Graph Terminology

CSE 373

Data Structures

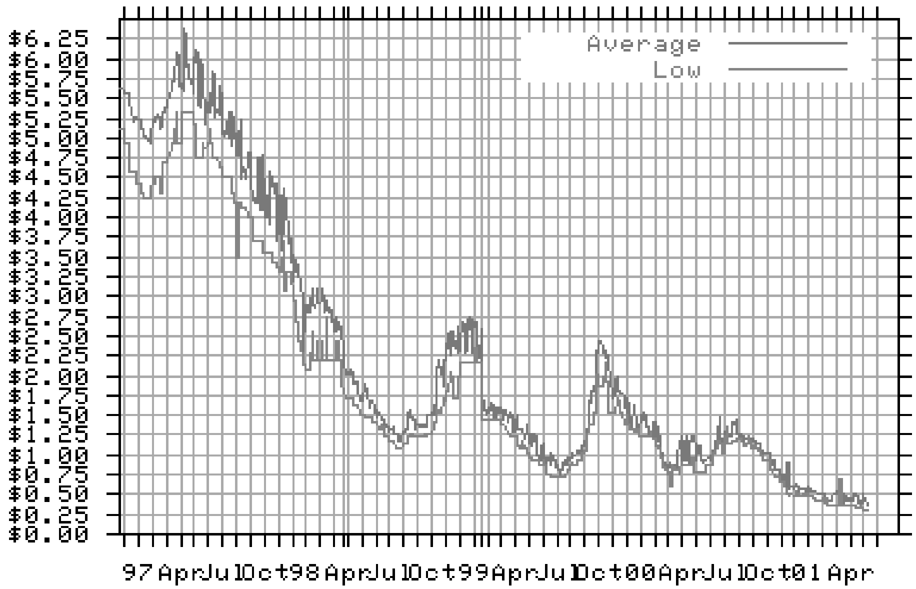
Lecture 17

Reading

- Reading
  - › Section 9.1

What are graphs?

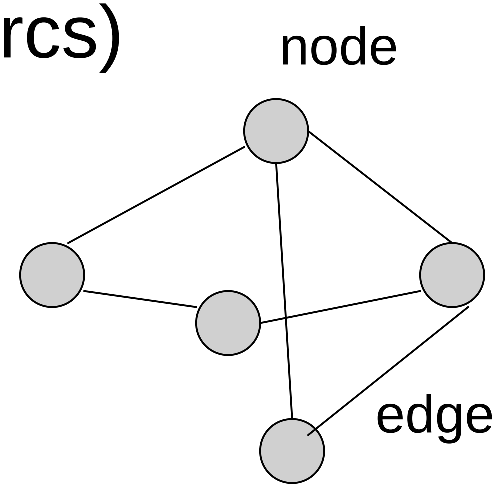
- Yes, this is a graph….



- But we are interested in a different kind of "graph"

Graphs

- Graphs are composed of
  - Nodes (vertices)
  - Edges (arcs)

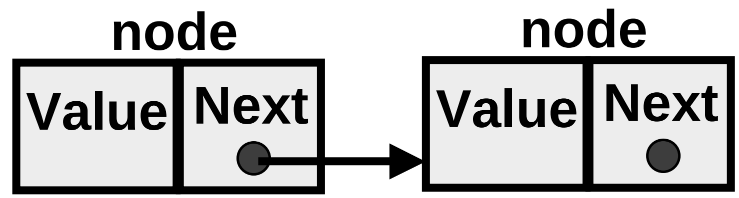


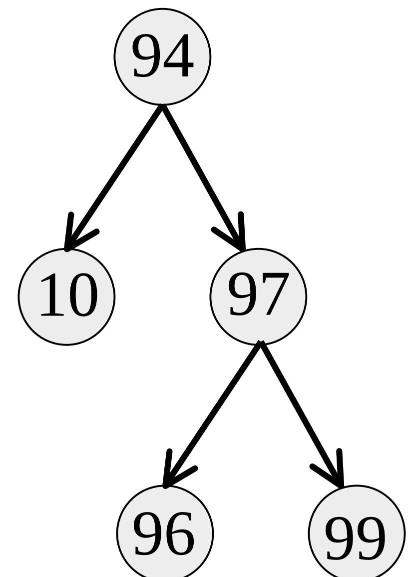
Varieties

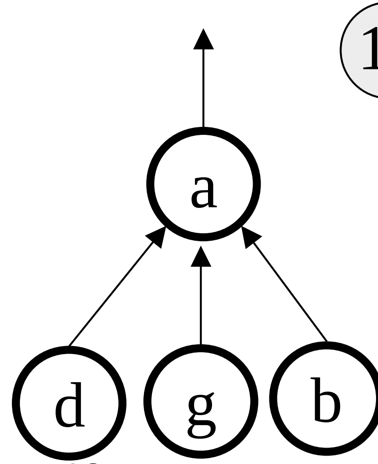
- Nodes
  - Labeled or unlabeled
- Edges
  - Directed or undirected
  - Labeled or unlabeled

Motivation for Graphs

- Consider the data structures we have looked at so far…
- <u>Linked list</u>: nodes with 1 incoming edge + 1 outgoing edge
- <u>Binary trees/heaps</u>: nodes with 1 incoming edge + 2 outgoing edges
- <u>Binomial trees/B-trees</u>: nodes with 1 incoming edge + multiple outgoing edges
- <u>Up-trees</u>: nodes with multiple incoming edges + 1 outgoing edge



