

NP

Part a: EXP, P, and NP

Ian Ludden

Learning Objectives

By the end of this lesson, you will be able to:

Learning Objectives

By the end of this lesson, you will be able to:

- Know that you can decide in polynomial time whether a graph is 2-colorable (a.k.a. bipartite).

Learning Objectives

By the end of this lesson, you will be able to:

- Know that you can decide in polynomial time whether a graph is 2-colorable (a.k.a. bipartite).
- Know that the Tower of Hanoi puzzle has been proved to require exponential time.

Learning Objectives

By the end of this lesson, you will be able to:

- Know that you can decide in polynomial time whether a graph is 2-colorable (a.k.a. bipartite).
- Know that the Tower of Hanoi puzzle has been proved to require exponential time.
- Define EXP, P, and NP.

Learning Objectives

By the end of this lesson, you will be able to:

- Know that you can decide in polynomial time whether a graph is 2-colorable (a.k.a. bipartite).
- Know that the Tower of Hanoi puzzle has been proved to require exponential time.
- Define EXP, P, and NP.
- Know that problems in NP can be solved in exponential time, but it's not known whether they can all be solved in polynomial time.

Categorizing Problems

- How hard is a given problem, i.e., what is its *computational complexity*?

Categorizing Problems

- How hard is a given problem, i.e., what is its *computational complexity*?
- Which problems are “easy” and which are “hard”?

Categorizing Problems

- How hard is a given problem, i.e., what is its *computational complexity*?
- Which problems are “easy” and which are “hard”?
- Tower of Hanoi: requires $2^n - 1$ moves, so $\Theta(2^n)$ time

Categorizing Problems

- How hard is a given problem, i.e., what is its *computational complexity*?
- Which problems are “easy” and which are “hard”?
- Tower of Hanoi: requires $2^n - 1$ moves, so $\Theta(2^n)$ time

Categorizing Problems

- How hard is a given problem, i.e., what is its *computational complexity*?
- Which problems are “easy” and which are “hard”?
- Tower of Hanoi: requires $2^n - 1$ moves, so $\Theta(2^n)$ time

Definition

The complexity class **EXP** (short for *exponential time*) is the set of all problems that can be solved in exponential* time in the input size (or faster).

Categorizing Problems

- How hard is a given problem, i.e., what is its *computational complexity*?
- Which problems are “easy” and which are “hard”?
- Tower of Hanoi: requires $2^n - 1$ moves, so $\Theta(2^n)$ time

Definition

The complexity class **EXP** (short for *exponential time*) is the set of all problems that can be solved in exponential* time in the input size (or faster).

Definition

The complexity class **P** (short for *polynomial time*) is the set of all problems that can be solved in polynomial* time in the input size (or faster).

What is NP?

What is NP?

Definition

The complexity class **NP** (short for *nondeterministic polynomial time*) is the set of all *decision* problems for which you can verify the answer is “yes” in polynomial time given a proof/witness/certificate.

What is NP?

Definition

The complexity class **NP** (short for *nondeterministic polynomial time*) is the set of all *decision* problems for which you can verify the answer is “yes” in polynomial time given a proof/witness/certificate.

Example 1: Graph Coloring

Given a graph G and integer k , does G have a proper coloring with k colors?

Theorem

$$P \subseteq NP \subseteq EXP$$

Theorem

$P \subseteq NP \subseteq EXP$

Example 2: Vertex Cover

Given a graph G and integer k , does G have a vertex cover of size k ?

More Problems in NP

Example 3: Independent Set

Given a graph G and integer k , does G have an independent set of size k ?

More Problems in NP

Example 3: Independent Set

Given a graph G and integer k , does G have an independent set of size k ?

Example 4: Circuit SAT

Given a Boolean circuit, is there an assignment to the inputs that makes the output true/1?

Recap: Learning Objectives

By the end of this lesson, you will be able to:

- Know that you can decide in polynomial time whether a graph is 2-colorable (a.k.a. bipartite).
- Know that the Tower of Hanoi puzzle has been proved to require exponential time.
- Define EXP, P, NP.
- Know that problems in NP can be solved in exponential time, but it's not known whether they can all be solved in polynomial time.