Introduction to Computational Learning

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What is Computational Learning

- Computational learning is modeling “learning” in the same method of modeling computation.
- Practical applications of computational learning includes learning or knowledge discovery from discrete data:

    strings, like texts, DNA sequences,…

    trees, like parsing trees, XML documents

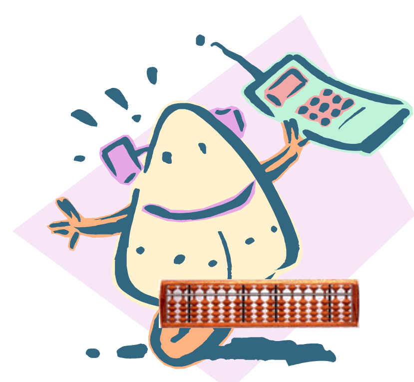
    tables (relational data),

    graphs,…

What is Computation?

- Computer is developed in order to simulate computation by human beings, based on its analysis.

$$(((2\times 3)+(4\times 6))+(7\times 8))\div(2+4)$$



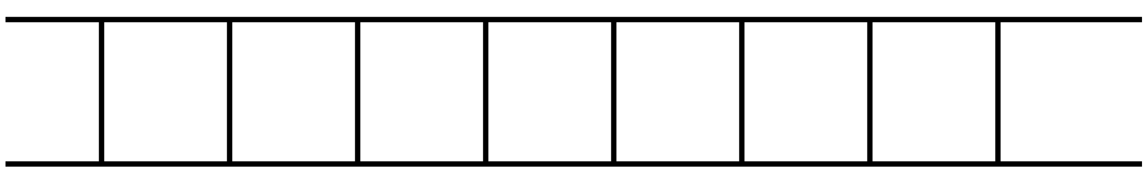
computer (計算手)　　　　computer (計算機)

Alan Turing [1936](1)

- Computing is normally done by writing certain symbols on paper. We may suppose this paper is divided into squares like a child's arithmetic book.

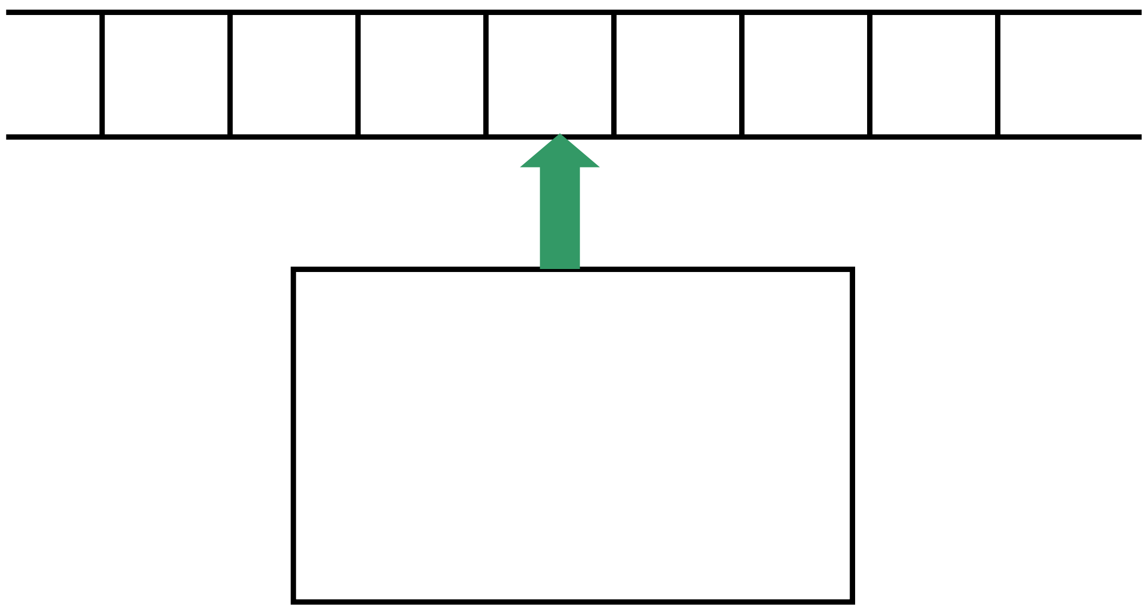
  ...

