CSE 421

Union Find DS
Dijkstra's Algorithm,

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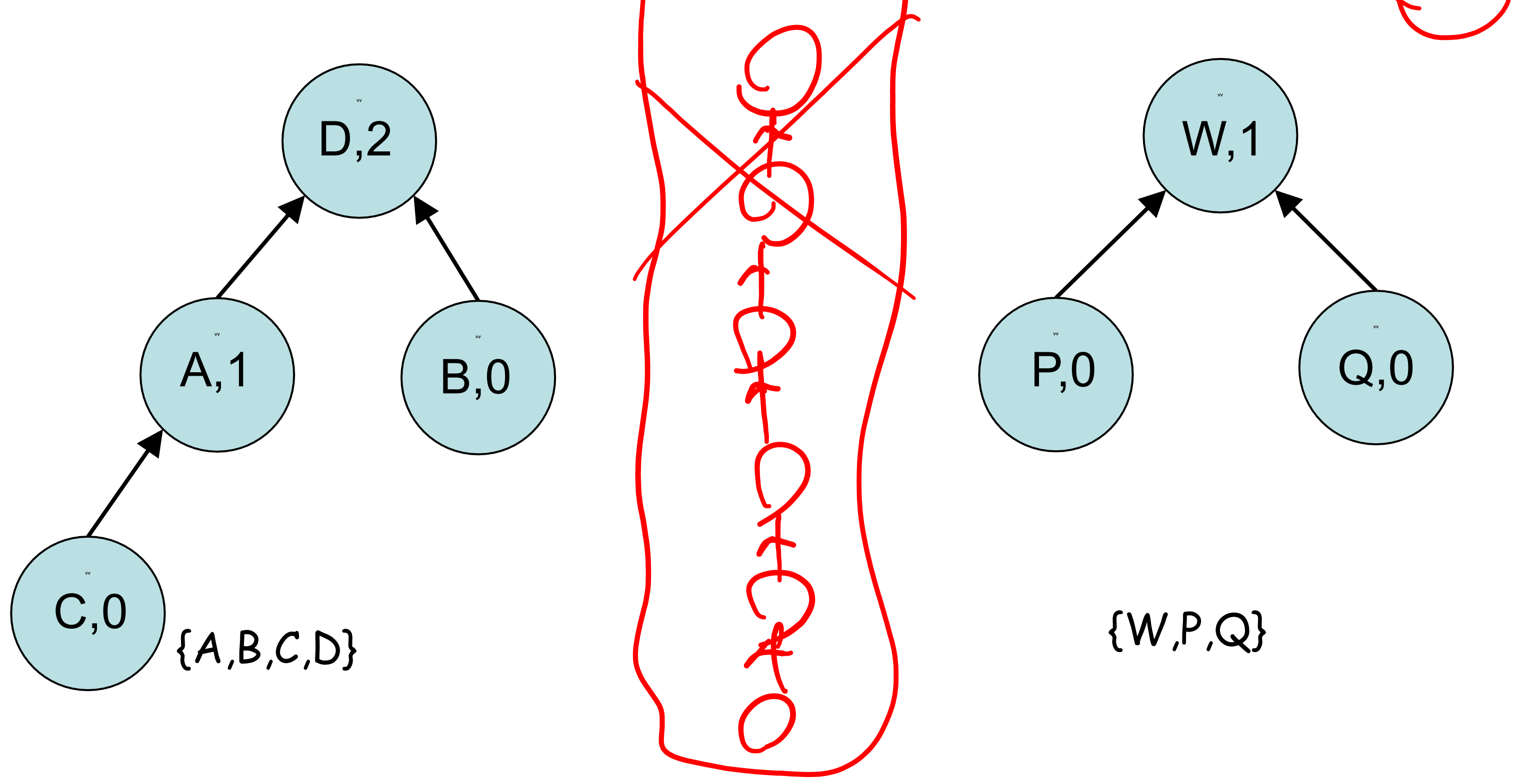
Union Find Data Structure

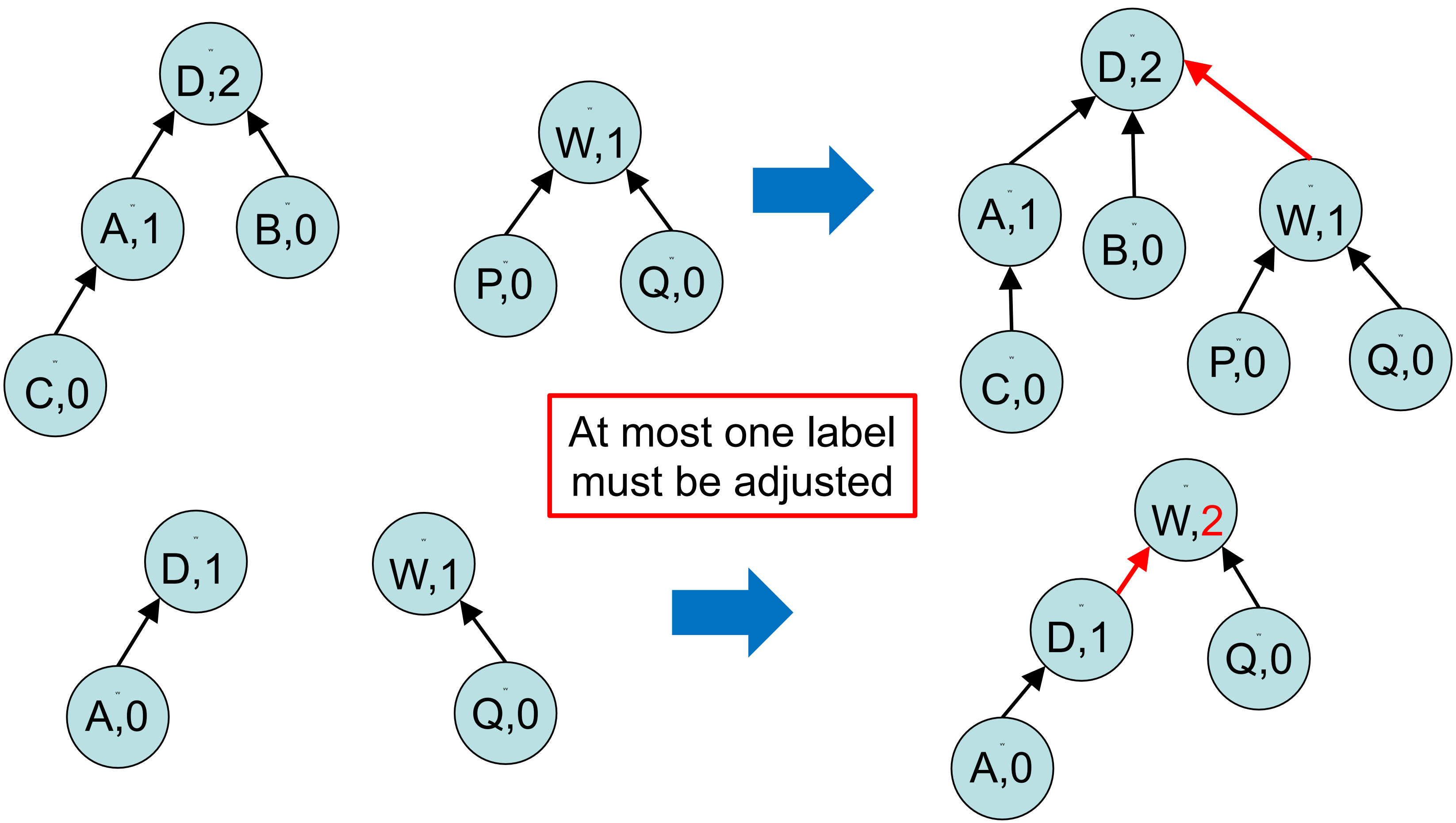
Each set is represented as a tree of pointers, where every vertex is labeled with longest path ending at the vertex

To check whether A,Q are in same connected component, follow pointers and check if root is the same.



Union Find Data Structure

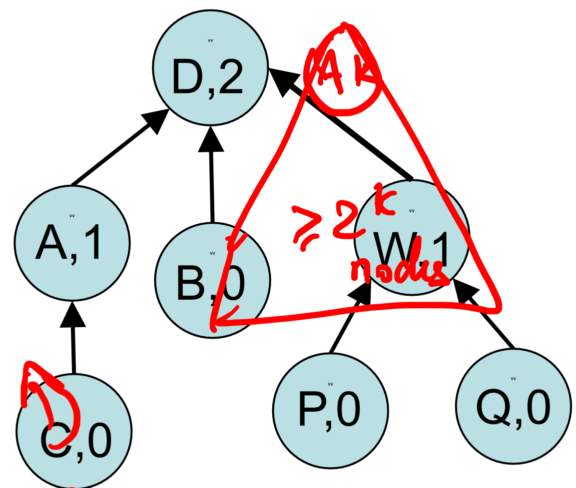
Merge: To merge two connected components, make the root with the smaller label point to the root with the bigger label (adjusting labels if necessary). Runs in O(1) time



Depth vs Size

Claim: If the label of a root is k, there are at least 2^k elements in the set.

Therefore the depth of any tree in algorithm is at most log n



So, we can check if u, v are in the same component in time $O(\log n)$

The label of all roots $\leq \log n$

Depth vs Size: Correctness

Claim: If the label of a root is k, there are at least 2^k elements in the set.

Pf: By induction on k.

Base Case (k = 0): this is true. The set has size 1.

IH: Suppose the claim is true until some time t

IS: If we merge roots with labels $k_1 > k_2$, the number of vertices only increases while the label stays the same.

If $k_1 = k_2$, the merged tree has label $k_1 + 1$,

and by induction, it has at least

$$2^{k_1} + 2^{k_2} = 2^{k_1+1}$$

elements.

Kruskal's Algorithm with Union Find

Implementation. Use the union-find data structure.

- Build set T of edges in the MST.
- Maintain a set for each connected component.
- O(m log n) for sorting and O(m log n) for union-find

```
Kruskal(G, c) {
   Sort edges weights so that c₁ ≤ c₂ ≤ ... ≤ cₘ.
   T ← ∅

   foreach (u ∈ V) make a set containing singleton {u}

   for i = 1 to m                     Find roots and compare
      Let (u,v) = eᵢ
      if (u and v are in different sets) {
         T ← T ∪ {eᵢ}
         merge the sets containing u and v
      }
   return T                      Merge at the roots
}
```

Removing weight Distinction Assumption

Suppose edge weights are not distinct, and Kruskal's algorithm sorts edges so

$$c_{e_1} \leq c_{e_2} \leq \cdots \leq c_{e_m}$$

Suppose Kruskal finds tree T of weight $c(T)$, but the optimal solution T^* has cost $c(T^*) < c(T)$.

Perturb each of the weights by a very small amount so that

$$c'_{e_1} < c'_{e_2} < \cdots \leq c'_{e_m}$$

$c'_{e_i} = c_{e_i} + i \cdot \varepsilon$

If the perturbation is small enough, $c'(T^*) < c(T)$.

$\approx c(T^*)$

However, this contradicts the correctness of Kruskal's algorithm, since the algorithm will still find T, and Kruskal's algorithm is correct if all weights are distinct.

