CSE 332 Summer 2024
Lecture 16: Graphs

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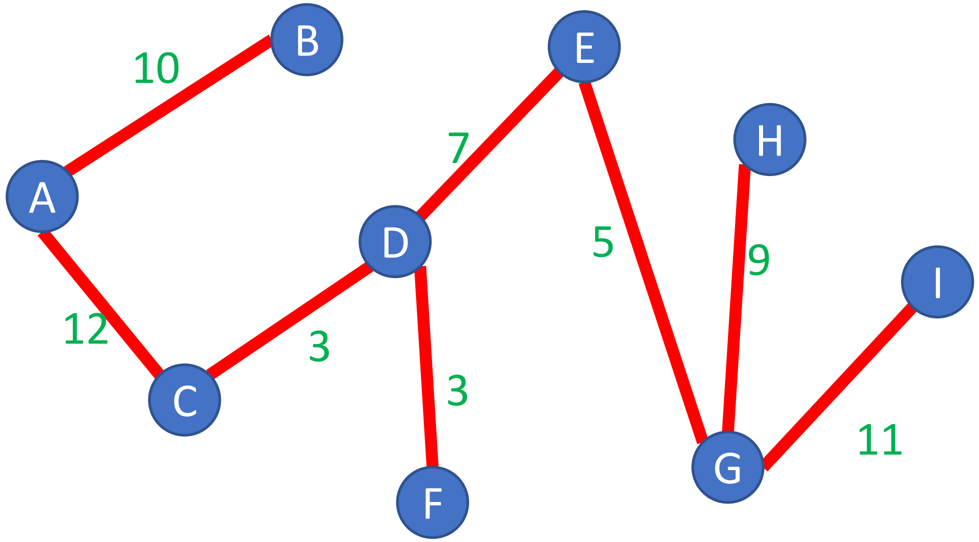
http://www.cs.uw.edu/332

Definition: Tree

A connected graph with no cycles



Note: A tree does not need a root, but they often do!

Definition: Tree

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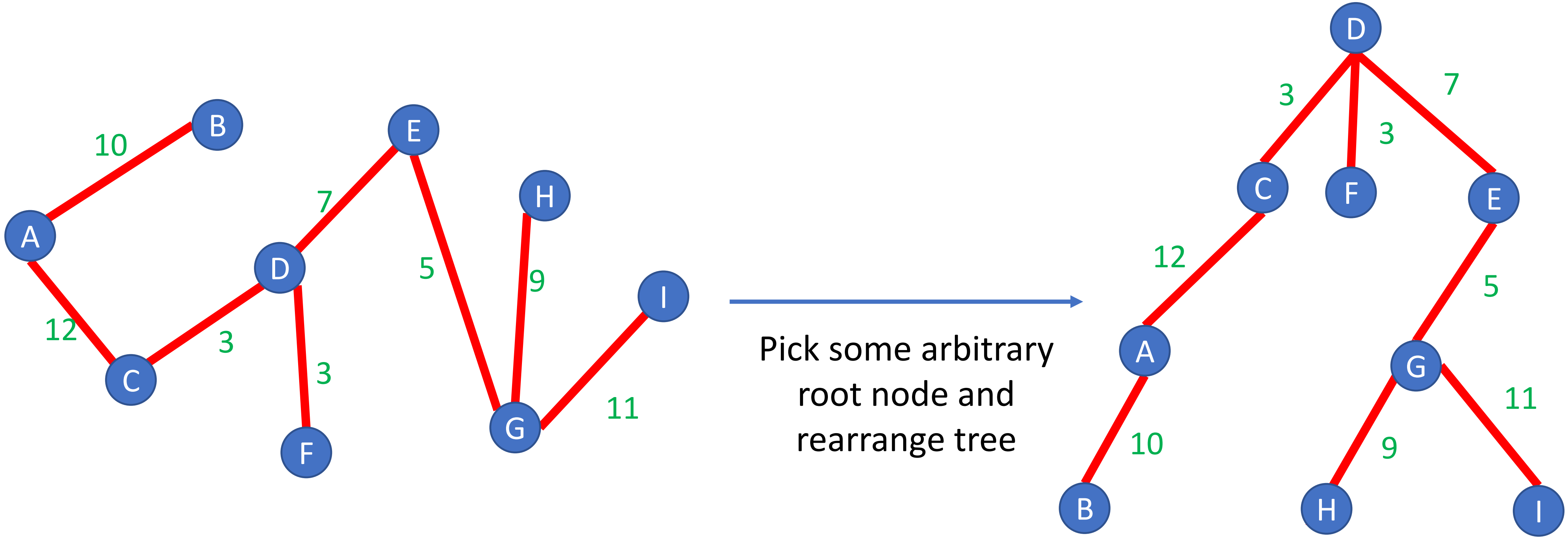
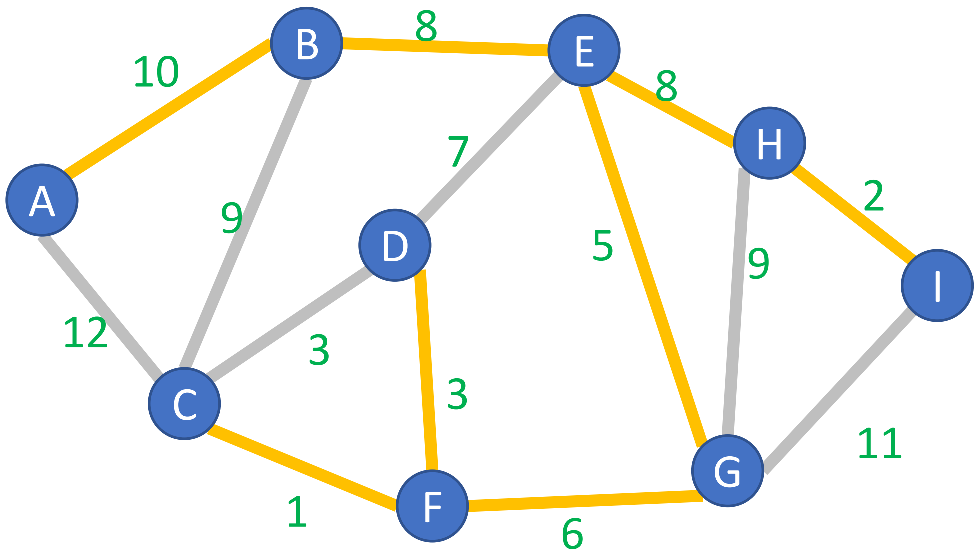


Definition: Spanning Tree

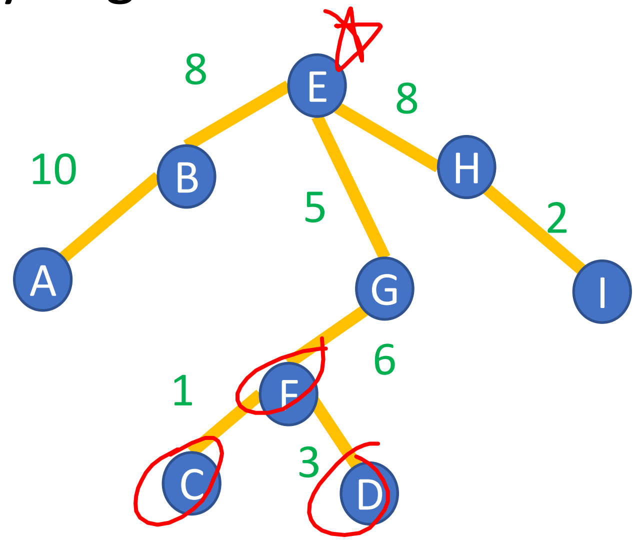
A Tree $T = (V_T, E_T)$ which connects ("spans") all the nodes in a graph $G = (V, E)$



Pick some arbitrary root node and rearrange tree

How many edges does T have?

