



Data Structure & Algorithms

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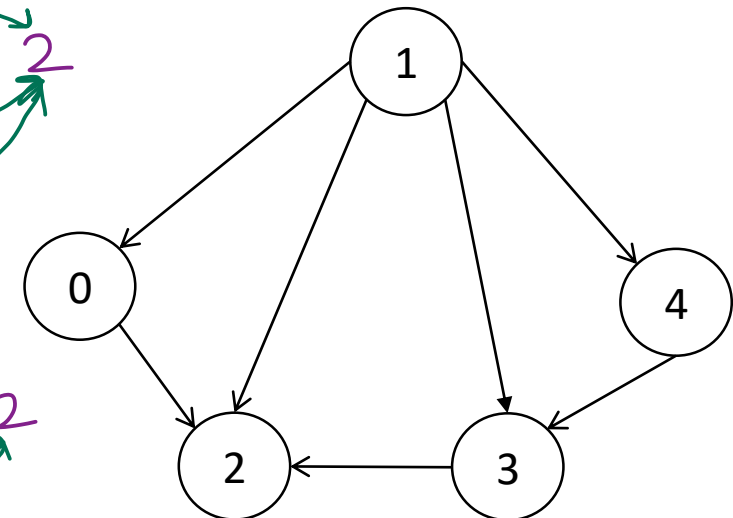
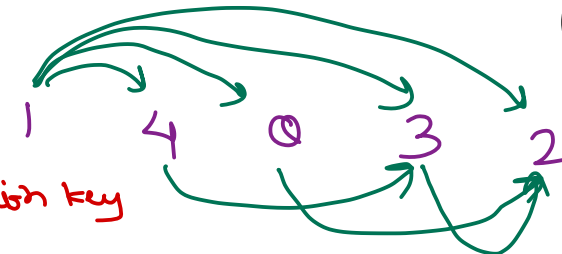
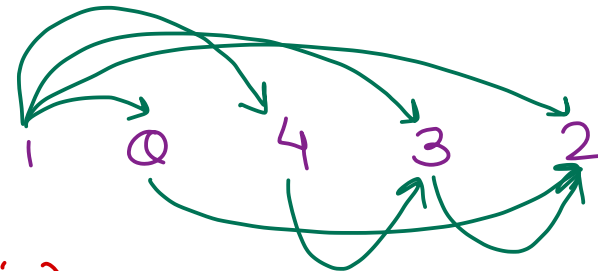
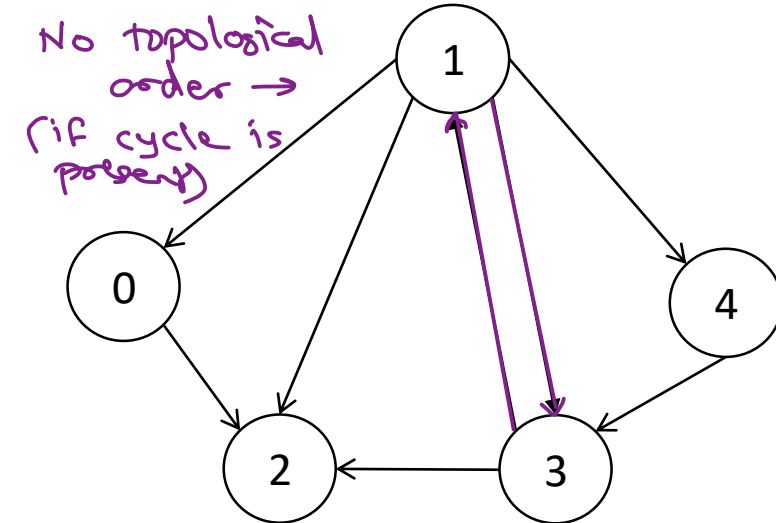
Topological sort / order

- Topological order is linear ordering of graph vertices such that for every directed edge $u \rightarrow v$, vertex u comes before vertex v .
- It is possible only for DAG.
- Directed Acyclic Graph
 - Edges have directions
 - Graph have no cycles
- Widely used in
 - Job scheduling
 - Instructions re-ordering → CPU arch - RISC (Pipeline optimization)
 - Resolving symbols while linking → compiler/linker design.
 - Building components
 - Data serialization
 - Database backup & restore (FK) → pri key & Foreign key

