UNIVERSITÄT
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Graphs and Trees

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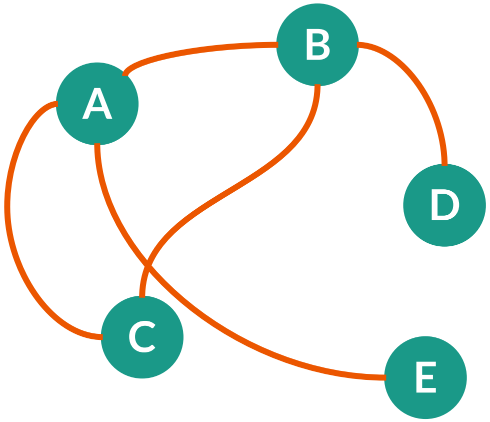
Software Skills Lab

Graphs

Graph data structure

A data structure to store a collection of elements (***vertices***) and relations between them (***edges***):

- 5 vertices: A, B, C, D, E
- 5 edges: (A,B), (A,E), (A,C), (B,D), (B,C)



Use whenever you need to study a network:

- city map (public transport routes and stops)
- social network (“share with friends of friends”)
- program call graph (which method calls which)
- …. and many more

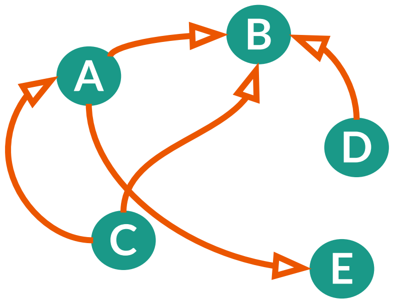
Graph properties

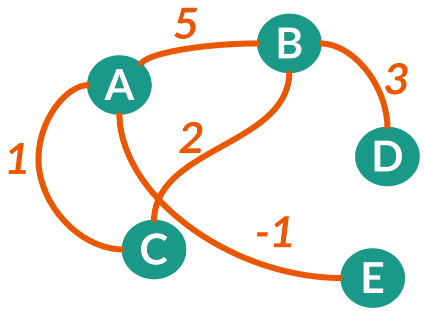
Edges can have additional properties:

- direction (=> "directed graph")
- weight (=> "weighted graph")

Most common tasks:

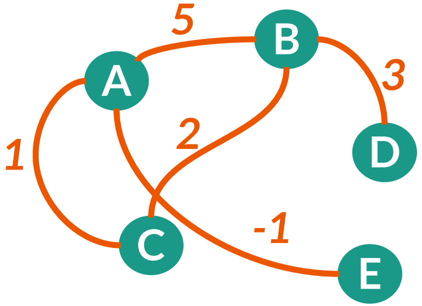
- find a path between two vertices
- find cycles (paths that begin and end at the same vertex)





Graph data structure implementation

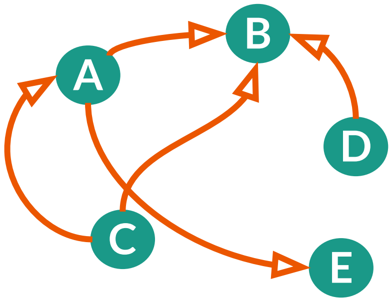
```
public class Graph {
    List<Edge> vertices;
}
```

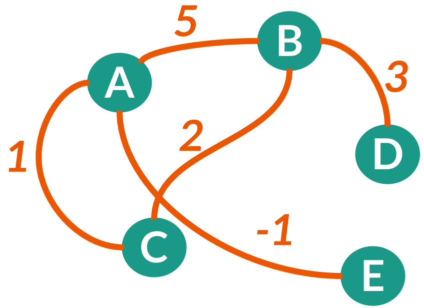



```
public class Edge {
    public Vertex start;
    public Vertex end;
    public int weight;
}
```

```
public class Vertex {
    public String label;
}
```

Adjacency matrix of a graph





	A	B	C	D	E
A	0	1	0	0	1
B	0	0	0	0	0
C	1	1	0	0	0
D	0	1	0	0	0
E	0	0	0	0	0

	A	B	C	D	E
A	0	5	1	0	-1
B	5	0	2	3	0
C	1	2	0	0	0
D	0	3	0	0	0
E	-1	0	0	0	0

Java and Graphs

Java doesn't have a default implementation of the graph data structure.

