Announcements

• Today’s lecture
  – Kleinberg-Tardos, 4.2, 4.3
• Next week
  – Kleinberg-Tardos, 4.4, 4.5
Greedy Algorithms

• Solve problems with the simplest possible algorithm
• The hard part: showing that something simple actually works
• Today’s problems (Sections 4.2, 4.3)
  – Homework Scheduling
  – Optimal Caching
  – Subsequence testing
Homework Scheduling

- Tasks to perform
- Deadlines on the tasks
- Freedom to schedule tasks in any order

- Can I get all my work turned in on time?
- If I can’t get everything in, I want to minimize the maximum lateness
Scheduling tasks

• Each task has a length $t_i$ and a deadline $d_i$
• All tasks are available at the start
• One task may be worked on at a time
• All tasks must be completed

• Goal minimize maximum lateness
  – Lateness = $f_i - d_i$ if $f_i >= d_i$
### Example

<table>
<thead>
<tr>
<th>Time</th>
<th>Deadline</th>
<th>Lateness</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Determine the minimum lateness

<table>
<thead>
<tr>
<th>Time</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
</tr>
</tbody>
</table>
Greedy Algorithm

• Earliest deadline first
• Order jobs by deadline

• This algorithm is optimal
Analysis

• Suppose the jobs are ordered by deadlines, $d_1 \leq d_2 \leq \ldots \leq d_n$

• A schedule has an *inversion* if job $j$ is scheduled before $i$ where $j > i$

• The schedule $A$ computed by the greedy algorithm has no inversions.

• Let $O$ be the optimal schedule, we want to show that $A$ has the same maximum lateness as $O$
List the inversions

<table>
<thead>
<tr>
<th>Time</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>a₁</td>
<td>3</td>
</tr>
<tr>
<td>a₂</td>
<td>4</td>
</tr>
<tr>
<td>a₃</td>
<td>2</td>
</tr>
<tr>
<td>a₄</td>
<td>5</td>
</tr>
</tbody>
</table>
Lemma: There is an optimal schedule with no idle time

- It doesn’t hurt to start your homework early!

- Note on proof techniques
  - This type of can be important for keeping proofs clean
  - It allows us to make a simplifying assumption for the remainder of the proof
Lemma

• If there is an inversion $i, j$, there is a pair of adjacent jobs $i', j'$ which form an inversion
Suppose there is a pair of jobs $i$ and $j$, with $d_i \leq d_j$, and $j$ scheduled immediately before $i$. Interchanging $i$ and $j$ does not increase the maximum lateness.
Proof by Bubble Sort

Determine maximum lateness
Real Proof

• There is an optimal schedule with no inversions and no idle time.
• Let O be an optimal schedule k inversions, we construct a new optimal schedule with k-1 inversions
• Repeat until we have an optimal schedule with 0 inversions
• This is the solution found by the earliest deadline first algorithm
Result

• Earliest Deadline First algorithm constructs a schedule that minimizes the maximum lateness
Homework Scheduling

• How is the model unrealistic?
Extensions

• What if the objective is to minimize the sum of the lateness?
  – EDF does not work

• If the tasks have release times and deadlines, and are non-preemptable, the problem is NP-complete

• What about the case with release times and deadlines where tasks are preemptable?
Optimal Caching

• Caching problem:
  – Maintain collection of items in local memory
  – Minimize number of items fetched
Caching example

A, B, C, D, A, E, B, A, D, A, C, B, D, A
Optimal Caching

• If you know the sequence of requests, what is the optimal replacement pattern?

• Note – it is rare to know what the requests are in advance – but we still might want to do this:
  – Some specific applications, the sequence is known
    • Register allocation in code generation
  – Competitive analysis, compare performance on an online algorithm with an optimal offline algorithm
Farthest in the future algorithm

• Discard element used farthest in the future

A, B, C, A, C, D, C, B, C, A, D
Correctness Proof

• Sketch
• Start with Optimal Solution O
• Convert to Farthest in the Future Solution F-F
• Look at the first place where they differ
• Convert O to evict F-F element
  – There are some technicalities here to ensure the caches have the same configuration . . .
Subsequence Testing

• Is $a_1a_2\ldots a_m$ a subsequence of $b_1b_2\ldots b_n$?
  – e.g. is T,R,E,E a subsequence of S,T,U,A,R,T,R,E,G,E,S

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T R E E
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S T U A R T R E G E S
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Next week