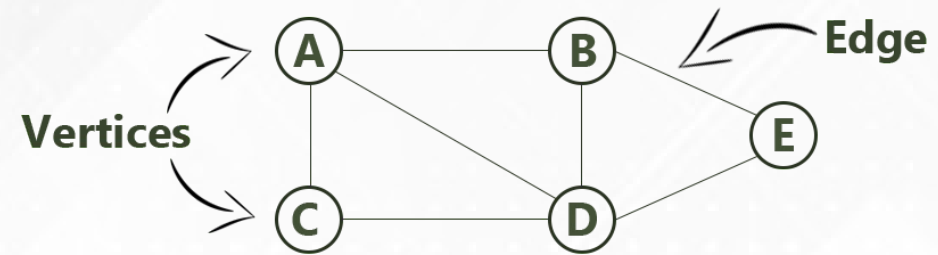




Unit-3 (Part 4)

Graph

Non-Linear Data Structure



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Graphs

- ▶ What is Graph?
- ▶ Representation of Graph
 - Matrix representation of Graph
 - Linked List representation of Graph
- ▶ Elementary Graph Operations
 - Breadth First Search (BFS)
 - Depth First Search (DFS)
 - Spanning Trees
 - Minimal Spanning Trees
 - Shortest Path

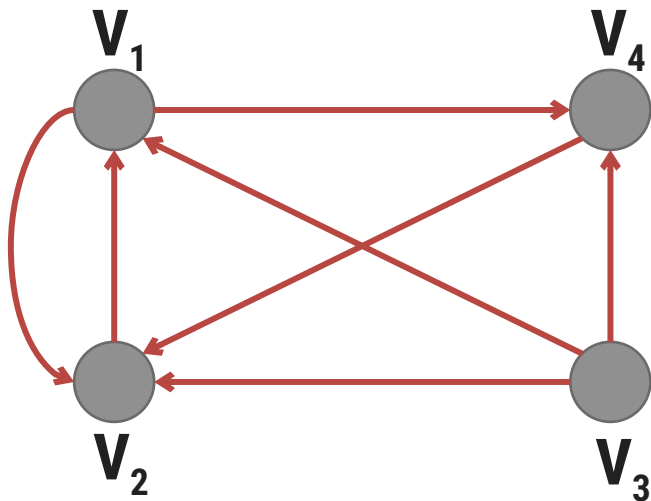
Adjacency matrix

- ▶ A **diagrammatic representation** of a **graph** may have limited usefulness. However such a representation **is not feasible** when number of **nodes** and **edges** in a graph **is large**
- ▶ It is easy to store and manipulate matrices and hence the graphs represented by them in the computer
- ▶ Let **$G = (V, E)$** be a simple **diagraph** in which **$V = \{v_1, v_2, \dots, v_n\}$** and the **nodes** are assumed to be **ordered** from **v_1** to **v_n**
- ▶ An $n \times n$ matrix **A** is called **Adjacency matrix** of the graph G whose **elements** **a_{ij}** are given by

$$a_{ij} = \begin{cases} 1 & \text{if } (V_i, V_j) \in E \\ 0 & \text{otherwise} \end{cases}$$

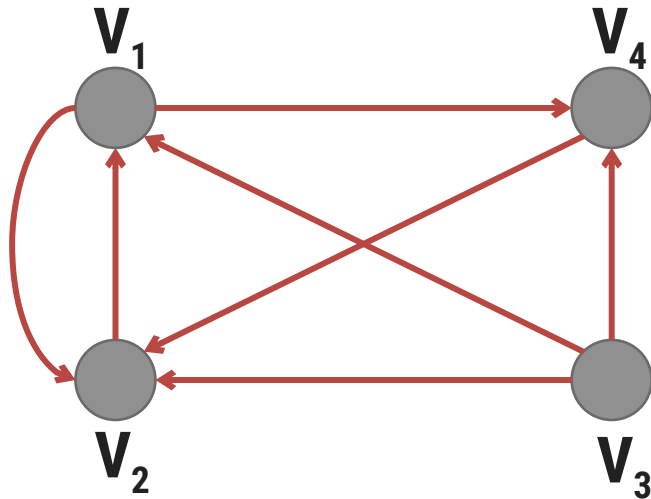
Adjacency matrix

- ▶ An **element** of the adjacency matrix is either **0** or **1**
- ▶ Any **matrix** whose **elements are either 0 or 1** is called **bit matrix** or **Boolean matrix**
- ▶ For a given graph $G = (V, E)$, an **adjacency matrix** depends upon the ordering of the elements of V
- ▶ For different ordering of the elements of V we get different adjacency matrices.



$$A = \begin{matrix} & \begin{matrix} V_1 & V_2 & V_3 & V_4 \end{matrix} \\ \begin{matrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{matrix} & \begin{pmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{pmatrix} \end{matrix}$$

Adjacency matrix



A =

$$\begin{matrix} & \mathbf{V}_1 & \mathbf{V}_2 & \mathbf{V}_3 & \mathbf{V}_4 \\ \mathbf{V}_1 & 0 & 1 & 0 & 1 \\ \mathbf{V}_2 & 1 & 0 & 0 & 0 \\ \mathbf{V}_3 & 1 & 1 & 0 & 1 \\ \mathbf{V}_4 & 0 & 1 & 0 & 0 \end{matrix}$$

- ▶ The **number of elements** in the **i^{th} row** whose **value is 1** is equal to the **out-degree** of node **V_i**
- ▶ The **number of elements** in the **j^{th} column** whose **value is 1** is equal to the **in-degree** of node **V_j**
- ▶ For a **NULL graph** which consist of only n nodes but no edges, the **adjacency matrix** has **all its elements 0**. i.e. the adjacency matrix is the NULL matrix

Power of Adjacency matrix

$$\mathbf{A} = \begin{pmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$\mathbf{A}^2 = \mathbf{A} \times \mathbf{A} = \begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 2 & 0 & 1 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$\mathbf{A}^3 = \begin{pmatrix} 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 2 & 2 & 0 & 1 \\ 0 & 1 & 0 & 1 \end{pmatrix}$$
$$\mathbf{A}^4 = \begin{pmatrix} 1 & 2 & 0 & 1 \\ 1 & 1 & 0 & 1 \\ 2 & 3 & 0 & 2 \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

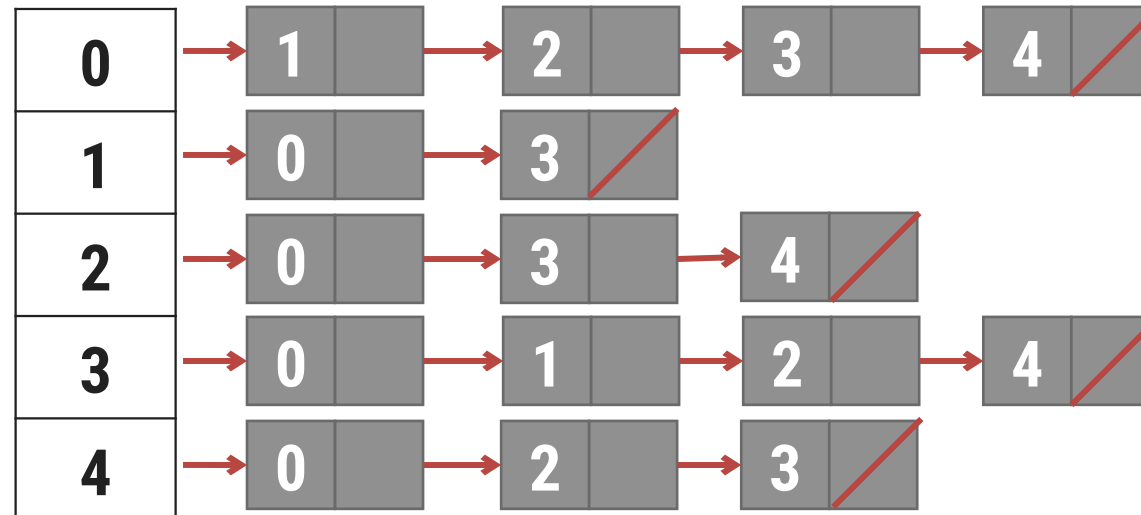
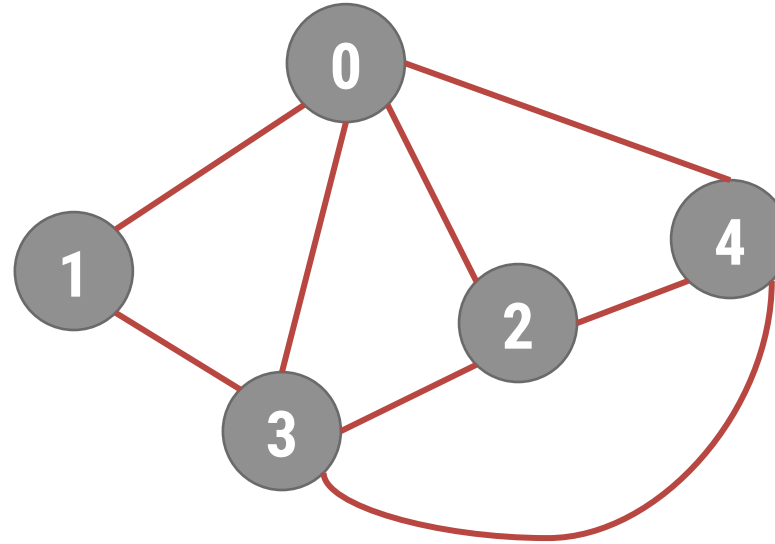
- ▶ Entry of **1** in **i^{th}** row and **j^{th}** column of **\mathbf{A}** shows existence of an **edge (V_i, V_j)** , that is a **path of length 1**
- ▶ Entry in **\mathbf{A}^2** shows **no of different paths** of **exactly length 2** from node **V_i** to **V_j**
- ▶ Entry in **\mathbf{A}^3** shows **no of different paths** of **exactly length 3** from node **V_i** to **V_j**

