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


IN CONGRESS, JULY 4, 1776.

A DECLARATION BY THE REPRESENTATIVES OF THE UNITED STATES OF AMERICA, IN GENERAL CONGRESS ASSEMBLED.

Signed by ORDER and in BEHALF of the CONGRESS,

JOHN HANCOCK, PRESIDENT.

ATTEST.

CHARLES THOMPSON, Secretary.

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


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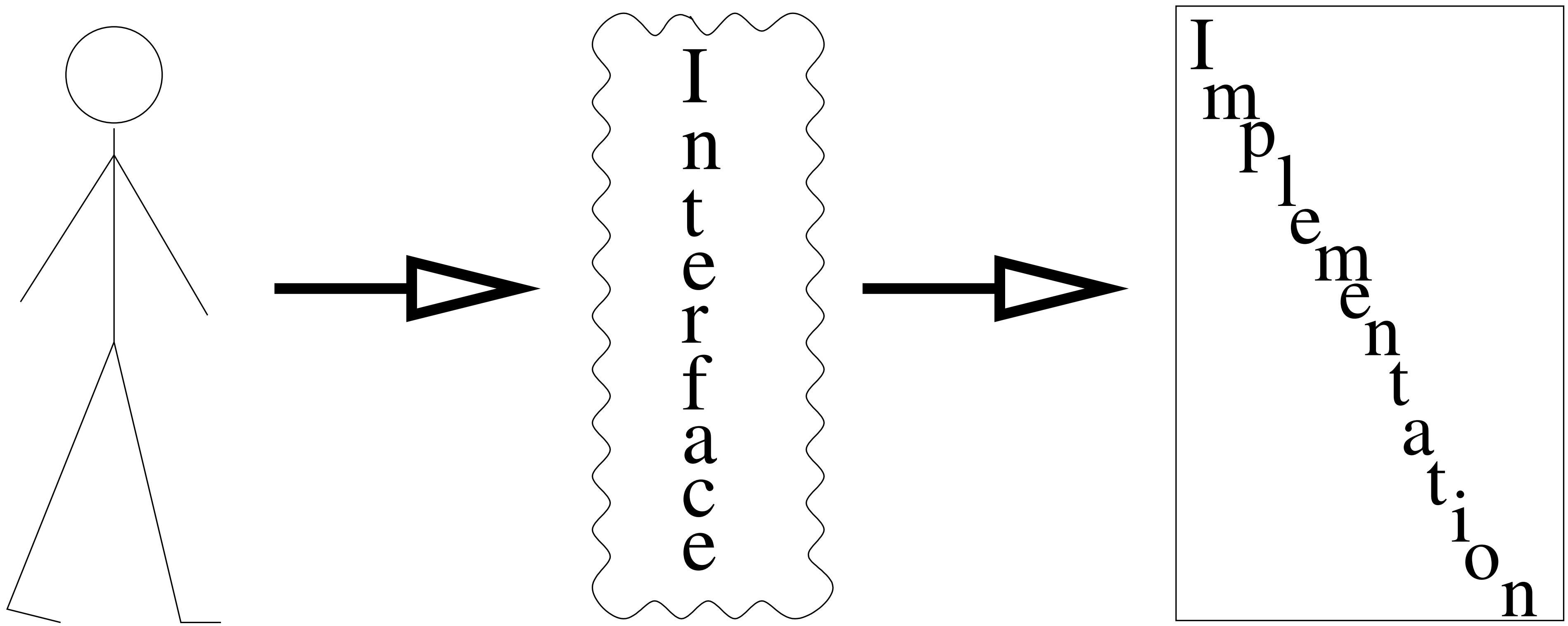
Object Oriented Programming

