



CS 400

Graphs: BFS Traversal

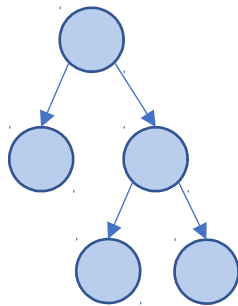
ID: 13-01

Traversal:

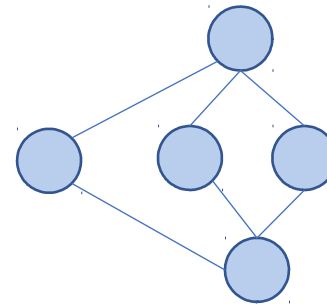
Objective: Visit every vertex and every edge in the graph.

Purpose: Search for interesting sub-structures in the graph.

We've seen traversal beforebut it's different:



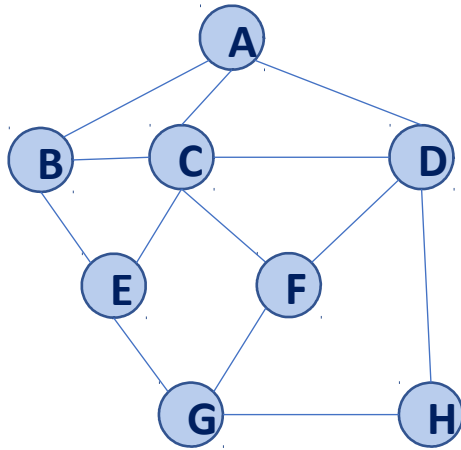
- Ordered
- Obvious Start
- Notation of completeness



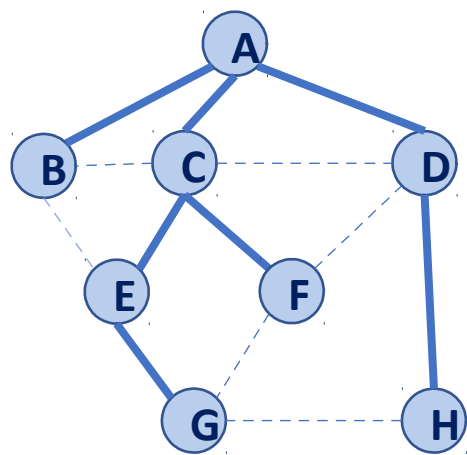
- not ordered
- no obvious starting point
- no notion of completeness

Traversal: BFS

visit all the adjacent nodes first



Traversal: BFS



d	p		Adjacent Edges
0	A	A	C B D
1	A	B	A C E
1	A	C	B A D E F
1	A	D	A C F H
2	C	E	B C G
2	C	F	C D G
3	E	G	E F H
2	D	H	D G



```
1 BFS (G) :
2   Input: Graph, G
3   Output: A labeling of the edges on
4           G as discovery and cross edges
5
6   foreach (Vertex v : G.vertices()):
7       setLabel(v, UNEXPLORED)
8   foreach (Edge e : G.edges()):
9       setLabel(e, UNEXPLORED)
10  foreach (Vertex v : G.vertices()):
11      if getLabel(v) == UNEXPLORED:
12          BFS (G, v)
```

```
14 BFS (G, v) :
15     Queue q
16     setLabel(v, VISITED)
17     q.enqueue(v)
18
19     while !q.empty():
20         v = q.dequeue()
21         foreach (Vertex w : G.adjacent(v)):
22             if getLabel(w) == UNEXPLORED:
23                 setLabel(v, w, DISCOVERY)
24                 setLabel(w, VISITED)
25                 q.enqueue(w)
26             elseif getLabel(v, w) == UNEXPLORED:
27                 setLabel(v, w, CROSS)
```



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Graphs: BFS Analysis

ID: 13-02

BFS Analysis

Q: Does our implementation handle disjoint graphs?
If so, what code handles this? [code line 10:13](#)

- ***How do we use this to count components?***

[add line 13: comp++ counter](#)

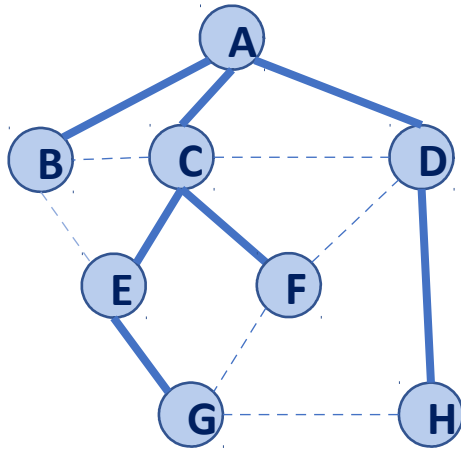
Q: Does our implementation detect a cycle? [yes](#)

- ***How do we update our code to detect a cycle?***

[add line 28: cycle=true](#)

Q: What is the running time? [line 19](#)

Running time of BFS



While-loop at :**19**? $O(n)$

For-loop at :**21**?