Path matrix or reachability matrix

- ▶ Let $G = (V, E)$ be a simple diagraph which contains **n nodes** that are assumed to be ordered.
- ▶ A **n x n** matrix **P** is called **path matrix** whose elements are given by

$$P_{ij} = \begin{cases} 1, & \text{if there exists path from node } V_i \text{ to } V_j \\ 0, & \text{otherwise} \end{cases}$$

Adjacency List Representation



Graph Traversal

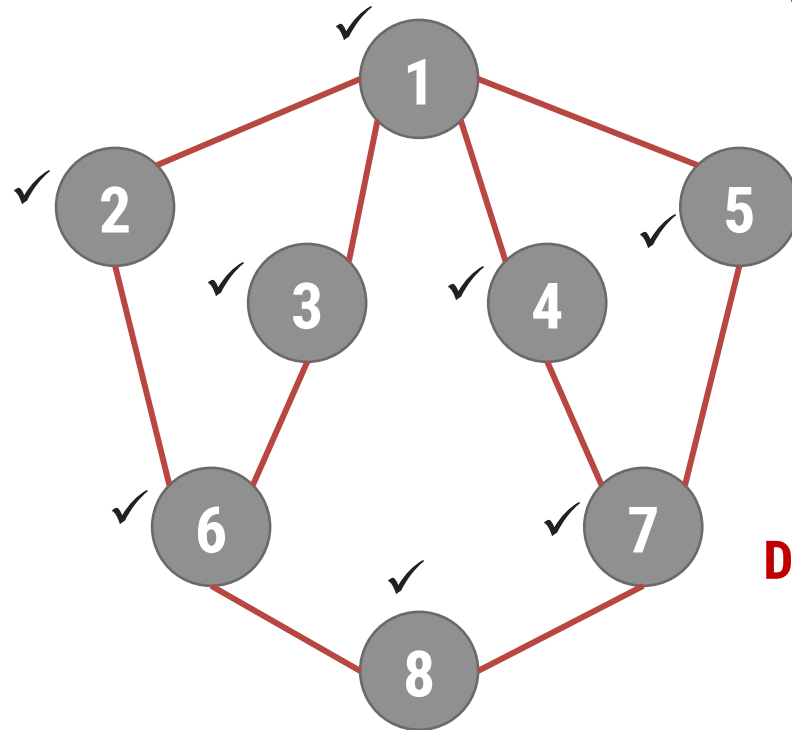
▶ Two Commonly used Traversal Techniques are

- ➔ Depth First Search (DFS)
- ➔ Breadth First Search (BFS)

Depth First Search (DFS)

- ▶ It is like preorder traversal of tree
- ▶ Traversal can start from any vertex V_i
- ▶ V_i is visited and then all vertices adjacent to V_i are traversed recursively using DFS

DFS (G, 1) is given by



Step 1: Visit (1)

Step 2: DFS (G, 2)

DFS (G, 3)

DFS (G, 4)

DFS (G, 5)

DFS (G, 2):

Step1: Visit(2)

Step 2: DFS (G, 6)

DFS (G, 6):

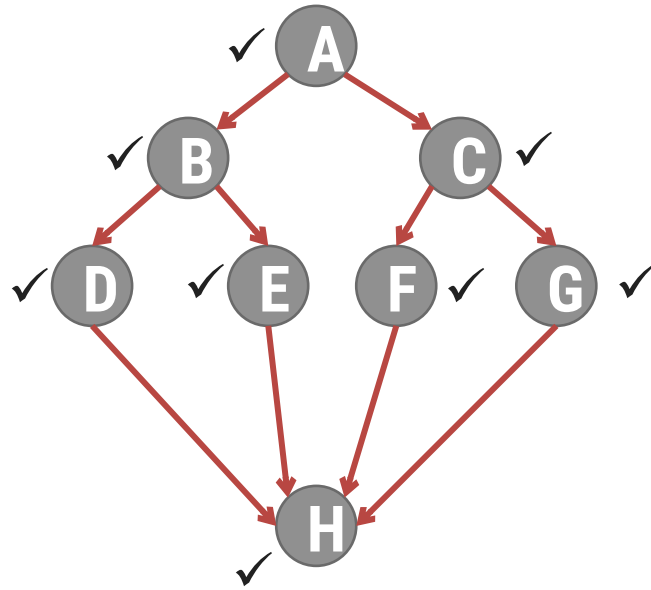
Step1: Visit(6)

Step 2: DFS (G, 3)

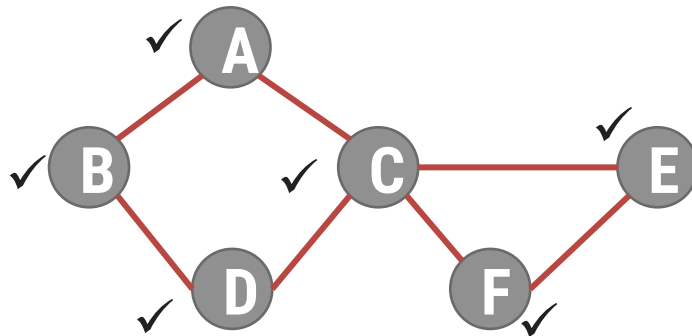
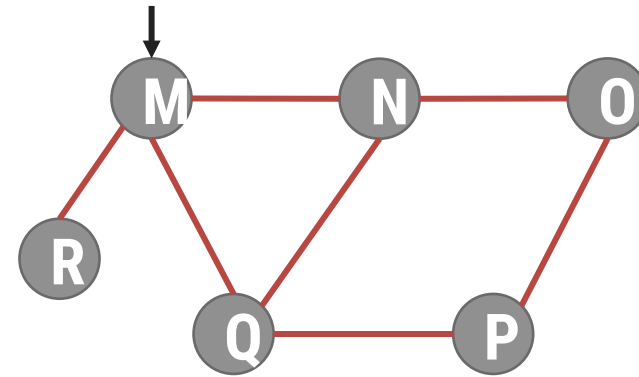
DFS of given graph starting from node 1 is given by

1 2 6 3 8 7 4 5

Depth First Search (DFS)



A B D H E C F G

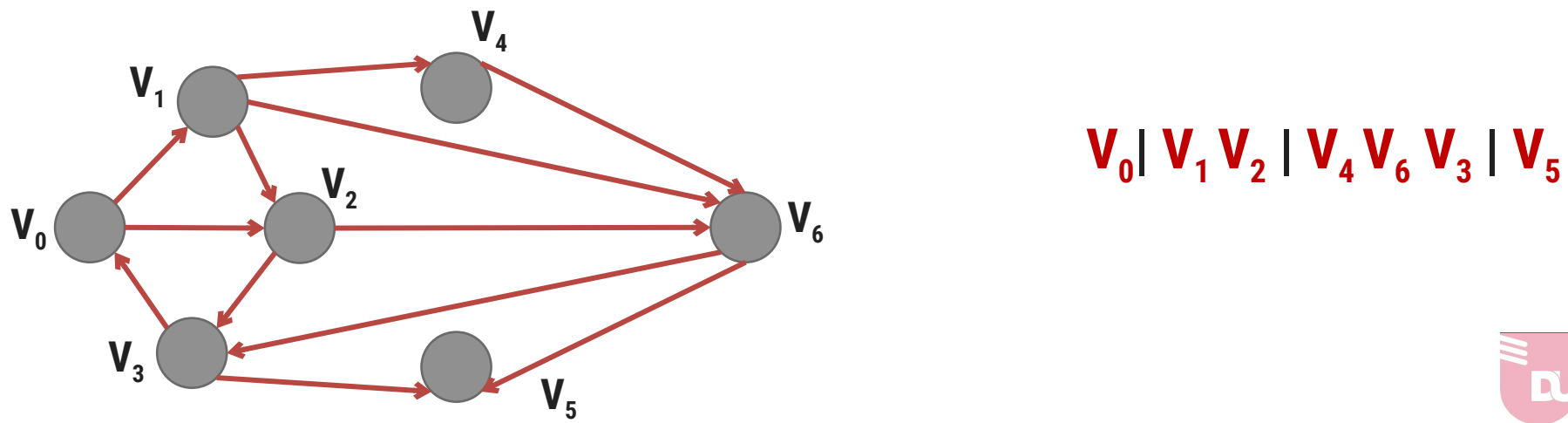
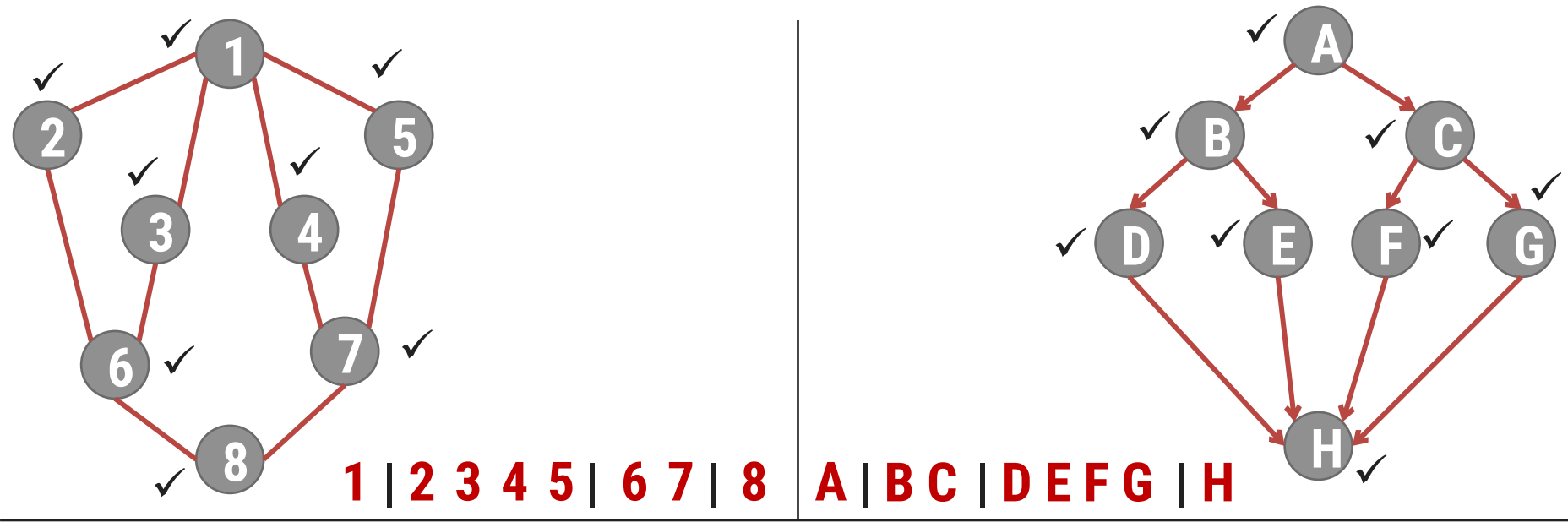