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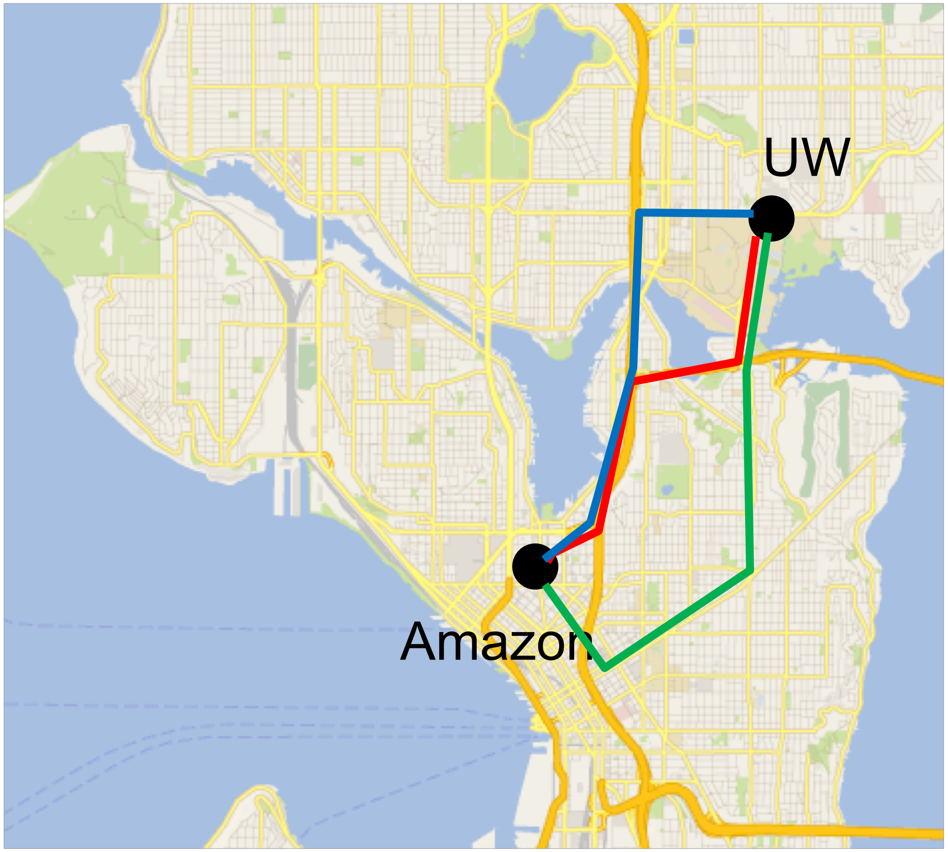
Single Source Shortest Path

Given an (un)directed graph G=(V,E) with non-negative edge weights $c_e \geq 0$ and a start vertex s

Find length of shortest paths from s to each vertex in G



Dijkstra's Algorithm

Maintain a set S of vertices whose shortest paths are known

- initially **S={s}**

Maintaining current best lengths of paths that only go through **S** to each of the vertices in G

- Path-lengths to elements of **S** will be right, to **V-S** they might not be right

Repeatedly add vertex **v** to **S** that has the shortest path-length of any vertex in **V-S**

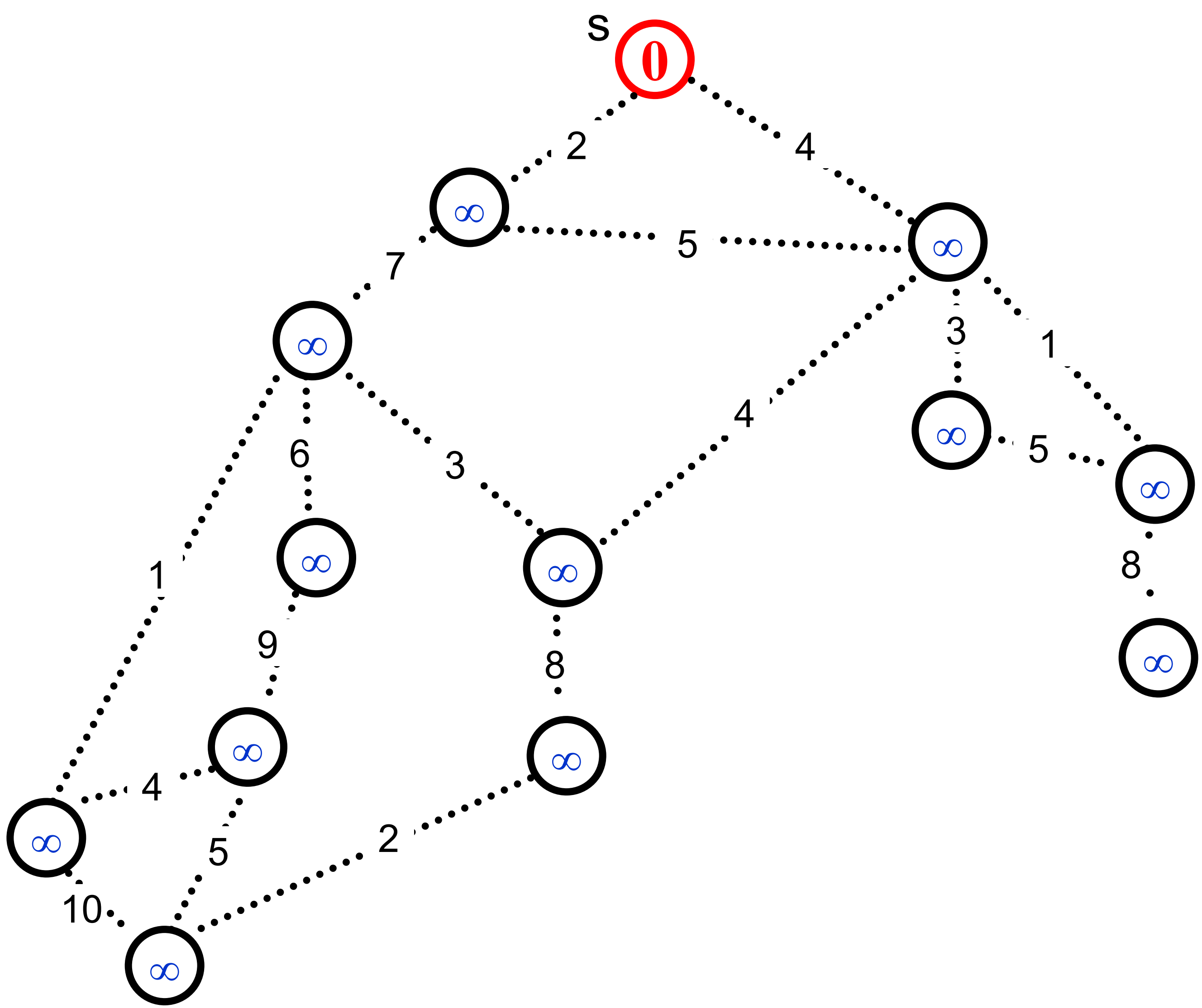
- Update path lengths based on new paths through v

Dijkstra's Algorithm

```
Dijkstra(G, c, s) {
   foreach (v ∈ V) d[v] ← ∞ //This is the key of node v
   d[s] ← 0
   foreach (v ∈ V) insert v onto a priority queue Q
   Initialize set of explored nodes S ← {s}

   while (Q is not empty) {
      u ← delete min element from Q
      S ← S ∪ { u }
      foreach (edge e = (u, v) incident to u)
          if ((v ∉ S) and (d[u]+c_e < d[v]))
             d[v] ← d[u] + c_e
             Decrease key of v to d[v].
             Parent(v) ← u
}
```

Dijkstra’s Algorithm: Example



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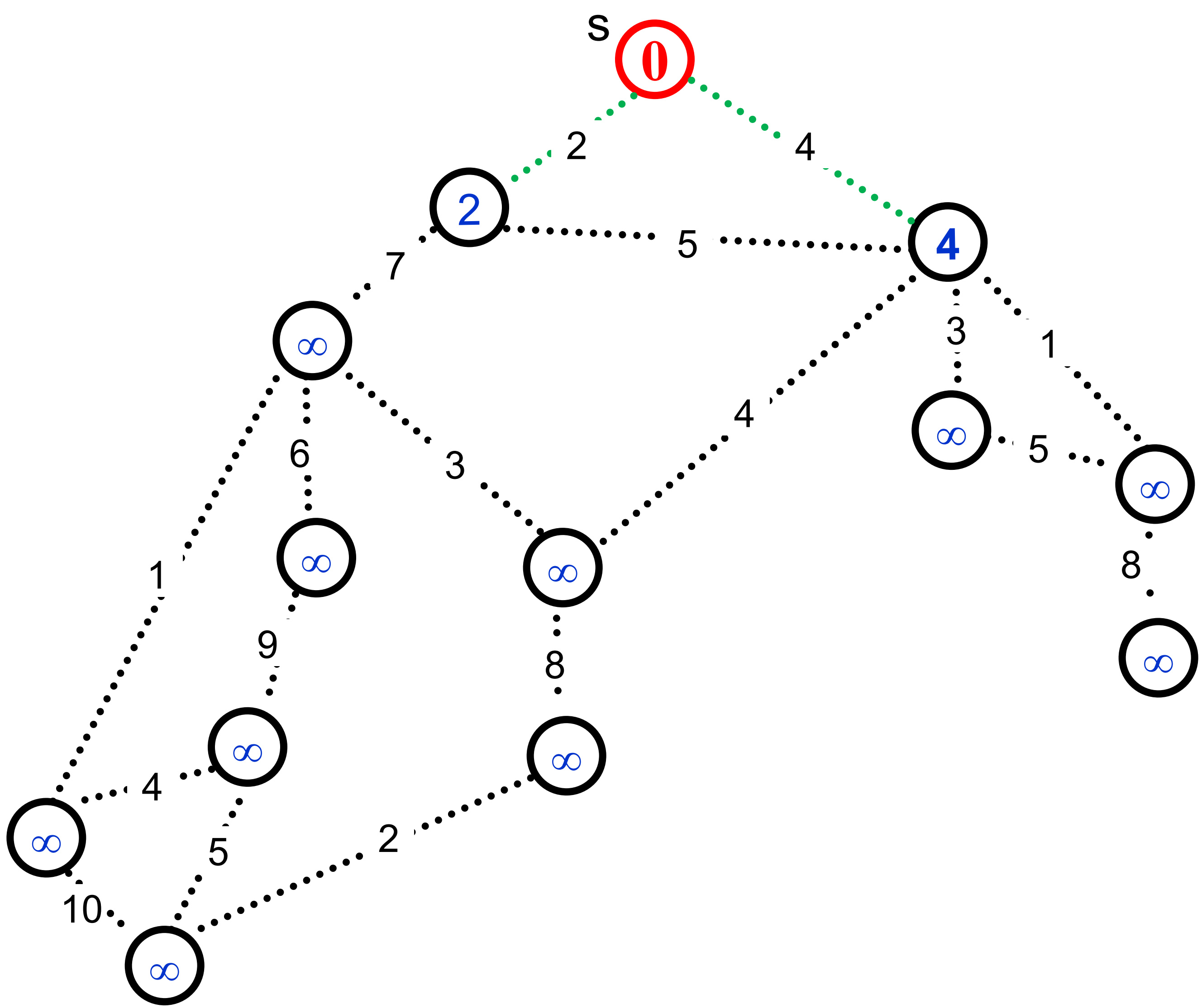

