

Understanding Deep Neural Networks

## Chapter One

# Introduction to Deep Neural Networks

---

Zhang Yi, *IEEE Fellow*  
Autumn, 2019

# Outline

- Concept of artificial intelligence
- An example: handwritten digits recognition
- How does a child recognize the handwritten digits
- Introduction to brain structure
- Assignment
- Discussions

# Concepts



March 2016, AlphaGo beat Lee Sedol, 4:1



May 2017, AlphaGo beat Ke Jie, 3:0



百度为您找到相关结果约6,680,000个

搜索工具

您可以仅查看: 英文结果

[AlphaGo\\_百度百科](#)



简介: 阿尔法围棋 (AlphaGo) 是第一个击败人类职业围棋选手、第一个战胜围棋世界冠军的人工智能机器人,由谷歌 (Google) 旗下DeepMind公司戴密斯·哈萨比斯领衔的团队开发。其主要工作原理是“深度学习”。2016年3月,阿尔法围棋与围棋世界冠军、职业九段棋手李世石进行围棋人机大战,以4比1的总比分获胜;20...

[旧版原理](#) [新版原理](#) [旧版战绩](#) [新版战绩](#) [版本介绍](#) [更多>>](#)

<https://baike.baidu.com/>

[手把手AlphaGo有啥了不起,我也能教你做一个\(附Python代码\)](#)

2018年2月22日 - 在2016年3月,Deepmind研发的AlphaGo以4:1的成绩,击败了曾荣获18次世界冠军的围棋选手,李世石(Lee Sedol)。超过2亿观众见证了这一历史时刻。一台机器已...

[https://baijiahao.baidu.com/s?... - 百度快照](https://baijiahao.baidu.com/s?...)

[AlphaGo China | DeepMind](#)

查看此网页的中文翻译,请点击 [翻译此页](#)

Team Go players enjoying the match with AlphaGo The match proved to be a pleasure to watch, giving spectators the unique opportunity to see world-class...

<https://deepmind.com/research/> - 百度快照

[AlphaGo之父关于围棋,人类3000年来犯了一个大错\\_科技\\_腾讯网](#)

2017年4月14日 - 对于5月23日至27日与围棋人工智能程序AlphaGo(阿尔法狗)的对弈,目前世界排名第一的中国职业九段柯洁放出...

[tech.qq.com/a/20170414... - 百度快照](http://tech.qq.com/a/20170414...)

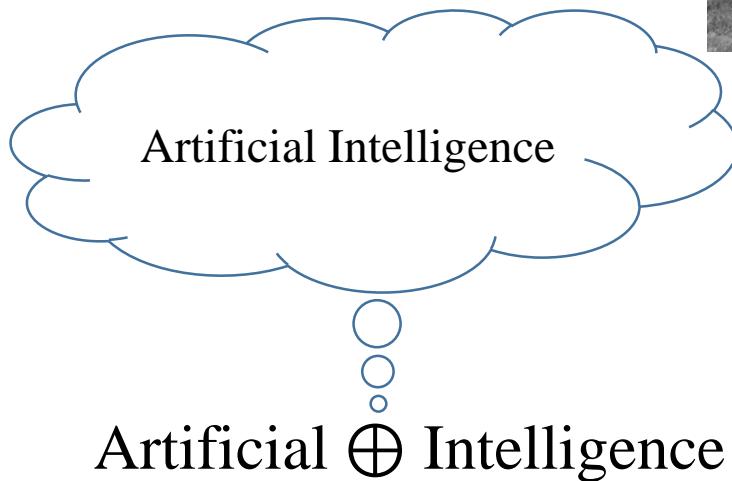
[从零开始,全凭自学,它用40天完虐AlphaGo!|科学人|果壳网 科技...](#)

2017年10月25日 - 席卷了世界之后,AlphaGo 宣布不再和人下棋。但它的制造者并没有因此停下脚步...

<https://www.guokr.com/article/> - 百度快照

[退役后的AlphaGo没有忘记人类,它还要教柯洁重新下棋|极客公园](#)

# Concepts



Dartmouth Conference, 1956

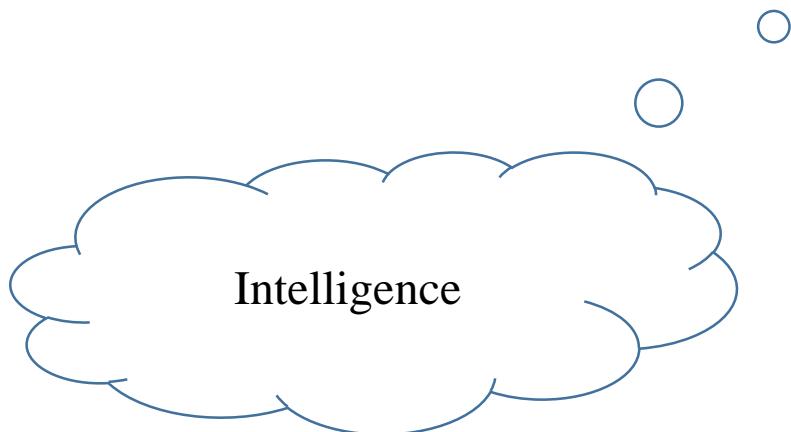
## ■ *Definition of Artificial*

- Not real or not made of natural things but made to be like something that is real or natural

## ■ *Definition of Intelligence*

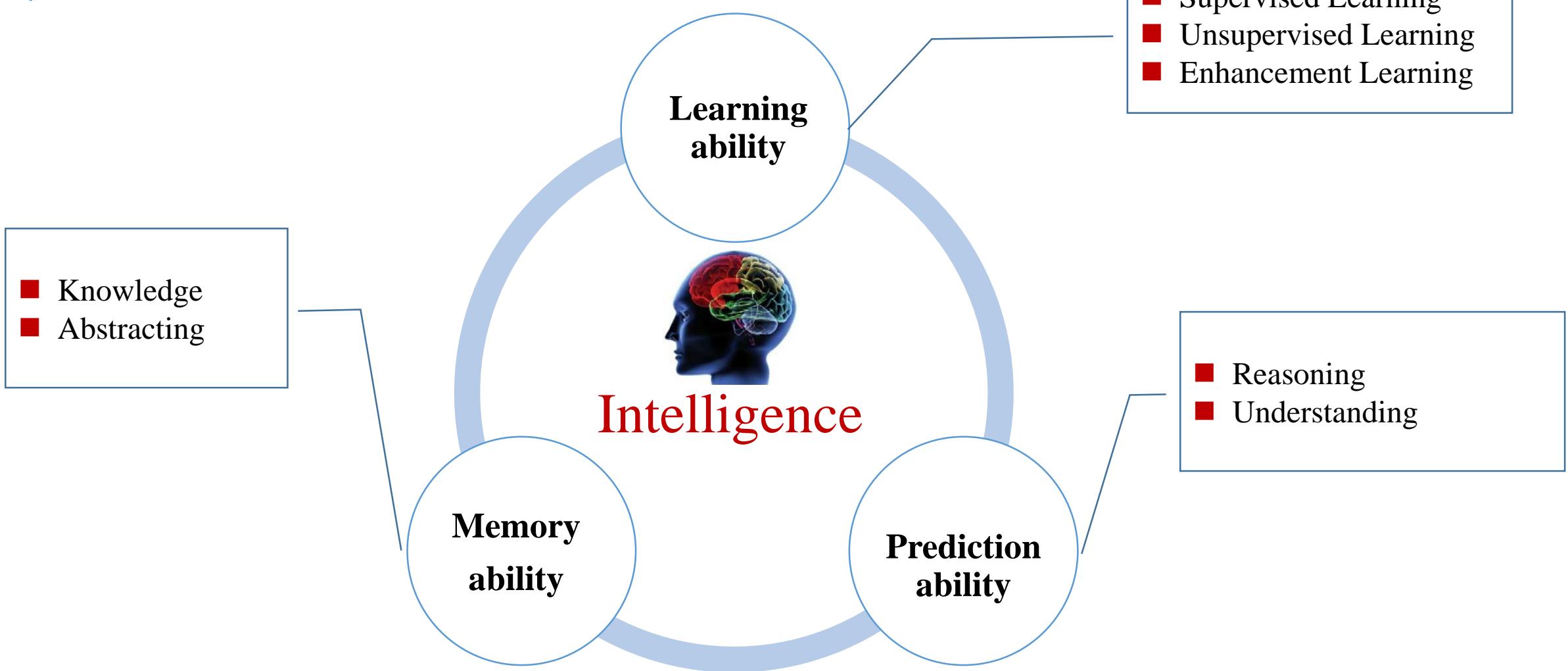
- There is still no standard definition of intelligence.
- There seem to be almost as many definitions of intelligence as there were experts asked to define it.
- How to understand intelligence?

# Concepts

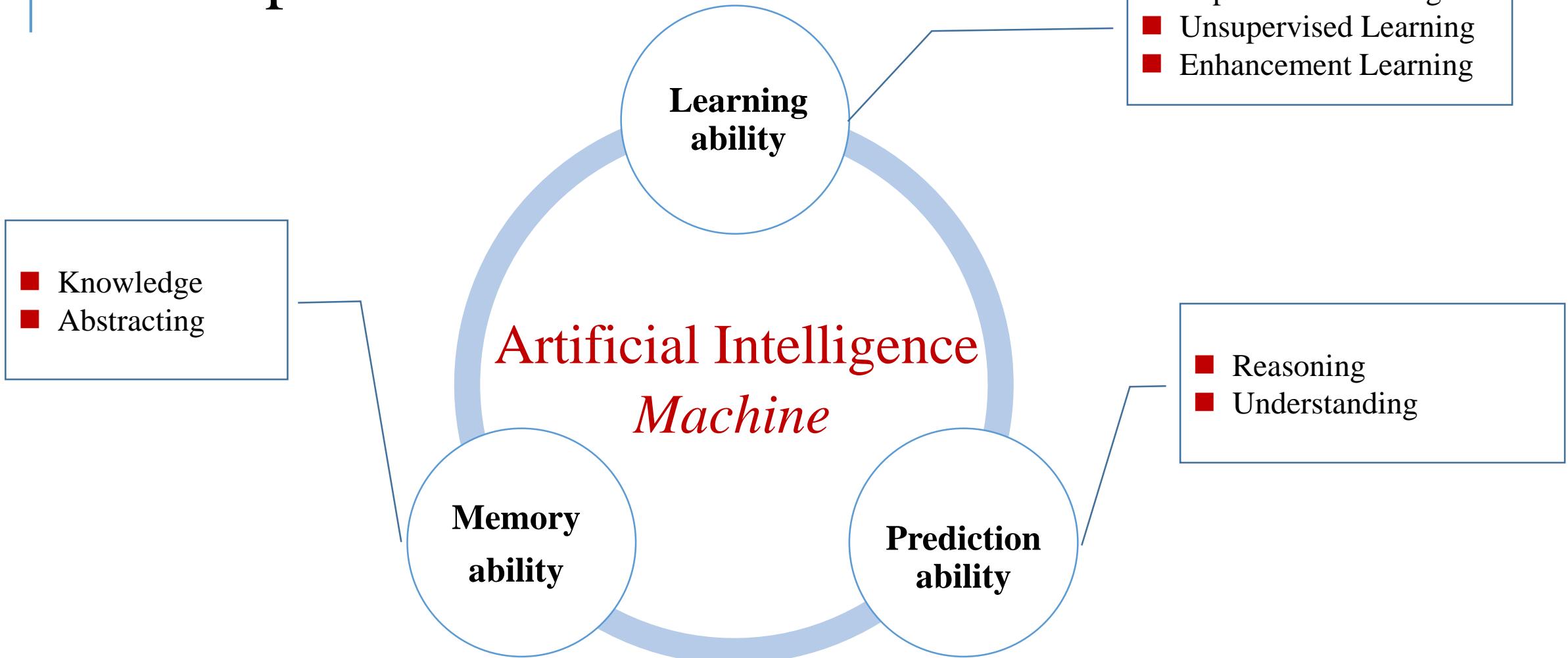


- ■ ***Examples of Definitions of Intelligence***
  - The **ability to use memory**, knowledge, experience, understanding, reasoning, imagination and judgment in order to solve problems and adapt to new situations. *AllWords Dictionary, 2006*
  - The **ability to learn, understand, and think** about things. *Longman Dictionary or Contemporary English, 2006*.
  - The capacity to learn, **reason**, and understand. *Wordsmyth Dictionary, 2006*.
  - Intelligence is the **ability to learn** about, learn from, understand, and interact with one's environment.
  - .....

# Concepts



# Concepts



Problem: How to implement artificial intelligence?

# Concepts

## Deep Neural Networks

*A way towards artificial intelligence*



Deep Neural Networks are computational models inspired from brain working principle.



# Concepts

## ■ Deep Learning

- Method to train Deep Neural Networks



Professor Geoffrey E. Hinton

## Reducing the Dimensionality of Data with Neural Networks

G. E. Hinton\* and R. R. Salakhutdinov

High-dimensional data can be converted to low-dimensional codes by training a multilayer neural network with a small central layer to reconstruct high-dimensional input vectors. Gradient descent can be used for fine-tuning the weights in such “autoencoder” networks, but this works well only if the initial weights are close to a good solution. We describe an effective way of initializing the weights that allows deep autoencoder networks to learn low-dimensional codes that work much better than principal components analysis as a tool to reduce the dimensionality of data.

Dimensionality reduction facilitates the classification, visualization, communication, and storage of high-dimensional data. A simple and widely used method is principal components analysis (PCA), which

finds the directions of greatest variance in the data set and represents each data point by its coordinates along each of these directions. We describe a nonlinear generalization of PCA that uses an adaptive, multilayer “encoder” network

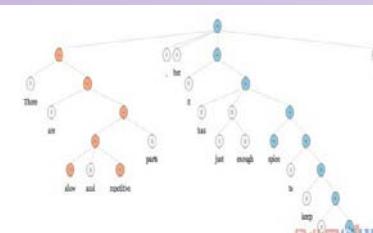
\* 2006 VOL 313 SCIENCE www.sciencemag.org

# Concepts

- **Speech recognition**: RBM network reduce the error rate by 30%, which is the most significant breakthrough in the past decade.
- **Image recognition**: CNN achieve over 95% recognition rate on Imagenet2012 dataset, which is comparable to human performance.
- **Nature language processing**: recurrent neural networks show superior performance than baseline methods in NLP problems..



Microsoft simultaneous interpretation

IM<sup>2</sup>GENET

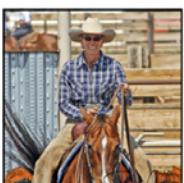
Stanford sentiment analysis



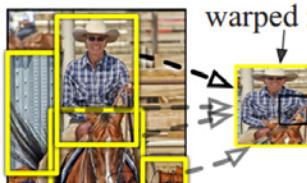
Google translation



Google voice assistance



1. Input image

R-CNN: *Regions with CNN features*

warped region

aeroplane? no.

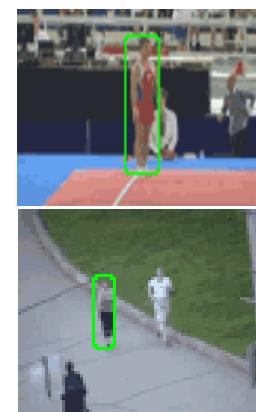
person? yes.

tvmonitor? no.

2. Extract region proposals (~2k)

3. Compute CNN features

4. Classify regions



A group of young men playing a game of soccer.



A black and white cat is sitting on a chair.

# Concepts

## ■ An advanced technology in computer science

Google search results for "deep learning" showing various links to deep learning resources, including Deep Learning, Deep Learning Tutorials, and Deep learning - Wikipedia.

Baidu search results for "deep neural networks" showing various links to deep learning resources, including Deep learning - Wikipedia, the free encyclopedia and Deep learning (Deep machine learning, or deep structured learning, or hierarchical learning, or sometimes DL) is a branch of machine learning based on a set of ...

