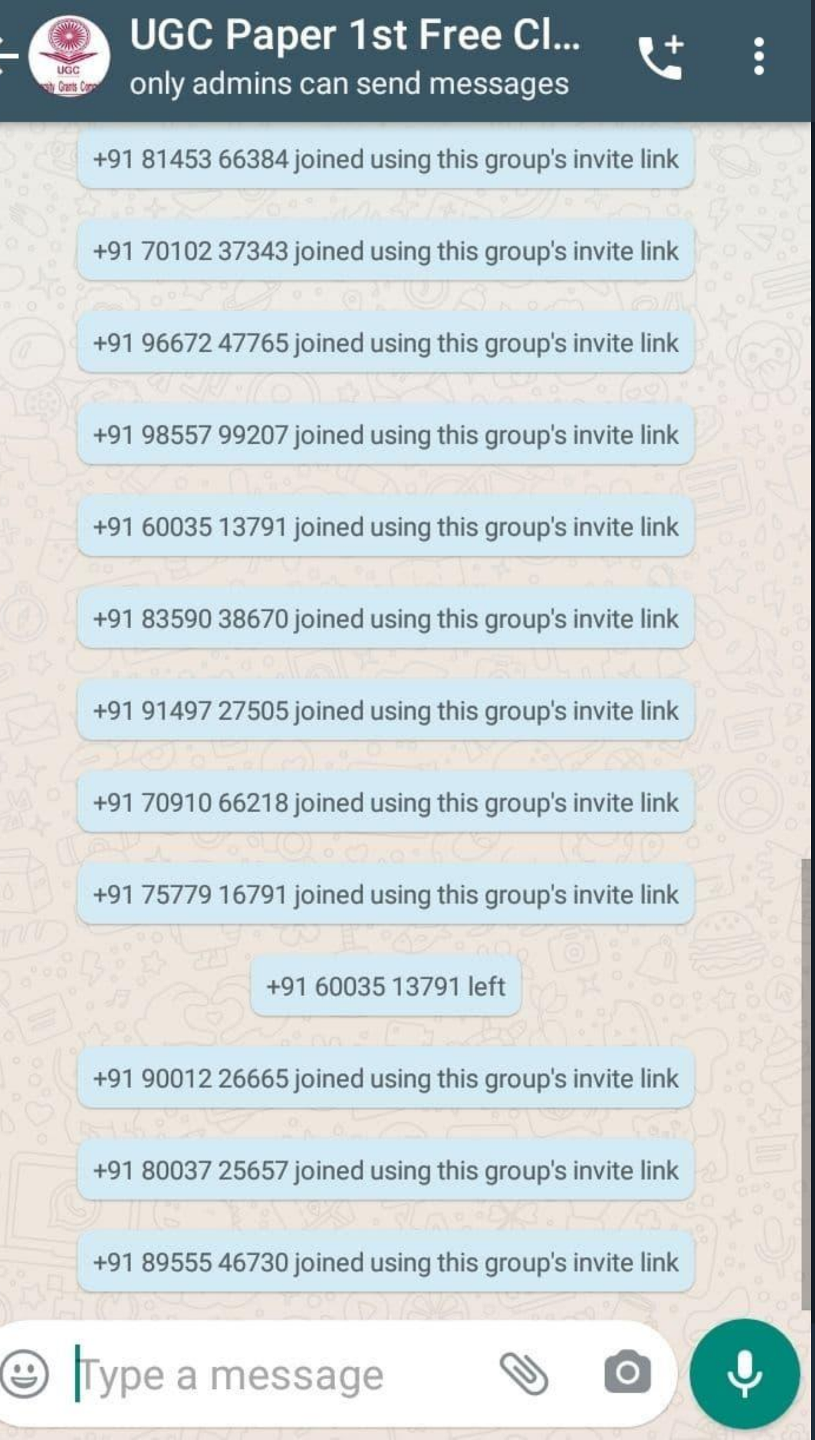
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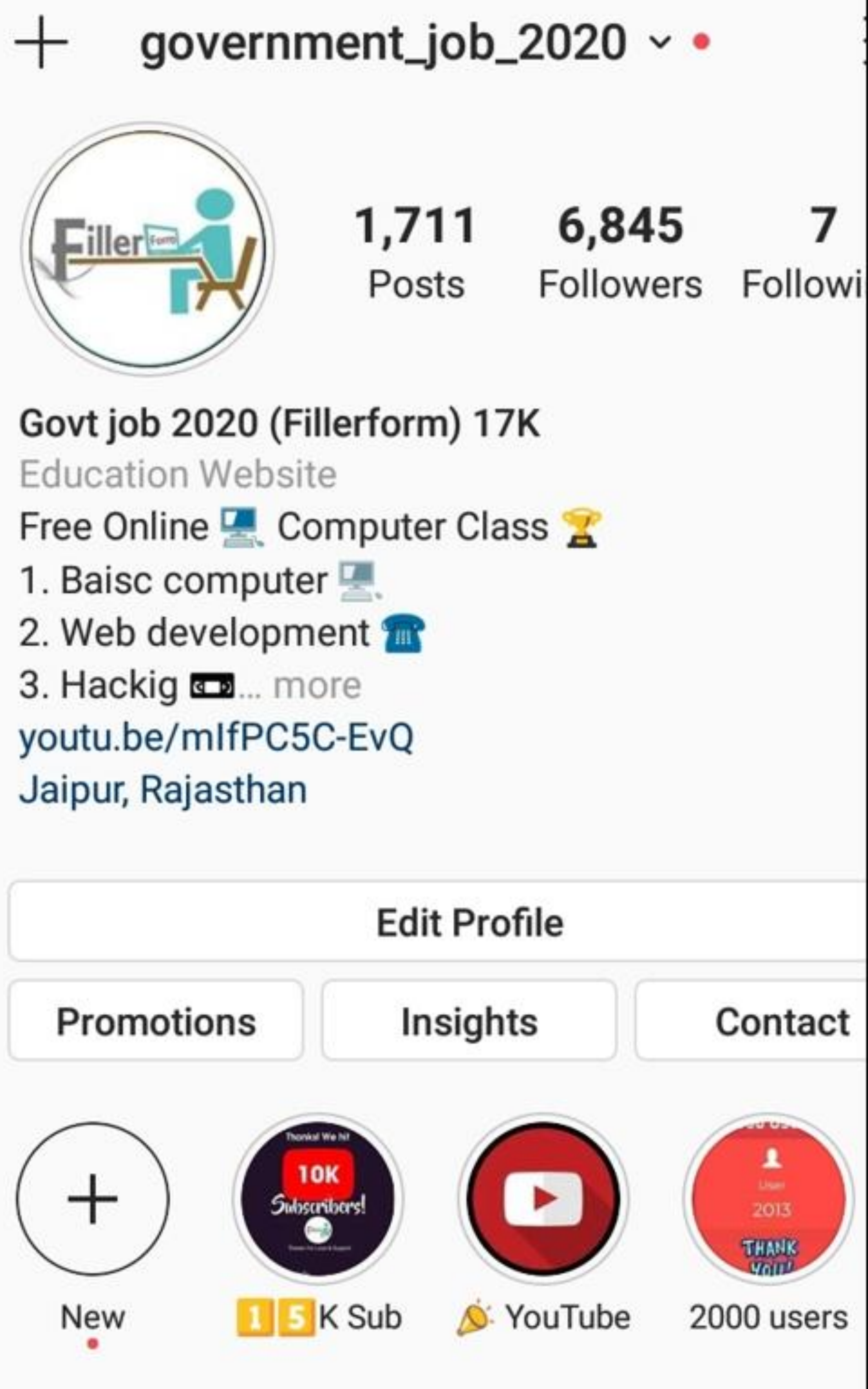
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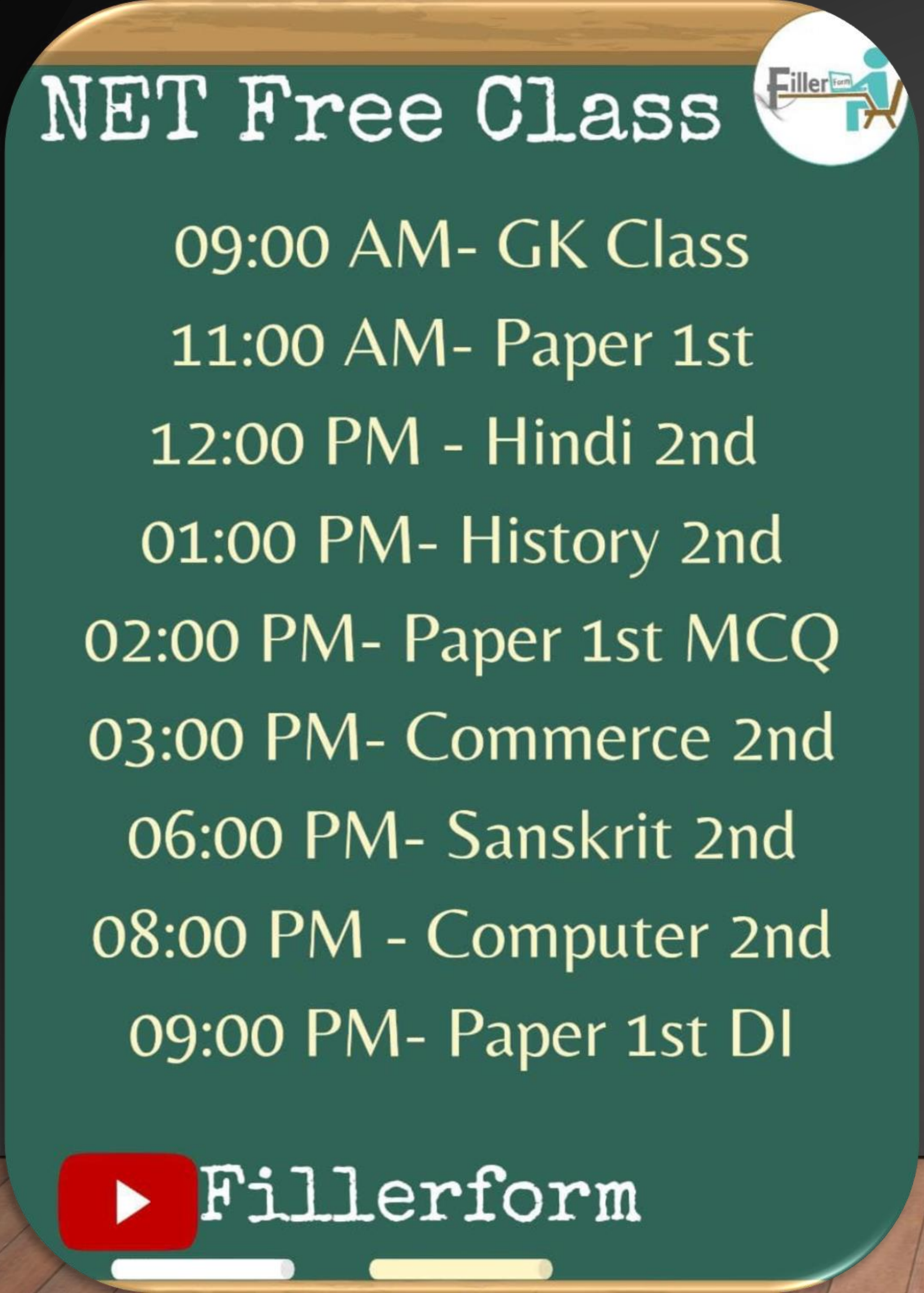