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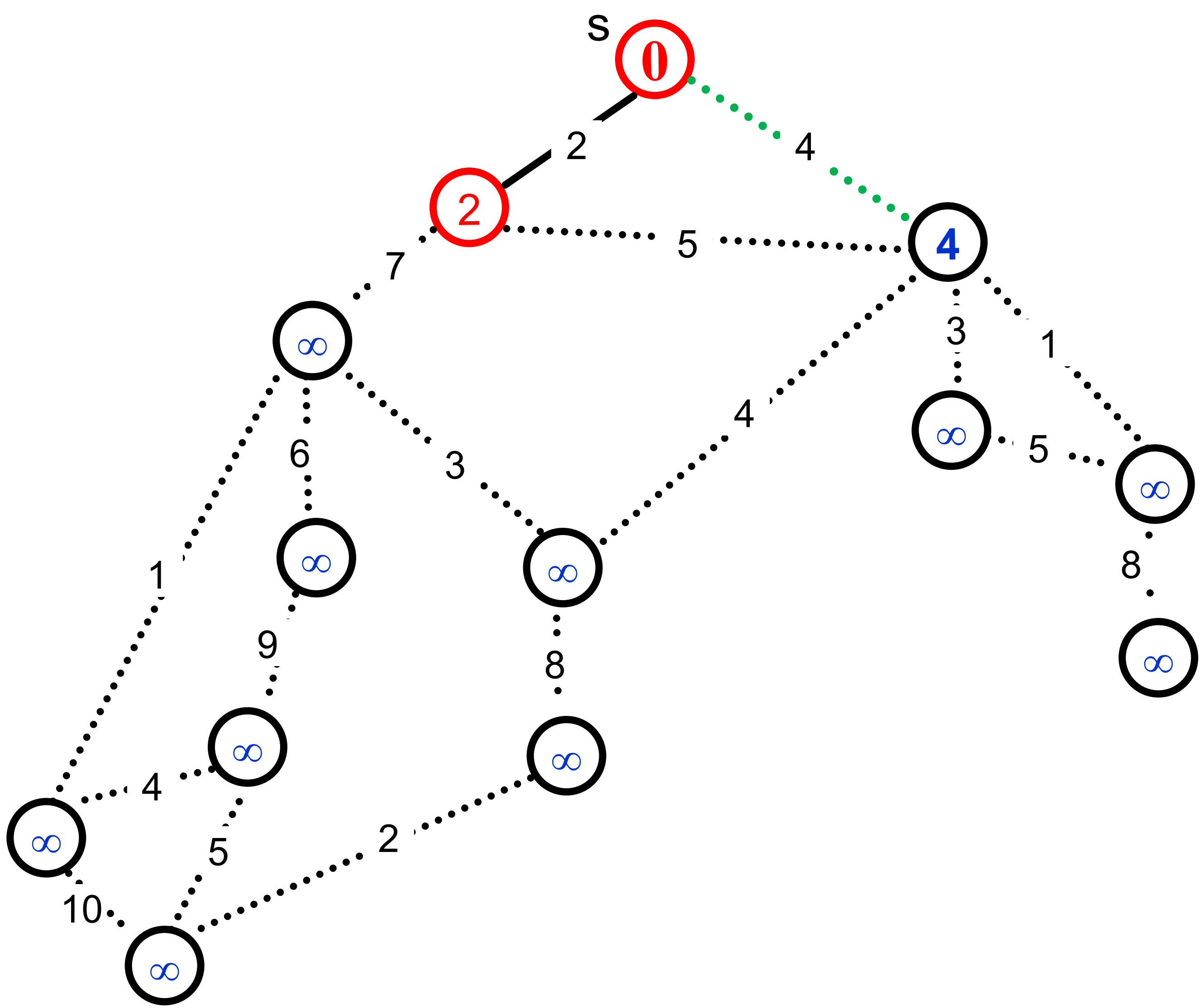

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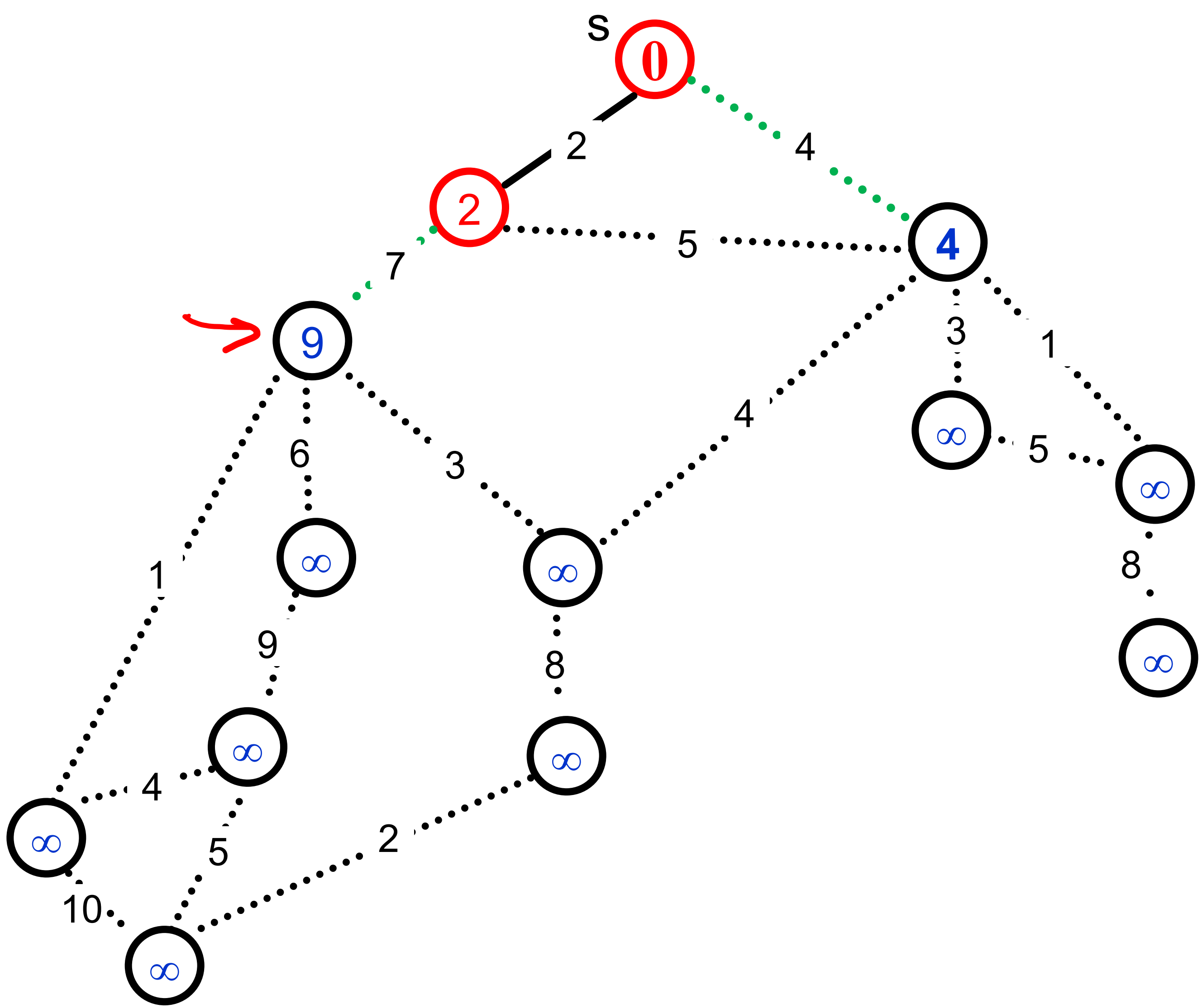

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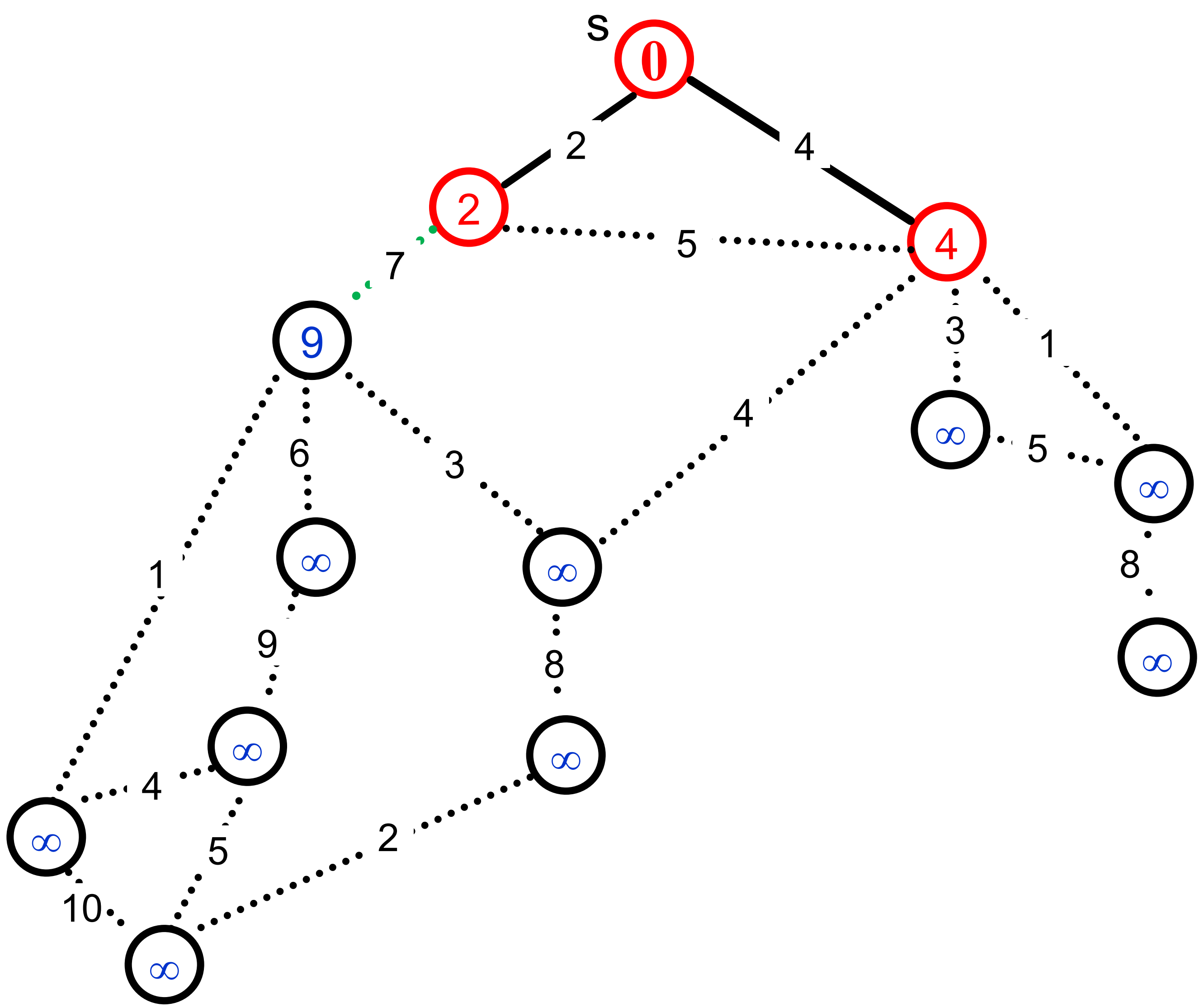

