COMP110: Principles of Computing

11: Data Structures II

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

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 (LIFO)** data structure
- Items can be **enqueued** to the **back** of the queue
- Items can be **dequeued** from the **front** of the queue

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

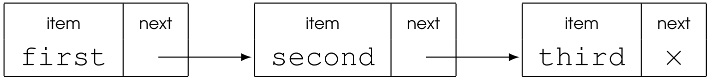
Linked lists

Lists in Python

- Implemented as a (variable-sized) **array**
- Appending is $O(1)$
- Inserting is $O(n)$
- Deleting is $O(n)$
- Changing size sometimes requires the entire array to be reallocated and copied

Linked list

- Composed of a number of **nodes**
- Each node contains:
  - An **item** — the actual data to be stored
  - A pointer or reference to the **next node** in the list (null for the last item)



Linked lists vs arrays

Operation	Array	Linked list
Append	$O(1)$	$O(1)$ [1]
Pop	$O(1)$	$O(1)$ [1]
Index lookup	$O(1)$	$O(n)$
Count elements	$O(1)$	$O(n)$
Insert	$O(n)$	$O(1)$ [2]
Delete	$O(n)$	$O(1)$ [2]

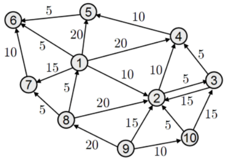
[1] If we already have a reference to the last node

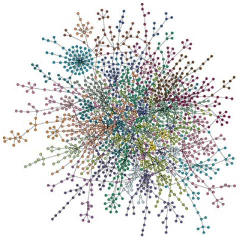
[2] If we already have a reference to the relevant node

Implementing a linked list

Graphs

Graphs



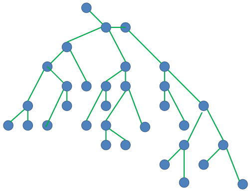


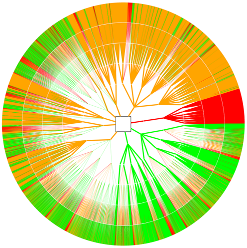
- A **graph** is defined by:
  - A collection of **nodes** or **vertices** (points)
  - A collection of **edges** or **arcs** (lines or arrows between points)
- Often used to model **networks** (e.g. social networks, transport networks, game levels, automata, ...)
- **Directed** graph: edges are arrows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

Implementing graphs

- A graph is a **collection of nodes**
- Each node has a **collection of edges**
- Each edge has exactly **two nodes** associated with it

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**

Tree traversal

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

Tree traversal

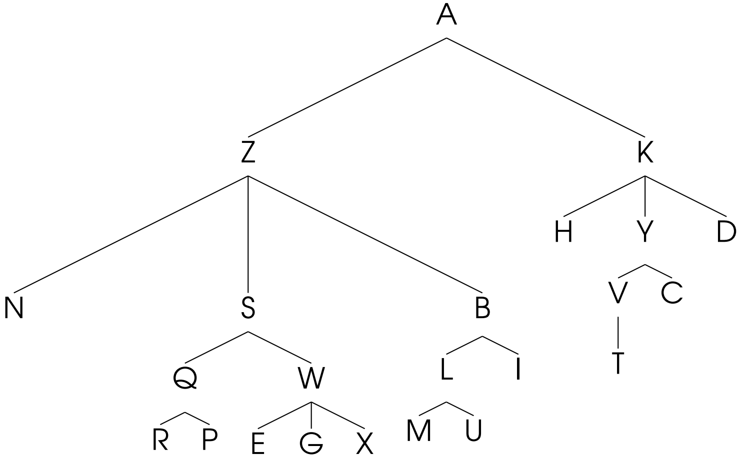
```
procedure DepthFirstSearch
    let S be a stack
    push root node onto S
    while S is not empty do
        pop n from S
        print n
        push children of n onto S
    end while
end procedure

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
```

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?

Tree traversal example



Worksheet D