CSE 421
Introduction to Algorithms

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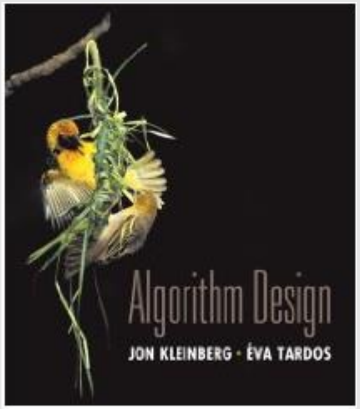
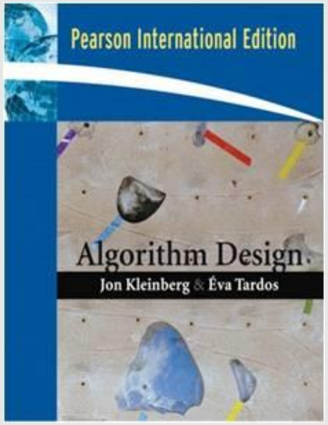
Winter 2024

Lecture 2

Course Mechanics

- Homework
  - Due Wednesdays
  - About 5 problems, sometimes programming
  - Target: 1 week turnaround on grading
- Exams (In class)
  - Midterm, Friday, February 9, 2024
  - Final, Monday, March 11, 2:30-4:20 pm
- Approximate grade weighting
  - HW: 50, MT: 15, Final: 35
- Course web
  - Slides, Homework, Section Materials
- Office Hours have been posted





Stable Matching: Formal Problem

- Input
  - Preference lists for $m_1, m_2, \ldots, m_n$
  - Preference lists for $w_1, w_2, \ldots, w_n$
- Output
  - Perfect matching M satisfying stability property (e.g., no instabilities) :

For all m', m'', w', w''
    If (m', w') $\in$ M and (m'', w'') $\in$ M then
        (m' prefers w' to w'') or (w'' prefers m'' to m')

Idea for an Algorithm

m proposes to w

- If w is unmatched, w accepts
- If w is matched to m_2
  - If w prefers m to m_2, w accepts m, dumping m_2
  - If w prefers m_2 to m, w rejects m

Unmatched m proposes to the highest w on its preference list that it has not already proposed to

Algorithm

Initially all m in M and w in W are free
While there is a free m
    w highest on m's list that m has not proposed to
    if w is free, then match (m, w)
    else
        suppose (m_2, w) is matched
        if w prefers m to m_2
            unmatch (m_2, w)
            match (m, w)

Example

m_1: w_1 w_2 w_3

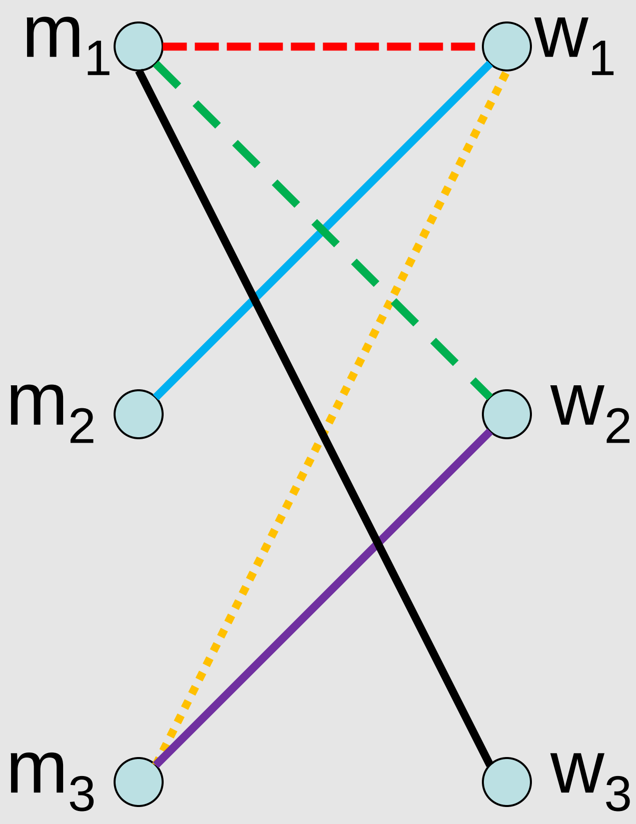
m_2: w_1 w_3 w_2

m_3: w_1 w_2 w_3

w_1: m_2 m_3 m_1

w_2: m_3 m_1 m_2

w_3: m_3 m_1 m_2



Order: m_1, m_2, m_3, m_1, m_3, m_1

Does this work?

- Does it terminate?
- Is the result a stable matching?

- Begin by identifying invariants and measures of progress
  – m’s proposals get worse (have higher m-rank)
  – Once w is matched, w stays matched
  – w’s partners get better (have lower w-rank)

Claim: If an m reaches the end of its list, then all the w's are matched

Claim: The algorithm stops in at most n^2 steps

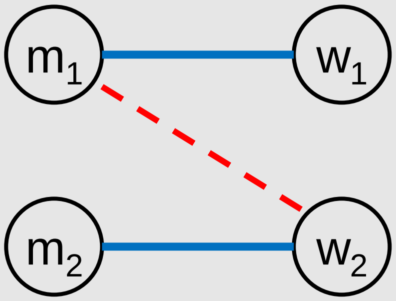
When the algorithms halts, every w is matched

Hence, the algorithm finds a perfect matching

The resulting matching is stable

Suppose

- $(m_1, w_1) \in M$, $(m_2, w_2) \in M$
- m_1 prefers w_2 to w_1



How could this happen?

