# Pattern Information Processing

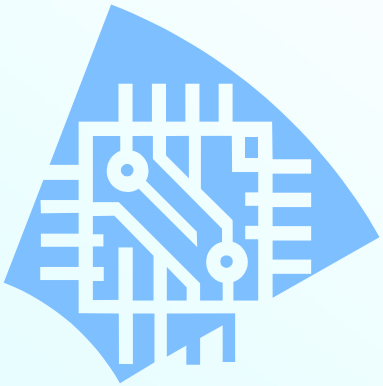
Masashi Sugiyama
(Department of Computer Science)

Contact: W8E-505
sugi@cs.titech.ac.jp

# Contents of This Lecture (1)

What I will provide in this course:

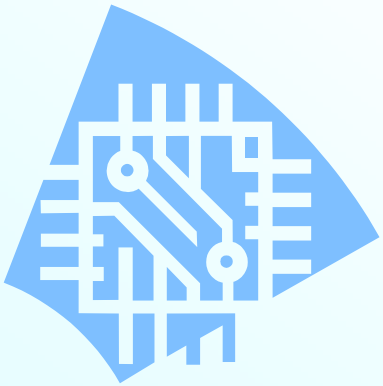
- Brief overview of the field of pattern information processing.
- Some state-of-the-art methods of statistical machine learning.



# Contents of This Lecture (2)

What you should learn in this course:

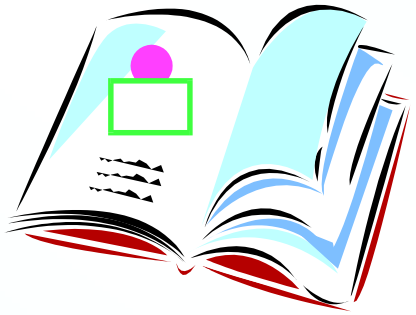
- How to utilize the learned materials in your own research.
- How to create novel research topics.



# About Syllabus (1)

Original syllabus：

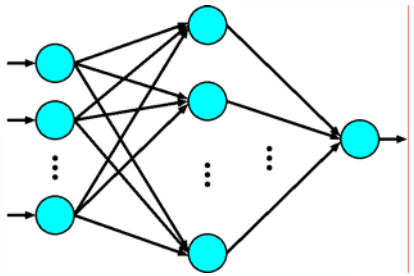
Human beings can process ambiguous data in a non-logical fashion. In this lecture, we learn mathematical neural network models for processing numerical, vague, or non-symbolic information.



# About Syllabus (2)

This year:

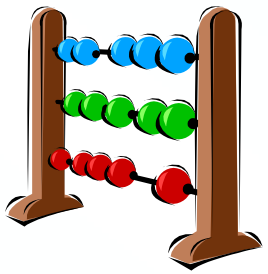
- We do not restrict ourselves to neural network models.
- We learn various state-of-the-art learning models that are useful and interesting for computer scientists and engineers.



# Brief Overview of the Course (1)

3 topics in learning research

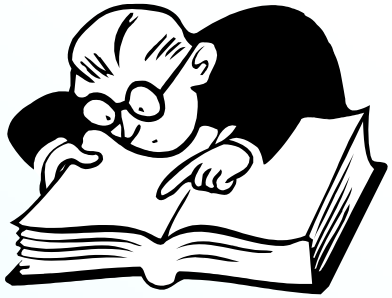
- Understanding human brains
- Developing learning machines
- Clarifying essence of learning mathematically

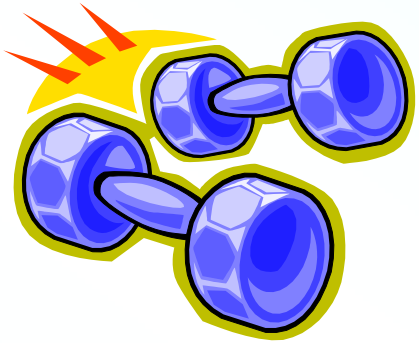


# Brief Overview of the Course (2)

3 types of learning

- Supervised learning
- Unsupervised learning
- Reinforcement learning

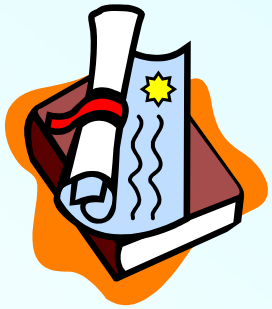




# Brief Overview of the Course (3)

- 3 key theories of supervised learning
  - Learning methods
  - Model selection
  - Active learning

# Grading

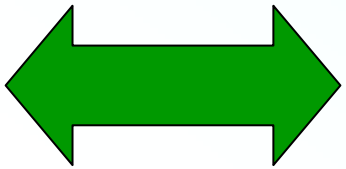


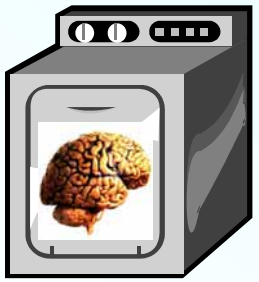
- Small reports
  - 2-3 times
  - Deadline: 1 week
- Final reports
  - Reading papers on pattern information processing, proposing of your own research project, etc.
  - Deadline: February 10, 2005 at 5 PM.