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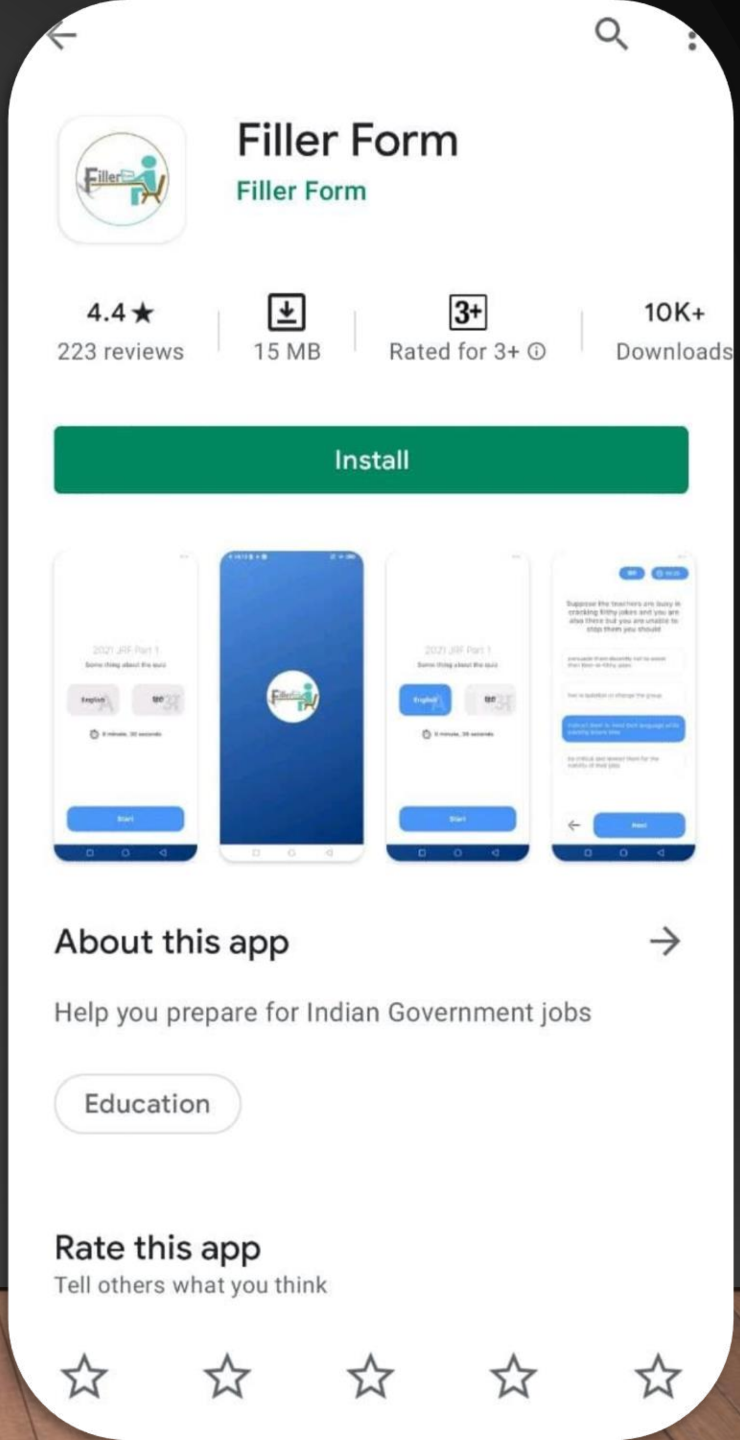
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# ❑ Discrete Structure and Optimization