Big Data frameworks
tez, Spark, Pig, Airflow ← DAG

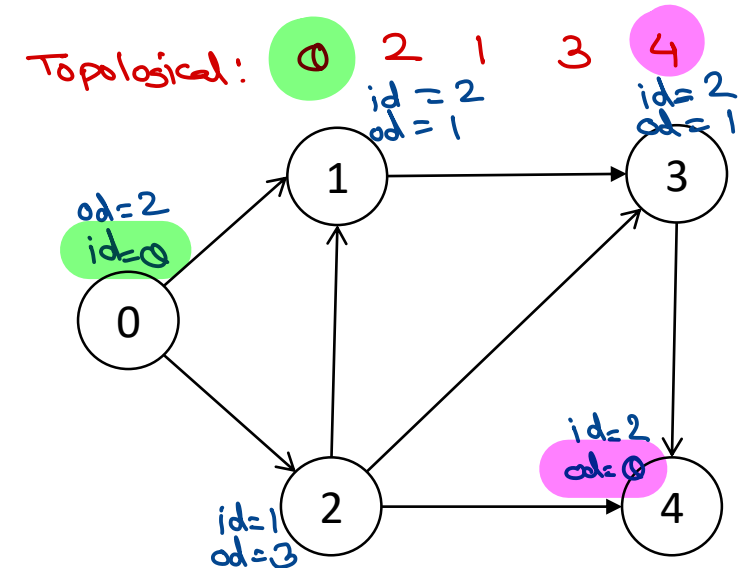
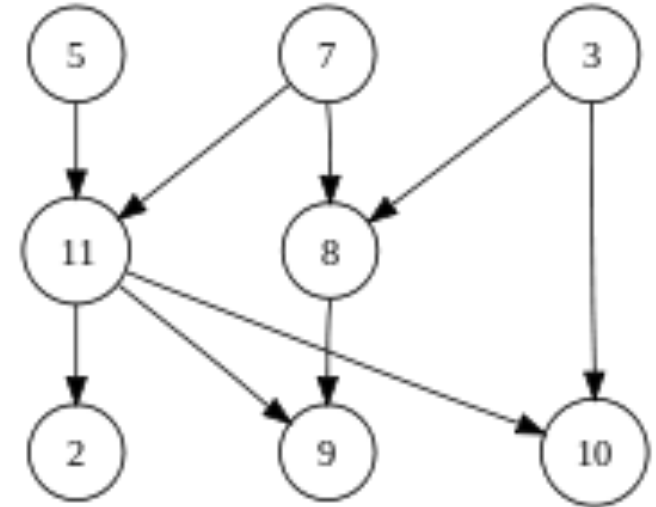
Topological:

Topological:



