Algorithms and Analysis

Lesson 3: *Declare your intentions (not your actions)*

ADTs, stacks, queues, priority queues, sets, maps

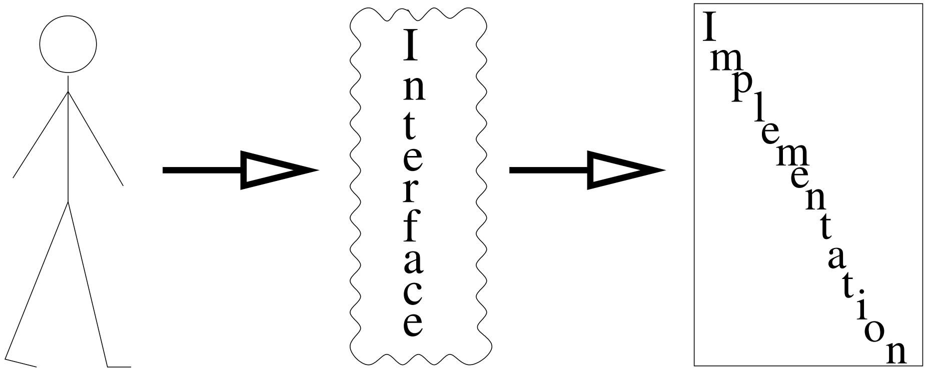
Outline

1. **Abstract Data Types (ADTs)**
2. Stacks
3. Queues and Priority Queues
4. Lists, Sets and Maps
5. Putting it Together

Object Oriented Programming

- OO-programming allows you to build large systems reliably
- In the OO-methodology you separate the interface from the implementation
- The **interface** is the public methods (functions) of a class
- The implementation is hidden (**encapsulated**) and may be changed without affecting how the class is used
- There exist other ways of programming, but C++ is designed to support the OO-methodology—for building systems it is brilliant

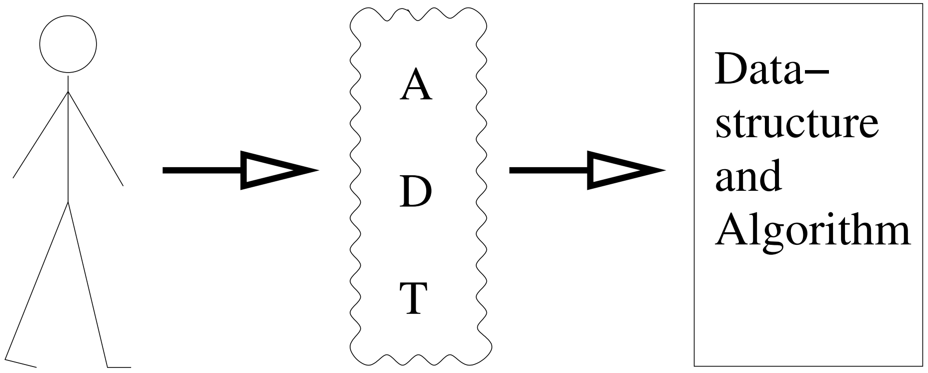
Object-Oriented Classes



Abstract Data Types

- With data structures there are some traditional interfaces called **Abstract Data Types** or ADTs
- These are implementation free data structures
- They are mathematical abstractions of the data structure
- Their purpose is to allow you to declare you intentions
- You are entering into an agreement that you only intend to use the underlying data structure in the way specified by the interface

ADTs



A D T

Data–structure and Algorithm

Say it with an ADT

- Common ADTs include stacks, queues, priority queues, sets, multisets and maps
- There are many possible implementations of these ADTs (some far from obvious)
- Each ADT has a limited set of methods associated with it
- They are an abstraction away from the implementation
- By declaring your intentions you are making your code easier to understand and maintain

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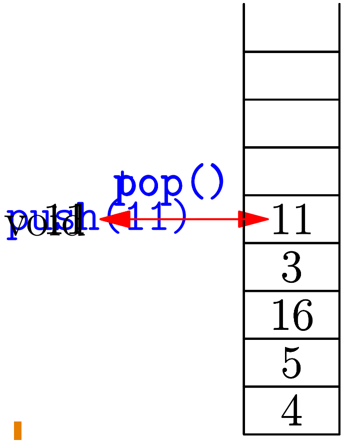
Attest.

