

Lecture09



CSE 417

Algorithms and Complexity

Winter 2023

Lecture 9 – Greedy Algorithms II

Announcements

- **Today's lecture**
 - Kleinberg-Tardos, 4.2, 4.3
- **Friday and Monday**
 - 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)
 - Graph Coloring
 - Homework Scheduling
 - Optimal Caching

Interval Scheduling

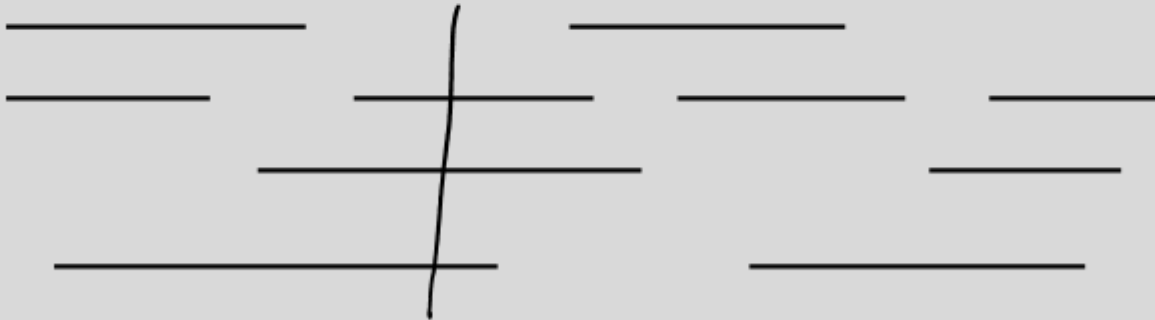
- Tasks occur at fixed times, single processor
- Maximize number of tasks completed



- Earliest finish time first algorithm optimal
- Optimality proof: stay ahead lemma
 - Mathematical induction is the technical tool

Scheduling all intervals with multiple processors

- Minimize number of processors to schedule all intervals



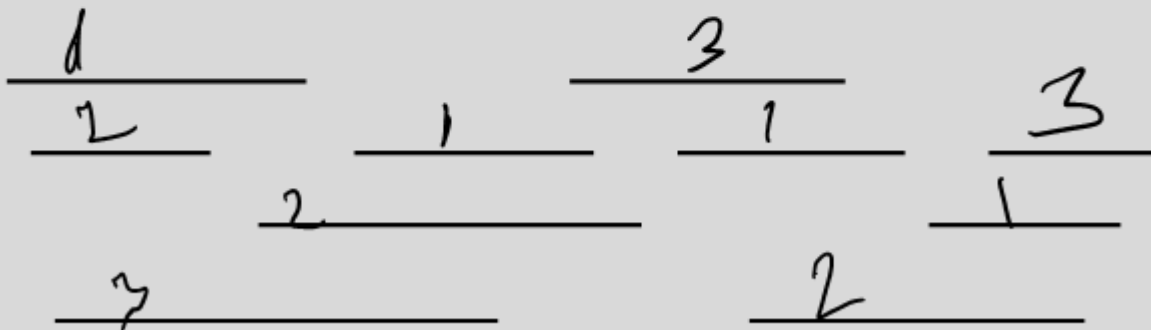
Depth: Maximum number of overlapping intervals

