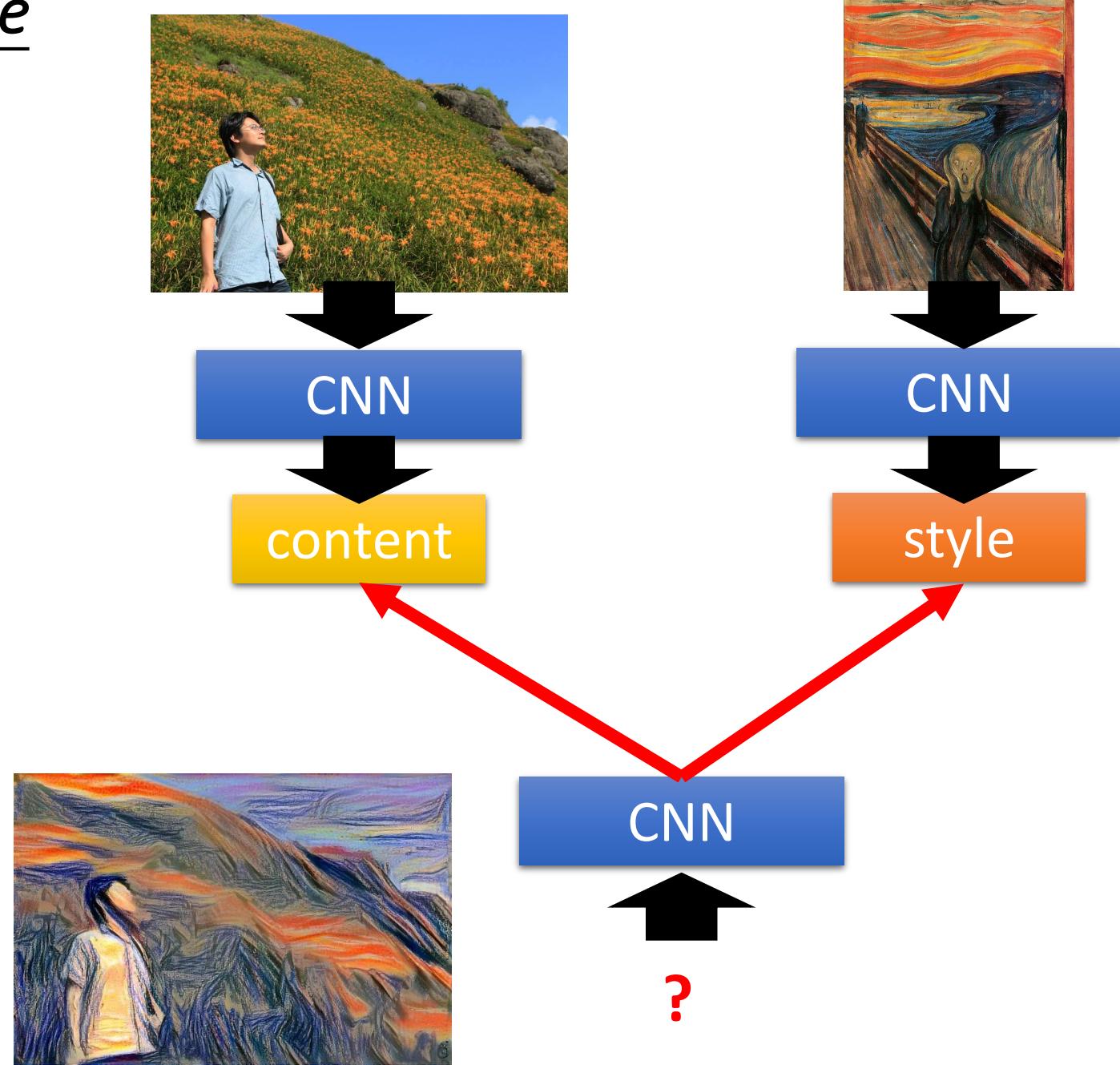
Deep Style

- Given a photo, make its style like famous paintings



<https://dreamscopeapp.com/>

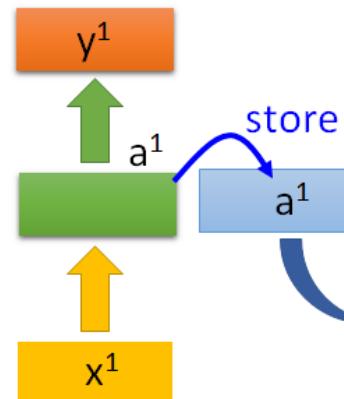
Deep Style



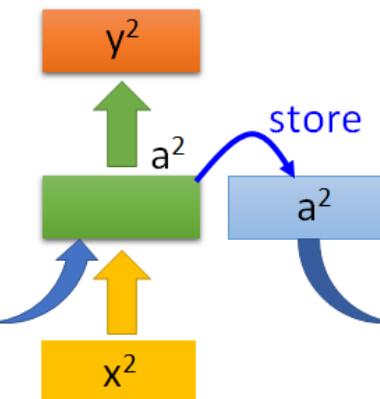
Generating Images by RNN



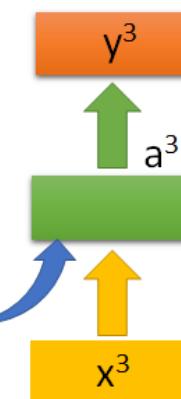
color of
2nd pixel



color of
3rd pixel



color of
4th pixel



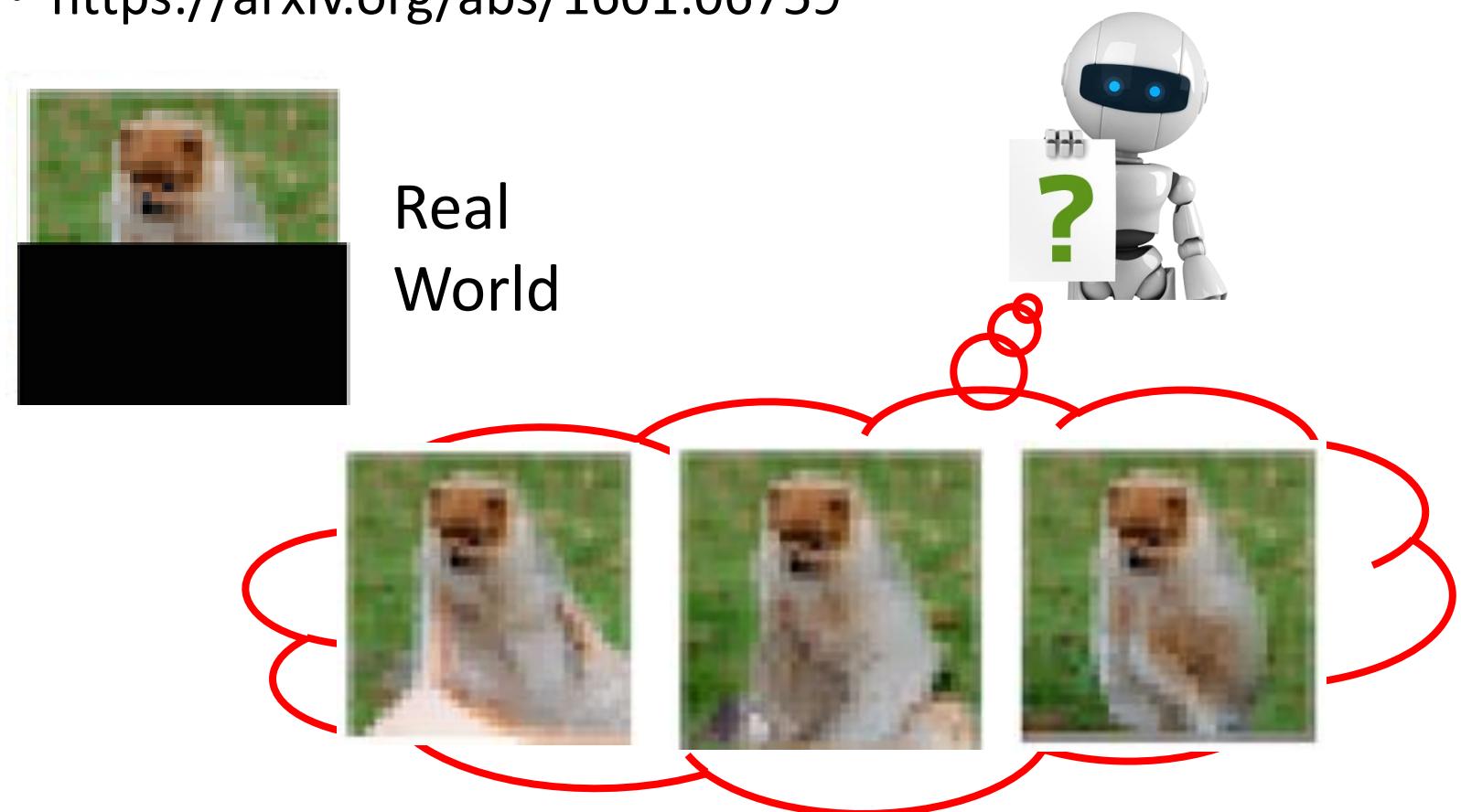