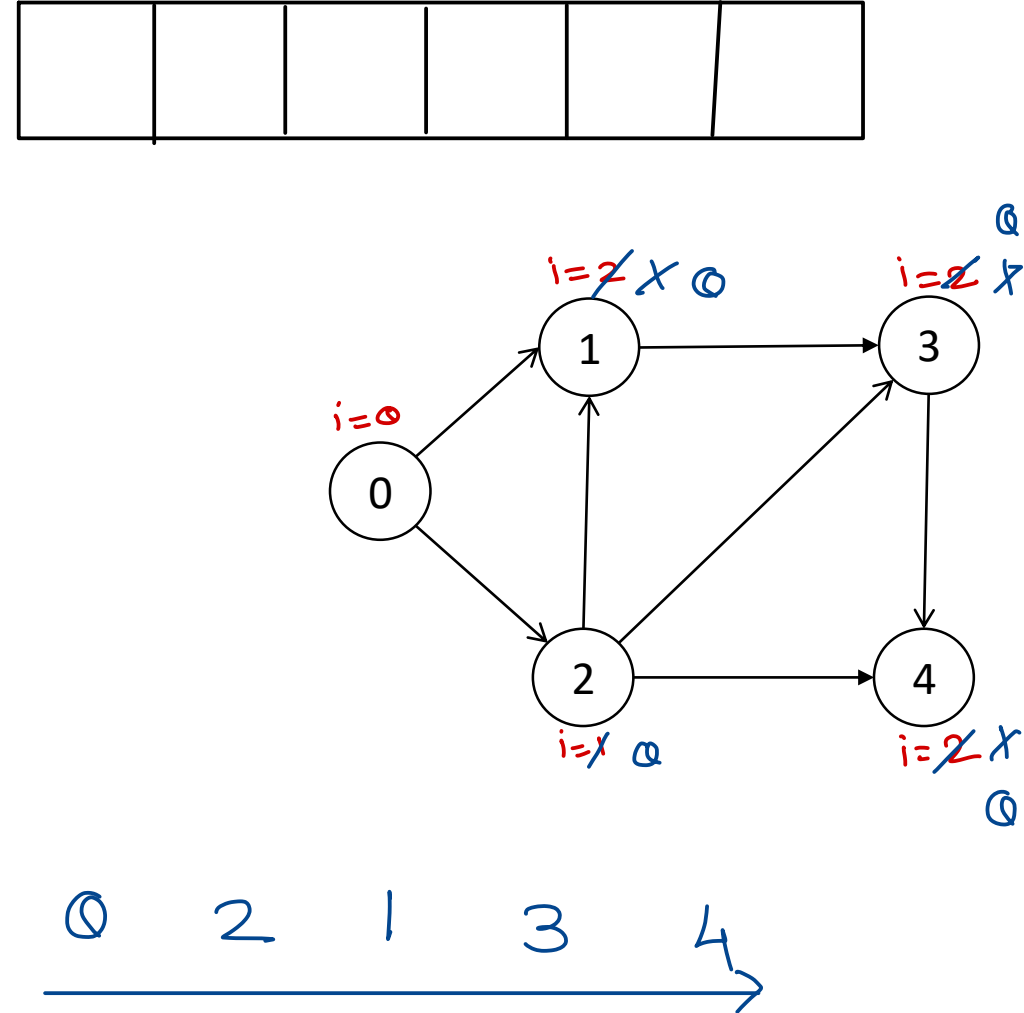
Topological order

- A graph may have multiple topological orders.
 - 5, 7, 3, 11, 8, 2, 9, 10 (visual left-to-right, top-to-bottom)
 - 3, 5, 7, 8, 11, 2, 9, 10 (smallest-numbered available vertex first)
 - 5, 7, 3, 8, 11, 10, 9, 2 (fewest edges first)
 - 7, 5, 11, 3, 10, 8, 9, 2 (largest-numbered available vertex first)
 - 5, 7, 11, 2, 3, 8, 9, 10 (attempting top-to-bottom, left-to-right)
 - 3, 7, 8, 5, 11, 10, 2, 9 (arbitrary)
- Few graphs may have single topological order.
- DAG properties
 - Each DAG will have at least one vertex with out-degree 0. ← end.
 - Each DAG will have at least one vertex with in-degree 0. ← start.
- Topological order algorithms
 - DFS based algorithm
 - ✓ Kahn's algorithm



Topological order

- Kahn's algorithm
 - Calculate in-degree of all vertices in the graph.
 - Push all vertices with in-degree 0 on a queue.
 - Until queue is empty
 - Pop a vertex from the queue.
 - Add it into topological order
 - Decrement in-degree of each adjacent vertex.
 - If adjacent vertex in-degree become 0, push it on the queue.
 - If number of vertices in topological order is not same as number of vertices, topological order is not possible.



Graph applications

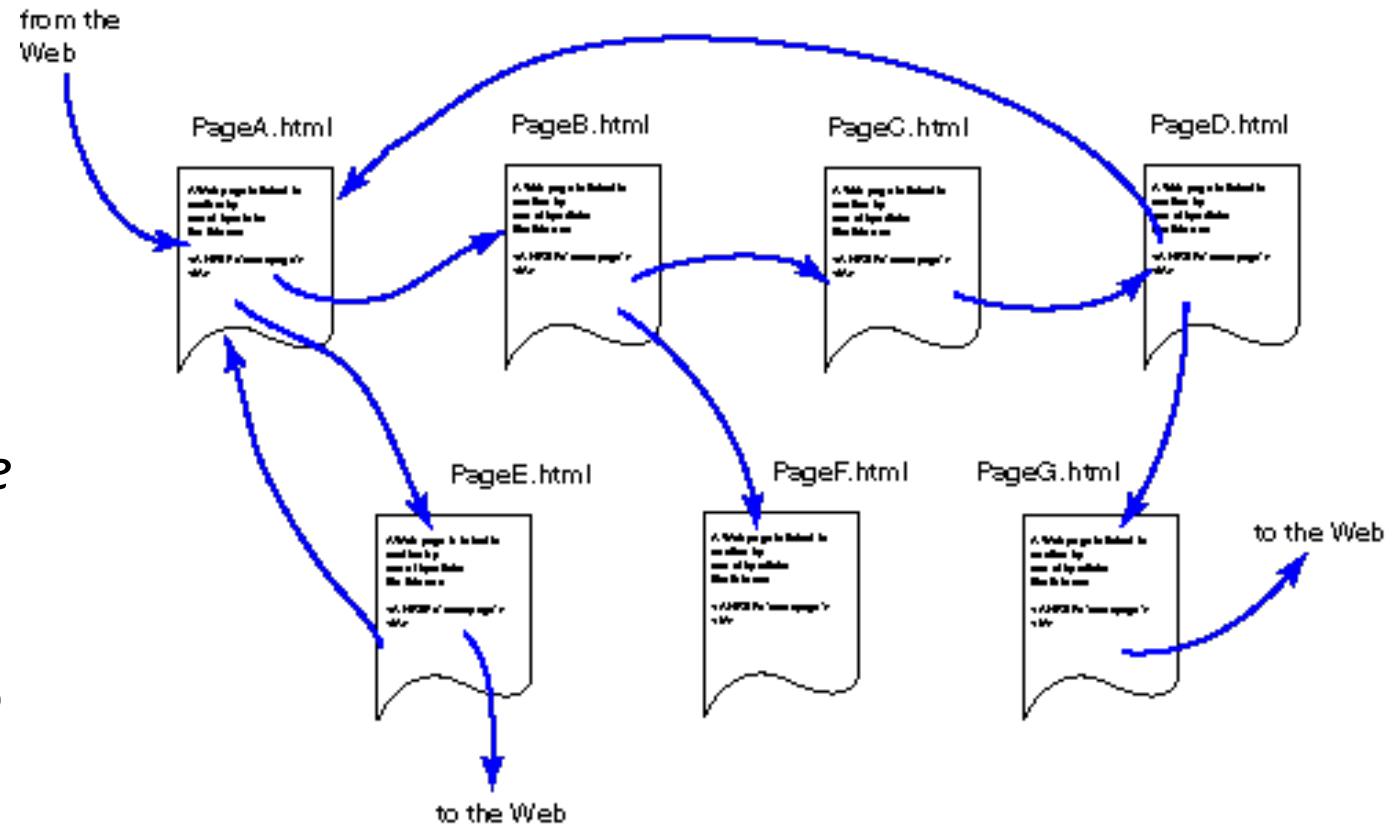
- Graph represents flow of computation/tasks. It is used for resource planning and scheduling. MST algorithms are used for resource conservation. DAG are used for scheduling in Spark or Tez.
- In OS, process and resources are treated as vertices and their usage is treated as edges. This resource allocation algorithm is used to detect deadlock.
- In social networking sites, each person is a vertex and their connection is an edge. In Facebook person search or friend suggestion algorithms use graph concepts.