Algorithm

Sort intervals by start time

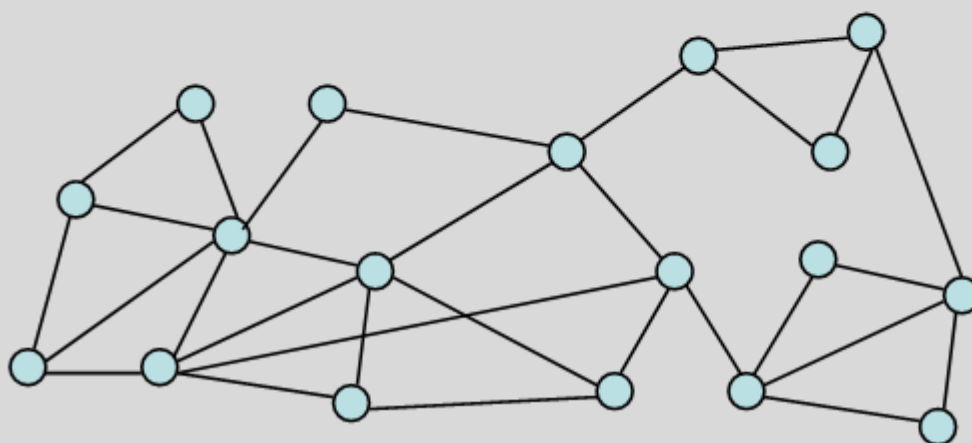
for $i = 1$ to n

 Assign interval i to the lowest numbered idle processor



Greedy Graph Coloring

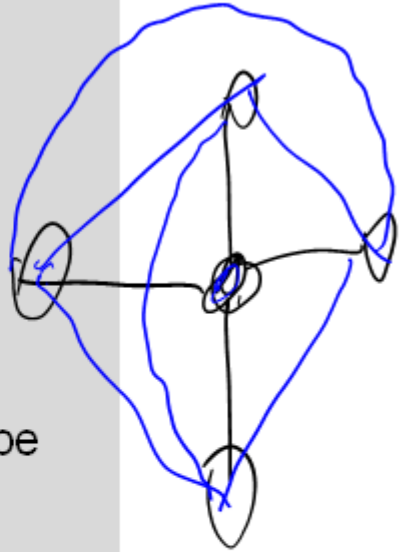
Theorem: An undirected graph with maximum degree K can be colored with $K+1$ colors



Greedy Coloring Algorithm

- Assume maximum degree K
- Pick a vertex v , and assign a color not in $N(v)$ from $[1, \dots, K + 1]$
- Always an available color

- In the worst case, this algorithm cannot be improved
 - There exists a graph of degree K requiring $K+1$ colors



Coloring Algorithm, Version 1

Let k be the largest vertex degree

Choose $k+1$ colors

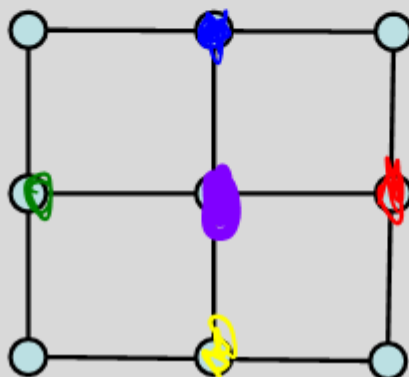
for each vertex v

 Color[v] = uncolored

for each vertex v

 Let c be a color not used in $N[v]$

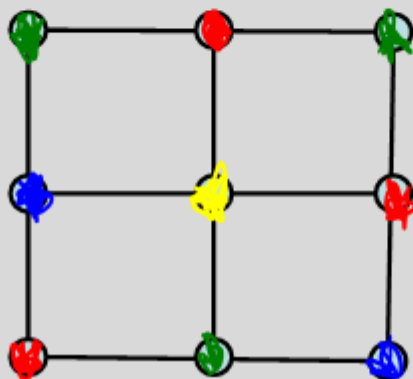
 Color[v] = c



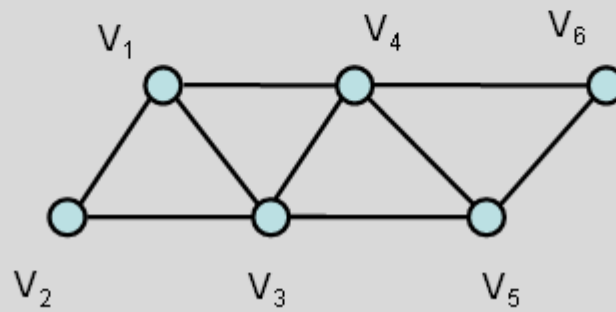
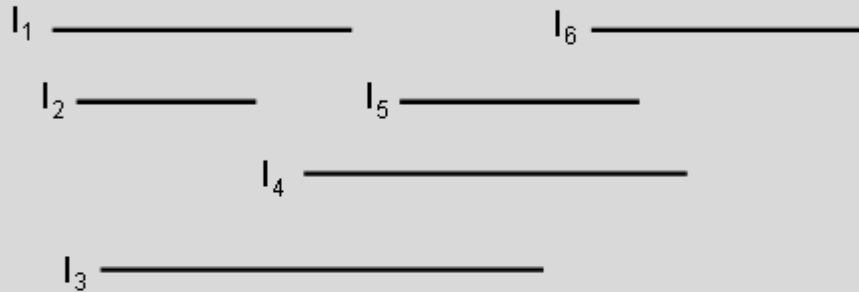
Coloring Algorithm, Version 2

```
for each vertex v  
    Color[v] = uncolored
```

```
for each vertex v  
    Let c be the smallest color not used in N[v]  
    Color[v] = c
```