color of
1st pixel

color of
2nd pixel

color of
3rd pixel

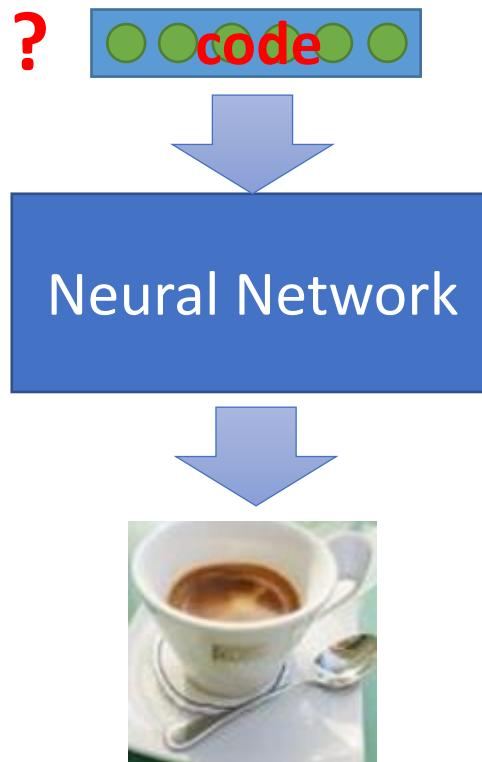
Generating Images by RNN

- **Pixel Recurrent Neural Networks**
 - <https://arxiv.org/abs/1601.06759>

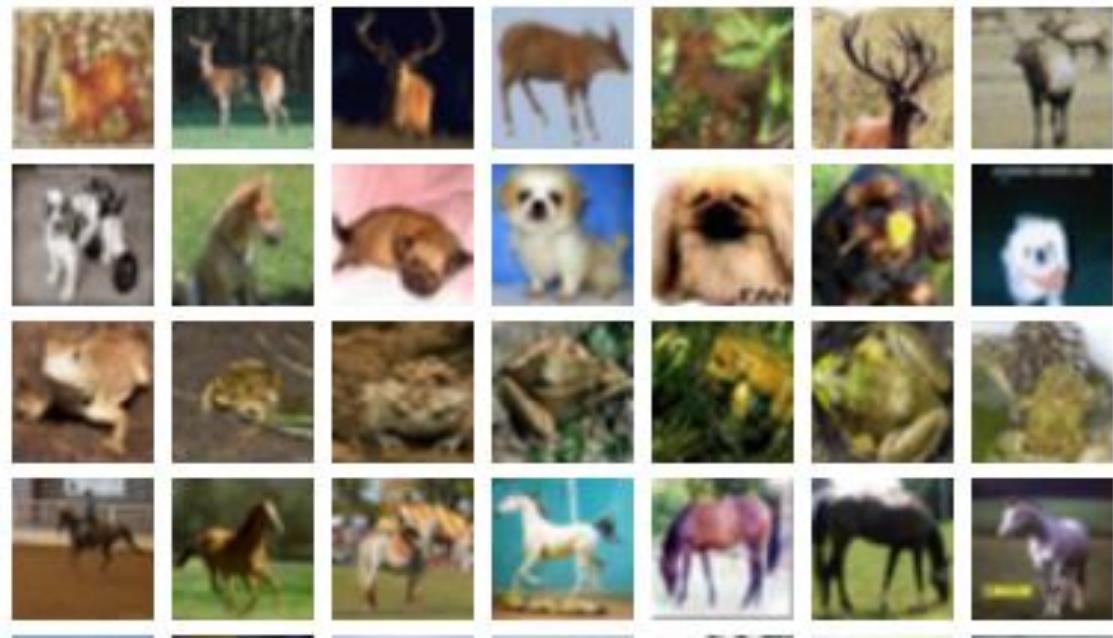


Generating Images

- Training a decoder to generate images is **unsupervised**

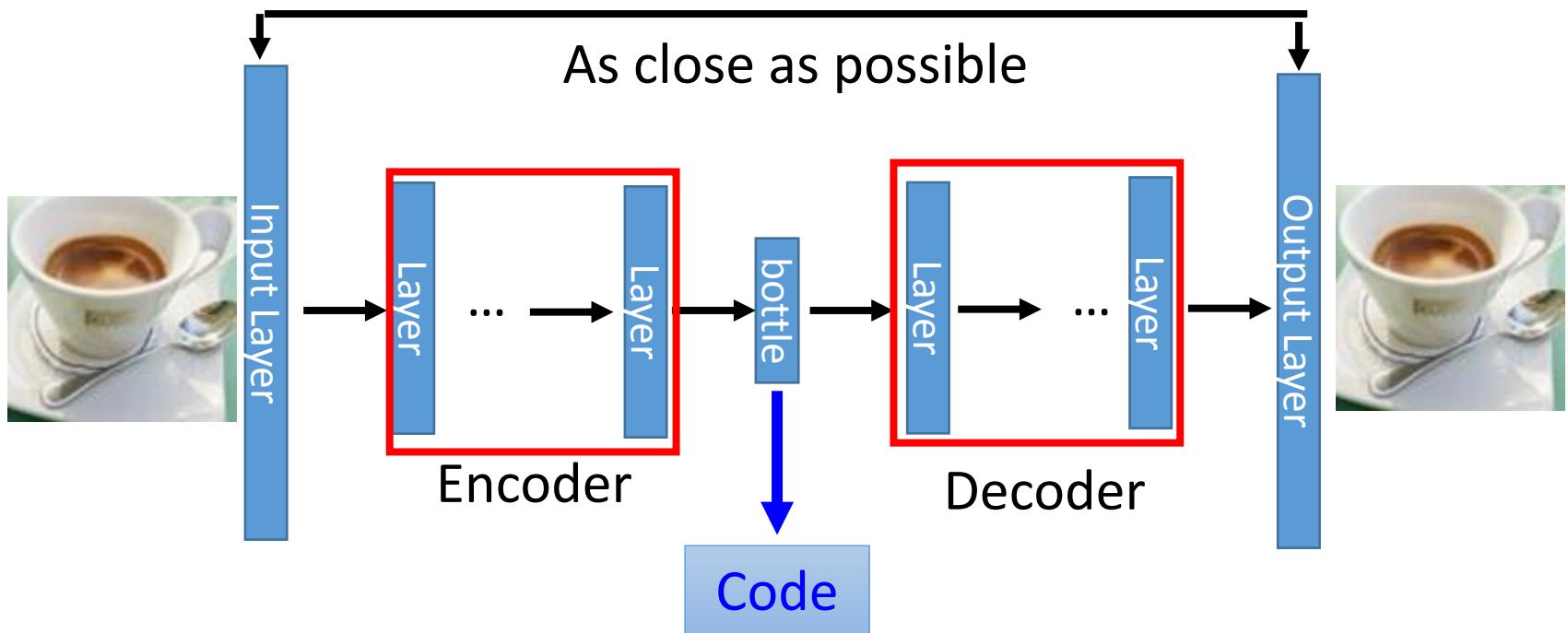
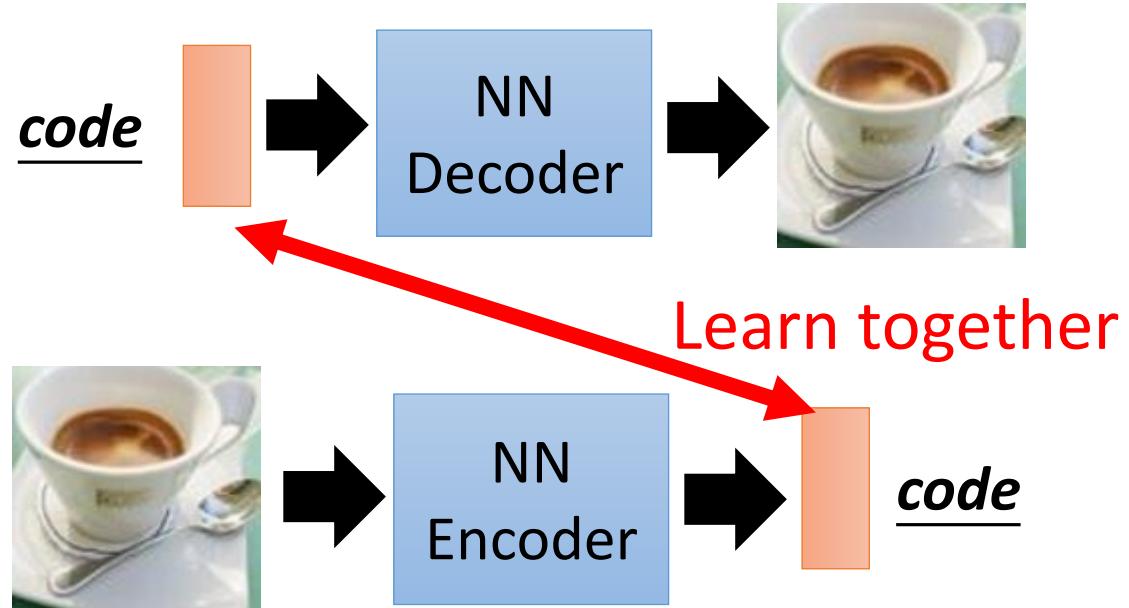


