Foundations of Information Processing

LUT University

Algorithmic problem solving

Problem solving

Problem

=>

General problem solving

=>

Algorithmic problem solving

=>

Implementation

General problem solving:
Different kinds of problems

Problem 1:

Connect nine points

The problem is limited which can/must be defined exactly.

How to define the points and their positions,

what does “connect” mean, etc.?

Different kinds of problems

Problem 2:

Fix the internet connection

which does not work

"Clear" technical steps.

A classic engineering problem.

Different kinds of problems

Problem 3:

Cope with the climate change

A very wide task, including

many opinions,

a lot of many measurements and observations,

statistical estimation,

uncertainties, etc.

Problem solving in general

In studying and in many tasks at work skills for problem solving and groupwork are needed.

What is needed for solving problems?

Could we “automate” data mining for problem solving?

How about producing ideas?

How about creativity? Could it be automated?

Problem solving in general

”Everyone knows that creativity has to be fun, lively, and crazy: so how can we have serious creativity?”

(Edward de Bono, a Maltese psychologist and author who proposed the concept of lateral thinking = breaking frameworks and logical formulas in creating new things)

- Requirements (what is needed in the beginning).
- Concepts and definitions (what are the considered matters).
- Problem categories (what to solve).
- Problem solving processes (how to solve).
- Creating ideas (how to stimulate your thinking).
- Innovations and creativity (possibilities and limitations).
- Illustration and documentation (how to present the solution).

Requirements: do you have to be a genius?

Source: TIEDE.FI June 2013.

- Intelligence quotient (IQ).
- IQ is varying among known masters.
- For example:
  - 190-199: Leibniz (philosophy) and Goethe (literature).
  - 189-189: Laplace (natural science), Berkeley (philosophy), Voltaire (literature).

  …
  - 150-159: Kepler (natural science), da Vinci (painting), Mozart (music).

  …
  - 130-139: Copernicus (natural science), Rousseau (philosophy), Burns (literature), Rossini (music).

- Thus, IQ is varying very much.
- Another matter:
  - How to measure IQ and is the current way the best possible?

Concepts and definitions

Source: V. Virkkala. Luova ongelmanratkaisu. Vilkko Virkkala, Helsinki, 1994. (in Finnish)

- Problem solving: use data by combing as reasonable pieces of information.
- Raw data vs. intelligent information: “just” data vs. a smart plan to process data.
  - Raw: In the winter there are more road accidents than in the summer.
  - Intelligent: A plan to increase the road safety in the winter.
- Qualitative vs. quantitative information: how to measure and to define?
  - Quantitative: the temperature outdoors is +30 C.
  - Qualitative: it is hot weather.
- Sources of information: selection and critical thinking (reliable source?).
- Critical evaluation of data/information (who talks and what):
  - “Expert filter”.
  - “Salesman filter”.
  - “Number filter”.
  - “Research filter”.
  - “Prejudice filter”.
  - “Showing own competence filter”.

Problem categories

Source: V. Virkkala. Luova ongelmanratkaisu, Helsinki, 1994.

Analysis problems:

- For example: Owners of the company are interested in the competitiveness of the company in the market segments of their products.
  - What matters affect the competitiveness and is the matter causal (genuine causality between the matter and the competitiveness)?

Synthesis problems:

- For example: A product of the company has been found to increasingly cause returns.
  - What should be the quality assessment of this product to get optimal profits?

Valuation problems:

- For example: The salary system of the company is based on the demand level of the job and the results.
  - What salary should be paid to employees with different kinds of jobs, and on what grounds?

Problem categories: research examples.

Analysis problems:

- Bacteriorhodopsin is a photosensitive protein which can be separated from a sheet of Halobacterium salinarium. An electric response can be measured from a thin membrane manufactured from this material.
  - What is this response based on?

Synthesis problems:

- The Bacteriorhodopsin membrane transfers photosensitivity to the electric response.
  - What kind a color camera could be built based on the Bacteriorhodopsin membrane?

Valuation problems:

- A sheet of Halobacterium salinarium is grown biotechically in a laboratory. The living material is being broken in the centrifuge in order to separate photosensitive protein.
  - Is this right ethically?