## Content:

1) Graph Theory (Part 1)

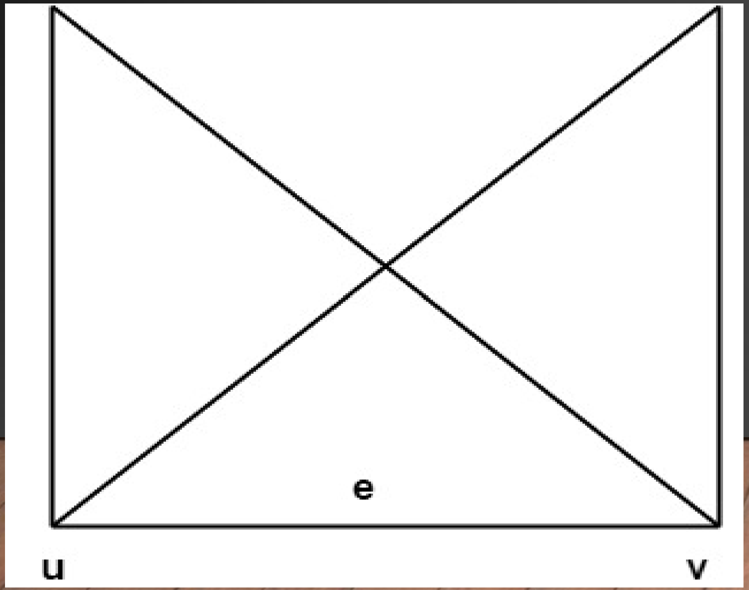
# Graph:

Graph G consists of two things:

1. A set V=V(G) whose elements are called vertices, points or nodes of G.

2. A set E = E(G) of an unordered pair of distinct vertices called edges of G.

3. We denote such a graph by G(V, E) vertices u and v are said to be adjacent if there is an edge e ={u, v}.




4. In such a case u and v are called the endpoint of e={u, v} and e are said to connect u and v.

# Point

**A point** is a particular position in a one-dimensional, two-dimensional, or three-dimensional space. For better understanding, a point can be denoted by an alphabet. It can be represented with a dot.

## Example


# Line

A **Line** is a connection between two points. It can be represented with a solid line.

**Example**


Here, ‘a’ and ‘b’ are the points. The link between these two points is called a line.

## Vertex

A vertex is a point where multiple lines meet. It is also called a **node**. Similar to points, a vertex is also denoted by an alphabet.

**Example**


Here, the vertex is named with an alphabet ‘a’.

## Edge

An edge is the mathematical term for a line that connects two vertices. Many edges can be formed from a single vertex. Without a vertex, an edge cannot be formed. There must be a starting vertex and an ending vertex for an edge.

**Example**

# Graph

A graph 'G' is defined as G = (V, E) Where V is a set of all vertices and E is a set of all edges in the graph.

**Example 1**


In the above example, ab, ac, cd, and bd are the edges of the graph. Similarly, a, b, c, and d are the vertices of the graph.

# Loop

In a graph, if an edge is drawn from vertex to itself, it is called a loop.

**Example 1**


In the above graph, V is a vertex for which it has an edge (V, V) forming a loop.

**Example 2**


In this graph, there are two loops which are formed at vertex a, and vertex b.

## Pendent Vertex

By using degree of a vertex, we have a two special types of vertices. A vertex with degree one is called a pendent vertex.

**Example**


## Isolated Vertex

A vertex with degree zero is called an isolated vertex.

**Example**

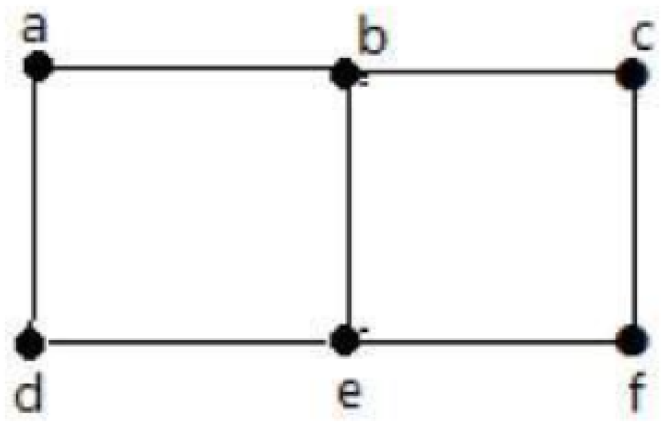

Here, the vertex 'a' and vertex 'b' has a no connectivity between each other and also to any other vertices. So the degree of both the vertices 'a' and 'b' are zero. These are also called as isolated vertices.

