Intro RWTH-BIT

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Lehrstuhl für Informatik I

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- algorithmic design principles

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- basics of complexity theory

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- basics of information theory

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- data structures
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- Question: What do you know about these subjects?

Data Structures

- Stacks and queues

Data Structures

- Stacks and queues
- Linked lists

Data Structures

- Stacks and queues
- Linked lists
- Hash tables

Data Structures

- Stacks and queues
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- Binary search trees

Data Structures

- Stacks and queues
- Linked lists
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- Red-Black Trees

Data Structures

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Data Structures

- Stacks and queues
- Linked lists
- Hash tables
- Binary search trees
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- B-Trees
- Heaps

Algorithmic design principles

- Dynamic Programming

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- Dynamic Programming
- Greedy Algorithms

Algorithmic design principles

- Dynamic Programming
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- Divide and conquer

Algorithmic design principles

- Dynamic Programming
- Greedy Algorithms
- Divide and conquer
- Sweep lines

Algorithms

- Sorting

Algorithms

- Sorting
- Single-Source Shortest Paths

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- All-Pair Shortest Paths

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- Sorting
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- Matchings

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- Maximum Flow

Algorithms

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- Single-Source Shortest Paths
- All-Pair Shortest Paths
- Matchings
- Maximum Flow
- Approximation Algorithms

Complexity theory: Introduction

- $\mathcal{NP}$-Complete Problems

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- $\mathcal{NP}$-Complete Problems
- The Class $\mathcal{P}$

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- $\mathcal{NP}$-Complete Problems
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- The Class $\mathcal{P}$
- The Class $\mathcal{NC}$
- $\mathcal{P}$-Complete Problems
- The Halting Problem

Contents (Revisited)

- data structures
- algorithmic design principles
- basics of complexity theory
- basics of information theory

- Question: What do you know about these subjects?
- We start with: basics of complexity theory

Complexity theory: Introduction

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  - Start with a machine independent model.
  - Find the first hard problem for this model.

Complexity theory: Introduction

- There are Problems with fast solutions, i.e. Sorting, ...
- There are Problems where no “fast” solution is known.
- How to see, that a Problem is hard?
  - Start with a machine independent model.
  - Find the first hard problem for this model.
  - Reduce any other hard problem to that first hard problem.

The Machine Model

- The Turing Machine Model

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- The Coding of the input

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  - $\mathcal{P} = \{L \mid \exists$D-TM which halts in polynomial time on $L\}$

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- Big open problem: $\mathcal{P} \stackrel{?}{\neq} \mathcal{NP}$

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Reductions

Definition (polynomial-time reducible)

Given languages L_1 and L_2. We say: L_1 is polynomial-time reducible to L_2 iff:

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Lemma

If $L_1 \leqslant_p L_2$ and $L_2 \in \mathcal{P}$ then $L_1 \in \mathcal{P}$.

$\mathcal{NP}$-Completeness

Definition ($\mathcal{NP}$-Completeness)

A language L is $\mathcal{NP}$-Complete iff:

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Notation: $L \in \mathcal{NPC}$

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Notation: $L \in \mathcal{NPC}$

These are the "hardest" problems in $\mathcal{NP}$.

Definition ($\mathcal{NP}$-Hardness)

A language L is $\mathcal{NP}$-Hard iff: $\forall L' \in \mathcal{NP} : L' \leqslant_p L$

Observations

Lemma

$L_1 \leqslant_p L_2$ *and* $L_2 \leqslant_p L_3$ *then* $L_1 \leqslant_p L_3$.

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Lemma

- *If* $L' \leqslant_p L$ *and*
- $L' \in \mathcal{NPC}$ *then*
- *is* L *NP-Hard.*

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Lemma

- *If* $L' \leqslant_p L$ *and*
- $L' \in \mathcal{NPC}$ *then*
- *is* L *NP-Hard.*
- *If* $L \in \mathcal{NP}$ *then* $L \in \mathcal{NPC}$ *holds.*

Circuit-SAT

Definition (Circuit-SAT)

Given (input): A boolean Formula $\mathcal{F}$
Question: is that formula satisfiable?

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$L_{C-SAT} = \{L \mid L \text{is a coding of a satisfiable boolean formula}$

Theorem

$L_{C-SAT} \in \mathcal{NP}$, i.e the language Circuit-SAT is in $\mathcal{NP}$.

Theorem

$L_{C-SAT} \in \mathcal{NPC}$, i.e the language Circuit-SAT is in $\mathcal{NPC}$.

SAT

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Given (input): A boolean Formula $\mathcal{F}$ in CNF
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Theorem

$L_{SAT} \in \mathcal{NP}$, i.e the language SAT is in $\mathcal{NP}$.

Theorem

$L_{SAT} \in \mathcal{NPC}$, i.e the language SAT is in $\mathcal{NPC}$.

3-SAT

Definition (3-SAT)

Given (input): A boolean Formula $\mathcal{F}$ in CNF where each clause contains at most three variables
Question: is that formula satisfiable?

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Given (input): A boolean Formula $\mathcal{F}$ in CNF where each clause contains at most three variables
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Theorem

The language 3-SAT is NP-complete.

