



CSE 332: Data Structures & Parallelism

Lecture 25: P, NP, NP-Complete (part 2)

Ruth Anderson

Spring 2023

Today's Agenda

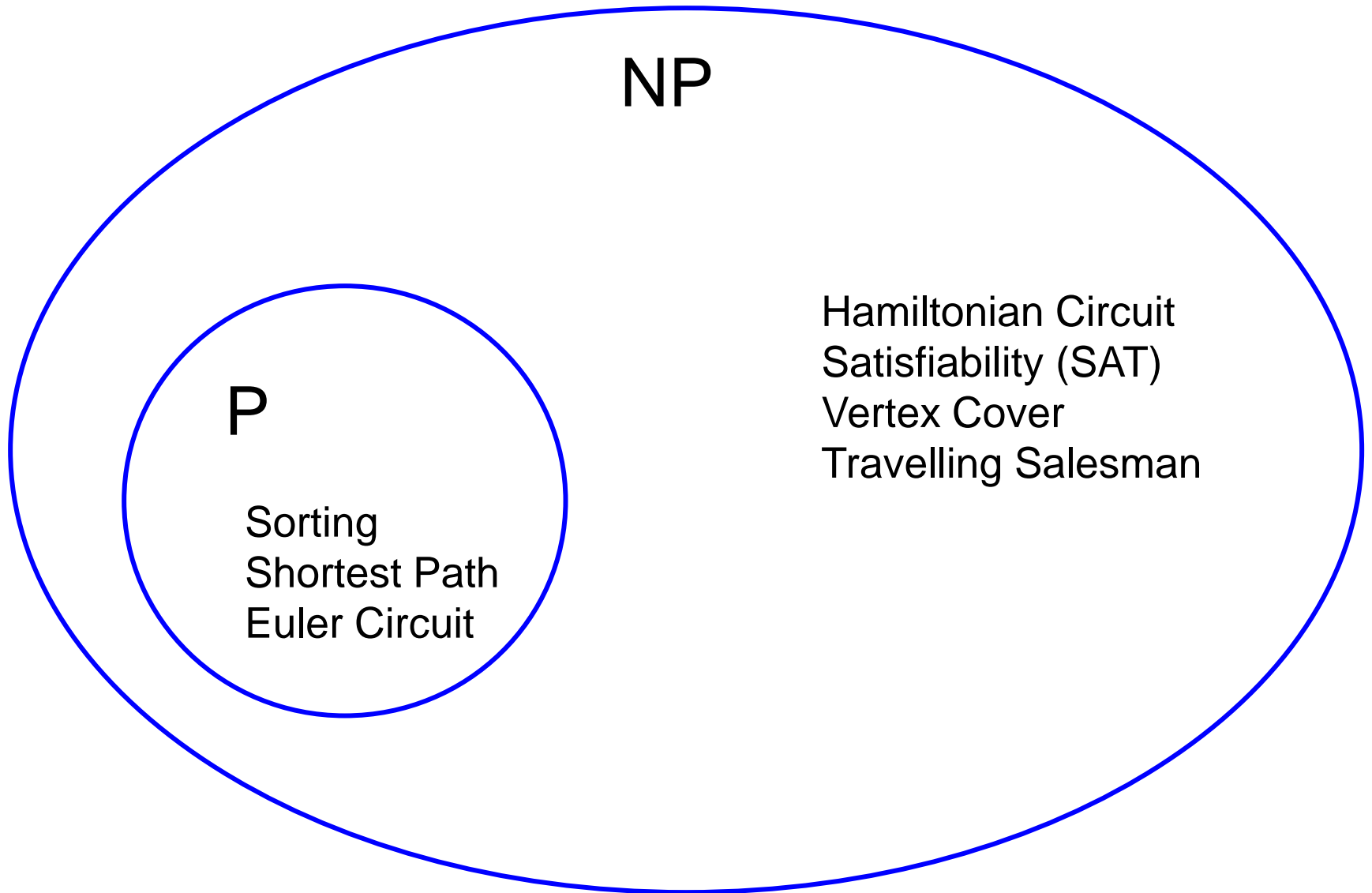
- A Few Problems:
 - Euler Circuits
 - Hamiltonian Circuits
- Intractability: P and NP
- NP-Complete
- What now?