# Adjacency

Here are the norms of adjacency –

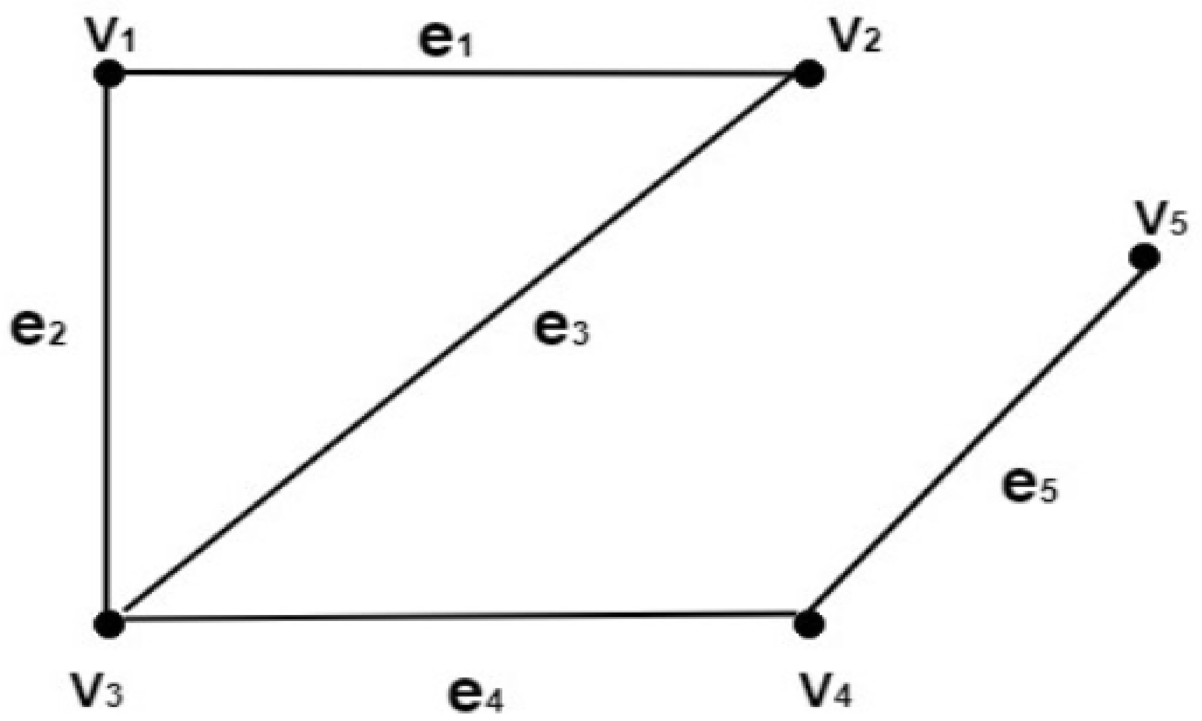
- In a graph, two vertices are said to be **adjacent**, if there is an edge between the two vertices. Here, the adjacency of vertices is maintained by the single edge that is connecting those two vertices.
- In a graph, two edges are said to be adjacent, if there is a common vertex between the two edges. Here, the adjacency of edges is maintained by the single vertex that is connecting two edges.

**Example 1**

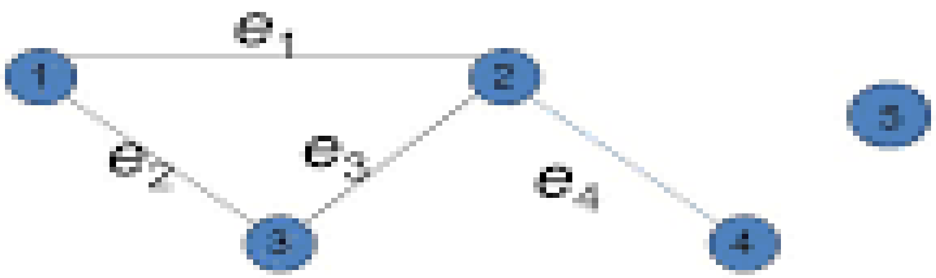


**Adjacent Vertices:** Two vertices are called adjacent if an edge links them. If there is an edge (u, v), then we can say vertex u is adjacent to vertex v, and vertex v is adjacent to vertex u.

**Example:** Consider the graph as shown in fig:



# Adjacent Vertices




1 is adjacent to 2 and 3
2 is adjacent to 1, 3, and 4
3 is adjacent to 1 and 2
4 is adjacent to 2
5 is not adjacent to any vertex

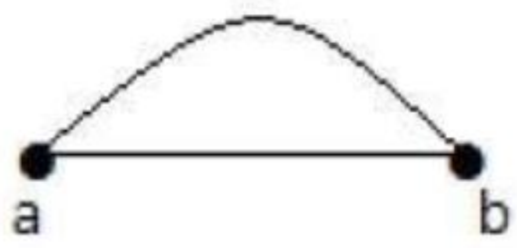
In graph a vertex is not adjacent to another vertex is called an isolated vertex.

In the above graph –

- ‘a’ and ‘b’ are the adjacent vertices, as there is a common edge ‘ab’ between them.
- ‘a’ and ‘d’ are the adjacent vertices, as there is a common edge ‘ad’ between them.
- ab’ and ‘be’ are the adjacent edges, as there is a common vertex ‘b’ between them.
- be’ and ‘de’ are the adjacent edges, as there is a common vertex ‘e’ between them.

## Parallel Edges

In a graph, if a pair of vertices is connected by more than one edge, then those edges are called parallel edges.

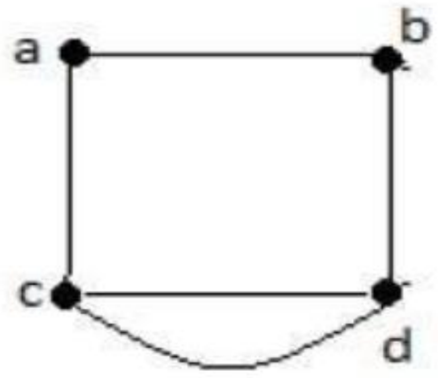



In the above graph, ‘a’ and ‘b’ are the two vertices which are connected by two edges ‘ab’ and ‘ab’ between them. So it is called as a parallel edge.