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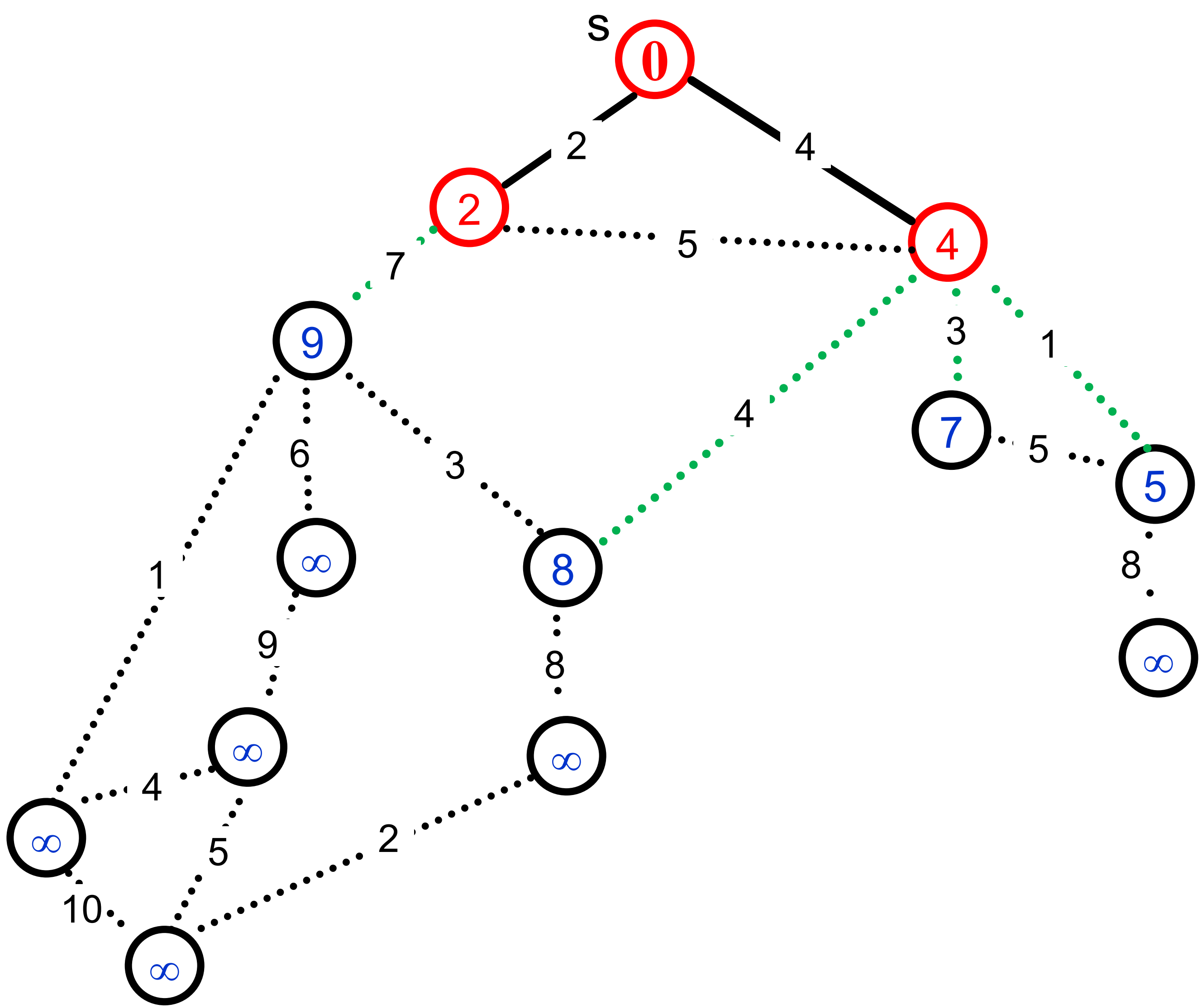

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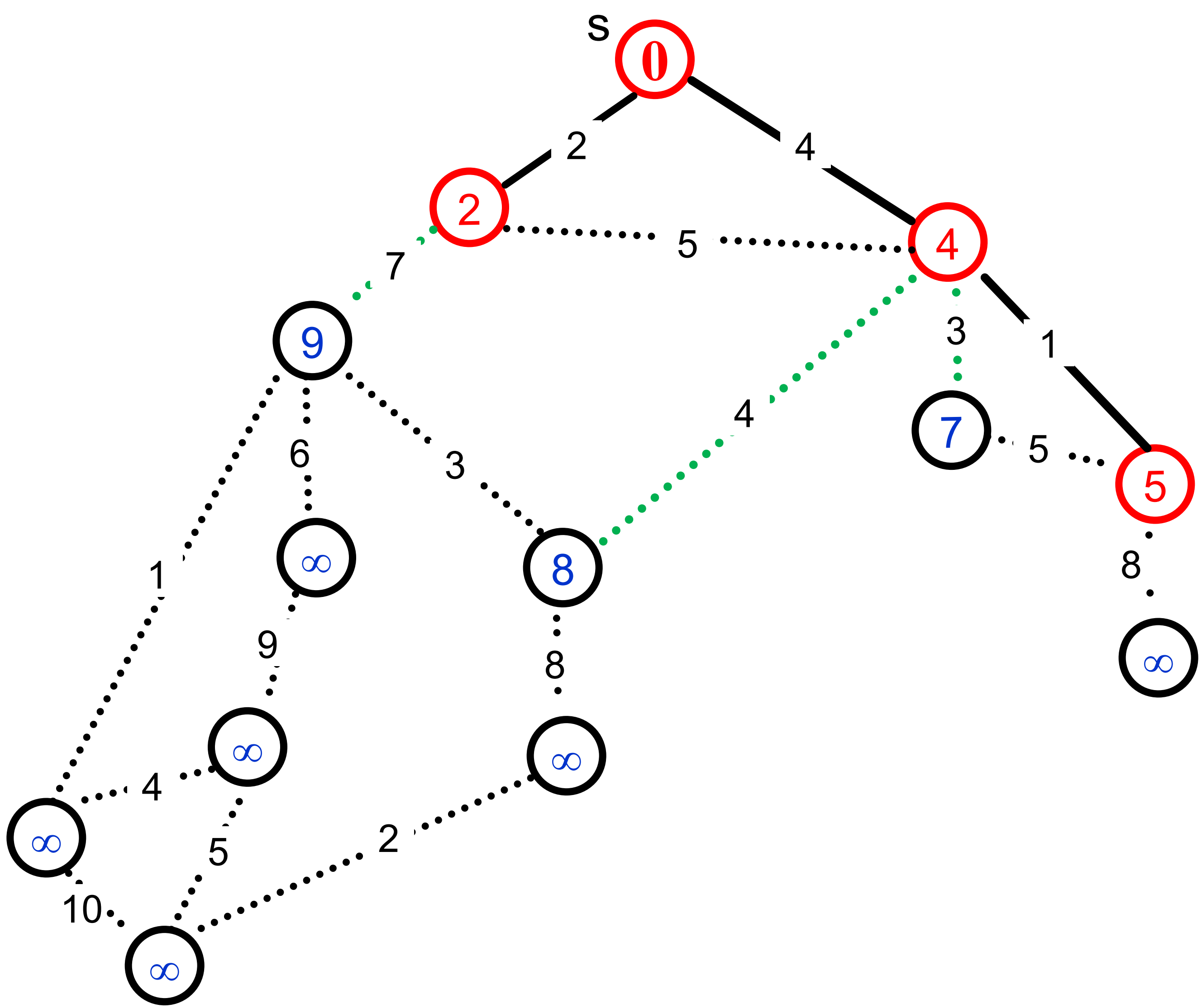

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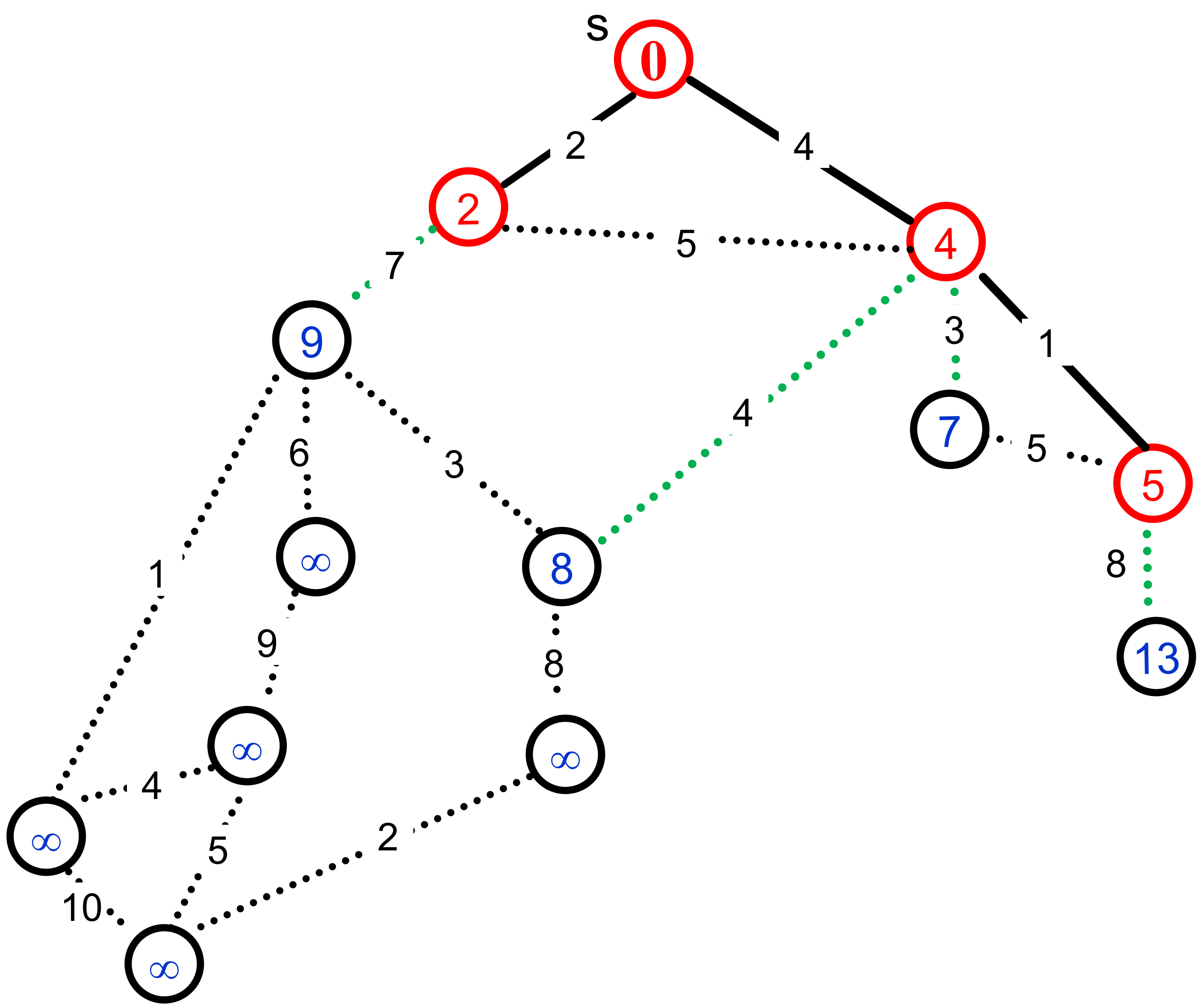

