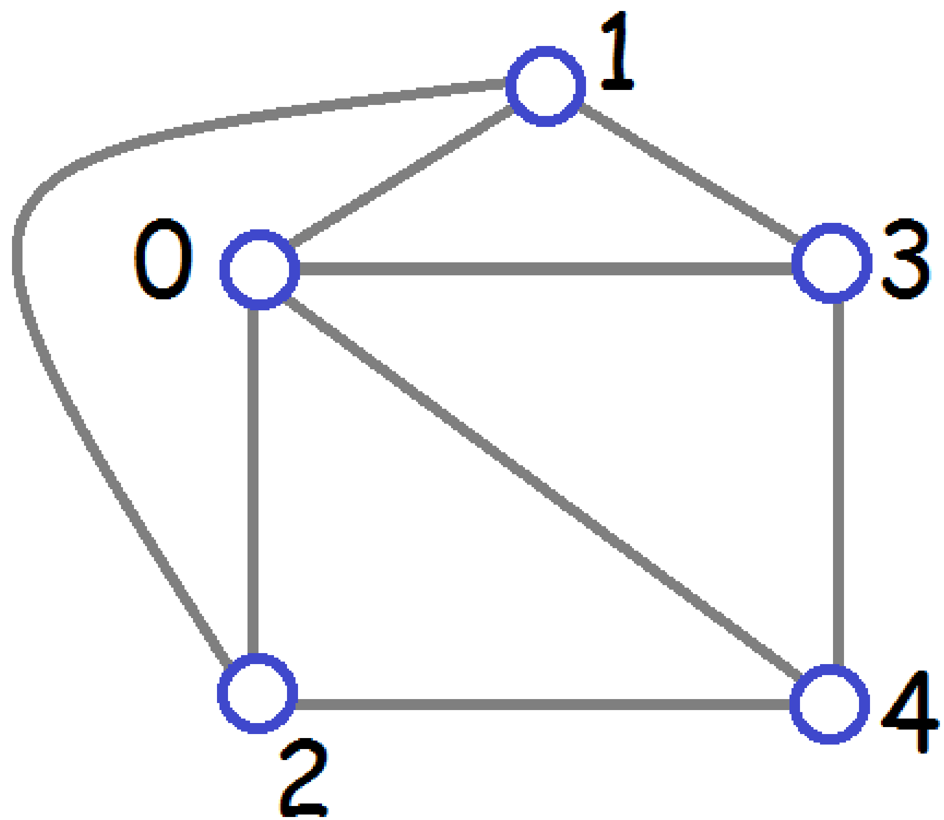
Show what you would type into the computer for the graph pictured using:

1. Upper triangular adjacency matrix format.
2. Adjacency list format (give a rotation system that represents the planar embedding).

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Breadth-first search: method for traversing all the vertices/edges of a graph.

I've programmed this more than any other graph algorithm!

Some uses: graph traversal, finding connected components, identifying cut vertices, finding cycles, isomorphism testing for 3-connected planar graphs, finding bridges for a planarity testing algorithm, finding a maximum flow in a network, reordering vertices so algorithms for hard problems (clique, independent set, dominating set) perform better...

Queue (used for BFS)

http://devcentral.f5.com/weblogs/images/devcentral_f5_com/weblogs/Joe/WindowsLiveWriter/PowerShellABCsQisforQueues_919A/queue_2.jpg

http://www.ac-nancy-metz.fr/enseign/anglais/Henry/bus-queue.jpg

Queue data structure:

Items are:

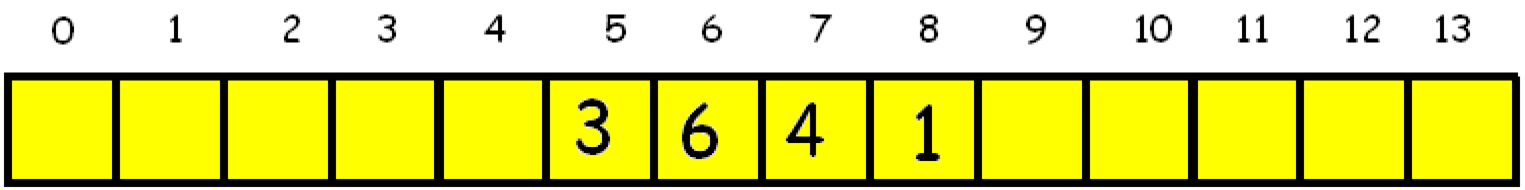
Added to the rear of the queue.