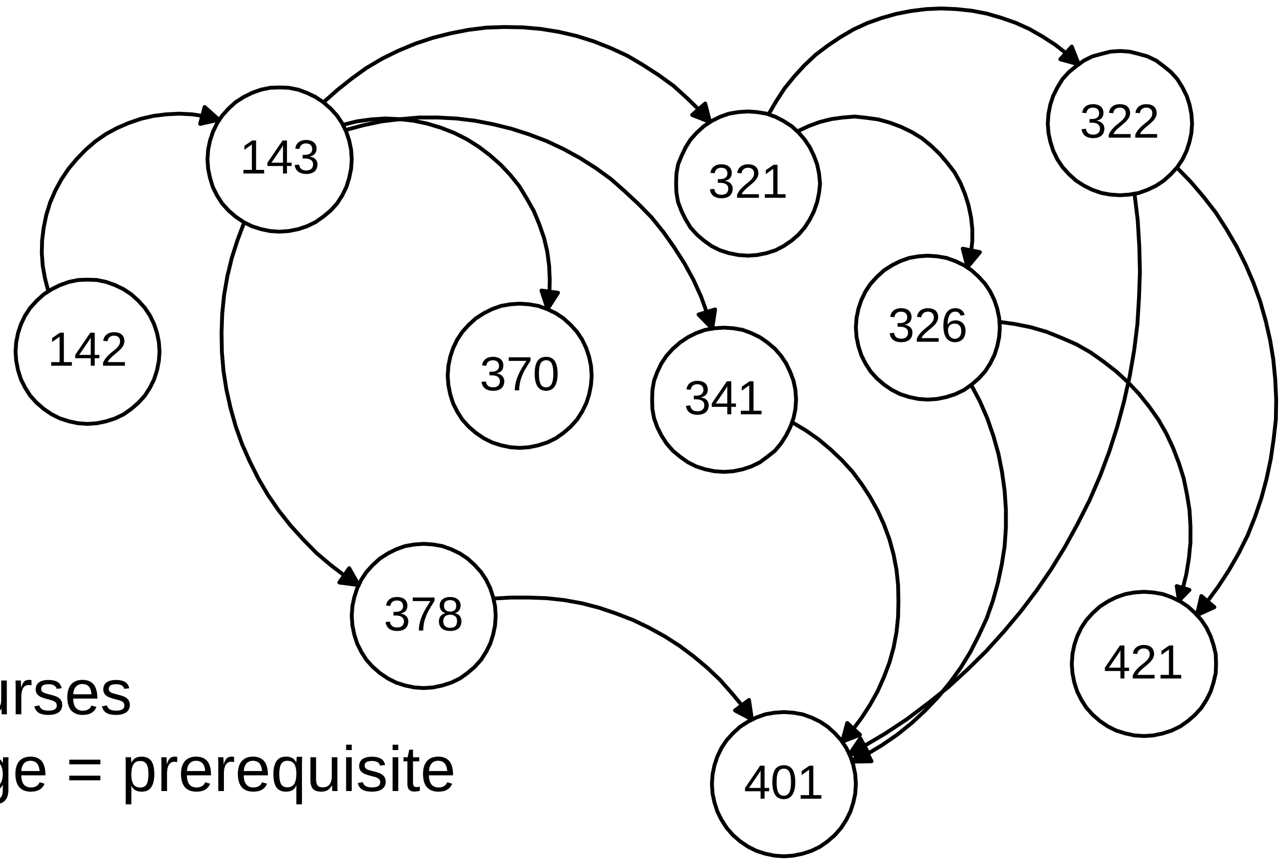




Motivation for Graphs

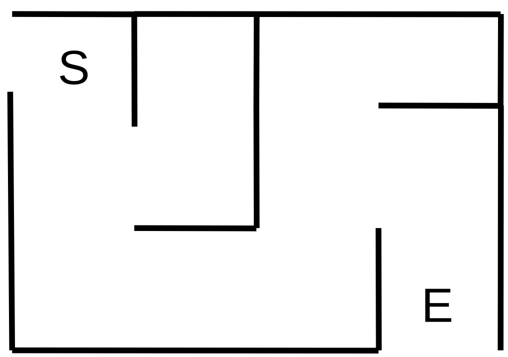
- How can you generalize these data structures?
- Consider data structures for representing the following problems…

