CSE 417
Practical Algorithms
(a.k.a. Algorithms & Computational Complexity)

UNIVERSITY *of* WASHINGTON

Outline for Today

> Course Goals & Overview ←
> Administrivia
> Greedy Algorithms

Why study algorithms?

> Learn the history of important algorithms

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- ~~Learn the history of important algorithms~~

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- ~~Impress your friends with your knowledge~~
- ~~Inventing new algorithms is part of the everyday work of computer scientists in practice~~
- Algorithms are critical to the successful use of computers in every subfield of CS

Applications of Important Algorithms

- compilers
- databases
- networking
- cryptography
- AI & machine learning
- computational biology
- signal processing
- computer graphics
- scientific computing
- web search
- big data analytics
- ...

Applications of Important Algorithms

"Everyone knows Moore's law — a prediction made in 1965 by Intel co-founder Gordon Moore that the density of transistors in integrated circuits would continue to double every 1 to 2 years.... In many areas, performance gains due to improvements in algorithms have vastly exceeded the dramatic performance gains due to increased processor speed."

— Excerpt from *Report to the President and Congress: Designing a Digital Future*, December 2010 (page 71)

Why study algorithms?

- Algorithms are critical to the successful use of computers in every subfield of computer science
  - understanding the underlying techniques will make these algorithms easier to follow when you encounter them in other subfields
- There will be opportunities to invent new algorithms in practice
  - and when you do so, it often has a *huge* impact
  - the previous slides are examples of this
- (Algorithms also come up in coding interviews.)

Course Goal

> Teach you techniques that you can use to create new algorithms **in practice** when the opportunity arises
  - (or in coding interviews)
  - they will also help you understand existing algorithms

Course Non-Goals

- Teach you the most historically important algorithms
  - we will see some important algorithms, but this will not be a survey course on important algorithms
- Teach you the *fastest* known algorithms for problems
  - they are usually not the best demonstrations of the techniques that we want to discuss

Course Topics

1. Shortest Paths (mainly in HW)
2. Binary Search
3. Divide & Conquer
4. Dynamic Programming
5. Network Flows
6. Branch & Bound

Course Topics

Design Techniques

1. Divide & Conquer
2. Dynamic Programming
3. Branch & Bound

Modeling Techniques

1. Shortest Paths
2. Binary Search
3. Network Flows

Course Topics

Design Techniques

1. Divide & Conquer
2. Dynamic Programming
3. Branch & Bound

Techniques that you can apply to design new algorithms

- each of these has a good chance of being useful in practice

Course Topics

Modeling Techniques

1. Shortest Paths
2. Binary Search
3. Network Flows

Solve new problems by transforming them into familiar ones

- these three are the most likely to show up in practice
- learning to recognize them is a useful skill

Course Topics vs Usual

1. Binary Search
2. Divide & Conquer
3. Dynamic Programming
4. Network Flows
5. Branch & Bound

1. Greedy
2. Divide & Conquer
3. Dynamic Programming
4. Network Flows
5. NP-Completeness

Course Topics vs Usual

1. *Binary Search*
2. Divide & Conquer
3. Dynamic Programming
4. Network Flows
5. *Branch & Bound*
   – (and NP-completeness)

1. ~~Greedy~~ (today only)
2. Divide & Conquer
3. Dynamic Programming
4. Network Flows
5. NP-Completeness

> Topics will be fairly standard, but emphasis will be different

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People

> **Instructor**	Kevin Zatloukal	kevinz at cs
> **TAs**	Phillip Dang	phdang1 at uw
	Angli Liu	anglil at uw
	Alon Milchgrub	alonmil at uw

About Me

> UW graduate

> Ph.D. from MIT
  – quantum algorithms

> Worked in industry for 15 years
  – Google, Microsoft, BEA Systems, startup

Prerequisites (from CSE 373)

- Asymptotic complexity and big-O notation

- Familiar with some algorithms for
  - sorting
  - shortest paths
  - minimum spanning trees