## Multi Graph

A graph having parallel edges is known as a Multigraph.

**Example 1**




In the above graph, there are five edges ‘ab’, ‘ac’, ‘cd’, ‘cd’, and ‘bd’. Since ‘c’ and ‘d’ have two parallel edges between them, it a Multigraph.

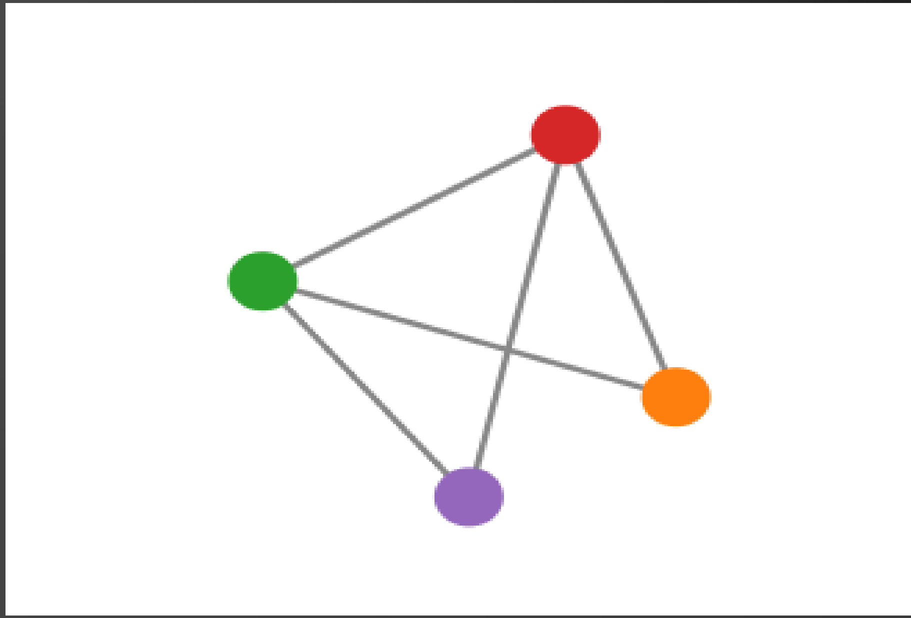
# Order and Size of a Graph

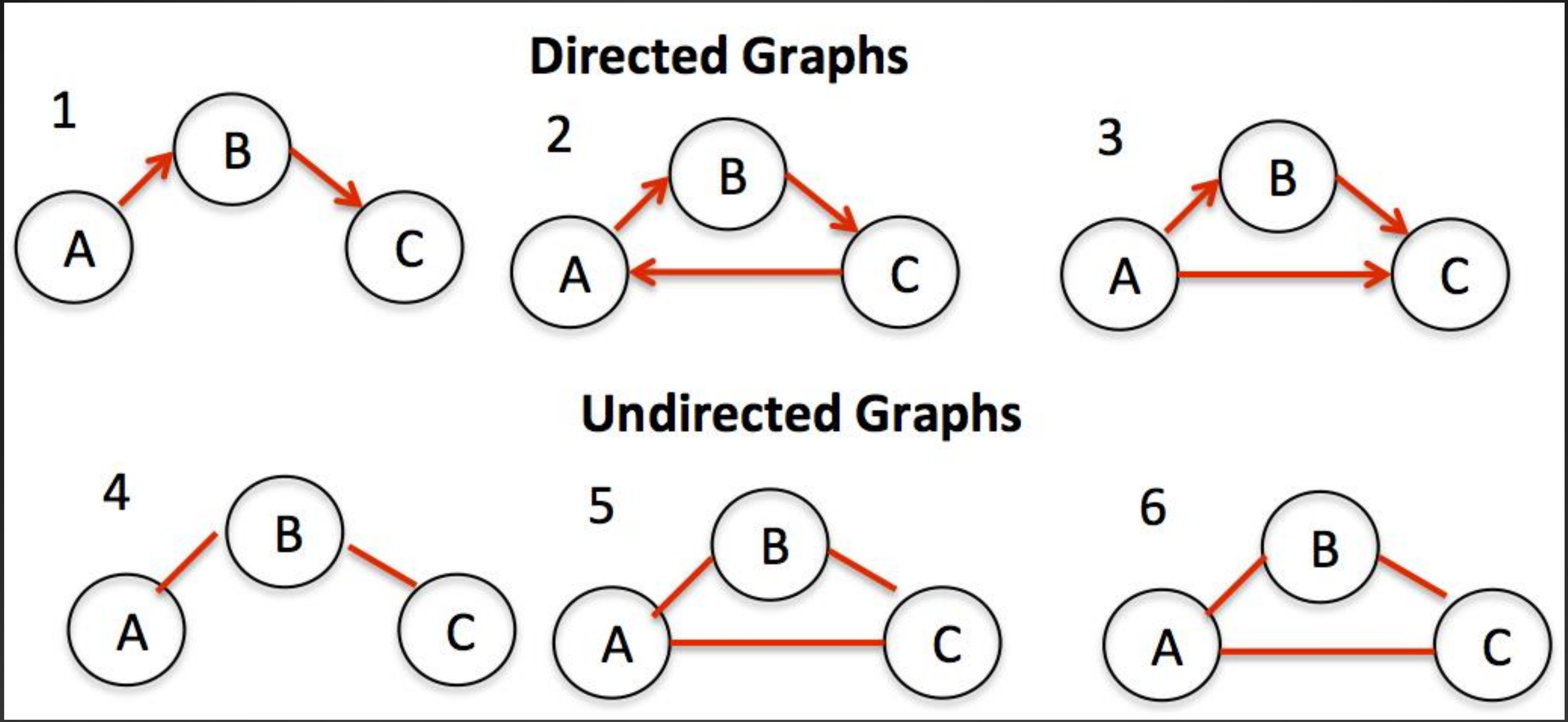
**Order** of a graph is the number of vertices in the graph.