Deep learning is a new area of machine learning research, which has been introduced with the objective of moving machine learning closer to one of its original goals: artificial intelligence.



**Geoffrey Hinton**  
University of Toronto  
Google



**Yann LeCun**  
New York University  
Facebook



**Andrew Ng**  
Stanford University  
Baidu



**Yoshua Bengio**  
University of Montreal



**Goodfellow**



SUPSI

Università  
della  
Svizzera  
italiana

Google

IBM



Microsoft

facebook

Baidu 百度

# Outline

- Concept of artificial intelligence
- An example: handwritten digits recognition
- How does a child recognize the handwritten digits
- Introduction to brain structure
- Assignment
- Discussions

# Handwritten Digits Recognition



Problem:

How to write a computer program to recognize the handwritten digits?



# Handwritten Digits Recognition

Handwritten digits

0 0 0 0 0 0 0 0 0 0

classification

labels

0

1 1 1 1 1 1 1 1 1 1

1

2 2 2 2 2 2 2 2 2 2

2

3 3 3 3 3 3 3 3 3 3

3

4 4 4 4 4 4 4 4 4 4

4

5 5 5 5 5 5 5 5 5 5

5

6 6 6 6 6 6 6 6 6 6

6

7 7 7 7 7 7 7 7 7 7

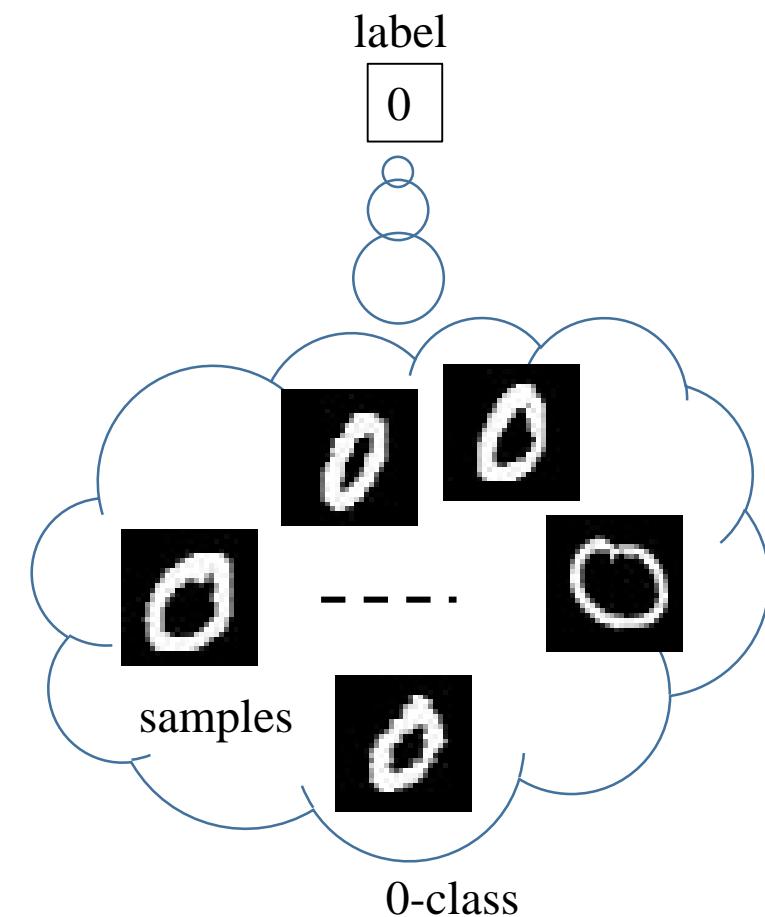
7

8 8 8 8 8 8 8 8 8 8

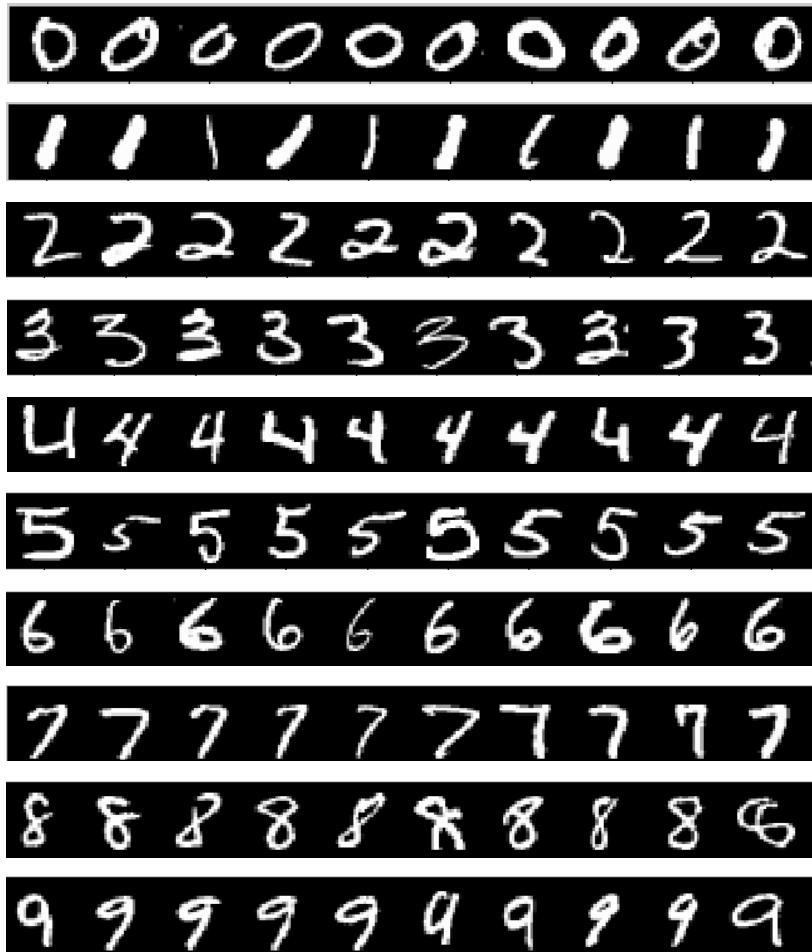
8

9 9 9 9 9 9 9 9 9 9

9



# Handwritten Digits Recognition



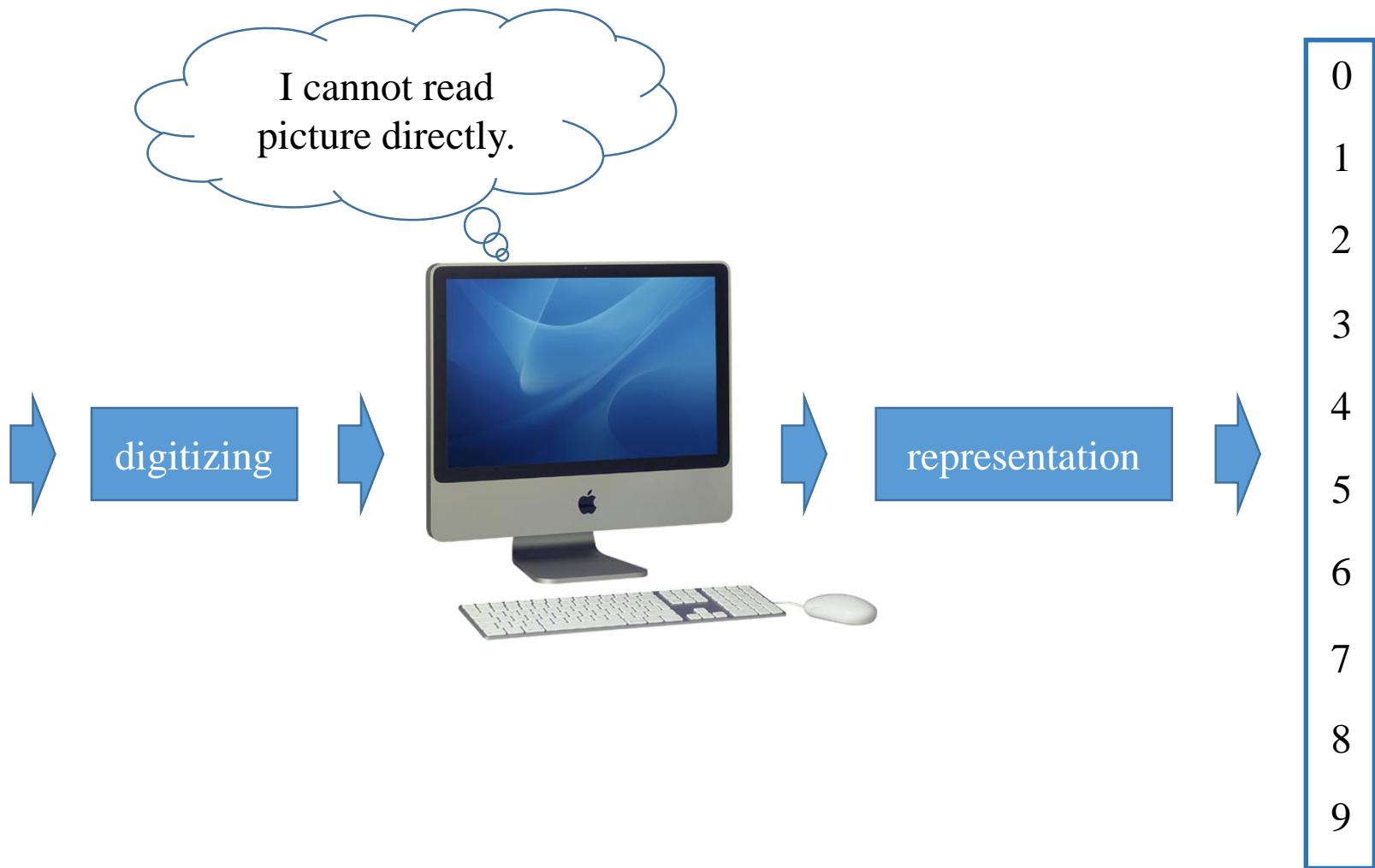
Recognition = classification



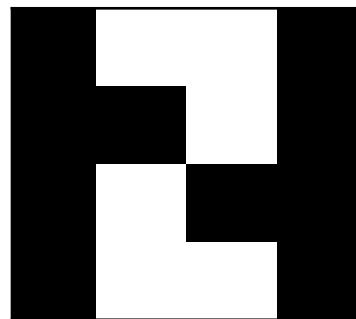
label

0
1
2
3
4
5
6
7
8
9

# Handwritten Digits Recognition

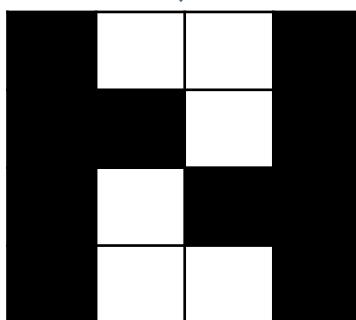


# Handwritten Digits Recognition

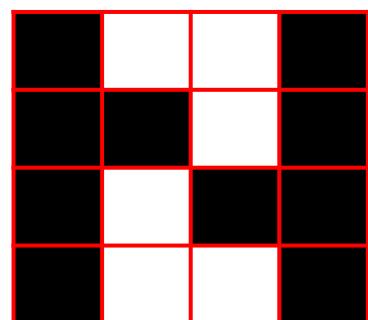


photo

digitizing



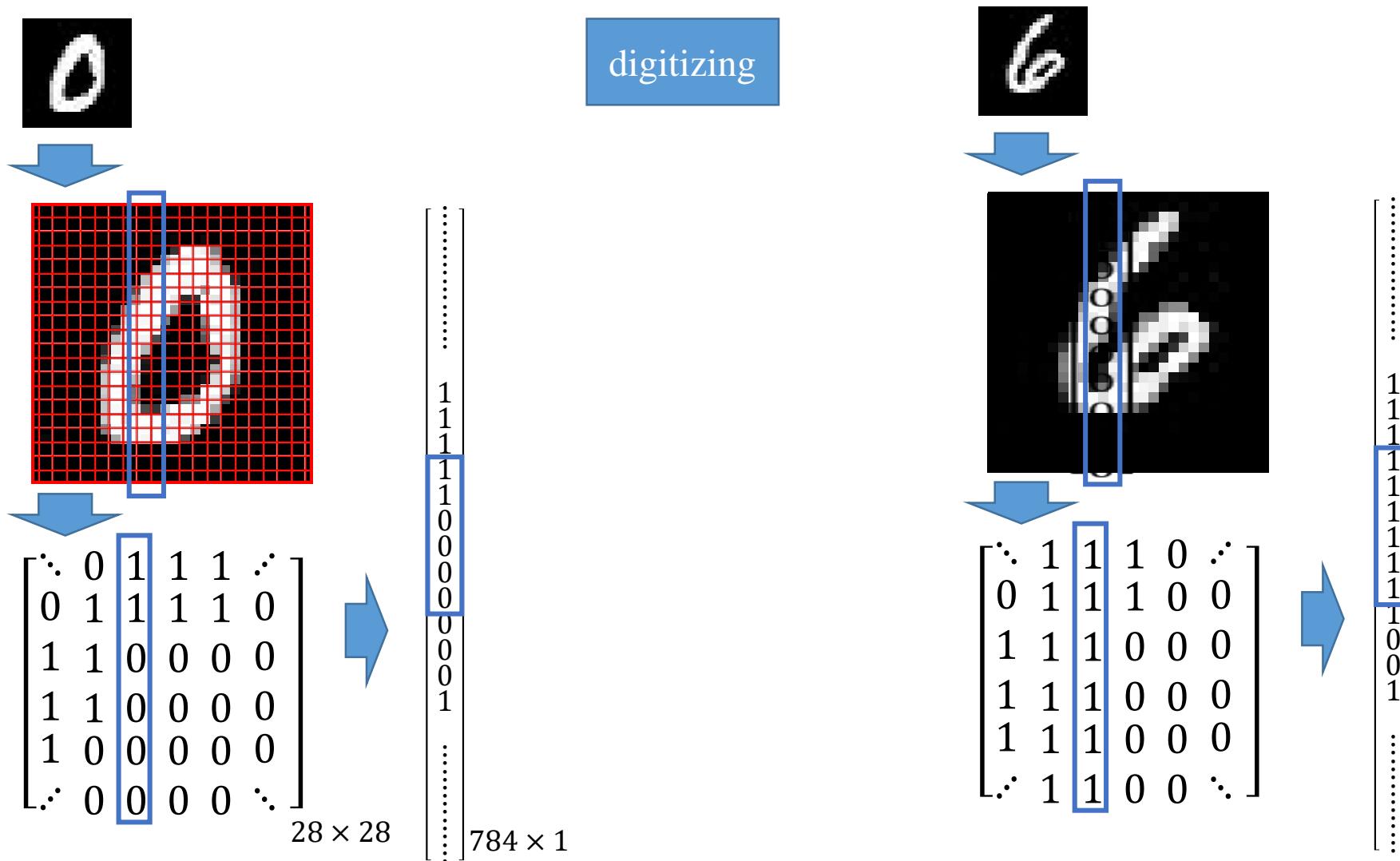
$4 \times 4$



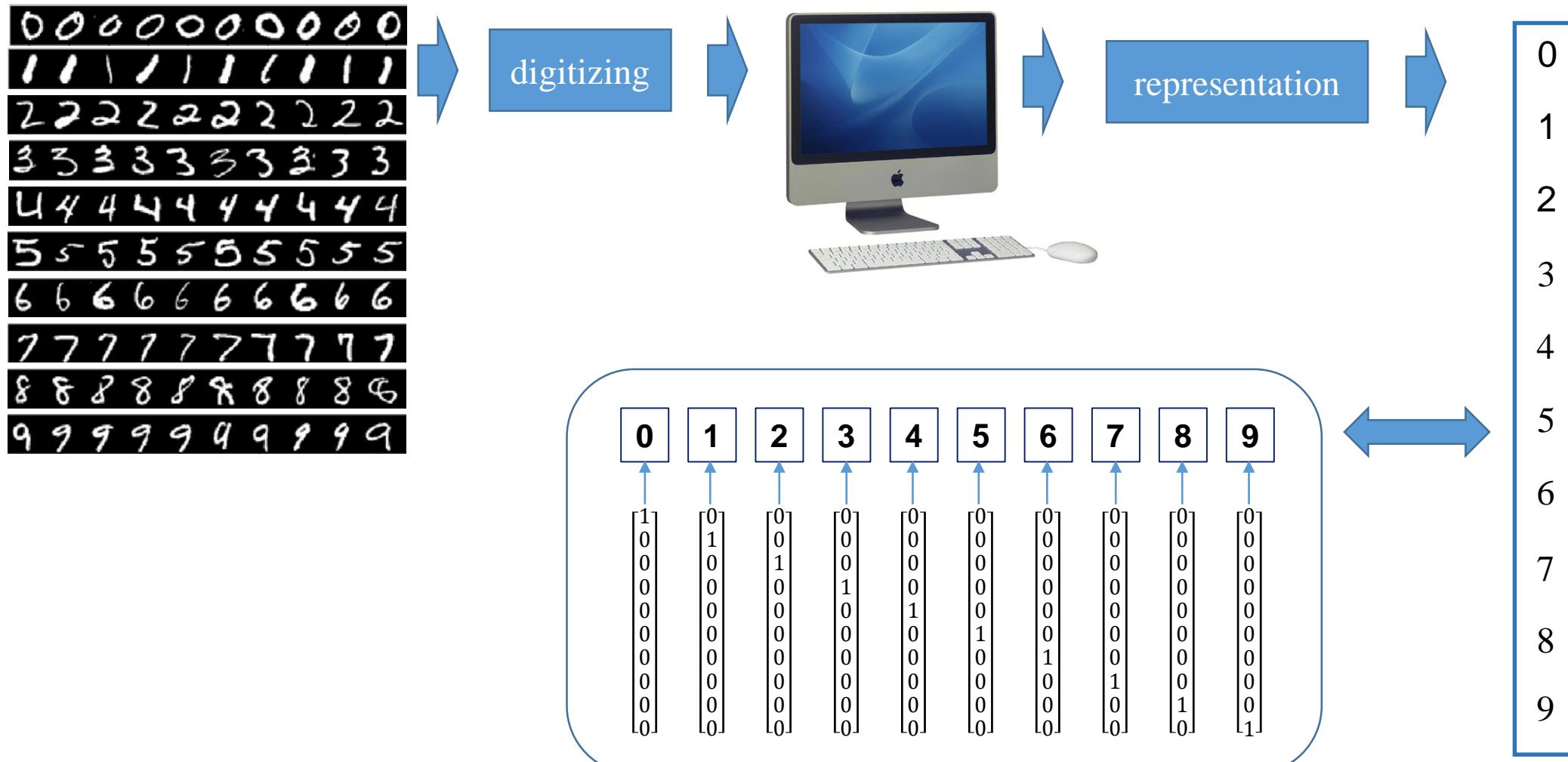
$$\begin{bmatrix} 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \end{bmatrix} \quad 4 \times 4$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad 16 \times 1$$

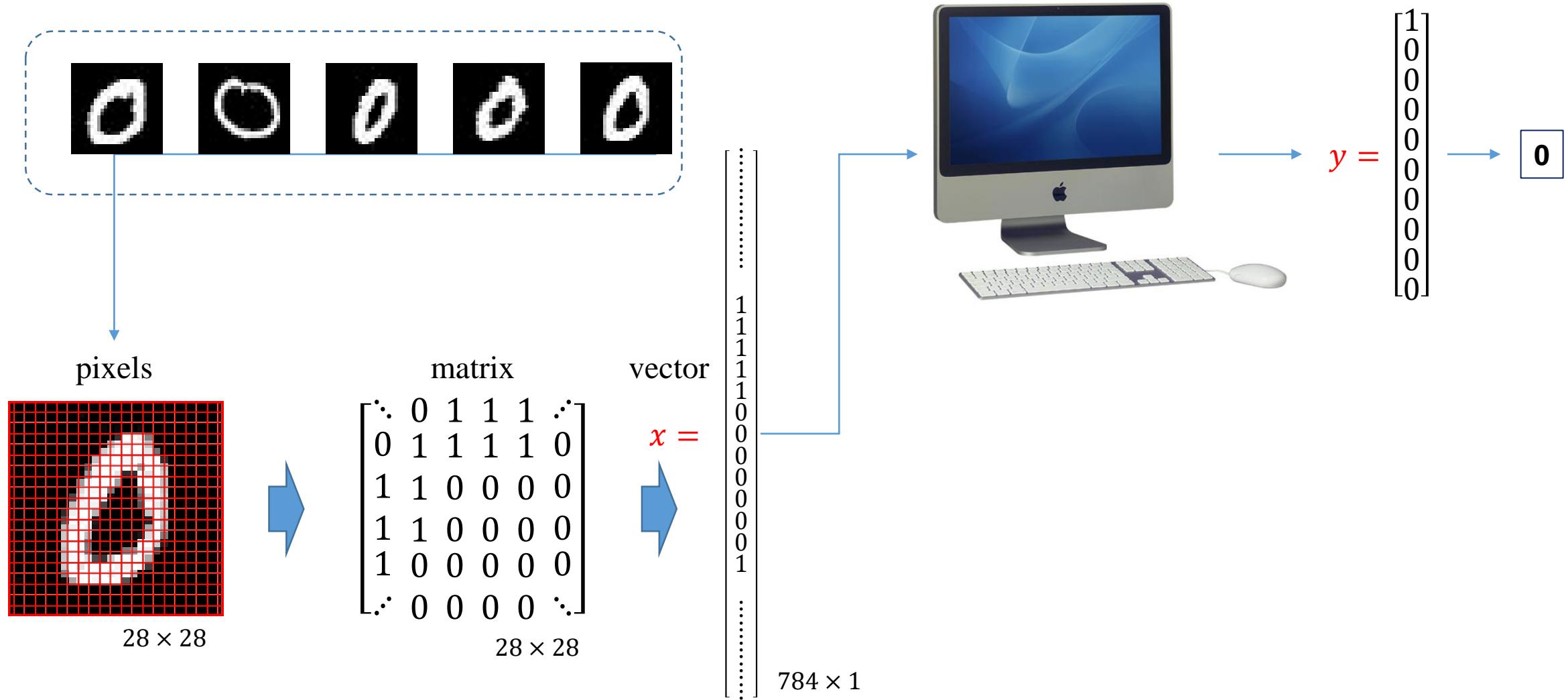
# Handwritten Digits Recognition



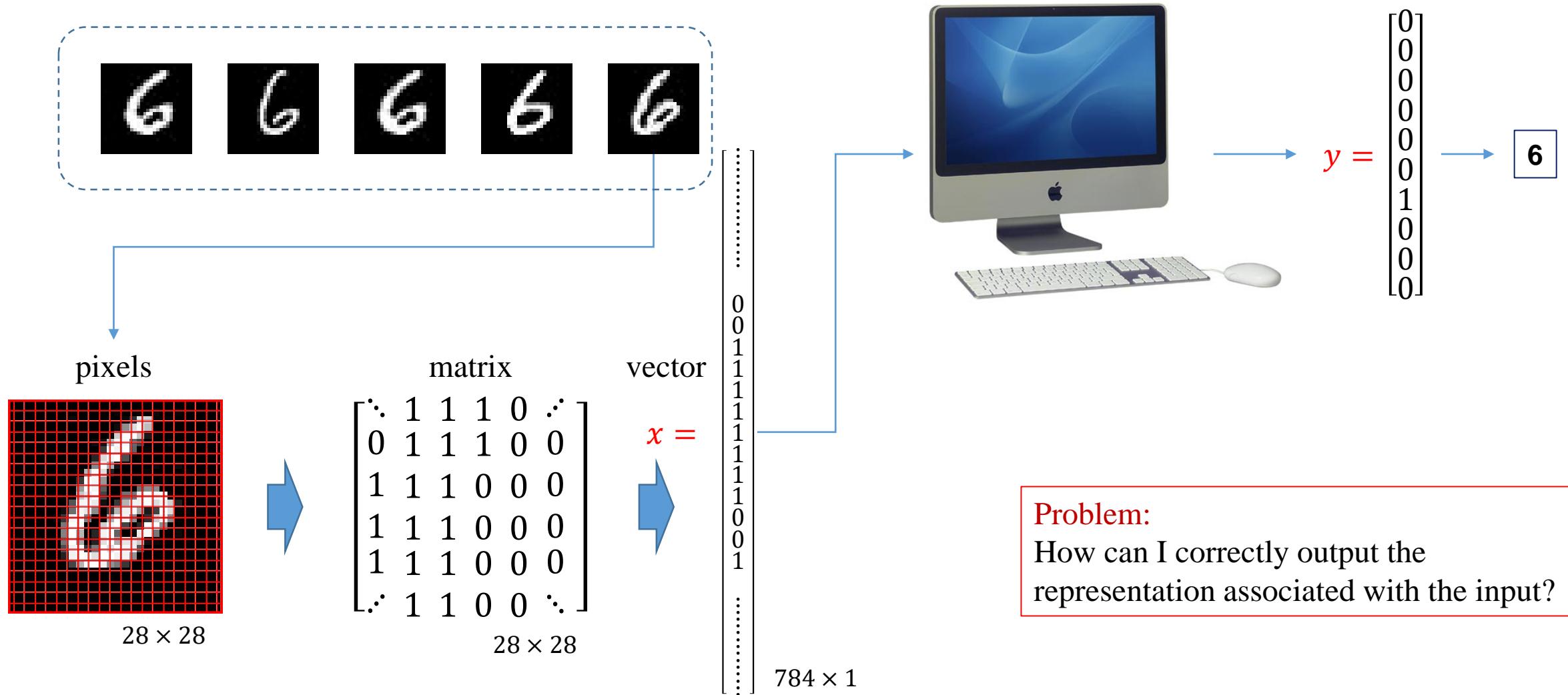
# Handwritten Digits Recognition



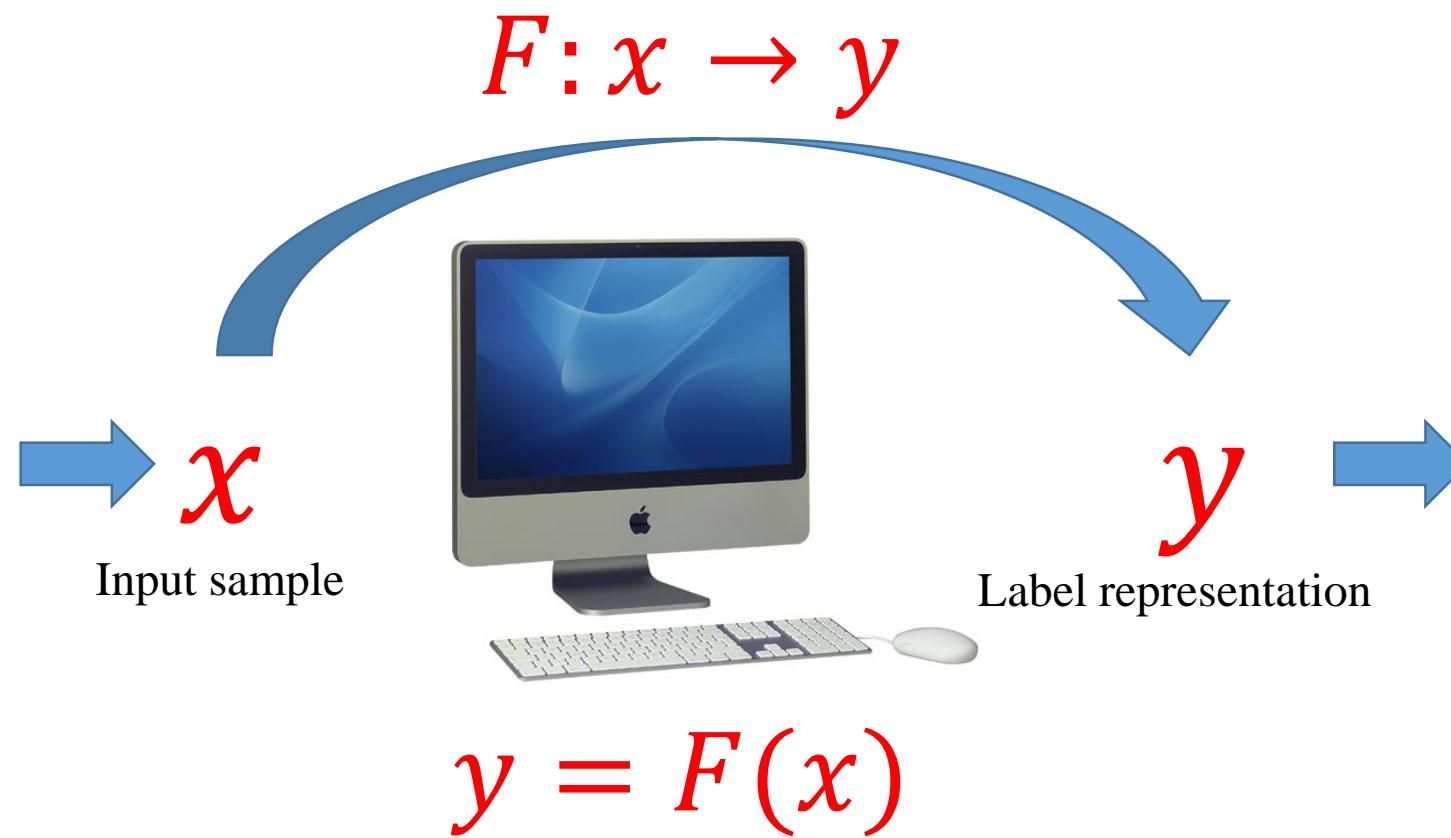
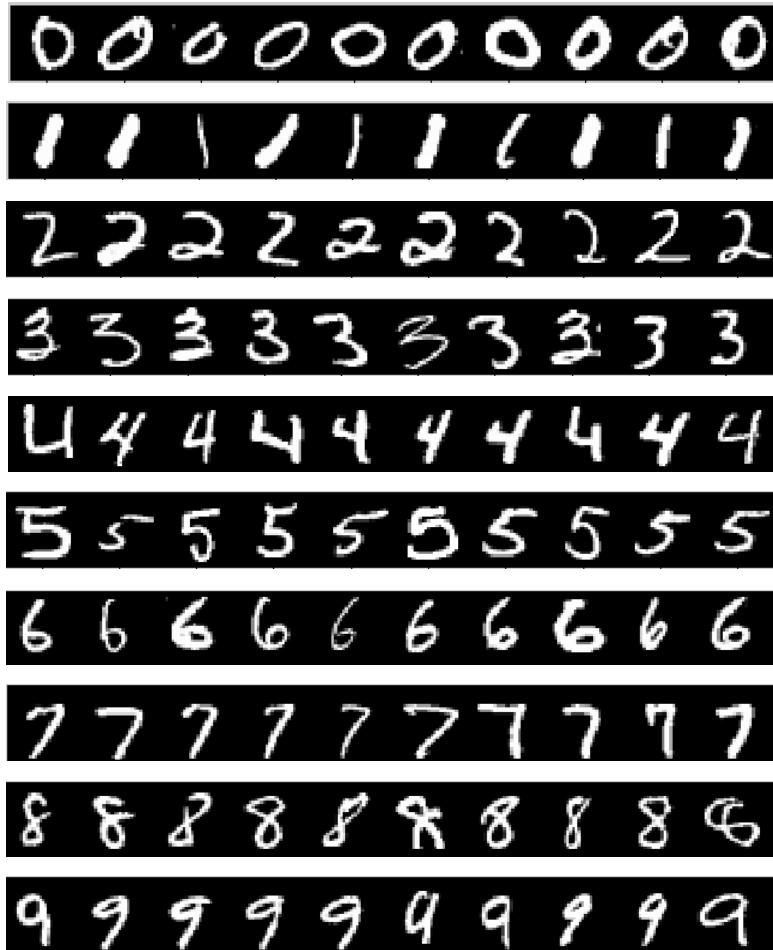
# Handwritten Digits Recognition



