CSE 417: Algorithms and Computational Complexity

Lecture 1: Overview

Winter 2022

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University of Washington
Computer Science & Engineering

CSE 417, Wi '22: Algorithms & Computational Complexity

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- E-mail Course Staff

Lecture Notes
- 1: Overview & Example

Lecture Recordings
- Here

Lecture: (By Zoom, Week 1 at least), MWF 9:30-10:20

Zoom: https://washington.zoom.us/j/94357067917 Requires login to Zoom with a UWNetID.

		Office Hours	Location	Phone
Instructor:	Larry Ruzzo, ruzzo@cs	TBD	Zoom	
TAs:	Nathan Akkaraphab, akkanath@cs	TBD		
	Todor Dimitrov, todord@cs	TBD		
	William Viet Nguyen, williamv@cs	TBD		
	Lin Qiu, lq9@cs	TBD		
	Luna Wang, zhengw28@cs	TBD		
	Yifan Zhang, yifanz47@cs	TBD		
	Yilin Zhang, yilinz24@cs	TBD		

Course Email: cse417a_wi22@uw.edu. Staff ... lectures, etc. The instructor and TAs are subscribed to this list. Enroll... ...iption options. Messages are automatically archived.

Discussi... ...cuss homework, etc.

...structures. Efficient algorithms for manipulating graphs and strings. Fast Fourier ...machines. Time and space complexity. NP-complete problems and undecidable problems.

http://courses.cs.washington.edu/417

...TBD

Late Policy: TBD

Required Text: *Algorithm Design* by Jon Kleinberg and Eva Tardos. Addison Wesley, 2006. (Available from U Book Store, Amazon, etc.)

References: See Schedule & Reading.

What you'll have to do

Homework (~~~55%~~ 100% of grade)

- Programming
  - Several small projects
- Written homework assignments
  - English exposition and pseudo-code
  - Analysis and argument as well as design

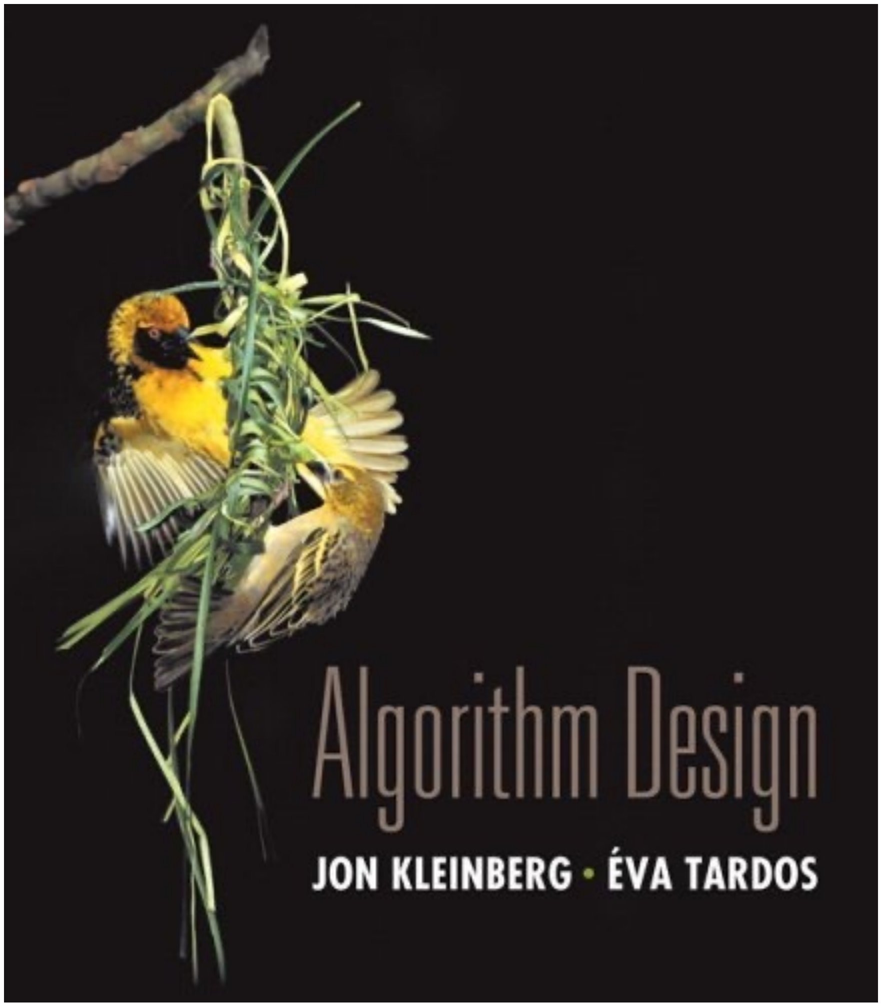
~~Midterm / Final Exam (~15% / 30%)~~

Late Policy: TBD

- ~~Papers and/or electronic turnins are due at the *start* of class on the due date. 10% off for one day late; 15% per day thereafter.~~

"Mastery Grading":
If you can solve it, you get credit for "mastering" the concept, with a chance to resubmit/regrade some work each week.
Details TBD

Textbook



Algorithm Design by Jon Kleinberg and Eva Tardos. Addison Wesley, 2006.