$V - 1$

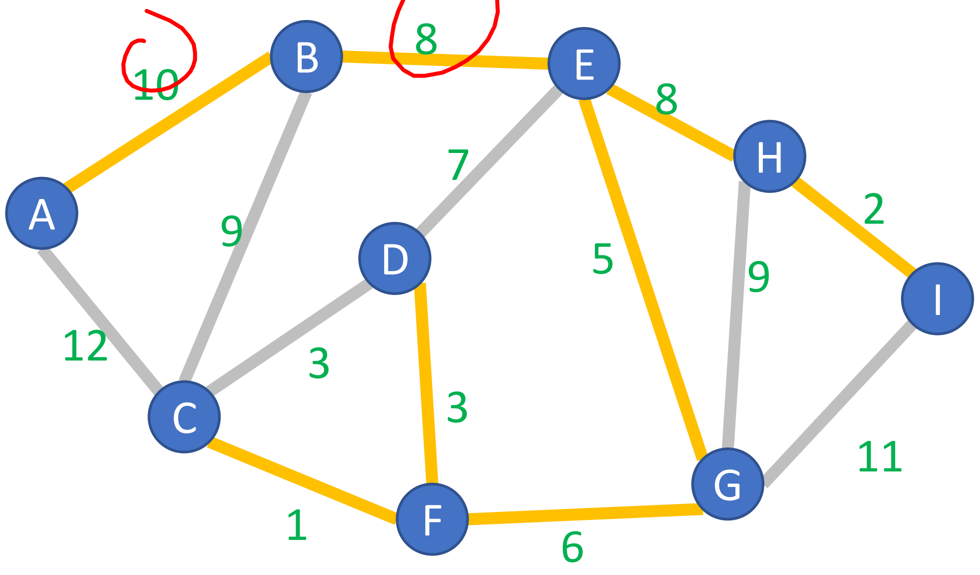


Any set of V-1 edges in the graph that doesn't have any cycles is guaranteed to be a spanning tree!

Any set of V-1 edges that connects all the nodes in the graph is guaranteed to be a spanning tree!

Definition: Minimum Spanning Tree

A Tree $\boldsymbol{T} = (V_T, E_T)$ which connects ("spans") all the nodes in a graph $G = (V, E)$, that has minimal cost

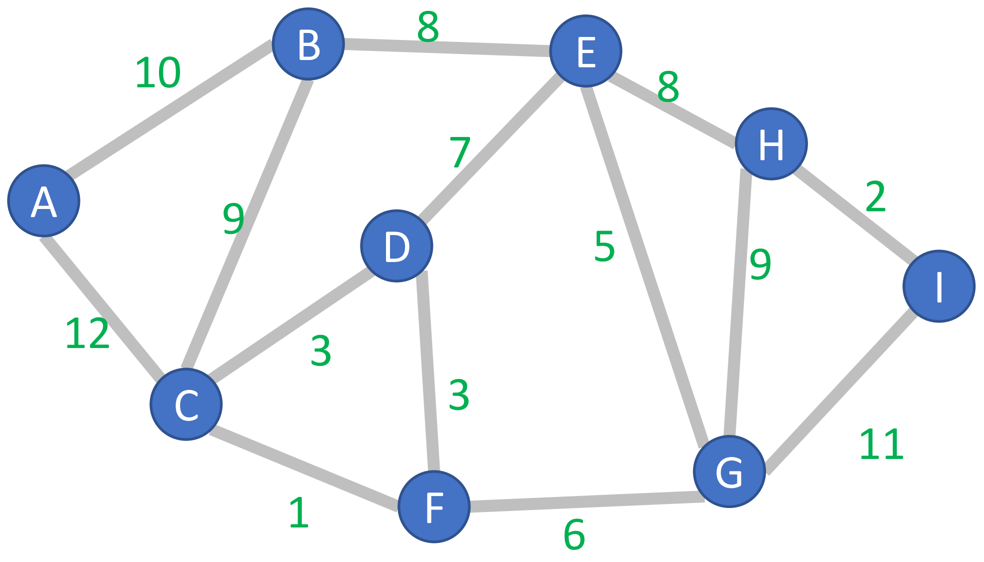


$$Cost(T) = \sum_{e \in E_T} w(e)$$

Kruskal's Algorithm

Start with an empty tree A

Add to A the lowest-weight edge that does not create a cycle



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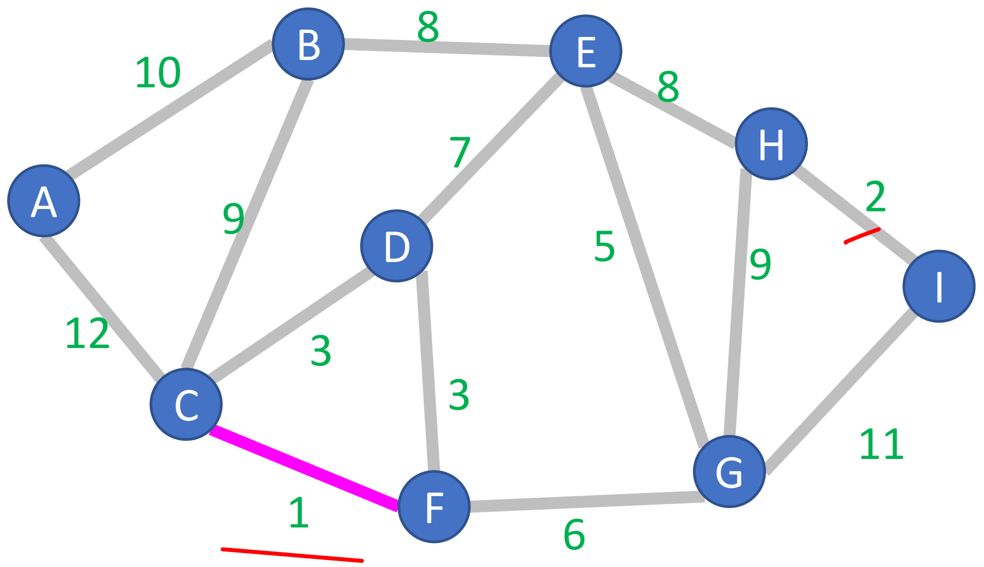

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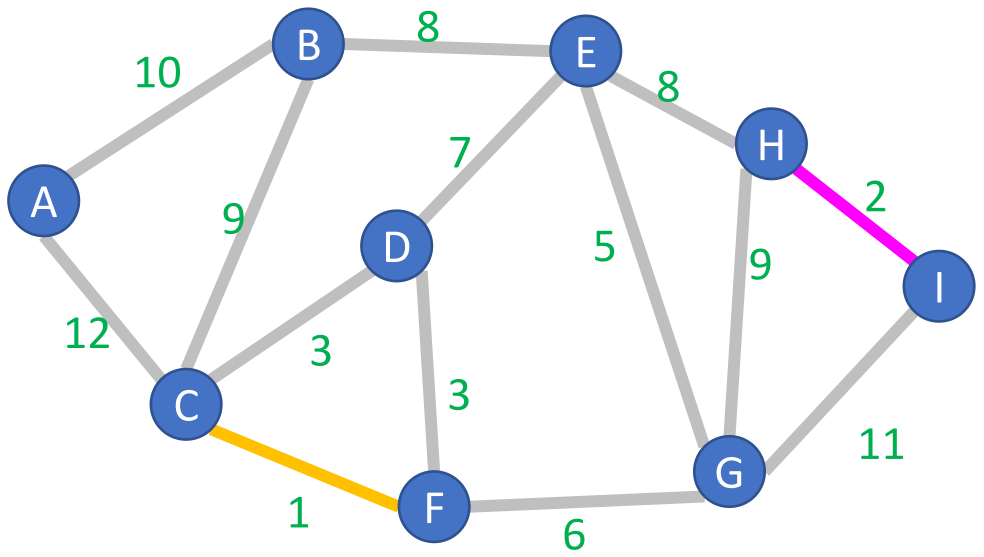