Clique

Definition (Clique)

Given: $k \in \mathbb{N}$ and a graph $G = (V, E)$
Question: does G contain a k-Clique?

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Theorem

The Clique Problem is NP-complete.

k-Clique

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Question: does G contain a k-Clique?

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Theorem

The k-Clique Problem is in P.

Independent Set

Definition (Independent Set)

Given: $k \in \mathbb{N}$ and a graph $G = (V, E)$
Question: does G contain a k-Independent Set?

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Question: does G contain a k-Independent Set?

Theorem

The Independent Set Problem is NP-complete.

Dominating Set

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Given: $k \in \mathbb{N}$ and a graph $G = (V, E)$
Question: does G contain a k-Dominating Set?

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Theorem

The Dominating Set Problem is NP-complete.

Vertex-Cover

Definition (Vertex-Cover)

Given: $k \in \mathbb{N}$ and a graph $G = (V, E)$
Question: does G contain a k-Vertex-Cover?

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Given: $k \in \mathbb{N}$ and a graph $G = (V, E)$
Question: does G contain a k-Vertex-Cover?

Theorem

The Vertex-Cover Problem is NP-complete.

3-Coloring

Definition (3-Coloring)

Given: A graph $G = (V, E)$
Question: does G have a 3-Coloring?

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Theorem

The 3-Coloring Problem is NP-complete.

2-Coloring

Definition (2-Coloring)

Given: A graph $G = (V, E)$
Question: does G have a 2-Coloring?

2-Coloring

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Question: does G have a 2-Coloring?

Theorem

The 2-Coloring Problem is in P.

3-Coloring-Planar

Definition (3-Coloring-Planar)

Given: A planar graph $G = (V, E)$
Question: does G have a 3-Coloring?

3-Coloring-Planar

Definition (3-Coloring-Planar)

Given: A planar graph $G = (V, E)$
Question: does G have a 3-Coloring?

Theorem

The 3-Coloring-Planar Problem is NP-complete.

3-Coloring-Planar-4

Definition (3-Coloring-Planar-4)

Given: A planar graph $G = (V, E)$ of degree 4
Question: does G have a 3-Coloring?

3-Coloring-Planar-4

Definition (3-Coloring-Planar-4)

Given: A planar graph $G = (V, E)$ of degree 4
Question: does G have a 3-Coloring?

Theorem

The 3-Coloring-Planar-4 Problem is NP-complete.

Hamilton Cycle

Definition (Hamilton Cycle)

Given: A graph $G = (V, E)$
Question: does G have a Hamilton Cycle?

Hamilton Cycle

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Theorem

The Hamilton Cycle Problem is NP-complete.

Traveling Salesman

Definition (Traveling Salesman)

Given: $k \in \mathbb{N}$ and a graph $G = (V, E)$ with weights on the edges
Question: does G contain a Hamilton Cycle with costs at most k.

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Theorem

The Traveling Salesman Problem is NP-complete.

More Problems in $\mathcal{NPC}$

- Subset Sum Problem

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- Coloring Circular Arc Graphs

More Problems in $\mathcal{NPC}$

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- Planar 3-SAT Problem

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More Problems in $\mathcal{NPC}$

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- Search number Problem

More Problems in $\mathcal{NPC}$

- Subset Sum Problem
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- Search number Problem
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More Problems in $\mathcal{NPC}$

- Subset Sum Problem
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- Subgraph Problem

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- Piano Movers Problem

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- Three node disjoint path problem
- And about 9652 more Problems

P-Completeness

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  - $\forall w \in \Sigma^* : w \in L \Leftrightarrow f(w) \in L'$

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Let $G = (V, E)$ be a graph.
$M \subseteq E$ is called a matching iff $\forall e, f \in M : e \cap f \neq \emptyset$.

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Output: matching M with: $\forall M' : M \subset M' \subseteq E : M'$ is not a matching.

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Theorem (Maximum Matching Problem)

The Maximum Matching Problem is in $\mathcal{P}$.

Method: Greedy

The Maximum Matching Problem

Algorithm:

- Input $G = (V < E)$

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The Maximal Matching Problem

Definition (Matching)

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Given: Graph $G = (V, E)$, $s, t \in V$ and $c : E \mapsto \mathbb{N}$
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Theorem (Maximal Flow)

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- Running Time if DFS is used: $O(|F| \cdot |E| + |V|)$
- Running Time if BFS is used: $O(|V| \cdot |E|^2 + |V|)$

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Theorem (Min-Cut-Max-Flow)

The value of the Maximal Flow is the same as the value of the Minimal Cut.

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Theorem (Euler Tour)

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Theorem

The TSP Problem may be approximated within a factor of 1.5 for metric graphs.

Data Structures

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Data Structures

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- Linked lists
- Hash tables
- Binary search trees

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- B-Trees
- Heaps

Algorithmic design principles

- Dynamic Programming

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- Greedy Algorithms

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- Dynamic Programming
- Greedy Algorithms
- Divide and conquer

Algorithmic design principles

- Dynamic Programming
- Greedy Algorithms
- Divide and conquer
- Sweep lines