A Glimmer of Hope

- If given a candidate solution to a problem, we can **check if that solution is correct in polynomial-time**, then maybe a polynomial-time solution exists?
- Can we do this with Hamiltonian Circuit?
 - Given a candidate path, is it a Hamiltonian Circuit?

The Complexity Class NP

- *Definition*: NP is the set of all problems for which a given *candidate solution* can be *tested* in polynomial time
- Examples of problems in NP:
 - *Hamiltonian circuit*: Given a candidate path, can test in linear time if it is a Hamiltonian circuit
 - *Vertex Cover*: Given a subset of vertices, do they cover all edges?
 - *All problems that are in P* (why?)



Why do we call it “NP”?

- NP stands for *Nondeterministic Polynomial time*
 - Why “nondeterministic”? Corresponds to algorithms that can guess a solution (if it exists), the solution is then verified to be correct in polynomial time
 - Can also think of as allowing a special operation that allows the algorithm to magically guess the right choice at each branch point.
 - Nondeterministic algorithms don't exist – purely theoretical idea invented to understand how hard a problem could be

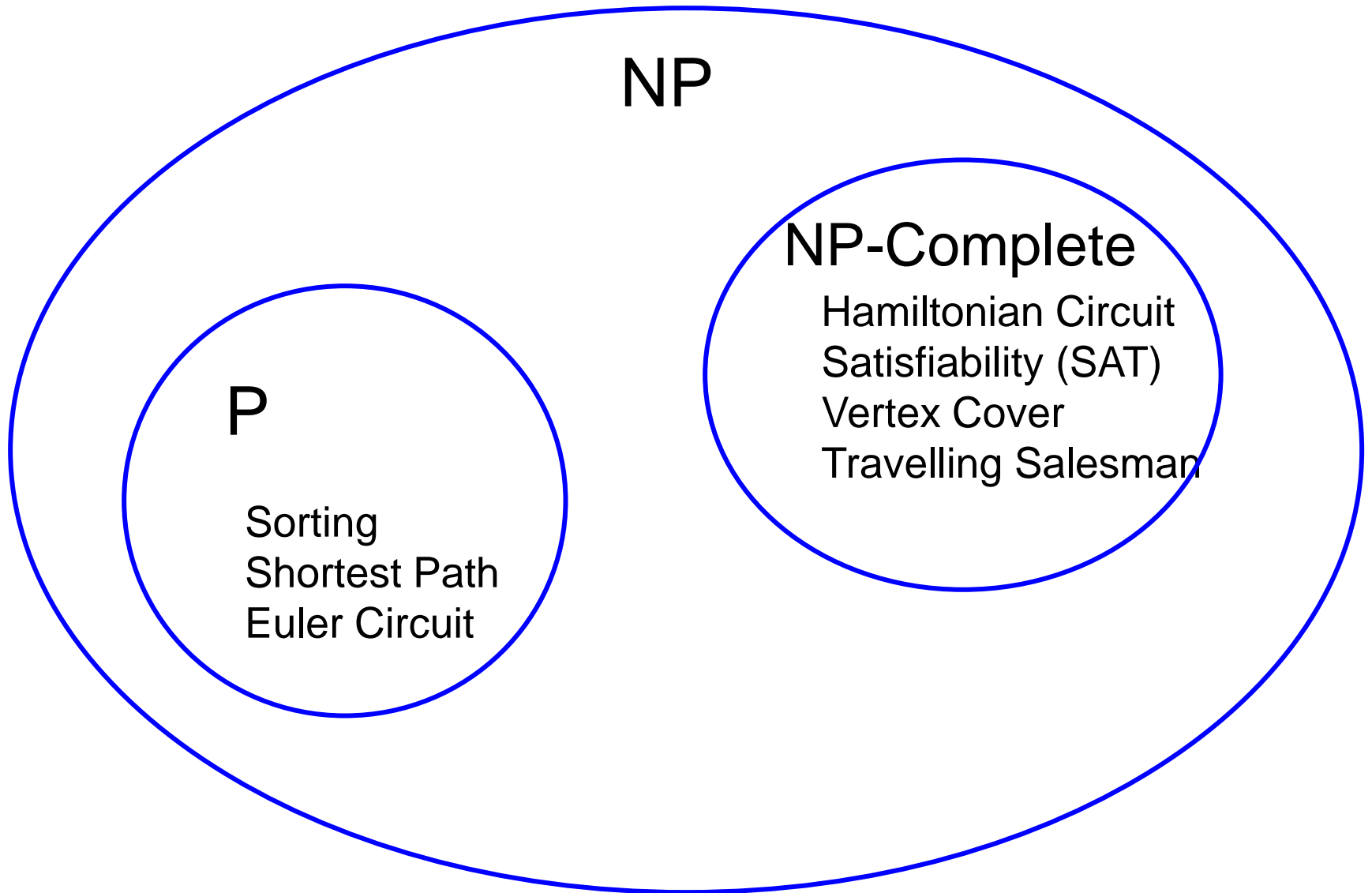
Your Chance to Win a Turing Award!