Interval scheduling is graph coloring



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

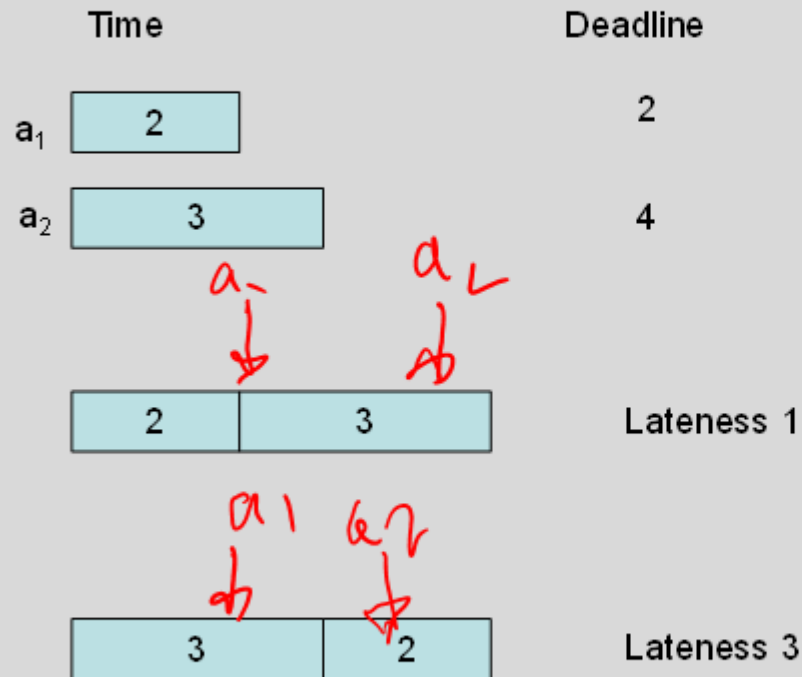
- Each task has a length t_i and a deadline d_i
- All tasks are available at the start
- One task may be worked on at a time
- All tasks must be completed

- Goal minimize maximum lateness

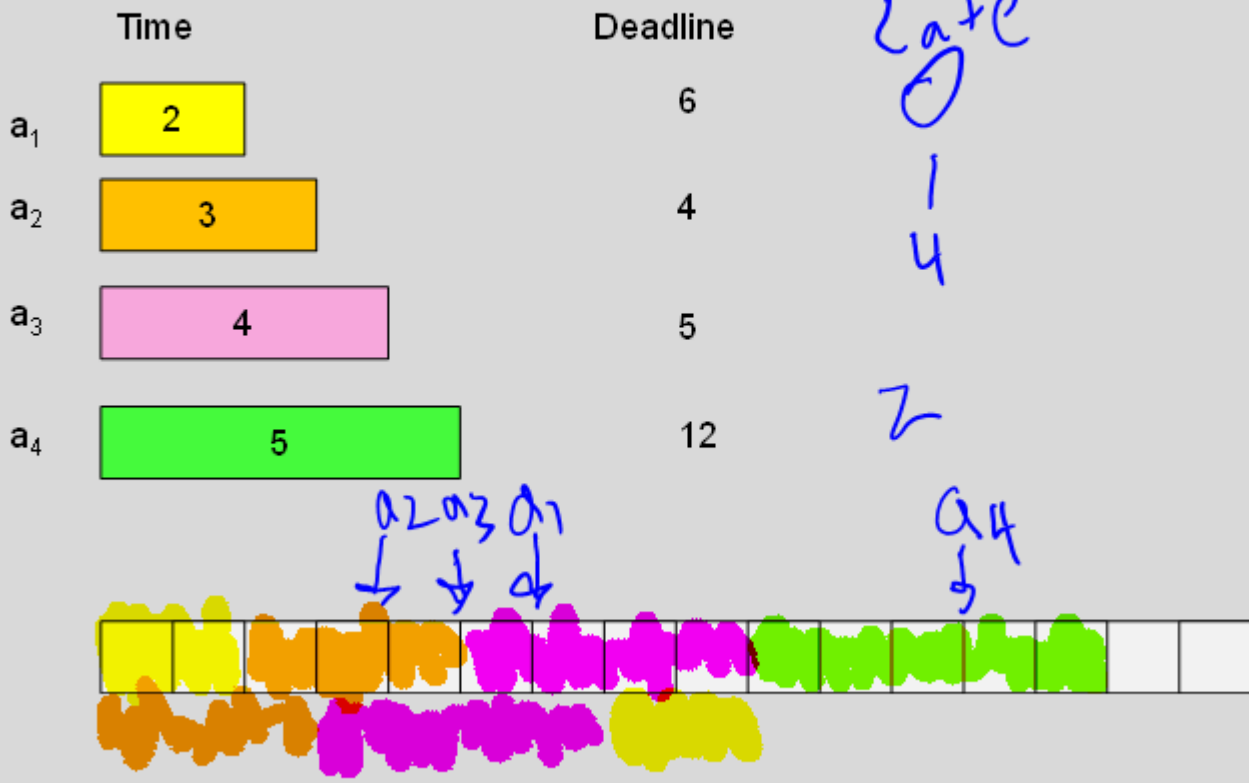
– Lateness: $L_i = f_i - d_i$ if $f_i \geq d_i$