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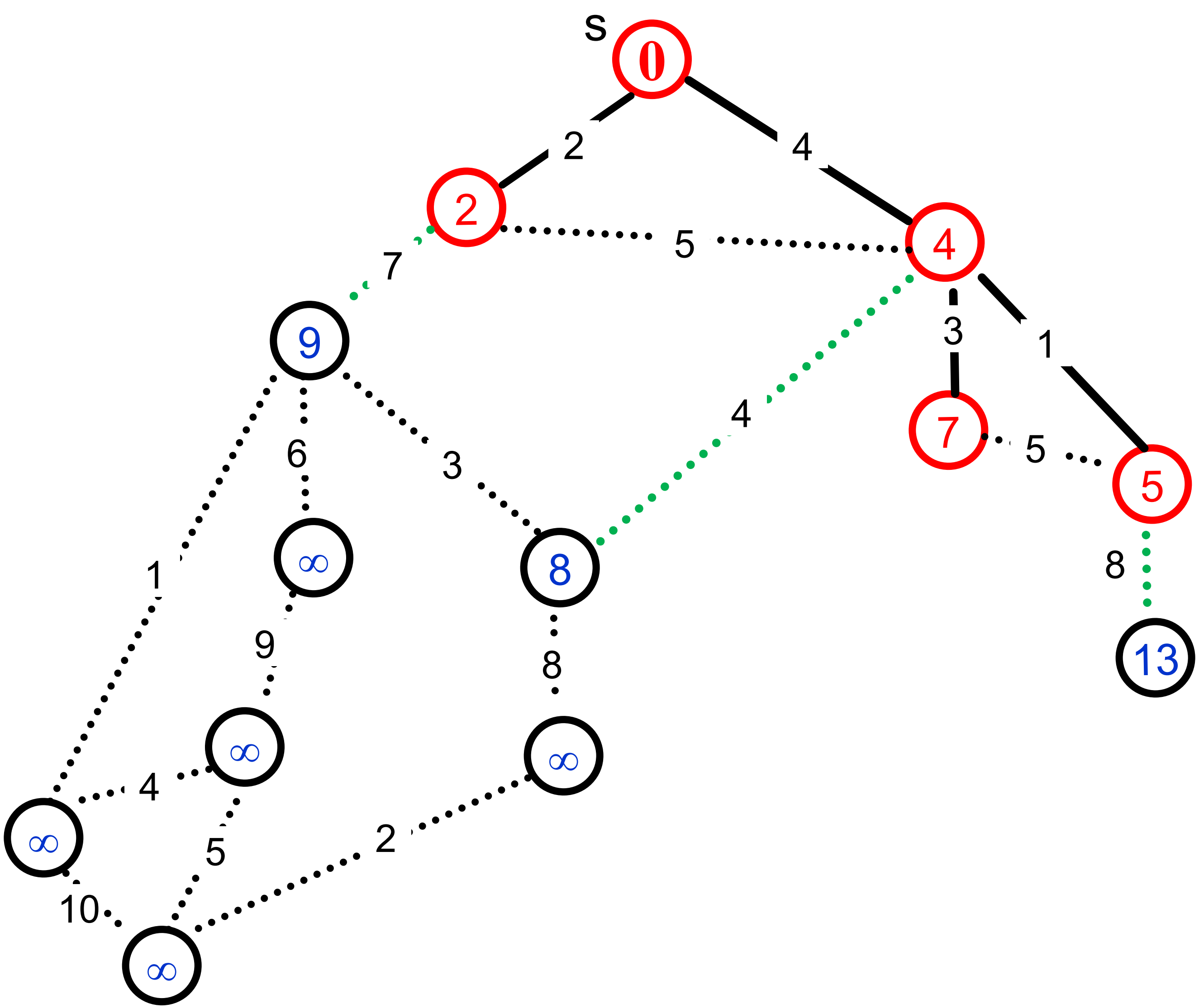

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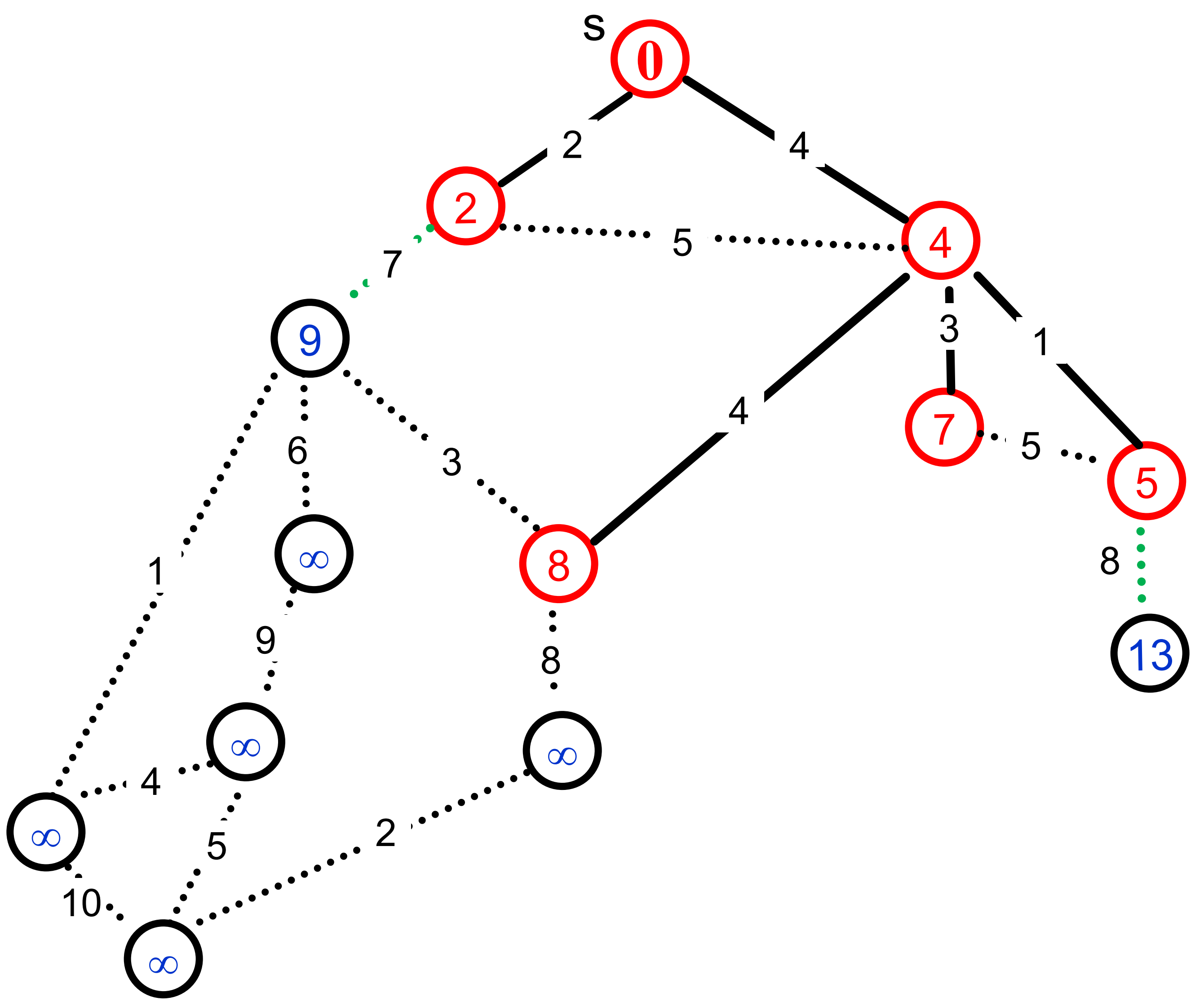

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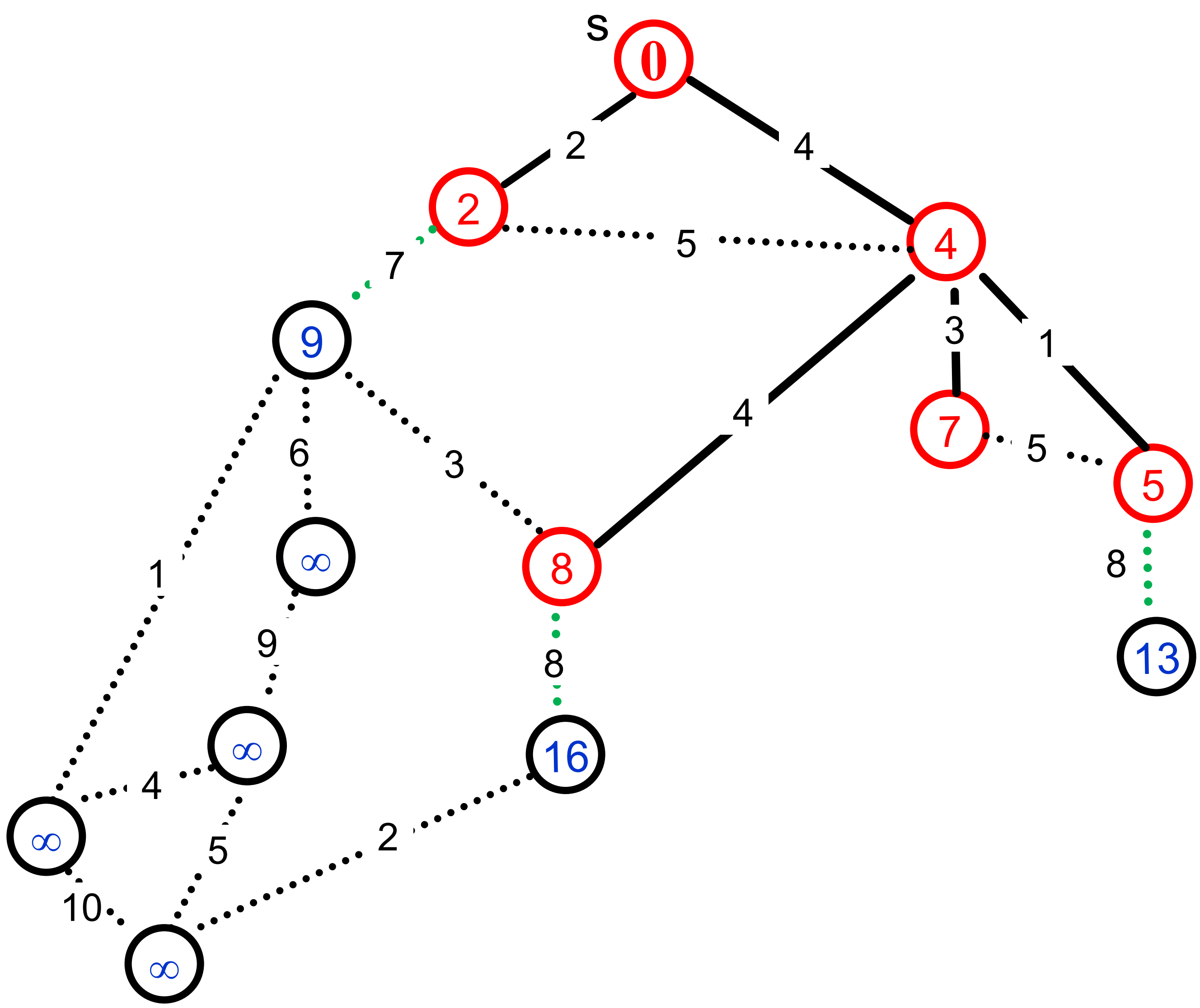