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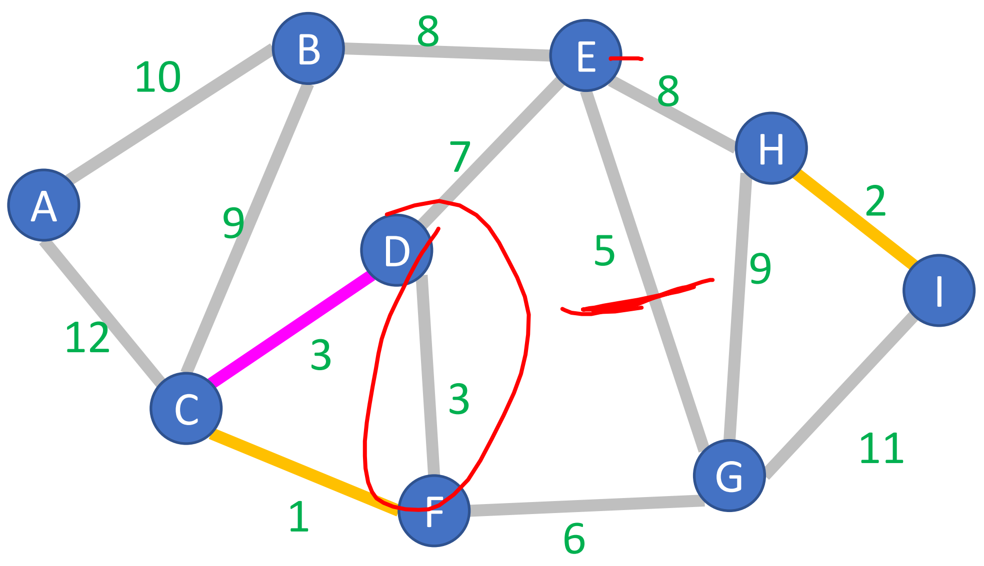

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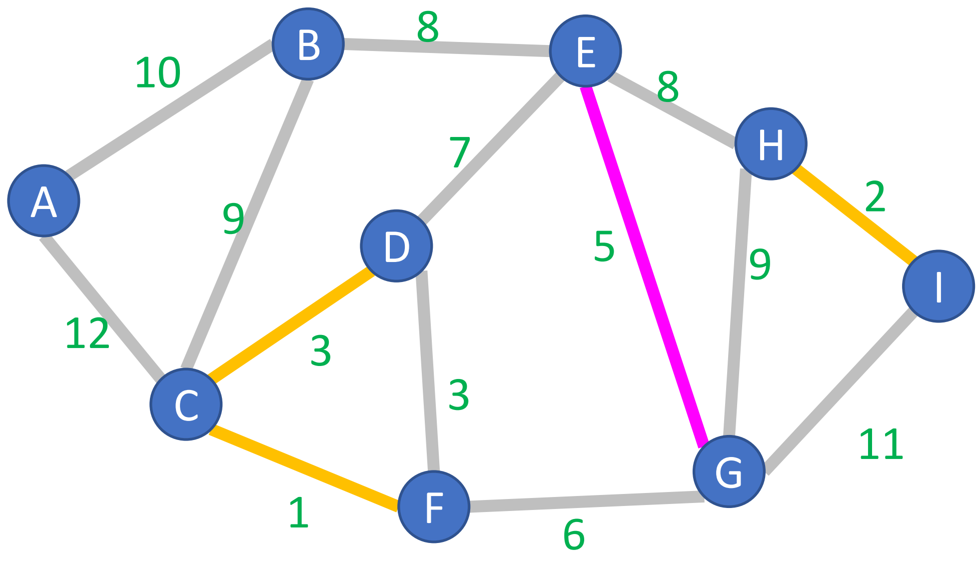