# Handwritten Digits Recognition

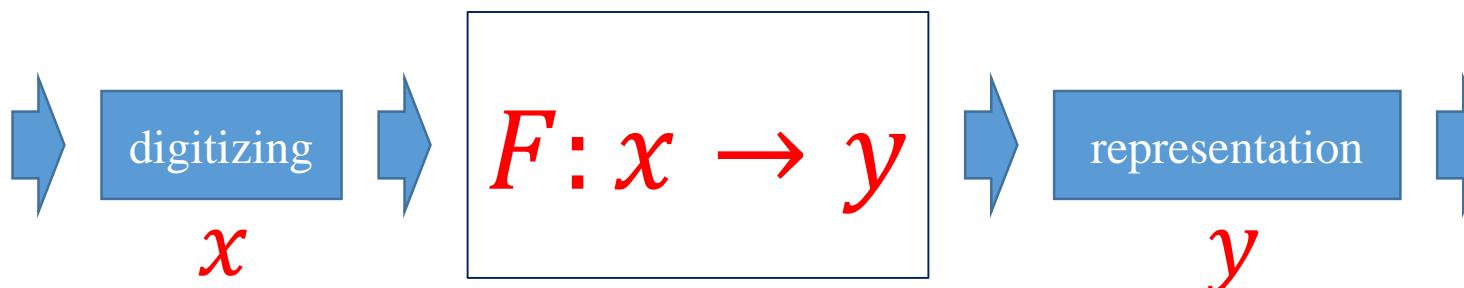
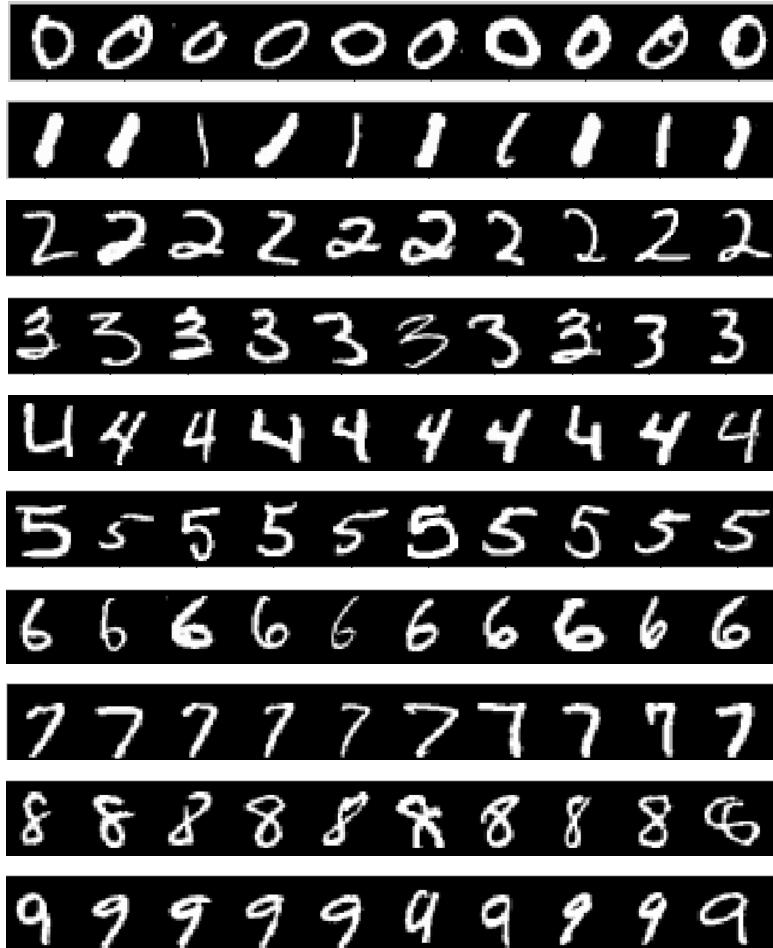


# Handwritten Digits Recognition



0  
1  
2  
3  
4  
5  
6  
7  
8  
9

# Handwritten Digits Recognition

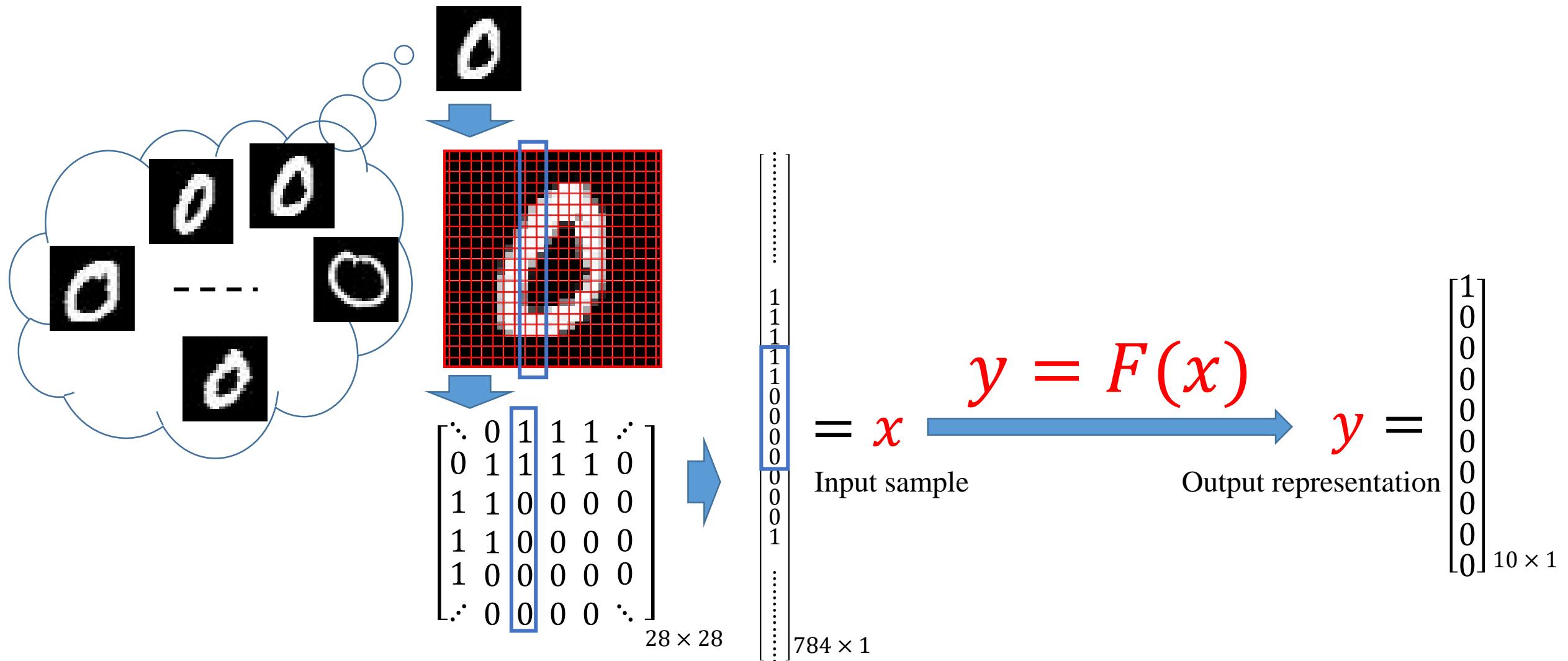


Problem:

How to construct the mapping  $F$ ?

0  
1  
2  
3  
4  
5  
6  
7  
8  
9

# Handwritten Digits Recognition



# Handwritten Digits Recognition

0000000000  
1111111111  
222222222222  
333333333333  
444444444444  
555555555555  
666666666666  
777777777777  
88888888888888  
99999999999999

00111111001

$$F: x \rightarrow y$$

$F$  is map, it maps from 784 dimensional space to 10 dimensional space.

# Handwritten Digits Recognition

A blue arrow pointing to the right, positioned below the equation  $x =$ .

$$y = F(x)$$

$y =$

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

## Problem:

How to construct the mapping  $F$  from 784 dimensional space to 10 dimensional space?

**It is almost impossible manually!**

Any other methods? Next, let's see how a child can easily do it.

# Outline

- Concept of artificial intelligence
- An example: handwritten digits recognition
- **How does a child recognize the handwritten digits**
- Introduction to brain structure
- Assignment
- Discussions

# How does a child recognize the handwritten digits?

0 0 0 0 0 0 0 0 0 0  
1 1 1 1 1 1 1 1 1 1  
2 2 2 2 2 2 2 2 2 2  
3 3 3 3 3 3 3 3 3 3  
4 4 4 4 4 4 4 4 4 4  
5 5 5 5 5 5 5 5 5 5  
6 6 6 6 6 6 6 6 6 6  
7 7 7 7 7 7 7 7 7 7  
8 8 8 8 8 8 8 8 8 8  
9 9 9 9 9 9 9 9 9 9

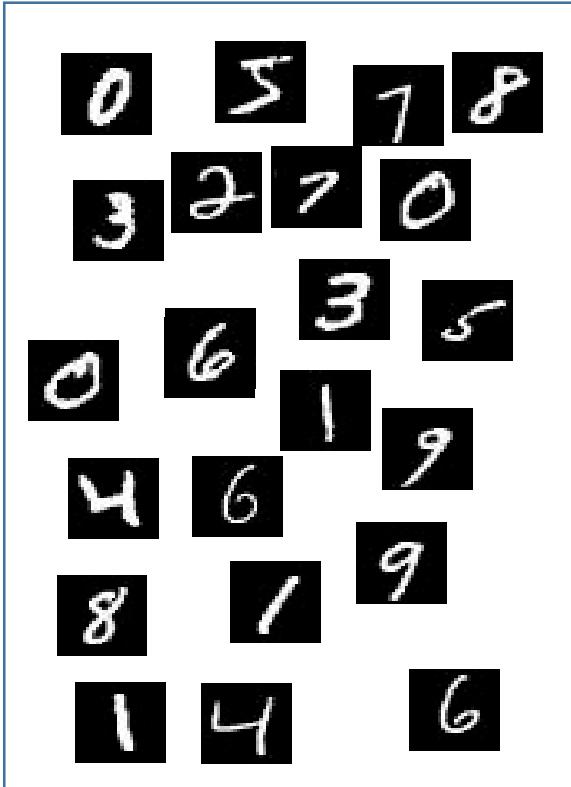


So easy!



0  
1  
2  
3  
4  
5  
6  
7  
8  
9

# How does a child recognize the handwritten digits?



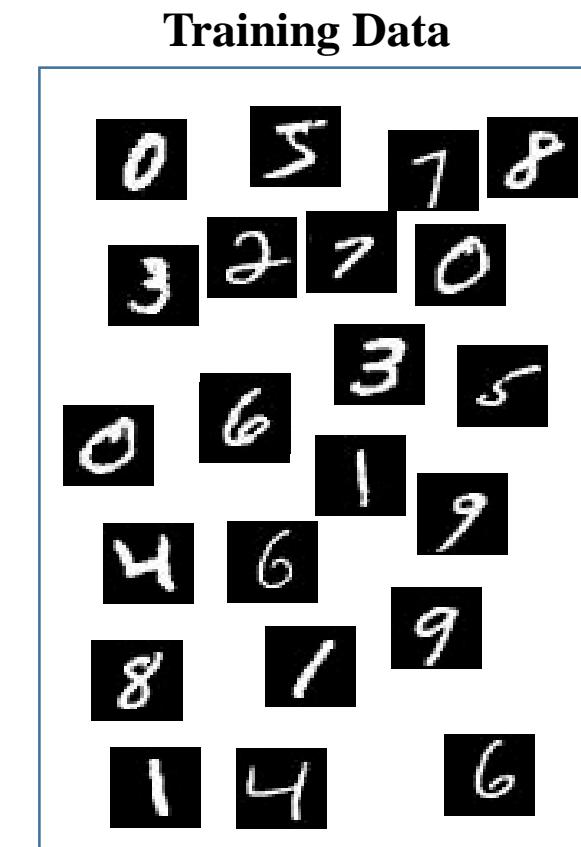
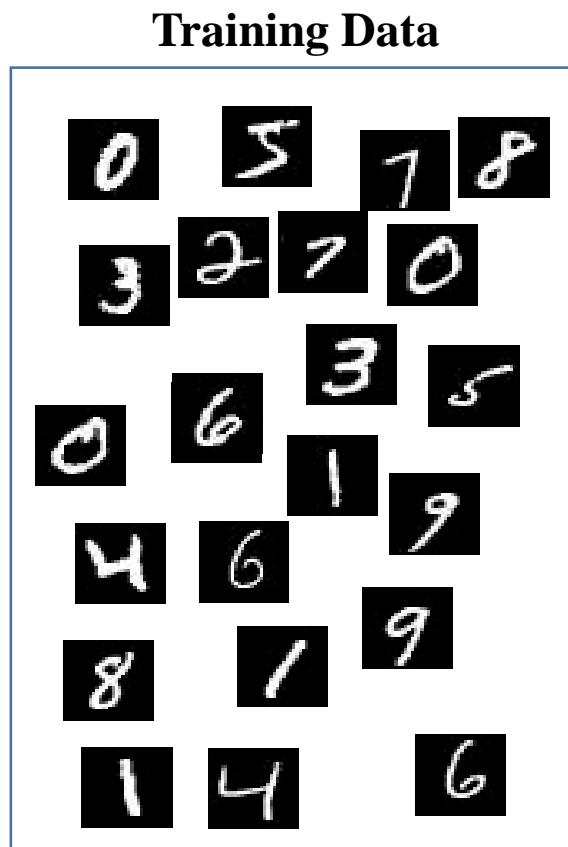
Training  
→



## Training Data Set

Training Data is a set of samples used during training.  
Each sample is a pair of digit image and its label.

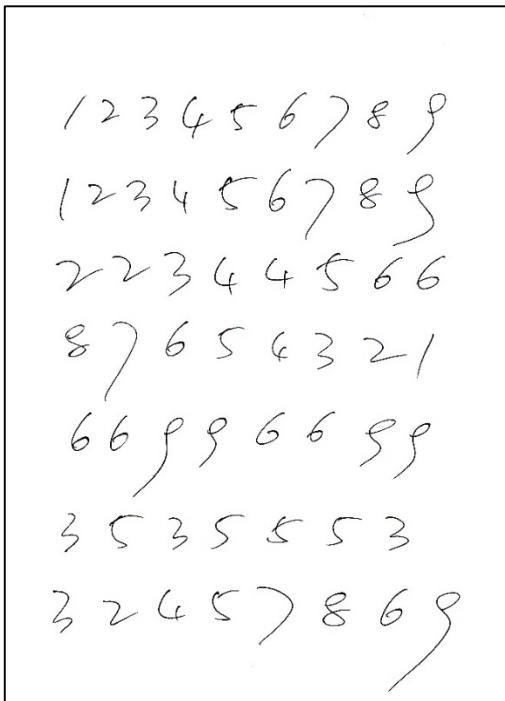
# How does a child recognize the handwritten digits?



Using Training Data for testing

**Under-fitting:** perform badly on training data set

# How does a child recognize the handwritten digits?



**Test Data Set**

Test Data is a set of samples used for testing.

Each sample is a pair of digit image and its label.

Note that, it is different from the training data.