- I assume then that the computation is carried out on one-dimensional paper, i.e. on a tape divided into squares.



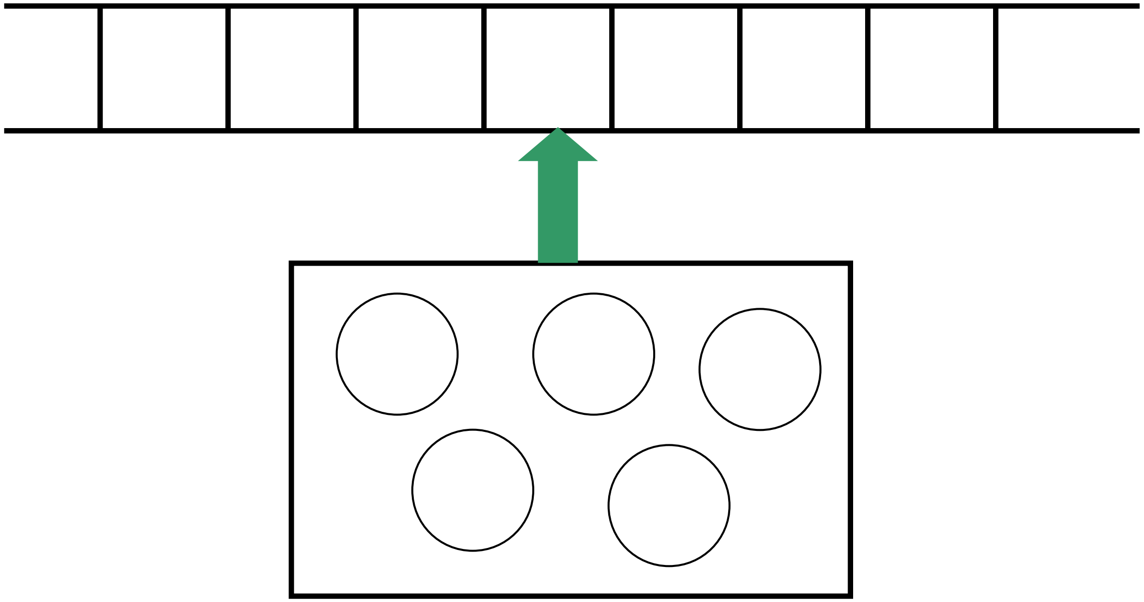
Alan Turing [1936](2)

- The behaviour of the computer at any moment is determined by the symbols which he is observing and his "state of mind" at that moment.



Alan Turing [1936](3)

- We will also suppose that the number of states of mind which need be taken into account is finite.



Alan Turing [1936](4)

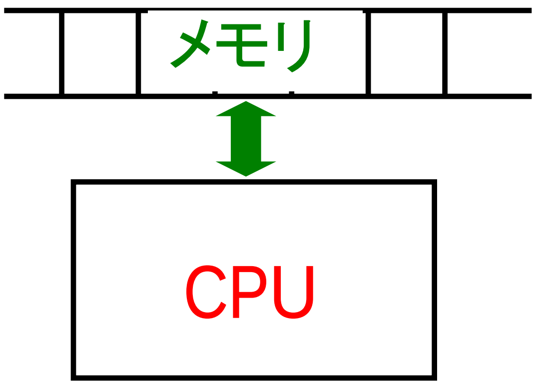
(a) Changes of the symbol on one of the observed squares.

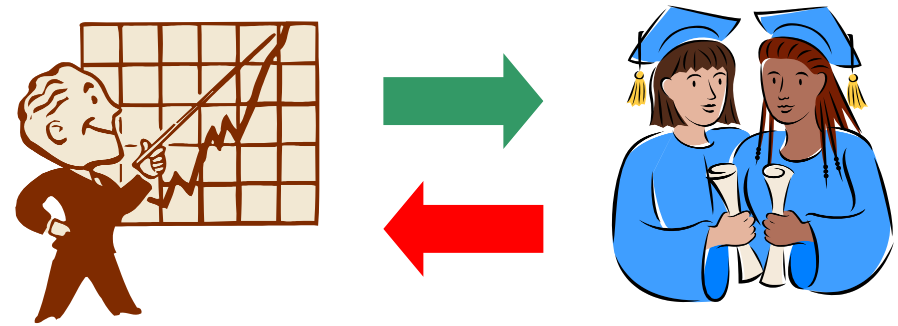
(b) Changes of one of the squares observed to another square within L squares of one of the previously observed squares.

