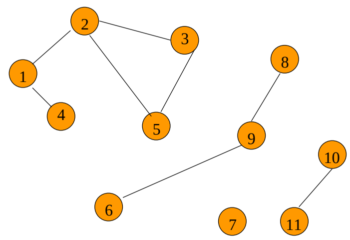
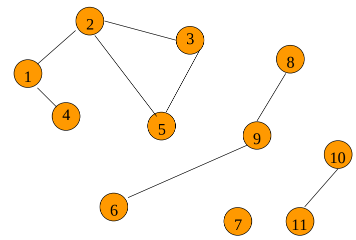
Graph Search Methods

- A vertex u is reachable from vertex v iff there is a path from v to u.



Graph Search Methods

- A search method starts at a given vertex v and visits/labels/marks every vertex that is reachable from v.



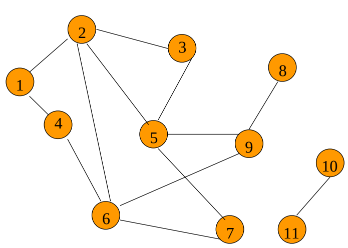
Graph Search Methods

- Many graph problems solved using a search method.
  - Path from one vertex to another.
  - Is the graph connected?
  - Find a spanning tree.
  - Etc.
- Commonly used search methods:
  - Breadth-first search.
  - Depth-first search.

Breadth-First Search

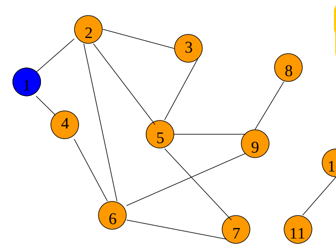
- Visit start vertex and put into a FIFO queue.
- Repeatedly remove a vertex from the queue, visit its unvisited adjacent vertices, put newly visited vertices into the queue.

Breadth-First Search Example



Start search at vertex 1.

Breadth-First Search Example

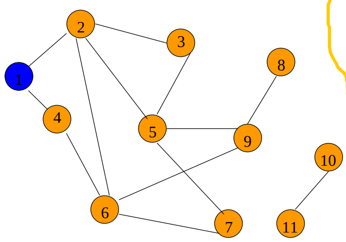


FIFO Queue

1

Visit/mark/label start vertex and put in a FIFO queue.

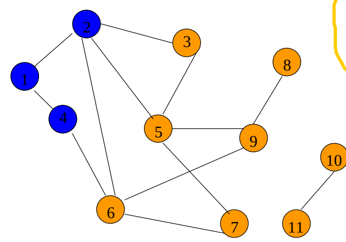
Breadth-First Search Example



FIFO Queue
1

Remove 1 from Q; visit adjacent unvisited vertices; put in Q.

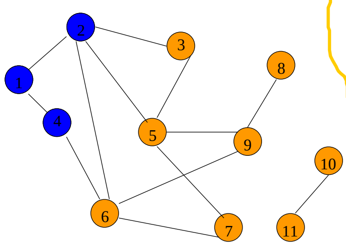
Breadth-First Search Example



FIFO Queue
2 4

Remove 1 from Q; visit adjacent unvisited vertices; put in Q.

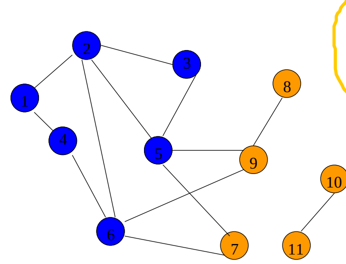
Breadth-First Search Example



FIFO Queue
2 4

Remove 2 from Q; visit adjacent unvisited vertices; put in Q.

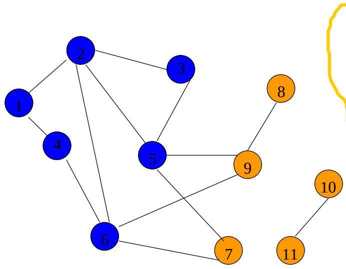
Breadth-First Search Example



FIFO Queue
4 5 3 6

Remove 2 from Q; visit adjacent unvisited vertices; put in Q.

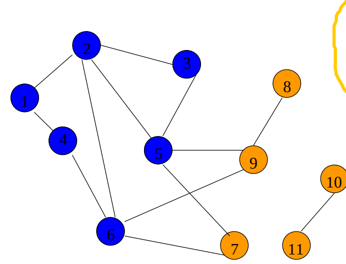
Breadth-First Search Example



FIFO Queue
4 5 3 6

Remove 4 from Q; visit adjacent unvisited vertices; put in Q.