It is generally believed that $P \neq NP$,
i.e. there are problems in NP that are **not** in P

- But no one has been able to show even one such problem!
- This is the fundamental open problem in theoretical computer science
- Nearly everyone has given up trying to prove it. Instead, theoreticians prove theorems about what follows once we assume $P \neq NP$!

NP-completeness

- Set of problems in NP that (we are pretty sure) **cannot** be solved in polynomial time.
- These are thought of as the **hardest** problems in the class NP.
- **Interesting fact:** If any one NP-complete problem could be solved in polynomial time, then **all** NP-complete problems could be solved in polynomial time.
- **Also:** If any NP-complete problem is in P, then all of NP is in P



Saving Your Job

- Try as you might, every solution you come up with for the Hamiltonian Circuit problem runs in exponential time.....
- You have to report back to your boss.
- Your options:
 - Keep working
 - Come up with an alternative plan...

In general, what to do with a Hard Problem

- Your problem seems really hard.
- If you can **transform a known NP-complete problem into the one you're trying to solve**, then you can stop working on your problem!

Your Third Task

- Your boss buys your story that others couldn't solve the last problem.
- Again, your company has to send someone by car to a set of cities. There is a road between every pair of cities.
- The primary cost is distance traveled (which translates to fuel costs).
- Your boss wants you to figure out how to drive to each city exactly once, then return to the first city, while staying within a fixed mileage budget k .

Travelling Salesman Problem (TSP)

- Your third task is basically TSP:
 - Given complete weighted graph G , integer k .
 - Is there a cycle that visits all vertices with cost $\leq k$?
- One of the canonical problems.
- Note difference from Hamiltonian cycle:
 - graph is complete
 - we care about weight.

Transforming Hamiltonian Cycle to TSP

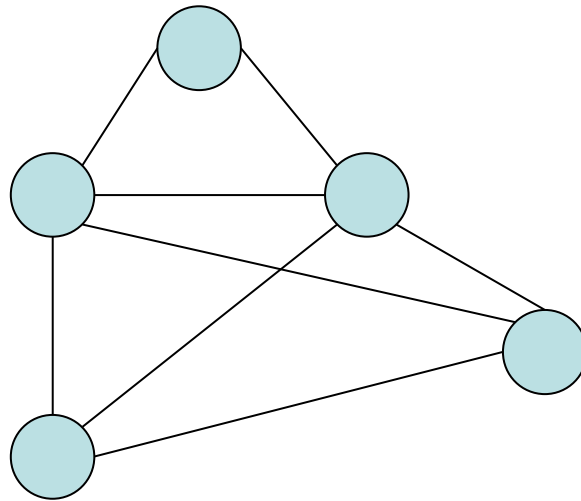
- We can “reduce” Hamiltonian Cycle to TSP.
- Given graph $G=(V, E)$:
 - Assign weight of 1 to each edge
 - Augment the graph with edges until it is a complete graph $G'=(V, E')$
 - Assign weights of 2 to the new edges
 - Let $k = |V|$.