A B D C F E

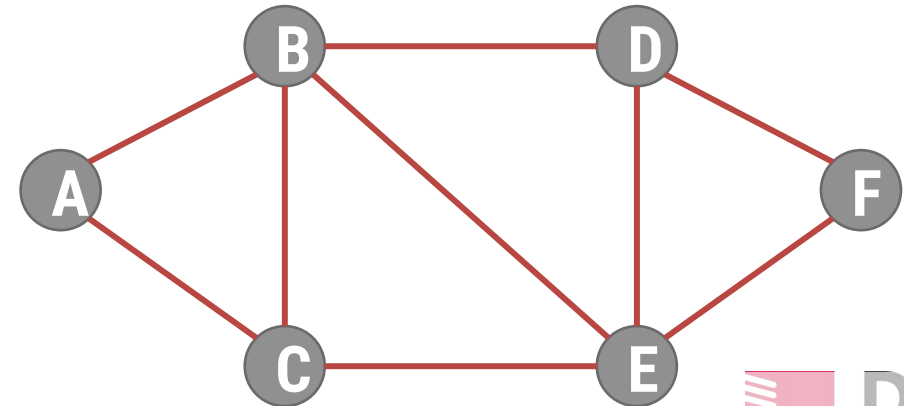
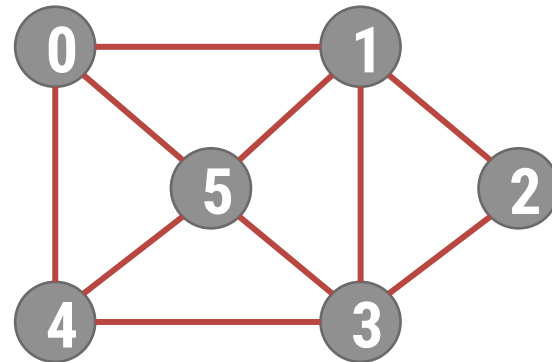
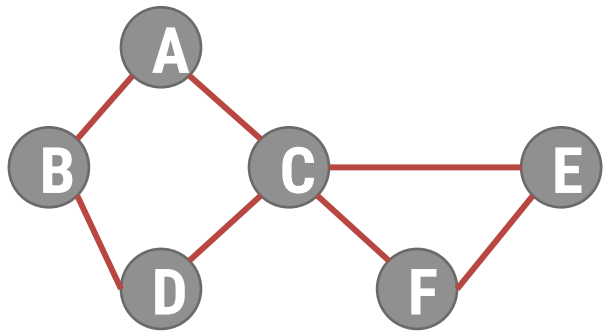
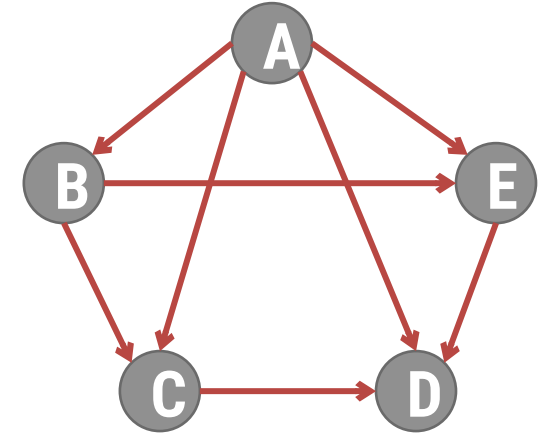
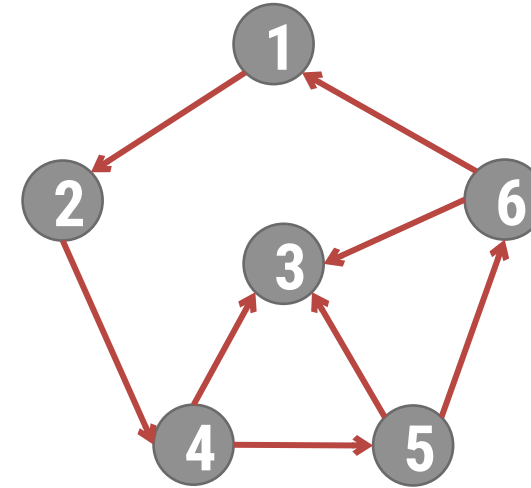
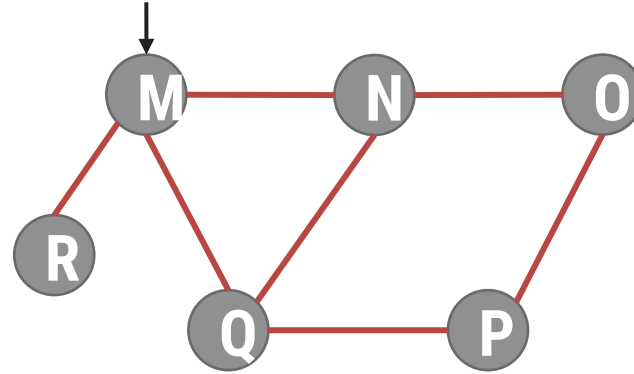
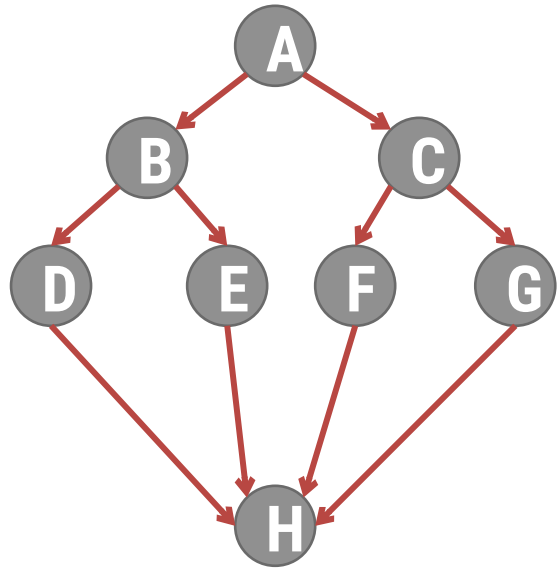
Breadth First Search (BFS)

- ▶ This method **starts** from vertex V_0
- ▶ V_0 is marked as **visited**. All **vertices adjacent to V_0** are **visited next**
- ▶ Let vertices adjacent to V_0 are V_1, V_2, V_2, V_4
- ▶ V_1, V_2, V_3 and V_4 are marked visited
- ▶ All unvisited vertices adjacent to V_1, V_2, V_3, V_4 are visited next
- ▶ The method **continuous until all vertices** are **visited**
- ▶ The algorithm for BFS has to maintain a list of vertices which have been visited but not explored for adjacent vertices
- ▶ The vertices which have been visited but not explored for adjacent vertices can be stored in **queue**

Breadth First Search (BFS)



Write DFS & BFS of following Graphs



Procedure : DFS (vertex V)

- ▶ This procedure **traverse the graph G in DFS** manner.
- ▶ V is a starting vertex to be explored.
- ▶ Visited[] is an array which tells you whether particular vertex is visited or not.
- ▶ W is a adjacent node of vertex V.
- ▶ S is a Stack, PUSH and POP are functions to insert and remove from stack respectively.