Graph applications

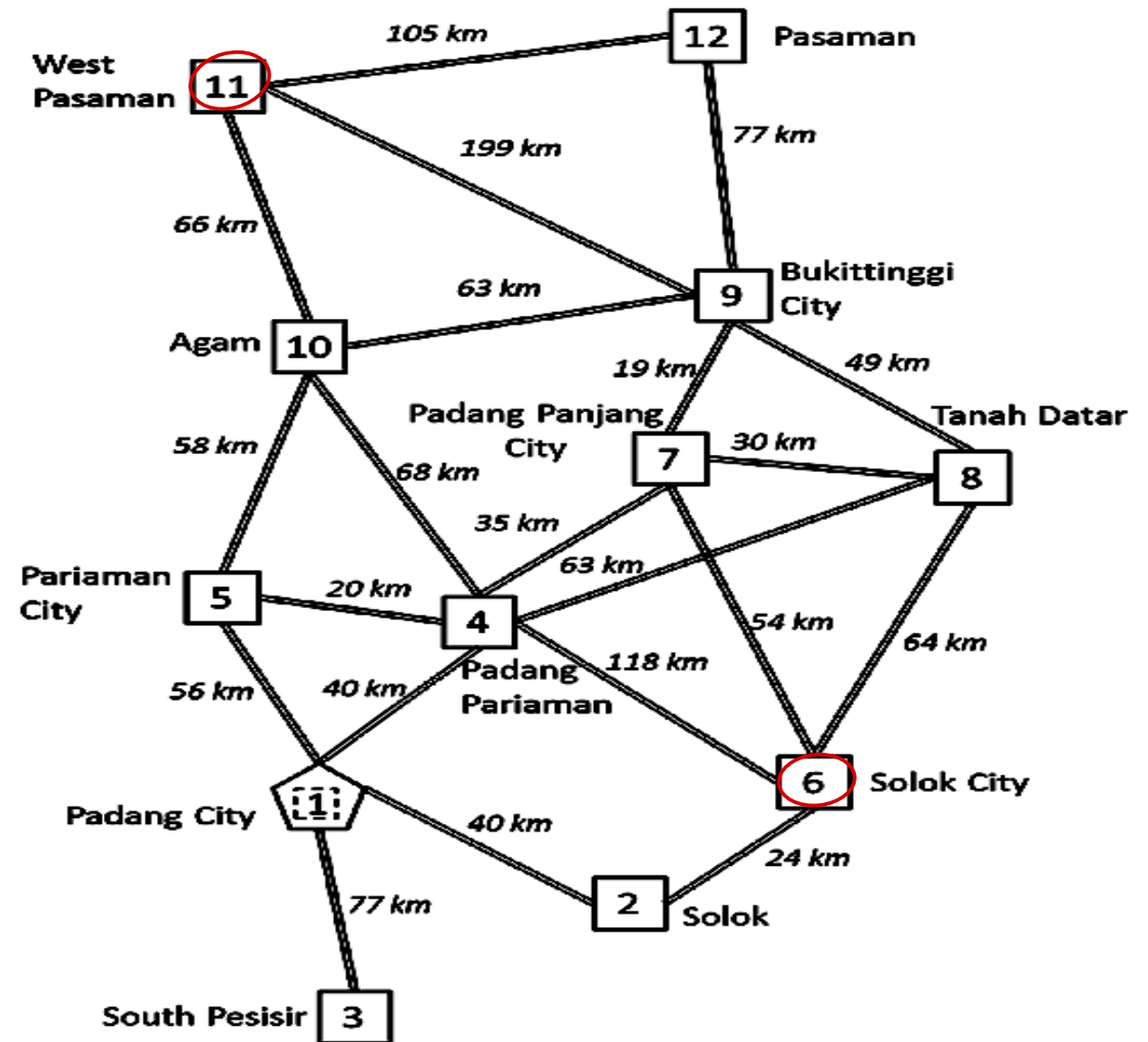
- In world wide web, web pages are like vertices; while links represents edges. This concept can be used at multiple places.
 - Making sitemap
 - Downloading website or resources
 - Developing web crawlers
 - Google page-rank algorithm

PageRank works by counting the number and quality of links to a page to determine a rough estimate of how important the website is. The underlying assumption is that more important websites are likely to receive more links from other websites.