CHARLES THOMSON, Secretary.

Stacks

- Last In First Out (LIFO) memory
- Standard functions
  - push(item)
  - T top()
  - T pop() except in C++ pop() doesn't return the top of the stack
  - boolean empty()
- Implemented using an array (or a linked-list)



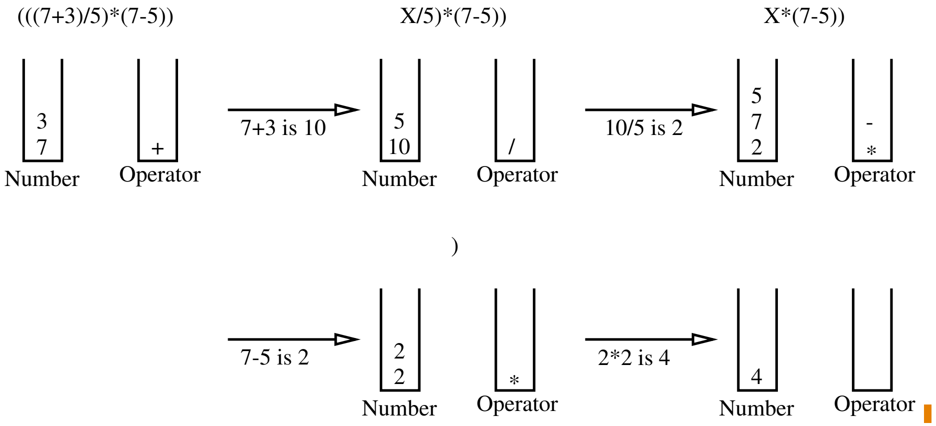
Why Use a Stack?

- Stacks reduces the access to memory—no longer random access
- Seems counter intuitive to reduce what you can do
- Gives you a very simple interface
- Prevents another programmer from using memory in a way that will break existing code
- Sufficient for large number of algorithms

Uses of Stacks

- Reversing an array
- Parsing expression for compilers
  - balancing parentheses
  - matching XML tags
  - evaluating arithmetic expression
- Clustering algorithm

Evaluating Arithmetic Expressions



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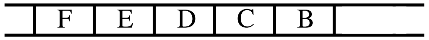
Queues

- First-in-first-out (FIFO) memory model
- `enqueue(elem)`
- `peek()`
- `dequeue()`
- C++ has a double ended queue (`deque`) with `push_front()`, `push_back()`, etc.

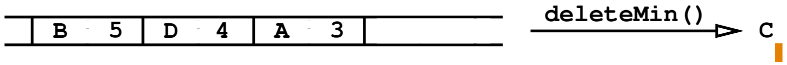


Uses of Queues

- Queues are heavily used in multi-threaded applications (e.g. operating systems)
- Multi-threaded applications need to minimise waiting and ensure the integrity of the data structure (for instance when an exception is thrown)
- Because of this they are more complicated than most data structures
- They can be implemented using linked-lists or circular arrays

Priority Queues

- Queue with priorities
- `insert(elem,priority)` (in C++ `push()`)
- `findMin()` (in C++ `top()`)
- `deleteMin()` (in C++ `pop()`)



Uses of Priority Queues

- Queues with priorities (e.g. which threads should run)
- Real time simulation
- Often used in "greedy algorithms"
  - ⋆ Huffman encoding
  - ⋆ Prim's minimum spanning tree algorithm

Implementation of Priority Queue

- Could be implemented using a binary tree or linked list
- Most efficient implementation uses a heap
- A heap is a binary tree implemented using an array

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Lists

- In C++ the standard list is known as `vector<T>`
- That is, it is a collection where the order in which you put items into the list counts
- You can have repetitions of elements
- It has random access, e.g. `v[i]`
- You can `push_back(i)`, `insert`, `erase`, etc.
- C++ has a linked list class `list<T>`

Sets

- Models mathematical sets
- Container with no ordering or repetitions
- Methods include `insert`, `find`, `size`, `erase`
- Provides fast search (`find`)
- This is the class to use when you have to rapidly find whether an object is in the set or not—don't use a list like `vector<T>`!

