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CSC6023 - Advanced Algorithms

Approximated Algorithms - Week 8

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The final week - Week 8

The last week has arrived. If you worked hard, this is a happy moment. Now, we will see approximated algorithms, and the Final Exam is upon us. The course is (almost) over.

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Agenda
Week 8
Presentation

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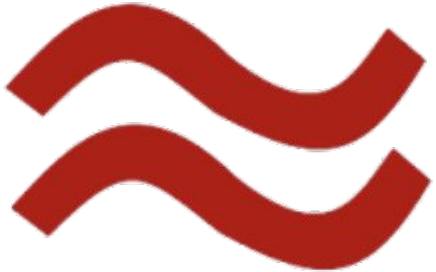
Approximated Algorithms

- When to settle with an approximation
    a. The alternative to brute force - to reduce cost
        i. The travelling salesperson problem
    b. The Real ($\mathbb{R}$) world - coping with infinite
        i. Linear equation systems
    c. Artificial Intelligence
        i. Machine learning
        ii. Automatic players
- Heuristics and Prune

Course Wrap-up

- The final exam
- The final grades
- The next steps in the Masters in CS

When to settle with an approximation



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Why not going for the optimal solution?

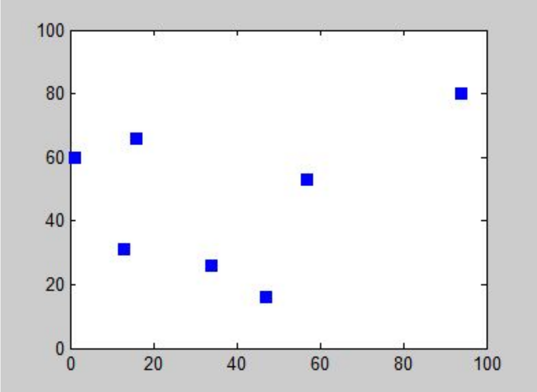
- The optimal solution may be:
  - too costly
    - Only an extremely costly brute force delivers the optimal solution
  - impossible to find
    - Theoretical infinite cannot be achieved in a finite machine
  - impossible to be recognized
    - The optimal solution is unknown
  - not really necessary
    - The problem does not require precision
- In any of such cases we may settle with an approximated algorithm

Approximated Algorithms

The traveling salesperson problem

Too costly

- Imagine a salesperson going physically to a series of ***n*** cities. What is the sequence of cities to visit to have the smallest path to cover
    - The brute force solution has ***O(n!)*** complexity, any ***n*** above 20 is impractical
    - The cutting edge exact solution using Dynamic Programming has $\boldsymbol{O(n^2 2^n)}$
    - For ***n*** in the range of thousands it is impractical to solve by a single machine in less than one day
- Heuristic solutions provide near optimal solution with much smaller cost
    - For example a Greedy algorithm (Nearest Neighbor) delivers solutions on average 25% larger than optimal with $\boldsymbol{O(n^2)}$



Wikipedia source

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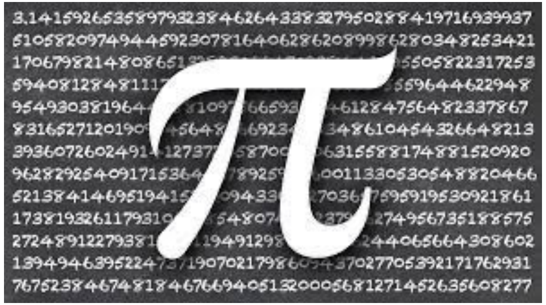
Approximated Algorithms

Impossible to find



Wikipedia source

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Only approximated value of π can be found!

- Since the very ancient times the value of π has been an important bit of knowledge in engineering endeavors (mostly building, but other applications too)
  - In 1706 William Jones, a Welsh mathematician first used the Greek letter π to refer to the ratio of a circle's circumference to its diameter
  - In 1761 Johann Heinrich Lambert, a French-Swiss mathematician proved π irrational
- What is the exact value of π?
  - Until 1946 π digits were computed by hand (they knew only 620 digits)
  - Since 1949 programs have computed new digits
    - In March 2022 the first 100 trillion digits were computed (it took 158 days)

"Impossible" to find

$$\begin{cases} x + 3y - 2z = 5 \\ 3x + 5y + 6z = 7 \\ 2x + 4y + 3z = 8 \end{cases}$$

$$\begin{bmatrix} 1 & 3 & -2 \\ 3 & 5 & 6 \\ 2 & 4 & 3 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 5 \\ 7 \\ 8 \end{bmatrix}$$

[Wikipedia source]