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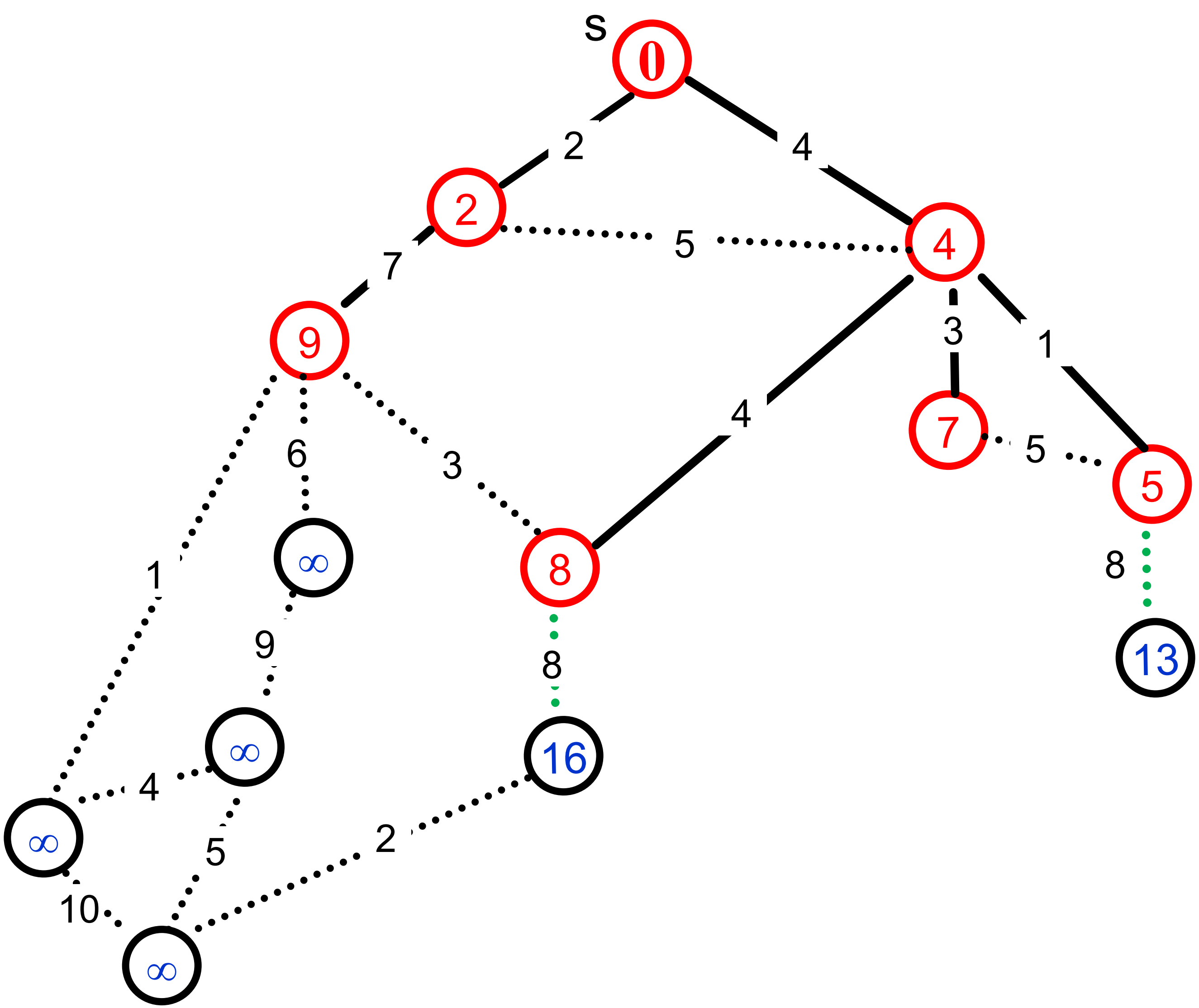

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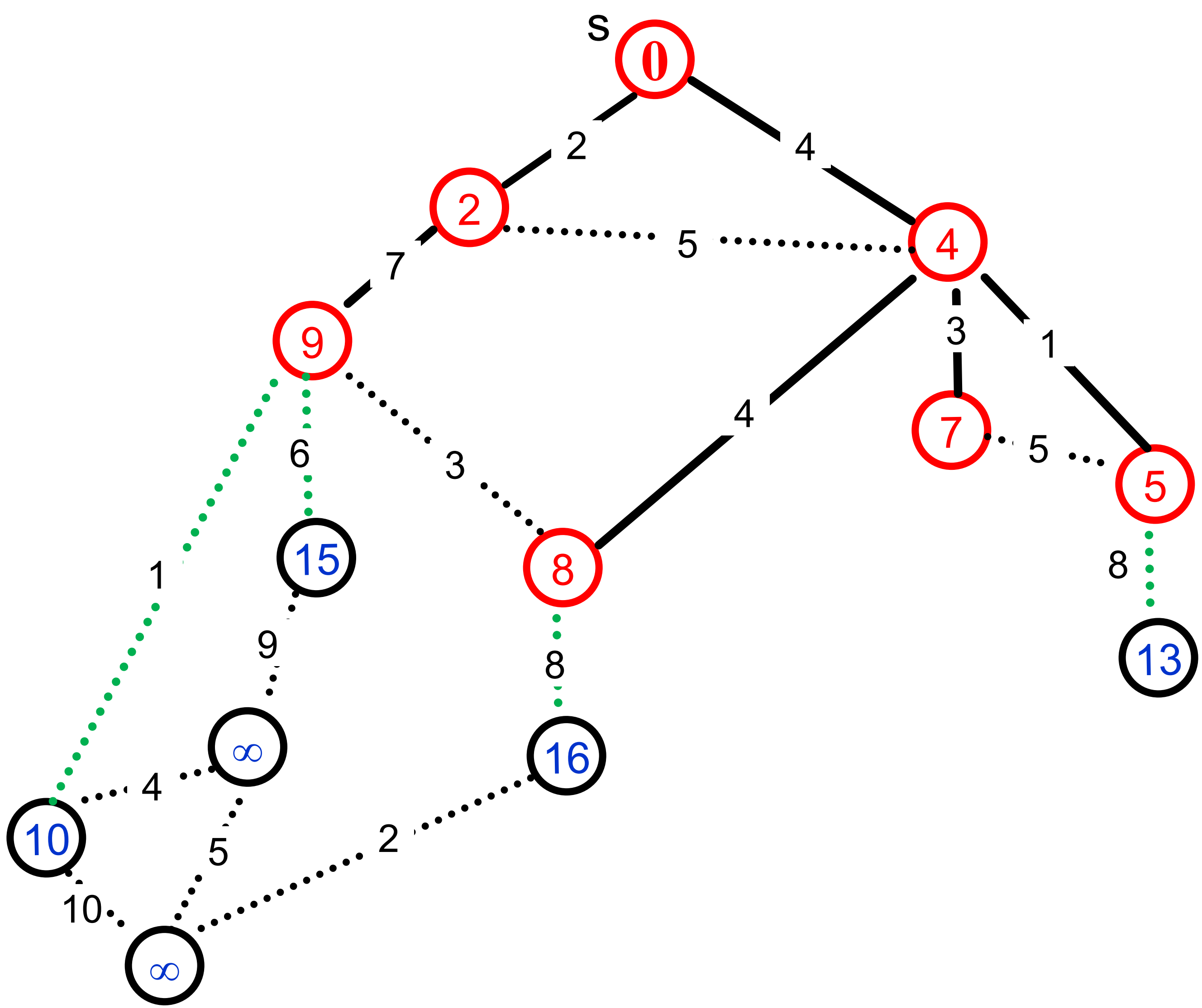

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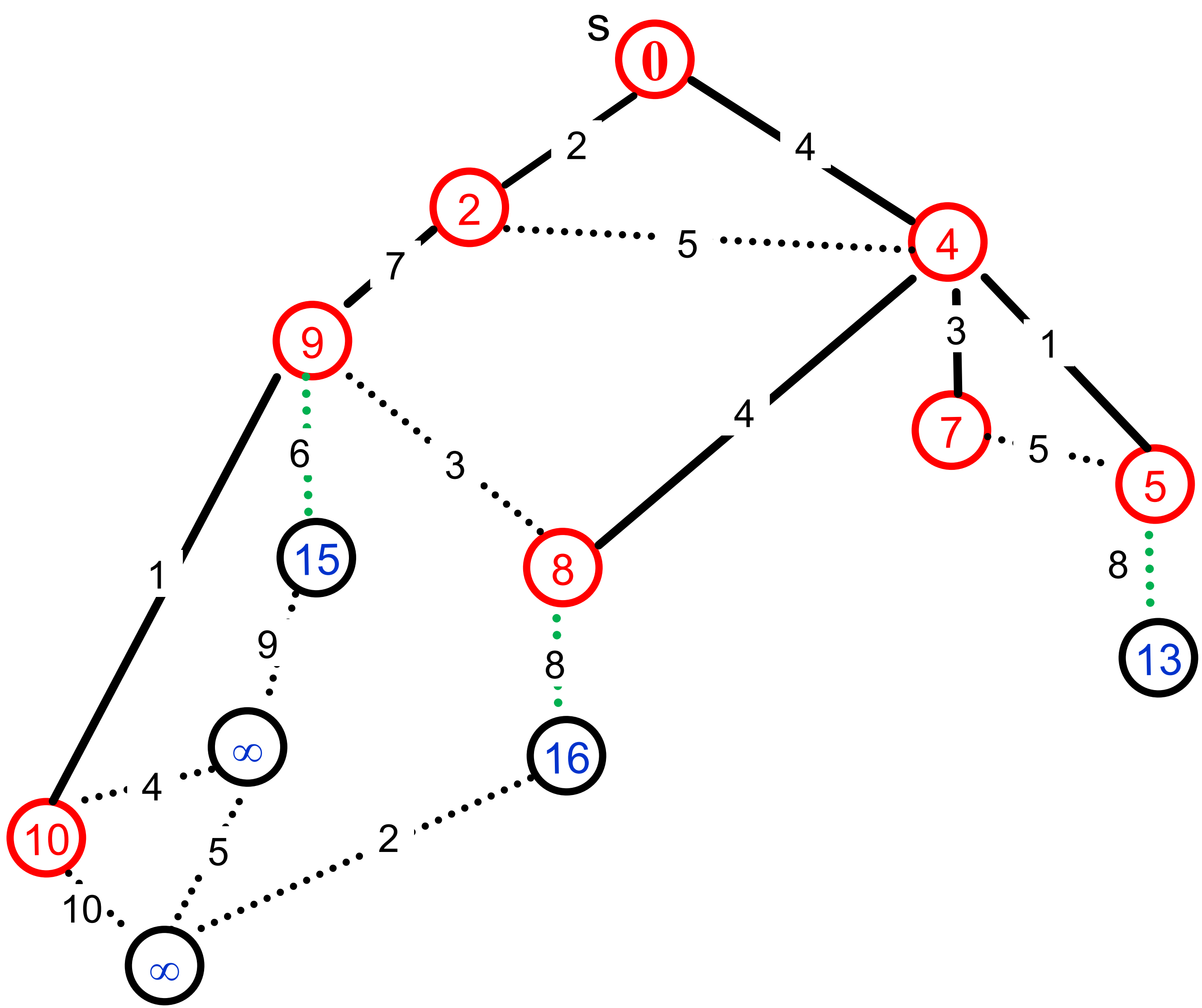