# Textbook

- Handouts are provided if necessary

# 3 Topics in Learning Research



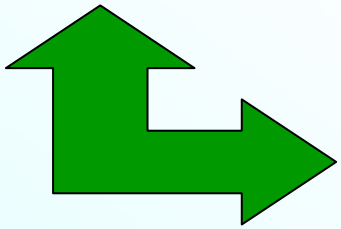


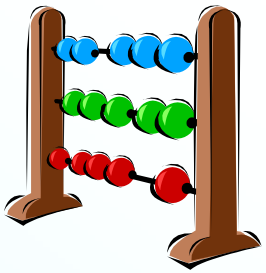
Understanding the brain

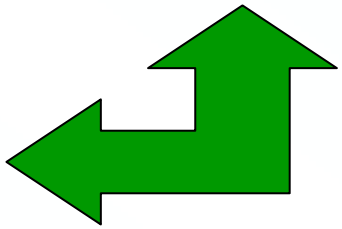
(physiology, psychology, neuroscience)

Developing learning machines

(computer and electronic engineering)







Clarifying learning mathematically

(computer and information science)

# Understanding the Brain (1)

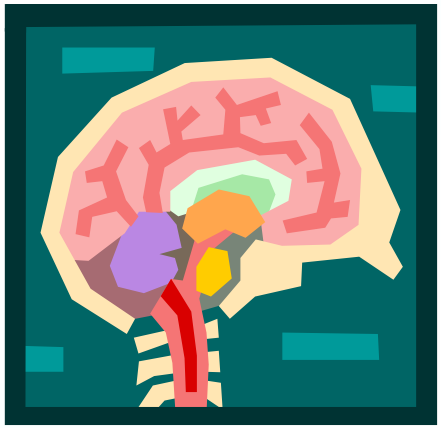
- Our brain consists of tens of billion neurons.
- Neurons are connected each other like a network.

# Understanding the Brain (2)

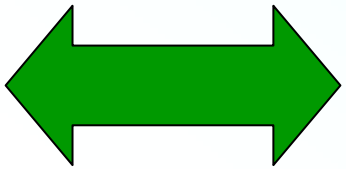
- Each neuron has dendrites and axons, and the axon connects to other neurons via synapses.
- Neurons receive signals from other neurons through dendrites and send signals through axons.

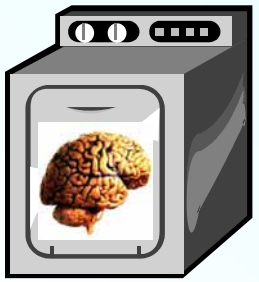
# Understanding the Brain (3)

- Structures and mechanisms of the brain have been clarified considerably.
- However, it is not still clear how learning is carried out with a number of neurons.



# 3 Topics in Learning Research



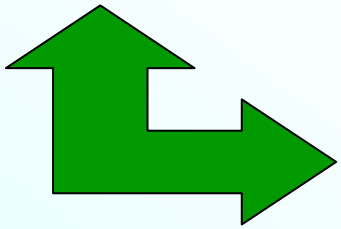


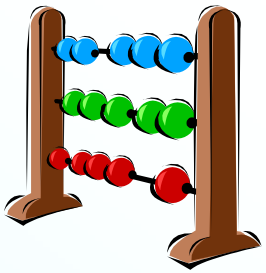
Understanding the brain

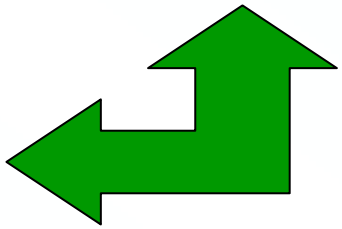
(physiology, psychology, neuroscience)

Developing learning machines

(computer and electronic engineering)





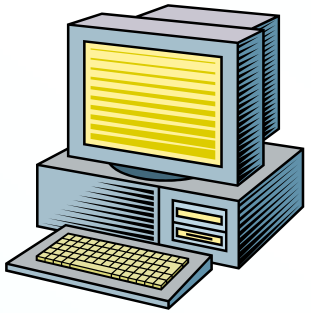


Clarifying learning mathematically

(computer and information science)

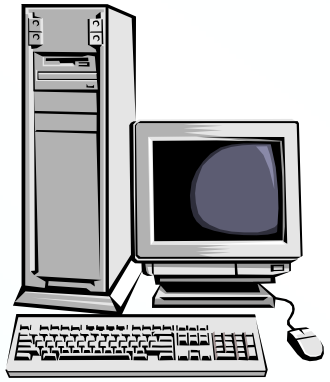
# Developing Learning Machines (1)

- Computers we are usually using are called the von Neumann-type.
- Computing principles are based on logical computation and symbol processing.
- Computational theories of Turing machines play central roles.



# Developing Learning Machines (2)

- Suitable for repeating simple straightforward calculation or processing the data following prescribed procedures.
- However, even state-of-the-art computers are inferior to babies in complex tasks such as recognizing humans' faces



# Developing Learning Machines (3)

- Recently, a computer that imitates the information processing carried out in our brains is being developed (neurocomputer).