**Size** of a graph is the number of edges in the graph.

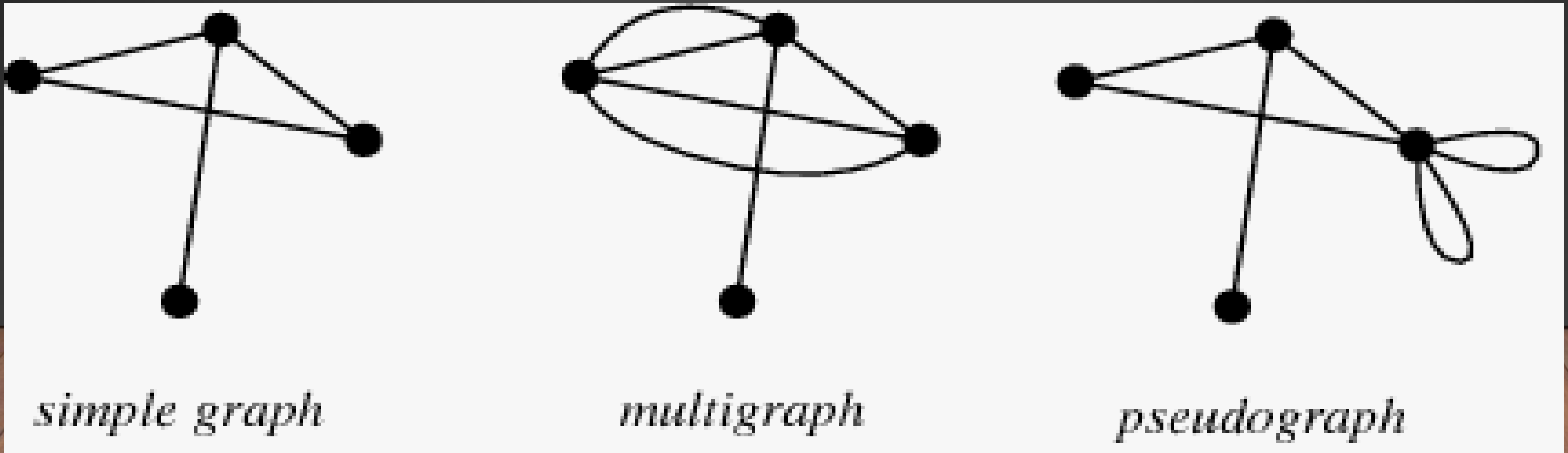
$$\text{Order} = 4$$

$$\text{Size} = 5$$




Directed Graphs
1
A
B
C
2
A
B
C
3
A
B
C
Undirected Graphs
4
A
B
C
5
A
B
C
6
A
B
C

| Graph name | SELF LOOP | MULTIPLE EDGE | PARALLEL |
|---|---|---|---|
| SIMPLE GRAPH | ✗ | ✗ | ✗ |
| MULTI GRAPH | ✗ | ✓ | ✓ |
| PSEUDOGRAPH | ✓ | ✓ | |



# Degree of Vertex

It is the number of vertices adjacent to a vertex V.

**Notation** – deg(V).

In a simple graph with n number of vertices, the degree of any vertices is –

$\deg(v) \leq n - 1 \ \forall \ v \in G$

A vertex can form an edge with all other vertices except by itself. So the degree of a vertex will be up to the **number of vertices in the graph minus 1**. This 1 is for the self-vertex as it cannot form a loop by itself. If there is a loop at any of the vertices, then it is not a Simple Graph.

Degree of vertex can be considered under two cases of graphs –

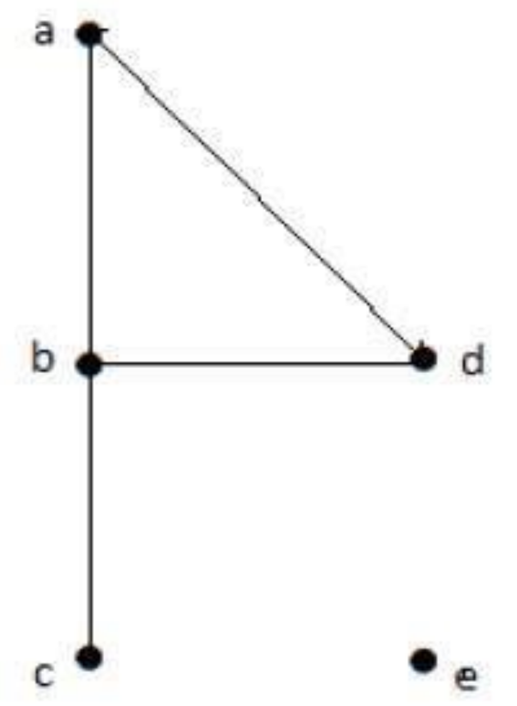
- Undirected Graph
- Directed Graph

# Degree of Vertex in an Undirected Graph

An undirected graph has no directed edges. Consider the following examples.

In the above Undirected Graph,

- deg(a) = 2, as there are 2 edges meeting at vertex ‘a’.
- deg(b) = 3, as there are 3 edges meeting at vertex ‘b’.
- deg(c) = 1, as there is 1 edge formed at vertex ‘c’
- So ‘c’ is a **pendent vertex**.
- deg(d) = 2, as there are 2 edges meeting at vertex ‘d’.
- deg(e) = 0, as there are 0 edges formed at vertex ‘e’.
- So ‘e’ is an **isolated vertex**.



# Degree of Vertex in a Directed Graph

In a directed graph, each vertex has an **indegree** and an **outdegree**.

## Indegree of a Graph

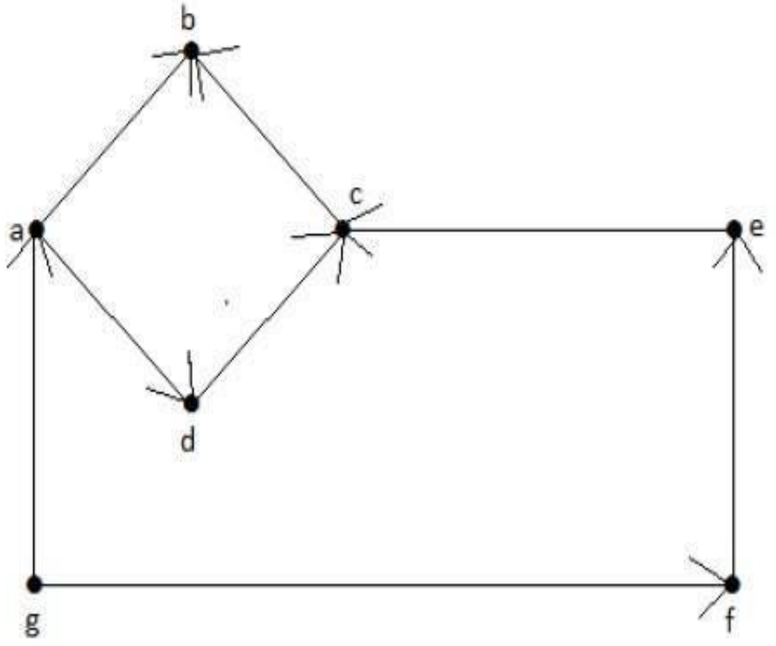
- Indegree of vertex V is the number of edges which are coming into the vertex V.
- **Notation** − deg−(V).