Training data is a lot of images



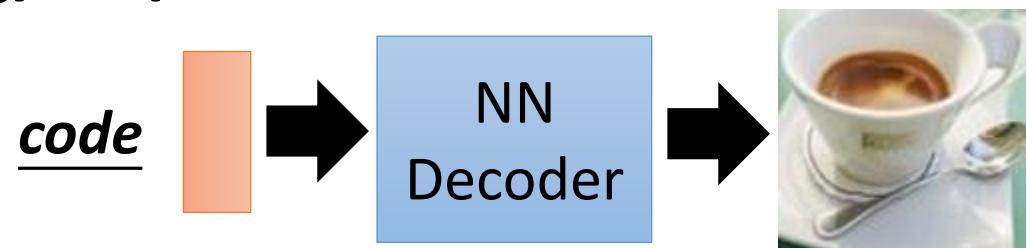
Auto-encoder

Not state-of-the-art approach

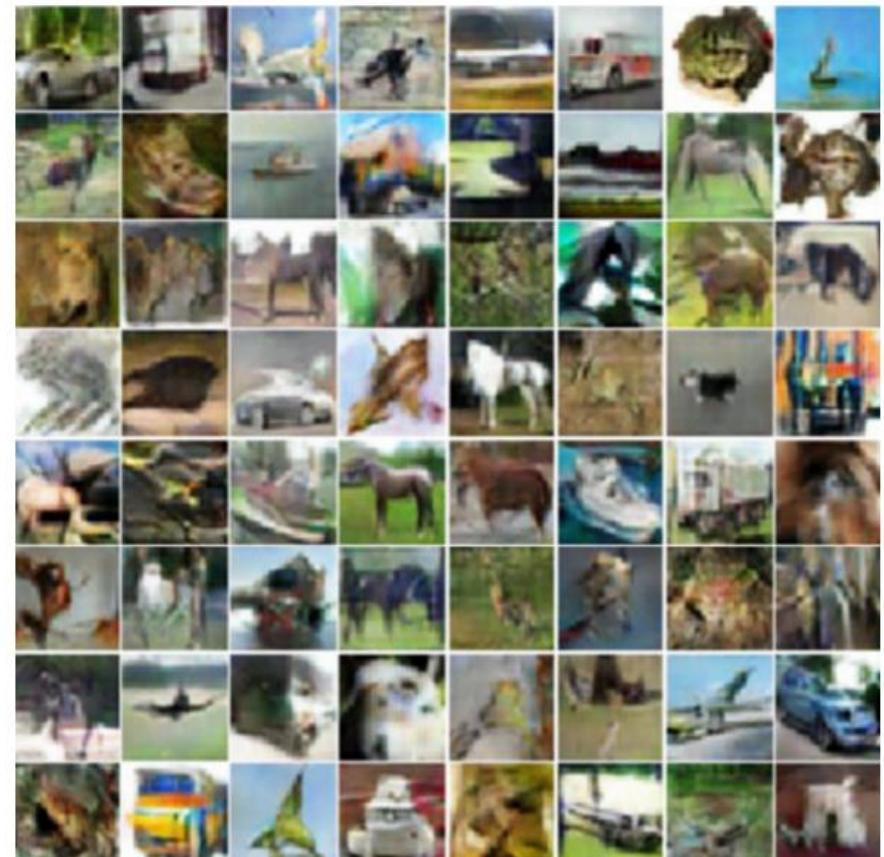
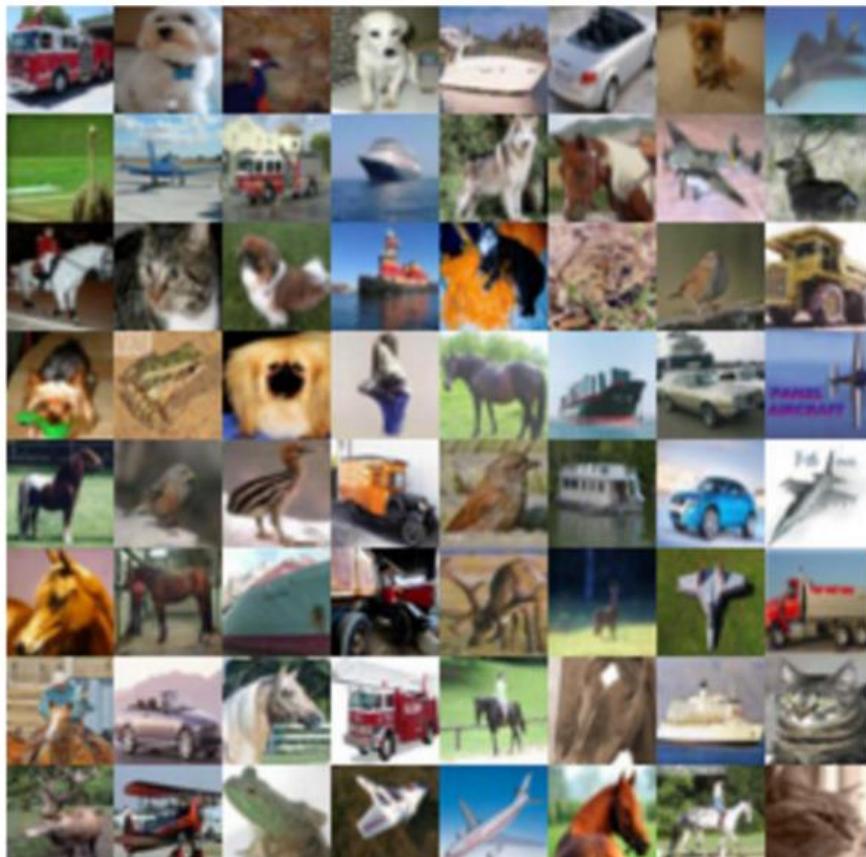


Generating Images

- Training a decoder to generate images is **unsupervised**
- Variation Auto-encoder (VAE)
 - Ref: **Auto-Encoding Variational Bayes**,
<https://arxiv.org/abs/1312.6114>
- Generative Adversarial Network (GAN)
 - Ref: **Generative Adversarial Networks**,
<http://arxiv.org/abs/1406.2661>