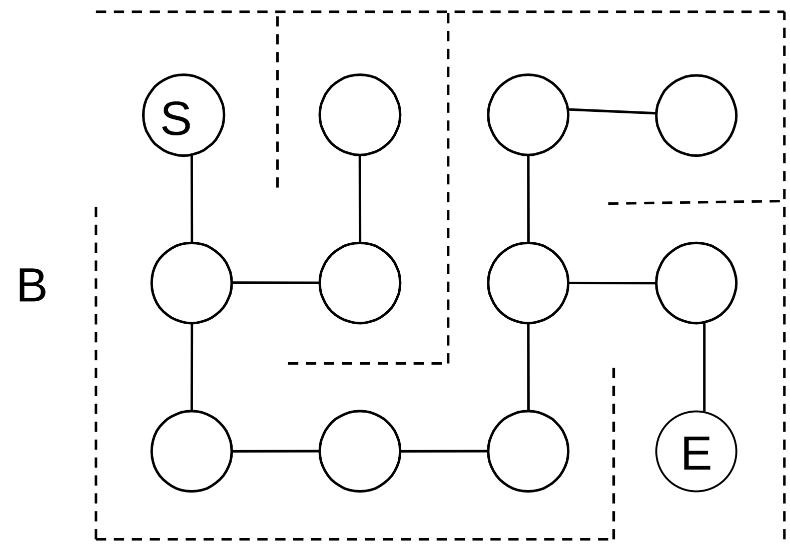
CSE Course Prerequisites at UW



Nodes = courses
Directed edge = prerequisite

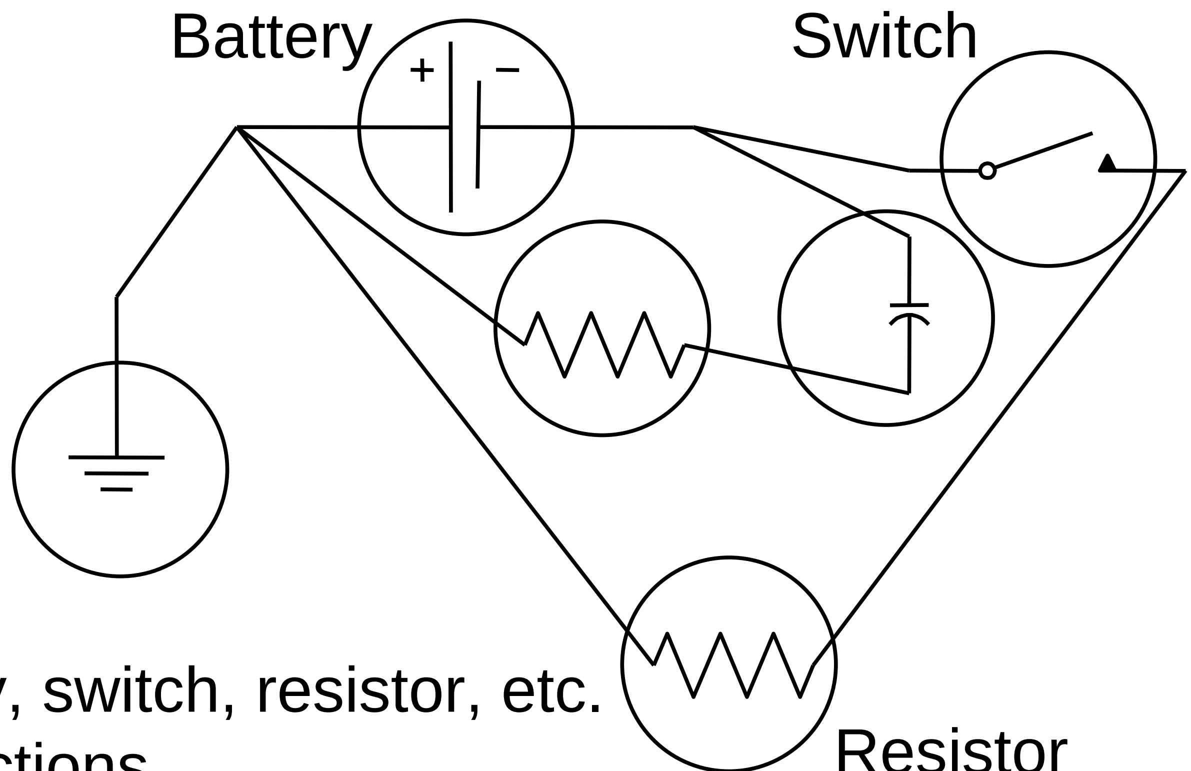
Representing a Maze





Nodes = rooms
Edge = door or passage

Representing Electrical Circuits



Nodes = battery, switch, resistor, etc.
Edges = connections

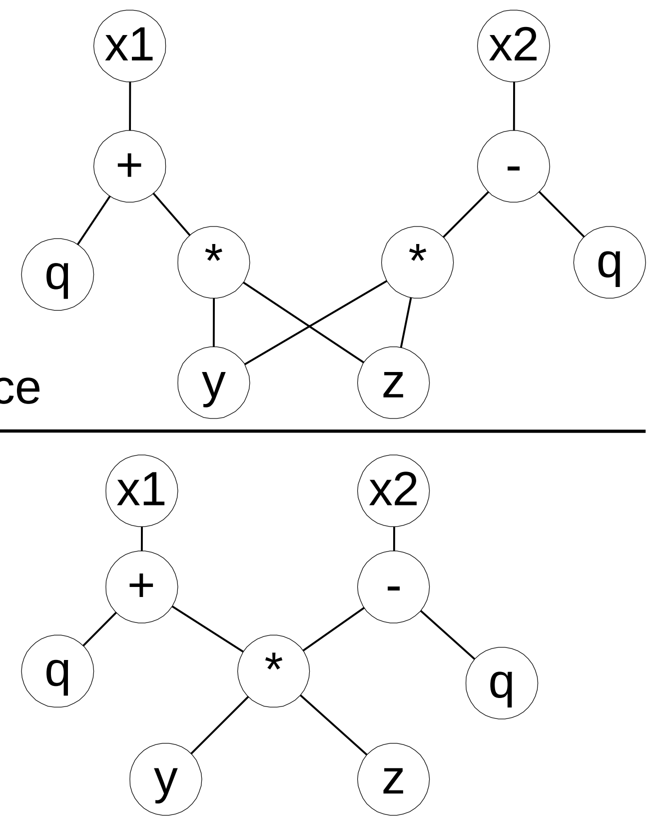
Program statements

```
x1=q+y*z
x2=y*z-q
```