Testing  
→

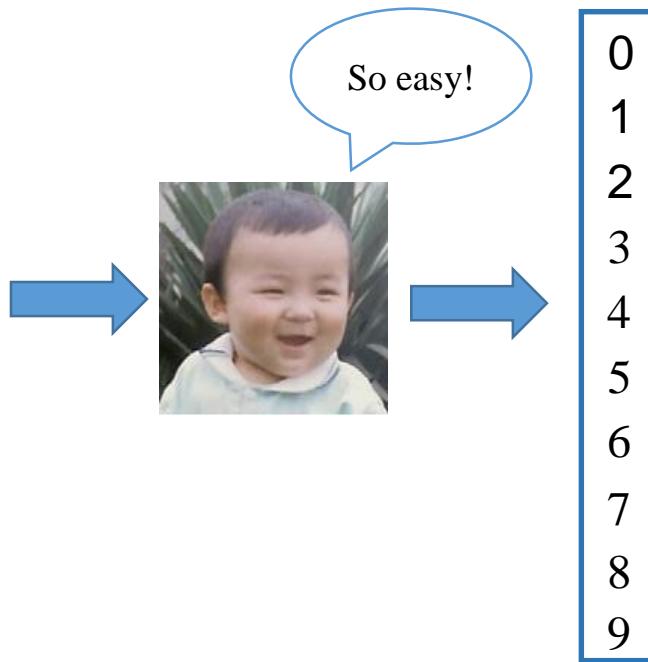


**Over-fitting:** perform very well on training data, but badly on test data

**Generation performance:** the performance on new data that hasn't been used during training

# How does a child recognize the handwritten digits?

0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 1 1
2 2 2 2 2 2 2 2 2
3 3 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4
5 5 5 5 5 5 5 5 5
6 6 6 6 6 6 6 6 6
7 7 7 7 7 7 7 7 7
8 8 8 8 8 8 8 8 8 8
9 9 9 9 9 9 9 9 9 9



The human brain is so powerful so that any child can recognize the handwritten digits easily. Two important factors:

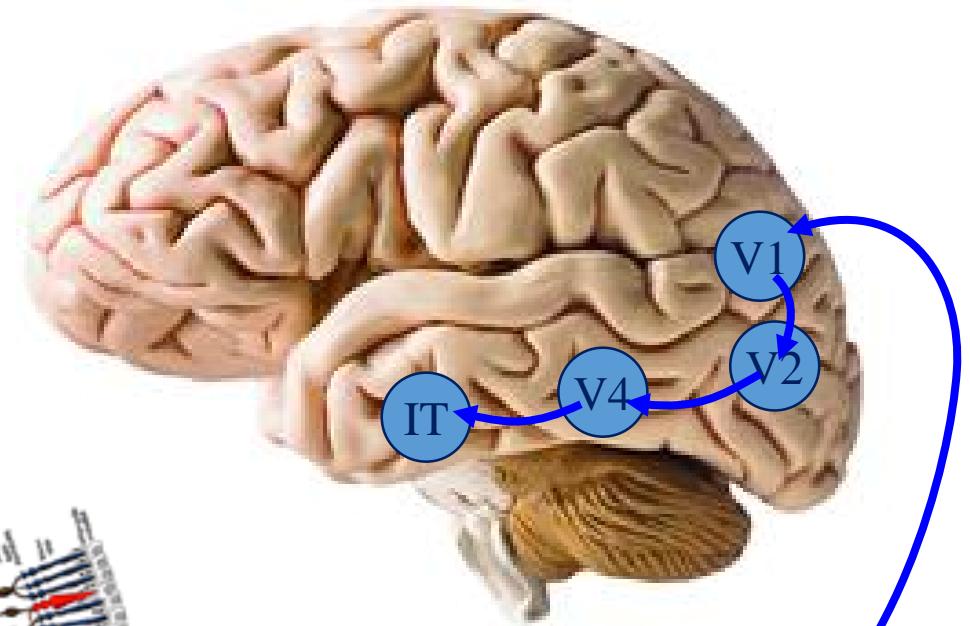
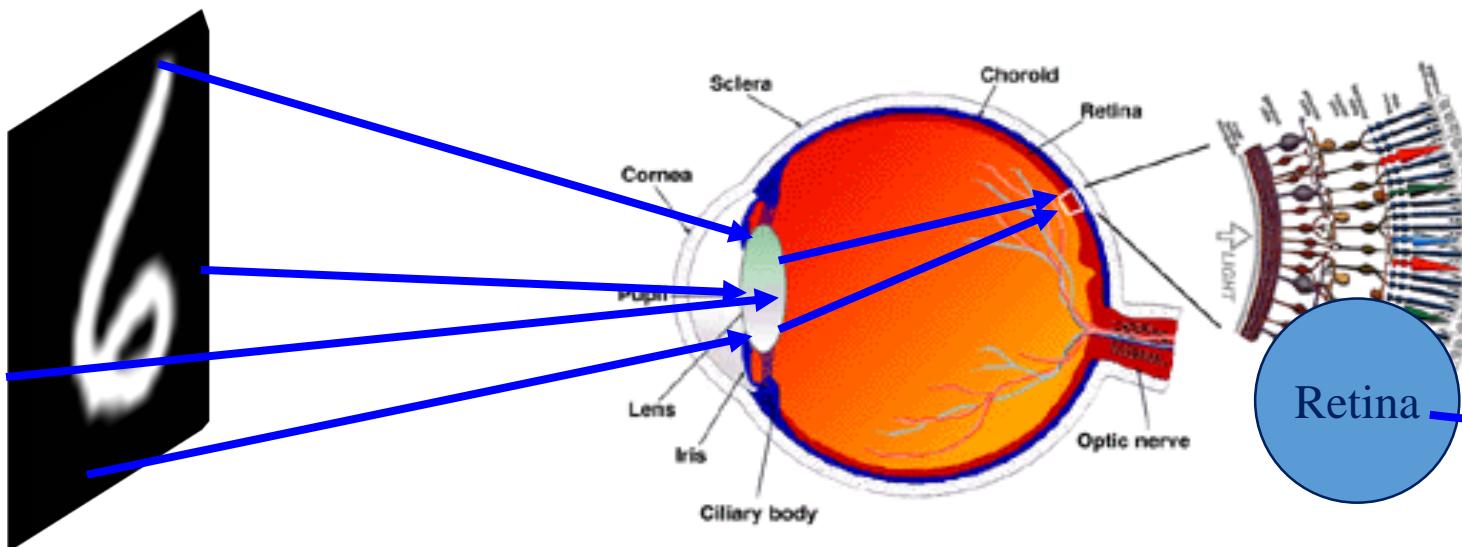
1. The brain has the structured ability.
2. Trained by some one.

**Problem: How to develop methods for recognition by exploring the brain?**

# How does a child recognize the handwritten digits?

A child can recognize the handwritten digits easily just because the brain is powerful.  
Exploring the brain plays important role.

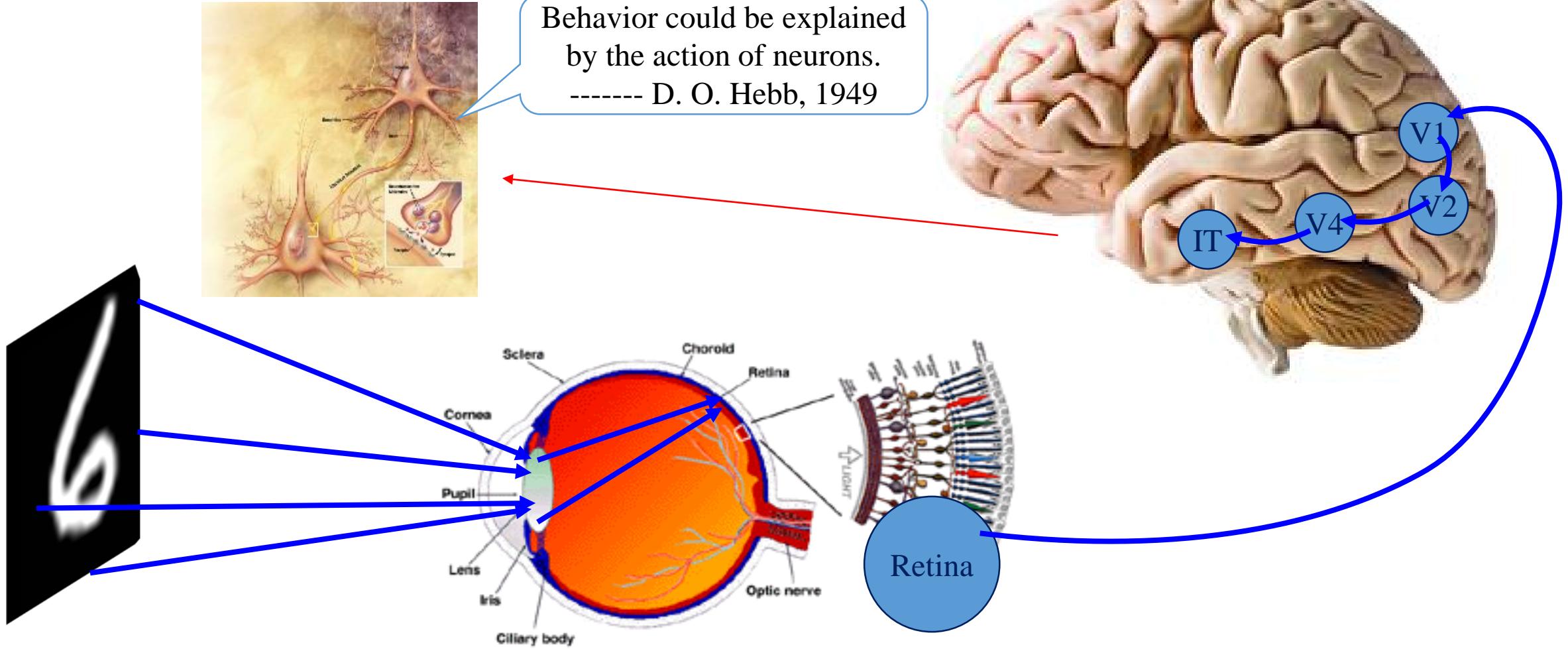
Next, a brief introduction to brain structure.



# Outline

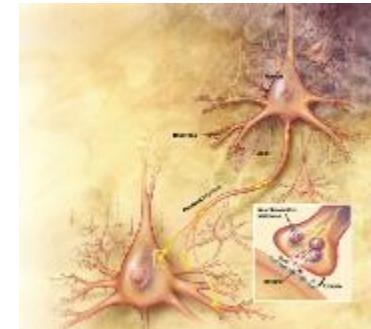
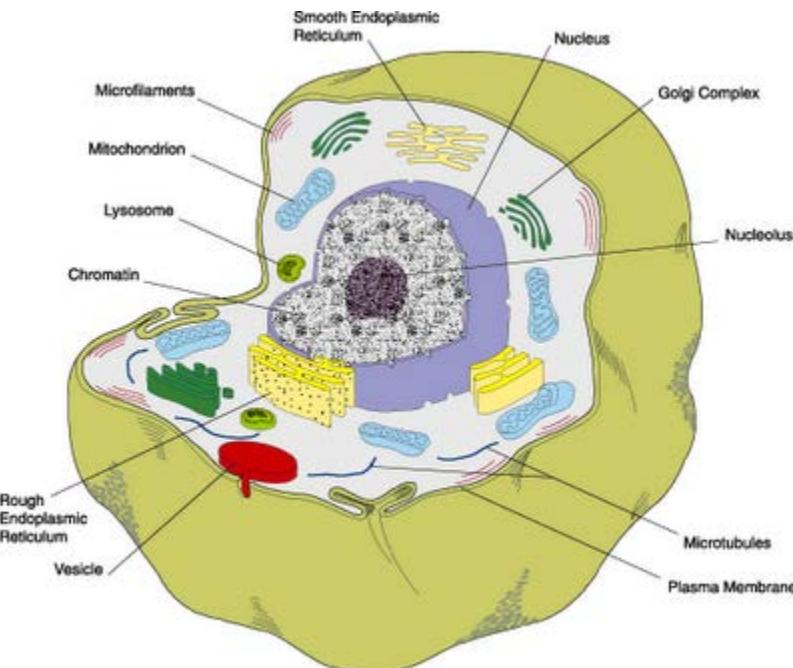
- Concept of artificial intelligence
- An example: handwritten digits recognition
- How does a child recognize the handwritten digits
- **Introduction to brain structure**
- Assignment
- Discussions

# Introduction to brain structure

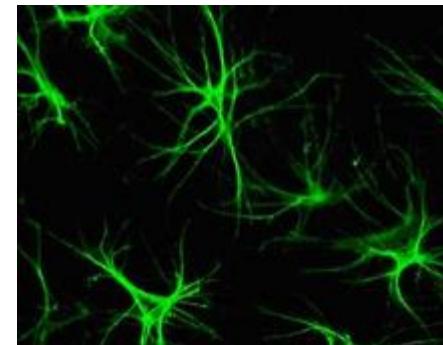


# Introduction to brain structure

- All tissues and organs in the body consist of cells.
- Cells in the nervous system: neurons and glia.



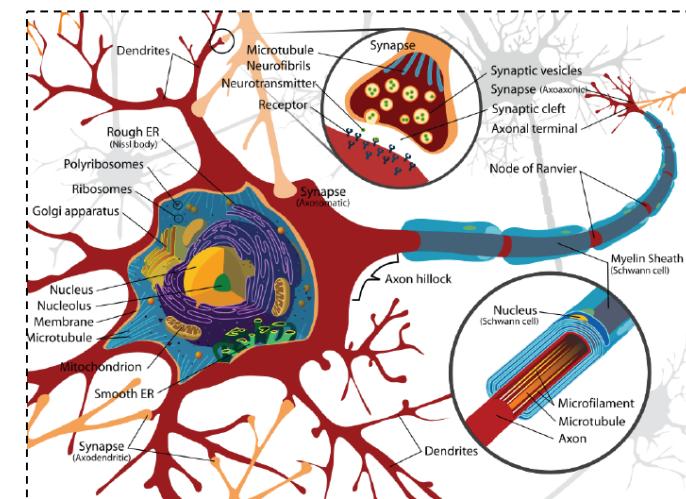
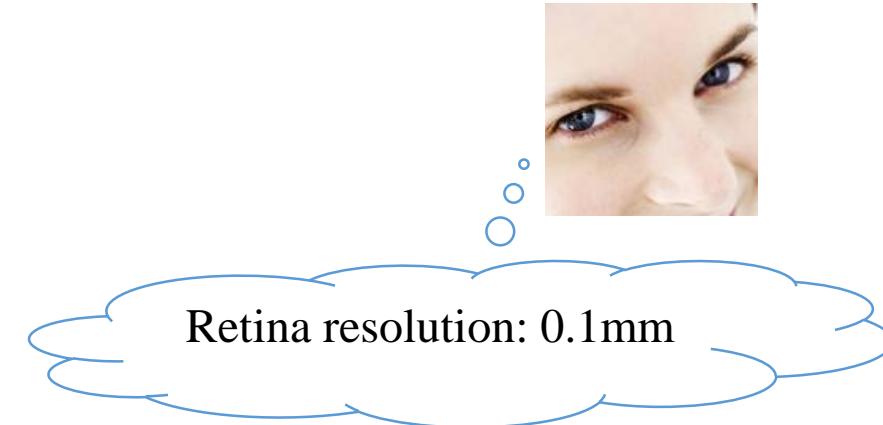
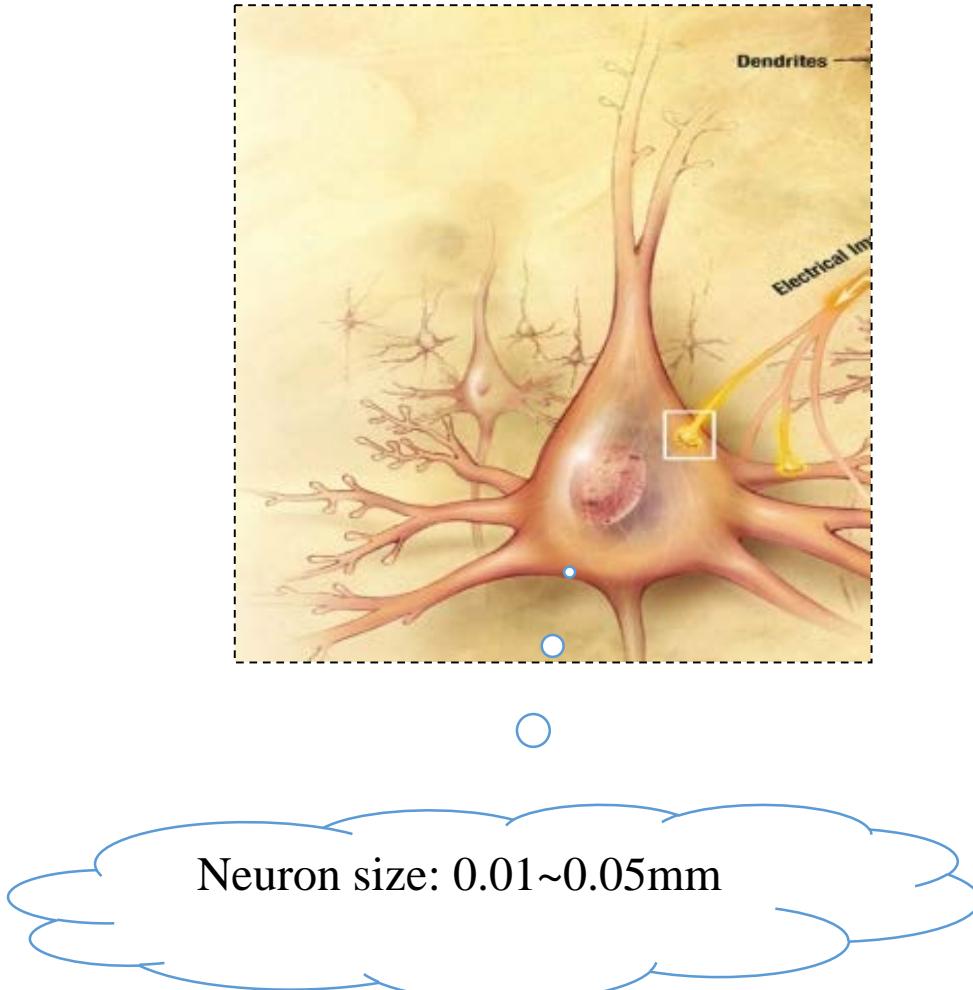
neurons