What the course is about

Design of Algorithms

- design methods
- common or important types of problems
- analysis of algorithms - efficiency
- correctness proofs

What the course is about

Complexity, NP-completeness and intractability

- solving problems in principle is not enough
  - algorithms must be *efficient*
- some problems have *no efficient solution*
- NP-complete problems
  - important & useful class of problems whose solutions (seemingly) cannot be found efficiently, but *can* be checked easily

Very Rough Division of Time

Algorithms (7-8 weeks)

- Analysis of Algorithms
- Basic Algorithmic Design Techniques
- Applications

Complexity & NP-completeness (2-3 weeks)

Check online schedule page for (evolving) details

University of Washington
Computer Science & Engineering

CSE 417, Wi '06: *Approximate* Schedule

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		Due	Lecture Topic	Reading
Week 1 1/2-1/6	M		Holiday	
	W		Intro, Examples & Complexity	Ch. 1; Ch. 2
	F		Intro, Examples & Complexity	
Week 2 1/9-1/13	M		Intro, Examples & Complexity	
	W		Graph Algorithms	Ch. 3
	F		Graph Algorithms	

Complexity Example

Cryptography (e.g., RSA, SSL in browsers)

Secret: p,q prime, say 512 bits each

Public: n which equals p x q, 1024 bits

In principle

there is an algorithm that given n will find p and q:
try all $2^{512} > 1.3 \times 10^{154}$ possible p's: kinda slow…

In practice

no fast algorithm known for this problem (on non-quantum computers)

security of RSA depends on this fact

("quantum computing": strongly driven by possibility of changing this)

Algorithms versus Machines

You may know about Moore's Law and the exponential improvements in hardware...

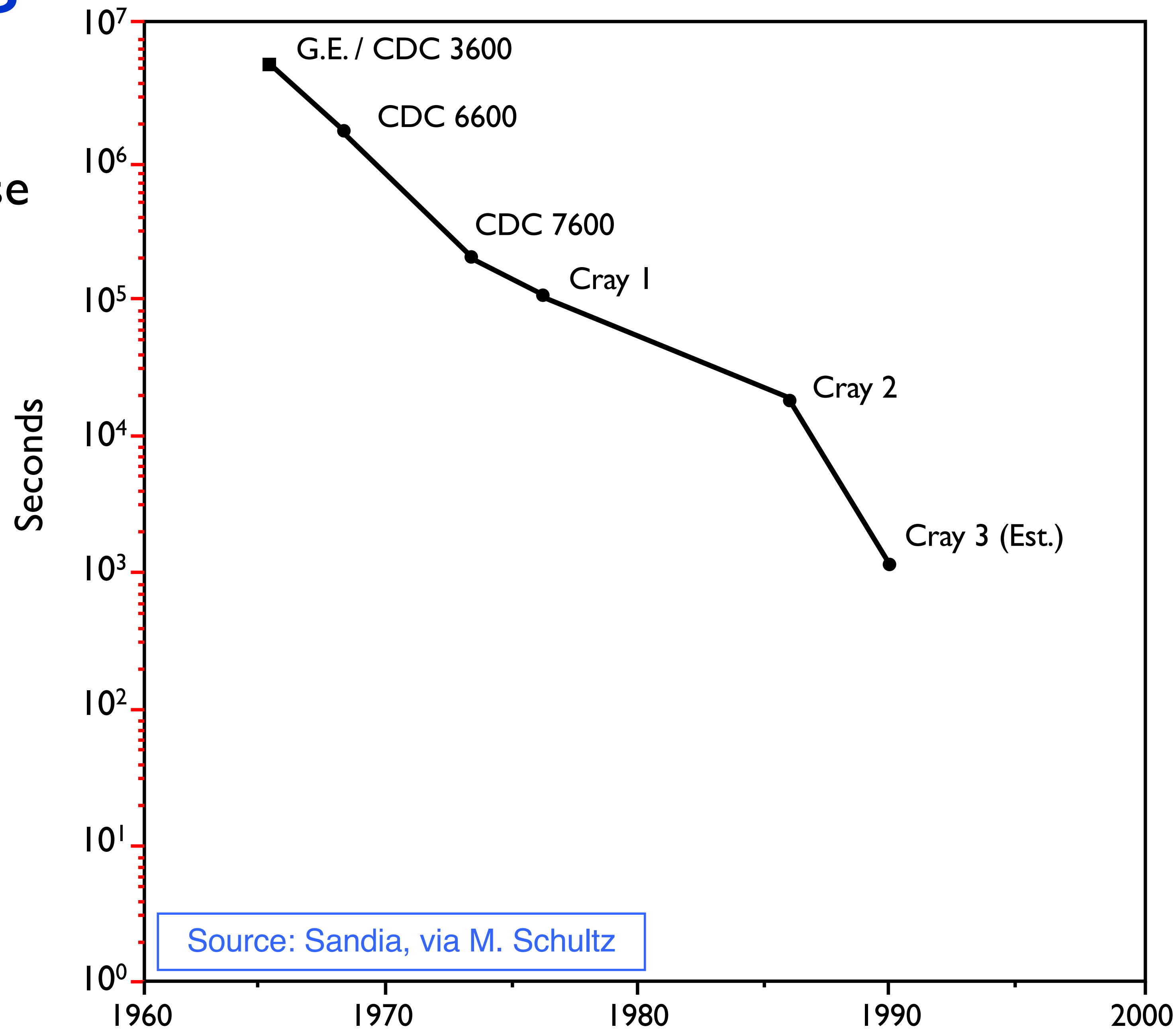
Ex: sparse linear equations over 25 years

10 orders of magnitude improvement!

Algorithms or Hardware?