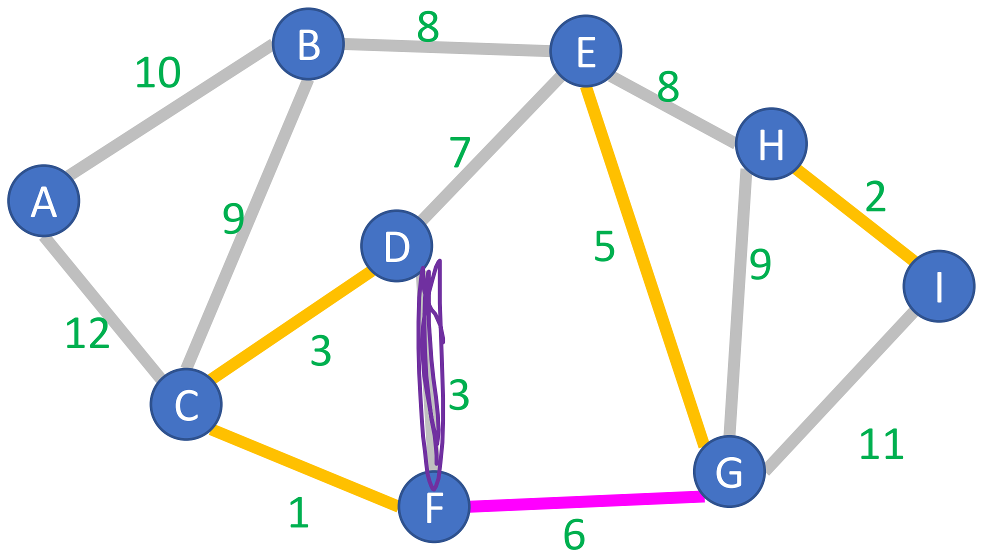
Kruskal’s Algorithm

$V \cdot E + V^2$ $\quad$ $V + E$

$V - 1$ {

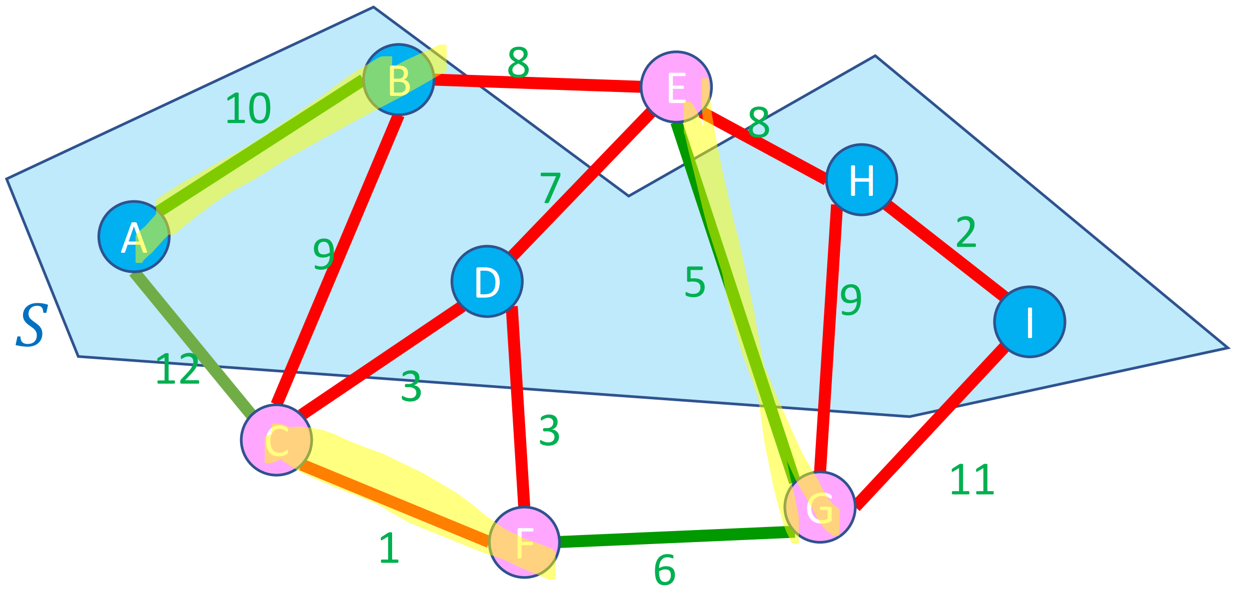
Start with an empty tree A

Add to A the lowest-weight edge that does not create a cycle



Definition: Cut

A Cut of graph $G = (V, E)$ is a partition of the nodes into two sets, S and $V - S$



Edge $(v_1, v_2) \in E$ crosses a cut if $v_1 \in S$ and $v_2 \in V - S$ (or opposite), e.g. (A, C)

A set of edges R Respects a cut if no edges cross the cut e.g. $R = \{(A, B), (E, G), (F, G)\}$

Cut Theorem

If a set of edges A is a subset of a minimum spanning tree T, let $(S, V - S)$ be any cut which A respects. Let e be the least-weight edge which crosses $(S, V - S)$. $A \cup \{e\}$ is also a subset of a minimum spanning tree.

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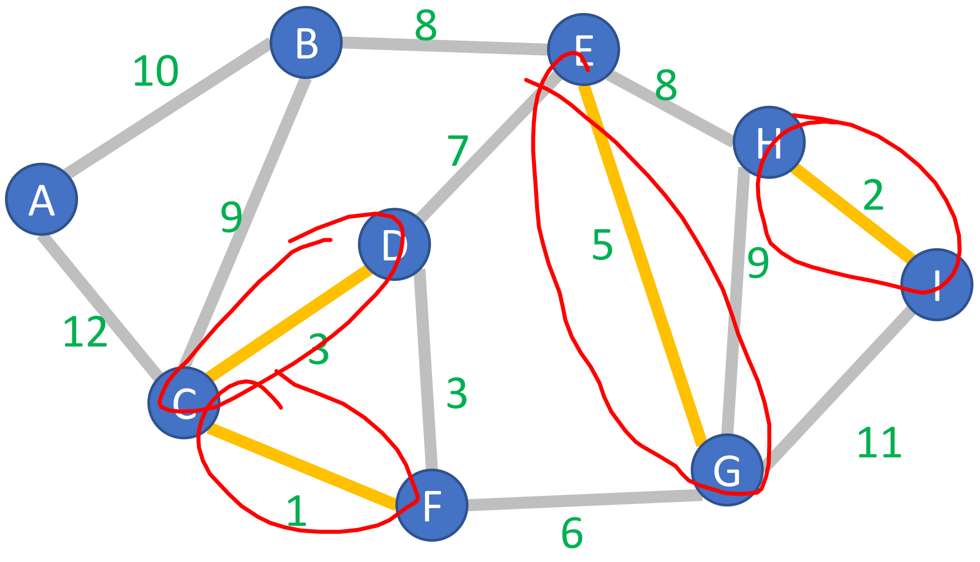

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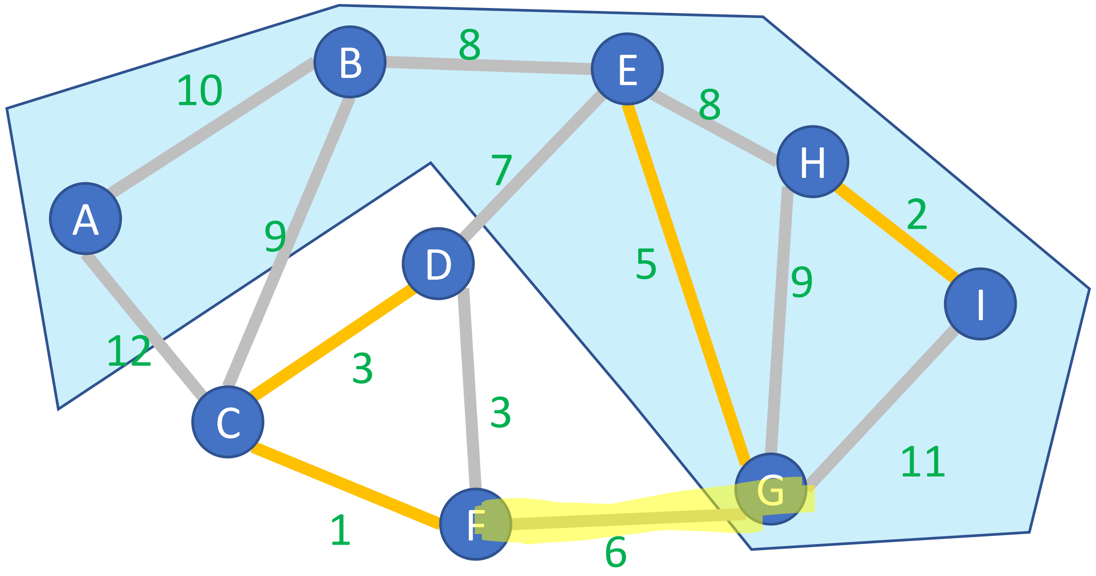

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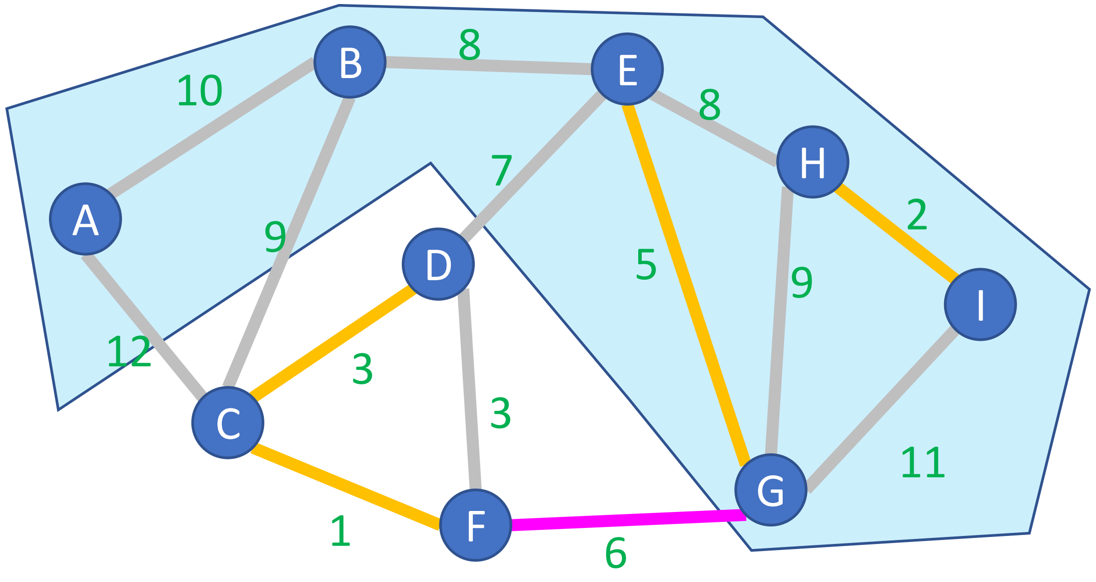