Naive:

y*z calculated twice

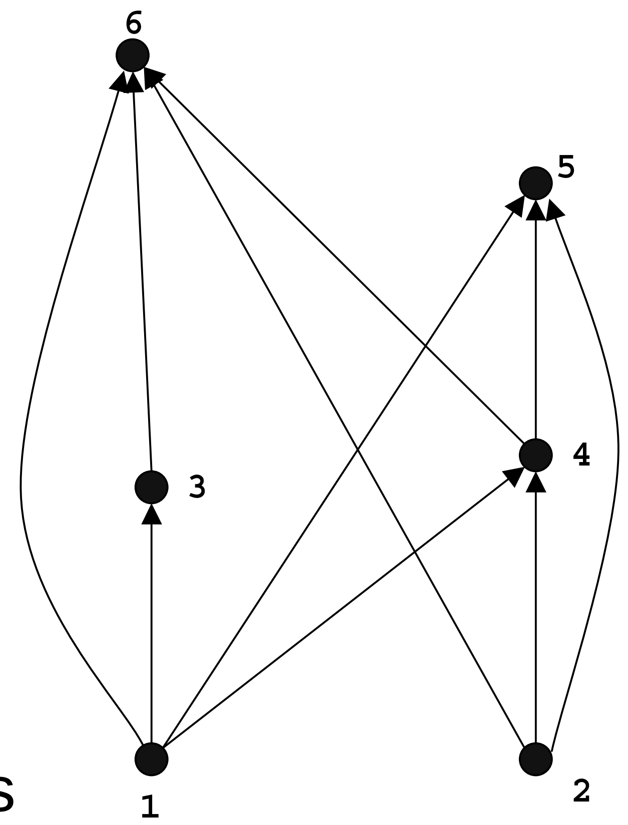
common subexpression eliminated:



Nodes = symbols/operators
Edges = relationships

Precedence

S_1	`a=0;`
S_2	`b=1;`
S_3	`c=a+1`
S_4	`d=b+a;`
S_5	`e=d+1;`
S_6	`e=c+d;`



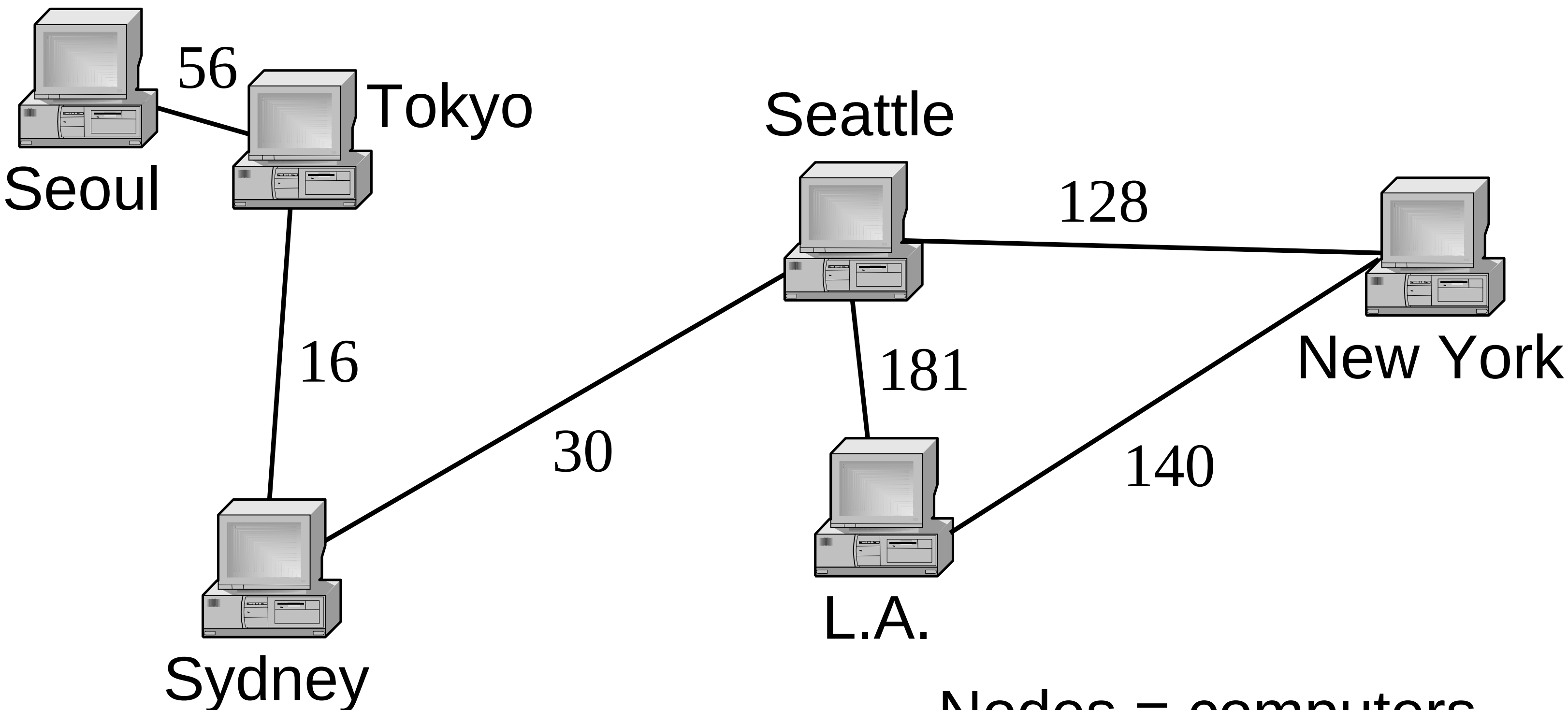
Which statements must execute before S_6?

