# CS F364: Design & Analysis of Algorithm

# 09 Matroids Application Mimimum Spanning Tree

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## Matroids

Theory for some situations in which the greedy yields optimal solutions

- **Matroids:** ordered pair $M = (S, I)$ satisfying the following
  1. $S$ is a finite set
  2. **Hereditary property:** $I$ is a nonempty family of subsets of S, called the independent subsets of $S$, such that $B \in I$ and $A \subseteq B$, then $A \in I$. (Question: is $\phi$ a member of $I$? Y)
  3. **Exchange property:** If $A \in I$, $B \in I$, and $|A| < |B|$ then there exists some element $x \in B - A$ such that $A \cup \{x\} \in I$.



## Graphic Matroid $M_G = (S_G, I_G)$

Defined in terms of a given undirected graph $G = (V, E)$

1. $S = E$
2. If A is a subset of E, then $A \in I_G$ if and only of A is acyclic. So $(V, A)$ is a forest

For $G = (V, E)$ a undirected graph $M_G = (S_G, I_G)$ is a matroid

**Proof:**

- $S_G$ is finite
- Hereditary property: subset of a forest is a forest
- Exchange property:
  Number of trees in a forest $(V, E_f)$ is $|V| - |E_f|$
  For $A, B \in I$ if $|A| < |B|$ then $B$ has fewer trees
  $\rightarrow$ Consider and edge $x \in B$ that links two trees in A

Extention: $x$ extends A
Maximal independent set: set that can not be extended



## All maximal independent set have same size

Suppose to the contrary that A is a maximal independent subset of M and there exists another larger maximal independent subset B of M

- Then due to exchange property $\exists x \in B - A$ so that A could be extended
- so A is not maximal independent set
- **Contradiction.**



## Weighted matroid

- $M = (S, I)$ is weighted if it is associated with weight function $w(x)$ for all $x \in S$
- $w(A)$ is defined as

$$w(A) = \sum_{x \in A} w(x)$$

- One example of $w$ be the weight of the edge
- $w'(e) = w_0 - w(e)$

See a minimization problem as maximization one

$$\begin{aligned} w'(A) &= \sum_{e \in A} w'(e) \\ &= \sum_{e \in A} (w_0 - w(e)) \\ &= (|V| - 1)w_0 - \sum_{e \in A} w(e) \\ &= (|V| - 1)w_0 - w(A) \end{aligned}$$



## Minimum Spanning Tree Problem

- Subset of the edges that connects all of the vertices together and has minimum total length
- It is like finding maximal independent set in $M_G$

**Algorithm 1:** Greedy( M, $w$ )

```
1 A = φ
2 sort M.S in decreasing order of weight w
3 for x ∈ M.s take in order do
4     if A ∪ {x} ∈ M.I then
5         A = A ∪ {x}
6 return A
```

Complexity $O(n \log n + nf(n))$

## Matroids exhibit the greedy-choice property

Consider $M = (S, I)$ with weight function w. Let S sorted in decreasing order. Consider x, the the first element of S such that $\{x\}$ is independent. if $\exists$ x then there exists an optimal subset A containing x

- Let B be any nonempty optimal subset with $x \notin B$
- No element of B has weight greater then $w(x)$
- Construct A by taking $x$ and then items from B
- A and B are of same size differing on only one item $y \in B$

$$\begin{aligned} w(A) &= w(B) - w(y) + w(x) \\ &\geq w(B) \end{aligned}$$

- Contradiction. As B was optimal



## Matroids exhibit the greedy-choice property

Let $M = (S, I)$ be any matroid. If x is an element of S that is an extension of some independent subset A of S, then x is also an extension of $\phi$

- Since x is an extension of A, we have that $A \cup \{x\}$ is independent. Since I is hereditary, $\{x\}$ must be independent. Thus, $x$ is an extension of $\phi$.

Let $M = (S, I)$ be any matroid. If x is an element of S such that x is not an extension of $\phi$, then x is not an extension of any independent subset A of S
contrapositive of above

Any elements that GREEDY passes over initially because they are not extensions of $\phi$ can be forgotten about, since they can never be useful.



## Matroids exhibit the optimal-substructure property

Let x be the first element of S chosen by GREEDY for the weighted matroid $M = (S, I)$.
We can reduce the problem to $M' = (S', I')$.

- $s' = \{y \in S : \{x, y\} \in I\}$
- $I' = \{B \subseteq S - \{x\} : B \cup \{x\} \in I\}$

This is because $A' = A - \{x\}$ is an independent subset of $M'$.



## Correctness of the greedy algorithm on matroids

If $M = (S, I)$ is a weighted matroid with weight function w, then GREEDY(M,w) returns an optimal subset

- Any elements that GREEDY passes over initially because they are not extensions of $\phi$ can be forgotten about, since they can never be useful.
- Once GREEDY selects the first element x, the algorithm does not err by adding x to A, since there exists an optimal subset containing x.
- Finally, the remaining problem is one of finding an optimal subset in the matroid M' that is the contraction of M by x.



## Thank You!

**Thank you very much for your attention! (Reference[1])**

**Queries ?**

[1] Book - *Introduction to Algorithm*, By THOMAS H. CORMEN, CHARLES E. LEISERSON, RONALD L. RIVEST, CLIFFORD STEIN