# Developing Learning Machines (4)

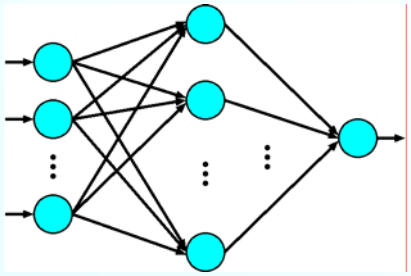
We want neurocomputes to equip the following functions:

- They are adaptable to new environments, i.e., we do not have to prescribe responses for all possible situations.
- They can process vague, noisy, and contradictory information.

# Developing Learning Machines (5)

We want neurocomputes to equip the following functions:

- They consist of a number of artificial neurons and each neuron works independently.
- They are robust against noise, especially, faults of other neurons.
- They are small and efficient in electricity consumption.



# Developing Learning Machines (6)

- Several realizations of neurocomputers with electronic or optical circuits have been proposed.

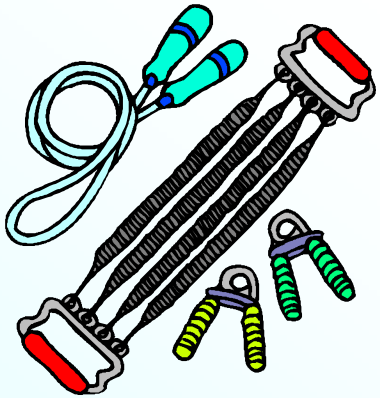
  Pulse Density Modulating Digital Neural Network System developed by University of Tsukuba

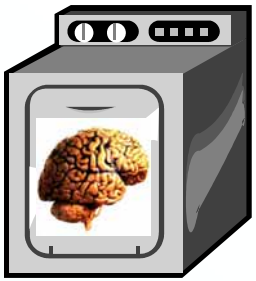
**See http://www.viplab.is.tsukuba.ac.jp/~hirai/PDM/index.html**

# Developing Learning Machines (8)

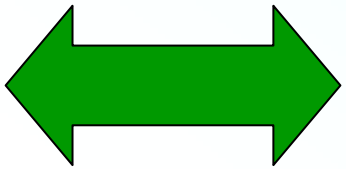
However, current neurocomputers have the following problems:

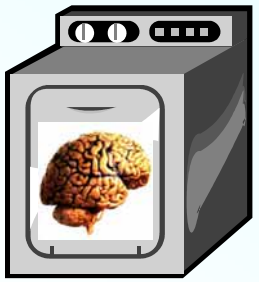
- The number of neurons are not so large.
- Size is big.
- It is not clear how to train the computer!!





# 3 Topics in Learning Research



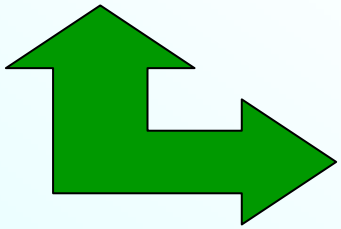


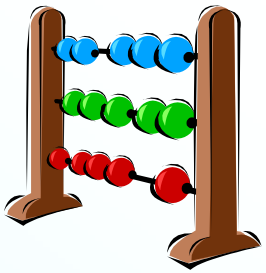
Understanding the brain

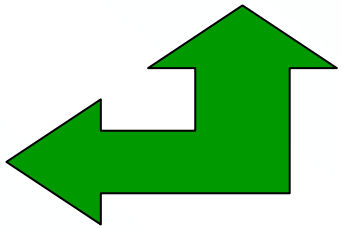
(physiology, psychology, neuroscience)

Developing learning machines

(computer and electronic engineering)





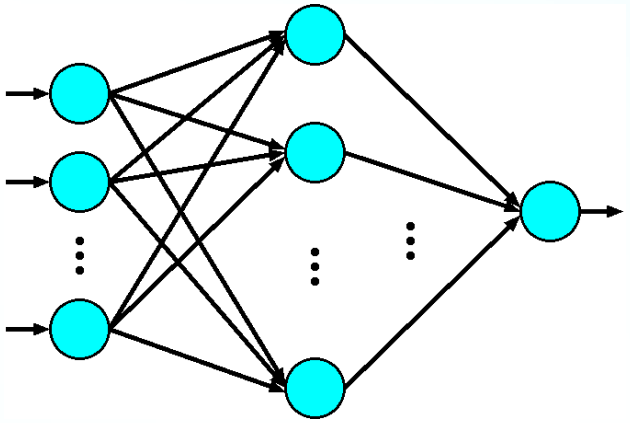


Clarifying learning mathematically

(computer and information science)

# Clarifying Learning Mathematically (1)

- In order to understand our brains and develop neurocomputers, we have to clarify how information is processed with a number of neurons.

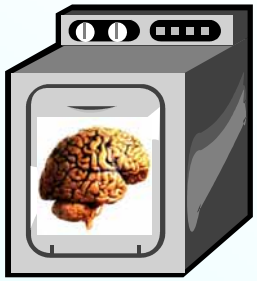


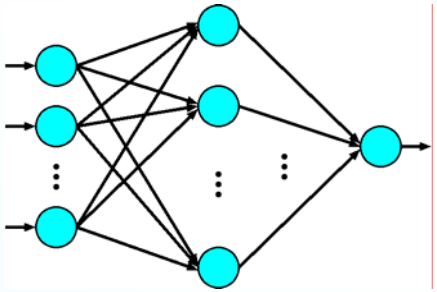
# Clarifying Learning Mathematically (2)

- Our brains have been formed through longtime evolution so they do not necessarily have the optimal structure.
- When developing learning machines, their architecture should be computer-scientifically suitable, rather than just imitating humans' brain.

