

Summary: Lecture 6

Summary for the chapter 8.2. [1, 7]

Completeness

Let C be a complexity class and let L be a language in C . L is called C -complete if any language $L' \in C$ can be reduced to L .

(Every language of a complexity class can be reduced to L .)

- reducibility is transitive \rightarrow problems are ordered by difficulty
- complete problems can capture the difficulty of a class
- problem is seen as completely understood if the problem is complete

Question:

Which problems can be reduced to a formal language?

SAT can be expressed as formal language. [6]

\Rightarrow SAT can be reduced to a formal language. (?)

SAT is in NP. [7]

Because CIRCUIT SAT can be reduced to SAT: CIRCUIT SAT can be reduced to a formal language. (?) CIRCUIT SAT is NP-complete. [3]

Any formal language $L \in \text{NP}$ can be reduced to CIRCUIT SAT? OR the other way around?

Formal language

Formal languages are abstract languages, which define the syntax of the words that get accepted by that language. It is a set of words that get accepted by the language and has a set of symbols that is called alphabet, which contains all the possible characters of the words. Those characters are called nonterminal symbols. [2, 8]

Kleene star

The Kleene star Σ^* of an alphabet Σ is the set of all words that can be created through concatenation of the symbols of the alphabet Σ . The empty word ϵ is included.

Formal language

A formal language L over an alphabet Σ is a subset of the Kleene star of the alphabet:
 $L \subseteq \Sigma^*$

Where to set the line between language decisions and other problems? Can every problem be contructed as a formal language?

Is everything that is reducible to SAT reducible to a formal language because of the transitivity?

I assume it does not have an influence on the complexity of a problem if it can be expressed as a formal language? Are formal languages part of specific complexity classes?

Closed under reduction

The following complexity classes are all closed under reductions:

P NP coNP L NL PSPACE EXP

A class C is closed under reductions if whenever L is reducible to L' and $L' \in C'$, then $L \in C'$.

If a complete problem in C belongs in a class $C' \subseteq C$, $C = C'$.

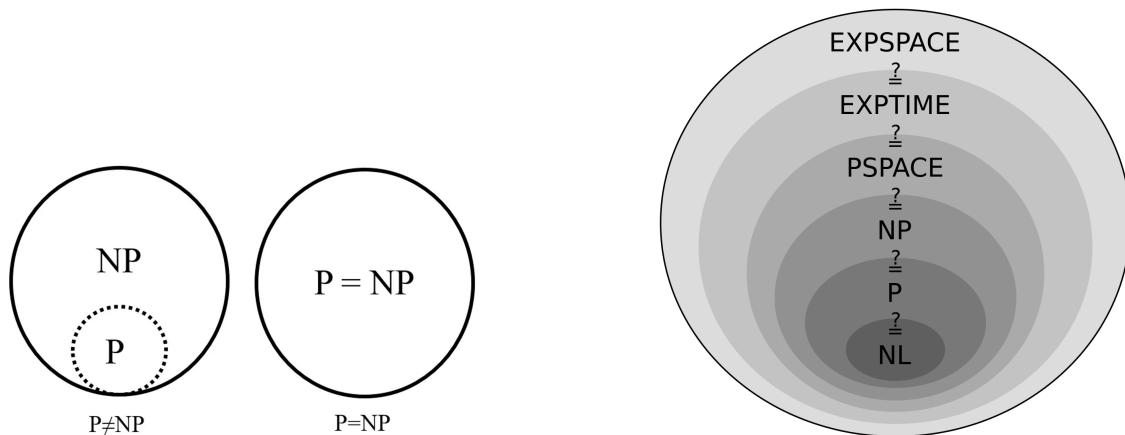


Figure 1: P and NP sets [5] and complexity classes [4]

- examples:
 - if an NP-complete language is in P, then $NP = P$
 - if a P-complete language is in L, then $P = L$
 - if a P-complete language is in NL, then $P = NL$
 - no EXP-complete language can be in P

P-completeness of CircuitValue

Problem: CircuitValue

The CIRCUITVALUE Problem is the problem of computing the output of a given Boolean circuit on a given input.

In terms of time complexity, it can be solved in linear time (topological sort).

- P-complete

Proof idea:

- CIRCUITVALUE is in P (prerequisite for being P-complete)
- show: any language $L \in P$ can be reduced to CIRCUITVALUE

TODO

proof!

Questions:

CircuitSat is NP-complete

Problem: CircuitSat

The circuit satisfiability problem (CIRCUITSAT) is the decision problem of determining whether a given Boolean circuit has an assignment of its inputs that makes the output true.

Input: a Boolean circuit C

Question: Is there a truth assignment which makes C output the value true?

- cook's theorem: CIRCUITSAT is NP-complete

Proof idea:

- circuit decides nondeterministically (?)
- a variable is added in the nondeterministic Turing Machine
- check if one of the variables is true: use this choice (?)
- problem: can we set these variables such that the Turing Machine accepts?
- answer corresponds direct to *is there a choice of nd decisions such that the turing machine accepts?*
- extremely direct reduction
- SAT is NP-complete

TODO

proof!