Format

> Lectures Mon, Wed, Fri
  - slides will be posted
  - but they are just visual aids

> No quiz sections

> Office hours Tue, Wed, Thu, Fri

Workload

> 9 homework assignments
  – 4 on paper
  – 5 coding

> final exam (no midterm)

Grading

- 25% written assignments
- 50% coding assignments
- 25% final exam

Coding assignments best test the skills I care about

Late Policy

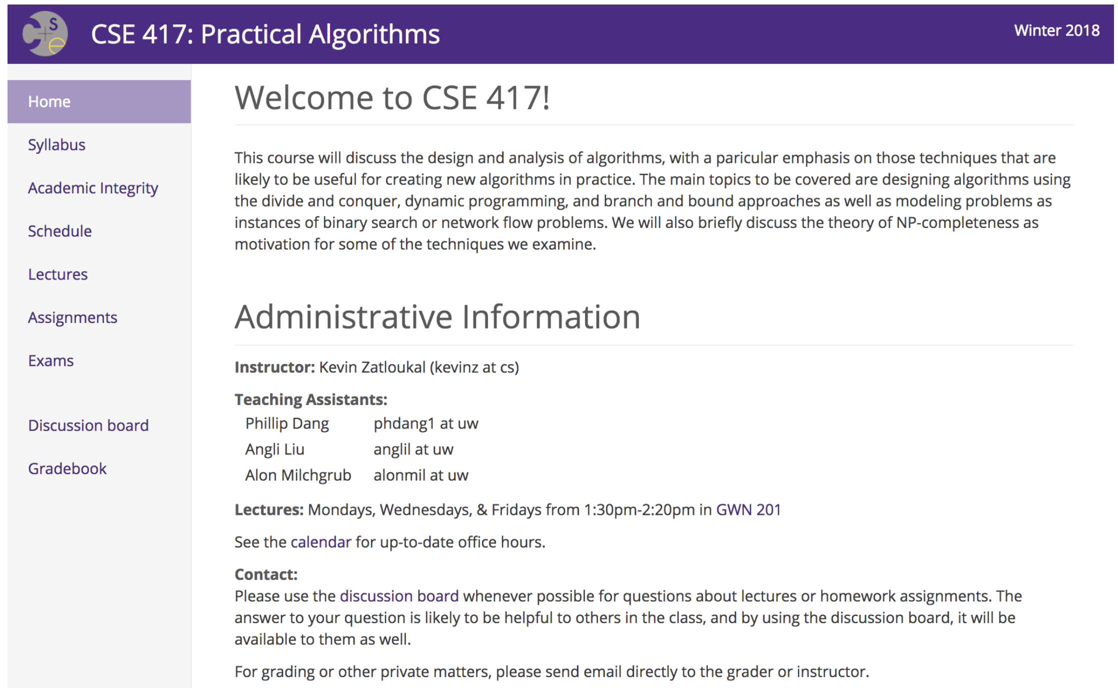
> 10 percent penalty per late day
  – but life happens so...

> 3 free late days for the quarter
  – each is a 24 hour extension
  – save for true emergencies

Collaboration

- Discussing course content with others is encouraged
- Be sure to use the Piazza discussion board
- BUT assignments are to be completed **individually**
  - misrepresenting others' work as your own is academic misconduct
- See the course web site for detailed policy

Web Site



> Main source of info:
  - OO times & locations
  - assignments
  - calendar
  - link to Piazza (discussion board)

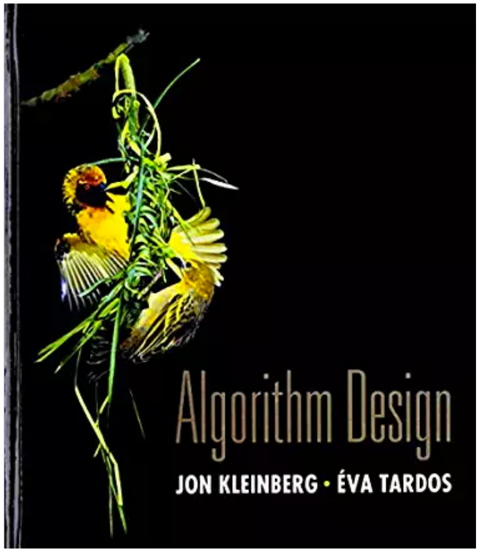
> https://courses.cs.washington.edu/courses/cse417/18wi