Result

- Simple, $O(n^2)$ algorithm to compute a stable matching
- Corollary
  - A stable matching always exists

A closer look

Stable matchings are not necessarily fair

m_1: w_1 w_2 w_3

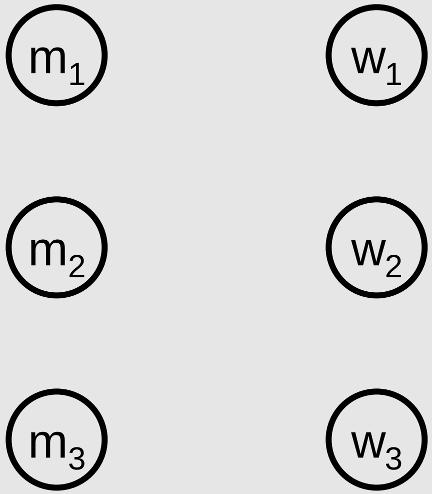
m_2: w_2 w_3 w_1

m_3: w_3 w_1 w_2

w_1: m_2 m_3 m_1

w_2: m_3 m_1 m_2

w_3: m_1 m_2 m_3



How many stable matchings can you find?

Algorithm under specified

- Many different ways of picking m's to propose
- Surprising result
  - All orderings of picking free m's give the same result

- Proving this type of result
  - Reordering argument
  - Prove algorithm is computing something mores specific
    - Show property of the solution – so it computes a specific stable matching

M-rank and W-rank of matching

- m-rank: position of matching w in preference list
- M-rank: sum of m-ranks
- w-rank: position of matching m in preference list
- W-rank: sum of w-ranks

m_1: w_1 w_2 w_3

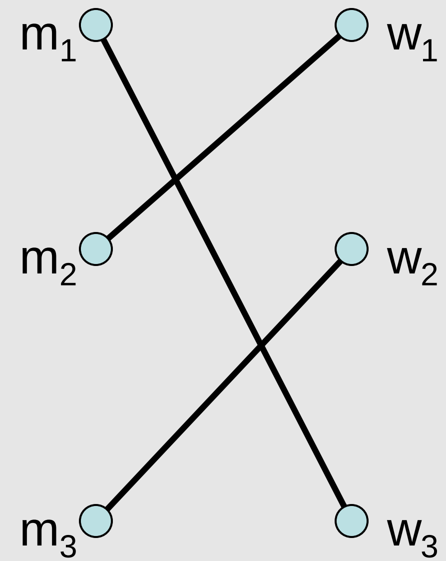
m_2: w_1 w_3 w_2

m_3: w_1 w_2 w_3

w_1: m_2 m_3 m_1

w_2: m_3 m_1 m_2

w_3: m_3 m_1 m_2



What is the M-rank?

What is the W-rank?

Suppose there are n m’s, and n w’s

- What is the minimum possible M-rank?
- What is the maximum possible M-rank?
- Suppose each m is matched with a random w, what is the expected M-rank?

Random Preferences

Suppose that the preferences are completely random

m_1: w_8 w_3 w_1 w_5 w_9 w_2 w_4 w_6 w_7 w_{10}
m_2: w_7 w_{10} w_1 w_9 w_3 w_4 w_8 w_2 w_5 w_6
…
w_1: m_1 m_4 m_9 m_5 m_{10} m_3 m_2 m_6 m_8 m_7
w_2: m_5 m_8 m_1 m_3 m_2 m_7 m_9 m_{10} m_4 m_6
…

If there are n m's and n w's, what is the expected value of the M-rank and the W-rank when the proposal algorithm computes a stable matching?

Generating a random permutation

```
public static int[] Permutation(int n, Random rand) {
    int[] arr = IdentityPermutation(n);

    for (int i = 1; i < n; i++) {
        int j = rand.Next(0, i + 1);
        int temp = arr[i];
        arr[i] = arr[j];
        arr[j] = temp;
    }
    return arr;
}
```

Stable Matching Algorithms

- M Proposal Algorithm
  - Iterate over all m's until all are matched
- W Proposal Algorithm
  - Change the role of m's and w's
  - Iterate over all w's until all are matched

- Compare M-Proposal and W-Proposal algorithms for moderate sized n ($n \cong 1000$)
  - Plot average m-rank and w-rank as a function of n. Do you have a mathematical explanation of the curves?

What is the run time of the Stable Matching Algorithm?

Initially all m in M and w in W are free

While there is a free m **Executed at most n^2 times**

    w highest on m's list that m has not proposed to

    if w is free, then match (m, w)

    else

        suppose (m_2, w) is matched

        if w prefers m to m_2

            unmatch (m_2, w)

            match (m, w)

O(1) time per iteration

- Find free m
- Find next available w
- If w is matched, determine m_2
- Test if w prefer m to m_2
- Update matching

What does it mean for an algorithm to be efficient?

Key ideas

- Formalizing real world problem
  - Model: graph and preference lists
  - Mechanism: stability condition
- Specification of algorithm with a natural operation
  - Proposal
- Establishing termination of process through invariants and progress measure
- Under specification of algorithm
- Establishing uniqueness of solution

A question to think about

- The problem has been formulated at a bipartite problem – with a matching between sets M and W
- What if all elements are in the same set X (and we assume $|X| = 2n$)
  - This is referred to as the stable roommates problem
- Does an analog of the G-S algorithm apply?
- Does the roommates problem always have a stable solution?