glia



# Introduction to brain structure



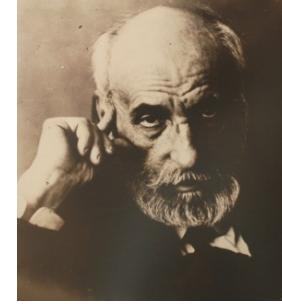
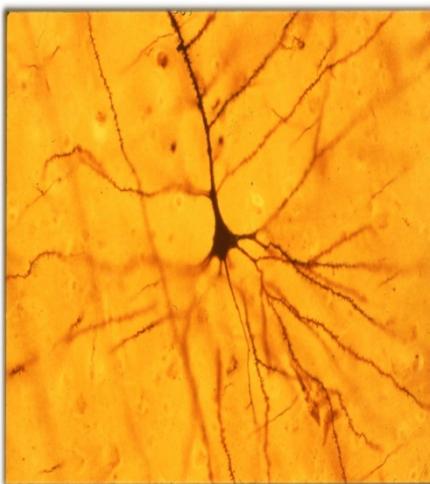
# Introduction to brain structure



Franz Nissl  
German, 19<sup>th</sup> century



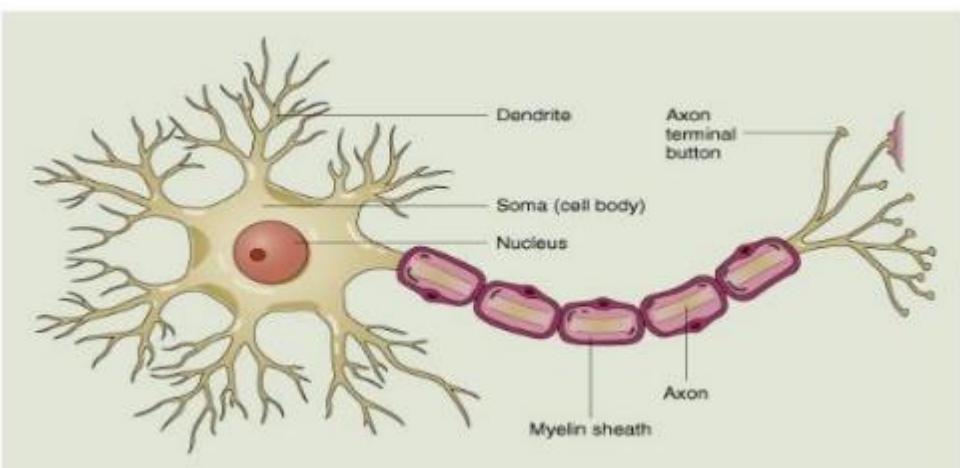
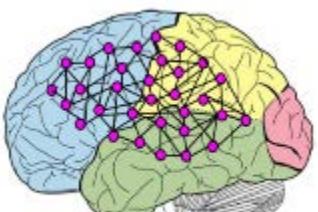
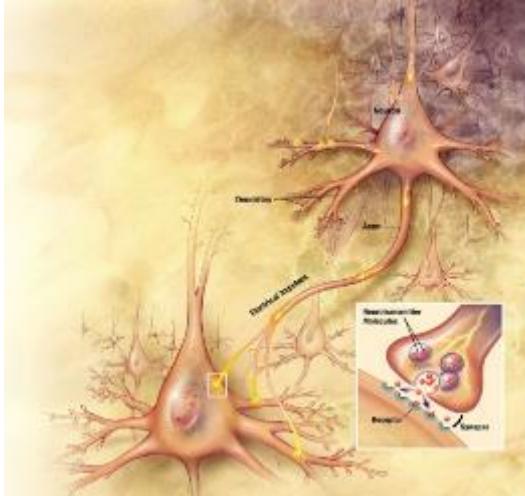
Camillo Golgi  
Italian, 19<sup>th</sup> century



Santiago Ramón Cajal  
Spanish, 19<sup>th</sup> century



# Introduction to brain structure



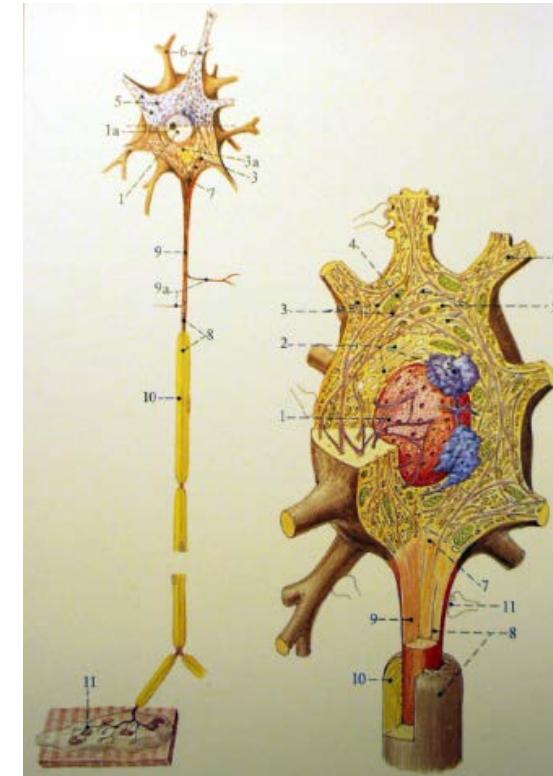
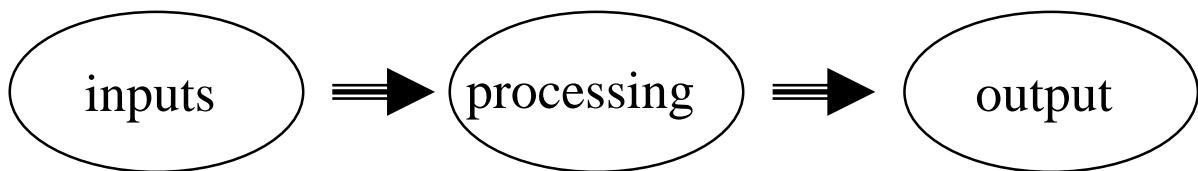
## What is a neuron?

- Three main components
  - Soma (cell body)
  - Dendrite
  - Axon
- A neuron is an electrically excitable cell in brain.
- Neuron processes and transmits information through electrical and chemical signals.

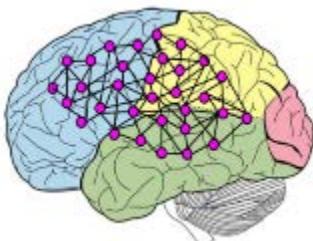
# Introduction to brain structure

## Brief statement of neuron

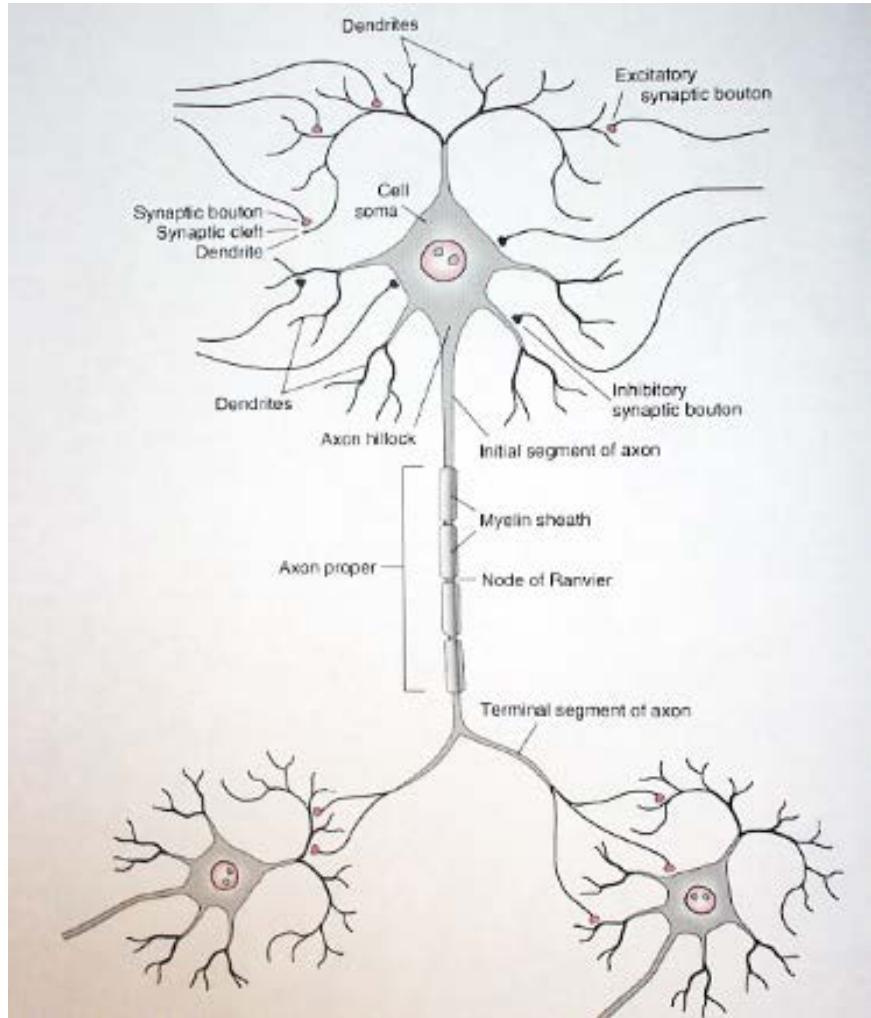
- Dendrites (inputs): receive chemical signals from other neurons.
- Soma (processing): collect and transfer and electrical signals.
- Axon (output): output signal to other neurons.



- A brain contains about  $10^{11}$  neurons



# Introduction to brain structure



Neural Network = Neurons + Connections

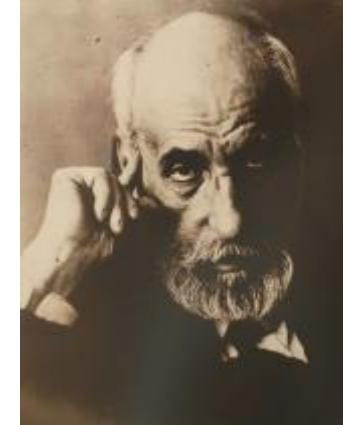
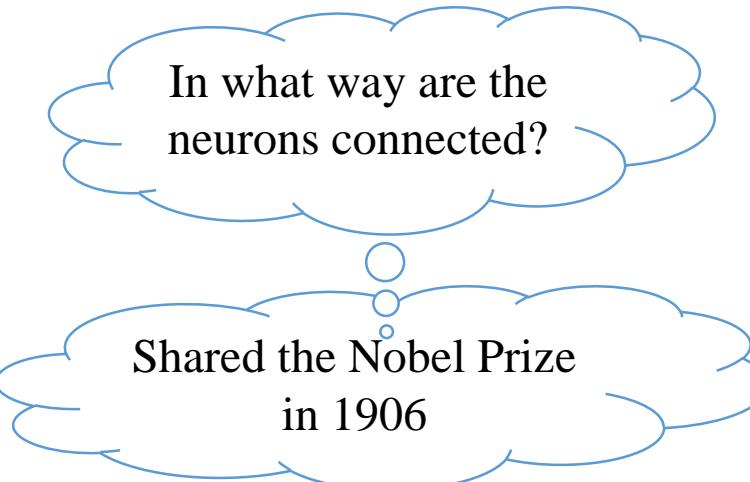
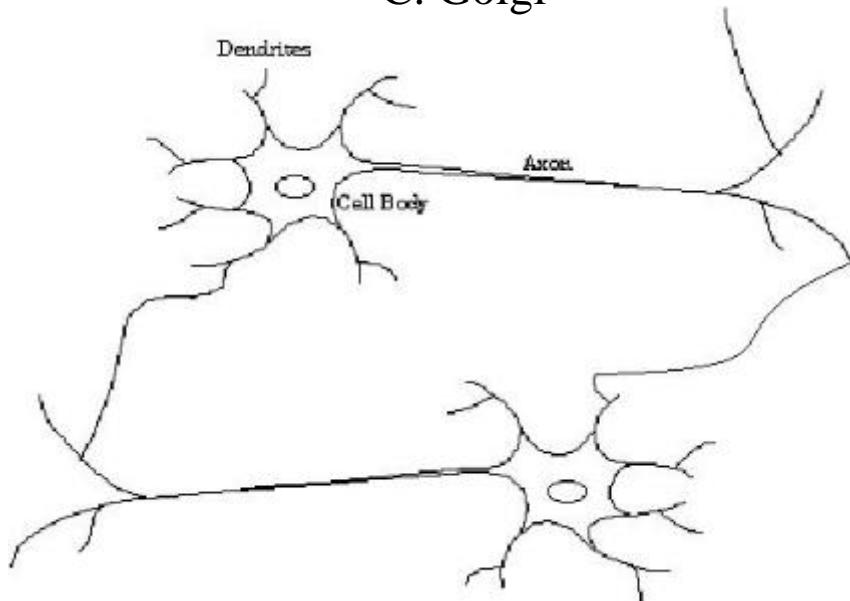
# Introduction to brain structure