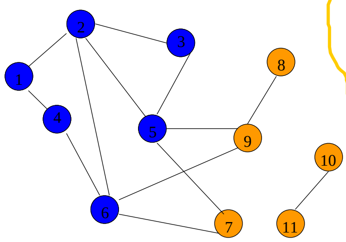
Breadth-First Search Example



FIFO Queue
5 3 6

Remove 4 from Q; visit adjacent unvisited vertices; put in Q.

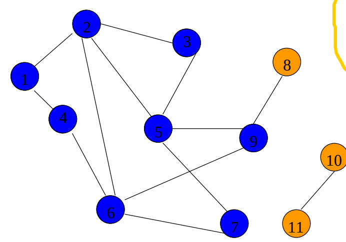
Breadth-First Search Example



FIFO Queue
5 3 6

Remove 5 from Q; visit adjacent unvisited vertices; put in Q.

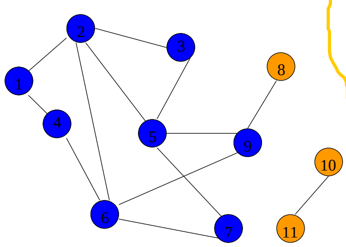
Breadth-First Search Example



FIFO Queue
3 6 9 7

Remove 5 from Q; visit adjacent unvisited vertices; put in Q.

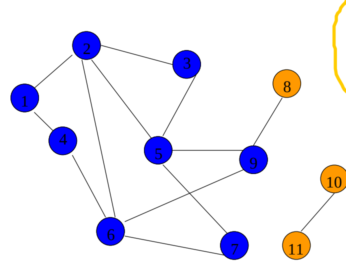
Breadth-First Search Example



FIFO Queue
3 6 9 7

Remove 3 from Q; visit adjacent unvisited vertices; put in Q.

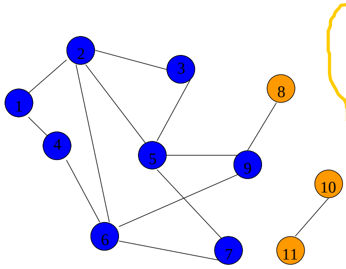
Breadth-First Search Example



FIFO Queue
6 9 7

Remove 3 from Q; visit adjacent unvisited vertices; put in Q.

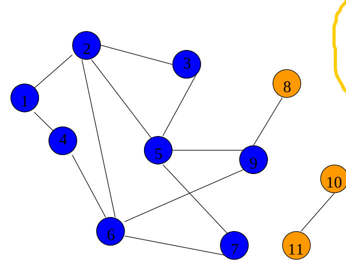
Breadth-First Search Example



FIFO Queue
6 9 7

Remove 6 from Q; visit adjacent unvisited vertices; put in Q.

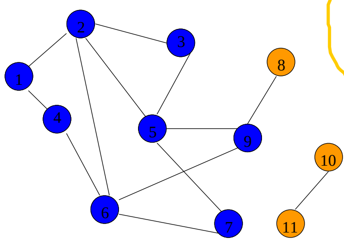
Breadth-First Search Example



FIFO Queue
9 7

Remove 6 from Q; visit adjacent unvisited vertices; put in Q.

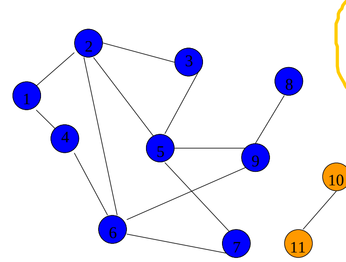
Breadth-First Search Example



FIFO Queue
9 7

Remove 9 from Q; visit adjacent unvisited vertices; put in Q.

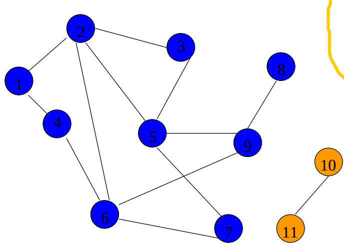
Breadth-First Search Example



FIFO Queue
7 8

Remove 9 from Q; visit adjacent unvisited vertices; put in Q.

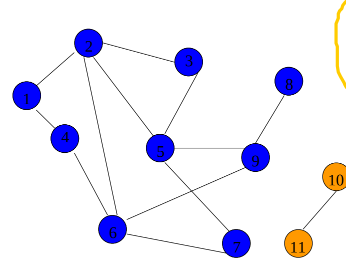
Breadth-First Search Example



FIFO Queue
7 8

Remove 7 from Q; visit adjacent unvisited vertices; put in Q.