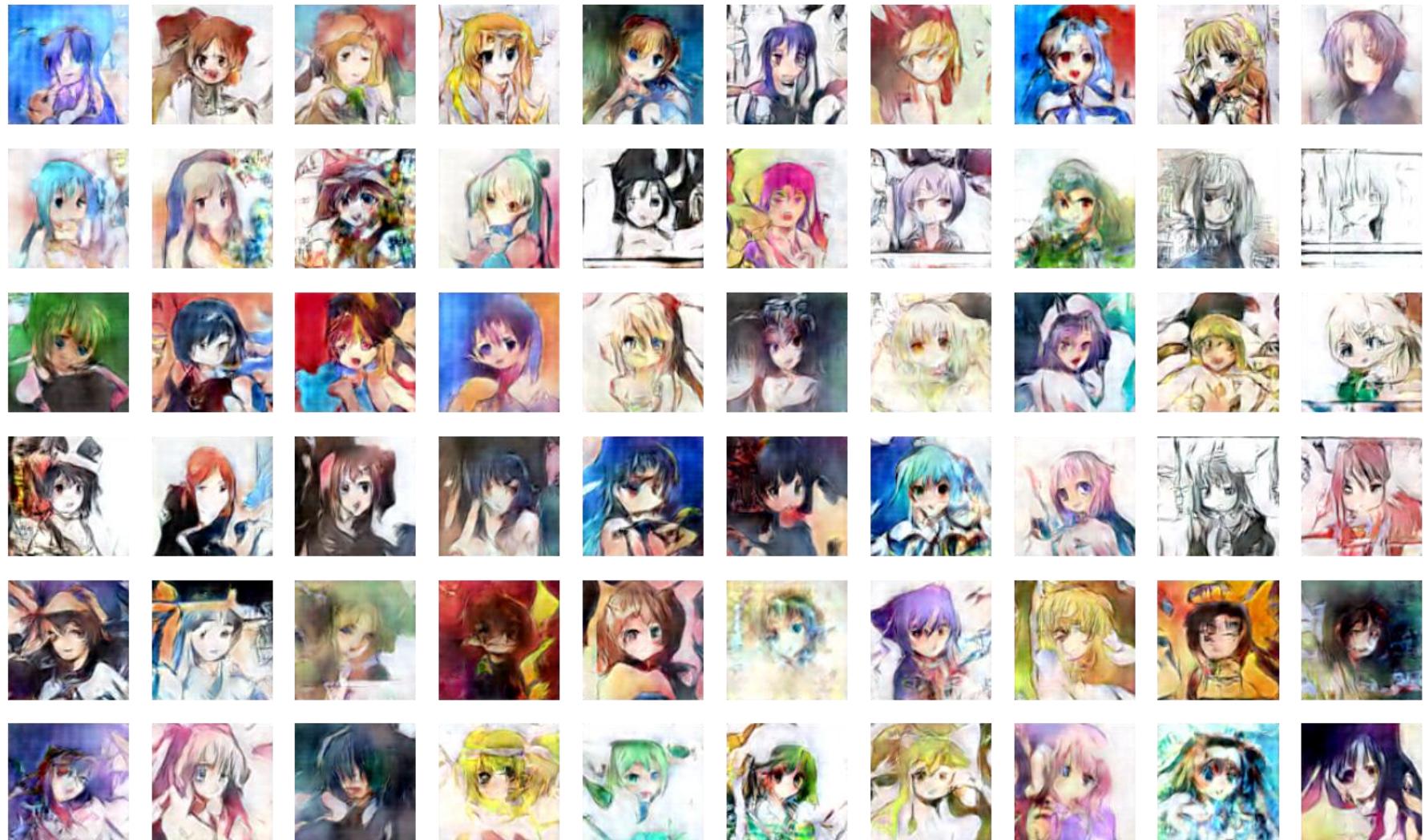
Which one is machine-generated?



Ref: <https://openai.com/blog/generative-models/>

畫漫畫!!!

<https://github.com/mattyachainer-DCGAN>



Outline

Supervised Learning

- Ultra Deep Network
 - Attention Model
- }
- New network structure

Reinforcement Learning

Unsupervised Learning

- Image: Realizing what the World Looks Like
- Text: Understanding the Meaning of Words
- Audio: Learning human language without supervision

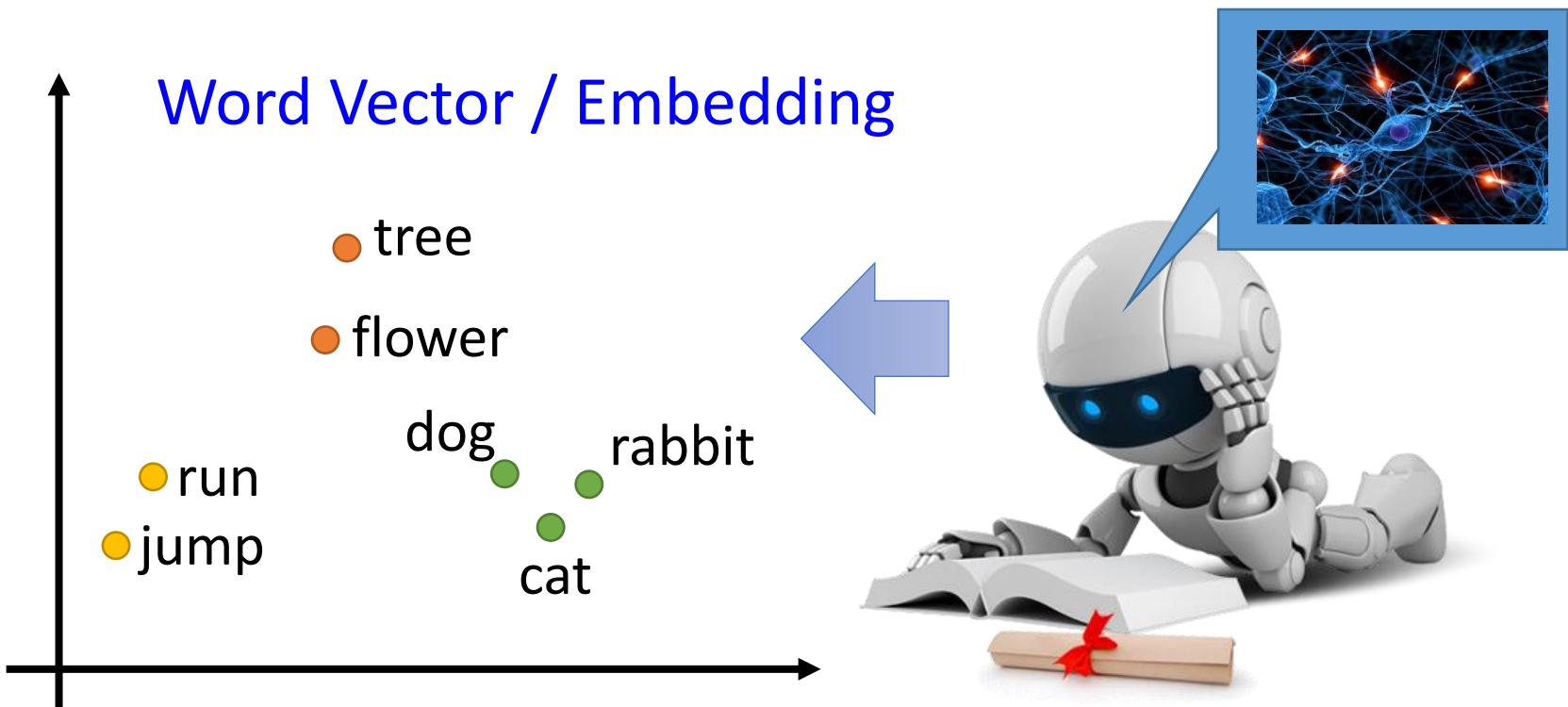
Machine Reading

- Machine learn the meaning of words from reading a lot of documents without supervision



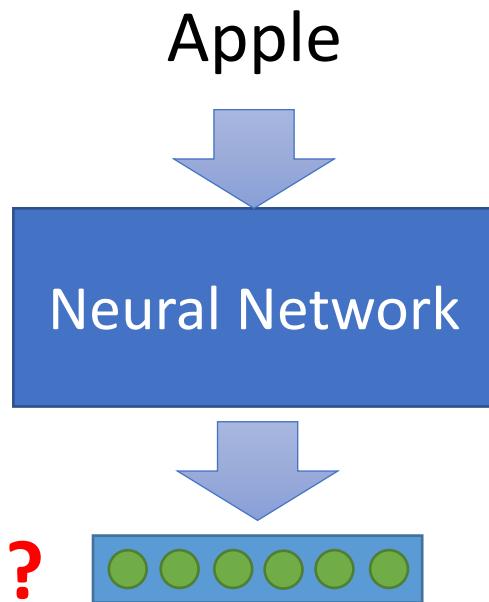
Machine Reading

- Machine learn the meaning of words from reading a lot of documents without supervision



Machine Reading

- Generating Word Vector/Embedding is **unsupervised**



Training data is a lot of text



Machine Reading

- Machine learn the meaning of words from reading a lot of documents without supervision
- A word can be understood by its context

