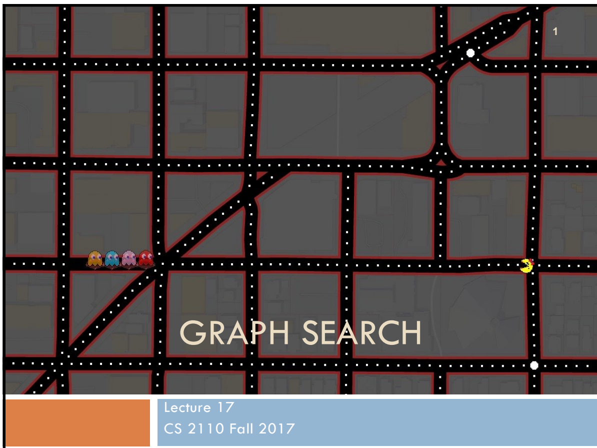
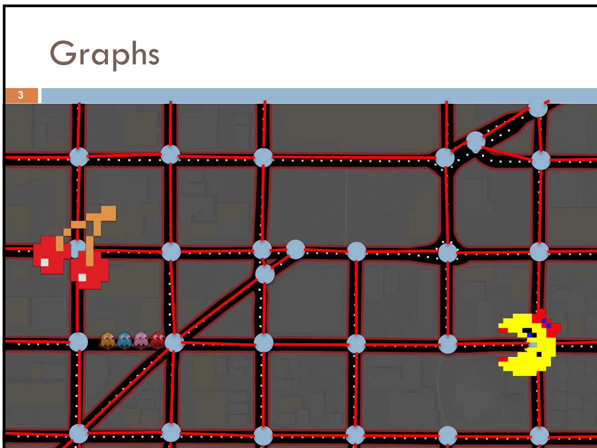


Announcements

- For the next lecture, you **MUST** watch the tutorial on the shortest path algorithm beforehand:
  http://www.cs.cornell.edu/courses/cs2110/2017fa/online/shortestPath/shortestPath.html
- Thursday's lecture **will assume** that you understand it. Watch the tutorial once or twice and execute the algorithm on a small graph.

Graphs



Representing Graphs

Adjacency List

- 1 → 2 → 4
- 2 → 3
- 3
- 4 → 2 → 3

Adjacency Matrix

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

Graph Algorithms

- Search
  - Depth-first search
  - Breadth-first search
- Shortest paths
  - Dijkstra's algorithm
- Spanning trees
  - Algorithms based on properties
  - Minimum spanning trees
  - Prim's algorithm
  - Kruskal's algorithm

Search on Graphs

- Given a graph (V, E) and a vertex $u \in V$
- We want to "visit" each node that is reachable from u

There are many paths to some nodes.

How do we visit all nodes efficiently, without doing extra work?

Depth-First Search

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Intuition: Recursively visit all vertices that are reachable along unvisited paths.

```
/** Visit all nodes reachable
on unvisited paths from u.
Precondition: u is unvisited.
*/
public static void dfs(int u)
{
    visited[u] = true;
    for all edges (u,v):
        if(!visited[v]):
            dfs(v);
}
```

dfs(1) visits the nodes in this order: 1, 2, 3, 5, 7, 8

Depth-First Search

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Intuition: Recursively visit all vertices that are reachable along unvisited paths.

```
/** Visit all nodes reachable
on unvisited paths from u.
Precondition: u is unvisited.
*/
public static void dfs(int u)
{
    visited[u] = true;
    for all edges (u,v):
        if(!visited[v]):
            dfs(v);
}
```

Suppose there are n vertices that are reachable along unvisited paths and e edges:

Worst-case running time? $O(n + e)$
Worst-case space? $O(n)$

Depth-First Search in Java

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```
public class Node {
    boolean visited;
    List<Node> neighbors;

/** Visit all nodes reachable on unvisited paths from
this node.
Precondition: this node is unvisited. */
    public void dfs() {
        visited= true;
        for (Node n: neighbors) {
            if (!n.visited) n.dfs();
        }
    }
}
```

Each vertex of the graph is an object of type Node

No need for a parameter. The object is the node.

Depth-First Search Iteratively

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Intuition: Visit all vertices that are reachable along unvisited paths from the current node.

```
/** Visit all nodes reachable on
unvisited paths from u.
Precondition: u is unvisited. */
public static void dfs(int u) {
    Stack s= (u);// Not Java!
    while (s is not empty) {
        u= s.pop();
        if (u not visited) {
            visit u;
            for each edge (u, v):
                s.push(v);
        }
    }
}
```

Stack: 5 5 5 8

Breadth-First Search

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Intuition: Iteratively process the graph in "layers" moving further away from the source node.

```
/** Visit all nodes reachable on
unvisited paths from u.
Precondition: u is unvisited. */
public static void bfs(int u) {
    Queue q= (u);// Not Java!
    while ( q is not empty ) {
        u= q.remove();
        if (u not visited) {
            visit u;
            for each (u, v):
                q.add(v);
        }
    }
}
```

Queue: 2 5 7 3 5 8 5

Analyzing BFS

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Intuition: Iteratively process the graph in "layers" moving further away from the source node.

```
/** Visit all nodes reachable on
unvisited paths from u.
Precondition: u is unvisited. */
public static void bfs(int u) {
    Queue q= (u);// Not Java!
    while (                ) {
        u= q.remove();
        if (u not visited) {
            visit u;
            for each (u, v):
                q.add(v);
        }
    }
}
```

Suppose there are n vertices that are reachable along unvisited paths and e edges:

Worst-case running time? $O(n + e)$
Worst-case space? $O(e)$

Comparing Search Algorithms

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DFS

- Visits: 1, 2, 3, 5, 7, 8
- Time: $O(n+e)$
- Space: $O(n)$

BFS

- Visits: 1, 2, 5, 7, 3, 8
- Time: $O(n+e)$
- Space: $O(e)$