Questions:

Relation between complexity classes

$$N \subseteq NL \subseteq NC \subseteq P \subseteq NP \subseteq PSPACE$$

TODO

NP-complete problems

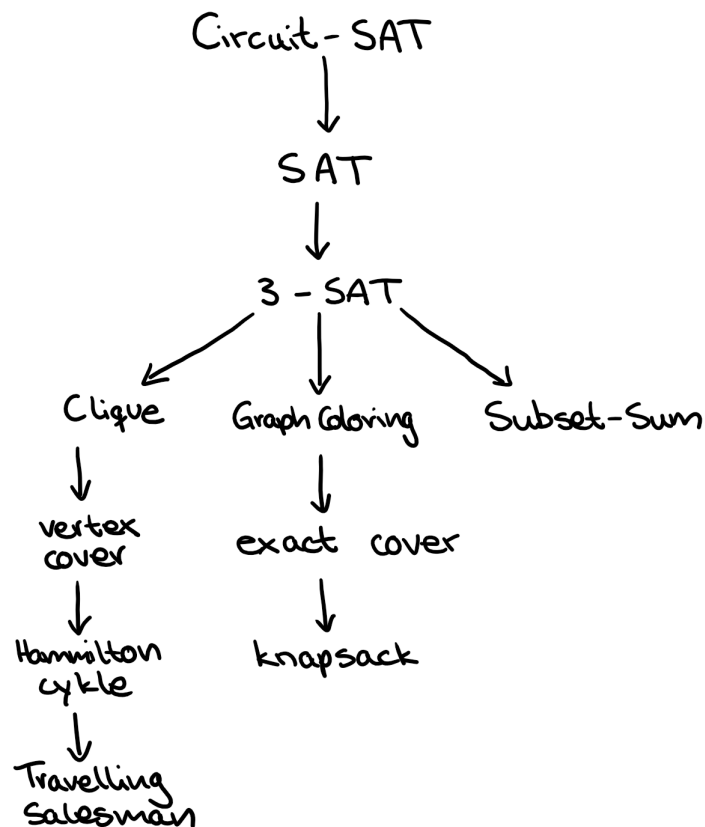


Figure 2: NP-complete problems in relation

- k -SAT for $k \geq 3$ is NP-complete

Circuit-SAT

The circuit satisfiability problem (CIRCUIT-SAT) is the decision problem of determining whether a given Boolean circuit has an assignment of its inputs that makes the output true.

SAT

The SAT (satisfiability) problem is the problem of determining if there exists an interpretation that satisfies a given Boolean formula. [9]

3-SAT

Like the SAT problem, 3-SAT is determining the satisfiability of a formula in CNF where each clause is limited to at most three literals.

Clique

The CLIQUE problem is the problem of finding cliques (subsets of vertices, all adjacent to each other, also called complete subgraphs) in a graph.

VertexCover

In graph theory, a VERTEXCOVER (sometimes NODECOVER) of a graph is a set of vertices that includes at least one endpoint of every edge of the grap

HamiltonCycle

A HAMILTONCYCLE is a graph cycle (i.e., closed loop) through a graph that visits each node exactly once.

TravellingSalesman

Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city exactly once and returns to the origin city?

GraphColoring

In graph theory, graph coloring is a special case of graph labeling. It is an assignment of colors to elements of a graph subject to certain constraints.

ExactCover

Given a collection S of subsets of set X , an exact cover is the subset S^* of S such that each element of X is contained is exactly one subset of S^* .

Knapsack

Given a set of items, each with a weight and a value, determine the number of each item to include in a collection so that the total weight is less than or equal to a given limit and the total value is as large as possible.

SubsetSum

The SUBSETSUM problem involves determining whether or not a subset from a list of integers can sum to a target value. For example, consider the list of $nums = [1, 2, 3, 4]$. If the target is 7 , there are two subsets that achieve this sum: $\{3, 4\}$ and $\{1, 2, 4\}$.

P-complete problems

- CIRCUITVALUE
- LINEARPROGRAMMING
- HORNSAT

CircuitValue

The CIRCUITVALUE Problem is the problem of computing the output of a given Boolean circuit on a given input.

In terms of time complexity, it can be solved in linear time (topological sort).

The problem is closely related to the SAT (Boolean Satisfiability) problem which is complete for NP and its complement, which is complete for co-NP.

LinearProgramming

HornSAT

TODO

NL problems

- 2-SAT
- REACHABILITY

2-Sat

Reachability

Given a graph G and two nodes $n_1, n_2 \in V$, is there path from n_1 to n_2 ?

A graph $G = (V, E)$ is a finite set V of nodes and a set E of edges as node pairs.

REACHABILITY can be nondeterministically solved in space $\log n$.

TODO

L problems

- 1-SAT

1-Sat

TODO

References

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- [5] *Image source: P-NP sets*. <https://www.techno-science.net/actualite/np-conjecture-000-000-partie-denouee-N21607.html>.
- [6] klaus-joern Lange. “The Boolean Formula Value Problem as Formal Language”. In: (Jan. 2012). DOI: 10.1007/978-3-642-31644-9_9.
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