Data Structures and Algorithms

CS245-2017S-18

Spanning Trees

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18-0: Spanning Trees

- Given a connected, undirected graph $G$
  - A subgraph of $G$ contains a subset of the vertices and edges in $G$
  - A Spanning Tree $T$ of $G$ is:
    - subgraph of $G$
    - contains all vertices in $G$
    - connected
    - acyclic
Spanning Tree Examples

- Graph
18-2: Spanning Tree Examples

- Spanning Tree
18-3: Spanning Tree Examples

- Graph

```
  0 -- 3 -- 5
  |     |     |
  2 -- 3 -- 6
  |     |     |
  1 -- 4
```

18-4: Spanning Tree Examples

- Spanning Tree

```
  0  1
 /   \
3-2-5 3-6-4
```
Minimal Cost Spanning Tree

- Given a weighted, undirected graph $G$
- Spanning tree of $G$ which minimizes the sum of all weights on edges of spanning tree
18-6: MST Example
18-7: MST Example

Graph representation of a Minimum Spanning Tree example.
Can there be more than one minimal cost spanning tree for a particular graph?
Can there be more than one minimal cost spanning tree for a particular graph?

YES!

What happens when all edges have unit cost?
Can there be more than one minimal cost spanning tree for a particular graph?

YES!

- What happens when all edges have unit cost?
- All spanning trees are MSTs
Two algorithms to calculate MST:

- Kruskal’s Algorithm
  - Build a “forest” of spanning trees
  - Combine into one tree

- Prims Algorithm
  - Grow a single tree out from a start vertex
18-12: Kruskal’s Algorithm

- Start with an empty graph (no edges)
- Sort the edges by cost
- For each edge $e$ (in increasing order of cost)
  - Add $e$ to $G$ if it would not cause a cycle
18-13: Kruskal’s Algorithm Examples

Graph representation of Kruskal’s algorithm examples.
Proof (by contradiction)

Assume that no optimal MST $T$ contains the minimum cost edge $e$

Add $e$ to $T$, which causes a cycle

Remove an edge other than $e$ to break the cycle

cost $T' \leq T$, a contradiction
• Coding Kruskal’s Algorithm:
  • Place all edges into a list
  • Sort list of edges by cost
  • For each edge in the list
    • Select the edge if it does not form a cycle with previously selected edges
    • How can we do this?
Kruskal’s Algorithm

- Determining of adding an edge will cause a cycle
  - Start with a forest of $V$ trees (each containing one node)
  - Each added edge merges two trees into one tree
  - An edge causes a cycle if both vertices are in the same tree
    - (examples)
We need to:

- Put each vertex in its own tree
- Given any two vertices $v_1$ and $v_2$, determine if they are in the same tree
- Given any two vertices $v_1$ and $v_2$, merge the tree containing $v_1$ and the tree containing $v_2$

... sound familiar?
18-18: Kruskal’s Algorithm

- Disjoint sets!
- Create a list of all edges
- Sort list of edges
- For each edge \( e = (v_1, v_2) \) in the list
  - if \( \text{FIND}(v_1) \neq \text{FIND}(v_2) \)
    - Add \( e \) to spanning tree
    - \( \text{UNION}(v_1, v_2) \)
Prim’s Algorithm

- Grow that spanning tree out from an initial vertex
- Divide the graph into two sets of vertices
  - vertices in the spanning tree
  - vertices *not* in the spanning tree
- Initially, Start vertex is in the spanning tree, all other vertices are not in the tree
  - Pick the initial vertex arbitrarily
While there are vertices not in the spanning tree
• Add the cheapest vertex to the spanning tree
18-21: Prim's Algorithm Examples
Prim’s Algorithm

- Use a table – much like Dijkstra table
- Path has the same meaning
- Cost is for vertex $v_k$
  - cost to add $v_k$ to the tree
  - (instead of length of path to $v_k$)
Prim’s Algorithm

- Code for Prim’s algorithm is very similar to the code for Dijkstra’s algorithm
- Make *one small change* to Dijkstra’s algorithm to get Prim’s algorithm
void Dijkstra(Edge G[], int s, tableEntry T[]) {
    int i, v;
    Edge e;
    for(i=0; i<G.length; i++) {
        T[i].distance = Integer.MAX_VALUE;
        T[i].path = -1;
        T[i].known = false;
    }
    T[s].distance = 0;
    for (i=0; i < G.length; i++) {
        v = minUnknownVertex(T);
        T[v].known = true;
        for (e = G[v]; e != null; e = e.next) {
            if (T[e.neighbor].distance > T[v].distance + e.cost) {
                T[e.neighbor].distance = T[v].distance + e.cost;
                T[e.neighbor].path = v;
            }
        }
    }
}
void Dijkstra(Edge G[], int s, tableEntry T[]) {
    int i, v;
    Edge e;
    for(i=0; i<G.length; i++) {
        T[i].distance = Integer.MAX_VALUE;
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    T[s].distance = 0;
    for (i=0; i < G.length; i++) {
        v = minUnknownVertex(T);
        T[v].known = true;
        for (e = G[v]; e != null; e = e.next) {
            if (T[e.neighbor].distance >
                e.cost) {
                T[e.neighbor].distance = e.cost;
                T[e.neighbor].path = v;
            }
        }
    }
}