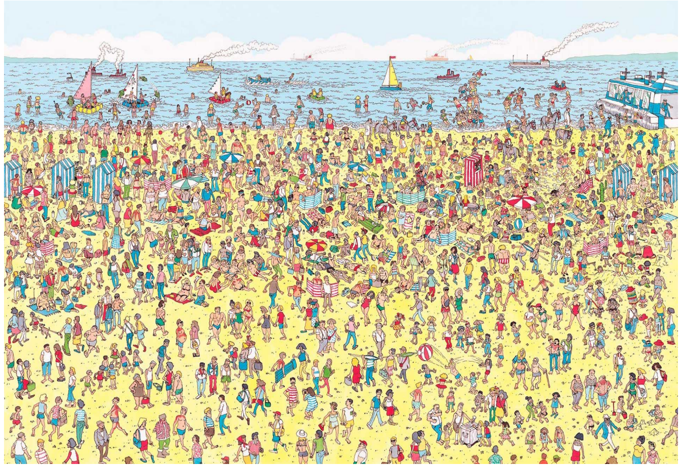
Solution of linear equation systems

- Given a linear equation system with ***n*** variables and ***n*** equations
  - The problem can be expressed as:
    - ***Ax = b***
  - There are exact algorithms, for example Gaussian Elimination, with ***O(n³)*** complexity
    - In a system with ***n = 100*** it is OK, but some industrial applications and mathematical models can easily go beyond millions of variables
  - For such systems approximative algorithms can be possible and a lot faster

Approximated Algorithms

Artificial Intelligence - Machine Learning

Impossible to recognize



- Machine learning techniques always deliver approximated solution, as the model to be learned can never be tested on all possible situations
    - The idea behind machine learning is to recognize patterns capable of identifying new inputs, which can, like any input, be of an unpredictable nature
        - The possible inputs are by definition infinite
- Either on classification, aggregation, or regression the result of machine learning is always a best effort solution

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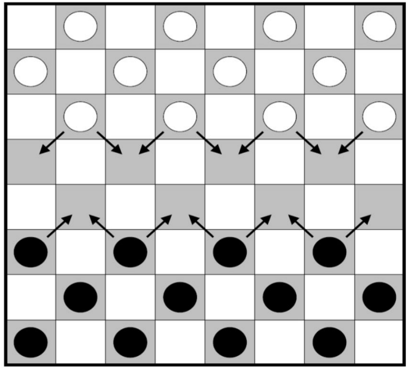
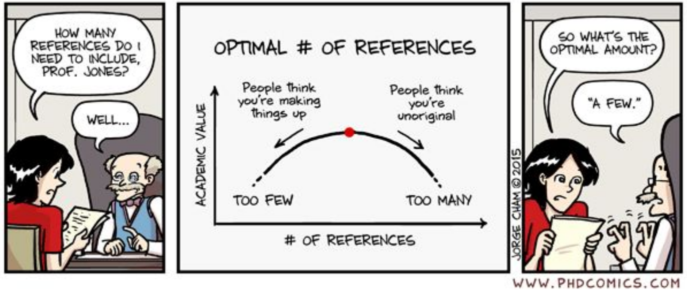
Artificial Intelligence - Automatic Players

Not really necessary



- Imagine a mobile device game designed to entertain the user with an adversarial game, for example, checkers (see references)
  - A brute force solution should analyze all possible decisions and somehow weigh all possible responses of the adversary - this may represent a too high cost in time
  - An alternative is to prune the tree of possibilities, which leads to an approximation (and possibly a worse automatic player)
    - Checkers is actually a solved game (just like tic-tac-toe), but to play it perfectly it requires computation
- A mobile implementation doesn't need to be optimal and so can reduce battery consumption

Heuristics and Prune



Heuristics

- An heuristic is a way to solve a problem with an approach that may or not work optimally
  - Out of CS it may also mean a non rational solution, not for CS...
  - Frequently, "heuristic algorithms" is used as a synonym for randomized algorithms
- Heuristics can introduce bias

Prune

- Often the search for a solution follows a tree or graph's recursive search structure; in such algorithms it is common to provide approximation by stopping the recursive search before going too deep
  - This is called pruning (cutting off the branches of a tree)

Course Wrap-Up

Final Exam

The rules and recommendations

- This Tuesday, at 9 PM EST the exam will be available on Canvas;
- The exam is to be taken online within 4 hours counting as you started;
- The exam has to be submitted no later than this Saturday 11:59 PM EST;
- The format for the submission is a single pdf file that may include typed textual file, print screens, photos of handwritten answers, etc.;
- The exam has 8 questions, one related to each topic, try not to spend more than 30 minutes to each question;
- The exam is open book, open notes, but you should not search information on the Internet.

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Course Wrap-Up

Final Grades

The final grades

- All grades, but the exam, should be available by Friday;
- The exam should be graded no later than next Monday;
- The final grades should be available no later than next Monday.

Activity	Percentage
Projects (7)	35%
Quizzes (7)	21%
Worksheets (7)	21%
Discussions (7)	7%
Final Exam	20%

Course Wrap-Up

Next Steps

MS in Computer Science

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The Program

- After CSC 6023, you have concluded the backbone of the program
    - You are a programmer, now!
- If you haven't, you need to take DSA 5300 - Data Governance and Privacy or CSC 6033 Languages, Automata and Decidability
- Other than that, now you have the advanced courses to take:
    - CSC 6301 - Software Design & Documentation
    - CSC 6302 - Database Principles
    - CSC 6303 - Systems & Languages Survey
    - CSC 6304 - Advanced Programming Concepts

That's all for this course folks!

This week's task

- The Exam, good luck!

Next term

- Next course

It was a privilege to be your instructor in this course

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Have a Great Next Term!