Procedure : DFS (vertex V)

1. [Initialize TOP and Visited]

visited[] \leftarrow 0

TOP \leftarrow 0

2. [Push vertex into stack]

PUSH (V)

3. [Repeat while stack is not Empty]

Repeat Step 3 while stack is not empty

 v \leftarrow POP()

 if visited[v] is 0

 then visited [v] \leftarrow 1

 for all W adjacent to v

 if visited [w] is 0

 then PUSH (W)

 end for

 end if

Procedure : BFS (vertex V)

- ▶ This procedure **traverse the graph G in BFS** manner
- ▶ **V** is a **starting vertex** to be explored
- ▶ Q is a queue
- ▶ visited[] is an array which tells you whether particular vertex is visited or not
- ▶ W is a adjacent node f vertex V.

Procedure : BFS (vertex V)

1. [Initialize Queue & Visited]

$visited[] \leftarrow 0$

$F \leftarrow R \leftarrow 0$

2. [Marks visited of V as 1]

$visited[v] \leftarrow 1$

3. [Add vertex v to Q]

InsertQueue(V)

4. [Repeat while Q is not Empty]

Repeat while Q is not empty

$v \leftarrow \text{RemoveFromQueue}()$

For all vertices W adjacent to v

If $visited[w]$ is 0

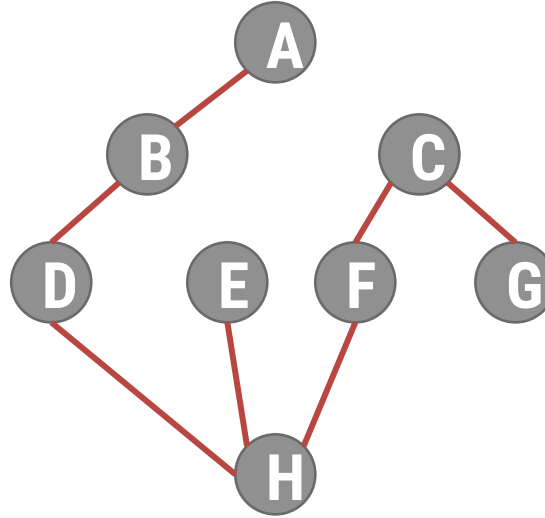
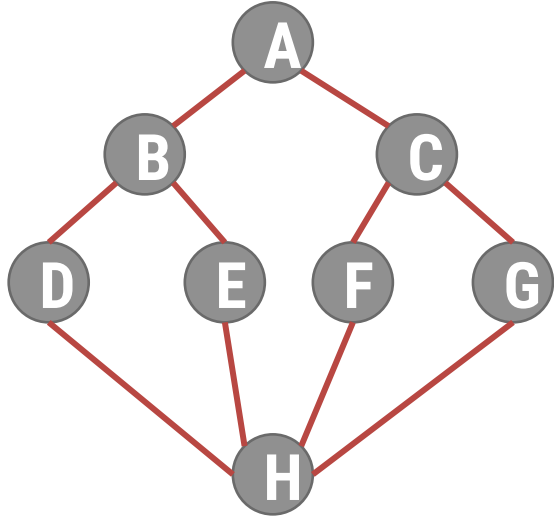
Then $visited[w] \leftarrow 1$

InsertQueue(w)

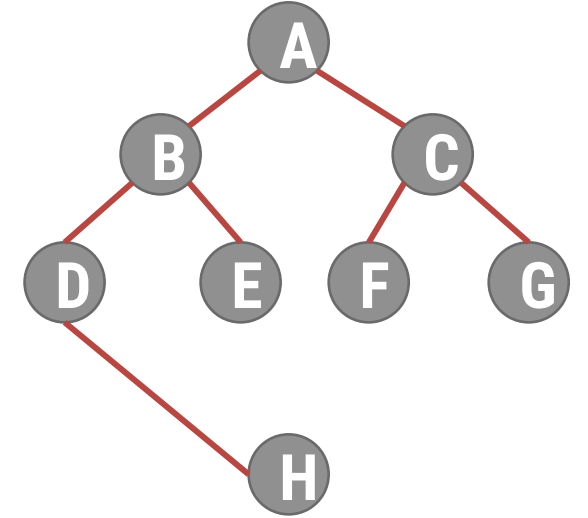
Spanning Tree

- ▶ A **Spanning tree** of a graph is an undirected tree **consisting of only those edges necessary to connect all the nodes** in the original graph
- ▶ A spanning tree has the **properties** that
 - ➔ For any **pair** of nodes there exists **only one path between them**
 - ➔ **Insertion** of any **edge** to a spanning tree **forms a unique cycle**
- ▶ The particular **Spanning for a graph** depends on the **criteria** used to **generate** it
- ▶ If **DFS search** is use, those edges traversed by the algorithm forms the edges of tree, referred to as **Depth First Spanning Tree**
- ▶ If **BFS Search** is used, the spanning tree is formed from those edges traversed during the search, producing **Breadth First Spanning tree**

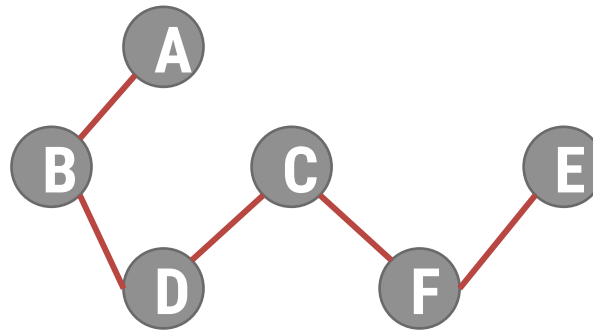
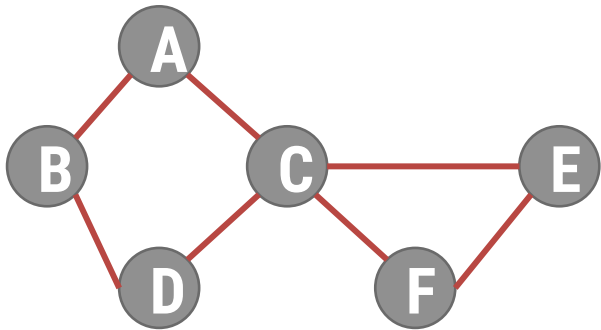
Construct Spanning Tree



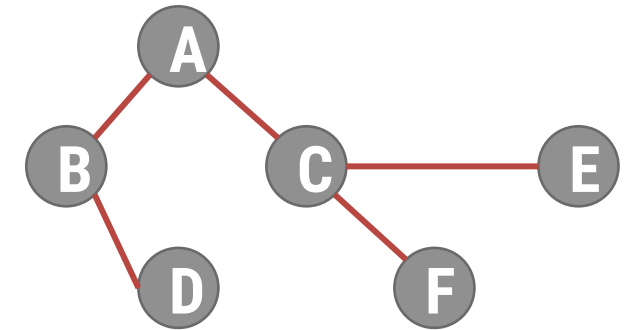
DFS Spanning Tree



BFS Spanning Tree



DFS Spanning Tree

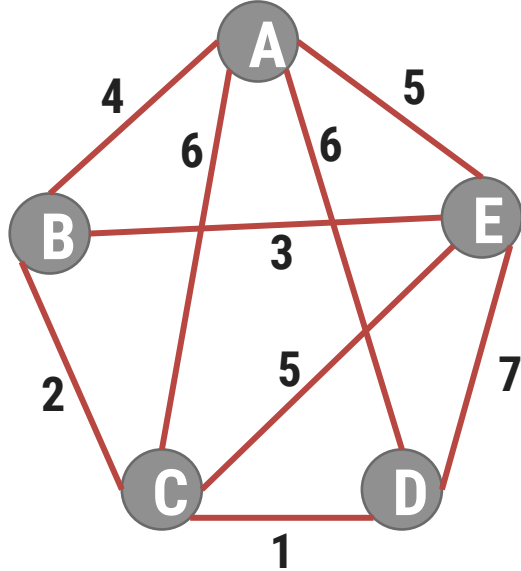


BFS Spanning Tree

Minimum Cost Spanning Tree

- ▶ The **cost of a spanning tree** of a weighted undirected graph is the sum of the costs(weights) of the edges in the spanning tree
- ▶ A **minimum cost spanning tree** is a spanning tree of least cost
- ▶ Two techniques for Constructing minimum cost spanning tree
 - ➔ Prim's Algorithm
 - ➔ Kruskal's Algorithm

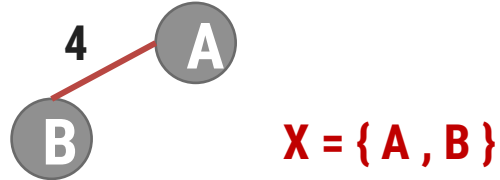
Prims Algorithm



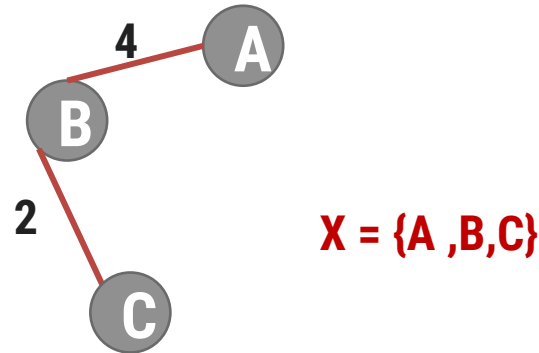
A - B 4	A - D 6	C - E 5
A - E 5	B - E 3	C - D 1
A - C 6	B - C 2	D - E 7