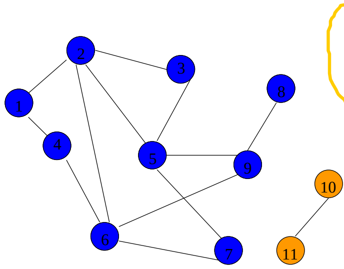
Breadth-First Search Example



FIFO Queue
8

Remove 7 from Q; visit adjacent unvisited vertices; put in Q.

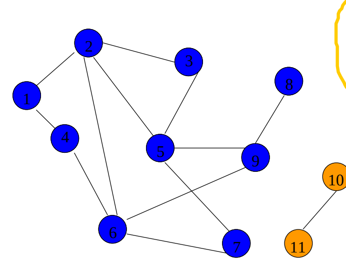
Breadth-First Search Example



FIFO Queue
8

Remove 8 from Q; visit adjacent unvisited vertices; put in Q.

Breadth-First Search Example



FIFO Queue

Queue is empty. Search terminates.

Breadth-First Search Property

- All vertices reachable from the start vertex (including the start vertex) are visited.

Time Complexity

- Each visited vertex is put on (and so removed from) the queue exactly once.
- When a vertex is removed from the queue, we examine its adjacent vertices.
  - O(n) if adjacency matrix used
  - O(vertex degree) if adjacency lists used
- Total time
  - O(mn), where m is number of vertices in the component that is searched (adjacency matrix)

Time Complexity

- O(n + sum of component vertex degrees) (adj. lists)

  = O(n + number of edges in component)

Path From Vertex v To Vertex u

- Start a breadth-first search at vertex v.
- Terminate when vertex u is visited or when Q becomes empty (whichever occurs first).
- Time
  - $O(n^2)$ when adjacency matrix used
  - O(n+e) when adjacency lists used (e is number of edges)

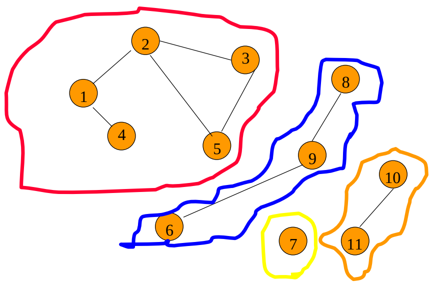
Is The Graph Connected?

- Start a breadth-first search at any vertex of the graph.
- Graph is connected iff all n vertices get visited.
- Time
  - $O(n^2)$ when adjacency matrix used
  - O(n+e) when adjacency lists used (e is number of edges)

Connected Components

- Start a breadth-first search at any as yet unvisited vertex of the graph.
- Newly visited vertices (plus edges between them) define a component.
- Repeat until all vertices are visited.

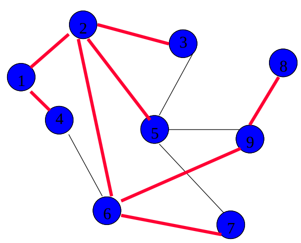
Connected Components



Time Complexity

- O(n^2) when adjacency matrix used
- O(n+e) when adjacency lists used (e is number of edges)

Spanning Tree



Breadth-first search from vertex 1.

Breadth-first spanning tree.

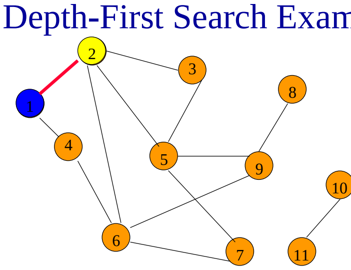
Spanning Tree

- Start a breadth-first search at any vertex of the graph.
- If graph is connected, the n-1 edges used to get to unvisited vertices define a spanning tree (breadth-first spanning tree).
- Time
  - O(n^2) when adjacency matrix used
  - O(n+e) when adjacency lists used (e is number of edges)

Depth-First Search

```
depthFirstSearch(v)
{
  Label vertex v as reached.
  for (each unreached vertex u
                        adjacent from v)
    depthFirstSearch(u);
}
```

Depth-First Search Example

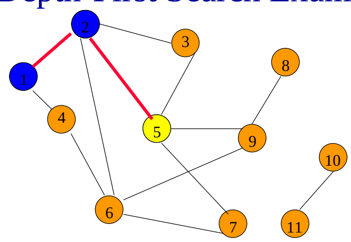


Start search at vertex 1.

Label vertex 1 and do a depth first search from either 2 or 4.

Suppose that vertex 2 is selected.

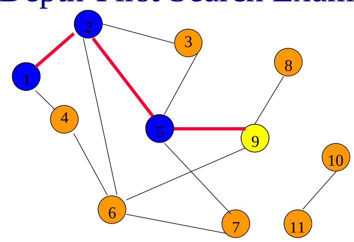
Depth-First Search Example



Label vertex 2 and do a depth first search from either 3, 5, or 6.