# Clarifying Learning Mathematically (3)

- Rather than restricting ourselves to neural network models, we have to develop learning theories for various models that are useful in computer science and engineering.





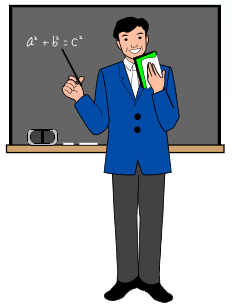
# Clarifying Learning Mathematically (4)

Mathematical tools for clarifying essence of learning

- Mathematical statistics
- Functional analysis
- Algebraic geometry
- Information geometry
- Statistical physics
- etc.

# We Have Learned …

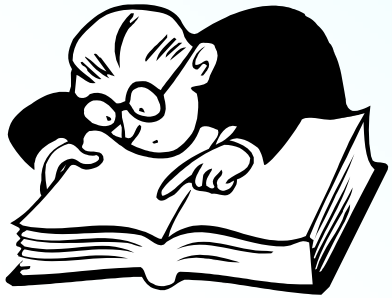
- There are 3 topics in learning research.
  - Understanding human brains
  - Developing learning machines
  - Clarifying essence of learning mathematically
- The third topic (Theories of learning) plays an important role for achieving the first two goals.



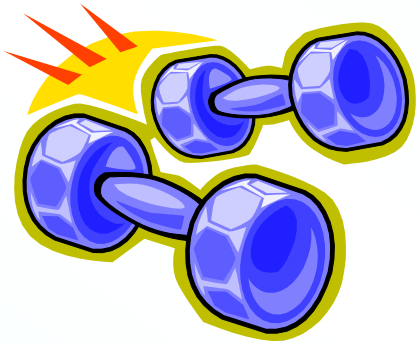
# Three Types of Learning

- Supervised learning

- Unsupervised learning

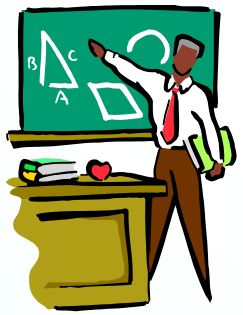


- Reinforcement learning



# Supervised Learning (1)

- The goal of supervised learning is to estimate an unknown rule.
- You are allowed to ask questions to the teacher who knows the rule, and the teacher answers your questions using the rule.



# Supervised Learning (2)

- Pairs of questions and answers are called the training examples.
- If the underlying rule can be successfully estimated, we can answer to the questions that we have never taught.
- Such an ability is called the generalization capability.

# Supervised Learning (3)

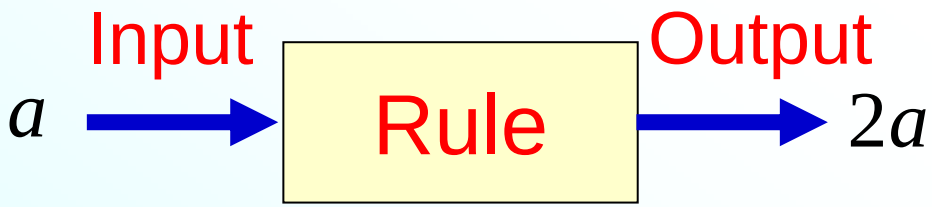
Example 1:

- Questions to the teacher are 2,4, and 7.
- The teacher taught us the answers 4, 8, and 14.
- From the training examples

  {(2,4),(4,8), (7,14)},

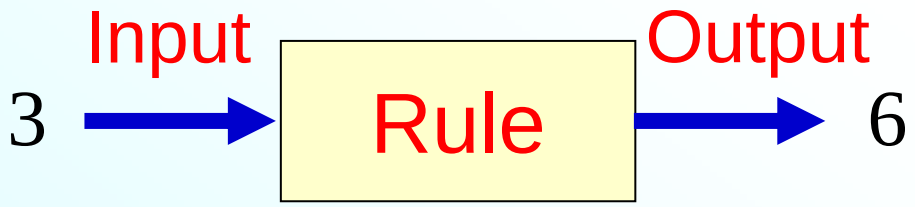
  we estimate the rule

  answer=question x 2



# Supervised Learning (4)

- Using the estimated rule, we can answer to the question that we have never learned.
- For example, for question 3, the answer is 6.