25 years progress solving sparse linear systems

hardware: 4 orders of magnitude

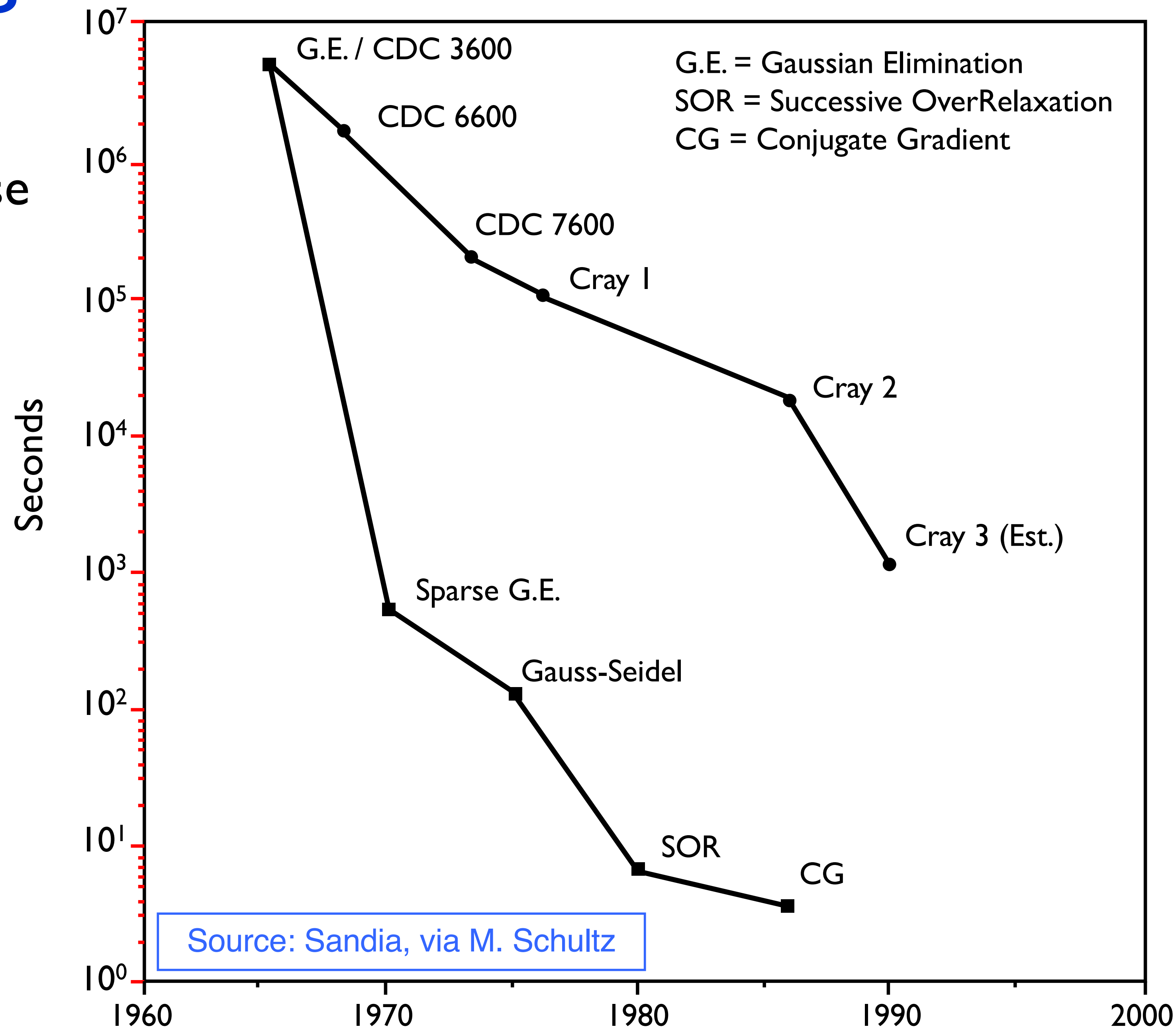


Algorithms or Hardware?

