

GEM 1501 Problem Solving With Computers

Lecture 6:

Inefficiency and Intractability

Martin Henz

Overview of Today's Lecture

- Growth of functions
- NP-complete problems
- Is P equal NP?
- Even worse problems

Summary of Previous Lecture

- Correctness of algorithms
 - Kinds of errors
 - Sources of errors
 - Correctness
- Efficiency of algorithms
 - Example
 - Big-O
 - Recurrences

Complexity of Towers of Hanoi

- For N rings, the number of moves is $2^N - 1$.
- On a 1 GHz computer with one move per clock cycle, it would take 36 years to move 60 rings!
- 70 rings would take about 40000 years!
- 80 rings would take about 50 million years!

What's the problem?

- The problem “Towers of Hanoi” is so hard, because the output (moves) is so long.
- How about problems with short answers?
- Let us focus on problems with yes/no answers!
- These problems are called “decision problems”.

Example: Monkey Puzzle

- Assume an $M \times M$ board with tiles.
- Arrange $N = M^2$ tiles so that the edges match.
- Simple solution: Try all possible ways!
- This approach is “impractical”!
- Why?

Growth of Functions

- Table of functions (10, 50, 300)
- Table for monkey puzzle (10, 50, 300)
- Log-log graph

Intractable Problems

- Polynomial problems can be solved in time $O(N^k)$ for some constant k .
- For exponential problems, there is no k such that the problem is in $O(N^k)$.
- For some problems, we don't know!

Can we wait for faster computers?

- What if we use a computer 100 times faster?
- What if we use 1000 computers hooked together?
- Polynomial problems and exponential problems really behave differently!

NP-Complete Problems

- For this class of problems, we don't know whether they are polynomial or exponential.
- We know that they can be solved in exponential time (upper bound).
- Solving many of them requires at least linear time (lower bound).

Examples of NP-Complete Problems

- Monkey problem
- Traveling salesman problem
- Timetabling problem
- Satisfiability problem
- Coloring a map with three colors
- Hamiltonian path problem

NP-Complete Problems have Short Certificates

- If the answer to the decision problem is "yes", we are asking for a proof.
- One way to prove the answer is to provide a "certificate".
- NP-Complete problems have small certificates (often linear) and the proof of the certificate is fast (also often linear).
- Examples:
 - Monkey problem
 - Timetabling problem
 - Satisfiability problem
 - Coloring a map with three colors

What does “NP” stand for?

- NP stands for “non-deterministic polynomial”
- A “non-deterministic computer” is a computer that can guess the right answer.
- Another way of thinking about it: Each time we have a choice between K alternatives, we make K copies of the computer.

NP-complete Problems Stand and Fall Together

- All NP-complete problems are equivalent!
- If we can solve one in polynomial time, we can solve all.
- How come?
- By transformation!
- Example: Transforming the Hamiltonian path problem into a traveling salesman problem.

Is P Equal to NP?

- Question lies at the heart of “Algorithmics”
- Unsolved since it was posed in 1971
- Most people believe that $P \neq NP$, but no one knows for sure
- NP-completeness is good evidence for its probable intractability

Update on Primality

- Book (second edition) says that primality testing is unsolved
- In 2002, Prof. Manindra Agarwal (IIT Kanpur) and two of his students, Nitin Saxena and Neeraj Kayal gave a polynomial algorithm ($O((\log n)^{12}f(\log \log n))$ where f is a polynomial)

Provably Intractable Problems

- Let us generalize checkers to an $N \times N$ board.
- Let us say you have a strategy of playing checkers.
- The problem is to decide whether the strategy always wins.
- This problem is provably intractable.
- There will *never* be a program that can efficiently decide whether a given strategy will always win.

Worse Than Exponential

- There are problems that need a runtime of 2^{2^N} .
- Example: Presburger arithmetic
- These problems are called “double-exponential”.
- There are also “triple-exponential”.
- Problems that are not “K-exponential” are called “nonelementary”.

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Next Week

- Midterm
- Noncomputability and undecidability