Iterators

- Wish to act on all members of the set
- Performed using an `iterator`
- Iterators are used by many collections
- In C++ iterators follow the pointer convention

```
set<string> words;

words.insert("hello");
words.insert("world");

for(auto iter = words.begin(); iter != words.end(); ++iter) {
  cout << *iter << endl;
}
```

Implementation of Sets

- Sets are very important and there are many implementations depending on their usage
- Two common implementations of sets are
  - hash tables: `unordered_set<T>`
  - binary trees: `set<T>`
- Which is most efficient depends on the application
- Binary trees allow you to iterate in order (iterating over a hash table will give you outputs in random order)
- `multiset<T>` are sets with repetition

Maps

- A map provides a content addressable memory for pairs *key: value*
- It provides fast access to the *value* through the *key*
- Implement as tree or hash table
- Multimaps allows different data to be stored with the same keyword

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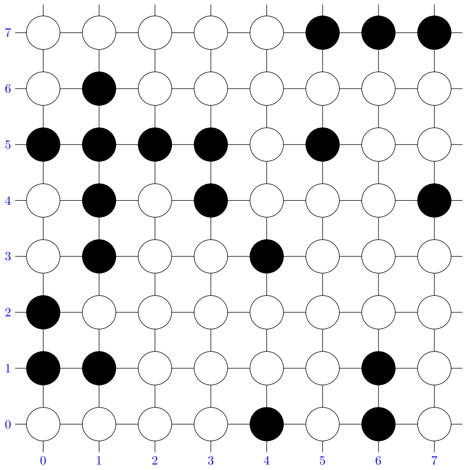
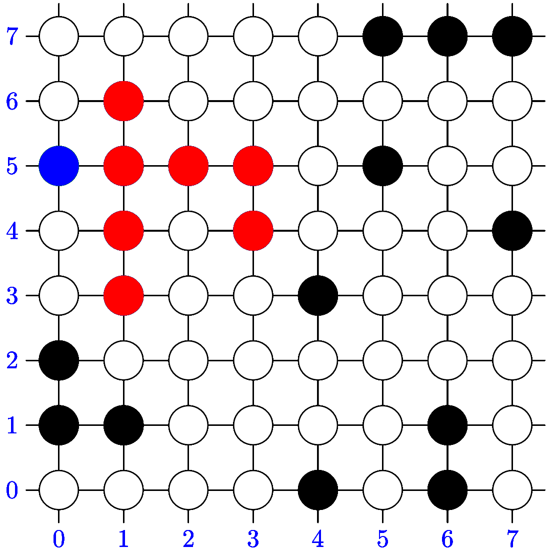
Connected Nodes



- A frequent problem is to find clusters of connected cells
- Applications in computer vision, computer go, graph connectedness, . . .

Connected Nodes



startNode = (2,5)

uncheckedNodes =

(1, 6)
(1, 4)
(0, 5)

clusterNodes = {(2, 5), (1, 5), (3, 5), (3, 4), (0, 5), (1, 4), (1, 6), (1, 3) }

Connected Node Algorithm

```
set<Node> findCluster(Node startNode, Graph graph)
{
  stack<Node> uncheckedNodes = new Stack<Node>();
  set<Node> clusterNodes = new HashSet<Node>();

  uncheckedNodes.push(startNode);
  clusterNodes.add(startNode);

  while (!uncheckedNodes.empty()) {
    Node next = uncheckedNodes.top();   uncheckedNodes.pop();
    vector<Node> neighbours = graph.getNeighbours(next);
    for (Node neigh: neighbours) {
      if (graph.isOccupied(neigh) && !clusterNodes.contains(neigh) ) {
        uncheckedNodes.push(neigh);
        clusterNodes.insert(neigh);
      }
    }
  }

  return clusterNodes;
}
```

Lessons

- Abstract Data Types (ADT) are interfaces to data
- Their purpose is to allow the programmer to declare their intentions
- They often have different implementations with different properties
- The most efficient implementation is not always obvious—we will see many of these implementations as we go through this course
- You need to know the common ADTs (e.g. Stack, Queue, List, Set, Map) and how and when to use them