S_1, S_2, S_3, S_4

Nodes = statements

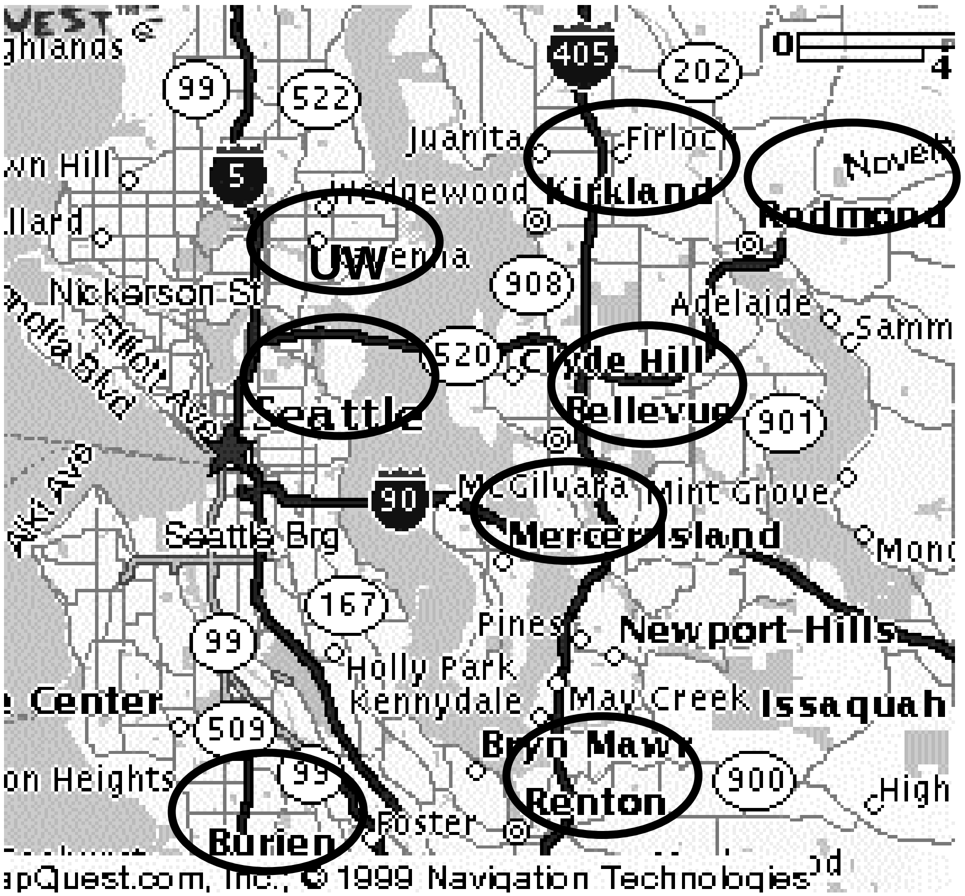
Edges = precedence requirements

Information Transmission in a Computer Network



Nodes = computers
Edges = transmission rates

Traffic Flow on Highways



Nodes = cities
Edges = # vehicles on connecting highway

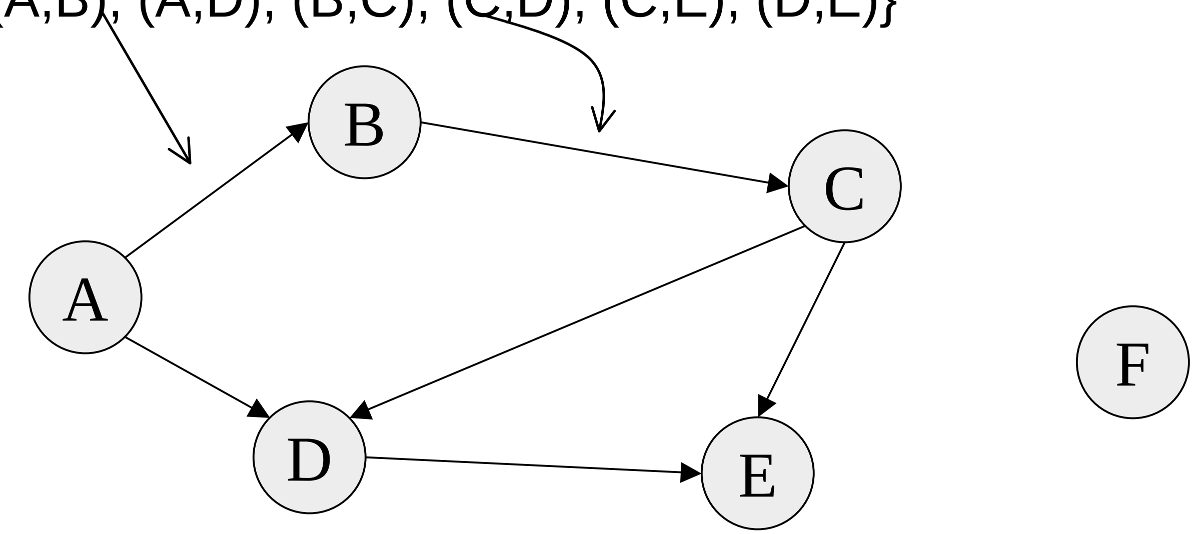
Graph Definition

- A graph is simply a collection of nodes plus edges
  - › Linked lists, trees, and heaps are all special cases of graphs
- The nodes are known as vertices (node = "vertex")
- Formal Definition: A graph G is a pair (V, E) where
  - › V is a set of vertices or nodes
  - › E is a set of edges that connect vertices

Graph Example

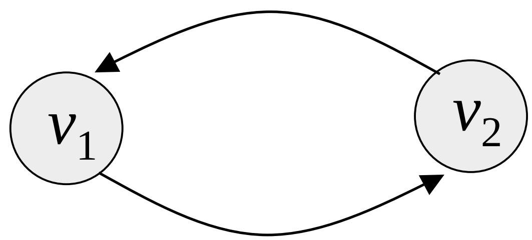
- Here is a directed graph $G = (V, E)$
  - Each <u>edge</u> is a pair (v_1, v_2), where v_1, v_2 are vertices in V
  - V = {A, B, C, D, E, F}