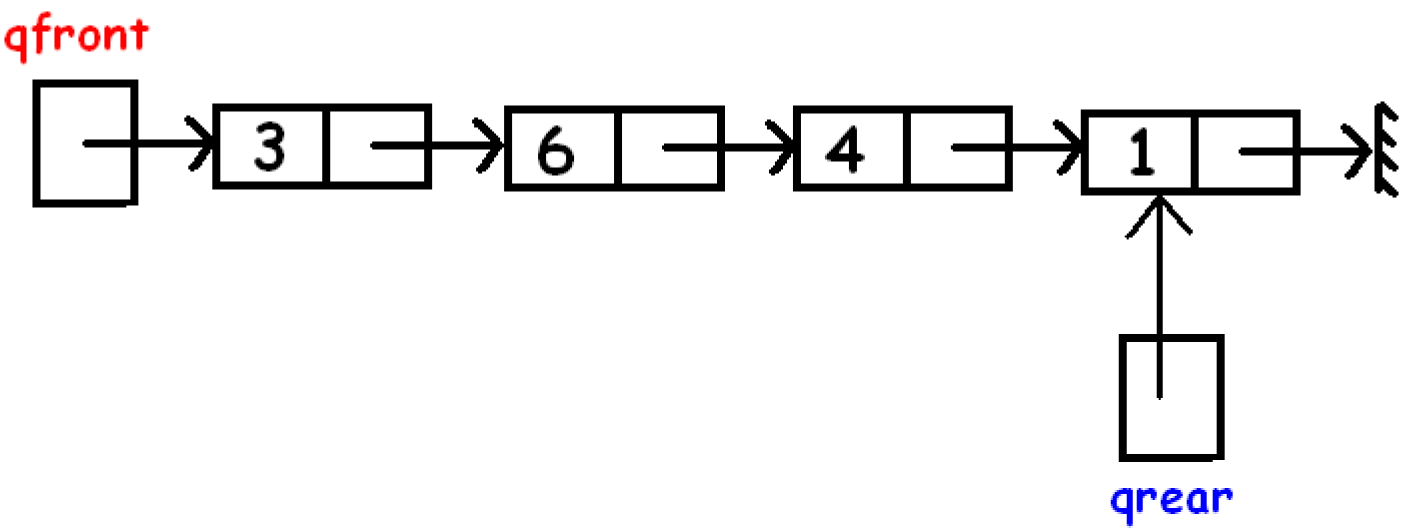
Removed from the front of the queue.

http://cs.wellesley.edu/~cs230/assignments/lab12/queue.jpg

If you have an upper bound on the lifetime size of the queue then you can use an array:
qfront=5, qrear=9

(qrear is next empty spot in array)





qfront=5, qrear=9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Q:						3	6	4	1					

To test if there is something in the queue:

if (qfront < qrear)

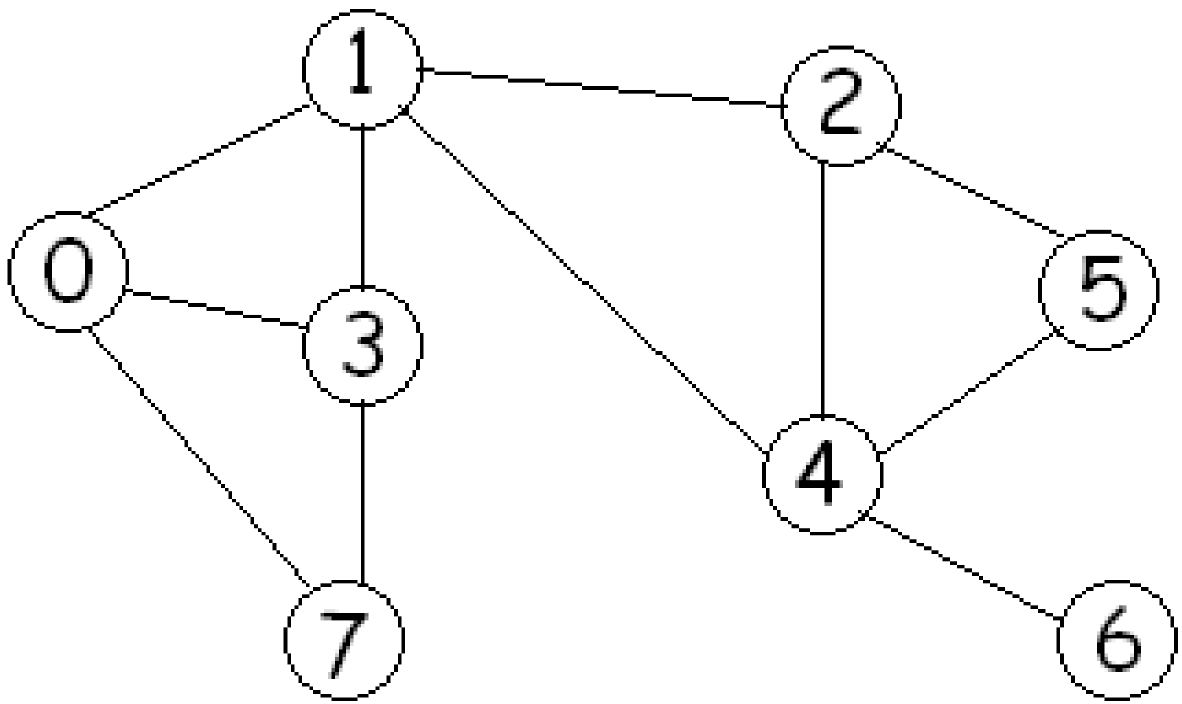
To add x to the queue:

Q[qrear]= x; qrear++;

To delete front element of the queue:

x= Q[qfront]; qfront++;

If the neighbours of each vertex are ordered according to their vertex numbers, in what order does a BFS starting at 0 visit the vertices?



BFS starting at a vertex s using an array for the queue:

Data structures:

A queue Q[0..(n-1)] of vertices, qfront, qrear.