25 years progress solving sparse linear systems

hardware: 4 orders of magnitude

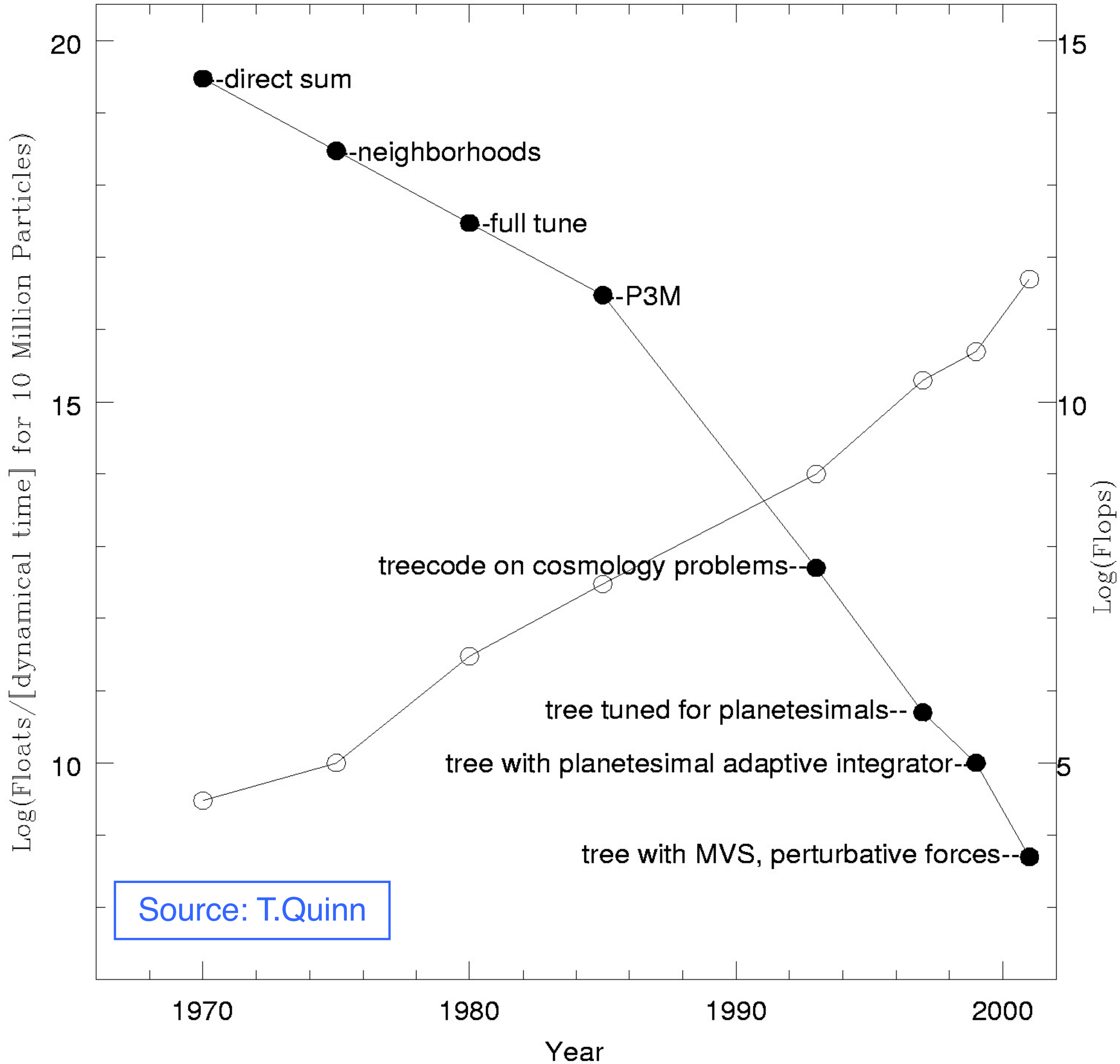
software: 6 orders of magnitude



Algorithms or Hardware?

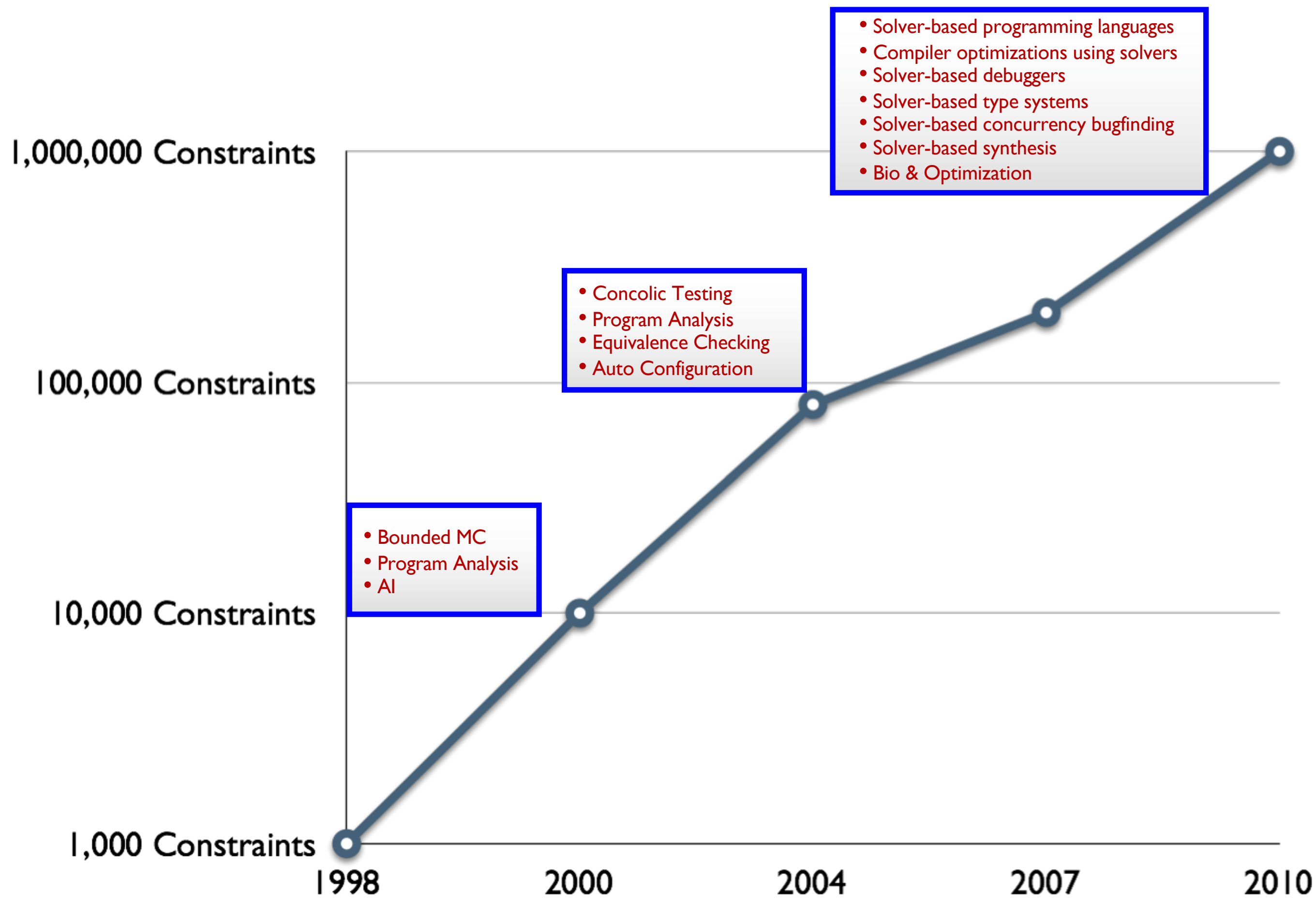
The N-Body Problem:

in 30 years
10^7 hardware
10^{10} software



Algorithms or Hardware?