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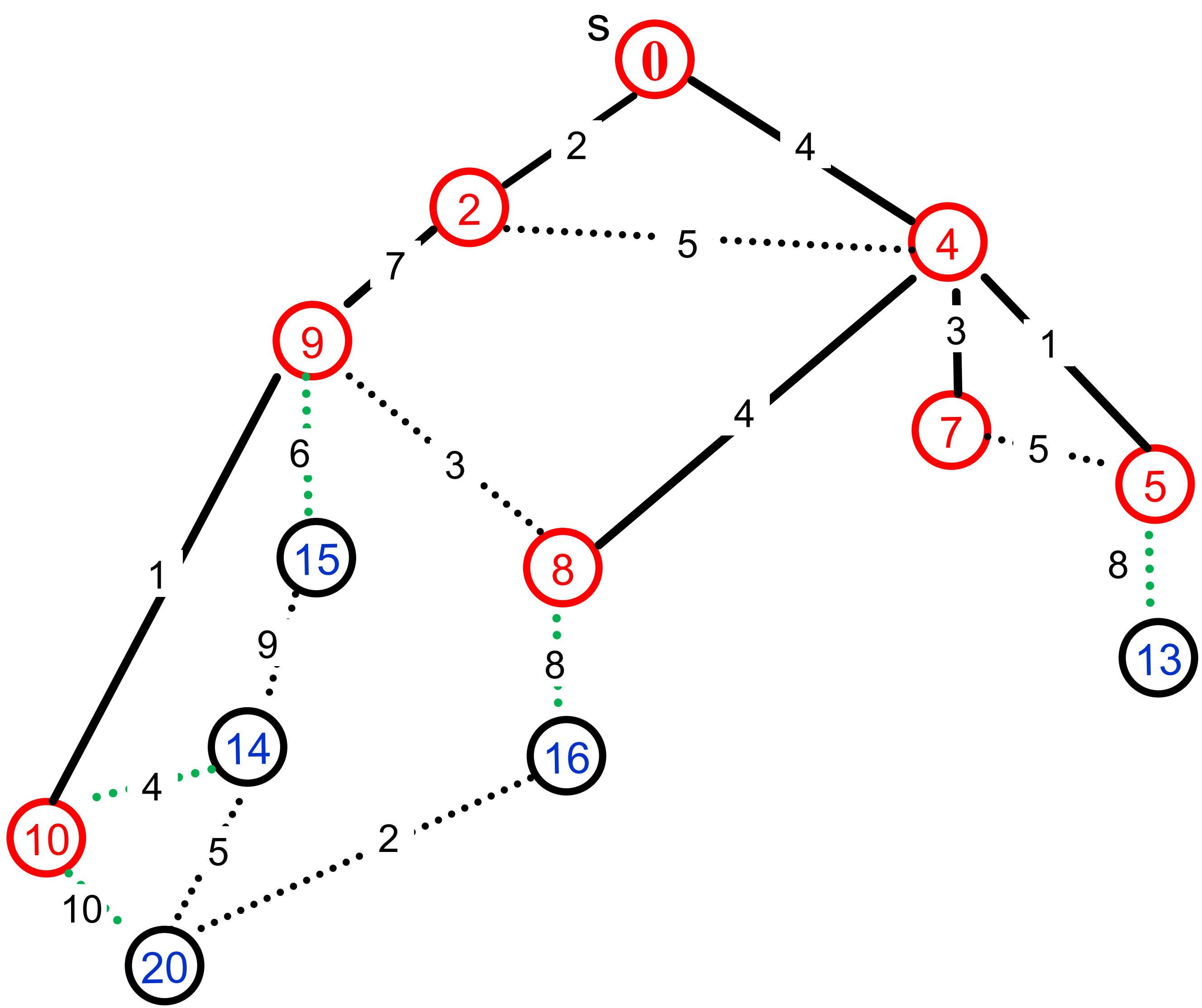

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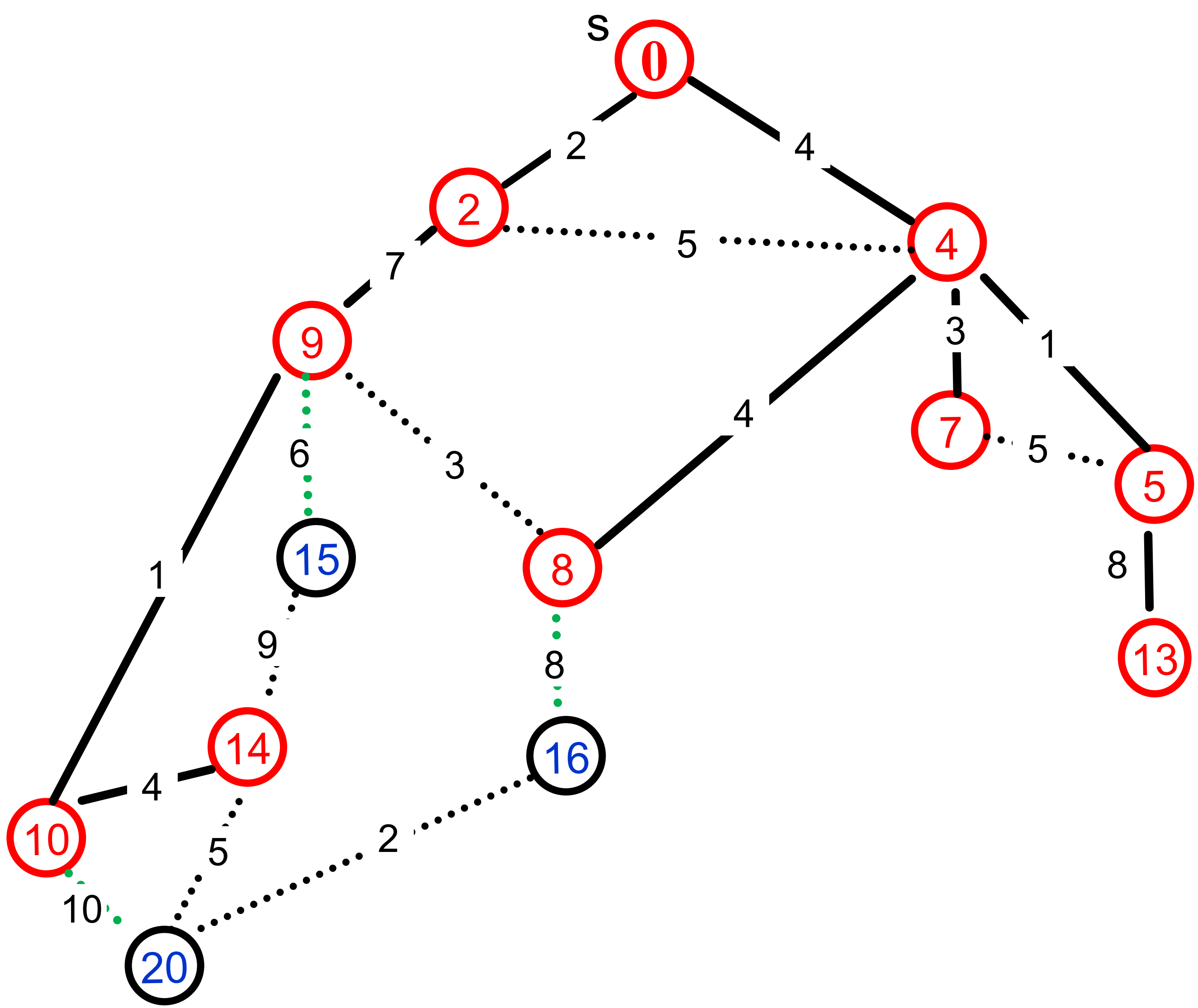

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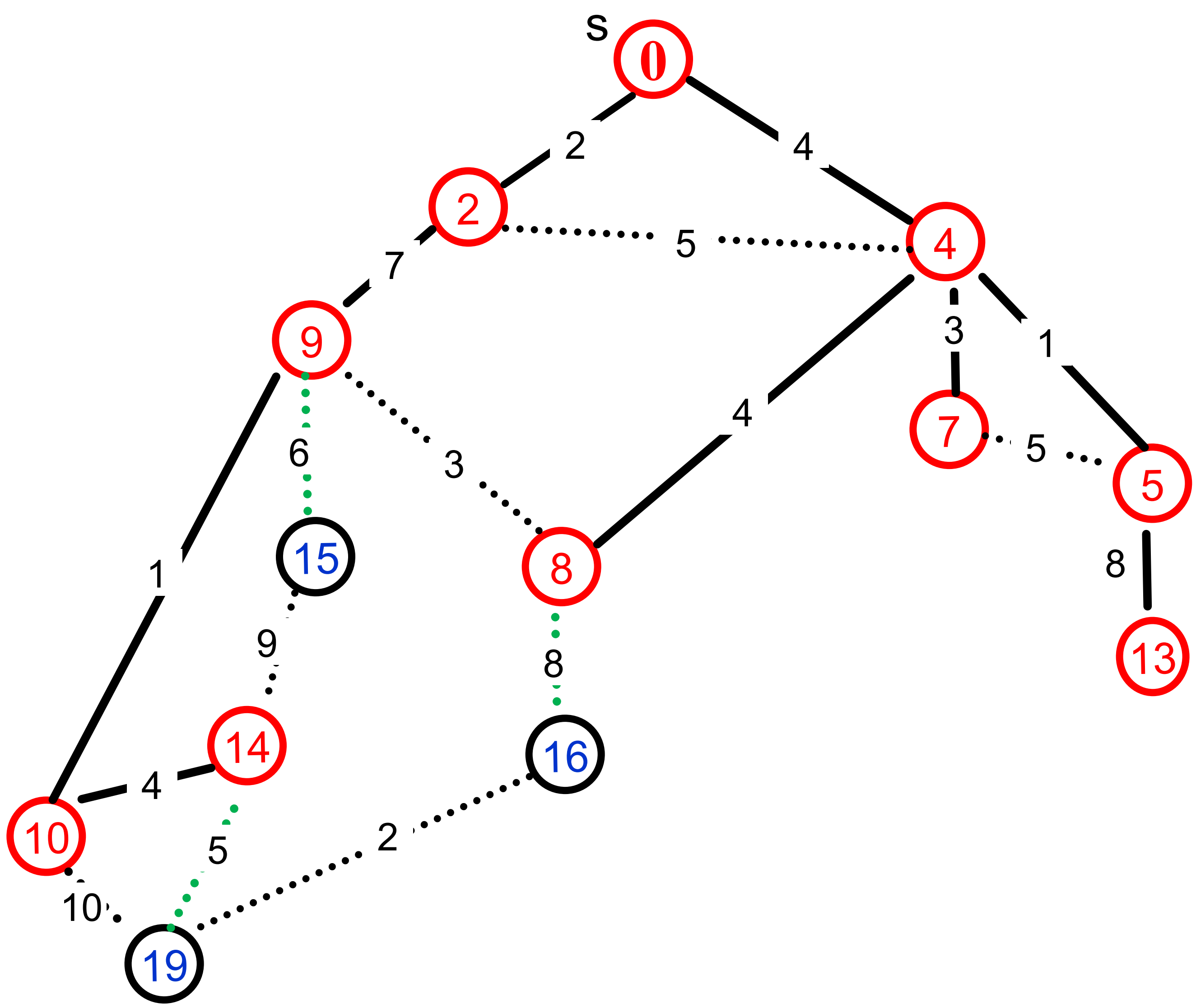