蔡英文、馬英九 are something very similar

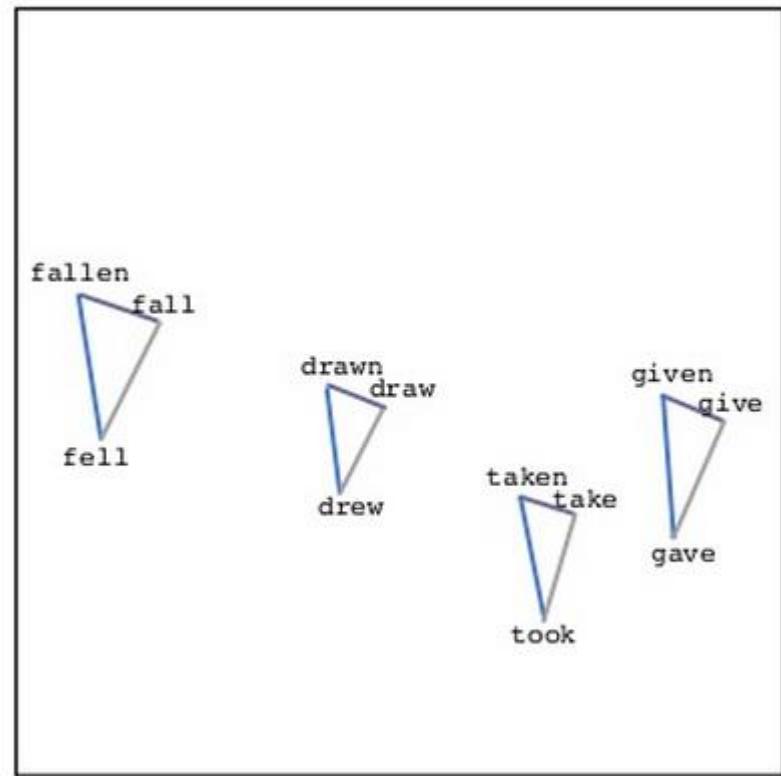
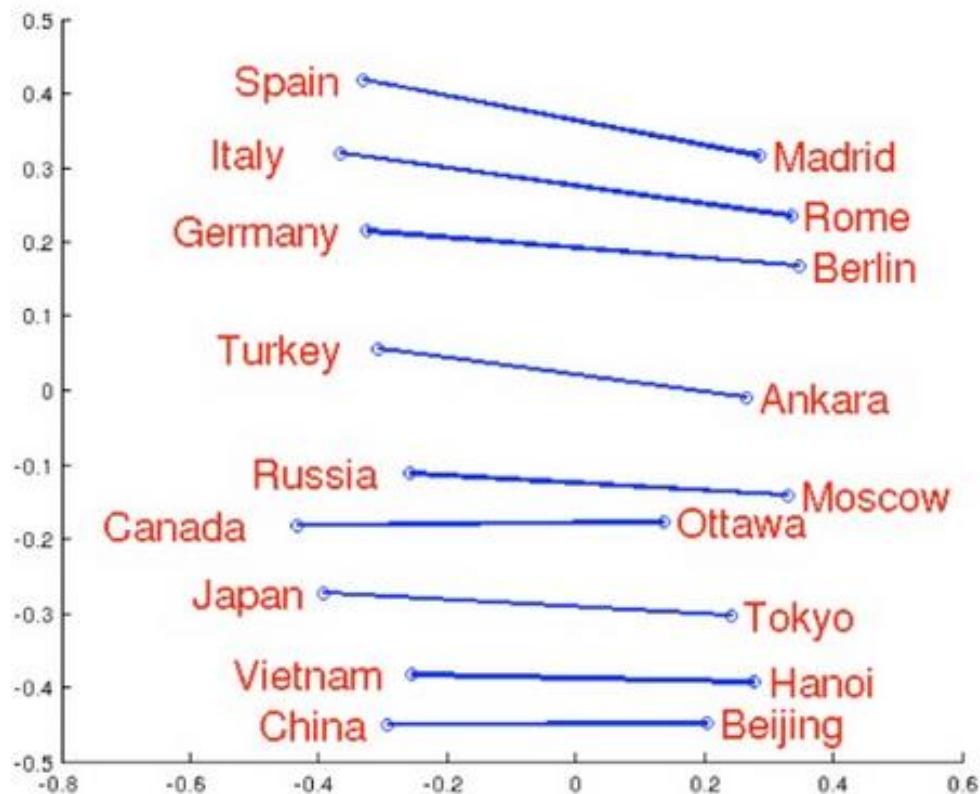
You shall know a word by the company it keeps

馬英九 520宣誓就職

蔡英文 520宣誓就職



Word Vector



Source: <http://www.slideshare.net/hustwj/cikm-keynotenov2014>

Word Vector

$$\approx V(Berlin) - V(Rome) + V(Italy)$$

- Characteristics

$$V(hotter) - V(hot) \approx V(bigger) - V(big)$$

$$V(Rome) - V(Italy) \approx V(Berlin) - V(Germany)$$

$$V(king) - V(queen) \approx V(uncle) - V(aunt)$$

- Solving analogies

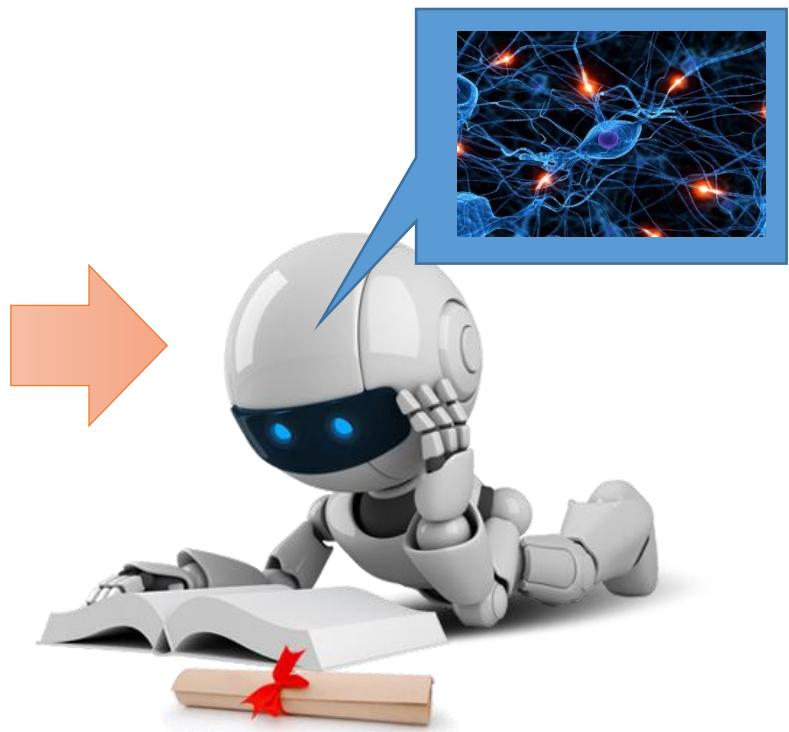
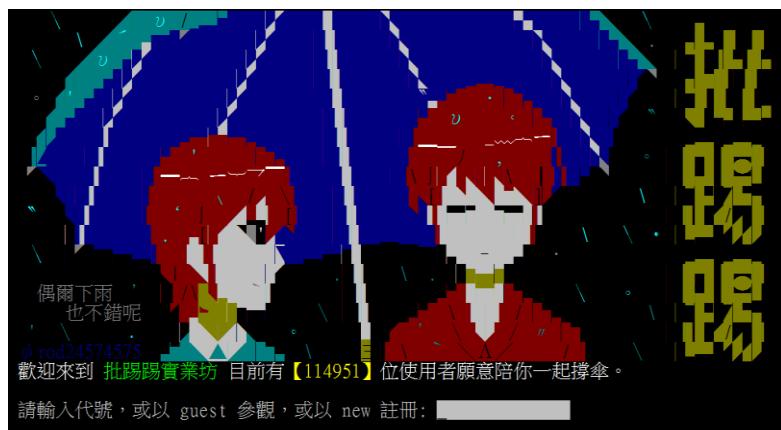
Rome : Italy = Berlin : ?

Compute $V(Berlin) - V(Rome) + V(Italy)$

Find the word w with the closest V(w)

Machine Reading

- Machine learn the meaning of words from reading a lot of documents without supervision



Demo

- Model used in demo is provided by 陳仰德
- Part of the project done by 陳仰德、林資偉
- TA: 劉元銘
- Training data is from PTT (collected by 葉青峰)

Outline

Supervised Learning

- Ultra Deep Network
 - Attention Model
- }
- New network structure

Reinforcement Learning

Unsupervised Learning

- Image: Realizing what the World Looks Like
- Text: Understanding the Meaning of Words
- Audio: Learning human language without supervision