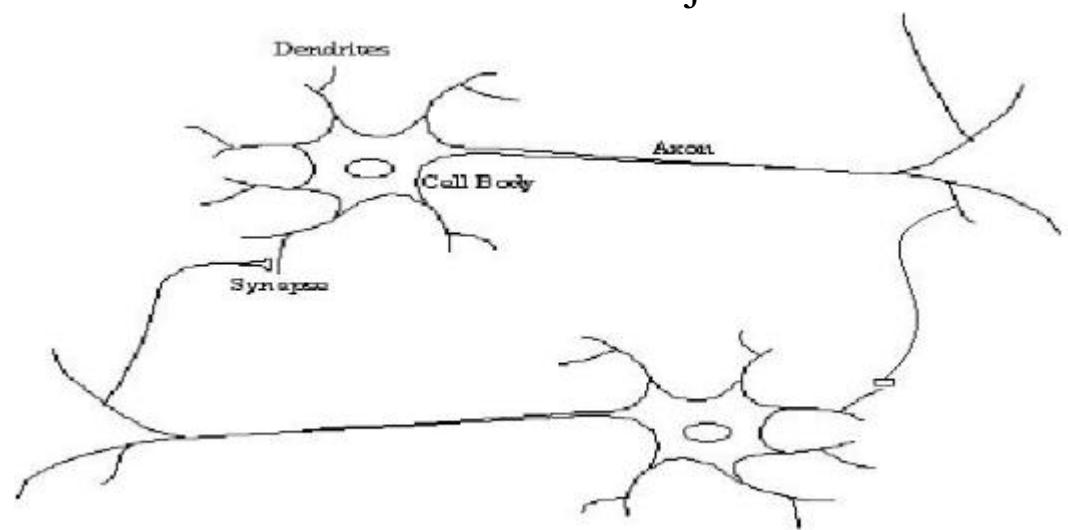
# Introduction to brain structure



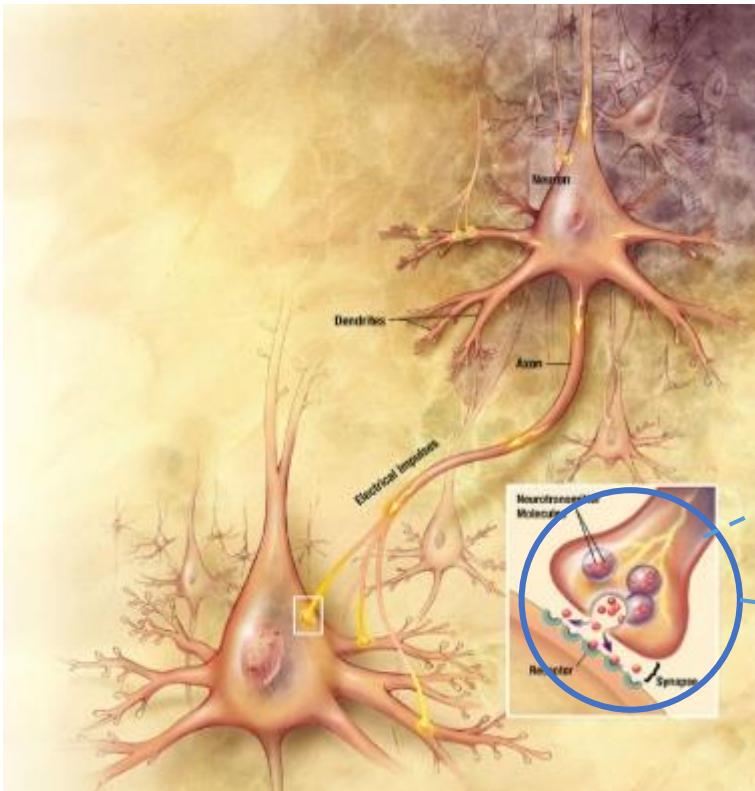
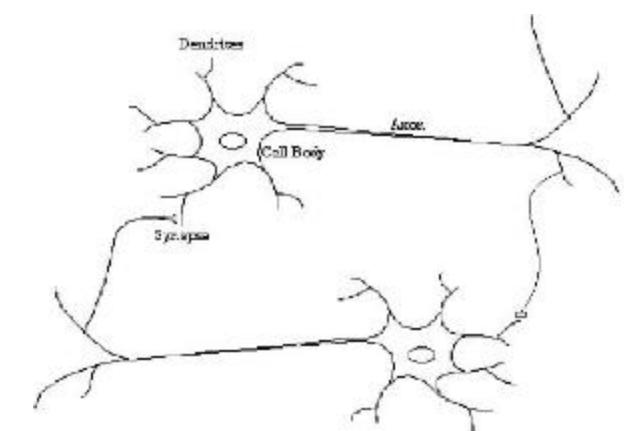
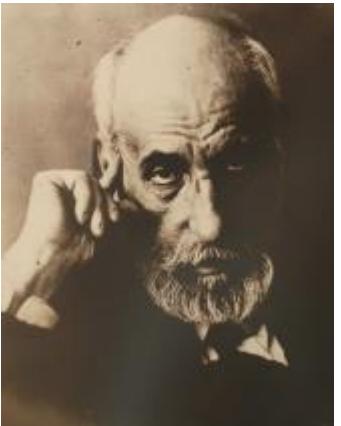
C. Golgi



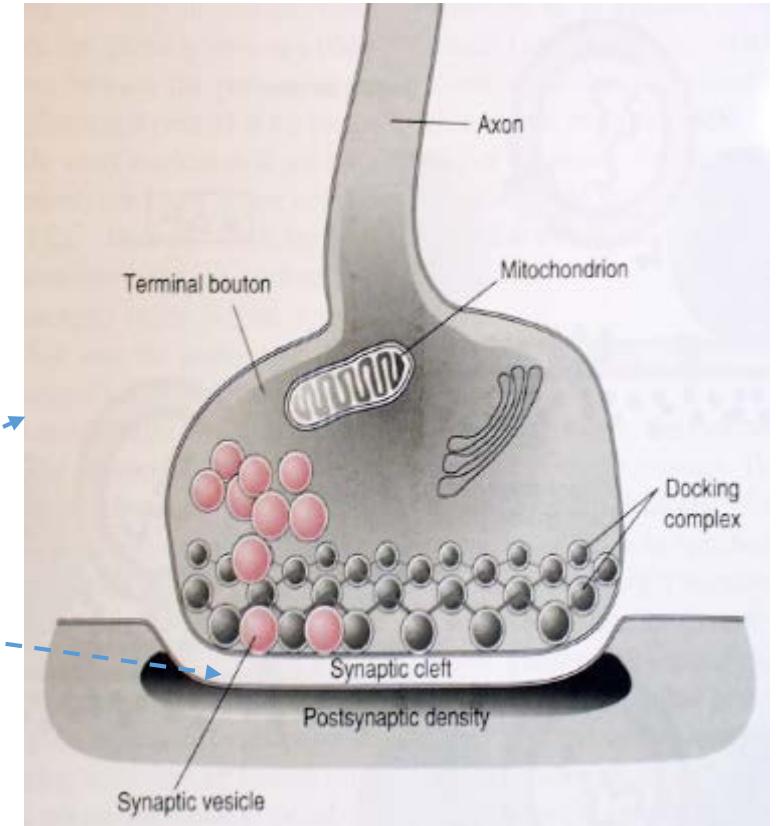
S. R. Cajal



# Introduction to brain structure



Synapse

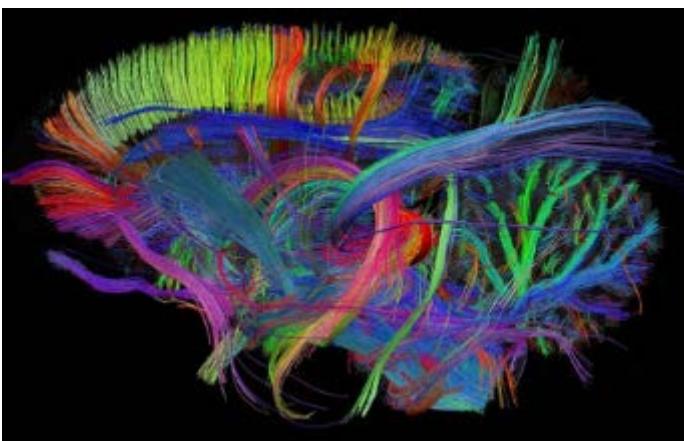
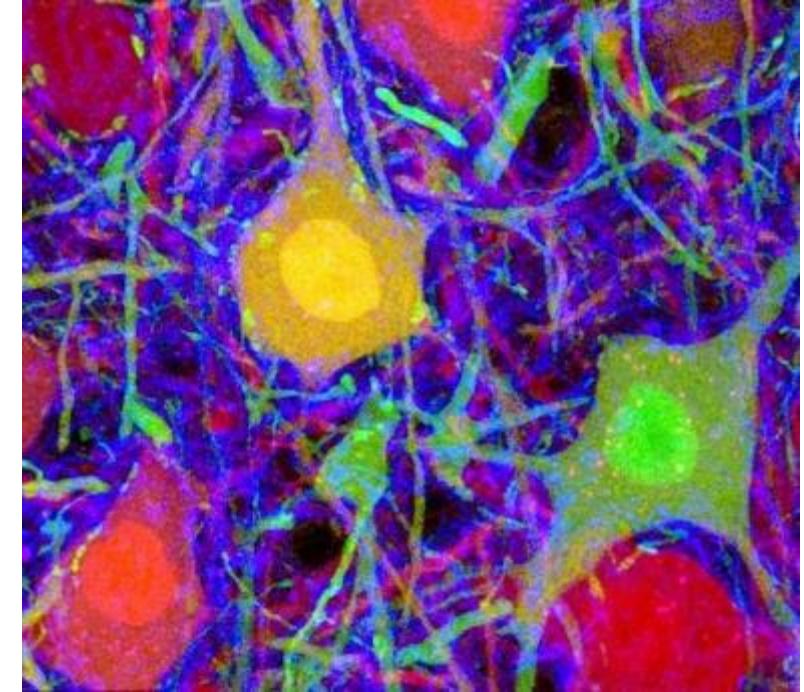
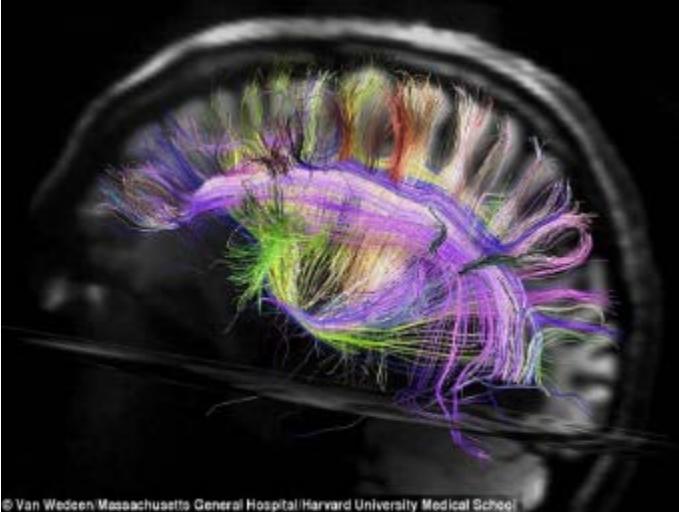


- A brain contains about  $10^{11}$  neurons
- Each neuron has about  $10^4$  connections

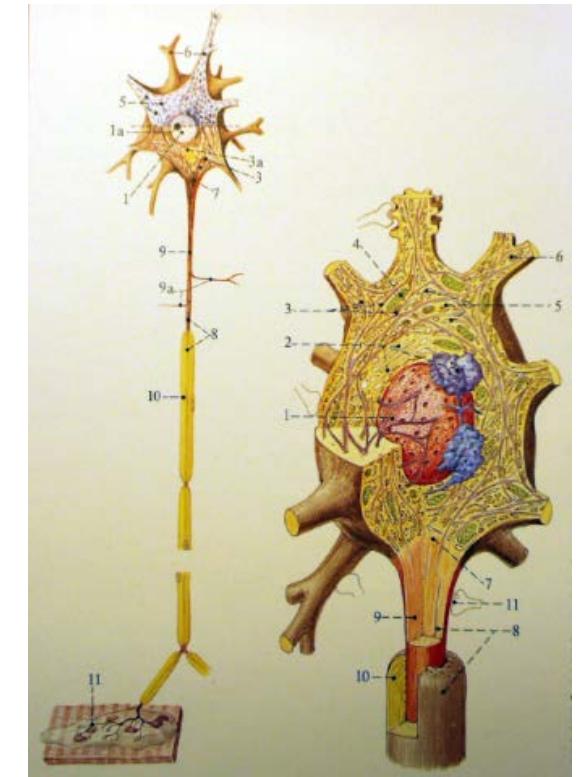
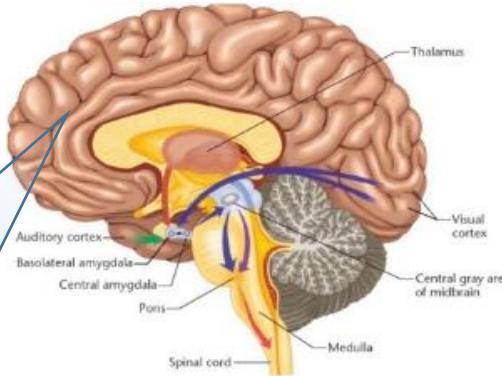
# Introduction to brain structure



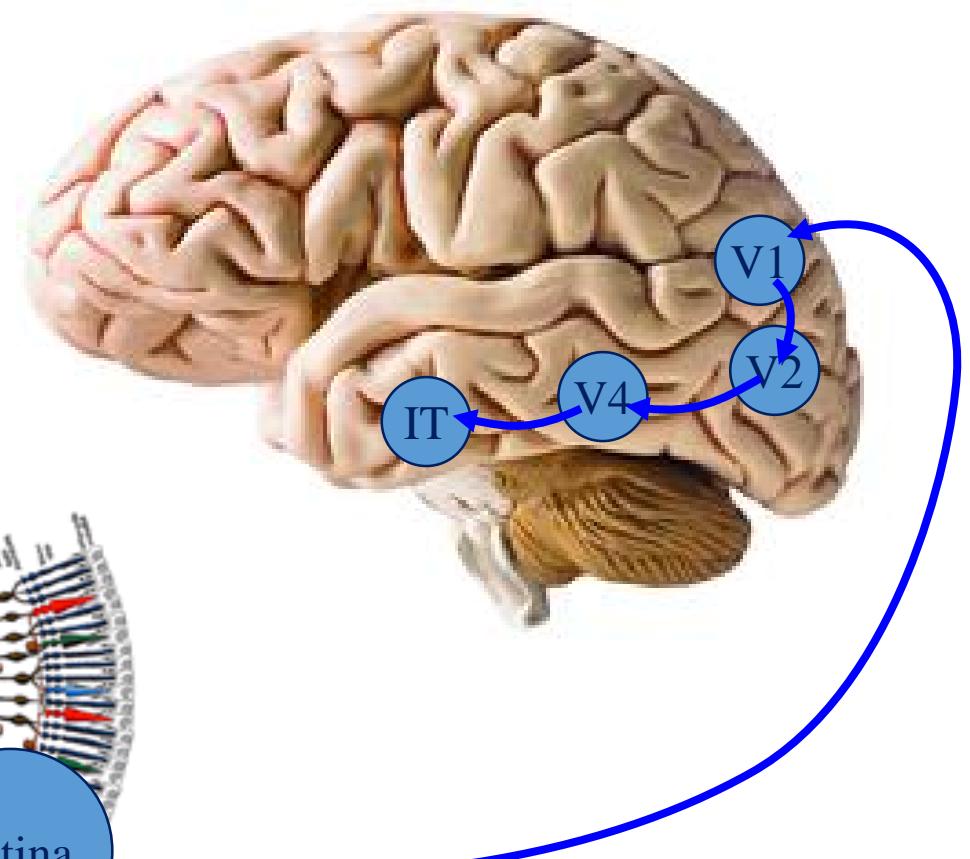
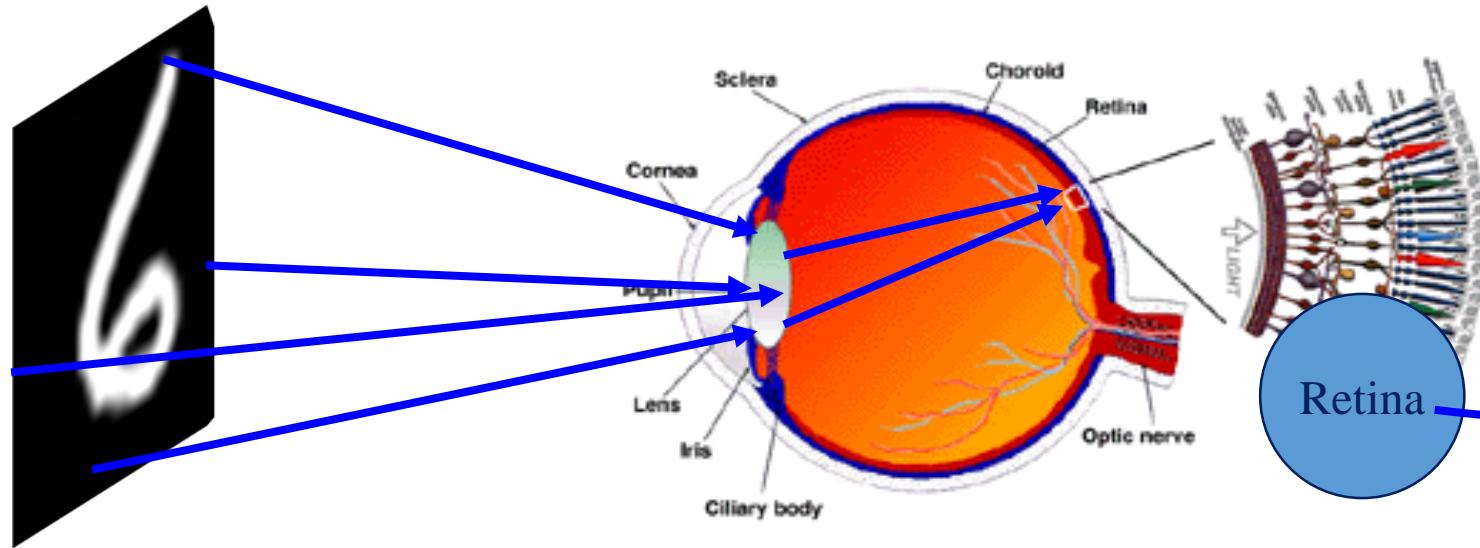
# Introduction to brain structure