SAT/SMT Solvers: 1000x improvement in a dozen years



Data courtesy of Dr. Vijay Ganesh, U. Waterloo

Algorithm: definition

Procedure to accomplish a task or solve a well-specified problem

- Well-specified: know what all possible inputs look like and what output looks like given them
- "accomplish" via simple, well-defined steps
- Ex: sorting names (via comparison)
- Ex: checking for primality (via +, -, *, /, ≤)

Goals

Correctness

- often subtle

Analysis

- often subtle

Generality, Simplicity, ‘Elegance’

Efficiency

- time, memory, network bandwidth, …

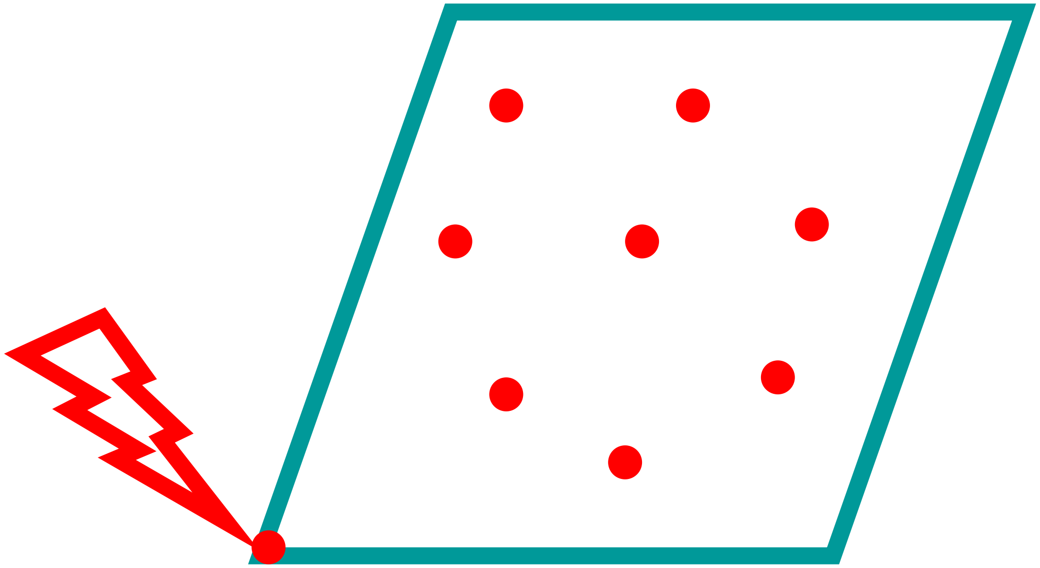
Algorithms: a sample problem

Printed circuit-board company has a robot arm that solders components to the board

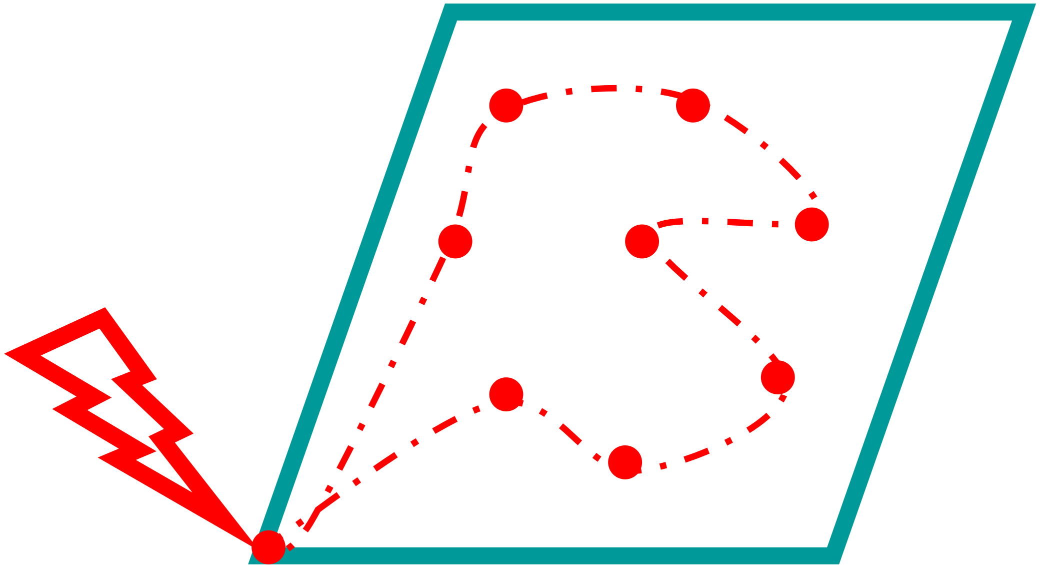
Time: proportional to total distance the arm must move from initial rest position around the board and back to the initial position

For each board design, find best order to do the soldering

Printed Circuit Board



Printed Circuit Board



A Well-defined Problem

Input: Given a set *S* of *n* points in the plane

Output: The shortest cycle tour that visits each point in the set *S* once.

Better known as "TSP"

How might you solve it?

Nearest Neighbor Heuristic

heuristic: A rule of thumb, simplification, or educated guess that reduces or limits the search for solutions in domains that are difficult and poorly understood. May be good, but *not* proven to give the best or fastest solution.