Learning from Audio Book



Machine does not have
any prior knowledge

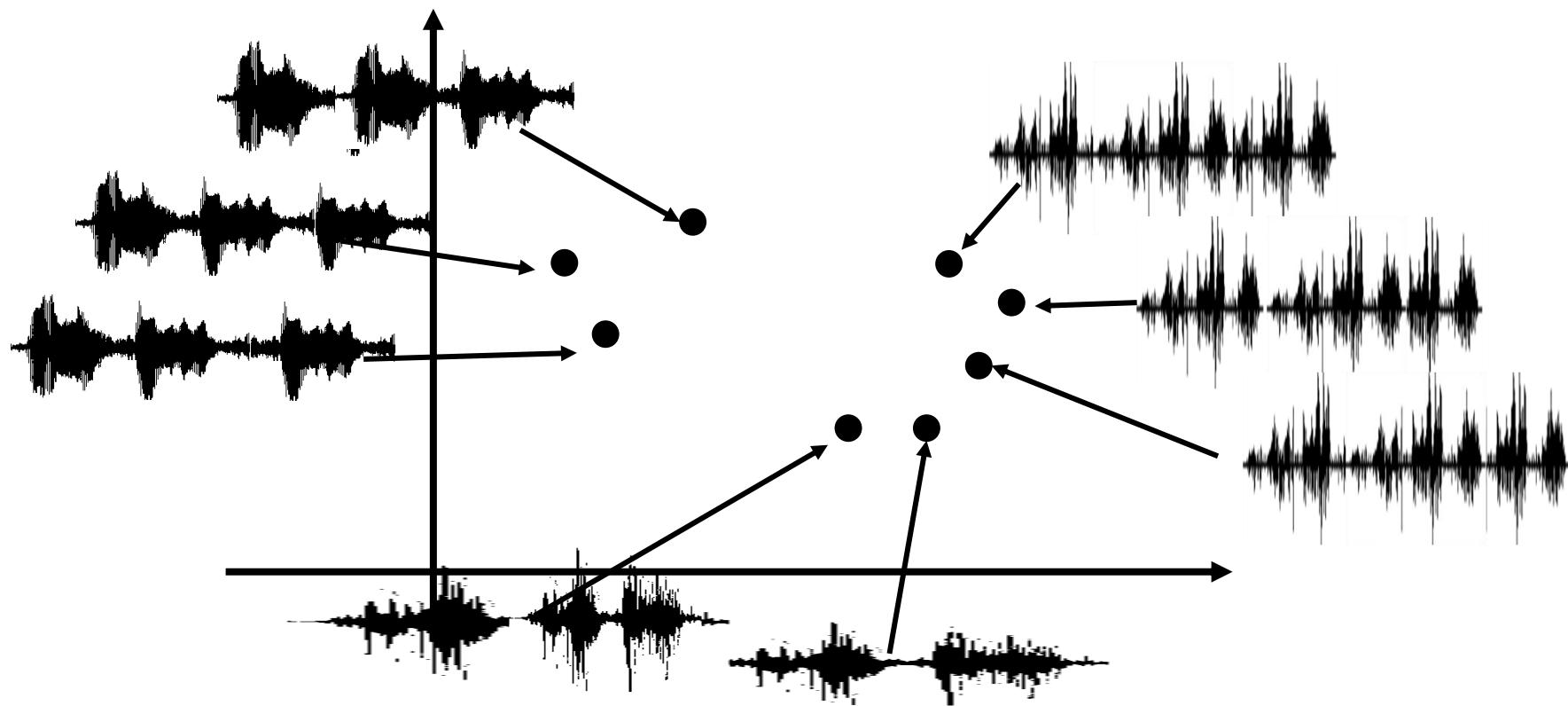
Machine listens to lots of
audio book

Like an infant

Audio Word to Vector

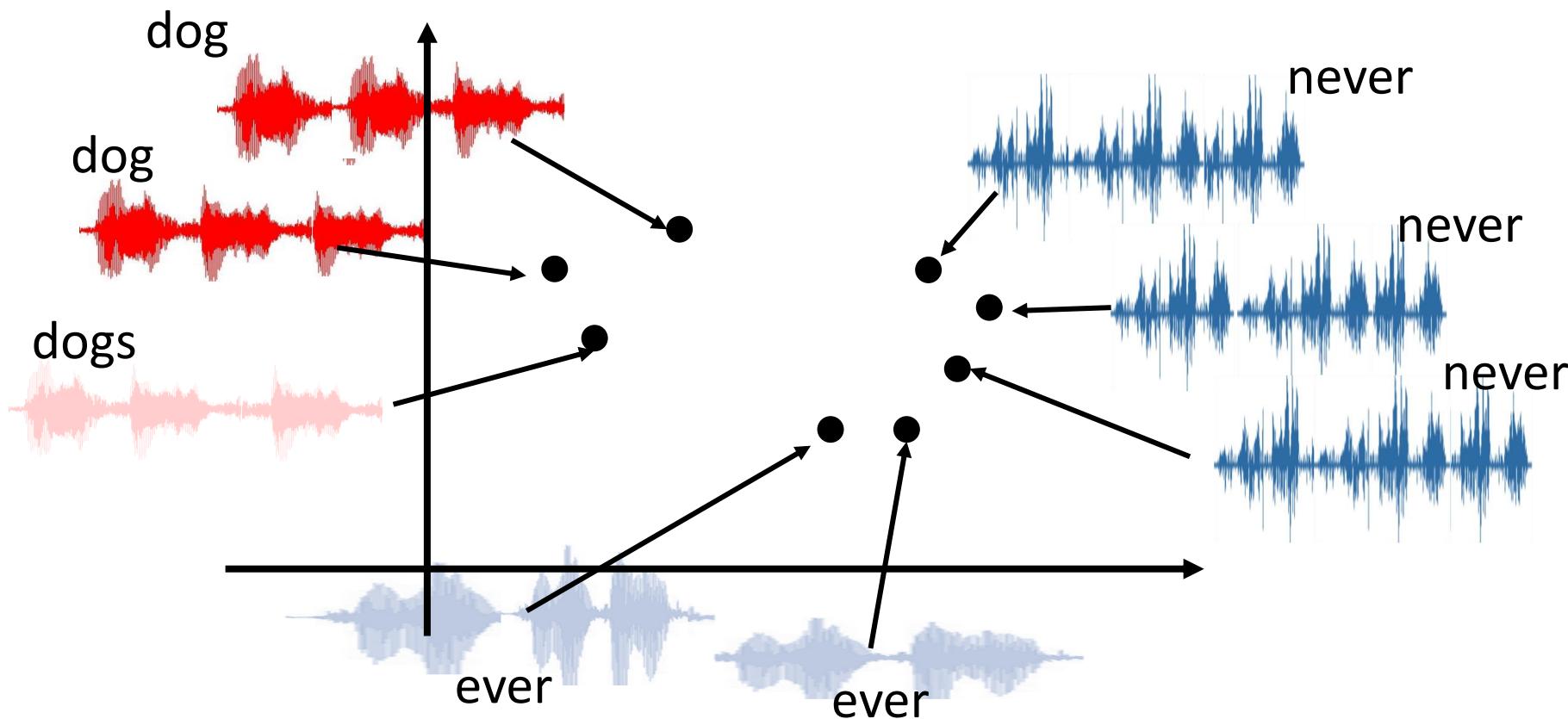
- Audio segment corresponding to an unknown word

→ Fixed-length vector



Audio Word to Vector

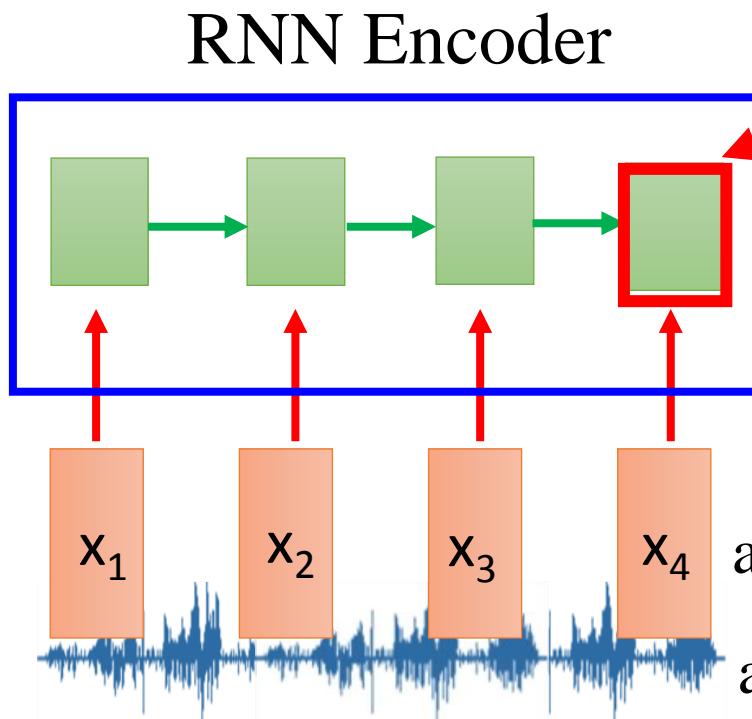
- The audio segments corresponding to words with similar pronunciations are close to each other.



