

COMP110: Principles of Computing

8: Data Structures

Learning outcomes

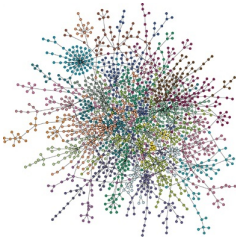
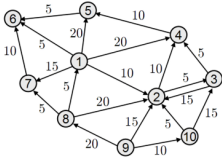
- ▶ **Define** the key concepts of graph theory
- ▶ **Distinguish** advanced data structures such as trees, DAGs and graphs
- ▶ **Determine** the complexity of accessing and manipulating data in these data structures
- ▶ **Choose** the correct data structure for a given task

Exercise Sheet iii

Due **next week**

Graphs

Graphs



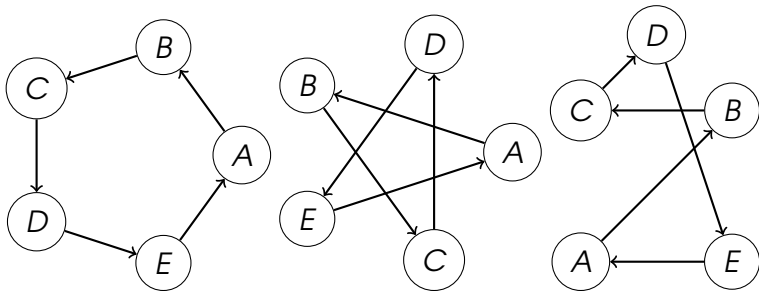
- ▶ A **graph** is defined by:
 - ▶ A collection of **nodes** or **vertices** (points)
 - ▶ A collection of **edges** or **arcs** (lines or arrows between points)
- ▶ Often used to model **networks** (e.g. social networks, transport networks, game levels, automata, ...)
- ▶ **Directed** graph: edges are arrows
- ▶ **Undirected** graph: edges are lines

Implementing graphs

- ▶ A graph has a **set of nodes** and a **set of edges**
- ▶ Each edge has exactly **two nodes** associated with it (e.g. "from" and "to")

Drawing graphs

- ▶ A graph does not necessarily specify the physical **positions** of its nodes
- ▶ E.g. these are technically the same graph:

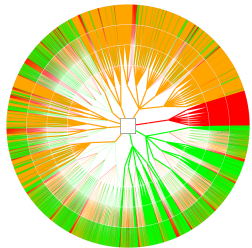
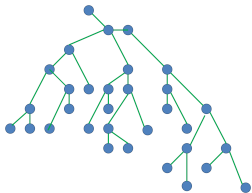


Planar graphs

- ▶ A graph is **planar** if it can be drawn with no overlapping edges
- ▶ A region enclosed by edges is called a **faces**
- ▶ A connected planar graph obeys **Euler's formula**:

$$n_{\text{nodes}} - n_{\text{edges}} + n_{\text{faces}} = 2$$

Trees



- ▶ A **tree** is a special type of directed graph where:
 - ▶ One node (the **root**) has no incoming edges
 - ▶ All other nodes have exactly 1 incoming edge
- ▶ Edges go from **parent** to **child**
 - ▶ All nodes except the root have exactly one parent
 - ▶ Nodes can have 0, 1 or many children
- ▶ Used to model **hierarchies** (e.g. file systems, object inheritance, scene graphs, state-action trees, ...)

Implementing trees

- ▶ A graph has a **root node**
- ▶ Each node has a **collection of children**
- ▶ Each node other than the root has a **single parent**

Stacks and queues

Stacks and queues



- ▶ A **stack** is a **last-in first-out (LIFO)** data structure
- ▶ Items can be **pushed** to the **top** of the stack
- ▶ Items can be **popped** from the **top** of the stack



- ▶ A **queue** is a **first-in first-out (FIFO)** data structure
- ▶ Items can be **enqueued** to the **back** of the queue
- ▶ Items can be **dequeued** from the **front** of the queue

Lists in Python

- ▶ Implemented as a (variable-sized) **array**
- ▶ Appending is $O(1)$
- ▶ Inserting is $O(n)$
- ▶ Deleting is $O(n)$

Stacks in Python

- ▶ Stacks can be implemented efficiently as lists
- ▶ `append` method adds an element to the end of the list
 - ▶ What is the time complexity?
- ▶ `pop` method removes and returns the last element of the list
 - ▶ What is the time complexity?

Queues in Python

- ▶ Queues can be implemented as lists, but not efficiently
- ▶ Could use `append(item)` to enqueue and `pop(0)` to dequeue
 - ▶ What is the time complexity of `pop(0)`?
- ▶ Could use `insert(0, item)` to enqueue and `pop()` to dequeue
 - ▶ What is the time complexity of `insert(0, item)`?
- ▶ `deque` (from the `collections` module) implements an efficient **double-ended queue**
- ▶ Provides methods `append`, `appendleft`, `pop`, `popleft`
 - ▶ All of which are $O(1)$

Stacks and function calls

- ▶ Stacks are used to implement **nested function calls**
- ▶ Each invocation of a function has a **stack frame**
- ▶ This specifies information like **local variable values** and **return address**
- ▶ Calling a function **pushes** a new frame onto the stack
- ▶ Returning from a function **pops** the top frame off the stack

Graph traversal

Tree traversal

- ▶ **Traversal:** visiting all the nodes of the tree
- ▶ Two main types
 - ▶ Depth first
 - ▶ Breadth first

Tree traversal

procedure DEPTHFIRSTSEARCH

let S be a stack

push root node onto S

while S is not empty **do**

pop n from S

print n

push children of n onto S

end while

end procedure

procedure BREADTHFIRSTSEARCH

let Q be a queue

enqueue root node into Q

while Q is not empty **do**

dequeue n from Q

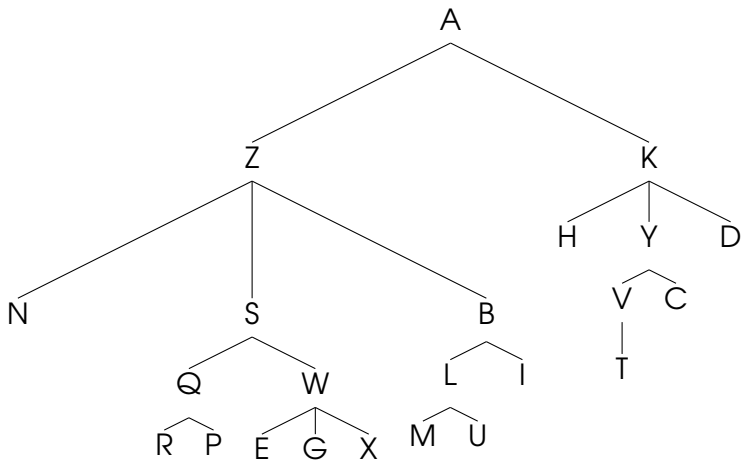
print n

enqueue children of n into Q

end while

end procedure

Tree traversal example



Recursive depth first search

```
procedure DEPTHFIRSTSEARCH( $n$ )  
  print  $n$   
  for each child  $c$  of  $n$  do  
    DEPTHFIRSTSEARCH( $c$ )  
  end for  
end procedure
```

- Compare to the pseudocode on the previous slide.
Where is the stack?