$O(m+n)$ could be $O(n*n)$

d	p	v	Adjacent
0	A	A	C B D
1	A	B	A C E
1	A	C	B A D E F
1	A	D	A C F H
2	C	E	B C G
2	C	F	C D G
3	E	G	E F H
2	D	H	D G




```
1 BFS (G) :  
2   Input: Graph, G  
3   Output: A labeling of the edges on  
4           G as discovery and cross edges  
5  
6   foreach (Vertex v : G.vertices()):  
7       setLabel(v, UNEXPLORED)  
8   foreach (Edge e : G.edges()):  
9       setLabel(e, UNEXPLORED)  
10  foreach (Vertex v : G.vertices()):  
11      if getLabel(v) == UNEXPLORED:  
12          BFS (G, v)
```

```
14 BFS (G, v) :  
15     Queue q  
16     setLabel(v, VISITED)  
17     q.enqueue(v)  
18  
19     while !q.empty():  
20         v = q.dequeue()  
21         foreach (Vertex w : G.adjacent(v)):  
22             if getLabel(w) == UNEXPLORED:  
23                 setLabel(v, w, DISCOVERY)  
24                 setLabel(w, VISITED)  
25                 q.enqueue(w)  
26             elseif getLabel(v, w) == UNEXPLORED:  
27                 setLabel(v, w, CROSS)
```

BFS Observations

Q: What is a shortest path from **A** to **H**?

A-D-H

Q: What is a shortest path from **E** to **H**?

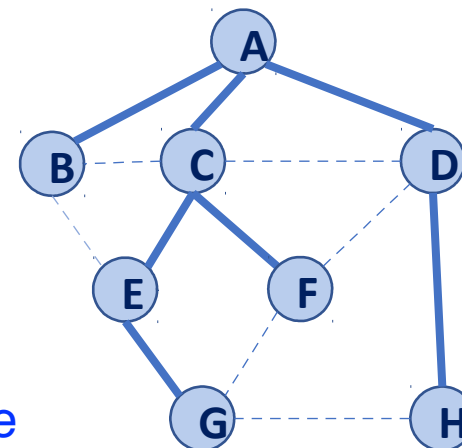
not possible with only BFS

Q: How does a cross edge relate to **d**?

no more than 1 from the start

Q: What structure is made from discovery edges? spanning tree

d	p	v	Adjacent
0	A	A	C B D
1	A	B	A C E
1	A	C	B A D E F
1	A	D	A C F H
2	C	E	B C G
2	C	F	C D G
3	E	G	E F H
2	D	H	D G



BFS Observations

Obs. 1: Traversals can be used to count components.

Obs. 2: Traversals can be used to detect cycles.

Obs. 3: In BFS, **d** provides the shortest distance to every vertex.

Obs. 4: In BFS, the endpoints of a cross edge never differ in distance, **d**, by more than 1:

$$|d(u) - d(v)| = 1$$

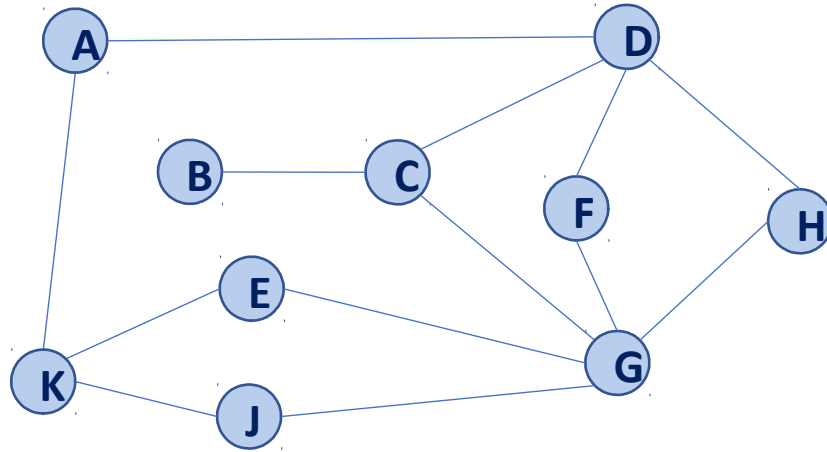


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Graphs: DFS Traversal

ID: 13-03

Traversal: DFS



visit nearby incident
nodes first

```
1 BFS (G) :
2   Input: Graph, G
3   Output: A labeling of the edges on
4           G as discovery and cross edges
5
6   foreach (Vertex v : G.vertices()):
7       setLabel(v, UNEXPLORED)
8   foreach (Edge e : G.edges()):
9       setLabel(e, UNEXPLORED)
10  foreach (Vertex v : G.vertices()):
11      if getLabel(v) == UNEXPLORED:
12          BFS (G, v)
```

```
14 BFS (G, v) :
15     Queue q
16     setLabel(v, VISITED)
17     q.enqueue(v)
18
19     while !q.empty():
20         v = q.dequeue()
21         foreach (Vertex w : G.adjacent(v)):
22             if getLabel(w) == UNEXPLORED:
23                 setLabel(v, w, DISCOVERY)
24                 setLabel(w, VISITED)
25                 q.enqueue(w)
26             elseif getLabel(v, w) == UNEXPLORED:
27                 setLabel(v, w, CROSS)
```

```
1 DFS(G) :
2   Input: Graph, G
3   Output: A labeling of the edges on
4           G as discovery and back edges
5
6   foreach (Vertex v : G.vertices()):
7       setLabel(v, UNEXPLORED)
8   foreach (Edge e : G.edges()):
9       setLabel(e, UNEXPLORED)
10  foreach (Vertex v : G.vertices()):
11      if getLabel(v) == UNEXPLORED:
12          DFS(G, v)
```

```
14 DFS(G, v) :
15 — Queue q
16   setLabel(v, VISITED)
17 — q.enqueue(v)
18
19 — while !q.empty():
20 — v = q.dequeue()
21   foreach (Vertex w : G.adjacent(v)) :
22       if getLabel(w) == UNEXPLORED:
23           setLabel(v, w, DISCOVERY)
24           setLabel(w, VISITED)
25           DFS(G, w)
26       elseif getLabel(v, w) == UNEXPLORED:
27           setLabel(v, w, BACK)
```

Running time of DFS

Labeling:

- Vertex: $2m \rightarrow O(n)$

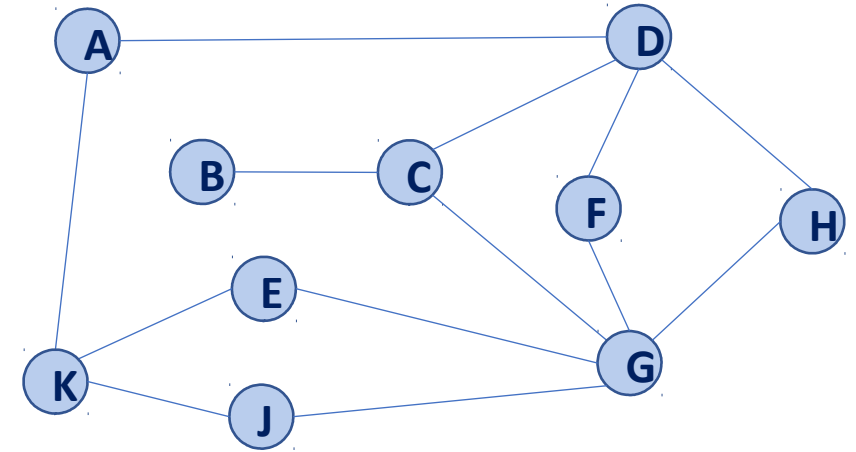
- Edge: $2*m \rightarrow O(n)$

total = $O(m+n)$

Queries:

- Vertex: $n \rightarrow O(n)$

- Edge: $\text{sum}(\text{deg}(v)) = 2m = O(m)$



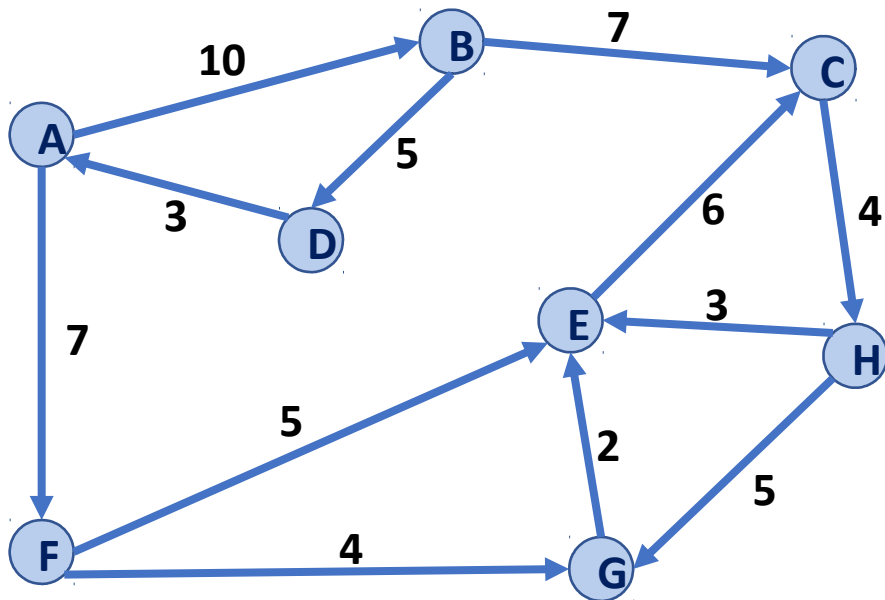


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Graphs: Dijkstra's Algorithm

ID: 15-01

Dijkstra's Algorithm (SSSP)



```
DijkstraSSSP(G, s):
```

```
6   foreach (Vertex v : G):
```

```
7       d[v] = +inf
```

```
8       p[v] = NULL
```

```
9       d[s] = 0
```

```
10
```

```
11   PriorityQueue Q // min distance, defined by d[v]
```

```
12   Q.buildHeap(G.vertices())
```

```
13   Graph T          // "labeled set"
```

```
14
```

```
15   repeat n times:
```

```
16       Vertex u = Q.removeMin()
```

```
17       T.add(u)
```

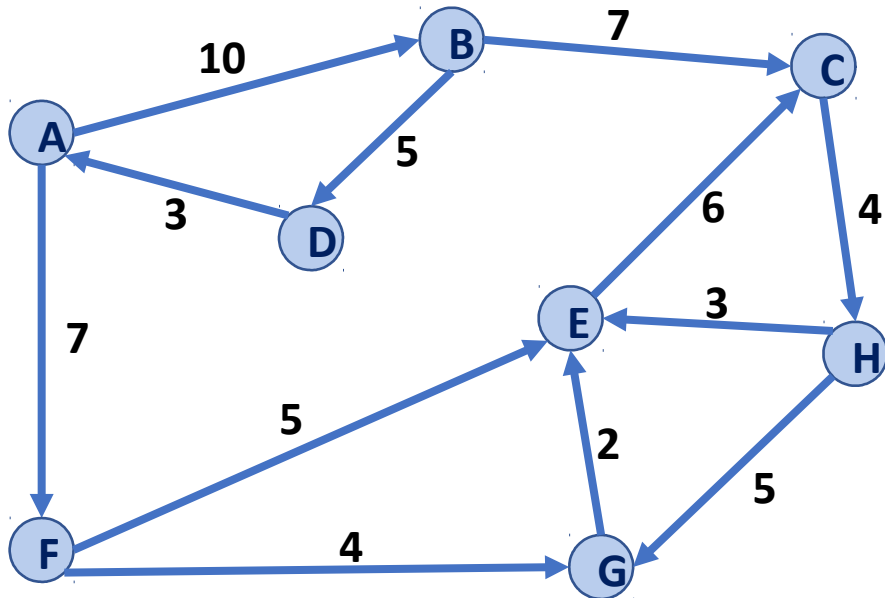
```
18       foreach (Vertex v : neighbors of u not in T):
```

```
19           if _____ < d[v]:
```

```
20               d[v] = _____
```

```
21               p[v] = m
```

Dijkstra's Algorithm (SSSP)



```
DijkstraSSSP(G, s):
```

```
6   foreach (Vertex v : G):
```

```
7       d[v] = +inf
```

```
8       p[v] = NULL
```

```
9       d[s] = 0
```

```
10
```

```
11   PriorityQueue Q // min distance, defined by d[v]
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12   Q.buildHeap(G.vertices())
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13   Graph T          // "labeled set"
```

```
14
```

```
15   repeat n times:
```

```
16       Vertex u = Q.removeMin()
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```
17       T.add(u)
```

```
18       foreach (Vertex v : neighbors of u not in T):
```