But there are several public libraries to use:

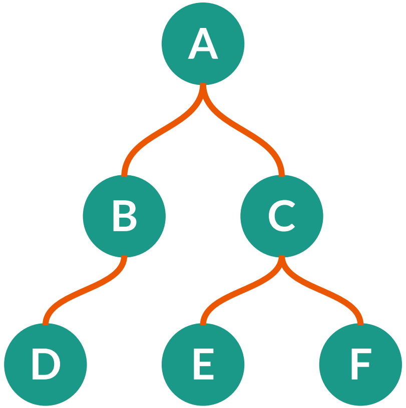
- JGraphT
- Google Guava
- Apache Commons Graph

Trees

Tree data structure

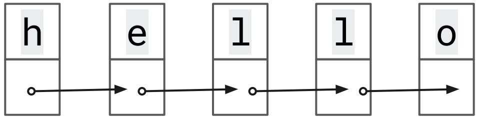
A data structure to store a collection of (usually, **ordered**) elements in a structured way:

- A is a tree ***root***
- B and C are regular nodes, ***children*** of A
- D and E, and F are ***leaf*** nodes
- ...but we do not have branches: we have ***sub-trees***!
- each tree has **depth**: the number of levels
- unlike a graph, never has a cycle



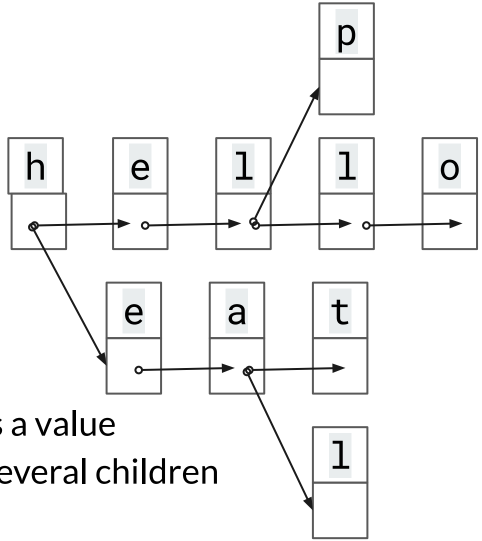
Trees and Lists

Single-linked list:



- each node holds a value
- each node has one child

Tree:

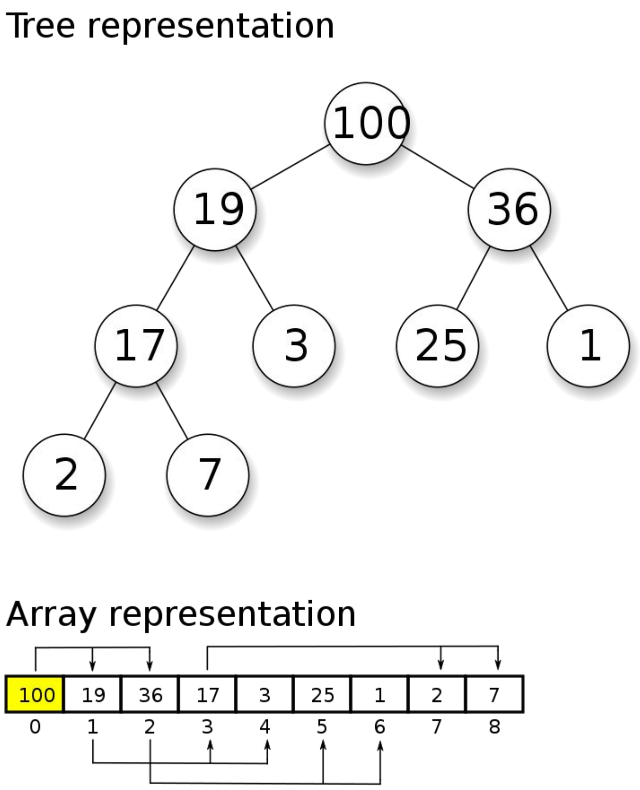


- each node holds a value
- each node has several children

Trees and Arrays

Any tree can be converted to an array:

- need to account for number of children of each node
- need to account for tree traversal order:
    - **breadth-first** (here), or
    - **depth-first**



Tree properties

Tree **elements are** typically **ordered** and it is reflected in the tree structure:

- Binary search tree
- Min/Max Heap

On top of that, many **trees are balanced** to minimize the difference in length of the branches (for performance reasons):

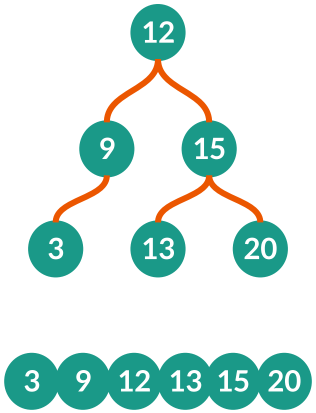
- AVL tree
- B-tree
- Red–black tree

Trees for search

Most commonly tree data structures are used to store data **sorted** according to some order and make the **search** of elements with specific values faster compared to data structures with linear lookup, such as arrays and lists.

Binary search tree:

- child on the left has smaller value than parent
- child on the right has larger value than parent



Insertion order:

12, 15, 20, 9, 13, 3

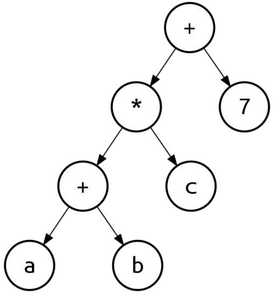
Steps (=cost) to check if 13 is present:

- list: 5 (linear)
- tree: <3 (**logarithmic**, at most its depth)

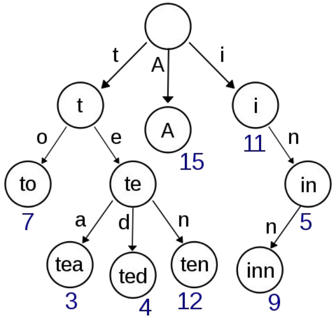
More trees use

Other tasks where it is convenient to store data in trees:

- parsing
- autocomplete
- indexing



A **parse tree** of an arithmetic expression (a+b)*c+7



A **trie** (prefix tree) for keys "A", "to", "tea", "ted", "ten", "i", "in", and "inn"

Java and Trees

Java doesn't have a default implementation of any tree data structures as general purpose collection classes or interfaces, but some data structures are using them internally:

- TreeMap (Java SE 11 & JDK 11) - A Red-Black tree based `NavigableMap` implementation
- TreeSet (Java SE 11 & JDK 11) - A `NavigableSet` implementation based on a `TreeMap`

Set and map data structures are coming in the next lecture!

Practice

Exercise

> *Reuse the `Matrix` implementation from the previous class and add the `toString()` method to it for pretty-printing the matrix*

Building graph adjacency matrix

- Write the 3 classes implementing the graph data structure (as in slide 7)
- attributes:
  - as provided
- methods:
  - in `Vertex` and `Edge`: constructors
  - in `Graph`: constructor to create an empty graph, and `Matrix toMatrix()` that returns an adjacency matrix of the graph

I/O

- read a graph from a CSV file where each row contains edges as triplets: `a,5,b`
- print the adjacency matrix to `System.out`

Tests

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