Suppose that vertex 5 is selected.

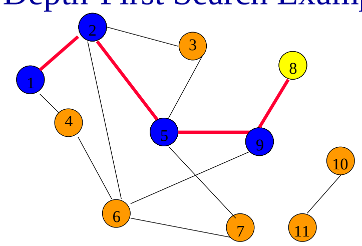
Depth-First Search Example



Label vertex 5 and do a depth first search from either 3, 7, or 9.

Suppose that vertex 9 is selected.

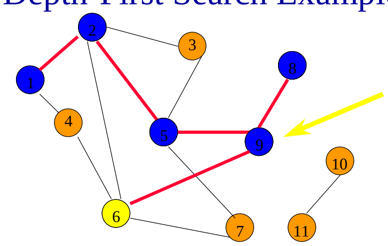
Depth-First Search Example



Label vertex 9 and do a depth first search from either 6 or 8.

Suppose that vertex 8 is selected.

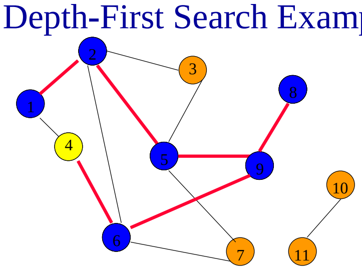
Depth-First Search Example



Label vertex 8 and return to vertex 9.

From vertex 9 do a dfs(6).

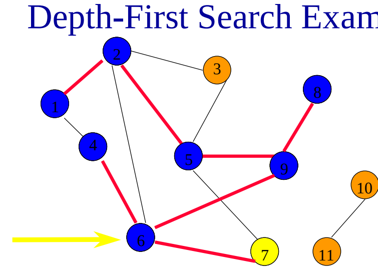
Depth-First Search Example



Label vertex 6 and do a depth first search from either 4 or 7.

Suppose that vertex 4 is selected.

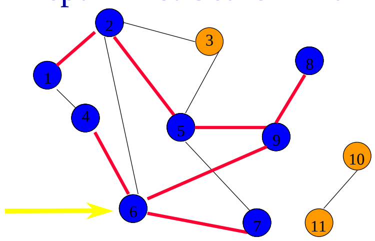
Depth-First Search Example



Label vertex 4 and return to 6.

From vertex 6 do a dfs(7).

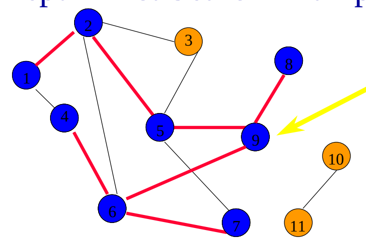
Depth-First Search Example



Label vertex 7 and return to 6.

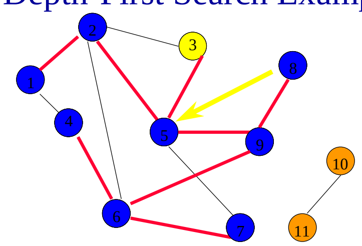
Return to 9.

Depth-First Search Example



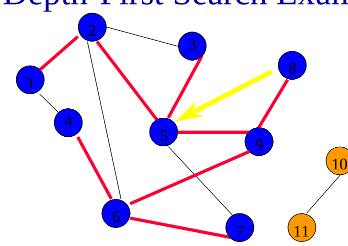
Return to 5.

Depth-First Search Example



Do a dfs(3).

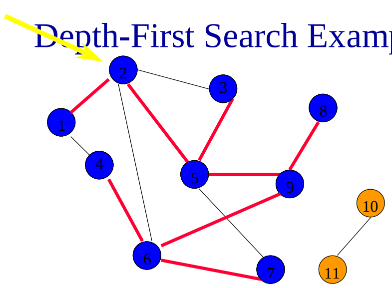
Depth-First Search Example



Label 3 and return to 5.

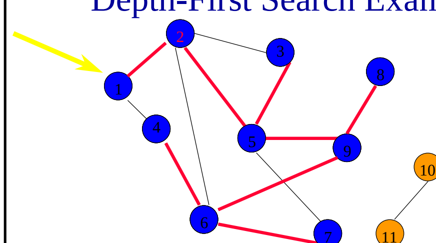
Return to 2.

Depth-First Search Example



Return to 1.

Depth-First Search Example



Return to invoking method.

Depth-First Search Properties

- Same complexity as BFS.
- Same properties with respect to path finding, connected components, and spanning trees.
- Edges used to reach unlabeled vertices define a depth-first spanning tree when the graph is connected.
- There are problems for which bfs is better than dfs and vice versa.