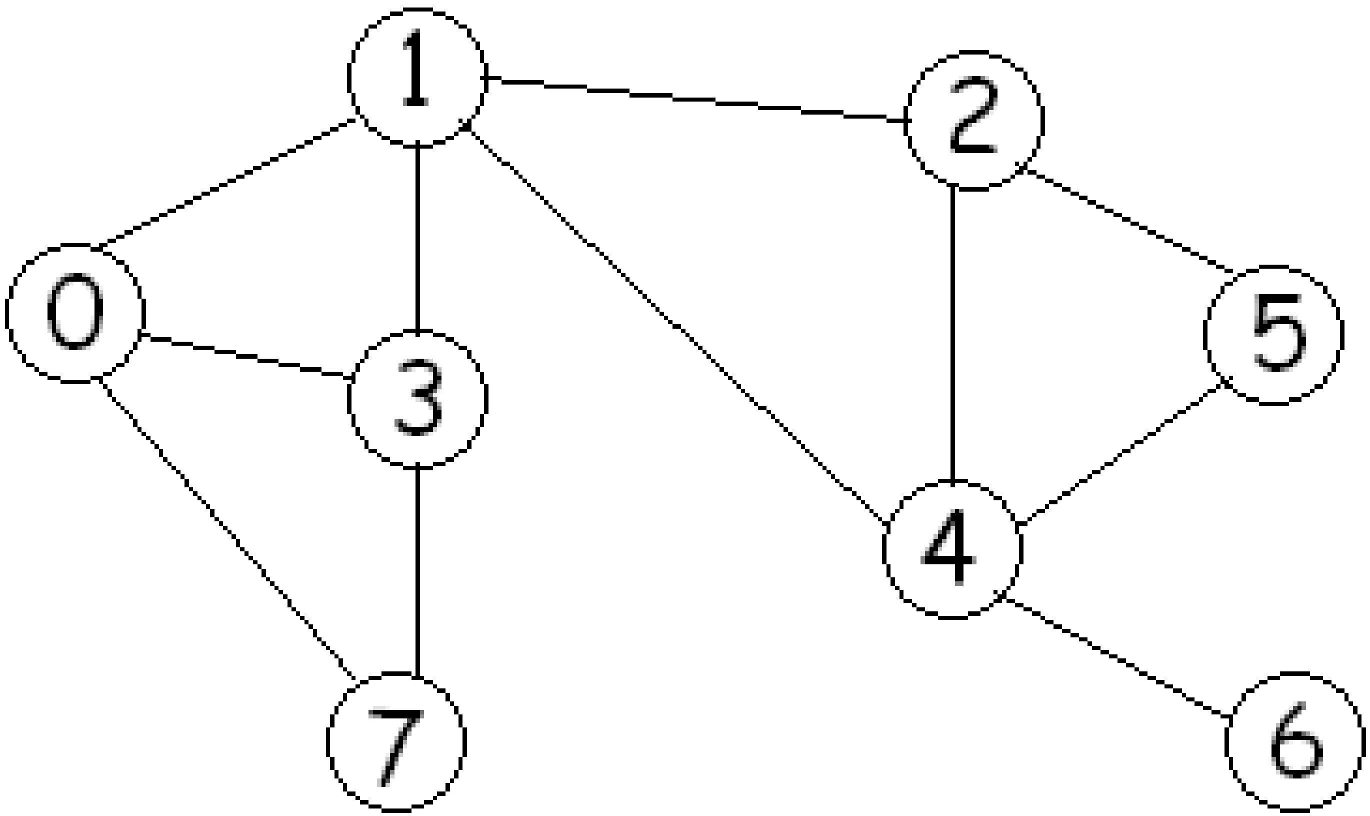
parent[i]= BFS tree parent of node i.

The parent of the root s is s.