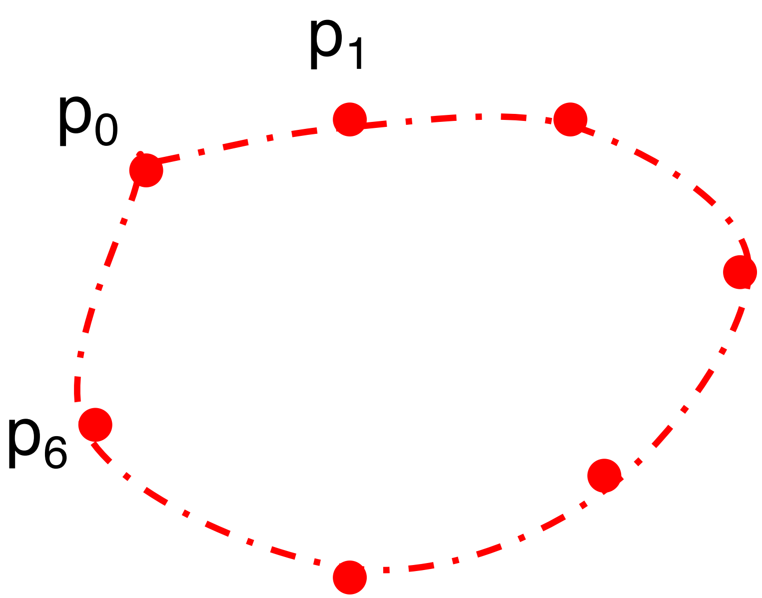
Start at some point p_0

Walk first to its nearest neighbor p_1

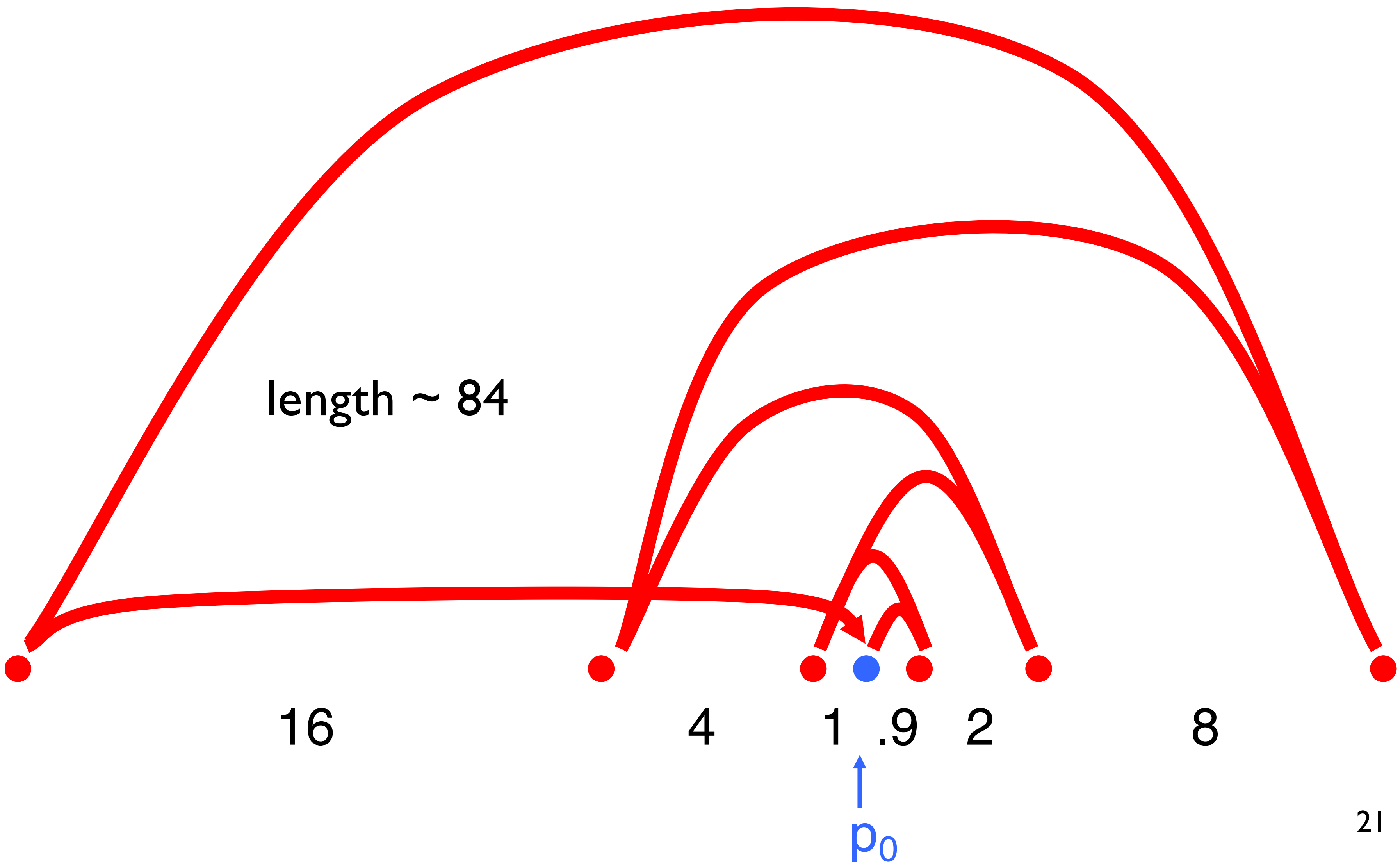
Repeatedly walk to the nearest unvisited neighbor p_2, then p_3,… until all points have been visited