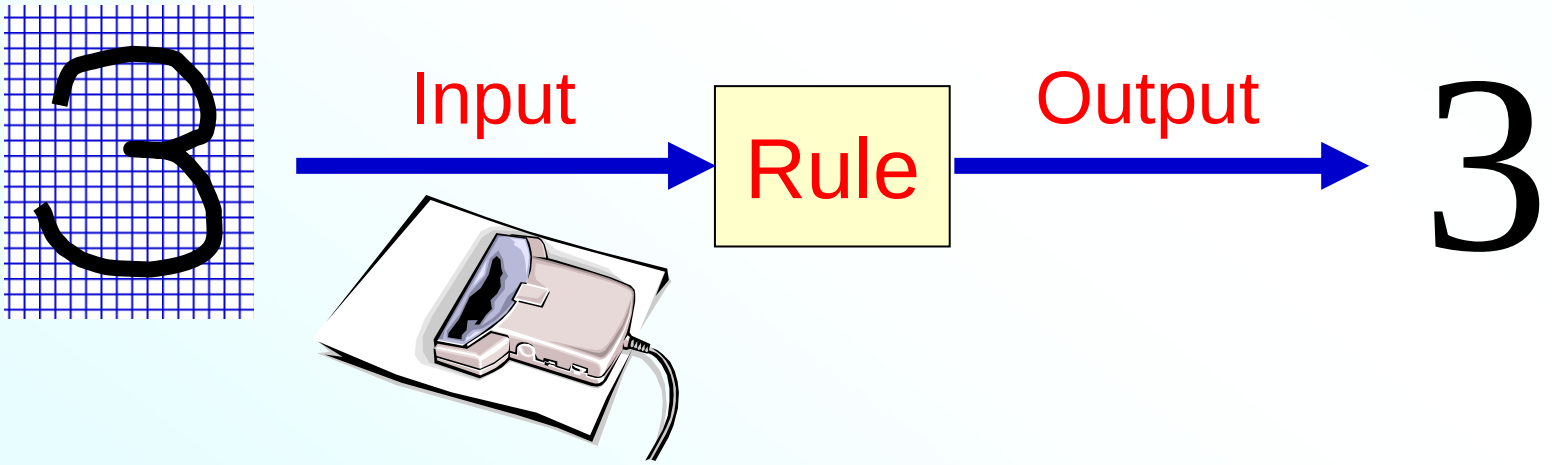

# Supervised Learning (5)

- Example 2: Hand-written number recognition

  We want to recognize the scanned hand-written characters.

# Supervised Learning (6)

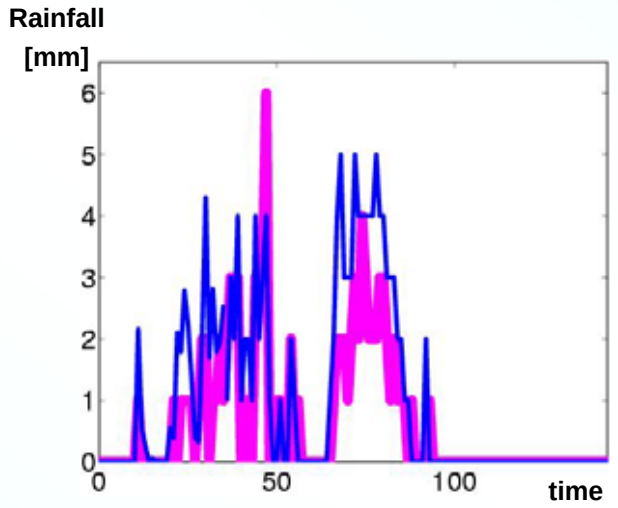
- Training examples consist of {(hand-written number, its recognition result)}.
- If underlying rule is successfully learned, unlearned hand-written numbers can be recognized.



# Supervised Learning (7)

- Example 3: Rainfall Estimation

  Using the past rainfall and weather radar data, we want to estimate the rainfall tomorrow.



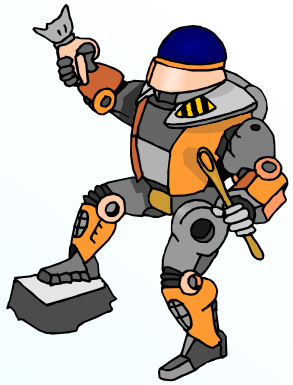
# Supervised Learning (8)

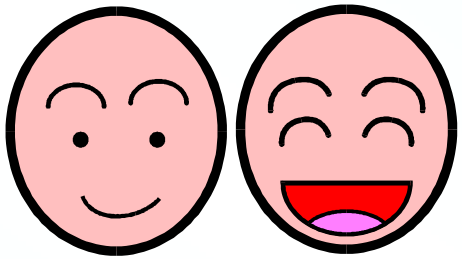
- Training examples are
  {(past rainfall and radar data,
  rainfall the next day)}
- If the rule is successfully learned, we can estimate the future rainfall by using the past rainfall and radar data.

# Supervised Learning (9)

In addition, many other real-world problems can be formulated as supervised learning, e.g.,

- Stock price estimation
- Robot motor control
- Recognition of human faces



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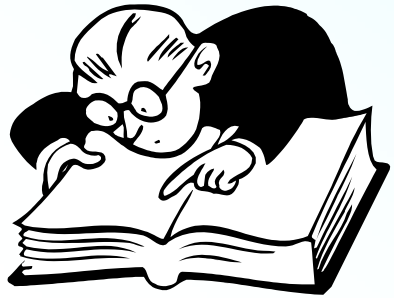
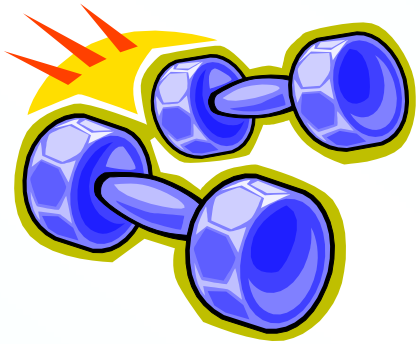
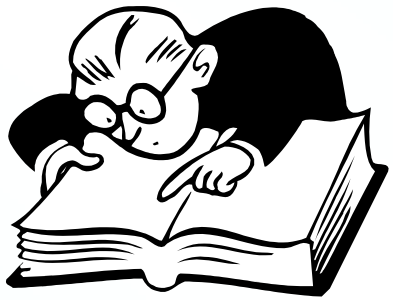


- Reinforcement learning



# Unsupervised Learning

- You are given questions without answers.
- The goal is to find a “meaningful” structure in the data.