E = {(A,B), (A,D), (B,C), (C,D), (C,E), (D,E)}

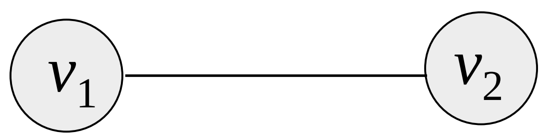


Directed vs Undirected Graphs

- If the order of edge pairs (v_1, v_2) matters, the graph is directed (also called a digraph): (v_1, v_2) $\neq$ (v_2, v_1)



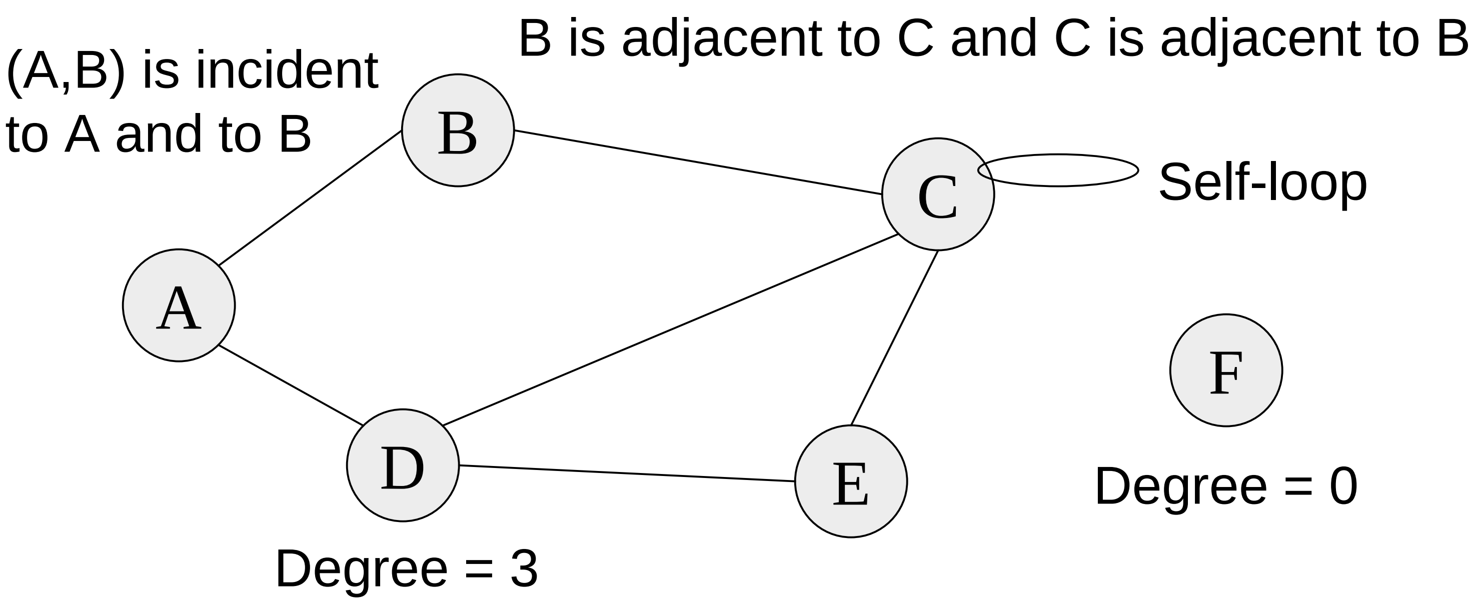
- If the order of edge pairs (v_1, v_2) does not matter, the graph is called an undirected graph: in this case, (v_1, v_2) = (v_2, v_1)



Undirected Terminology

- Two vertices u and v are adjacent in an undirected graph G if {u,v} is an edge in G
  - edge e = {u,v} is incident with vertex u and vertex v
- The degree of a vertex in an undirected graph is the number of edges incident with it
  - a self-loop counts twice (both ends count)
  - denoted with deg(v)

Undirected Terminology

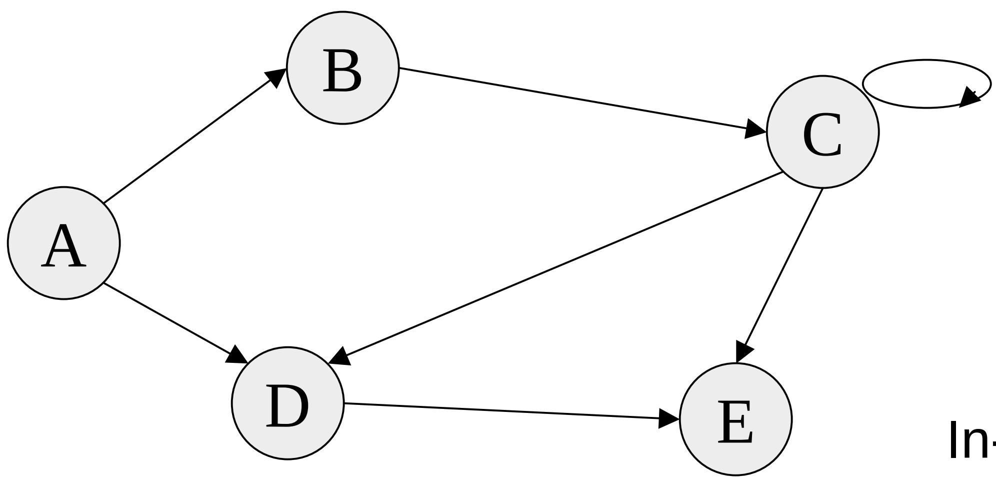


Directed Terminology

- Vertex u is adjacent to vertex v in a directed graph G if (u,v) is an edge in G
  - › vertex u is the initial vertex of (u,v)
- Vertex v is adjacent from vertex u
  - › vertex v is the terminal (or end) vertex of (u,v)
- Degree
  - › in-degree is the number of edges with the vertex as the terminal vertex
  - › out-degree is the number of edges with the vertex as the initial vertex