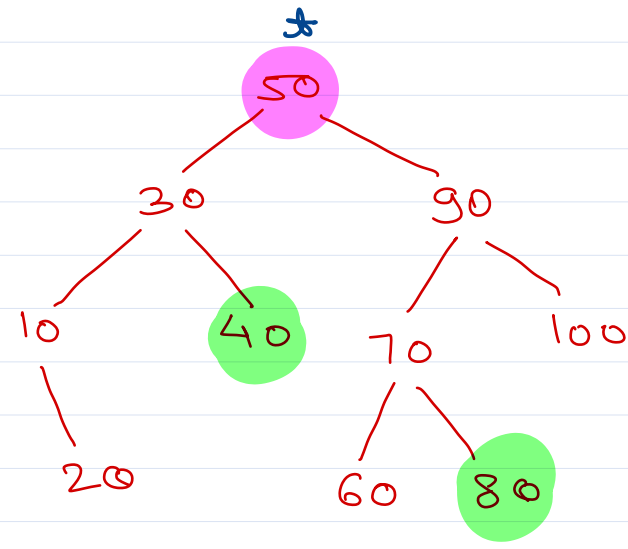
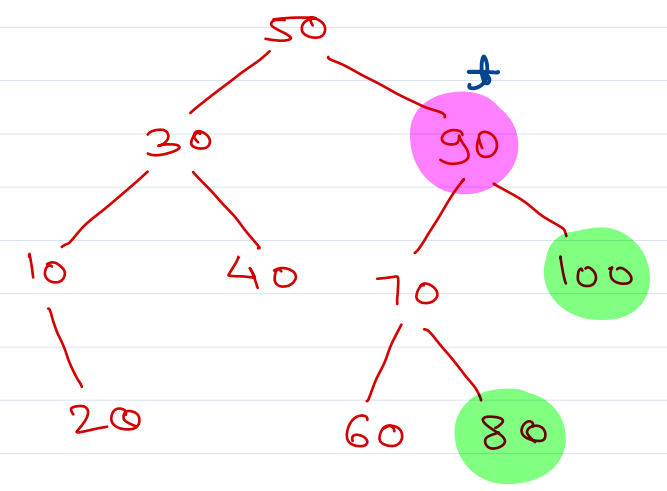
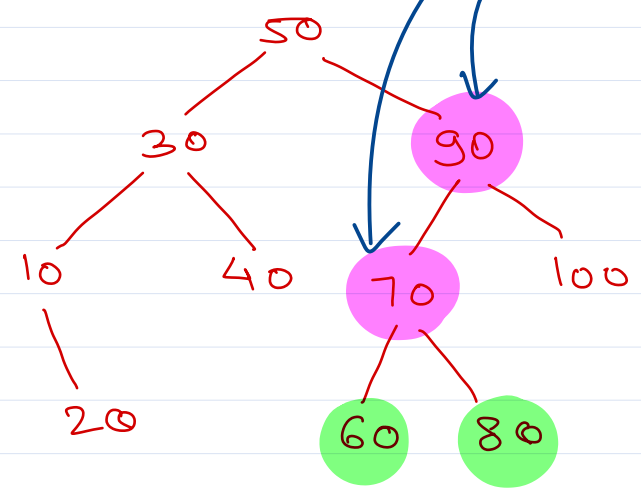
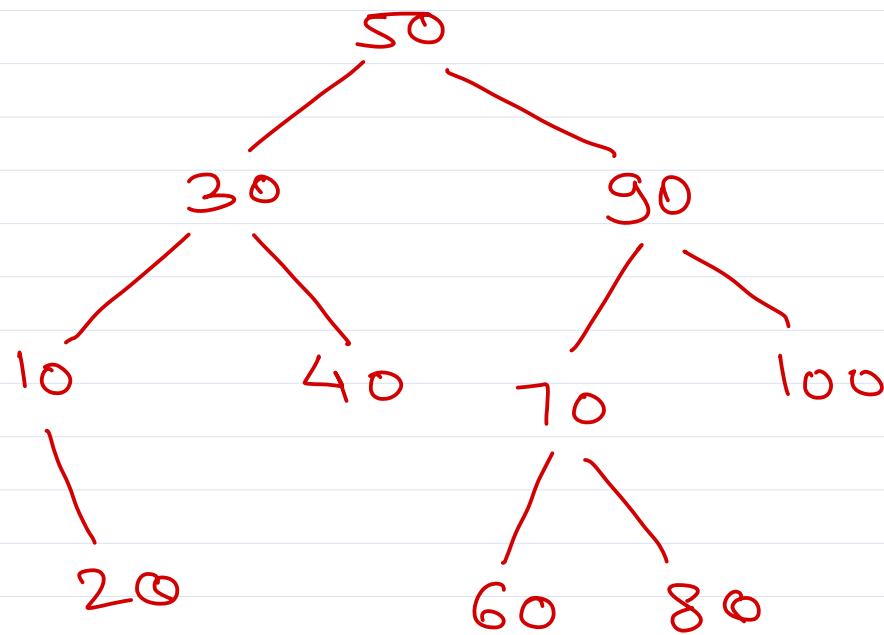


Graph applications

- Maps uses graphs for showing routes and finding shortest paths.
Intersection of two (or more) roads is considered as vertex and the road connecting two vertices is considered to be an edge.