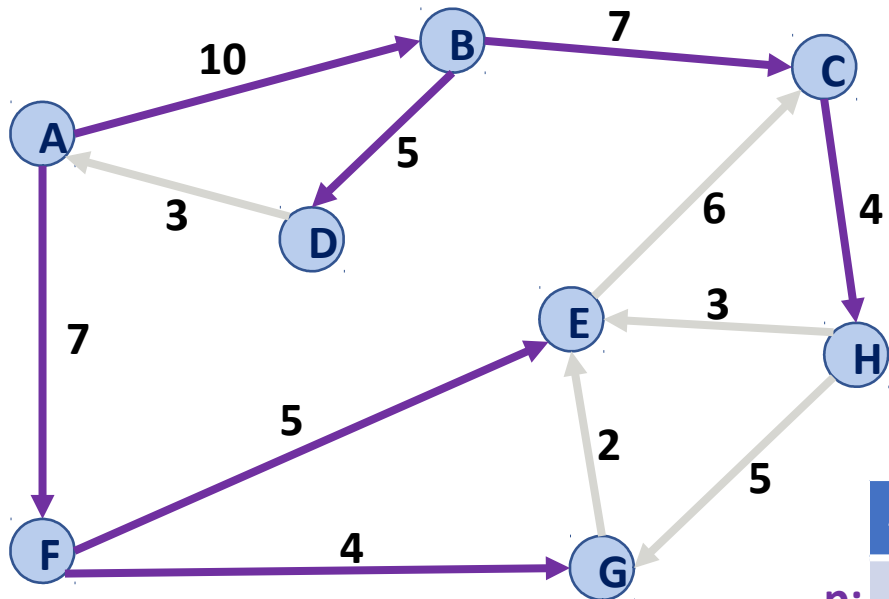
```
19           if cost(u, v) + d[u] < d[v]:
```

```
20               d[v] = cost(u, v) + d[u]
```

```
21               p[v] = u
```

Dijkstra's Algorithm (SSSP)

Dijkstra gives us the shortest path from our path (single source) to **every** connected vertex!



	A	B	C	D	E	F	G	H
p:	NULL	A	B	B	F	A	F	C
d:	0	10	17	15	12	7	11	21



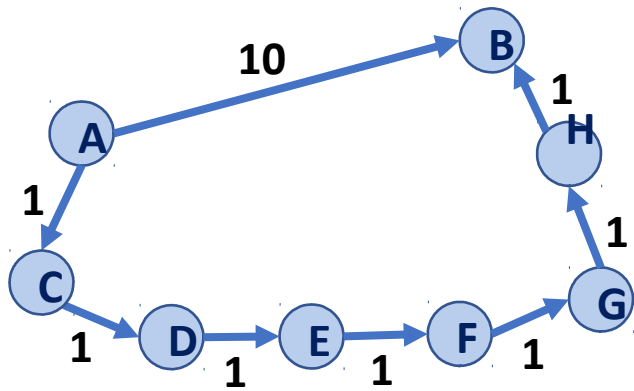
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Graphs: Dijkstra's Edge Cases

ID: 15-02

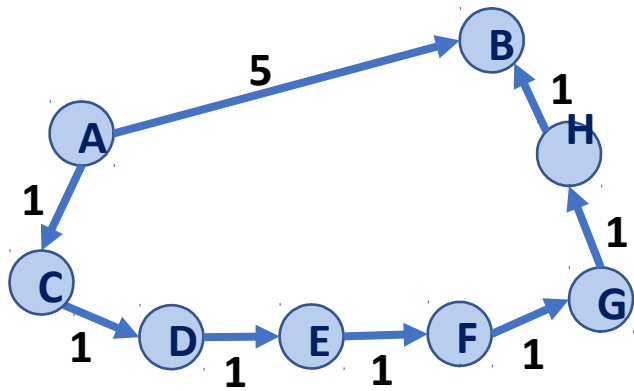
Dijkstra's Algorithm (SSSP)

Q: How does Dijkstra handle a single heavy-weight path vs. many light-weight paths?



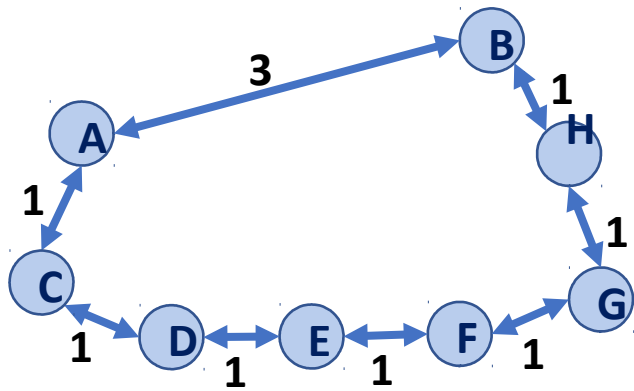
Dijkstra's Algorithm (SSSP)

Q: How does Dijkstra handle a single heavy-weight path vs. many light-weight paths?