# Dimensionality Reduction

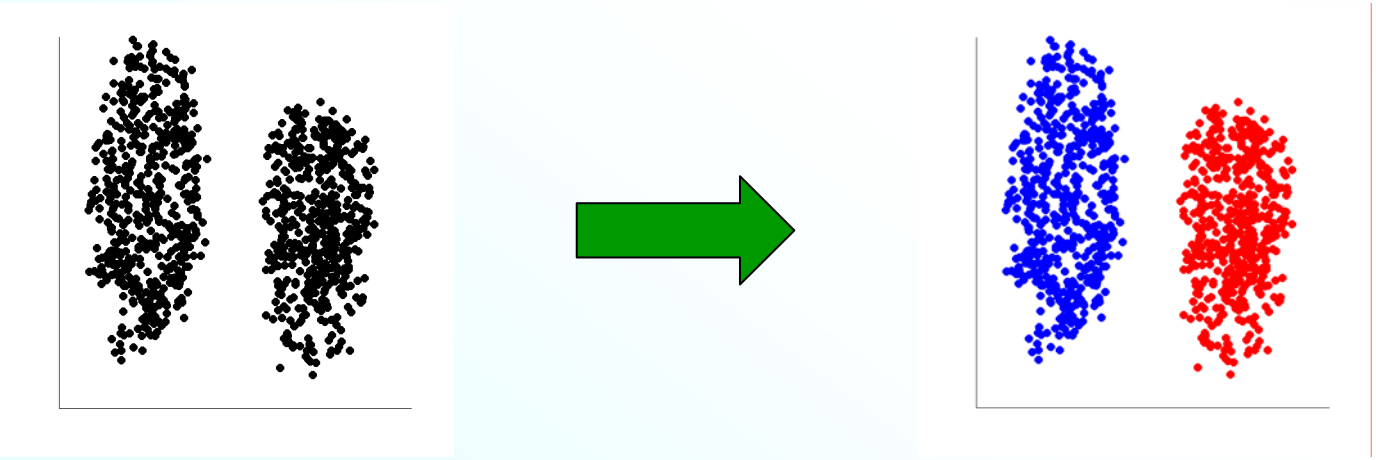
- Dimensionality reduction
  - We are given high-dimensional data
  - We want to have a low-dimensional expression of the data without losing intrinsic information.