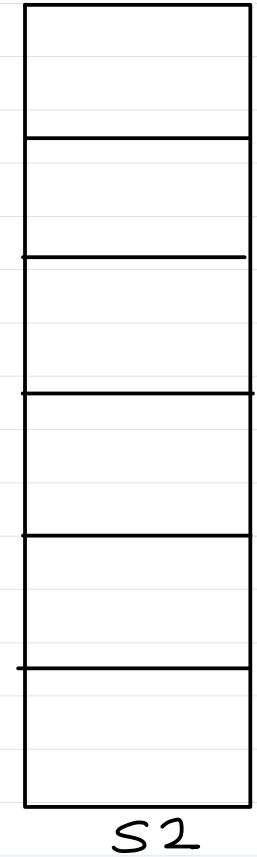
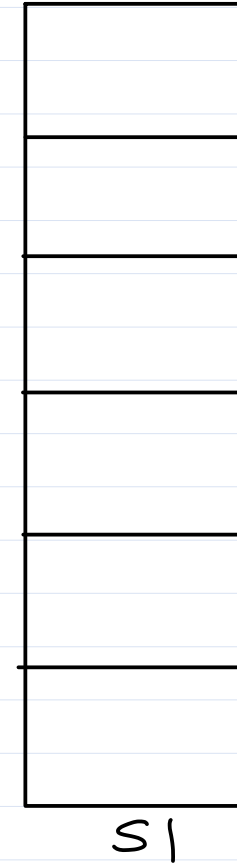
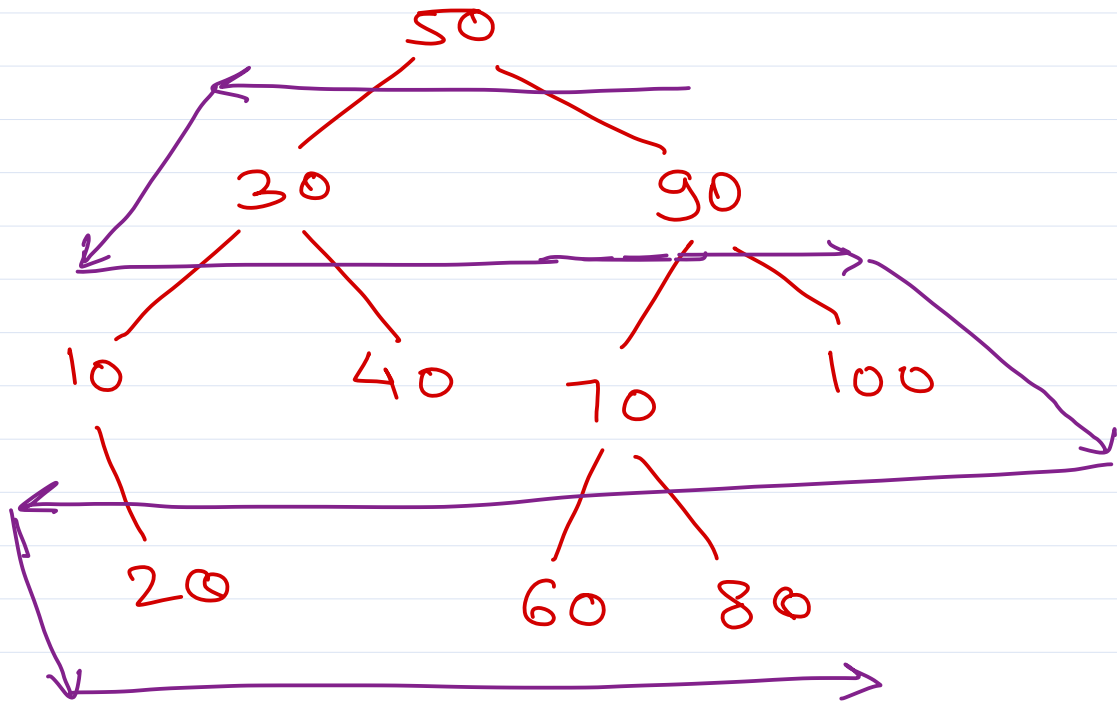