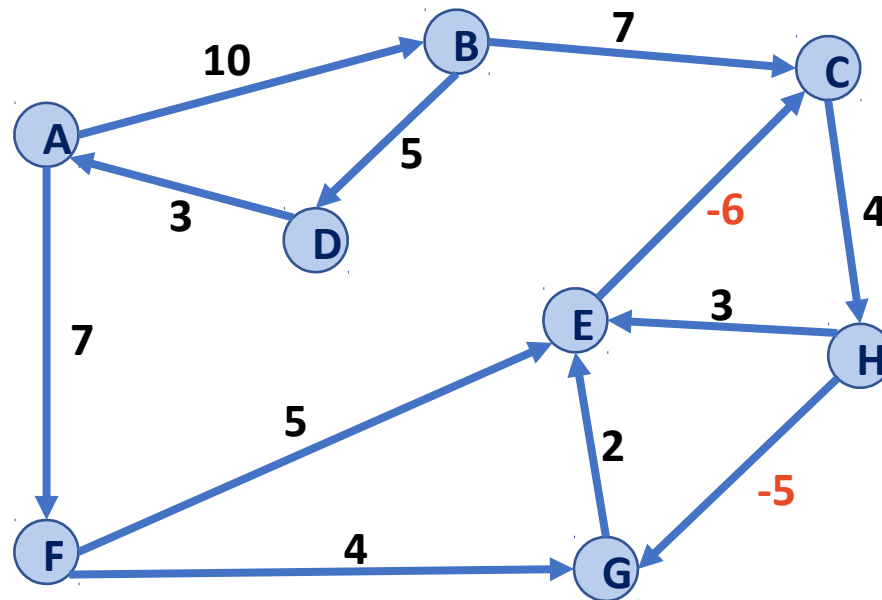
Dijkstra's Algorithm (SSSP)

Q: How does Dijkstra handle undirected graphs?



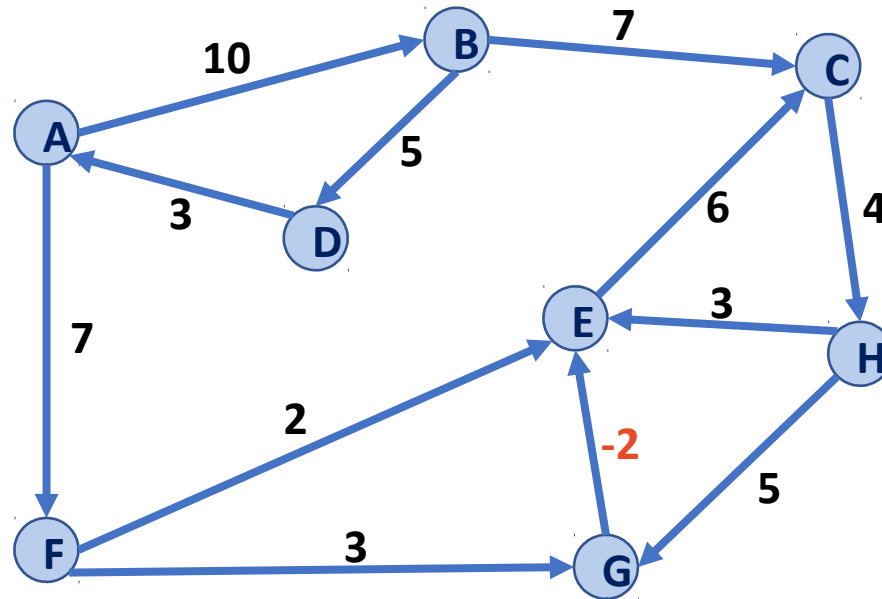
Dijkstra's Algorithm (SSSP)

Q: How does Dijkstra handle negative weight cycles?



Dijkstra's Algorithm (SSSP)

Q: How does Dijkstra handle negative weight edges, without a negative weight cycle?