## Outdegree of a Graph

- Outdegree of vertex V is the number of edges which are going out from the vertex V.
- **Notation** − deg+(V).

## Example 1

Take a look at the following directed graph. Vertex 'a' has two edges, 'ad' and 'ab', which are going outwards. Hence its outdegree is 2. Similarly, there is an edge 'ga', coming towards vertex 'a'. Hence the indegree of 'a' is 1.



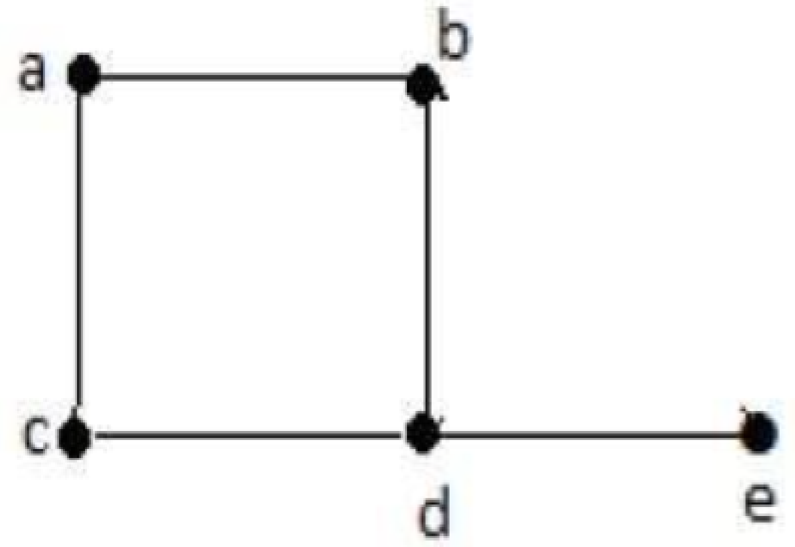

The indegree and outdegree of other vertices are shown in the following table −

| Vertex | Indegree | Outdegree |
|---|---|---|
| a | 1 | 2 |
| b | 2 | 0 |
| c | 2 | 1 |
| d | 1 | 1 |
| e | 1 | 1 |
| f | 1 | 1 |
| g | 0 | 2 |

# Degree Sequence of a Graph

If the degrees of all vertices in a graph are arranged in descending or ascending order, then the sequence obtained is known as the degree sequence of the graph.

**Example 1**




| **Vertex** | A | b | c | d | e |
|---|---|---|---|---|---|
| **Connecting to** | b,c | a,d | a,d | c,b,e | d |
| **Degree** | 2 | 2 | 2 | 3 | 1 |

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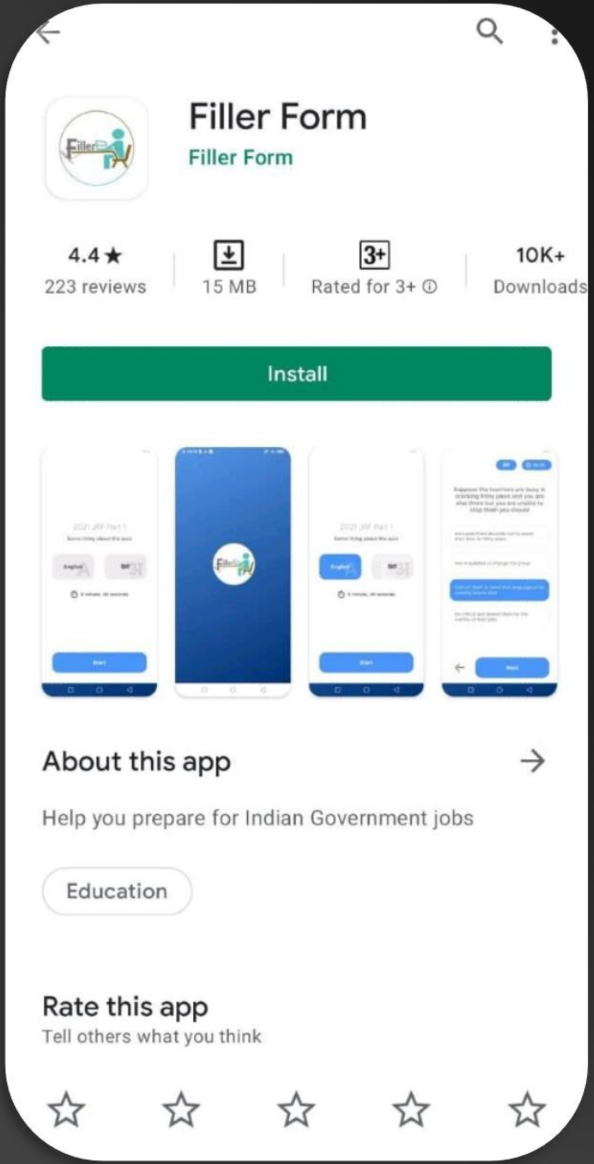