Largest Common Ancestor



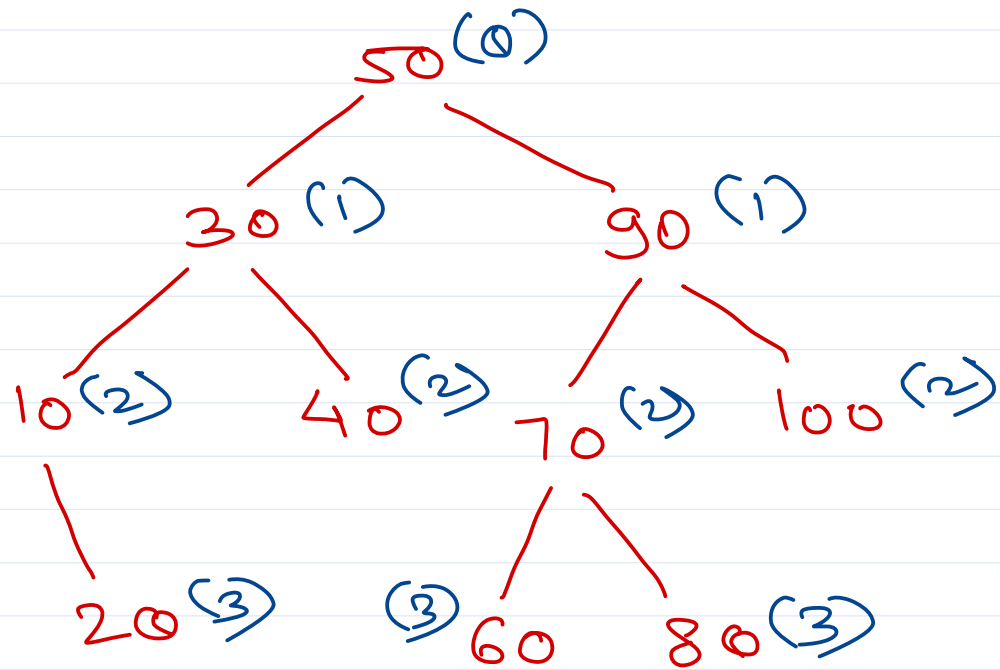
nearest largest
" " " "

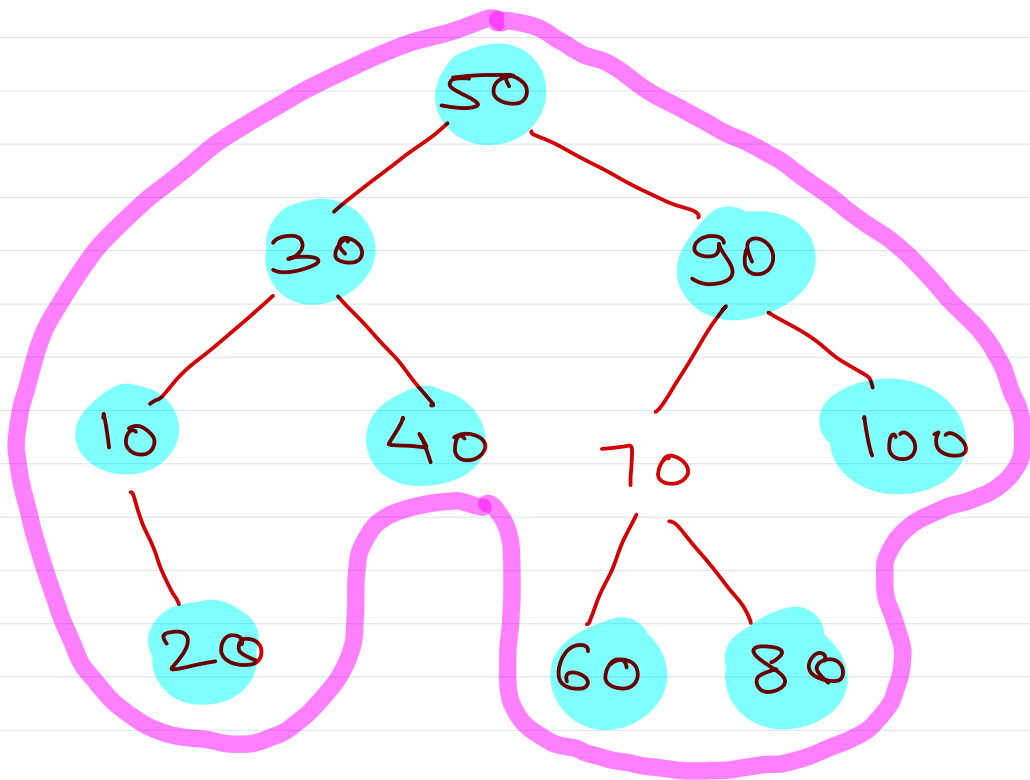




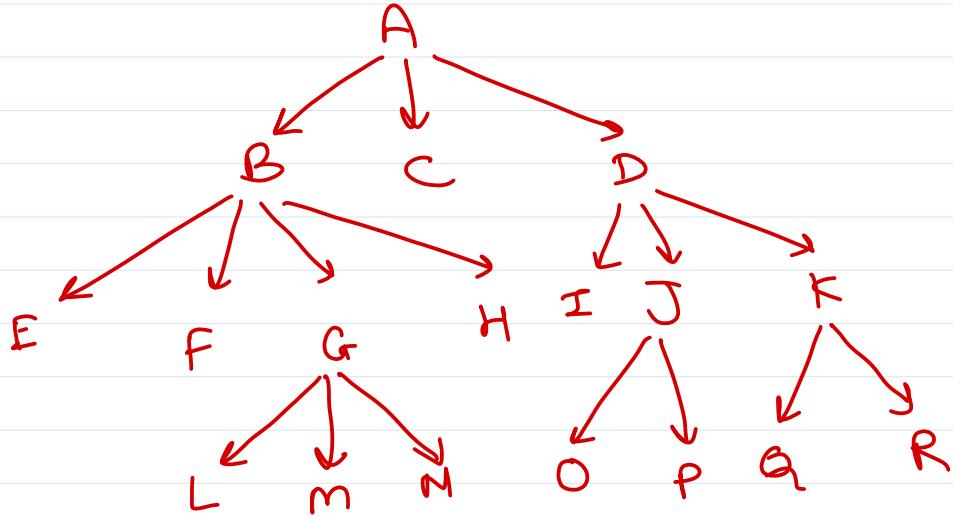
50 30 90 100 70 40 10 20 60 80
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# Multi-way Tree



n-way tree ( $n=4$ )  
or 4-tree (degree 4)

```
class Node {  
    char data;  
    Node [] child;  
    Node(char val) {  
        data = val;  
        child = new Node[4];  
    }  
}
```



# Trie

\* Trie is a multi-way tree.