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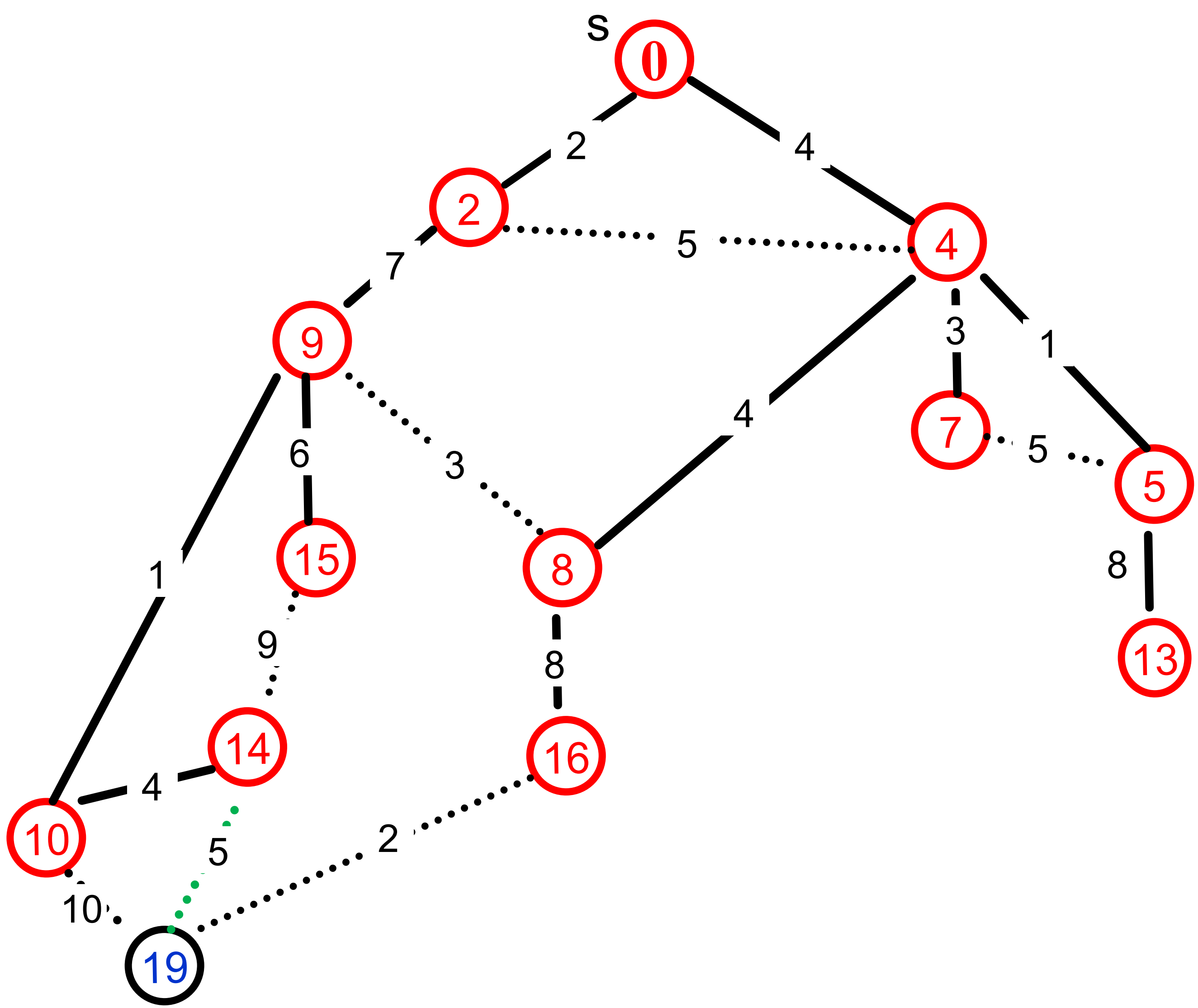

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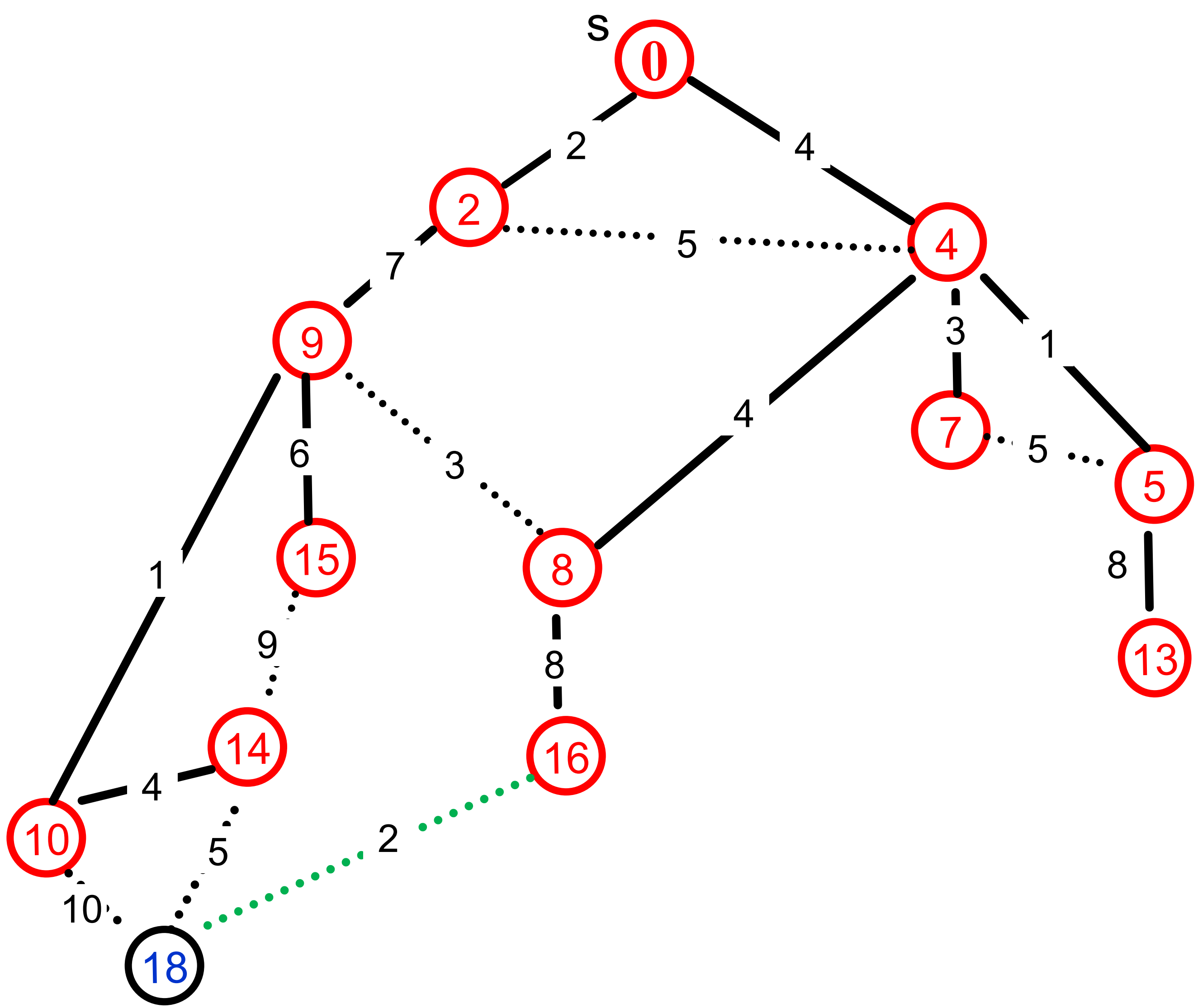

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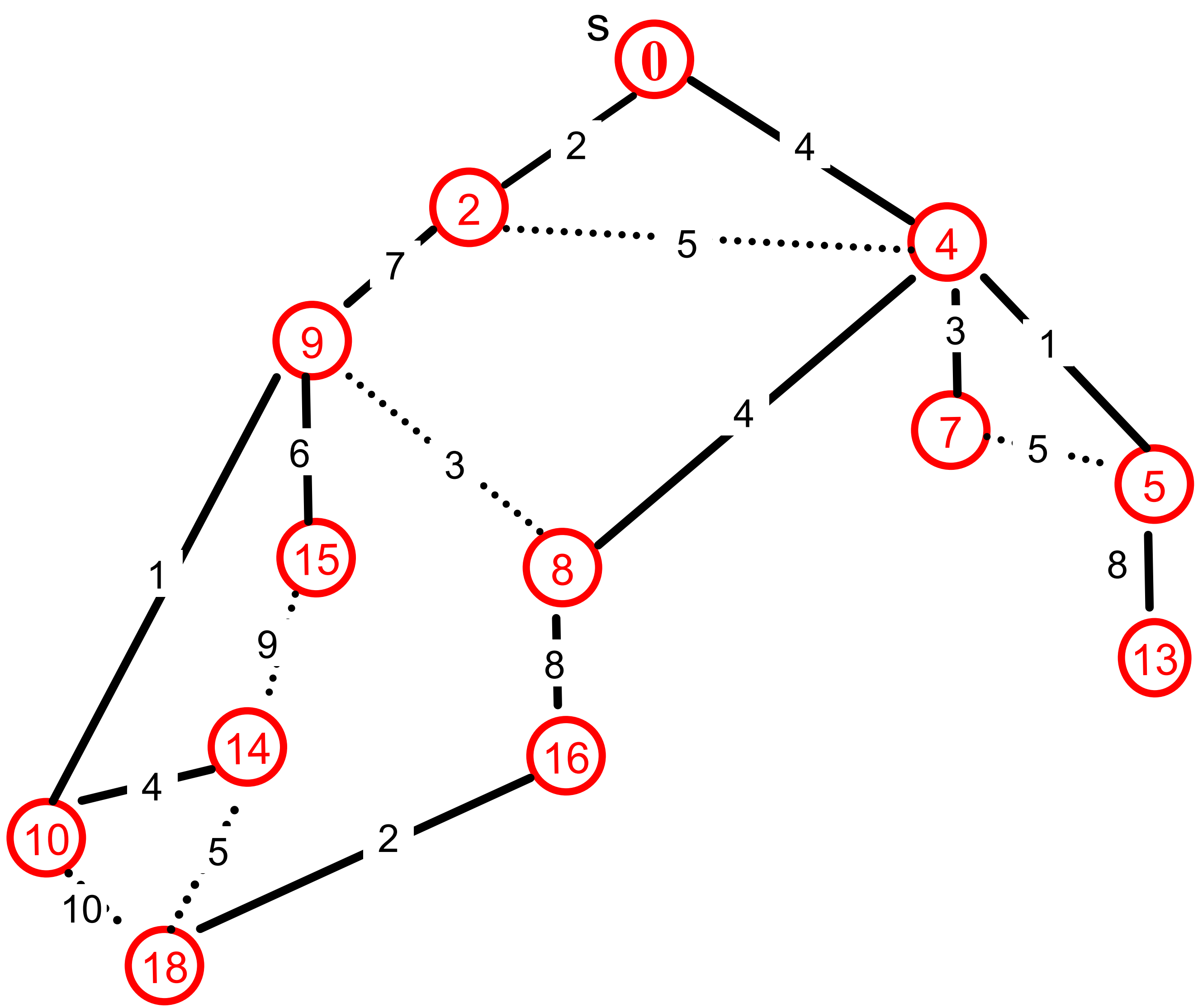

Disjkstra's Algorithm: Correctness

Prove by induction that throughout the algorithm, for any $u \in S$, the path P_u in the shortest from s to u.

Base Case: This is always true when $S = \{s\}$.

IH: Suppose $|S| = k$ and the claim holds for S

IS: Say v is the k+1-st vertex that we add to S. Let {u,v} be last edge on P_v. If P_v is not the shortest path there is a path P to s which is shorter.

Consider the first time that P leaves S (with edge {x,y}).

S -> x has weight (at least) d(x)

So, $c(P) \geq d(x) + c_{x,y} \geq d(v) = c(P_v)$.

A contradiction.