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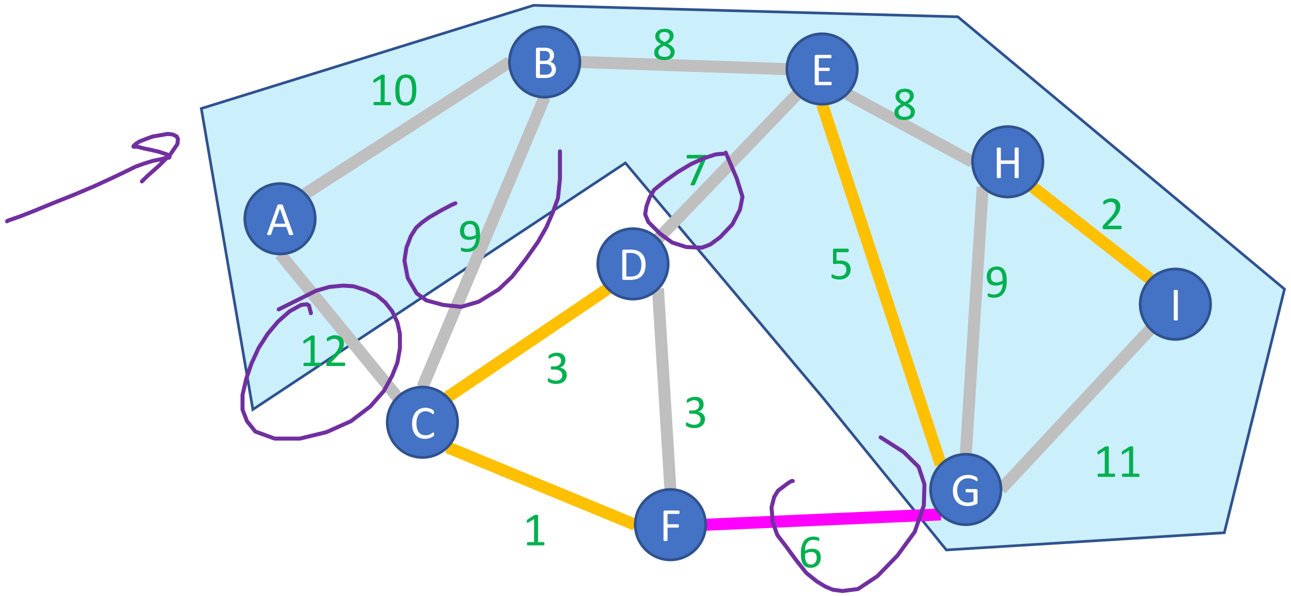
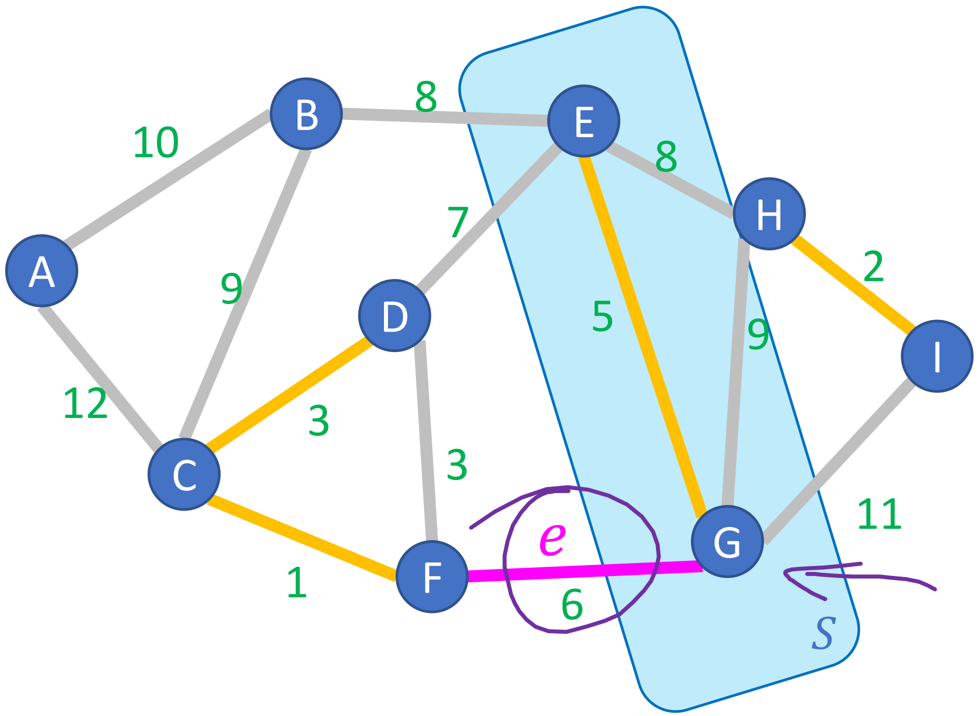


Proof of Kruskal's Algorithm

Start with an empty tree A

Repeat $V - 1$ times:

Add the min-weight edge that doesn't cause a cycle



Proof: Suppose we have some arbitrary set of edges A that Kruskal's has already selected to include in the MST. $e = (F, G)$ is the edge Kruskal's selects to add next

We know that there cannot exist a path from F to G using only edges in A because e does not cause a cycle

We can cut the graph therefore into 2 disjoint sets:

- nodes reachable from G using edges in A
- All other nodes

e is the minimum cost edge that crosses this cut, so by the Cut Theorem, Kruskal's is optimal!

Kruskal's Algorithm Runtime

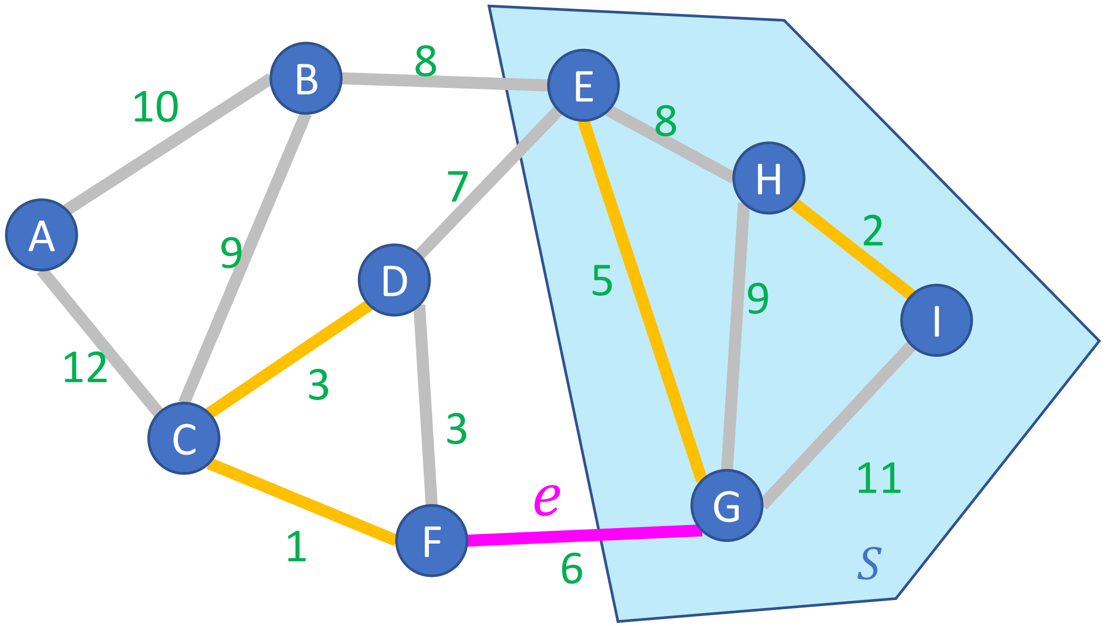
Start with an empty tree A

Repeat $V - 1$ times:

Add the min-weight edge that doesn't cause a cycle

Keep edges in a Disjoint-set data structure (very fancy)

$O(E \log V)$



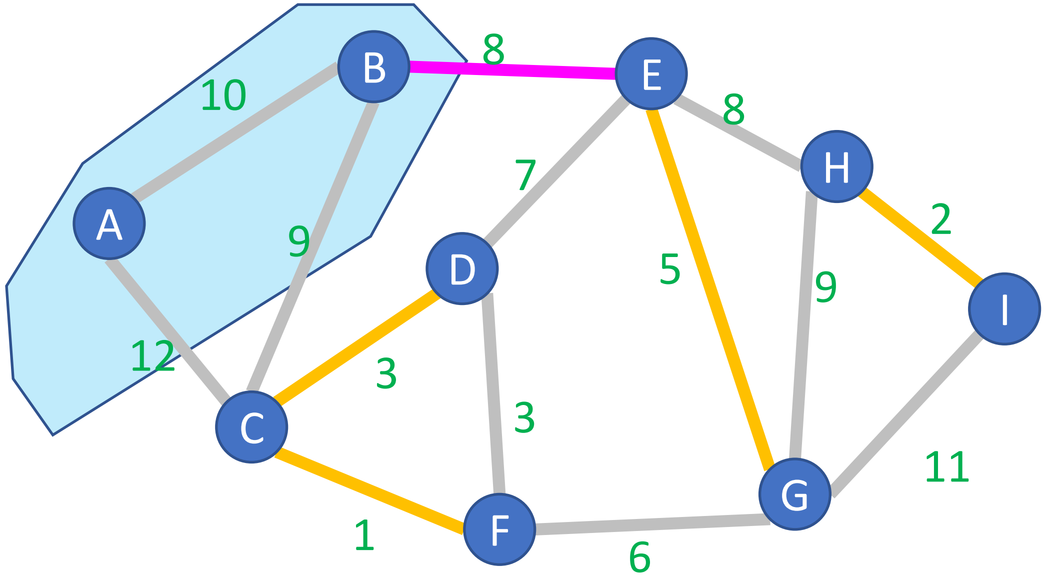
General MST Algorithm

Start with an empty tree A

Repeat $V - 1$ times:

Pick a cut $(S, V - S)$ which A respects (typically implicitly)

Add the min-weight edge which crosses $(S, V - S)$



Prim's Algorithm

Start with an empty tree A

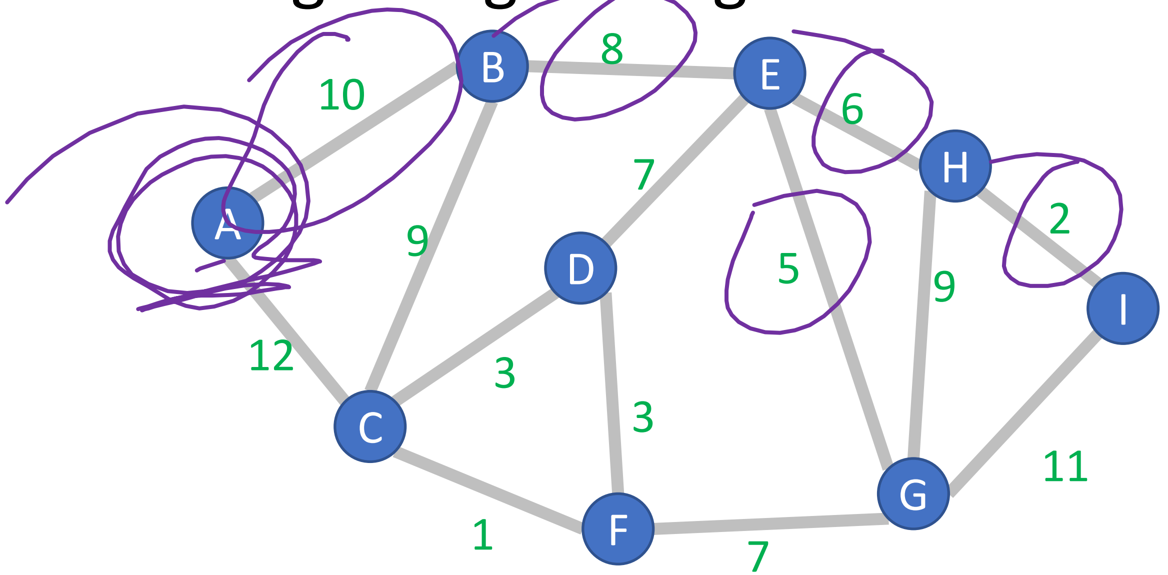
Repeat $V - 1$ times:

  Pick a cut $(S, V - S)$ which A respects

  Add the min-weight edge which crosses $(S, V - S)$

S is all endpoint of edges in A

e is the min-weight edge that grows the tree



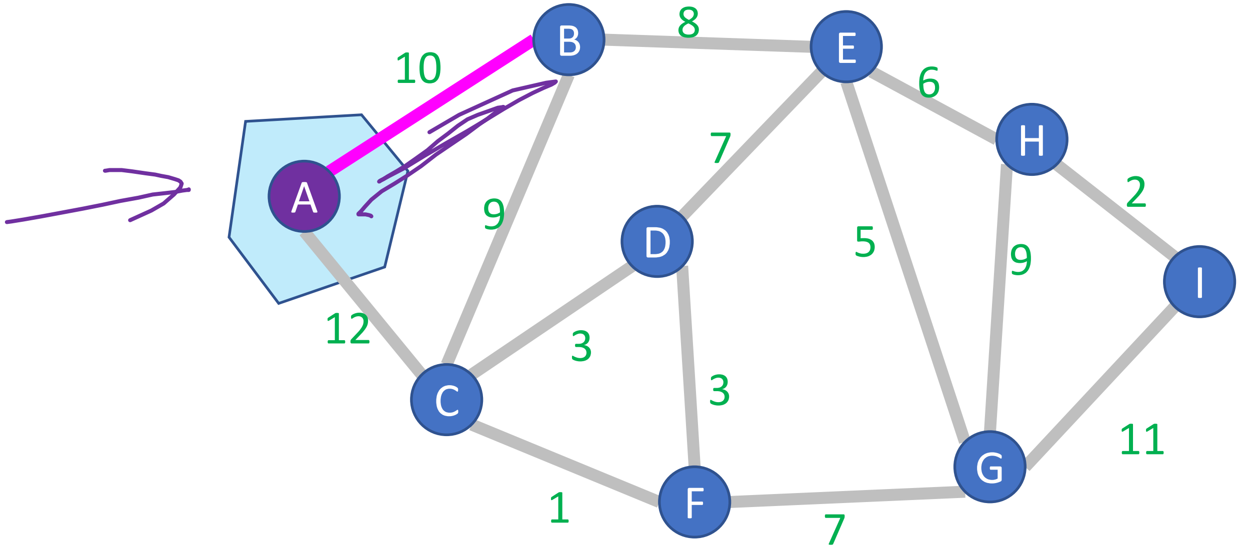
Prim's Algorithm

Start with an empty tree A

Pick a start node

Repeat $V - 1$ times:

Add the min-weight edge which connects to node in A with a node not in A



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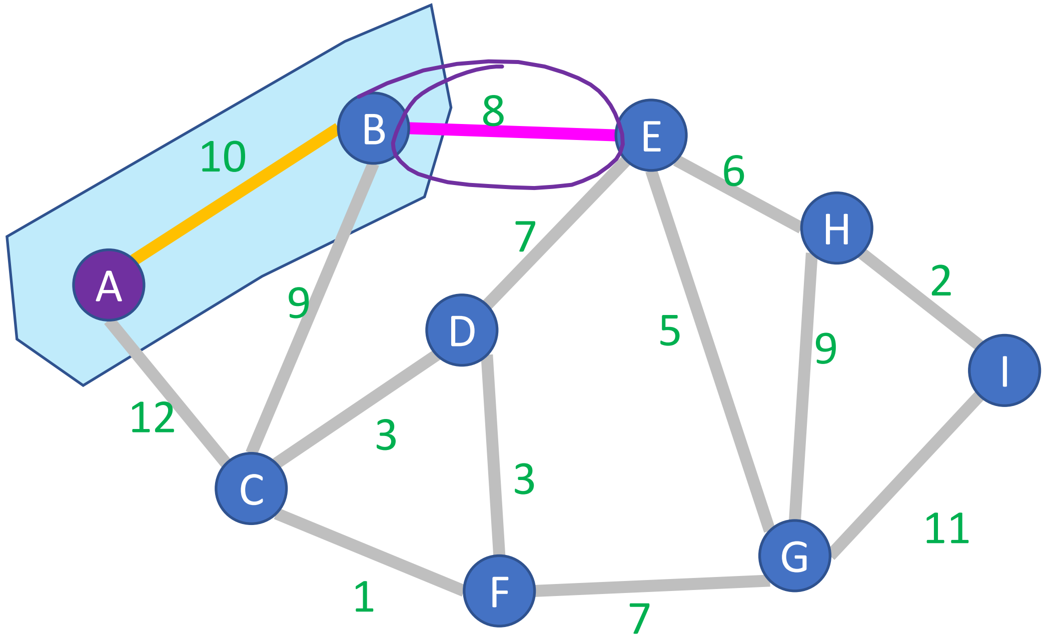

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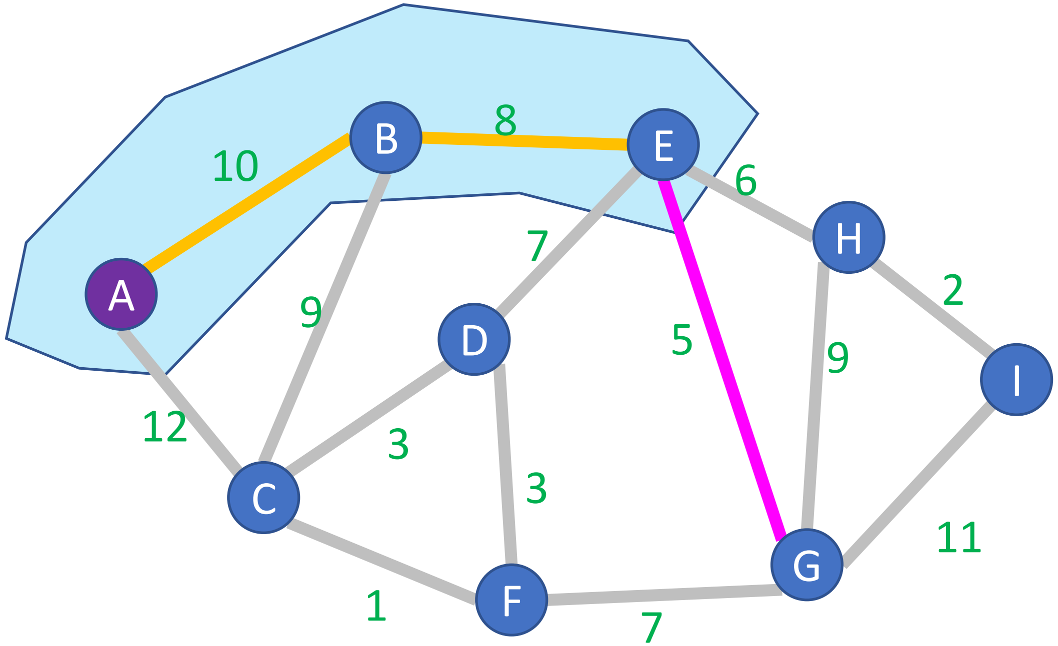

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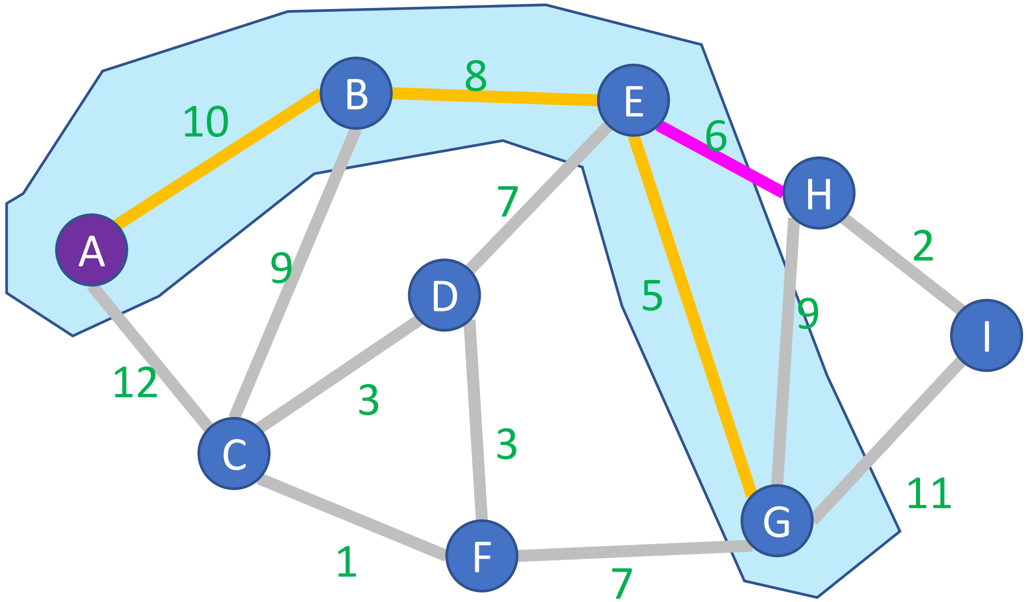