Notes:

- The transformation must take polynomial time
- You reduce the known NP-complete problem into your problem (not the other way around)

6/02/2023 In this case we are assuming Hamiltonian Cycle is our known NP-complete problem (in reality, both are known NP-complete) 15

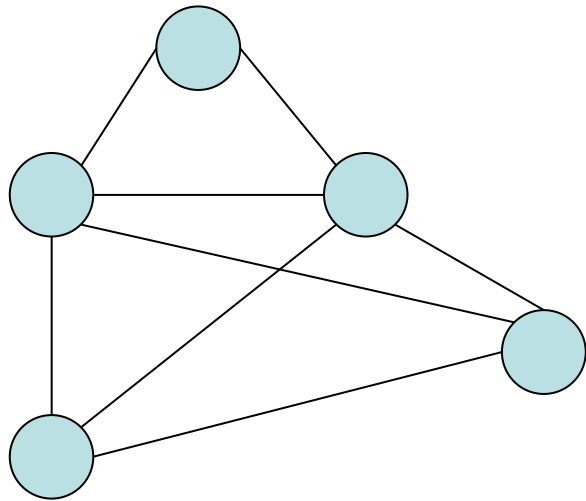
Example



G

Input to Hamiltonian
Circuit Problem

Example

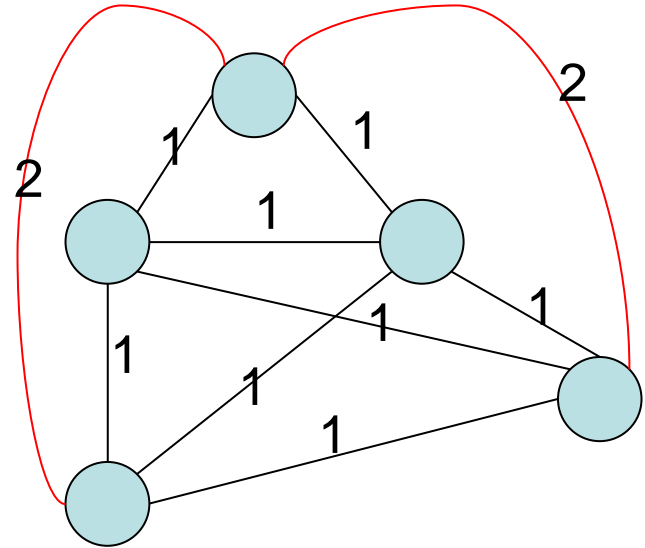


G

Input to Hamiltonian
Circuit Problem



Polynomial time
transformation



G'

Input to Traveling
Salesman Problem

Polynomial-time transformation

- G' has a TSP tour of weight $|V|$ iff G has a Hamiltonian Cycle.
- What was the cost of transforming HC into TSP?
- In the end, because there is a polynomial time transformation from HC to TSP, we say *TSP is “at least as hard as” Hamiltonian cycle.*

What do we do about it?

- Approximation Algorithm:
 - Can we get an efficient algorithm that guarantees something *close* to optimal? (e.g. Answer is guaranteed to be within 1.5x of Optimal, but solved in polynomial time).
- Restrictions:
 - Many hard problems are easy for restricted inputs (e.g. graph is always a tree, degree of vertices is always 3 or less).
- Heuristics:
 - Can we get something that seems to work well (good approximation/fast enough) *most* of the time? (e.g. In practice, n is small-ish)

Great Quick Reference

- *Computers and Intractability: A Guide to the Theory of NP-Completeness*, by Michael S. Garey and David S. Johnson