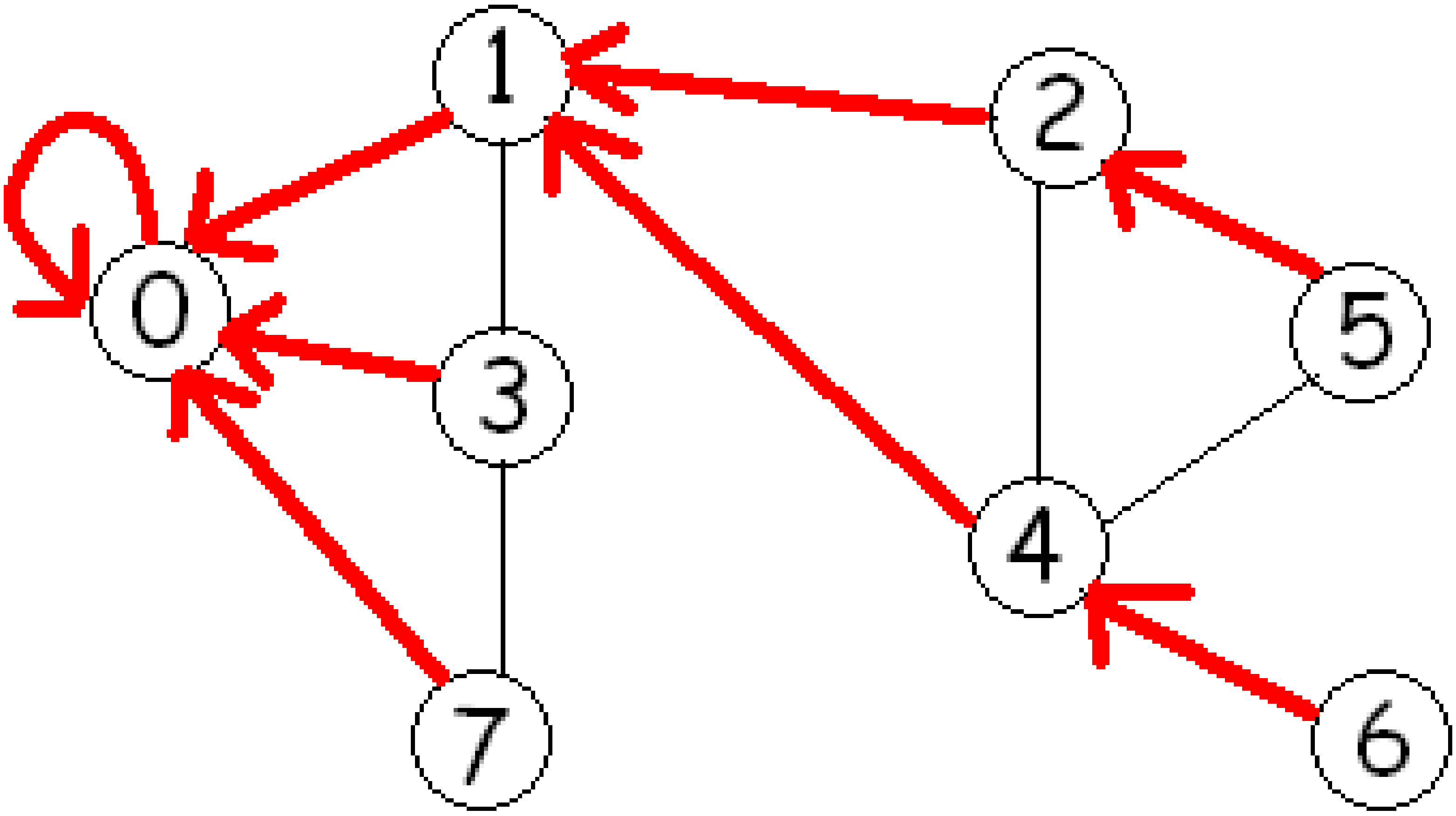
To initialize:

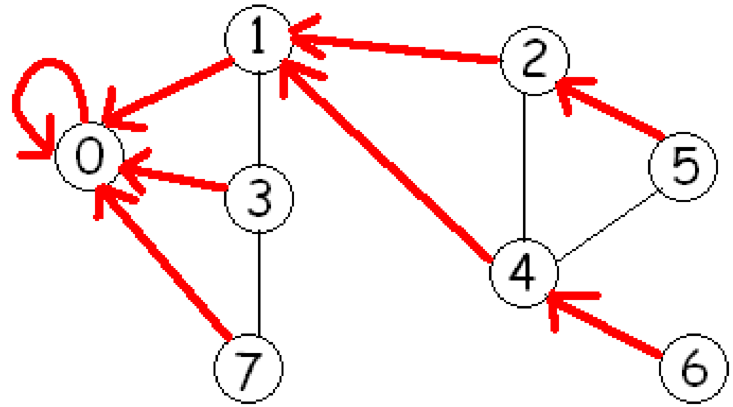
```
// Set parent of each node to be -1 to indicate
// that the vertex has not yet been visited.
for (i=0; i < n; i++) parent[i]= -1;

// Initialize the queue so that BFS starts at s
qfront=0; qrear=1; Q[qfront]= s;
parent[s]=s;
```

```
while (qfront < qrear) // Q is not empty
    u= Q[qfront]; qfront++;
    for each neighbour v of u
        if (parent[v] == -1) // not visited
            parent[v]= u;
            Q[qrear]= v; qrear++;
        end if
    end for
end while
```