# Clustering(1)

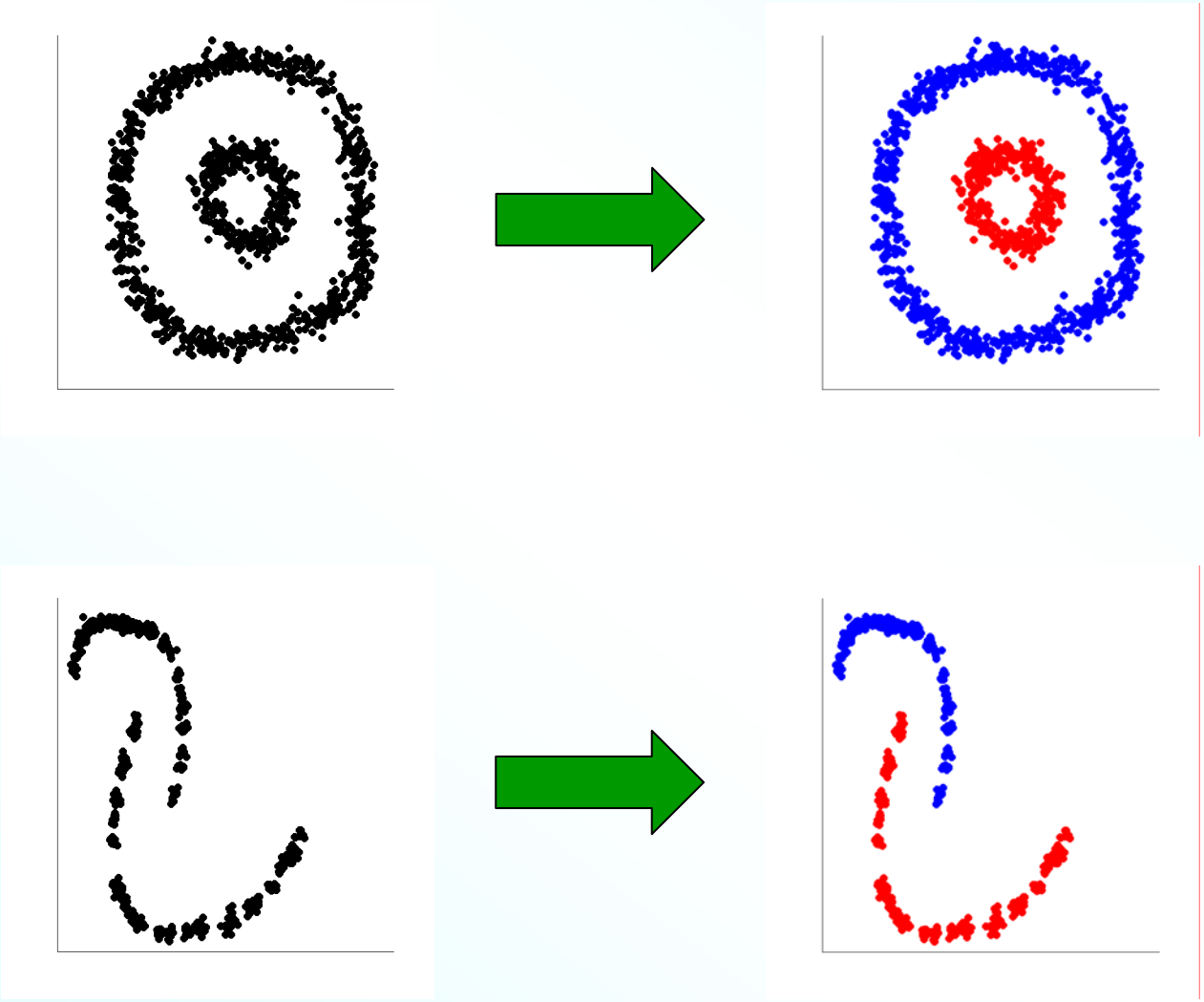
- Clustering

  We want to divide the data into disjoint groups so that

  - Data in the same group have similar characteristics.
  - Data in the different group have different characteristics.



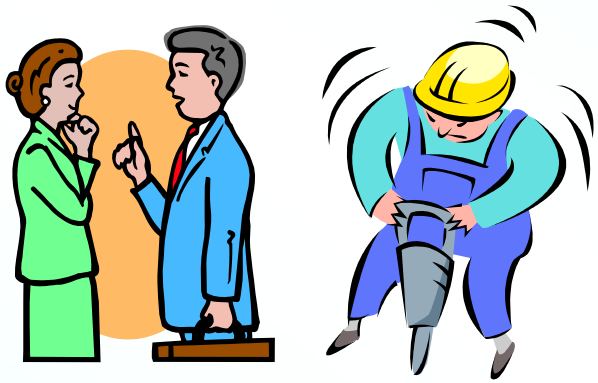
# Clustering(2)



# ICA(1)

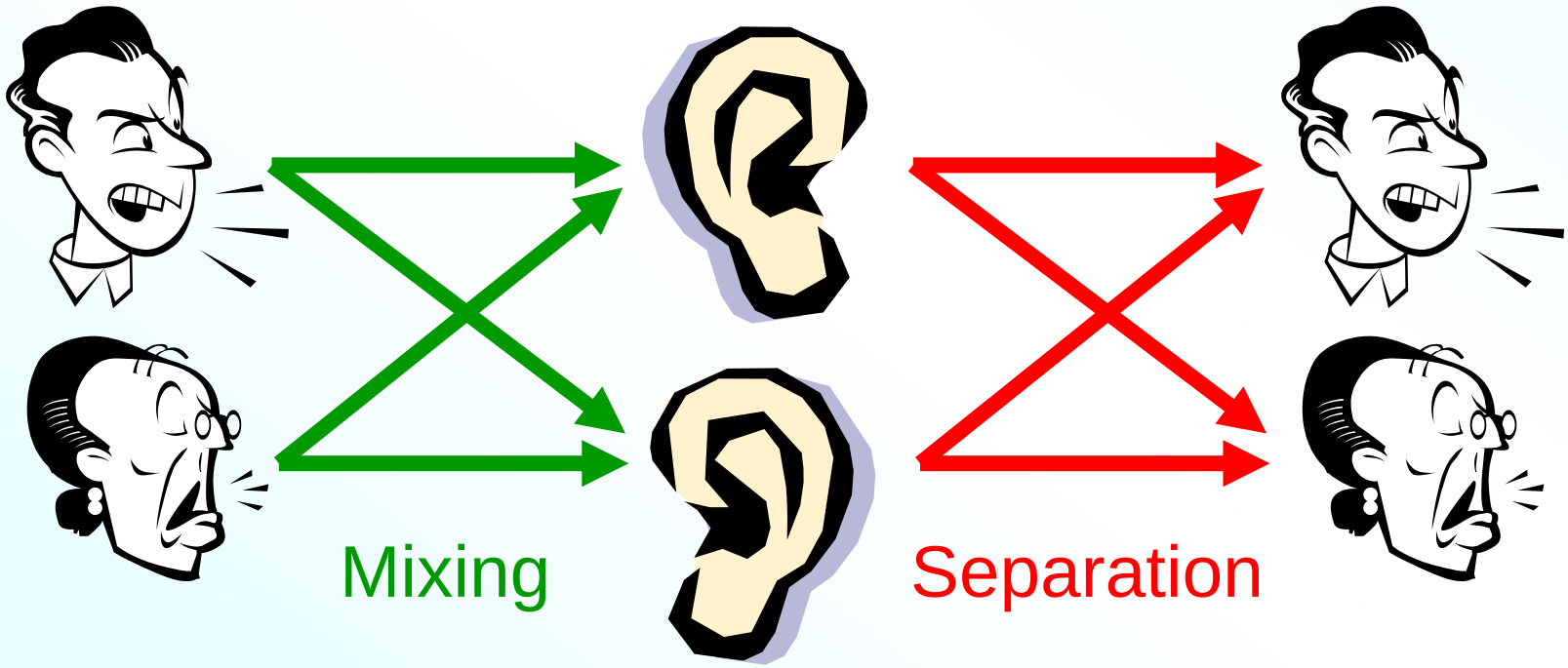
- Independent Component Analysis (ICA)
- Extract independent signals from mixtures of several signals.
- Syotoku-taishi can distinguish 10 conversations?
- Even ordinary person can listen to a conversation in a noisy environment.