Sequence-to-sequence Auto-encoder



vector



The values in the memory
represent the whole audio
segment

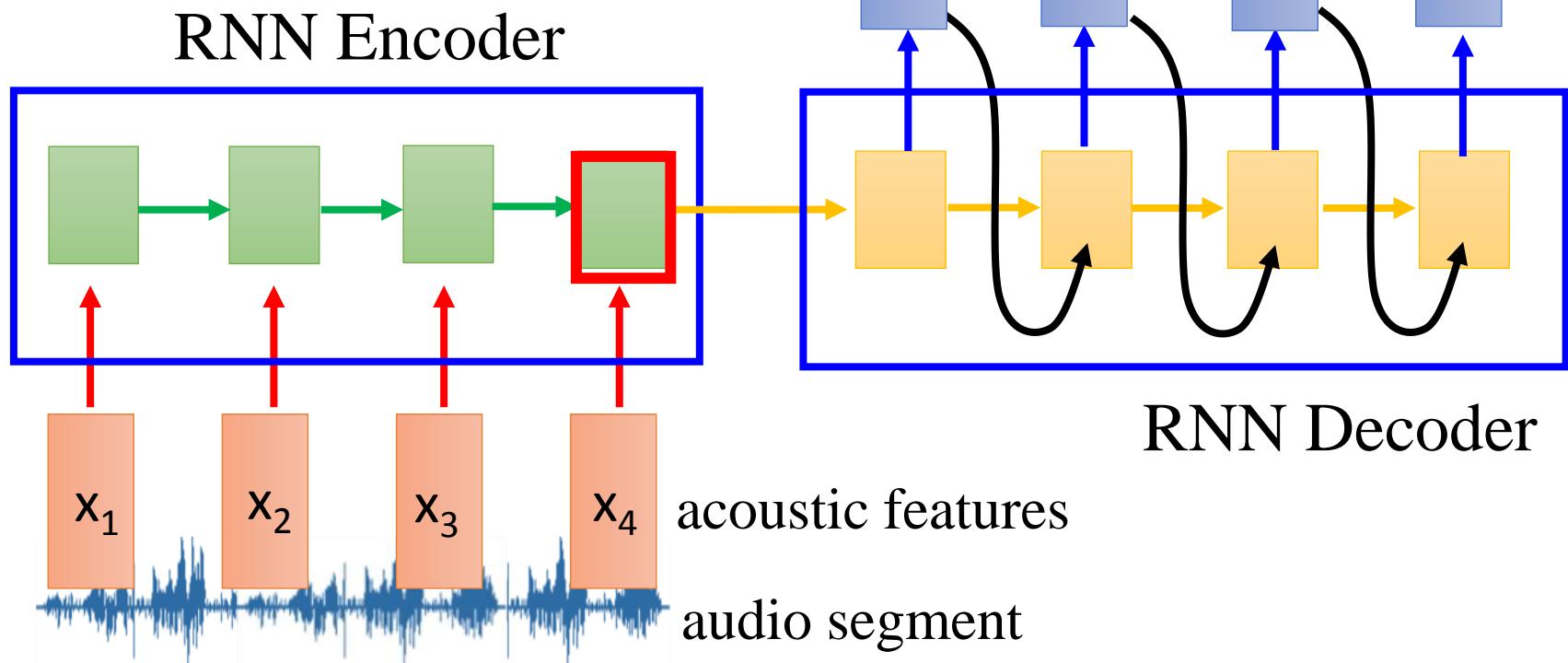
The vector we want

How to train RNN Encoder?

acoustic features
audio segment

Sequence-to-sequence Auto-encoder

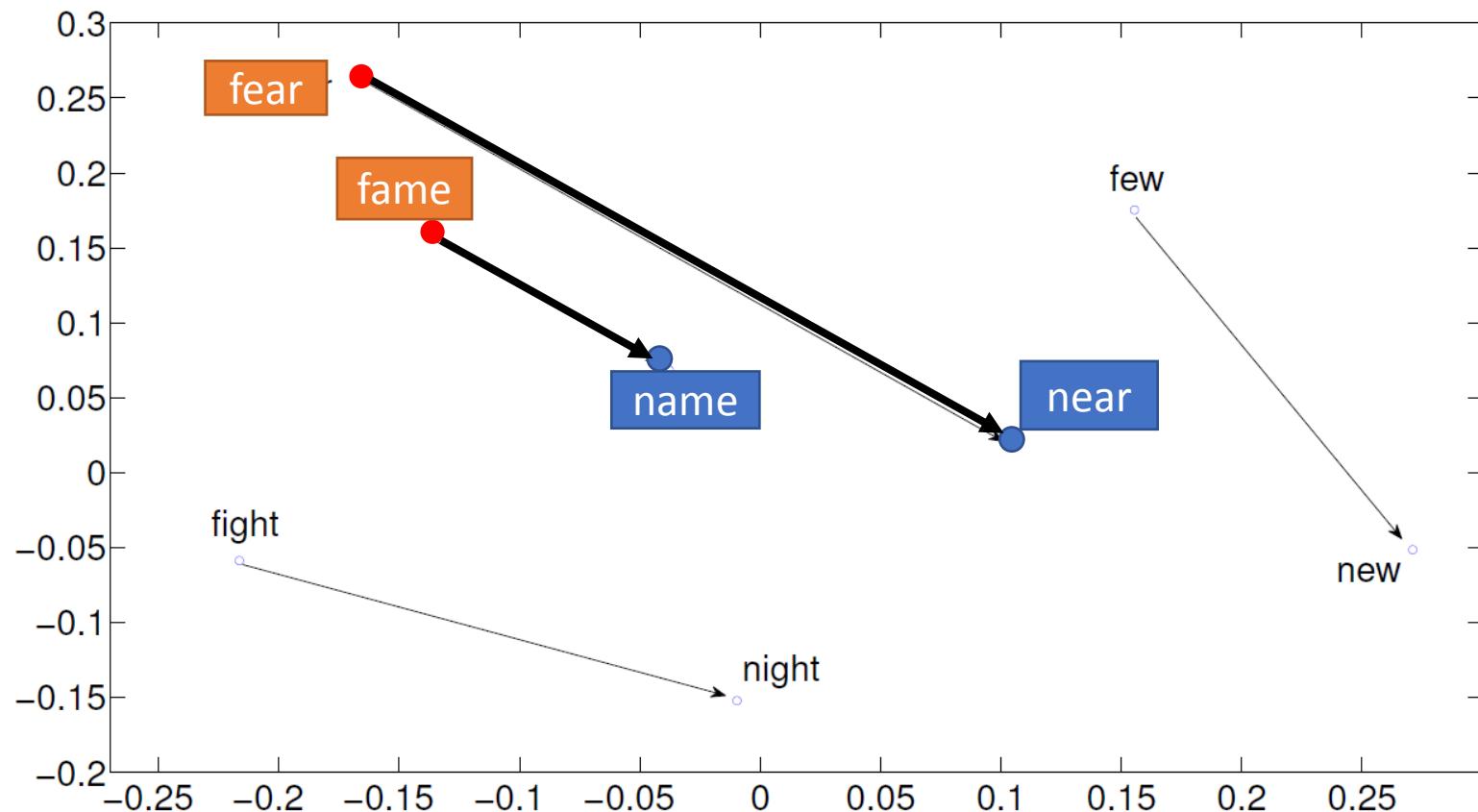
The RNN encoder and
decoder are jointly trained.