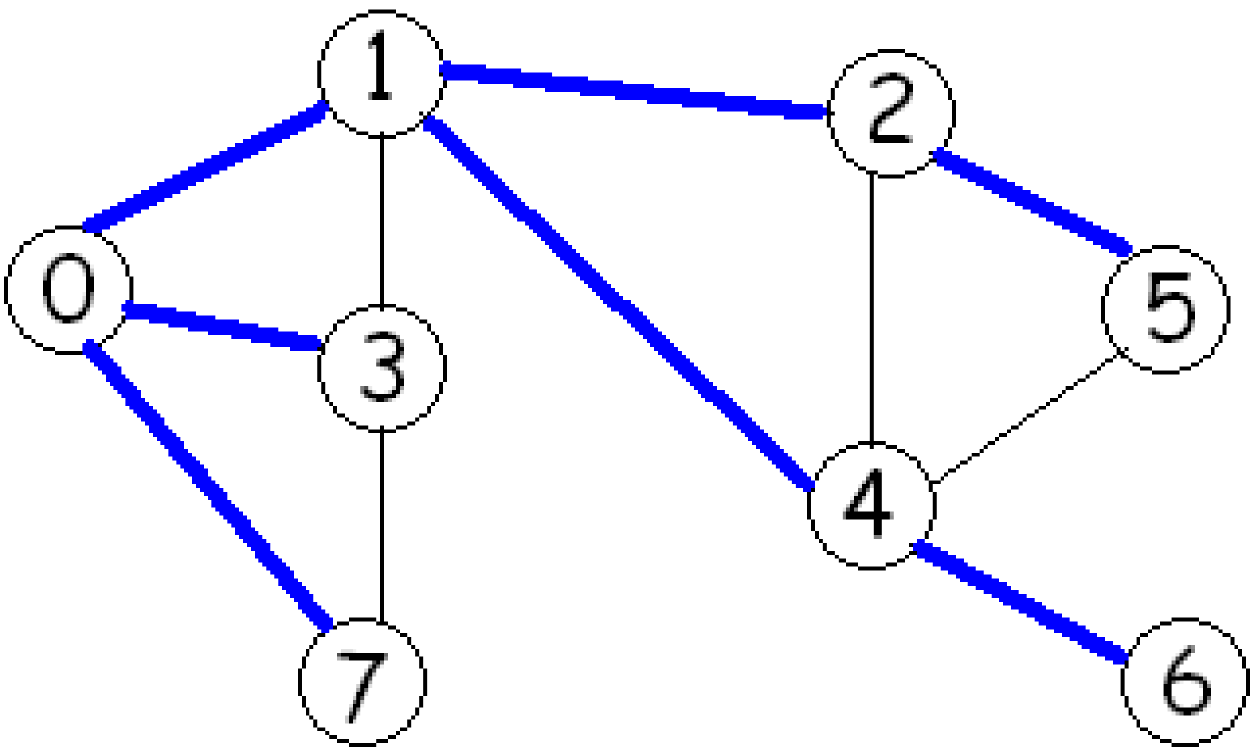

1
2
0
3
5
4
7
6

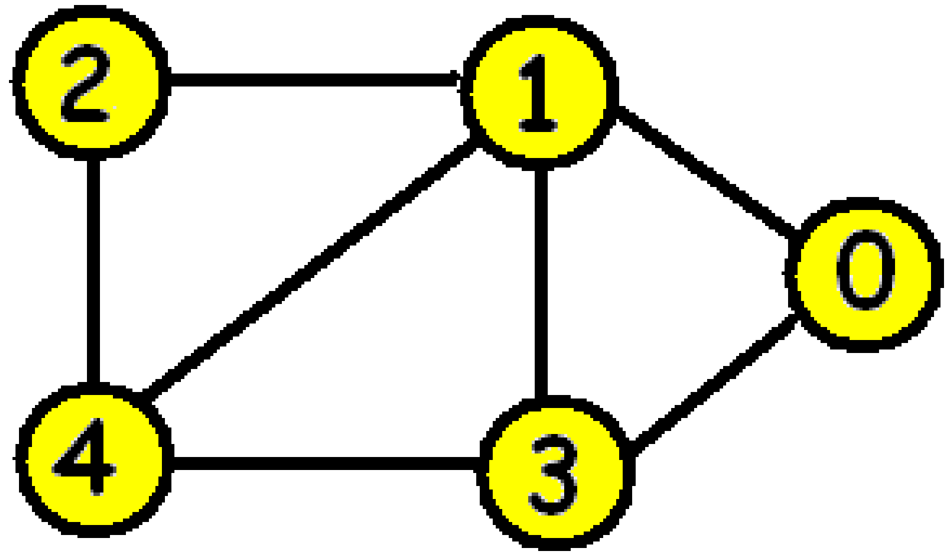
Red arcs represent parent information:





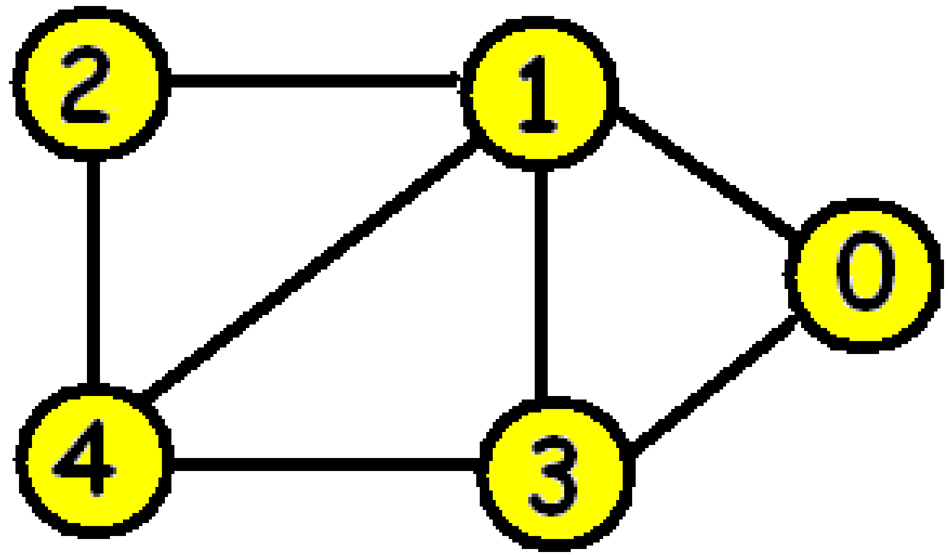
The blue spanning tree is the BFS tree.