Let X be the set of nodes explored, initially $X = \{A\}$

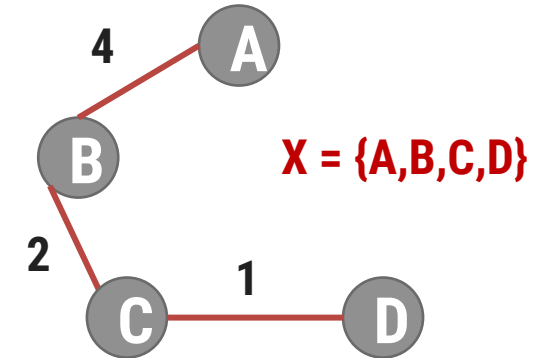
Step 1: Taking minimum Weight edge of all Adjacent edges of $X = \{A\}$



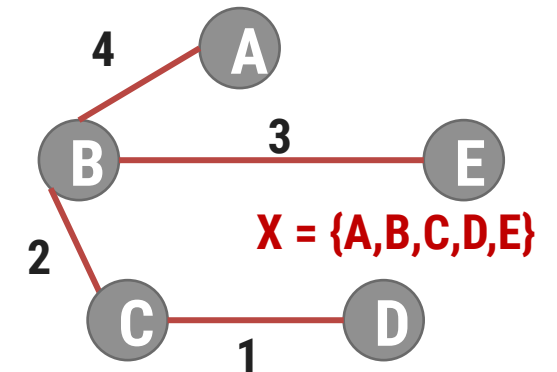
Step 2: Taking minimum weight edge of all Adjacent edges of $X = \{A, B\}$



Step 3: Taking minimum weight edge of all Adjacent edges of $X = \{A, B, C\}$

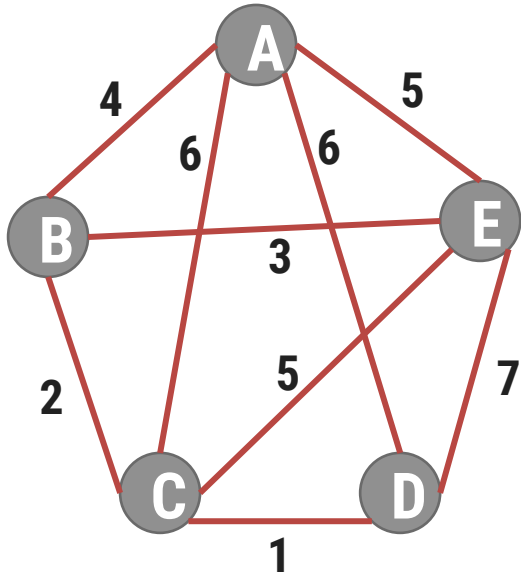


Step 4: Taking minimum weight edge of all Adjacent edges of $X = \{A, B, C, D\}$



We obtained minimum spanning tree of cost:
 $4 + 2 + 1 + 3 = 10$

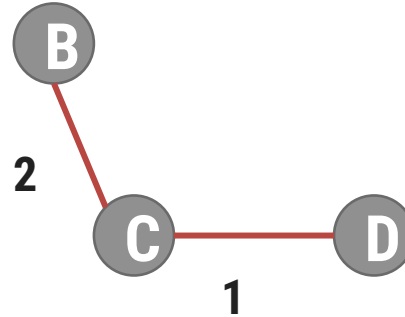
Kruskal's Algorithm



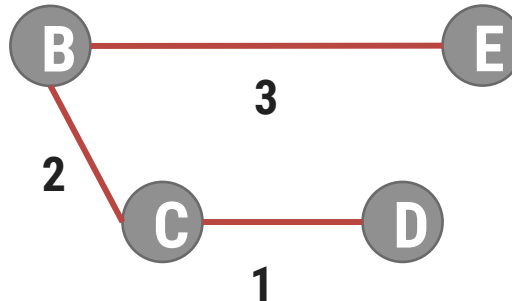
Step 1: Taking min edge (C,D)



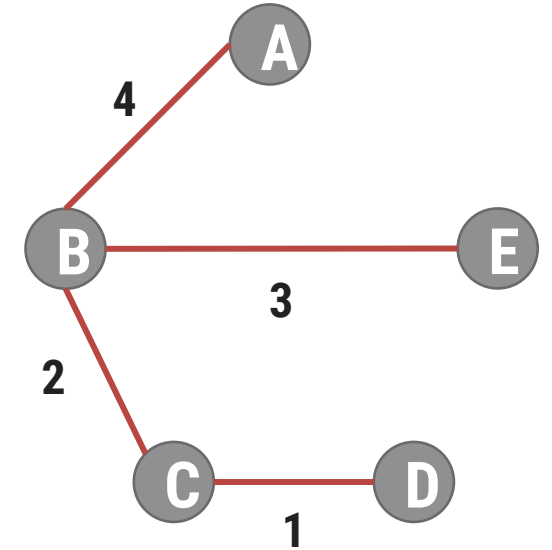
Step 2: Taking next min edge (B,C)



Step 3: Taking next min edge (B,E)

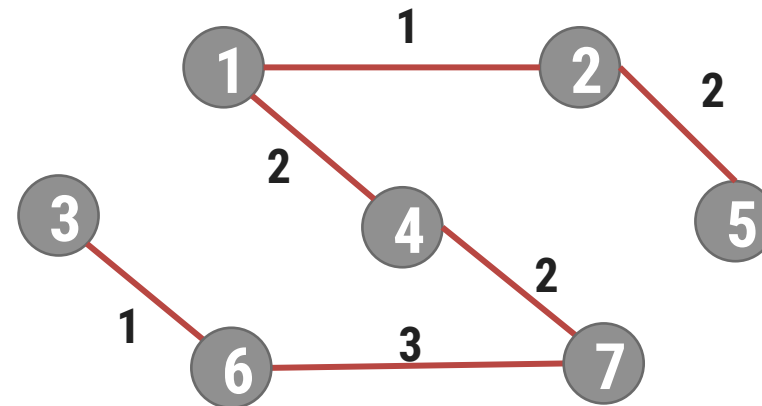
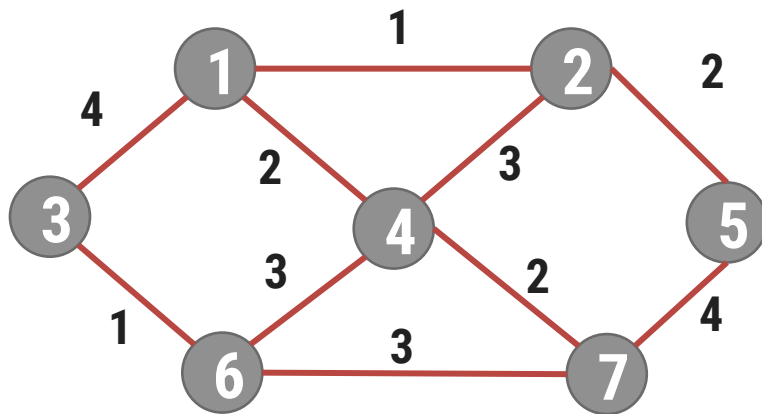
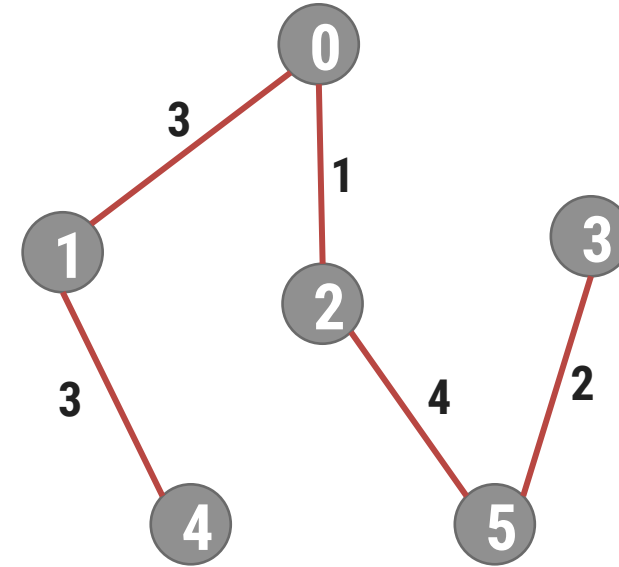
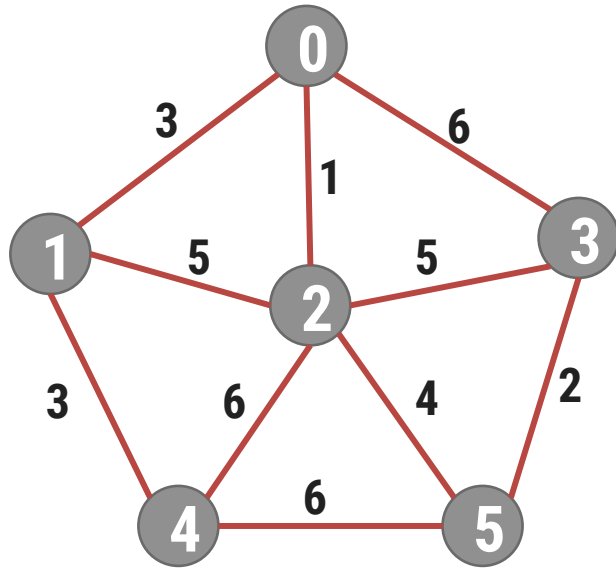