Directed Terminology

B adjacent to C and C adjacent from B



In-degree = 2
Out-degree = 1

In-degree = 0
Out-degree = 0

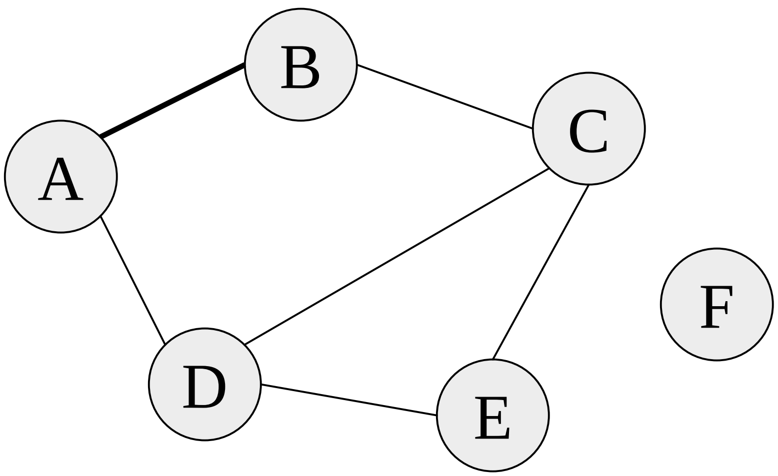
Handshaking Theorem

- Let G=(V,E) be an undirected graph with |E|=e edges
- Then $2e = \sum_{v \in V} \deg(v)$
- Every edge contributes +1 to the degree of each of the two vertices it is incident with
  - › number of edges is exactly half the sum of deg(v)
  - › the sum of the deg(v) values must be even

Graph Representations

- Space and time are analyzed in terms of:
  - Number of vertices = $|V|$ and
  - Number of edges = $|E|$
- There are at least two ways of representing graphs:
  - The *adjacency matrix* representation
  - The *adjacency list* representation

Adjacency Matrix

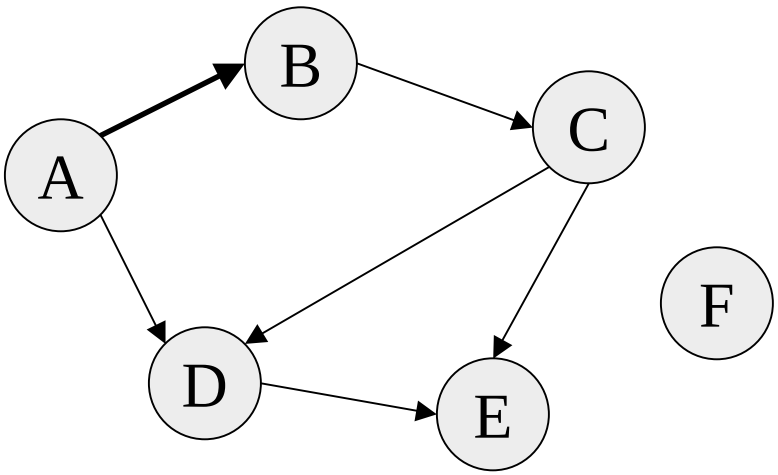


$$M(v, w) = \begin{cases} 1 \text{ if } (v, w) \text{ is in E} \\ 0 \text{ otherwise} \end{cases}$$

$$\begin{array}{c|c} & \begin{array}{cccccc} A & B & C & D & E & F \end{array} \\ \begin{array}{c} A \\ B \\ C \\ D \\ E \\ F \end{array} & \begin{pmatrix} 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \end{array}$$

Space = $|V|^2$

Adjacency Matrix for a Digraph



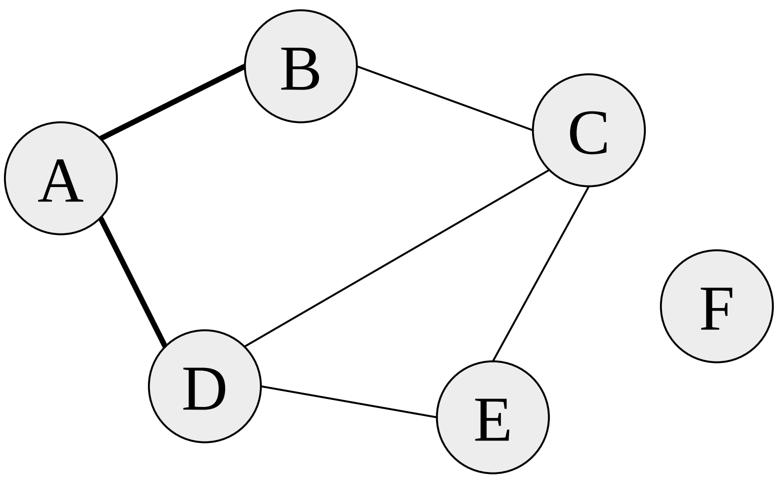
$$\begin{array}{c|c} & \begin{matrix} A & B & C & D & E & F \end{matrix} \\ \begin{matrix} A \\ B \\ C \\ D \\ E \\ F \end{matrix} & \begin{pmatrix} 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \end{array}$$