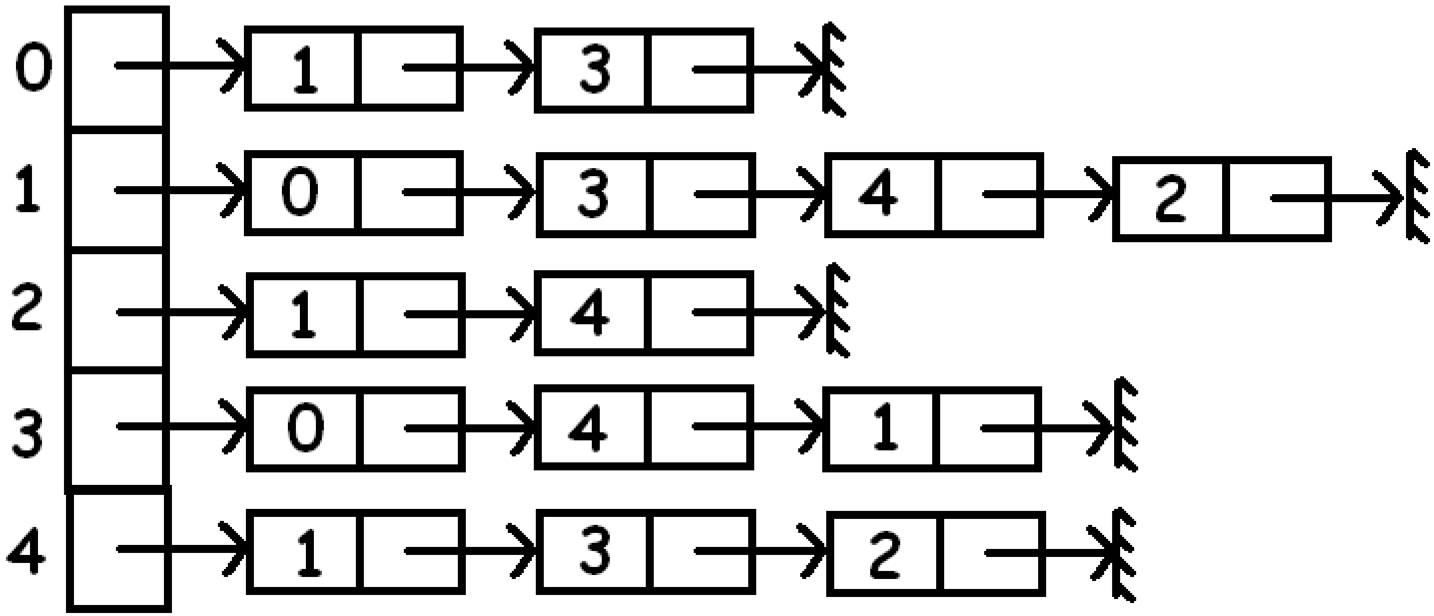


Adjacency matrix:

	0	1	2	3	4
0	0	1	0	1	0
1	1	0	1	1	1
2	0	1	0	0	1
3	1	1	0	0	1
4	0	1	1	1	0



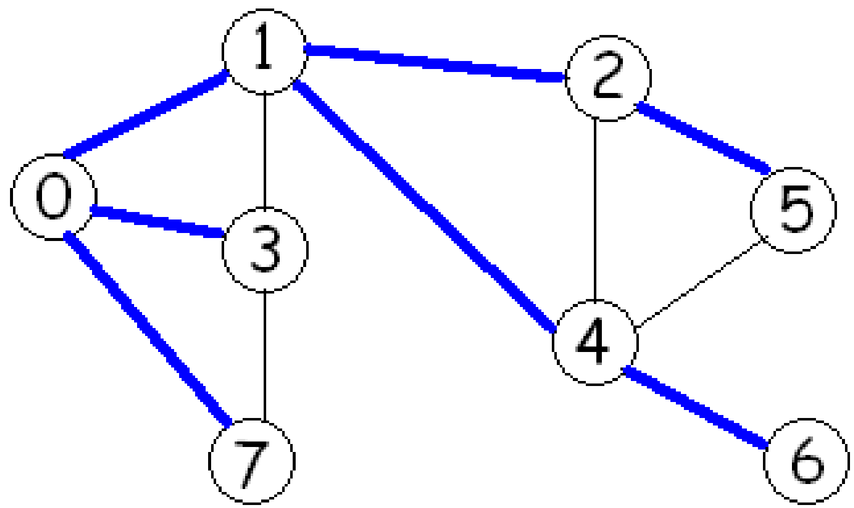
Adjacency list:



BFI[v]= Breadth first index of v

= step at which v is visited.

The BFI[v] is equal to v's position in the queue.