Step 4: Taking next min edge (A,B)

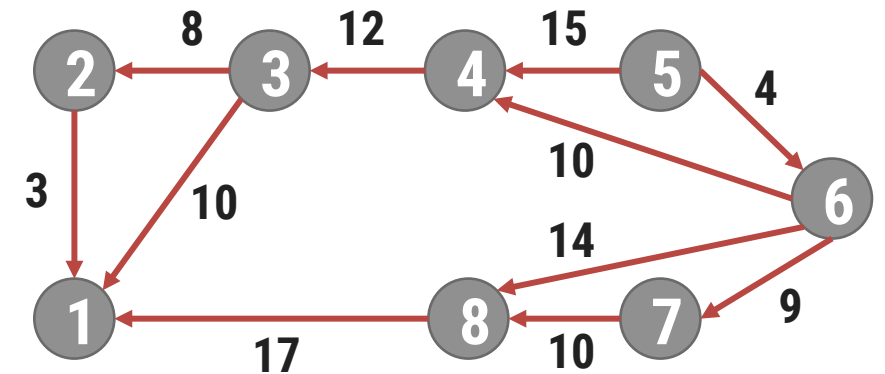
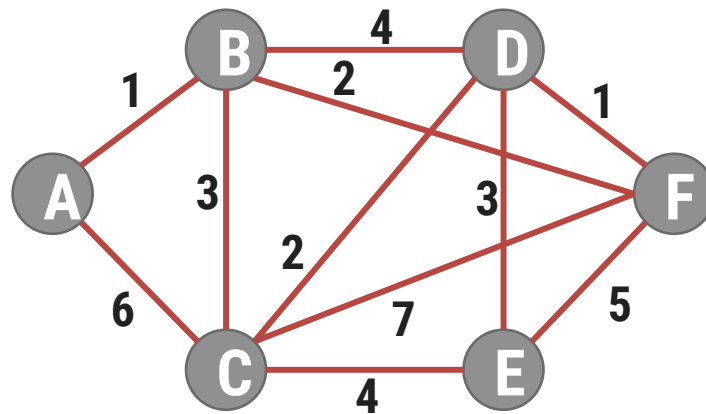
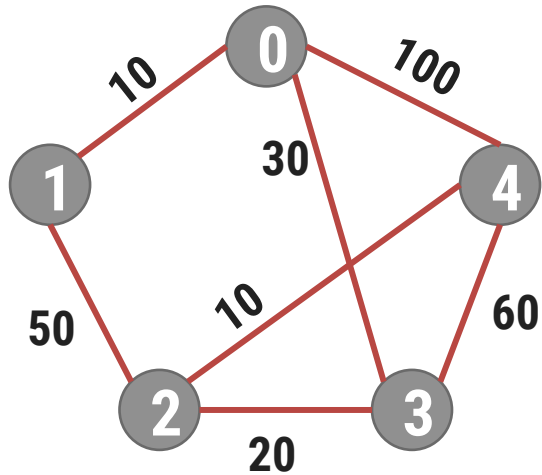
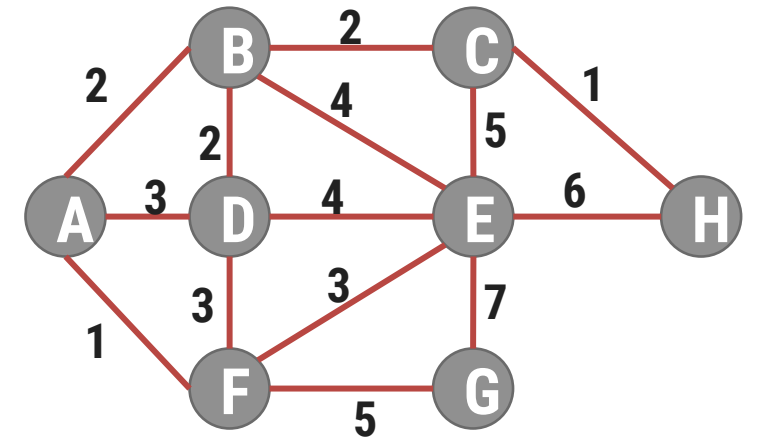
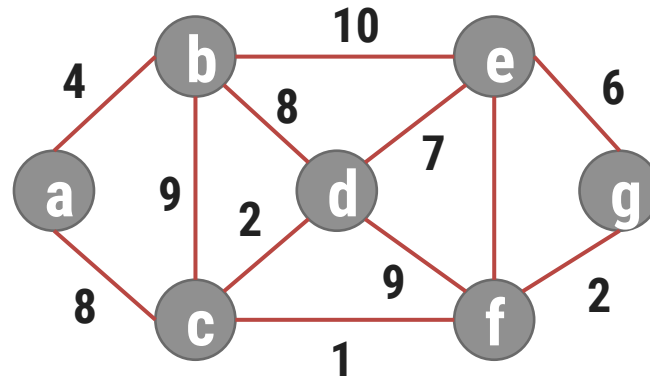
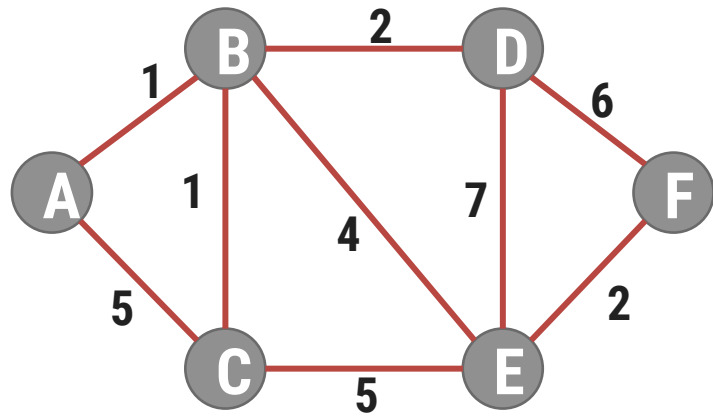


so we obtained minimum
spanning tree of cost:
 $4 + 2 + 1 + 3 = 10$

Construct Minimum Spanning Tree



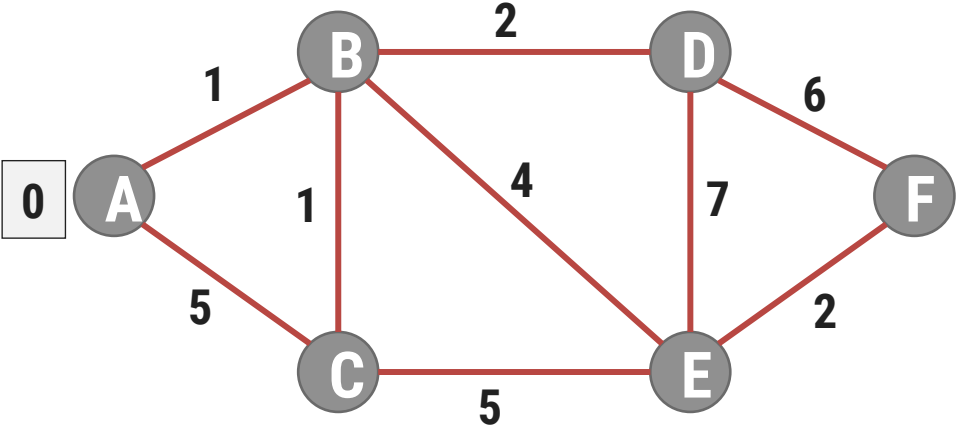
Draw minimum spanning tree using Prim's & Kruskal's algorithm



Shortest Path Algorithm

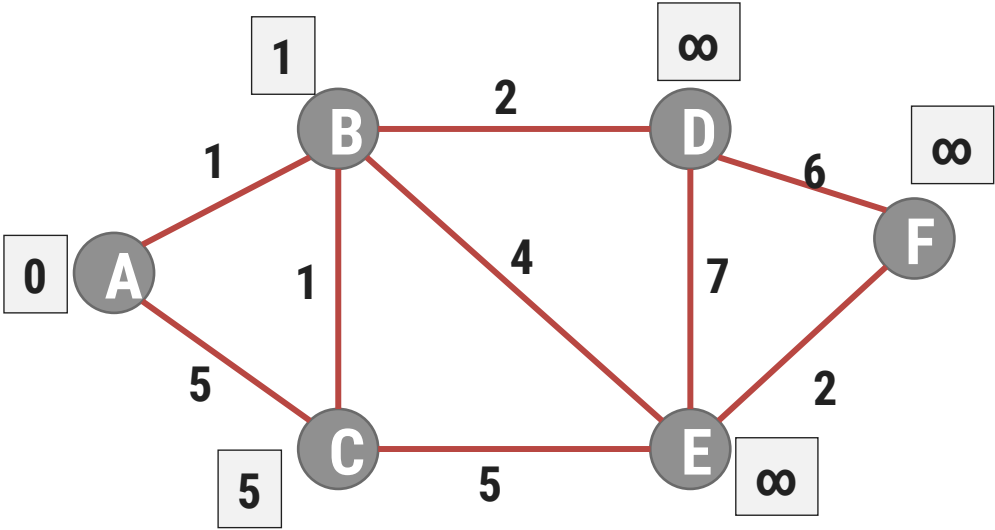
- ▶ Let $G = (V, E)$ be a simple diagraph with **n vertices**
- ▶ The problem is to **find out shortest distance** from a **vertex to all other vertices** of a graph
- ▶ **Dijkstra Algorithm** – it is also called Single Source Shortest Path Algorithm