Textbook

> *Algorithm Design* by Kleinberg & Tardos
  – good introduction and useful reference

> Many other good books:
  – e.g. Introduction to Algorithms by Cormen, Leiserson, & Rivest

> I may also make use of other sources, especially:
  – Combinatorial Optimization by Papadimitriou & Steiglitz
  – Network Flows by Ahuja, Magnanti, & Orlin
  – both are advanced texts but could be useful after the course



Other Materials

- Tim Roughgarden (Stanford) has video lectures posted on youtube
- They cover many of the topics that we will discuss
  - He also has lectures from follow-on courses on some more advanced topics
- Also testing out recording of these lectures...

Warning

- Designing this version of the course from scratch
  - all new assignments, some new topics, etc.
- Will **need your feedback**
  - reasonableness of workload
  - choice of due dates
  - topics that do and don't make sense
  - etc.

Outline for Today

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- Greedy Algorithms ⇐

What is a *greedy* algorithm?

- For problems that involve a series of **choices**
  - often an optimization problem (e.g., max or min something)
- Greedy approach makes each decision in a way that is optimal for that **individual choice** ignoring implications for future choices
- Rarely does this ever produce optimal solutions...

Real-life example

- When the alarm goes off in the morning, hitting the snooze button six times in a row seems like a great idea
  - maximizes happiness during that time period
- But those decisions affect future options available...
- Sleeping through lecture is probably not optimal

What is a *greedy* algorithm?

- The greedy approach rarely produces optimal solutions
  But sometimes it does!

- Those are **greedy algorithms**
  - they compute the actual solution
  - (otherwise, it is called a “greedy heuristic”)

Example: minimum spanning tree

- **Input**: connected, weighted graph G with n nodes

- let F be an empty graph on the same nodes
  for i = 1 to n – 1:
          add the lowest weight edge of G that does not create a cycle

- This is Kruskal's algorithm
  - returns a spanning tree: a graph with n – 1 edges and no cycles
- For each of the n – 1 decisions of which edge to add, it chooses the edge of lowest weight
  - no regard for implications on future choices

Example: minimum spanning tree

- Clear that it returns a spanning tree
- **Not clear** that it returns the *minimum weight* spanning tree

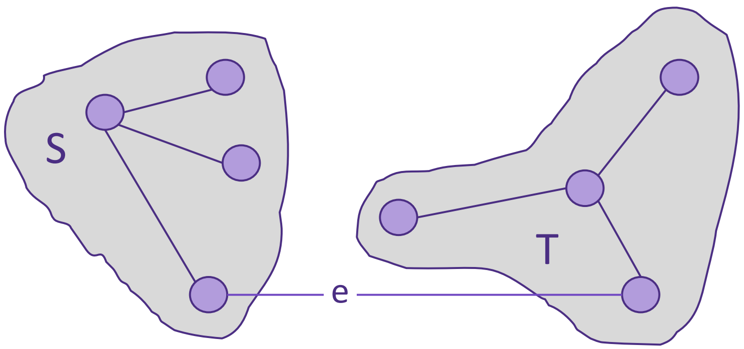
- Choices we make in one iteration affect later iterations
  - by picking the lowest weight edge in one cycle, we could miss out on an edge that we need in a later iteration
  - adding one edge means some others won't be allowed in the future because they *now create a cycle*

- We need an explanation of why this can't happen...