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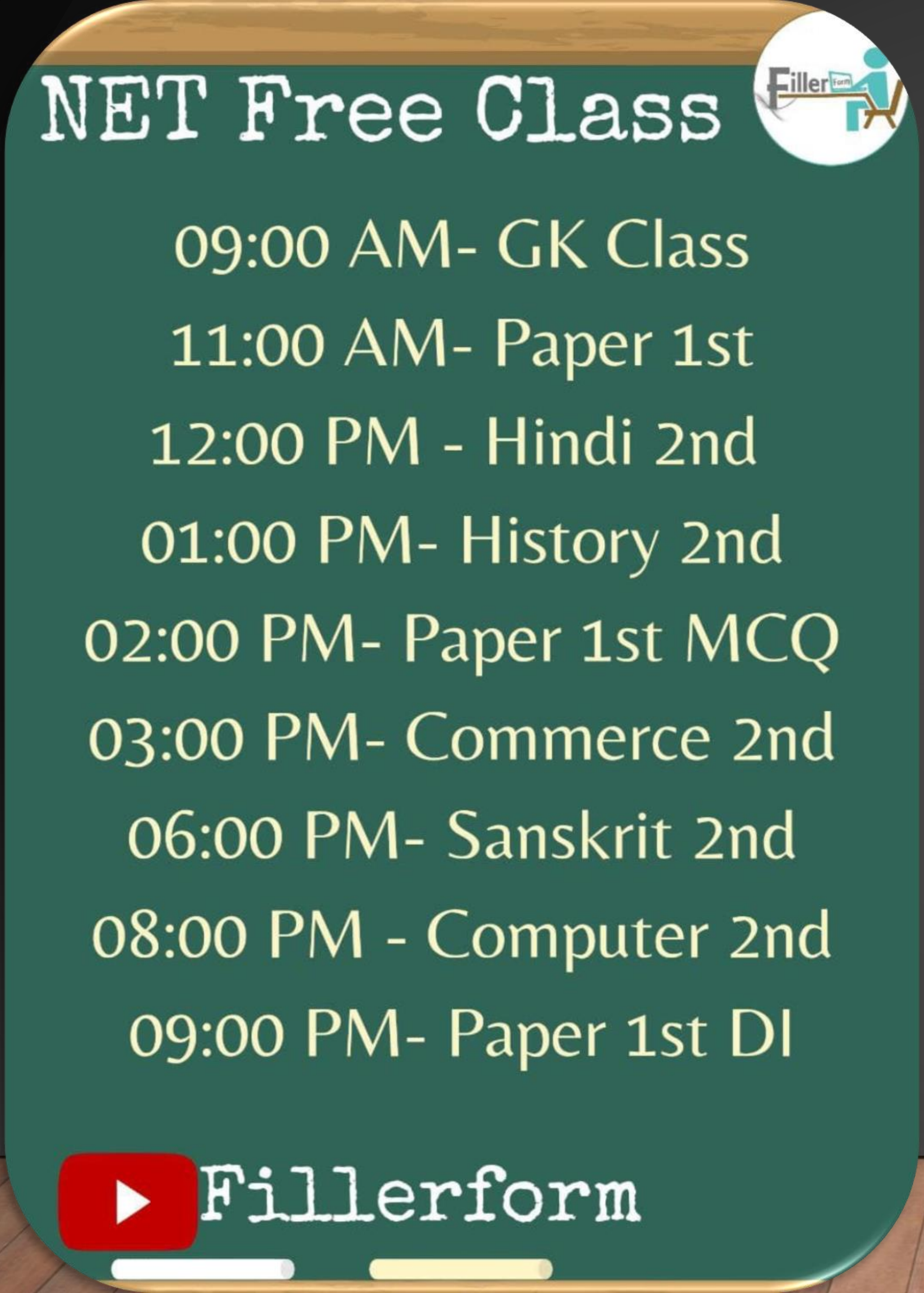
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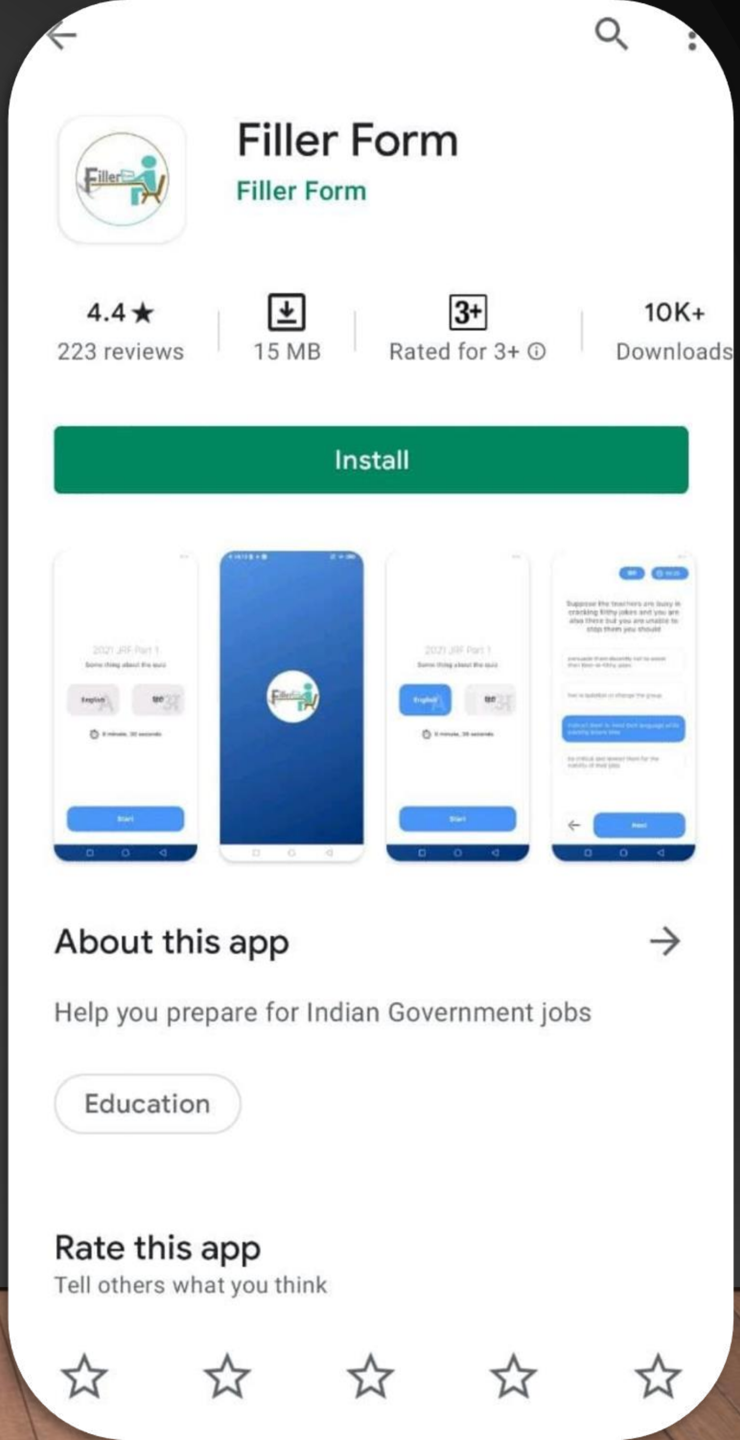
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