Shortest paths

The Bellman-Ford algorithm

- Most basic algorithm for the shortest-path problem
- Allow negative-weight edges
- Compute $d[v]$ and $\pi[v]$ for all $v \in V$
  - $d[v] = \delta(s, v)$: the shortest-path weight from the source s to v.
  - $\pi[v]$: the parent (predecessor) of v.
- Return TRUE if no negative-weight cycles reachable from source s, FALSE otherwise.

Shortest paths

The Bellman-Ford algorithm – pseudocode

```
Bellman-Ford(G, w, s)
for each vertex v in V               // initialization
    d[v] = infty
    pi[v] = nil
endfor
d[s] = 0
for i = 1 to |V|-1                   // |V|-1 passes
    for each edge (u,v) in E         // in a prescribed order
        if d[v] > d[u] + w(u,v)      // relax if necessary
            d[v] = d[u] + w(u,v)
            pi[v] = u
    endfor
endfor
for each edge (u,v) in E             // final check pass
    if d[v] > d[u] + w(u,v)
       return FALSE
endfor
return TRUE, d, pi
```

Shortest paths

The Bellman-Ford algorithm

- Run and illustrate the Bellman-Ford algorithm
- Running time: $\Theta(|V| \cdot |E|)$.
- Values you get on each pass and how quickly it converges depends on order of relaxation (processing edges). But guaranteed to converge after $|V| - 1$ passes, assuming no negative-weight cycles.

Shortest paths

Dijkstra's algorithm

- No negative weight edges
- Like BFS. If all weights $= 1$, use BFS.
- Use $Q =$ priority queue keyed by $d[v]$
  (vs. BFS uses FIFO queue)
- Have two sets of vertices:
  - $S =$ vertices whose final shortest-path weights are determined
  - $Q =$ priority queue $= V - S$

Shortest paths

Dijkstra's algorithm – pseudocode

```
Dijkstra(G, w, s)
for each vertex v in V              // Initialization
    d[v] = infty
    pi[v] = nil
endfor
d[s] = 0
S = empty
Q = V                               // priority queue keyed by d[v]
while Q is not empty
    u = Extract-Min(Q)
    S = S U {u}
    for each vertex v in Adj[u]
        if d[v] > d[u] + w(u,v)     // Relax if necessary
            d[v] = d[u] + w(u,v)
            pi[v] = u
        endif
    endfor
endwhile
return d, pi
```

Shortest paths

Dijkstra's algorithm

- Run and illustrate Dijkstra's algorithm
- Running time: $O(|E| \lg |V|)$ (binary heap)
- Similar to the BFS and MST-algorithms, Dijkstra's algorithm is a greedy algorithm. It always chooses the "lightest" or "closest" vertex in $V - S$ to insert into S

Shortest paths

The SSSP in DAG

- DAG: can have negative-weight edges, but no negative-weight cycle.
- How fast can do it?

  Answer: $O(|V| + |E|)$, instead of $\Theta(|V| \cdot |E|)$ by Bellman-Ford

Shortest paths

The SSSP in DAG – pseudocode

```
DAG-Shortest-Path(G, w, s)
Topological sort of the vertices of G
for each vertex v in V
    d[v] = infty
    pi[v] = nil
endfor
d[s] = 0
for each vertex u taken in topologically sorted order
   for each vertex v in Adj[u]
       if d[v] > d[u] + w(u,v)
            d[v] = d[u] + w(u,v)
            pi[v] = u
       endif
   endfor
endfor
return d, pi
```