Problem solving process

Source: V. Virkkala. Luova ongelmanratkaisu,, Helsinki, 1994. (in Finnish)

1) Planning

- The problem to be solved

⇒Facts

⇒Ideas

⇒Solution

2) Implementation

- The solution in practice.

3) Verification and acceptance

- Make sure that the solution works.
- Convince people to accept the solution.

Creating ideas

Source: V.Virkkala. Luova ongelmanratkaisu, Helsinki, 1994.

- Many techniques: some of them introduced here.
- Considering known solutions:
  - Is this possible consider widely enough available solutions?
- Joining remote ideas: analogies and “crazy” combinations:
  - Join ideas which are distant to each other.
  - Jump out of the box in your thinking.
  - For example, watershed segmentation in the segmentation of digital images where the idea actually comes from geology.
- Brainstorming:
  - Steps: pre, warming up, creating ideas, selecting ideas.
  - Documentation and analysis (SWOT).
    - Strengths, weaknesses, opportunities, and threats.

Creating ideas (continued)

- Modifying ideas via the list of questions:
  - Enlarge/shrink, divide/combine, replace, point out, reverse upside down.
- “Double team”:
  - Two persons as a pair first create ideas how to solve the problem and then select the best ideas.
  - Next two pairs are combined as the group of 4 persons, and the ideas are merged, and the best ideas are selected.
  - Hierarchical structure: groups of 2 => groups of 4 => groups of 8 =>
  - Finally, the most popular ideas are selected.
  - Techniques to create ideas are not limited.
  - What does happen when the ideas of two groups are combined. The risk to lose some ideas?
- Now and in future: creating ideas using AI-based tools.

Innovations and creativity

Source: V. Virkkala. Luova ongelmanratkaisu, Helsinki, 1994 (in Finnnish).

- Innovations:
  - It is not so easy: "… results obtained by systematic creating ideas are very varying …"
- Motivating creativity:
  - Environment, rewarding, own goals, own opinions, …
- Obstacles of creativity:
  - Environment, attitude, leadership and management, …
- What would be a creative organization?
  - Not too much restrictions of thinking?
  - Not too much limitations of actions?
  - Democracy vs. dictatorship?

Illustration and documentation

Source: V. Virkkala. Luova ongelmanratkaisu, Helsinki, 1994 (in Finnish).

- To understand the solution, and especially to receive acceptance from other people, the solution must be documented:
  - Written sentences.
  - Evaluation matrices.
  - Mind maps.
  - Flow charts.
  - ...
- Different roles, habits, and work cultures influence to illustration and documentation:
  - Researchers, engineers, salespersons, directors, etc.

Summary: problem solving in general

- Problem solving can be defined in general as combing data for functioning steps to create the solution.
- Finding new solutions require (academic) research and data mining, processing, combining, and analysis.
- Innovative and critical thinking & qualified documentation are very important.

Towards **algorithmic problem solving**: About the example problems

Problem 1:

Connect nine points

Let us specify more:

Connect nine points which coordinates are stored in the memory, connecting them with continuous lines which are formed of four straight line segments at maximum.

(More definitions could be introduced to understand the problem better, but let us not go too much into details since the main goal here is just to understand the type of the problem as compared to the other examples)

Problem 2:

Fix the internet connection

which does not work

Fix the connection using the properties of a computer and the interface to a service provider.

Problem 3:

Cope with the climate change

Make the plan to limit the climate change by taking advantage of all possible views on the Internet and the scientific facts about the history and the current situation.

Algorithmic problem solving: the starting point

If *well defined* problems which can be *formalized* appear continuously again in the same form, it is worthwhile to find the repeatable solution to avoid routine work.

Is it possible *mechanize* (automate) problem solving?

If the solution to a certain problem exists, is it possible to mechanize solving *the corresponding problems*?

How to define an algorithm? What is it?

Algorithmic problem solving

”An algorithm must be seen to be believed”

(Prof. Donald E. Knuth, an American computer scientist and mathematician, Caltech, Princeton, Stanford)

- Planning algorithms.
- Properties of algorithms.
- Presenting algorithms.

Step	Problem solving in general	Algorithmic problem solving
1	Understanding the problem	?
2	Making the plan to solve the problem	?
3	Implementing the plan	?
4	Evaluating the solution	?

Algorithms and making them

Source: J. Boberg, Johdatus tietojenkäsittelytieteeseen, Turun yliopisto, 2010 (in Finnish).