Then walk back to p_0

Nearest Neighbor Heuristic



An input where NN works badly



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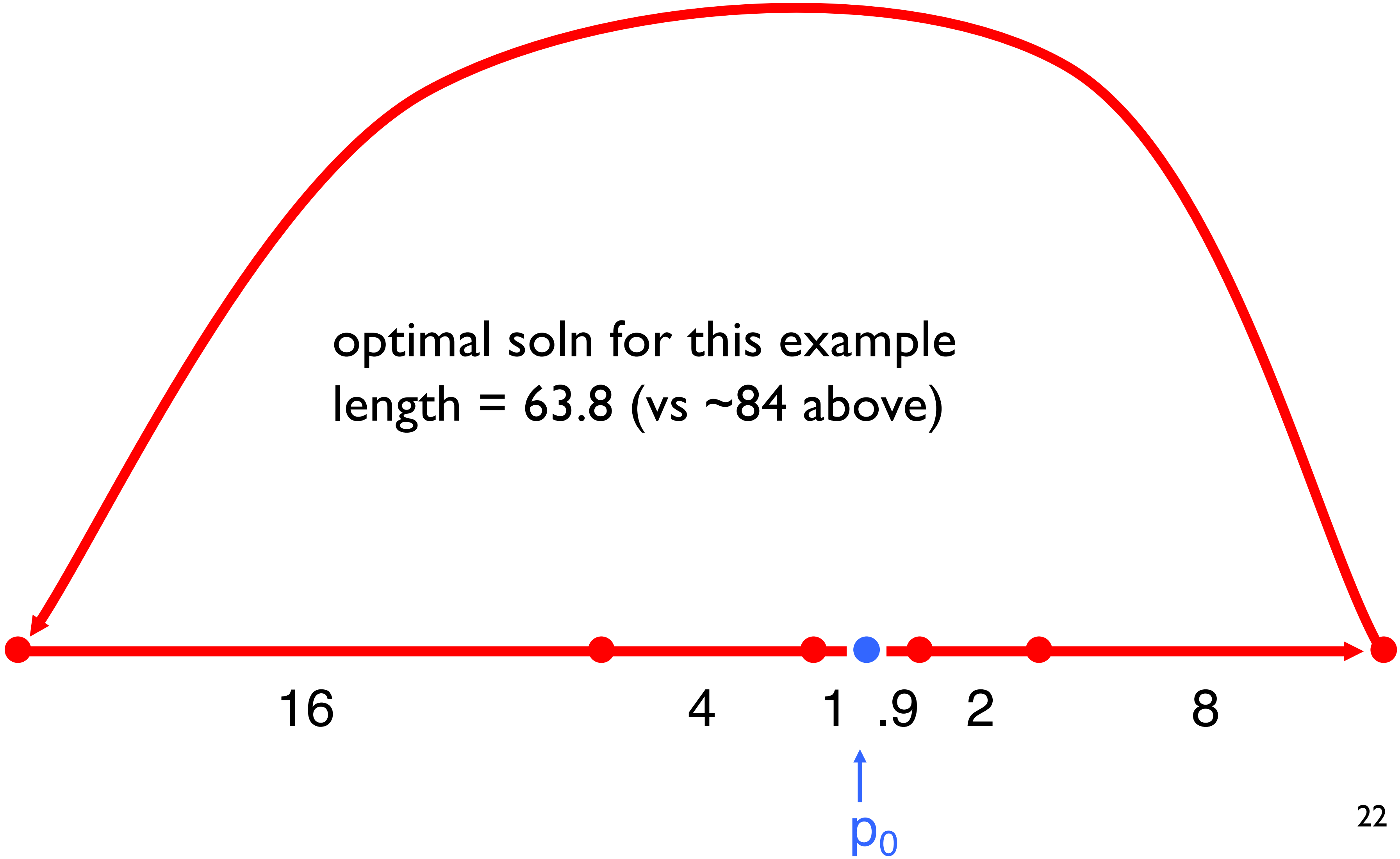
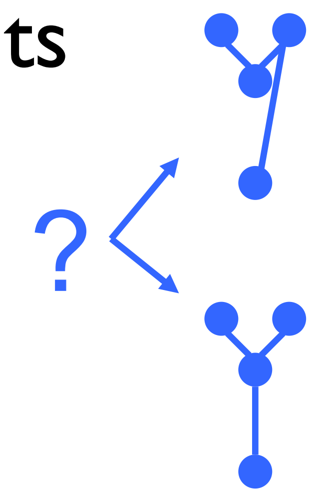


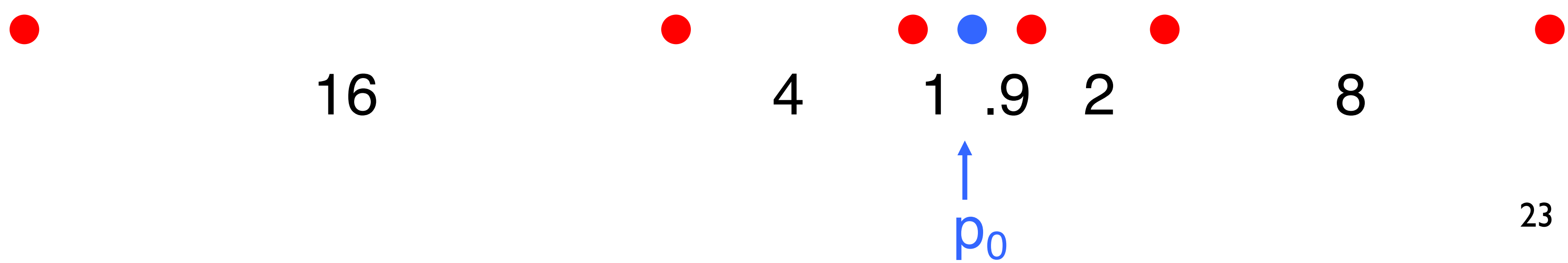
Revised idea - Closest pairs first

Repeatedly join the closest pair of points

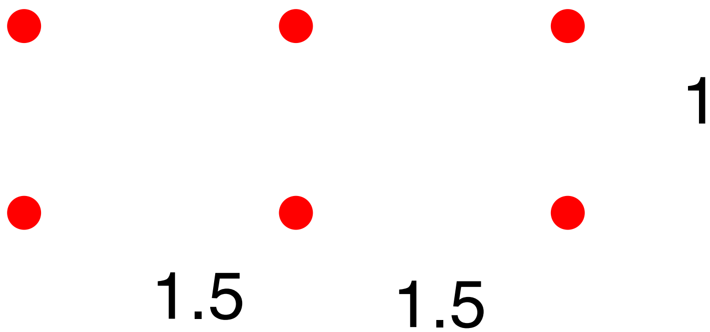
(s.t. result can still be part of a single loop in the end. I.e., join endpoints, but not points in middle, of path segments already created.)