	0	1	2	3	4	5	6	7
Q	0	1	3	7	2	4	5	6

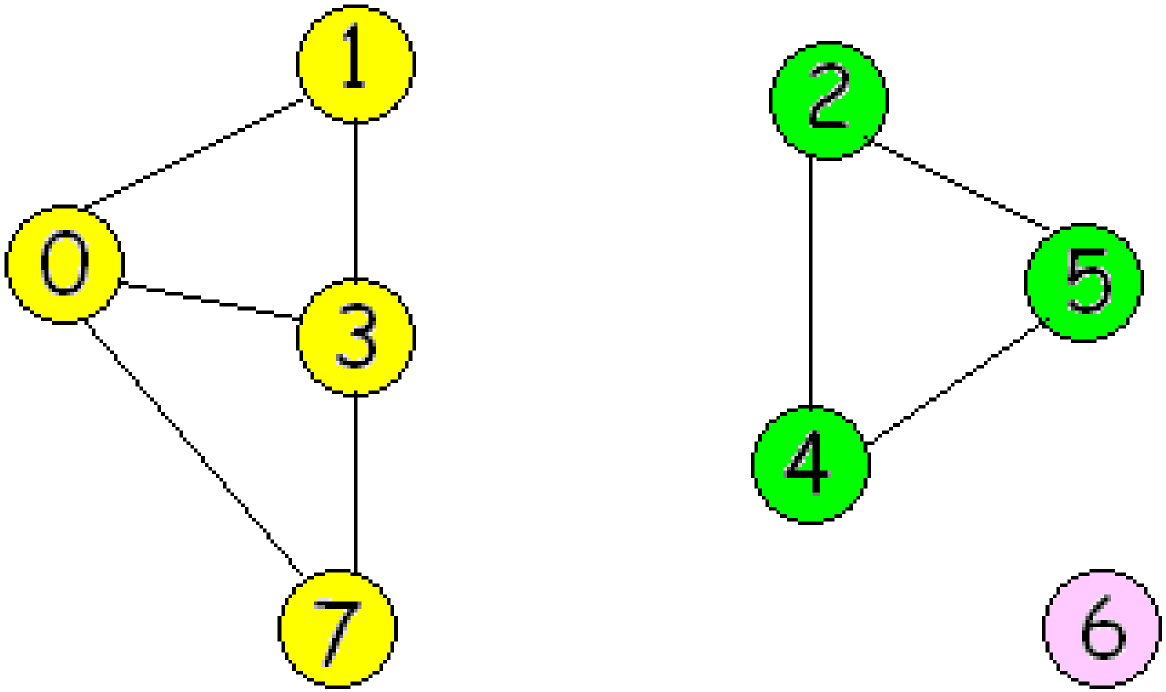
To initialize:

```
// Set parent of each node to be -1 to indicate
// that the vertex has not yet been visited.
for (i=0; i < n; i++) parent[i]= -1;

// Initialize the queue so that BFS starts at s
qfront=0; qrear=1; Q[qfront]= s;
parent[s]=s;

BFI[s]= 0;
```

```
while (qfront < qrear) // Q is not empty
    u= Q[qfront]; qfront++;
    for each neighbour v of u
        if (parent[v] == -1) // not visited
            parent[v]= u; BFI[v]= qrear;
            Q[qrear]= v; qrear++;
        end if
    end for
end while
```

One application:

How many connected components does a graph have and which vertices are in each component?



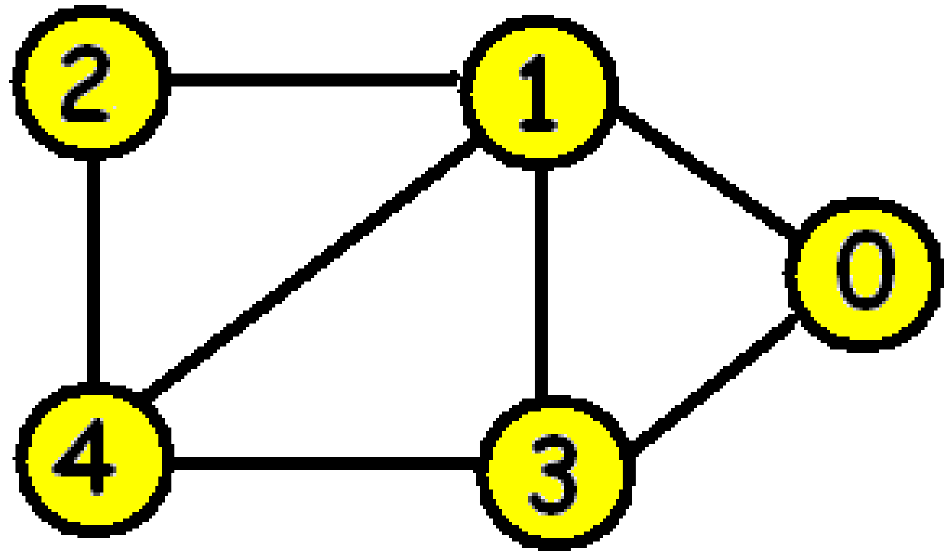
To find the connected components:

```
for (i=0; i < n; i++)
    parent[i]= -1;
nComp= 0;
for (i=0; i < n; i++)
    if (parent[i] == -1)
        nComp++;
        BFS(i, parent, component, nComp);
```

```
BFS(s, parent, component, nComp)

// Do not initialize parent.

// Initialize the queue so that BFS starts at s

qfront=0; qrear=1; Q[qfront]= s;

parent[s]=s;

component[s]= nComp;
```

```
while (qfront < qrear) // Q is not empty
    u= Q[qfront]; qfront++;
    for each neighbour v of u
        if (parent[v] == -1) // not visited
            parent[v]= u; component[v]= nComp;
            Q[qrear]= v; qrear++;
        end if
    end for
end while
```