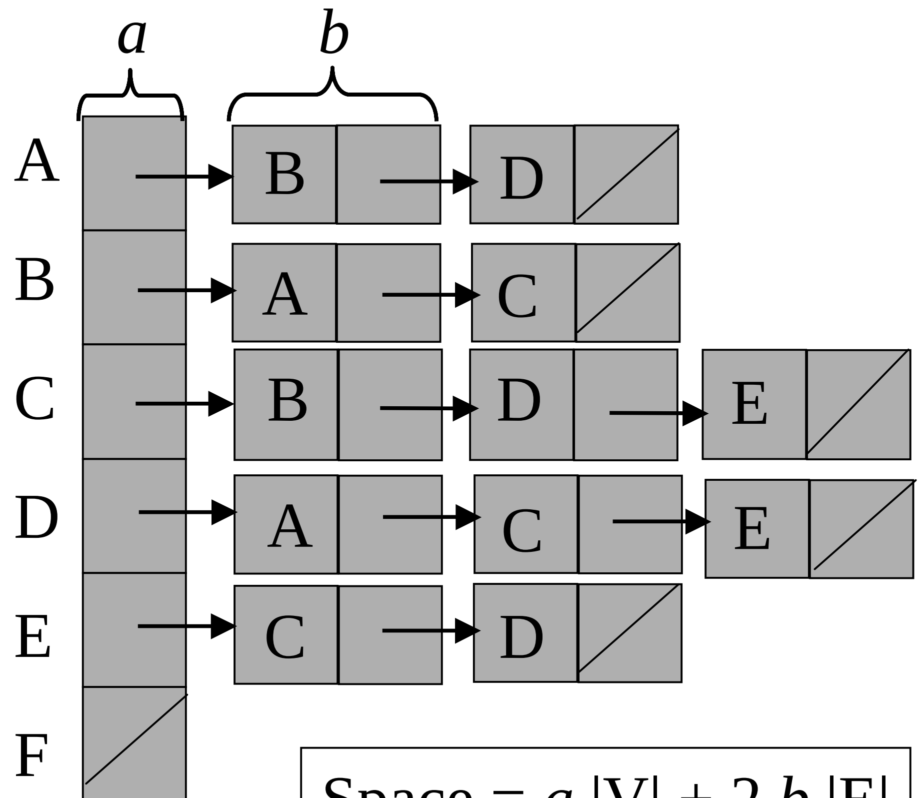
$$M(v, w) = \begin{cases} 1 \text{ if } (v, w) \text{ is in E} \\ 0 \text{ otherwise} \end{cases}$$

Space = $|V|^2$

Adjacency List

For each *v* in *V*, *L*(*v*) = list of *w* such that (*v*, *w*) is in *E*

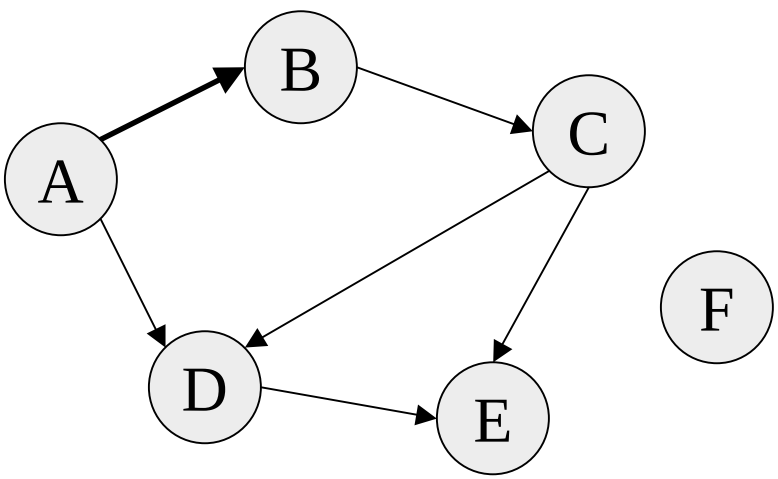


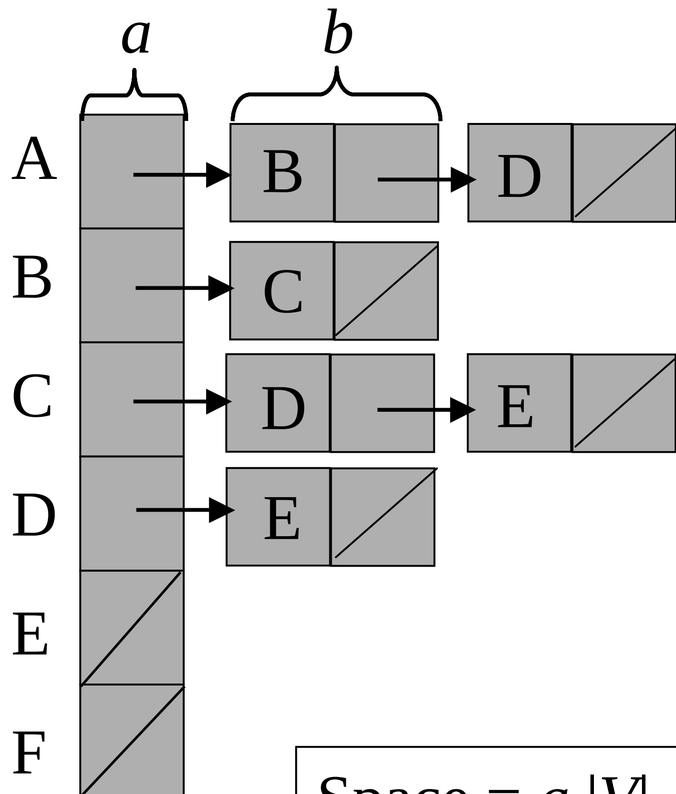


Space = $a\,|V| + 2\,b\,|E|$

Adjacency List for a Digraph

For each v in V, $L(v)$ = list of w such that (v, w) is in E





Space = $a\,|V| + b\,|E|$