Kruskal: proof of correctness

- Suppose that we pick edge **e** that is not in the MST
- Removing **e** from F would disconnected graph into S & T

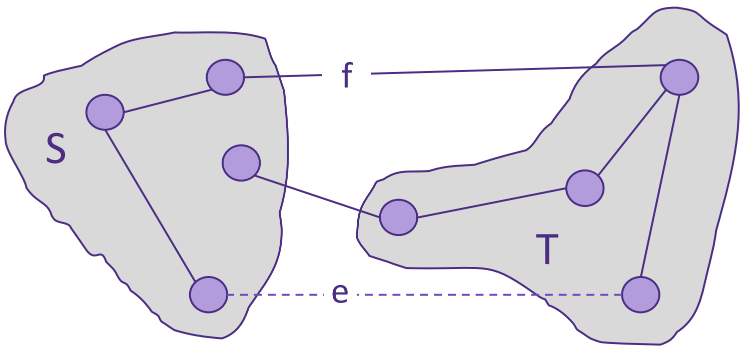
F



Kruskal: proof of correctness

- Suppose that we pick edge **e** that is not in the MST
- Removing **e** from F would disconnected graph into S & T
- In the MST, adding **e** would create a cycle spanning S & T
- Let **f** be another edge on this cycle that connects S and T:

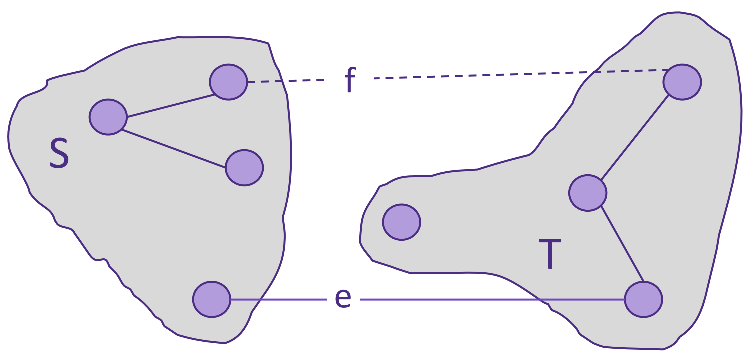
MST



Kruskal: proof of correctness

- At the point in Kruskal's algorithm when **e** was added:
  - graph F had a subset of the final edges, so S & T were disconnected
  - hence, adding **f** would not have created a cycle either… so it was eligible to add
- Since **e** had lowest weight amongst those: *weight* **e** <= *weight* **f**

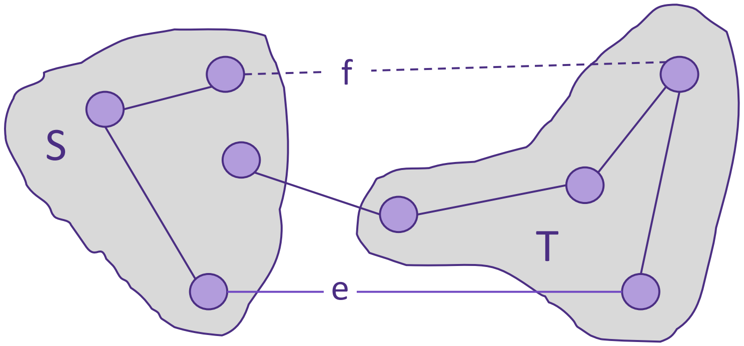
F when about to add **e**



Kruskal: proof of correctness

- Replacing f with e in the MST cannot increase it's weight
- Hence, there is an MST that includes e!
- Now, repeat this for every edge until the MST is our tree...

MST*



Why not cover greedy?

en.wikipedia.org/Siberian_tiger

> Usually have complex proofs of correctness
  - skipped important details in the Kruskal example
  - better for a math course than this one (see MATH 409)

> Rarely encountered **in nature**
  - most have names you know: Dijkstra, Kruskal, Prim

> Lulls you into thinking the greedy approach is usually correct
  - it isn't!
  - even when you aren't looking for exact solutions, greedy heuristics are rarely the best approach

Reminders

- HW1 is posted
  - due next Wednesday
- Information on overloading on Friday