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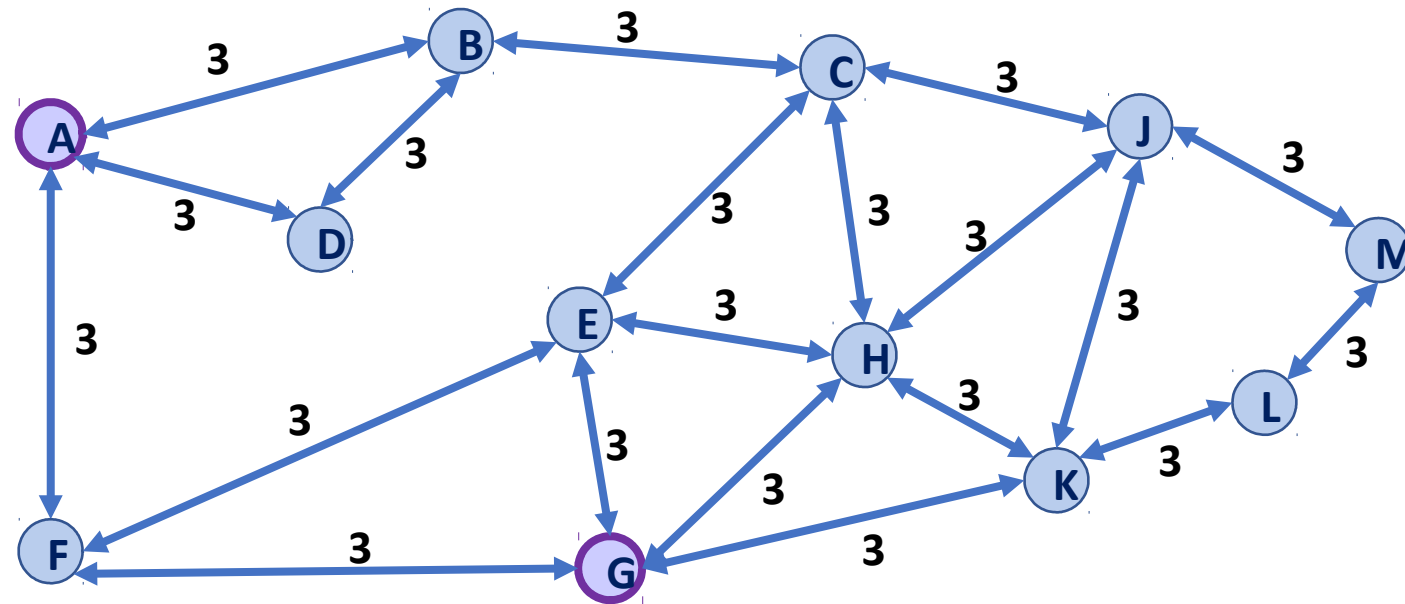
Graphs: Landmark Path Problem

ID: 15-03

Landmark Path Problem

Suppose you want to travel from **A** to **G**.

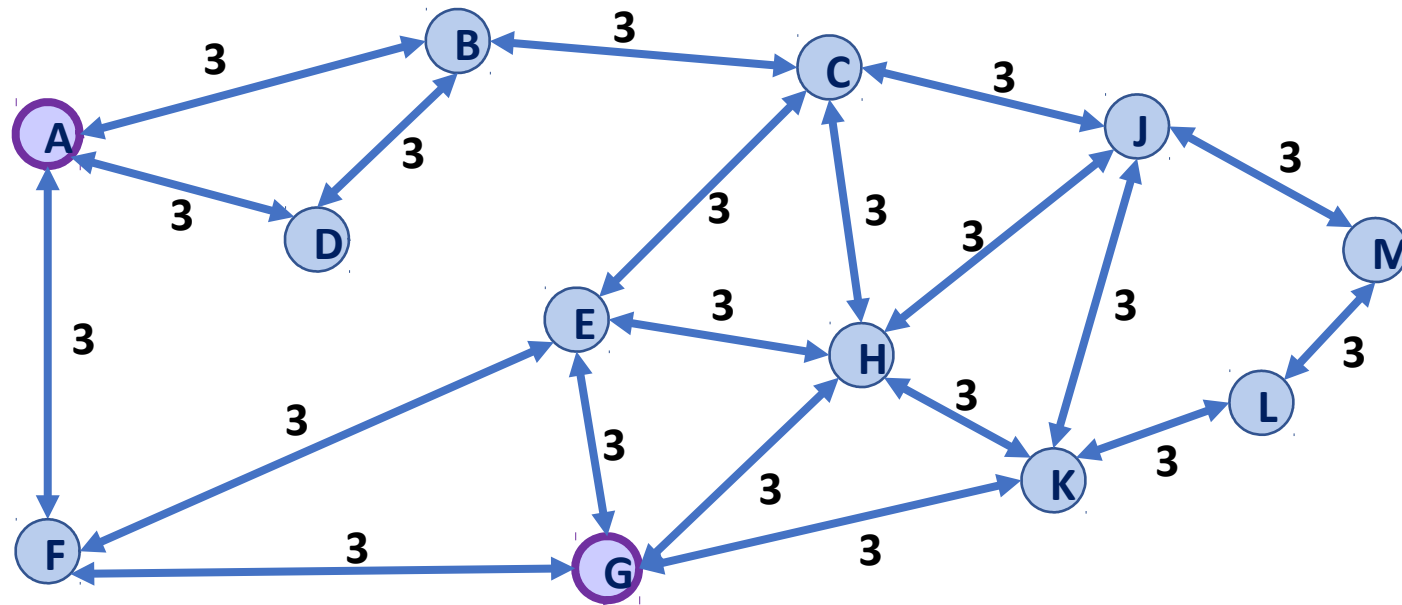
Q1: What is the shortest path from **A** to **G**?