$$L_i = 0 \text{ if } f_i \leq d_i$$

Example



Determine the minimum lateness



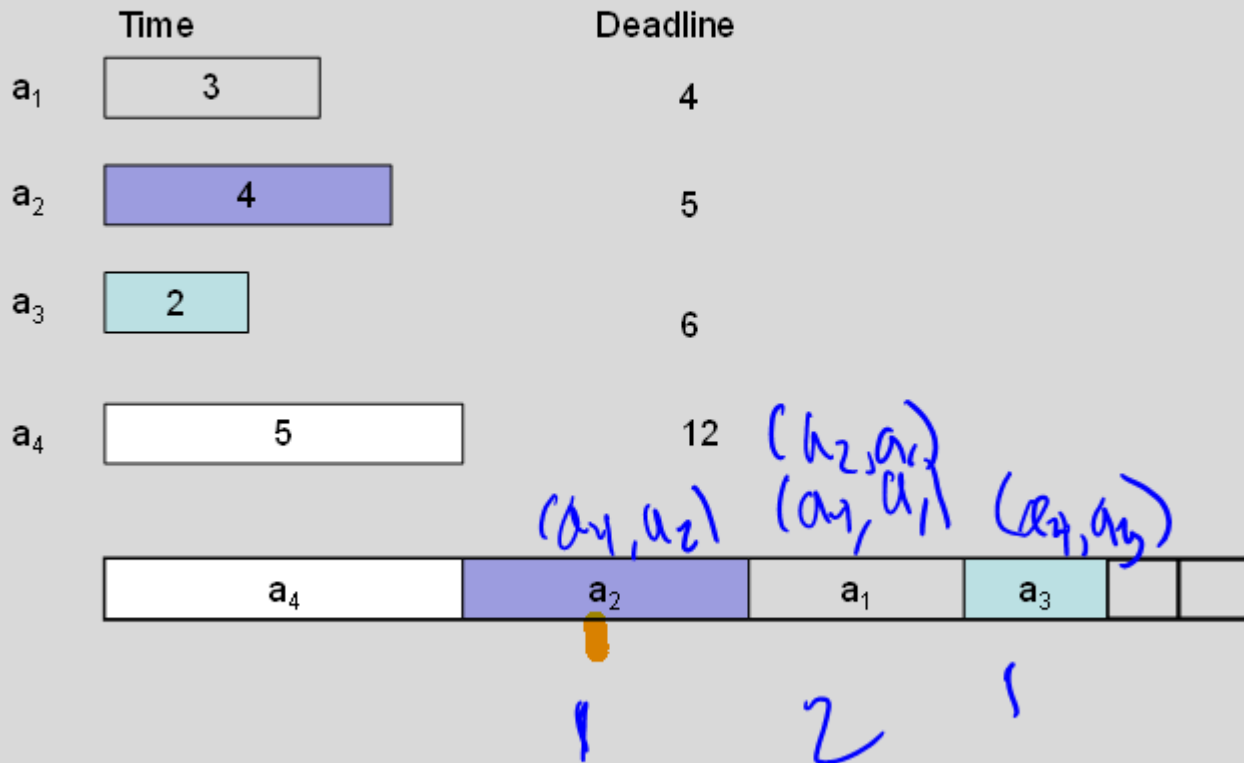
Greedy Algorithm

- Earliest deadline first
- Order jobs by deadline
- This algorithm is optimal

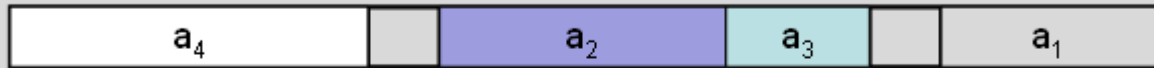
Analysis

- Suppose the jobs are ordered by deadlines, $d_1 \leq d_2 \leq \dots \leq d_n$
- 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