Dijkstra Algorithm – Shortest Path



	A	B	C	D	E	F
Distance	0	∞	∞	∞	∞	∞
Visited	0	0	0	0	0	0

1st Iteration: Select **Vertex A** with minimum distance



	A	B	C	D	E	F
Distance	0	1	5	∞	∞	∞
Visited	1	0	0	0	0	0

Dijkstra Algorithm – Shortest Path

2nd Iteration: Select **Vertex B** with minimum distance

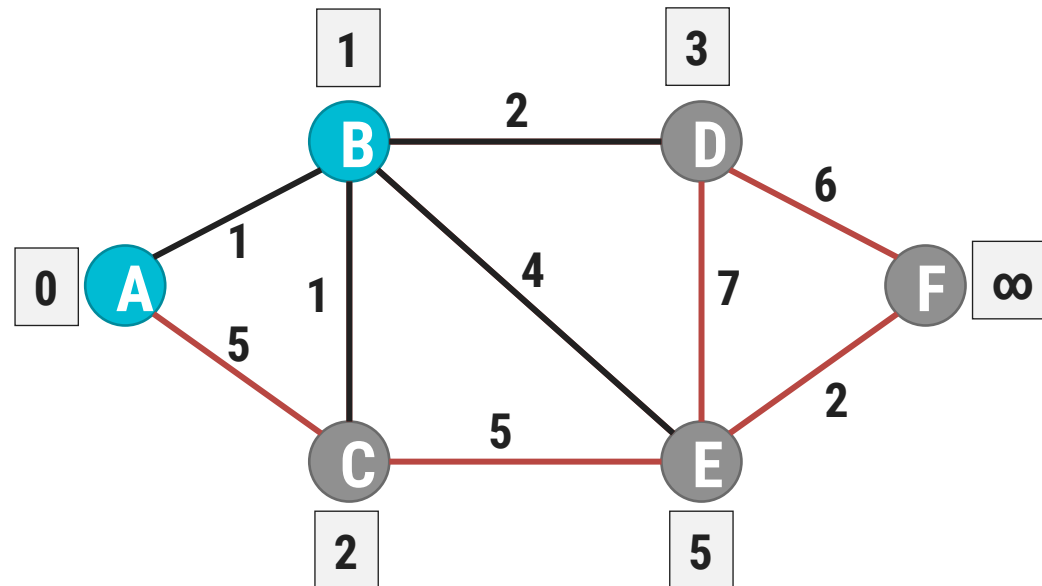
Cost of going to C via B = $\text{dist}[B] + \text{cost}[B][C] = 1 + 1 = 2$

Cost of going to D via B = $\text{dist}[B] + \text{cost}[B][D] = 1 + 2 = 3$

Cost of going to E via B = $\text{dist}[B] + \text{cost}[B][E] = 1 + 4 = 5$

Cost of going to F via B = $\text{dist}[B] + \text{cost}[B][F] = 1 + \infty = \infty$

	A	B	C	D	E	F
Distance	0	1	5	∞	∞	∞
Visited	1	0	0	0	0	0



	A	B	C	D	E	F
Distance	0	1	2	3	5	∞
Visited	1	1	0	0	0	0

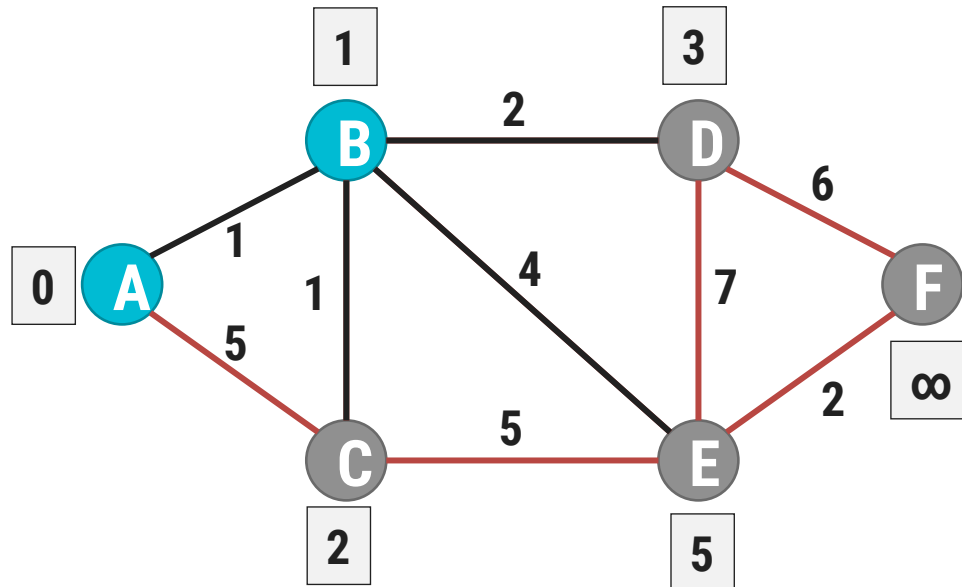
Dijkstra Algorithm – Shortest Path

3rd Iteration: Select **Vertex C** via B with minimum distance

Cost of going to D via C = $\text{dist}[C] + \text{cost}[C][D] = 2 + \infty = \infty$

Cost of going to E via C = $\text{dist}[C] + \text{cost}[C][E] = 2 + 5 = 7$

Cost of going to F via C = $\text{dist}[C] + \text{cost}[C][F] = 2 + \infty = \infty$



	A	B	C	D	E	F
Distance	0	1	2	3	5	∞
Visited	1	1	0	0	0	0

	A	B	C	D	E	F
Distance	0	1	2	3	5	∞
Visited	1	1	1	0	0	0

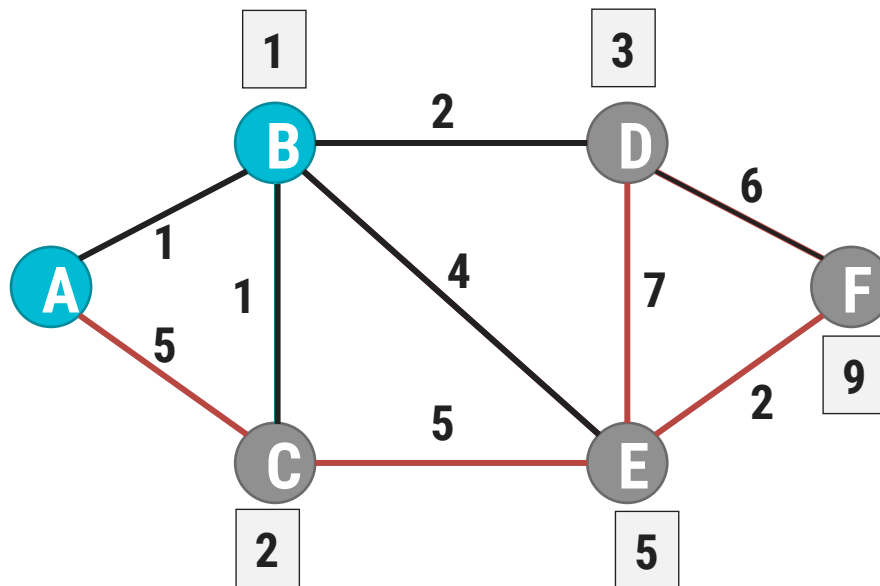
Dijkstra Algorithm – Shortest Path

4th Iteration: Select **Vertex D** via path A - B with minimum distance

Cost of going to E via D = $\text{dist}[D] + \text{cost}[D][E] = 3 + 7 = 10$

Cost of going to F via D = $\text{dist}[D] + \text{cost}[D][F] = 3 + 6 = 9$

	A	B	C	D	E	F
Distance	0	1	2	3	5	∞
Visited	1	1	1	0	0	0



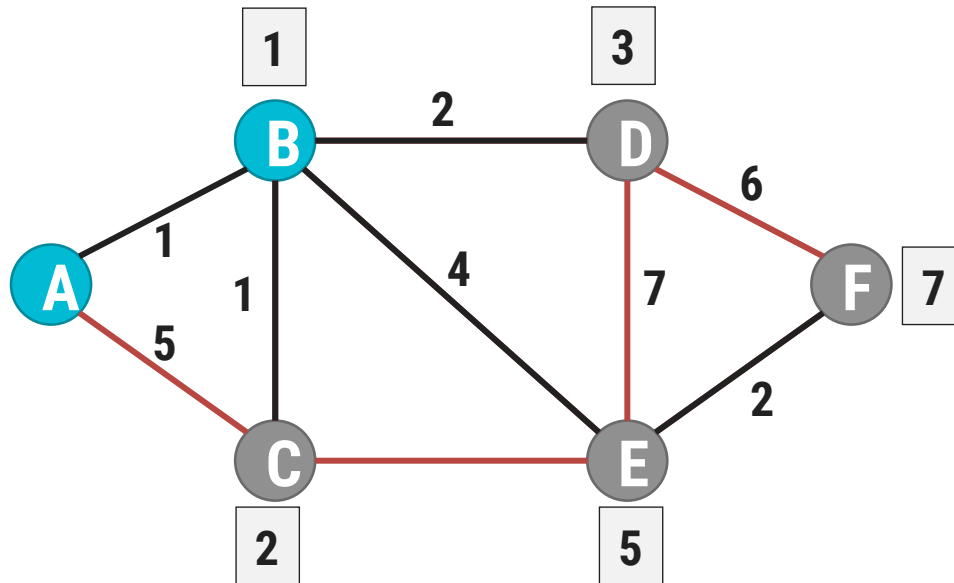
	A	B	C	D	E	F
Distance	0	1	2	3	5	9
Visited	1	1	1	1	0	0