Prim's Algorithm

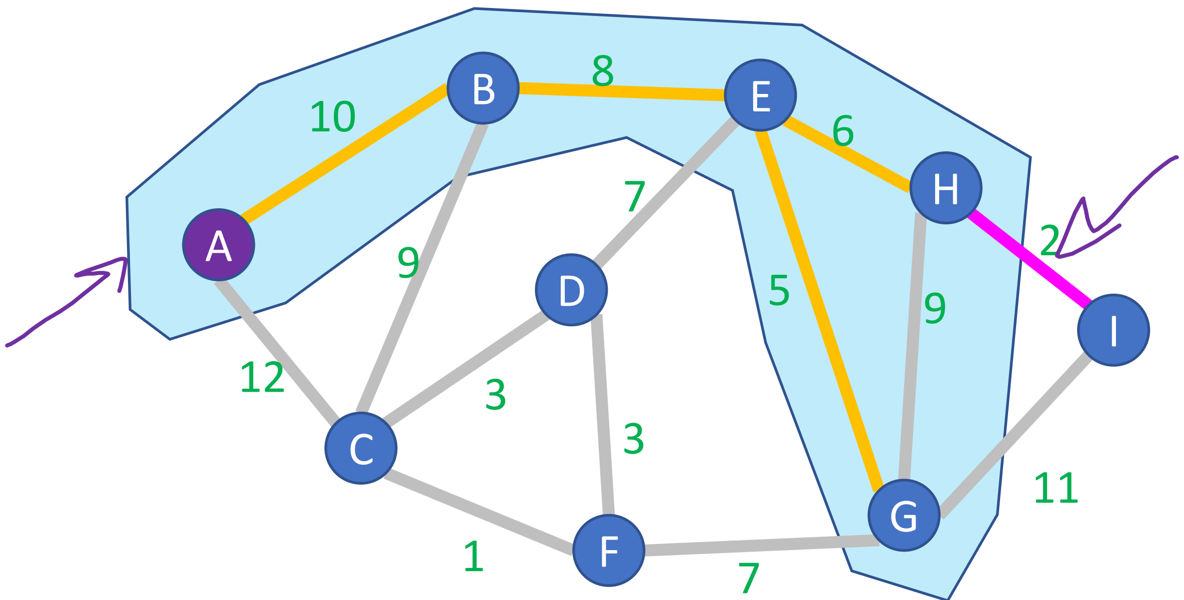
Start with an empty tree A

Pick a start node

Repeat $V - 1$ times:

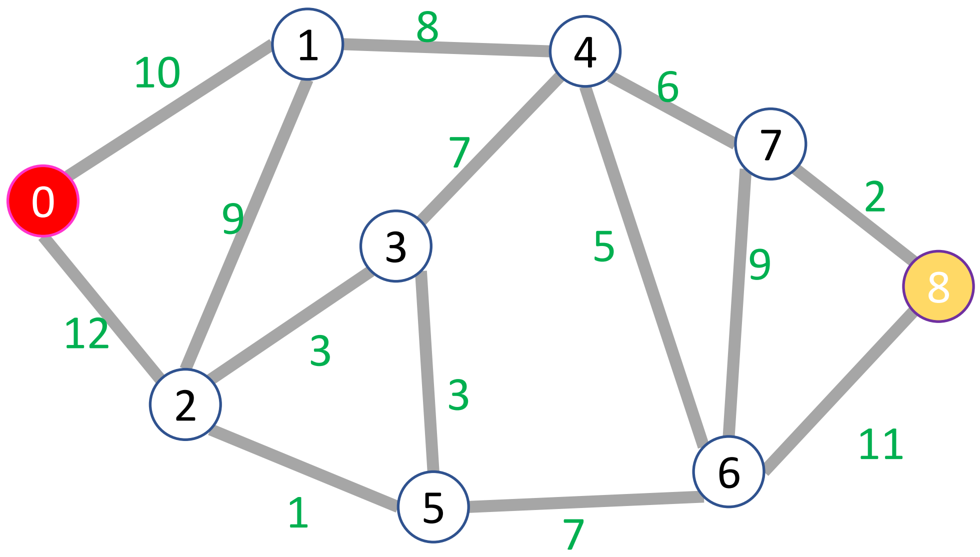
Add the min-weight edge which connects to node in A with a node not in A

Keep edges in a Heap
$O(E \log V)$



Dijkstra’s Algorithm

```
int dijkstras(graph, start, end){
	distances = [∞, ∞, ∞,…];  // one index per node
	done = [False,False,False,…];  // one index per node
	PQ = new minheap();
	PQ.insert(0, start);  // priority=0, value=start
	distances[start] = 0;
	while (!PQ.isEmpty){
		current = PQ.extract();
		done[current] = true;
		for (neighbor : current.neighbors){
			if (!done[neighbor]){
				new_dist = distances[current]+weight(current,neighbor);
				if(distances[neighbor] == ∞){
					distances[neighbor] = new_dist;
					PQ.insert(new_dist, neighbor);
				}
				if (new_dist < distances[neighbor]){
					distances[neighbor] = new_dist;
					PQ.decreaseKey(new_dist,neighbor); }
			}
		}
	}
	return distances[end]
}
```



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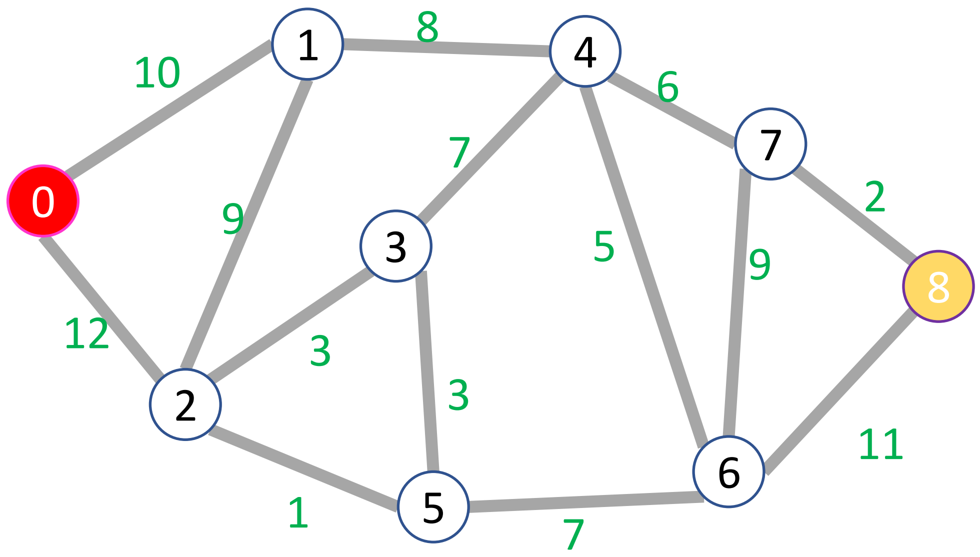

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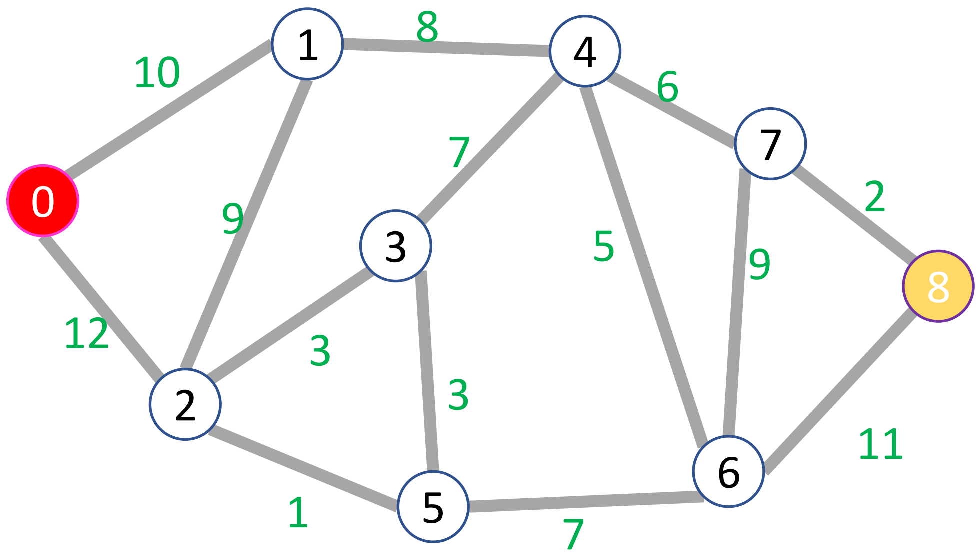

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