A. A possible change (a) of symbol together with a possible change of state of mind.

B. A possible change (b) of observed squares, together with a possible change of state of mind.

Computer Learner





Computational learning is formalizing learning just in the same way of formalizing computation.

Formal languages

- We mainly treat learning formal languages.
  - Formal language theory is one of the basic part of theory of computation today, and threats strings in computational methods.
  - Applications of the formal language theory are

    developing programming languages,

    developing mark-up languages,

    analysis of natural languages,

    analysis of data in bio-informatics,…

2-1 Preliminaries

- We provide foundations of formal language theory which are necessary for computational learning.
  - Mathematical definition of languages as sets
  - Which languages are computable?
- We also give a new view to the formal language theory by using formal concept analysis.
  - Formal concept analysis was born from mathematics, in particular, Algebraic-Geometry, but now is known to be quite useful in machine learning.

2-1 Formalization of Learning

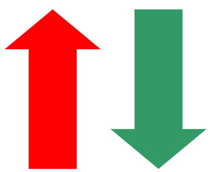
- We discuss how to model learning in computational manner.
  - What are targets of learning?
  - Representation of targets and hypotheses
  - How do we provide examples to a learning machine?
  - How the learning machine works?
  - Why and when can we say that the learning machine works correctly and achieves “learning”?

2-2 Learning in the Limit

- We introduce a simple learning model called "identification in the limit".
  - Several assumptions on targets, and their representation
  - Providing positive and negative examples to completely
  - Learning machines which search hypotheses (representation of targets) by enumeration
  - Justification of the learning

2-2 Learning with Queries

- While learning machines in the "identification in the limit" model are passive, we introduce ability of using queries into learning machines.
  - Which type of queries can be considered in learning formal languages?
  - Basic results on learning with queries.



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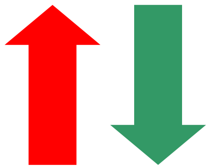
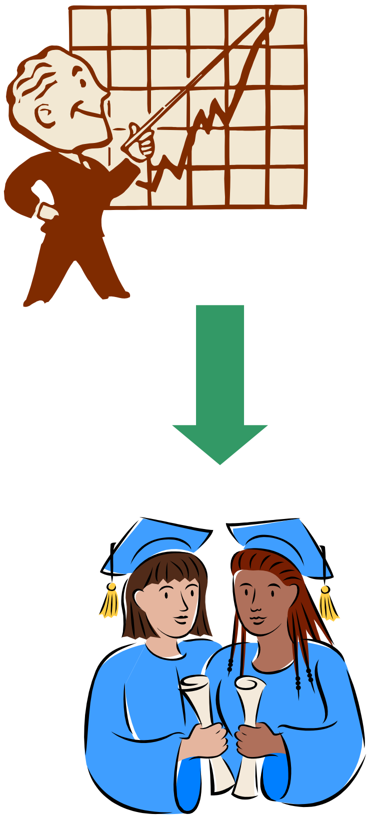


2-3 Learning from Positive Data

- We explain why learning from positive only data is difficult.
  - Learning from positive and negative data corresponds to classification, while learning from positive only data to clustering.
  - Fundamental results on learning from positive only data.
  - The hierarchy of difficulty of learning, like the hierarchy of difficulty of computation.



2-3 Mathematics and Learning

- Learning from positive data is closely related to computational algebra, in particular the theory of polynomial ideals.
  - Polynomials can be regarded as “sentences” in formal languages.
  - Learning from positive data gives a procedural meaning of Hilbert’s basis theorem, and some axioms used in modern mathematics.

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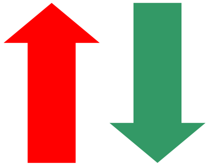

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