From http://www.boj.or.jp/money/now/1man.htm



# ICA(2)

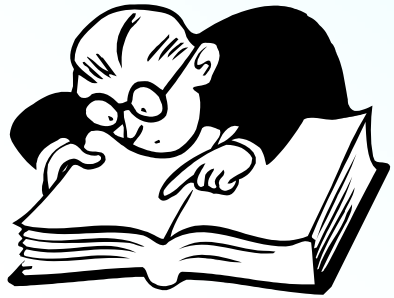
- Cocktail-party problem



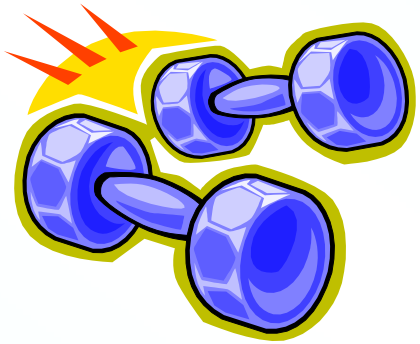
# Three Types of Learning

- Supervised learning

- Unsupervised learning

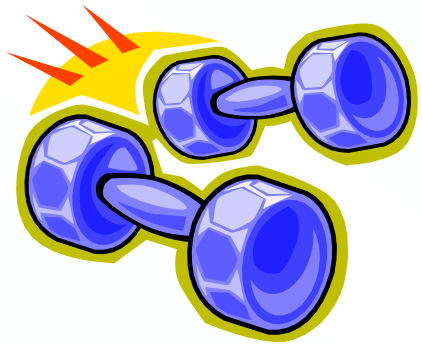


- Reinforcement learning



# Reinforcement Learning (1)

- The goal of reinforcement learning is the same as supervised learning, i.e., to estimate an unknown underlying rule.
- However, different from supervised learning, we are not allowed to ask questions to the teacher.
- Instead, we can get rewards (reinforcement signals) for our estimated answer



# Reinforcement Learning (2)

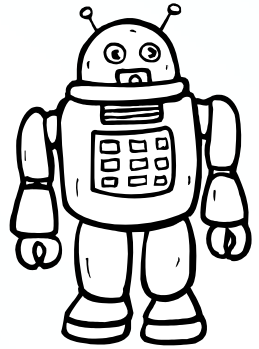
- Practically, we assume that the rule that maximizes the rewards is the underlying rule.
- Under this assumption, the rule is learned so that the rewards is maximized.
- Reinforcement learning can be regarded as being placed between supervised learning and unsupervised learning.

# Reinforcement Learning (3)

- Example: Learning stand-up motion
- The robot consists of 3 links connected by 2 joints. Joint angles can be controlled.
- The goal is to learn the control rule for stand up.
- Control rule: mapping from inner states to control signal.

# Reinforcement Learning (4)

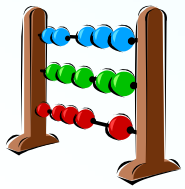
- Essentially, reward is given when stand-up motion has been succeeded, otherwise reward is zero. However, this does not work well in practice.
- Continuous reward is preferred. For example, stand-up is equivalent to lifting the head, the reward is designed such that the higher the head is, the more the reward is.

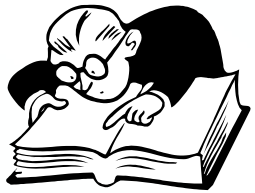
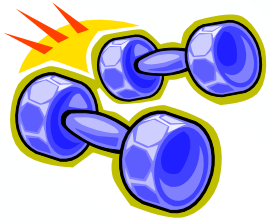


# Conclusions

- There are 3 topics in learning research.
  - Understanding human brains
  - Developing learning machines
  - Clarifying essence of learning mathematically
- There are 3 types of learning.
  - Supervised learning
  - Unsupervised learning
  - Reinforcement learning





# Small Reports

- Write your original applications of
  - supervised learning,
  - unsupervised learning,
  - reinforcement learning.
- Relating to your own research topics would be a good idea.

- Deadline: Nov. 12 (Fri)
- E-mail your report to sugi@cs.titech.ac.jp or bring it to me in the beginning of the next class.