\* Each node has multiple child nodes.

\* Used for faster searching of strings.

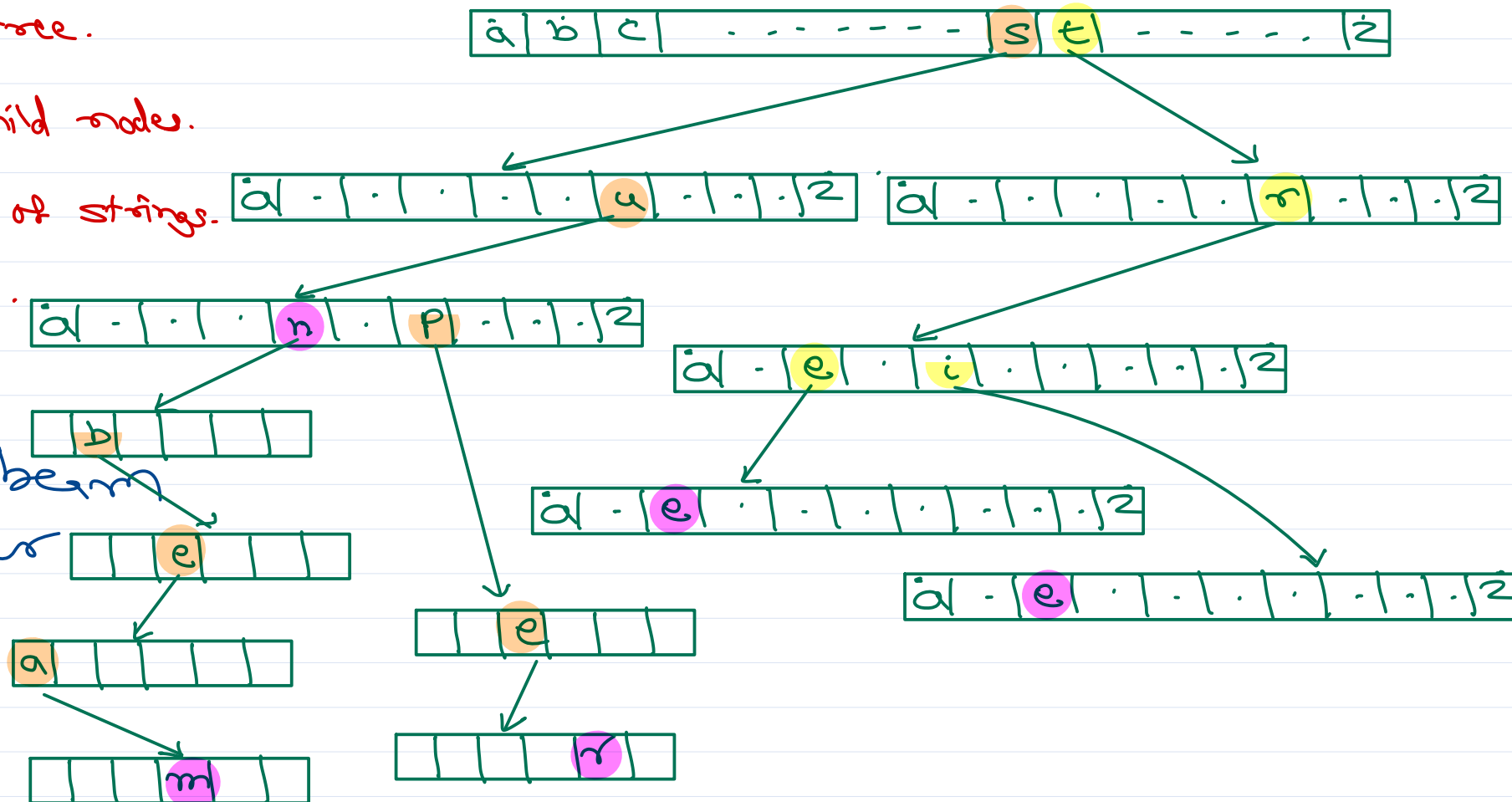
\* Time Complexity:  $O(\text{len})$ .  
len = string length.

add words

- ✓ ① tree
- ✓ ② trie
- ✓ ③ sum
- ✓ ④ sunbeam
- ✓ ⑤ super

Applications:

- ① Dictionary
- ② Auto-complete/Intellisense
- ③ Faster searching





*Thank you!*

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