- Algorithmic problem solving is to present the exact *step-by-step instructions* to solve a given problem.
- This set of the instructions is called as *the algorithm*.
- To make the algorithm is needed
  - an inclusive and unambiguous *task description*,

  since for a person who uses the algorithm
  - following the set of the instructions and
  - the instructions themselves

  must be totally clear.

Making vs. executing the algorithms

Source: J. Boberg, Johdatus tietojenkäsittelytieteeseen, Turun yliopisto, 2010 (in Finnish).

- Making algorithms is not the algorithmic action, as creativity is needed in making

  $\Rightarrow$ it is not possible to write an algorithm

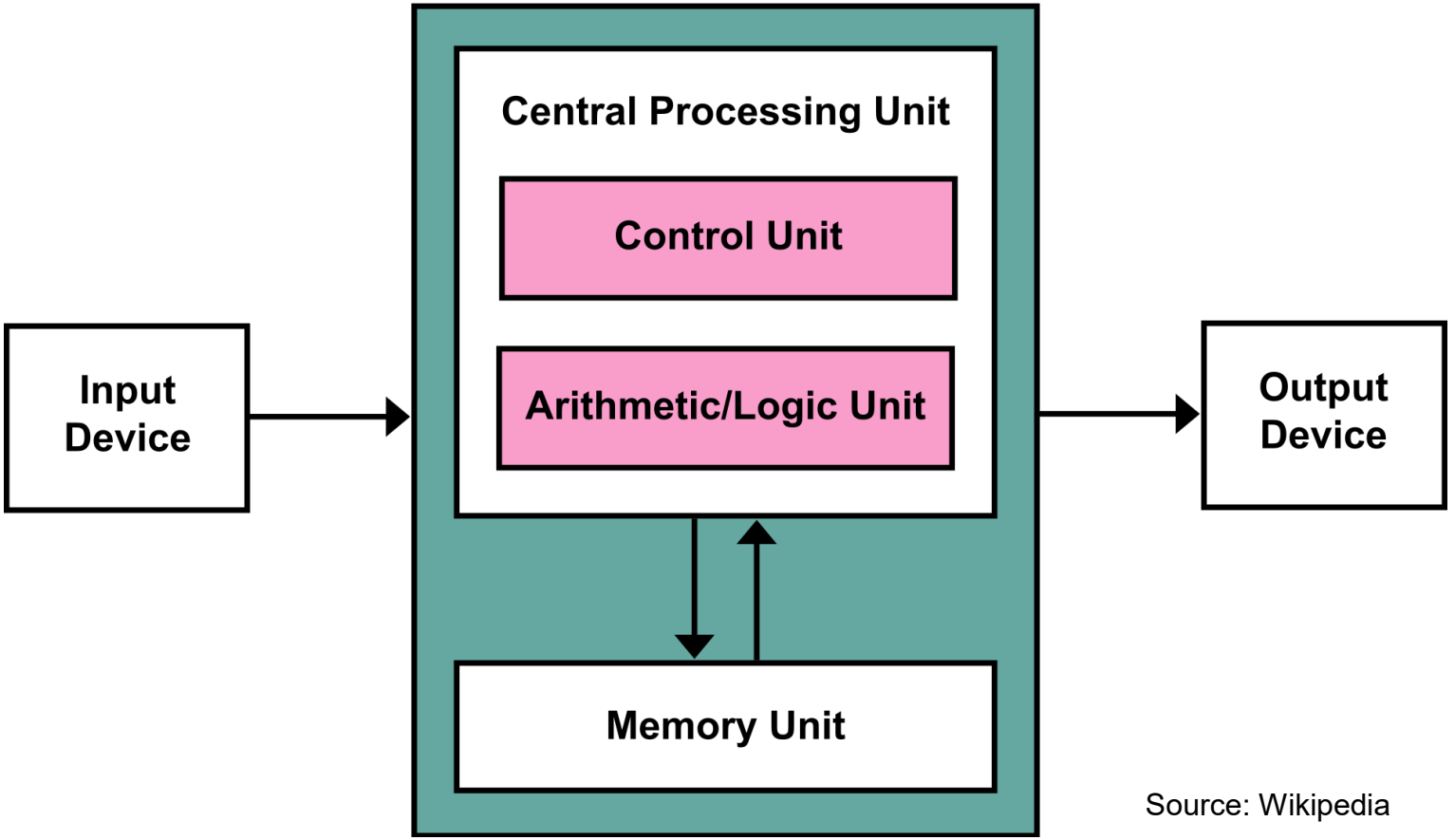
  to make an algorithm.
- It is quite a systematic task to use the algorithm which has been made to solve a given problem:
  - Program the algorithm.
  - Transfer (compile) the program to the computer-based language (machine language).
  - Execute the transferred (complied) program.