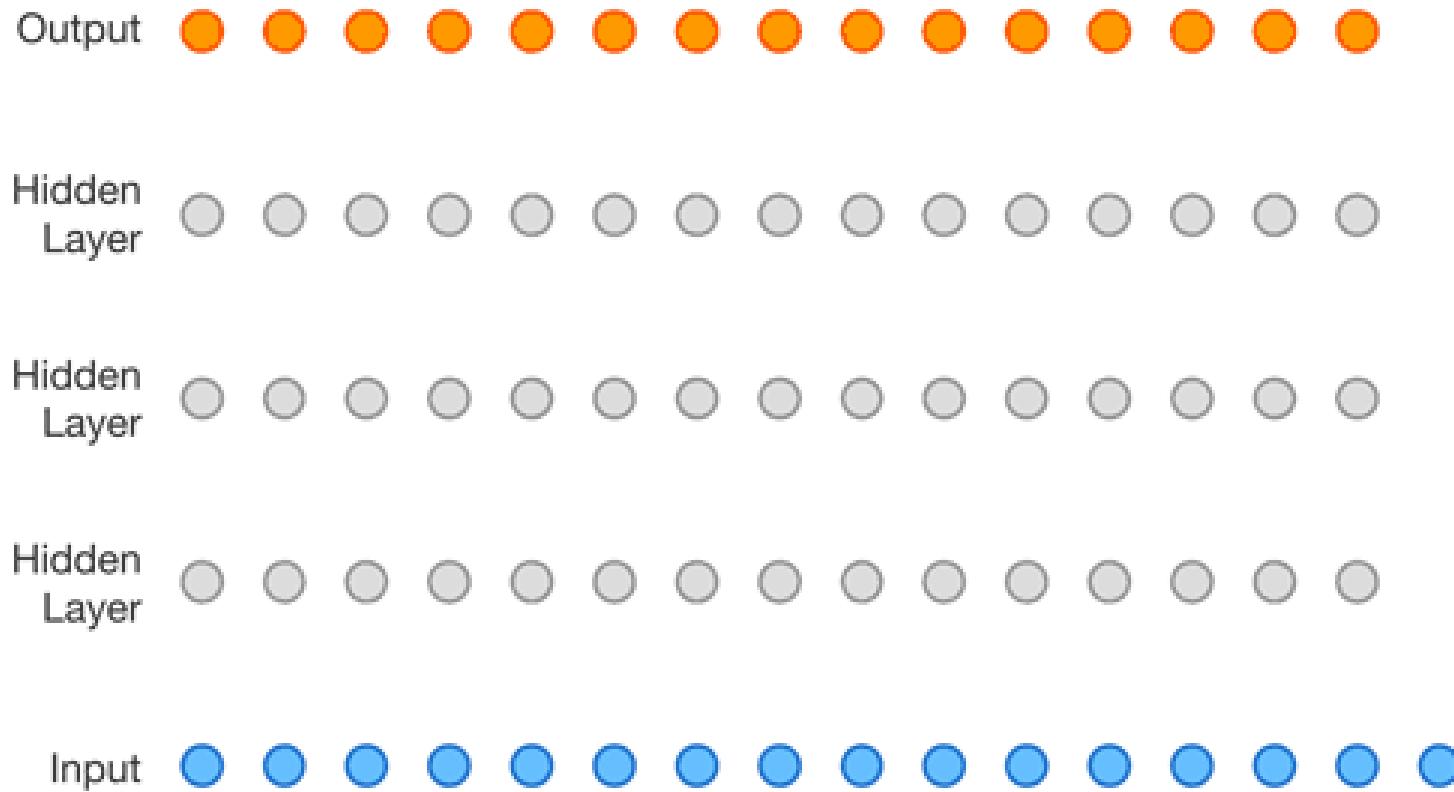
Audio Word to Vector

- Results

- Visualizing embedding vectors of the words



WaveNet (DeepMind)



<https://deepmind.com/blog/wavenet-generative-model-raw-audio/>

Concluding Remarks

Concluding Remarks

Lecture I: Introduction of Deep Learning



Lecture II: Tips for Training Deep Neural Network



Lecture III: Variants of Neural Network



Lecture IV: Next Wave

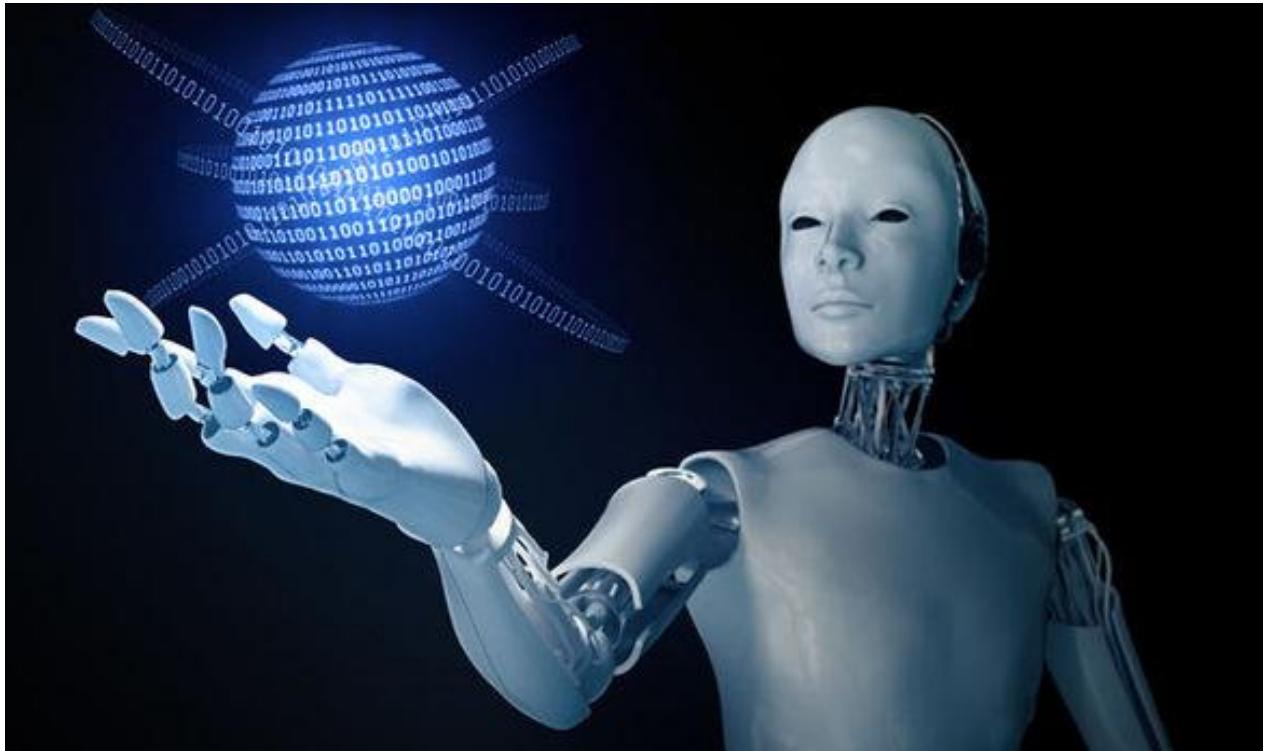
AI 即將取代多數的工作？

- New Job in AI Age



AI 訓練師

(機器學習專家、
資料科學家)



<http://www.express.co.uk/news/science/651202/First-step-towards-The-Terminator-becoming-reality-AI-beats-champ-of-world-s-oldest-game>

AI 訓練師



機器不是自己會學嗎？
為什麼需要 AI 訓練師

戰鬥是寶可夢在打，
為什麼需要寶可夢訓練師？

AI 訓練師

Step 1:
define a set
of function

Step 2:
goodness of
function

Step 3: pick
the best
function

寶可夢訓練師

- 寶可夢訓練師要挑選適合的寶可夢來戰鬥
 - 寶可夢有不同的屬性
- 召喚出來的寶可夢不一定能操控
 - E.g. 小智的噴火龍
 - 需要足夠的經驗

AI 訓練師

- 在 step 1，AI 訓練師要挑選合適的模型
 - 不同模型適合處理不同的問題
- 不一定能在 step 3 找出 best function
 - E.g. Deep Learning
 - 需要足夠的經驗

AI 訓練師

- 厲害的 AI ， AI 訓練師功不可沒
- 讓我們一起朝 AI 訓練師之路邁進



以神奇寶貝大師為目標一直進行著修煉



台大電機系 資料科學與智慧網路組 首屆招生：

碩士生甄試20名，考試入學10名

博士生甄試2名，考試入學1名



招生公告：105.09.20



報名期間：105.10.04 ~ 10.12



招生網址：

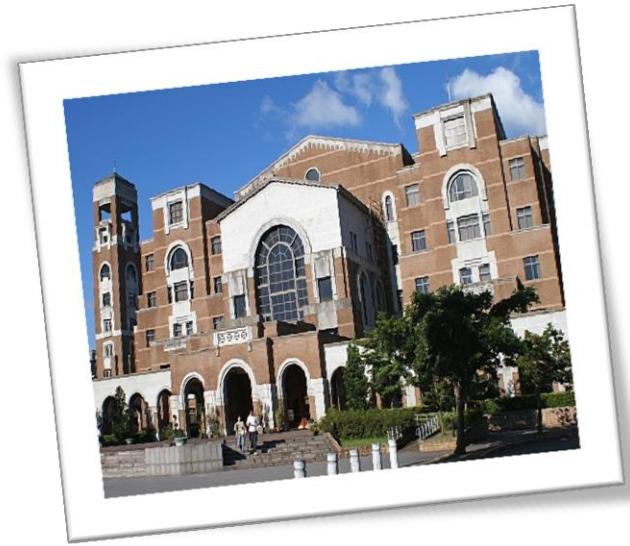
<https://comm.ntu.edu.tw/new/Master.php>



招生說明會：

時間：105.09.28 12:20

地點：台大博理館 112 R



國立臺灣大學
National Taiwan University
電信工程學研究所丙組
資料科學與智慧網路組

Python
Machine Learning
Deep Learning
Computer Vision
Big Data
NTU-GICE
Data Mining
Smart Networking
Cloud Computing
Blockchain
AI Ethics