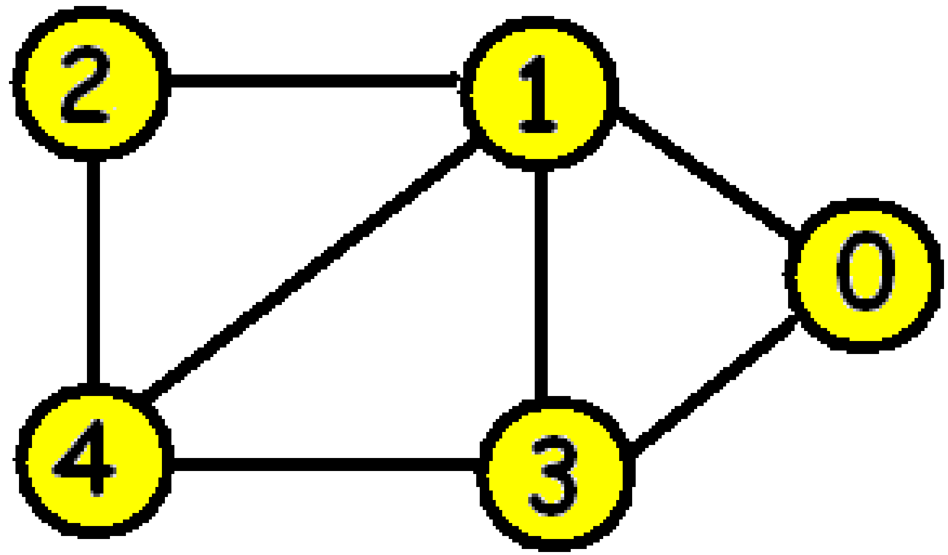
How much time does BFS take to indentify the connected components of a graph when the data structure used for a graph is an adjacency matrix?



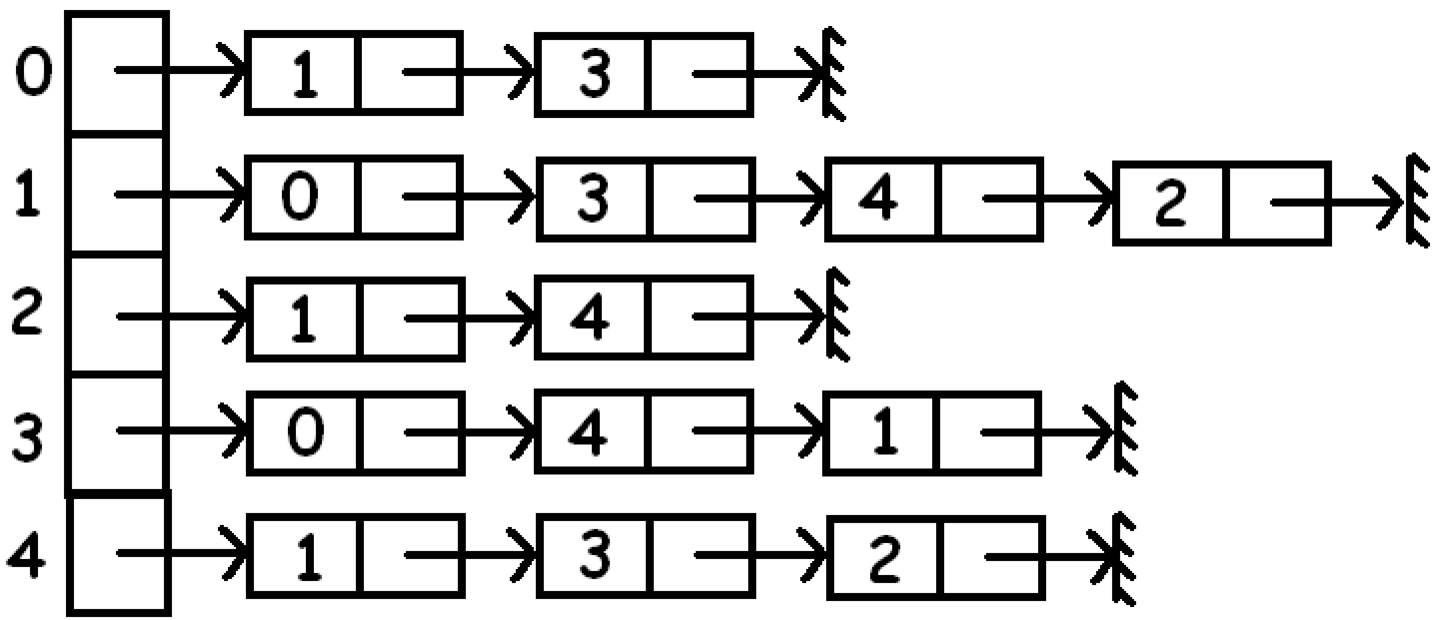
Adjacency matrix:

	0	1	2	3	4
0	0	1	0	1	0
1	1	0	1	1	1
2	0	1	0	0	1
3	1	1	0	0	1
4	0	1	1	1	0

How much time does BFS take to indentify the connected components of a graph when the data structure used for a graph is an adjacency list?



Adjacency list:



How could you modify BFS to determine if v is a cut vertex?

-

A bridge with respect to a subgraph H of a graph G is either:

1. An edge e=(u, v) which is not in H but both u and v are in H.
2. A connected component C of G-H plus any edges that are incident to one vertex in C and one vertex in H plus the endpoints of these edges.

How can you find the bridges with respect to a cut vertex v?