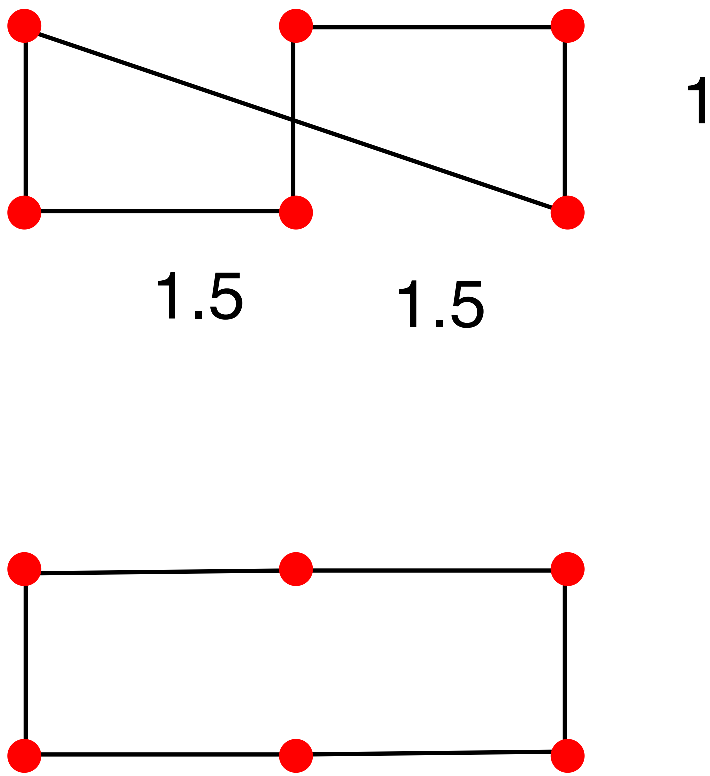
How does this work on our bad example?



A bad example for "close pairs"



A bad example for “close pairs”



$6+\sqrt{10} \approx 9.16$

vs

8

Something that works

"Brute Force Search":

For each of the $n! = n(n-1)(n-2)\ldots1$ orderings of the points, check the length of the cycle you get

Keep the best one

(Easy to see that it's correct, but slow!)

Two Notes

The two *in*correct algorithms were "greedy"

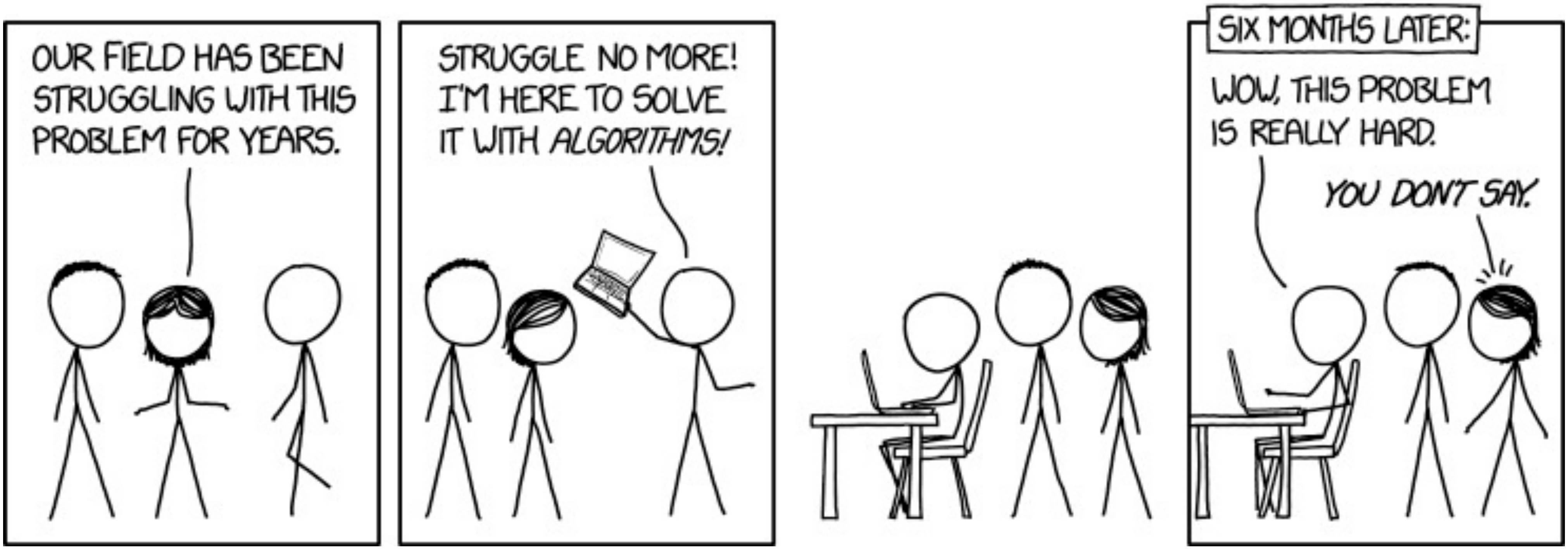
- Often very natural & tempting ideas
- They make choices that look great "locally" (and never reconsider them)
- When greed works, the algorithms are typically efficient
- BUT: often does not work - you get boxed in

Our correct alg avoids this, but is incredibly slow

- 20! is so large that checking one billion orderings per second would take 2.4 billion seconds (around 70 years!)
- And *growing*: $n! \sim \sqrt{2 \pi n} \cdot (n/e)^n \sim 2^{O(n \log n)}$

The Morals of the Story

- Algorithms are important
  - Many software gains outstrip hardware gains (Moore's law)
- Simple problems can be hard
  - Factoring, TSP
- Simple ideas don't always work
  - Nearest neighbor, closest pair heuristics
- Simple algorithms can be very slow
  - Brute-force factoring, TSP
- For some problems, even the *best* algorithms are slow
- Course Goals:
  - formalize these ideas, and
  - develop more sophisticated approaches



https://xkcd.com/