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

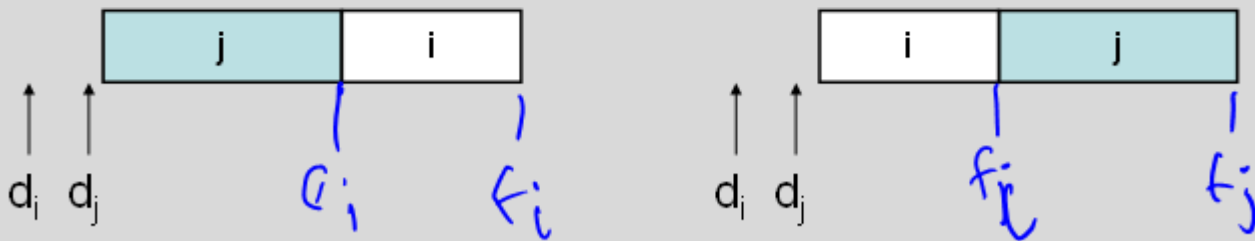
- If there is an inversion i, j , there is a pair of adjacent jobs i', j' which form an inversion



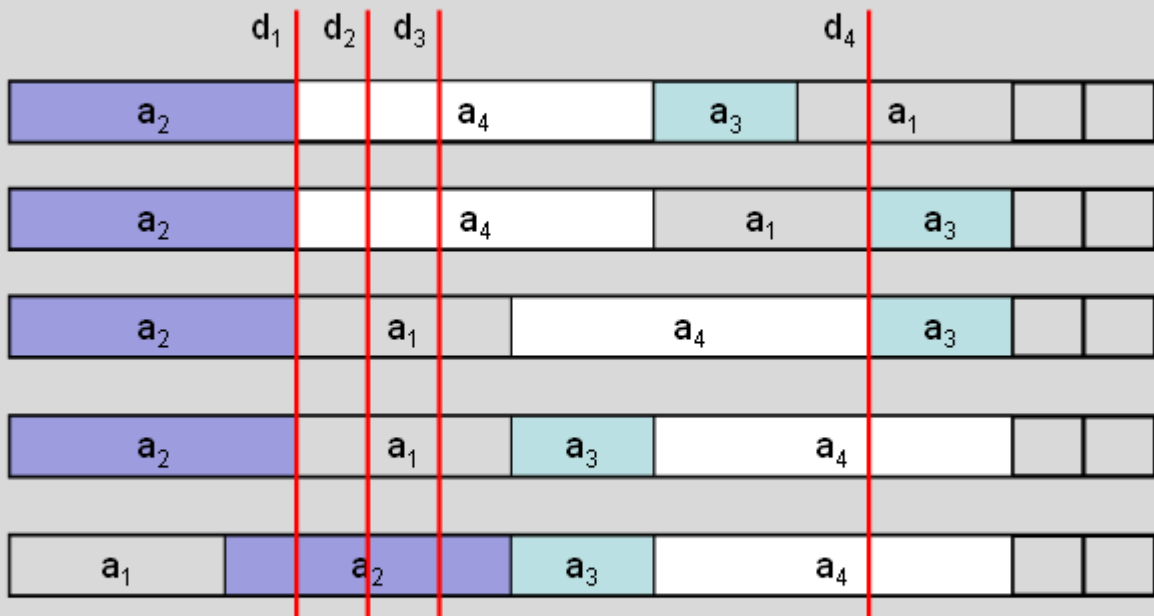
$j' i'$

Interchange argument

- 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 with 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?

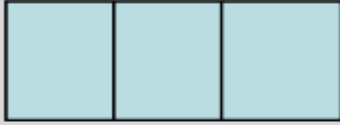
Extensions

- 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



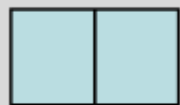
A, B, C, D, A, E, B, A, D, A, C, B, D, A

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 . . .

Later this week