Landmark Path Problem

Suppose you want to travel from **A** to **G**.

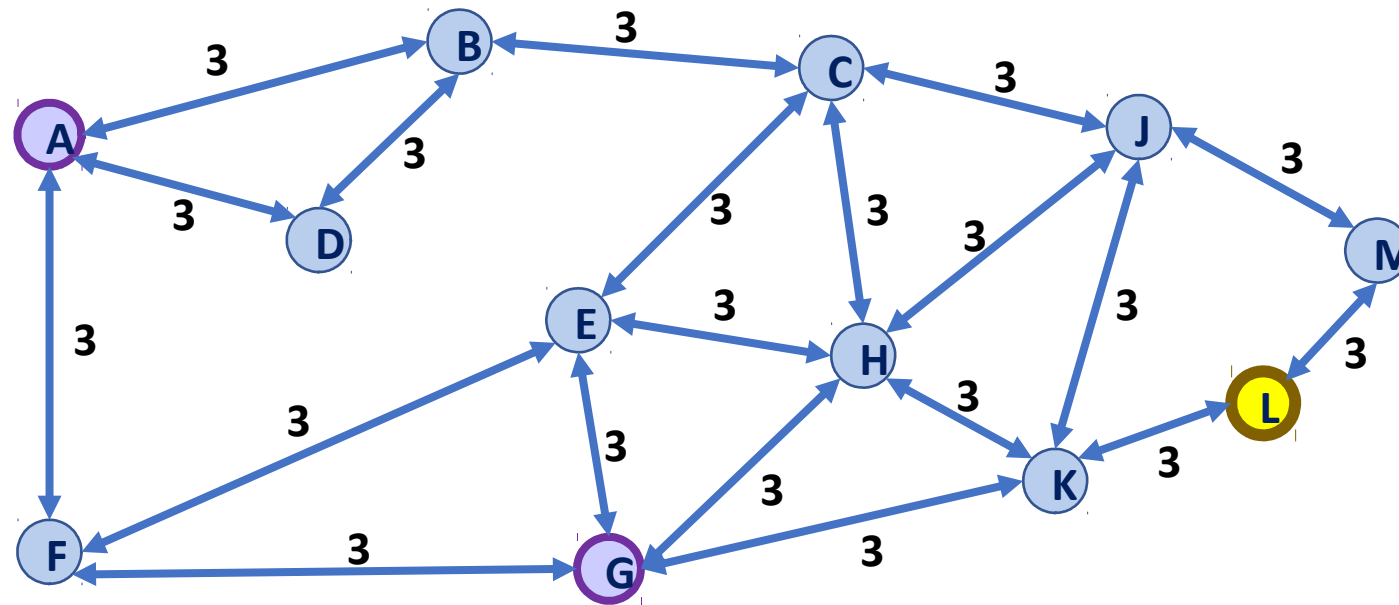
Q2: What is the fastest algorithm to use to find the shortest path?



Landmark Path Problem

In your journey between **A** and **G**, you also want to visit the landmark **L**.

Q3: What is the shortest path from **A** to **G** that visits **L**?



Landmark Path Problem

In your journey between **A** and **G**, you also want to visit the landmark **L**.

Q4: What is the fastest algorithm to find this path?

Q5: What are the specific call(s) to this algorithm?