# Introduction to brain structure

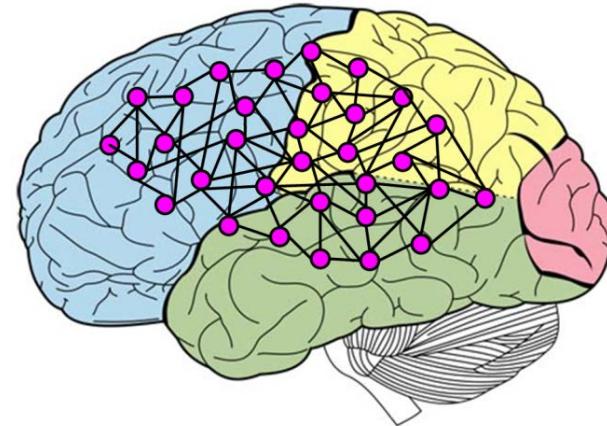


# Introduction to brain structure



# Introduction to brain structure

0 0 0 0 0 0 0 0 0  
1 1 1 1 1 1 1 1 1  
2 2 2 2 2 2 2 2 2  
3 3 3 3 3 3 3 3 3  
4 4 4 4 4 4 4 4 4  
5 5 5 5 5 5 5 5 5  
6 6 6 6 6 6 6 6 6  
7 7 7 7 7 7 7 7 7  
8 8 8 8 8 8 8 8 6  
9 9 9 9 9 9 9 9 9

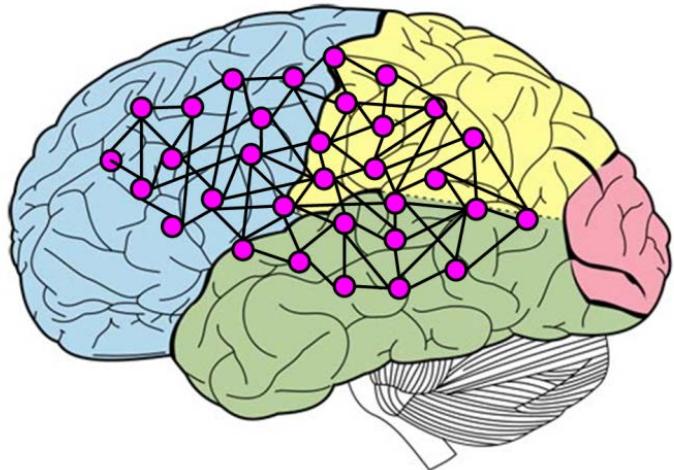


0  
1  
2  
3  
4  
5  
6  
7  
8  
9

## Problem:

- How to construct the computational model of brain?
- How to train the model of brain?  
How to develop the learning algorithm?

# Introduction to brain structure



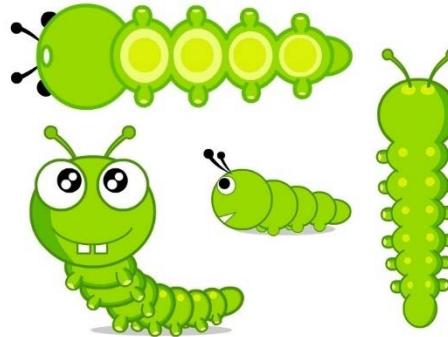
- What's next?
  - Constructing the network model.
  - Developing learning algorithm.

# Outline

- Concept of artificial intelligence
- An example: handwritten digits recognition
- How does a child recognize the handwritten digits
- Introduction to brain structure
- Assignment
- Discussions

# Assignment

Suppose there are photos of two classes of worms:  
doted worms and smooth worms.



Doted worms



Smooth worms



# Assignment

The photos of these worms can be digitized as:

Doted worms

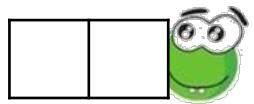


$$\begin{bmatrix} 0 \\ 1 \end{bmatrix}$$



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

Smooth worms



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

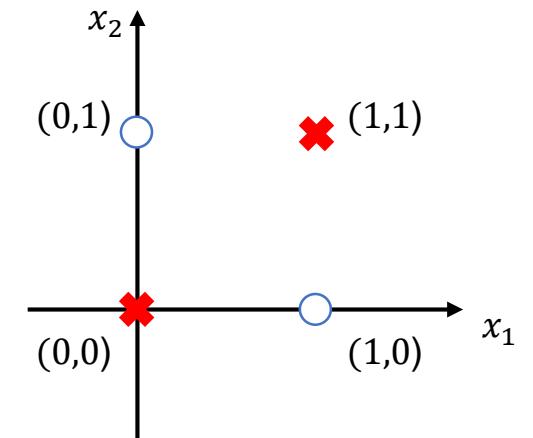


$$\begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

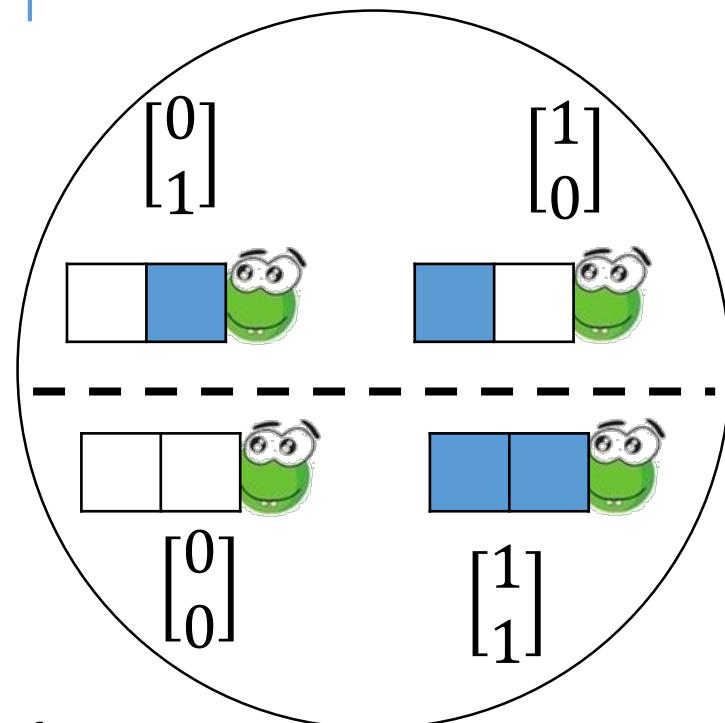
These two classes can be labeled as 1 for doted worms and 0 for smooth worms, respectively.

1

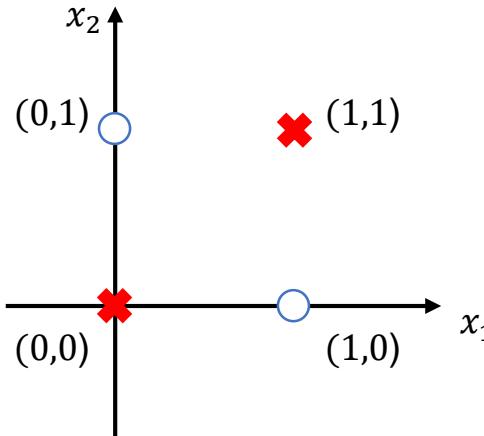
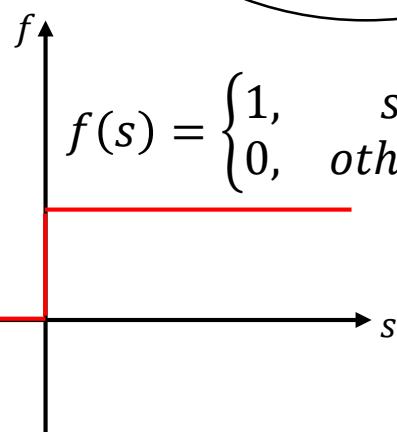
0



# Assignment



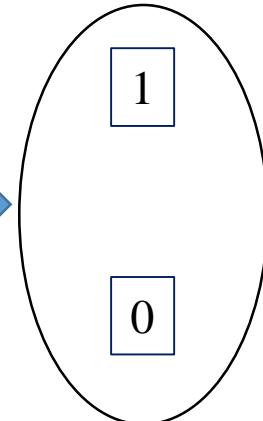
$$f(s) = \begin{cases} 1, & s \geq 0 \\ 0, & \text{otherwise} \end{cases}$$



Classification for this two classes can be called as XOR-Worms problem.

We can construct a function to classify these two classes.

$$F\left(\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}\right) = f[f(2x_1 + 2x_2 - 1) + f(-x_1 - x_2 + 1.5) - 1.5]$$



$$F\left(\begin{bmatrix} 0 \\ 1 \end{bmatrix}\right) = f[f(2 \cdot 0 + 2 \cdot 1 - 1) + f(-0 - 1 + 1.5) - 1.5] = 1$$

$$F\left(\begin{bmatrix} 1 \\ 1 \end{bmatrix}\right) = f[f(2 \cdot 1 + 2 \cdot 1 - 1) + f(-1 - 1 + 1.5) - 1.5] = 0$$

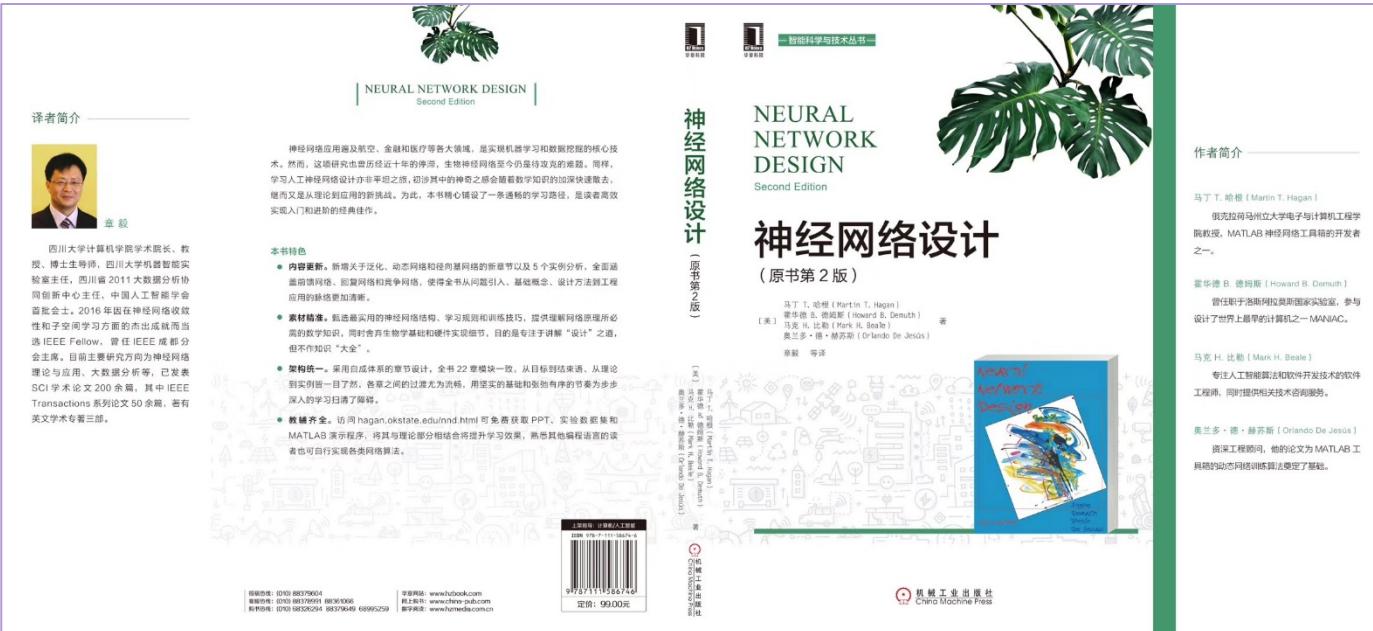
Please implement the XOR-Worms problem classification by using MATLAB.

# Outline

- Concept of artificial intelligence
- An example: handwritten digits recognition
- How does a child recognize the handwritten digits
- Introduction to brain structure
- Assignment
- **Discussions**

# Discussions

## Reference Books



# Discussions

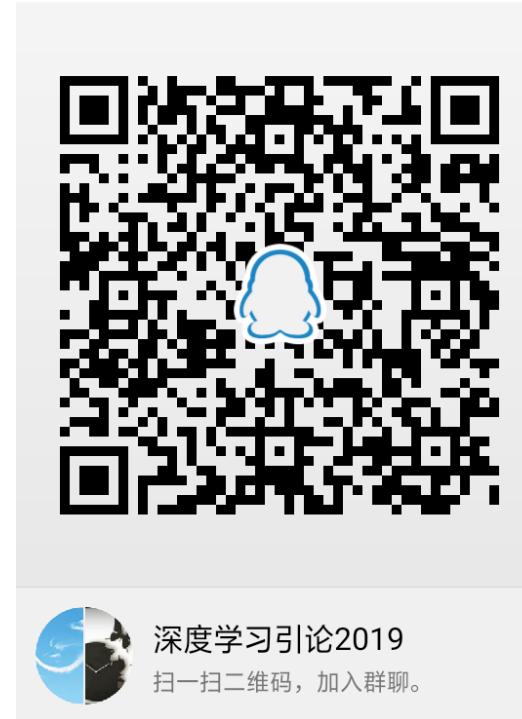
TAs



Tao He



Lei Xu



<http://www.machineilab.org/>

<http://www.machineilab.org/users/zhangyi/index.html>

*Thanks*