  $\Rightarrow$ the execution of the algorithm is a mechanical operation.

The computer: the tool for executing algorithms

Von Neumann architecture

(John von Neumann/János Lajos Neumann, 1945, a Hungarian computer scientist, mathematician, physicist, engineer, University of Pázmány Péter, University of Berlin, Princeton University)



Source: Wikipedia

Algorithm: as a program for the computer

Algorithm

↓

Programming (with the rules of the used language)

↓

Program (higher level programming language)

↓

Compilation (with the compiler)

↓

Program (machine language)

↓

Linking (other needed programs linked)

↓

Program (executable machine language)

↓

Input → Execution →Output

Algorithmic problem solving: real problem => real solution

From
a real-world problem
via a *formalized solution*
and *programming*
back to
a real-world solution.

Real-world problem =>
Task definition =>
Formalized problem =>
Problem solving =>
Algorithmic solution:
algorithm + data structure =>
Programming =>
Program =>
Execution of program =>
Formalized solution =>
Interpretation of solution =>
Real-world solution

Algorithms: required properties

Source: J. Boberg, Johdatus tietojenkäsittelytieteeseen, Turun yliopisto, 2010 (in Finnish).
Source:E. Horowitz et al. Fundamentals of Data Structures in C. Computer Science Press, 1993.

- **Generalizability**: suitable to all the cases of the task.
- **Determinism**: the solution must be deterministic and at each step it is known unambiguously what to do next.
- **Output**:
  - Correctness: the result is always correct.
  - Finiteness: the algorithm always terminates.
- **Input**: the range of input and how it affects the result.
- **Effectiveness**: how robust the solution is as a function of time and space.

Are these requirements unambiguous?

For example, non-deterministic problems like playing games.

Algorithmic problem solving: steps

G. Polya, How to Solve It, 1945.
J.G. Bookshear: Computer Science - An overview, 10th Edition, Addison-Wesley, 2009.

Step	**Problem solving in general**	**Algorithmic problem solving**
1	Understanding the problem	Understanding the problem
2	Making the plan to solve the problem	Planning the algorithm
3	Implementing the plan	Making the algorithm and presenting it as a program
4	Evaluating the solution	Evaluating accuracy and generalizability

Presenting the algorithm

- Language or flow chart?
- Natural (expressive) language vs. formal (strictly defined) language.
- Concepts of the language:
  - Syntax ≈ grammar.
    - ”A monkey ate a banana”: subject verb object => ok.
  - Semantics ≈ meaning.
    - ”A banana ate a monkey”: syntax ok, semantics not ok.
  - Pragmatics ≈ context-dependent meaning.
    - For example, sentences of a paragraph affect the meaning of individual sentences and words.
    - Maybe you have heard: “My comments have been quoted out of the context, and I would like to correct …”.
- Images, mind maps, flow charts, state machines, …

Example: algorithm based on the (English) language

- After a couple weeks of studying, Mr. Brian Kottarainen faced a problem: he ran out of clean socks. Happily, Brian found a washing machine in the basement of his LOAS student house.
- However, how to wash clothes?
- Please help Brian and write an algorithm for him. Based on the English language it could be as follows:

1. Gather the dirty socks.
2. Go to the washing room.
3. Wash the socks.
4. Dry the socks.
5. Pick up the socks from the washing room.

The algorithm can be extended and refined step by step.

This will be considered in the next lectures.

Summary

Algorithmic problem solving is based on making the set of step-by-step instructions to solve the problem, or *the algorithm*.

The algorithm is *exactly defined* concept: it must satisfy the required properties.

There is no algorithm to make the algorithm since *making* needs *creativity*.

Executing the algorithm is (supposed to be) *mechanical* operation.