Dijkstra Algorithm – Shortest Path

4th Iteration: Select **Vertex E** via path A – B – E with minimum distance

Cost of going to F via E = $\text{dist}[E] + \text{cost}[E][F] = 5 + 2 = 7$

	A	B	C	D	E	F
Distance	0	1	2	3	5	9
Visited	1	1	1	1	0	0



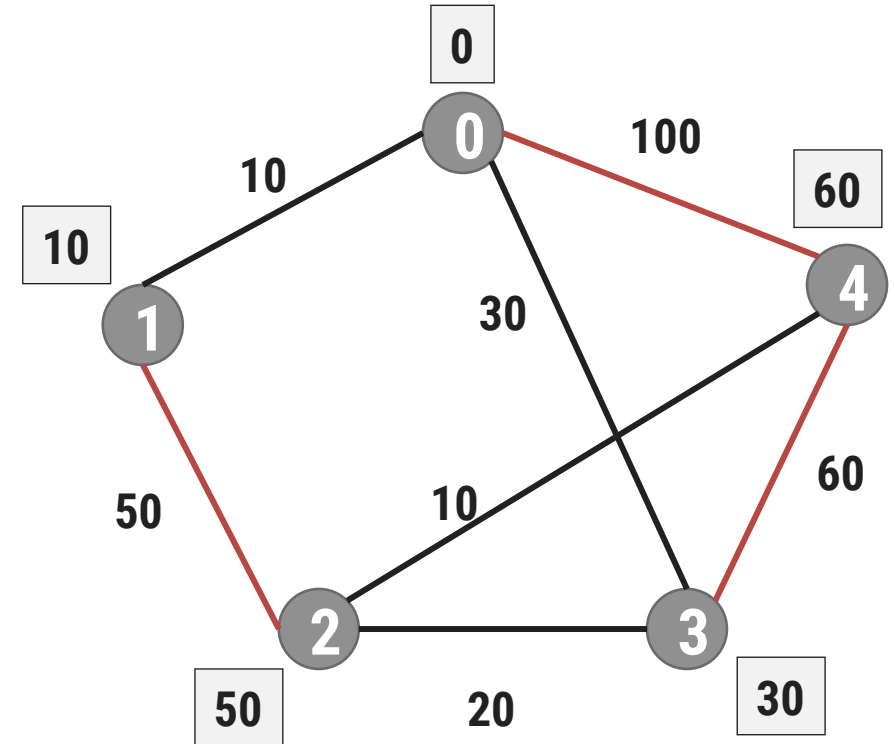
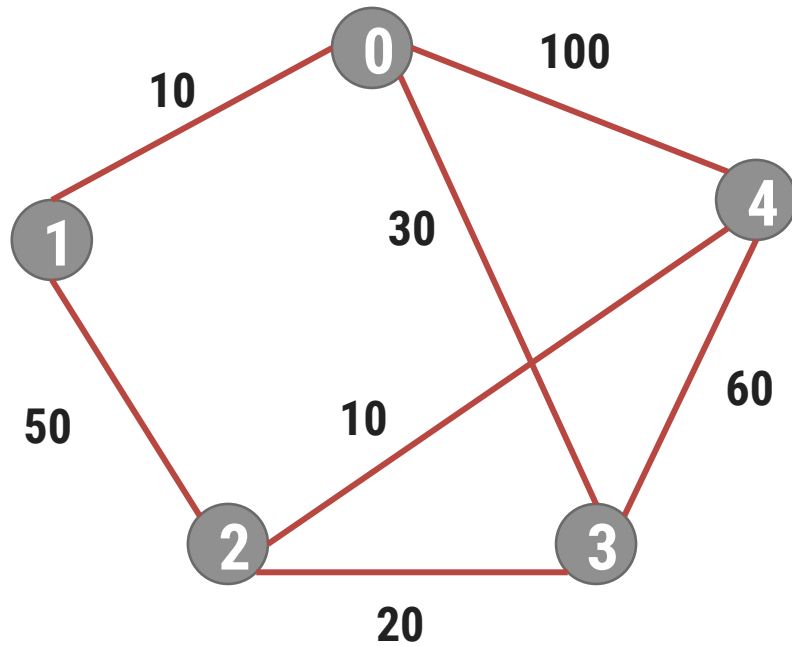
	A	B	C	D	E	F
Distance	0	1	2	3	5	7
Visited	1	1	1	1	1	0

Shortest Path from A to F is

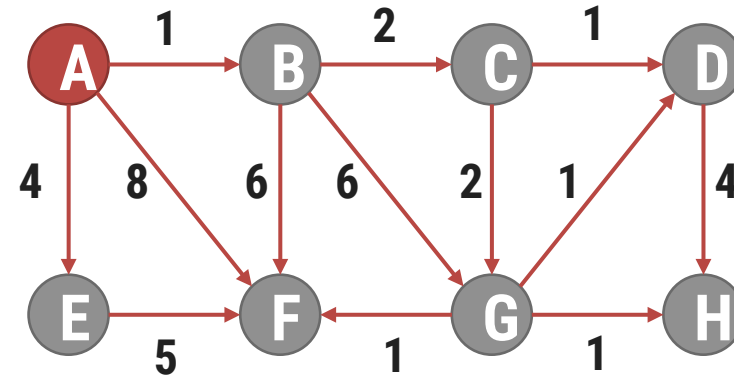
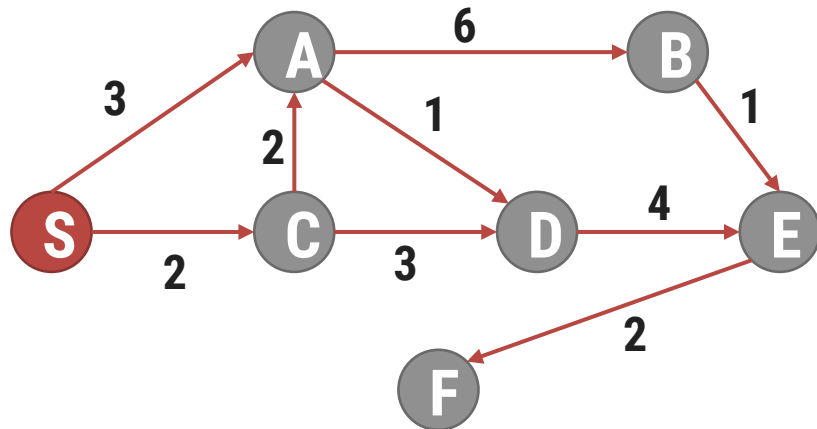
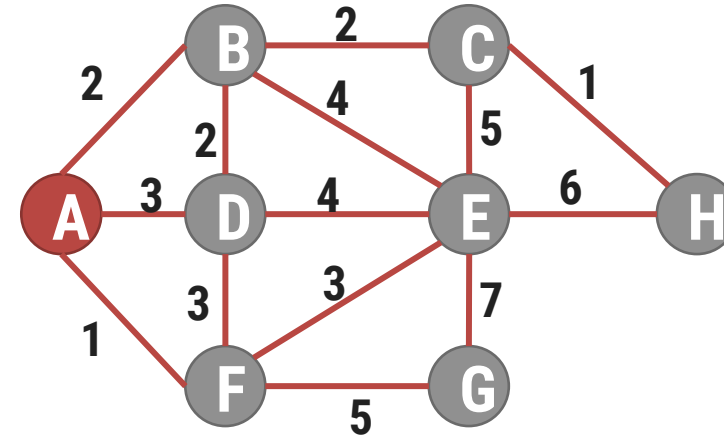
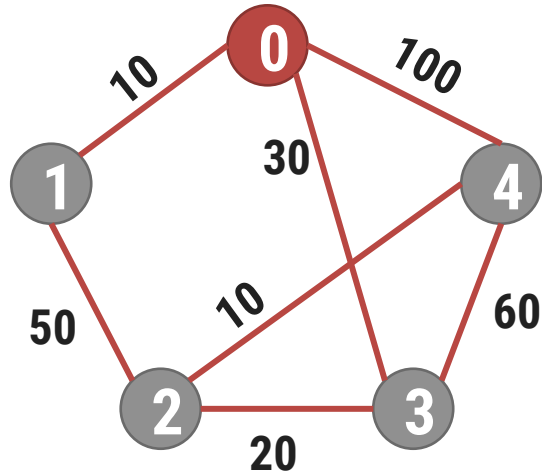
A → B → E → F = 7

Shortest Path

Find out shortest path from node 0 to all other nodes using Dijkstra Algorithm



Find shortest path between given nodes using Dijkstra's algorithm



***Thank
You***



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