- 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

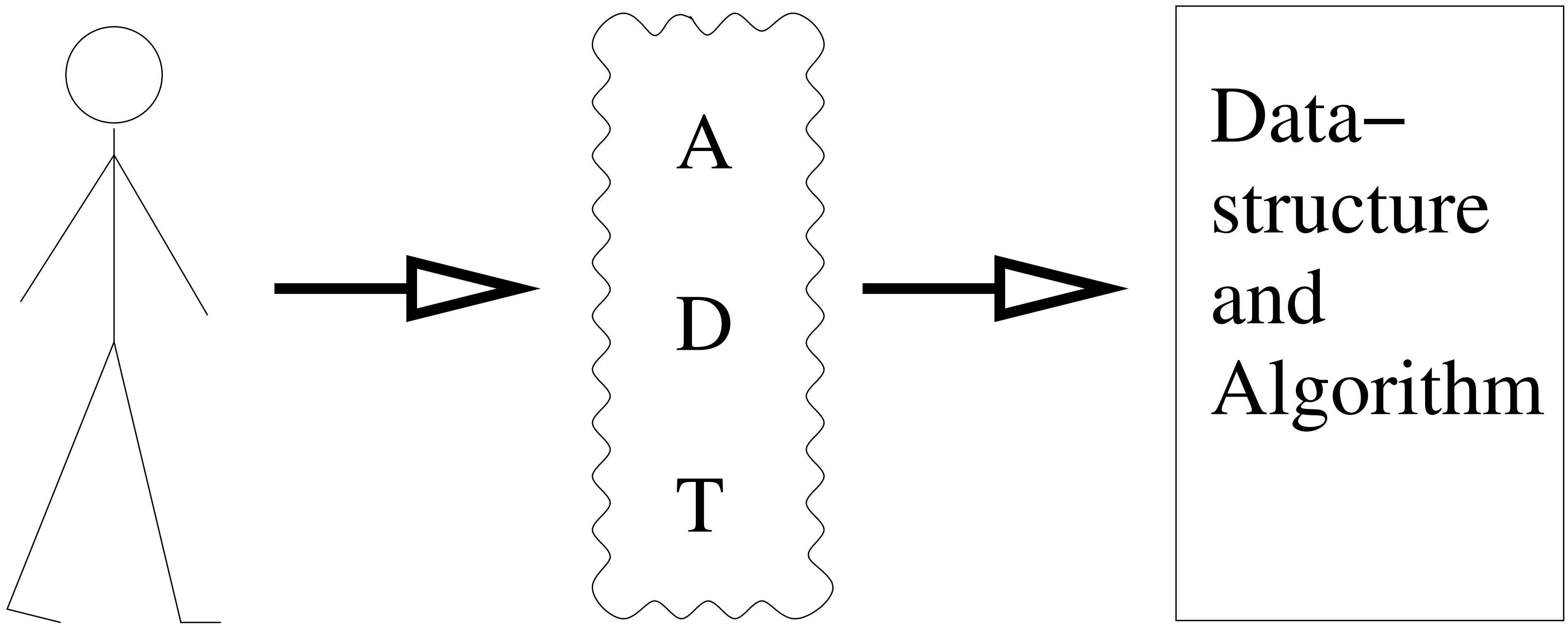
Object-Oriented Classes



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



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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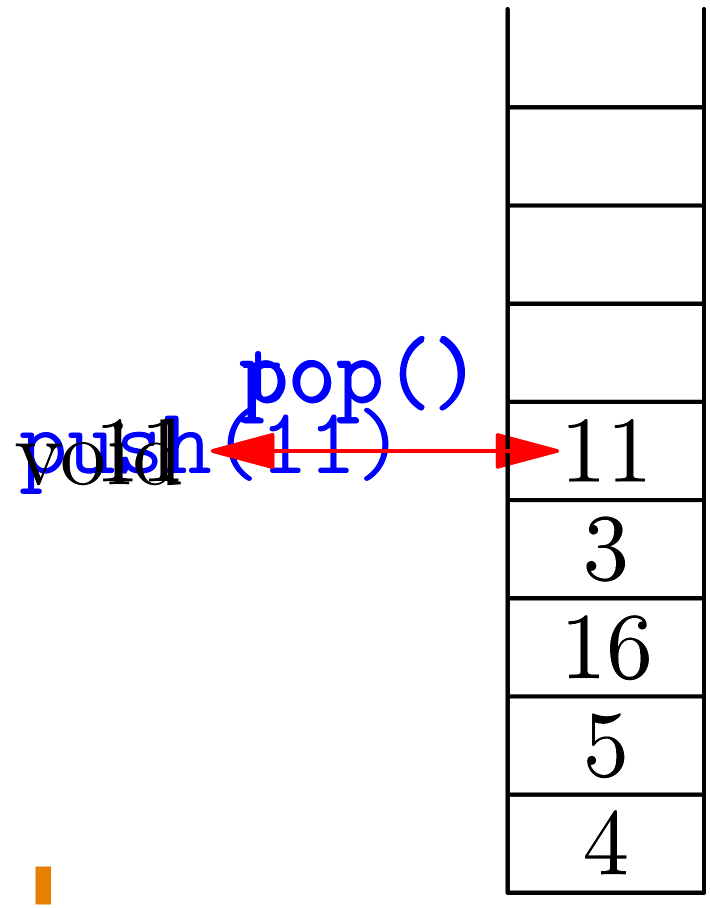
Stacks

- 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)



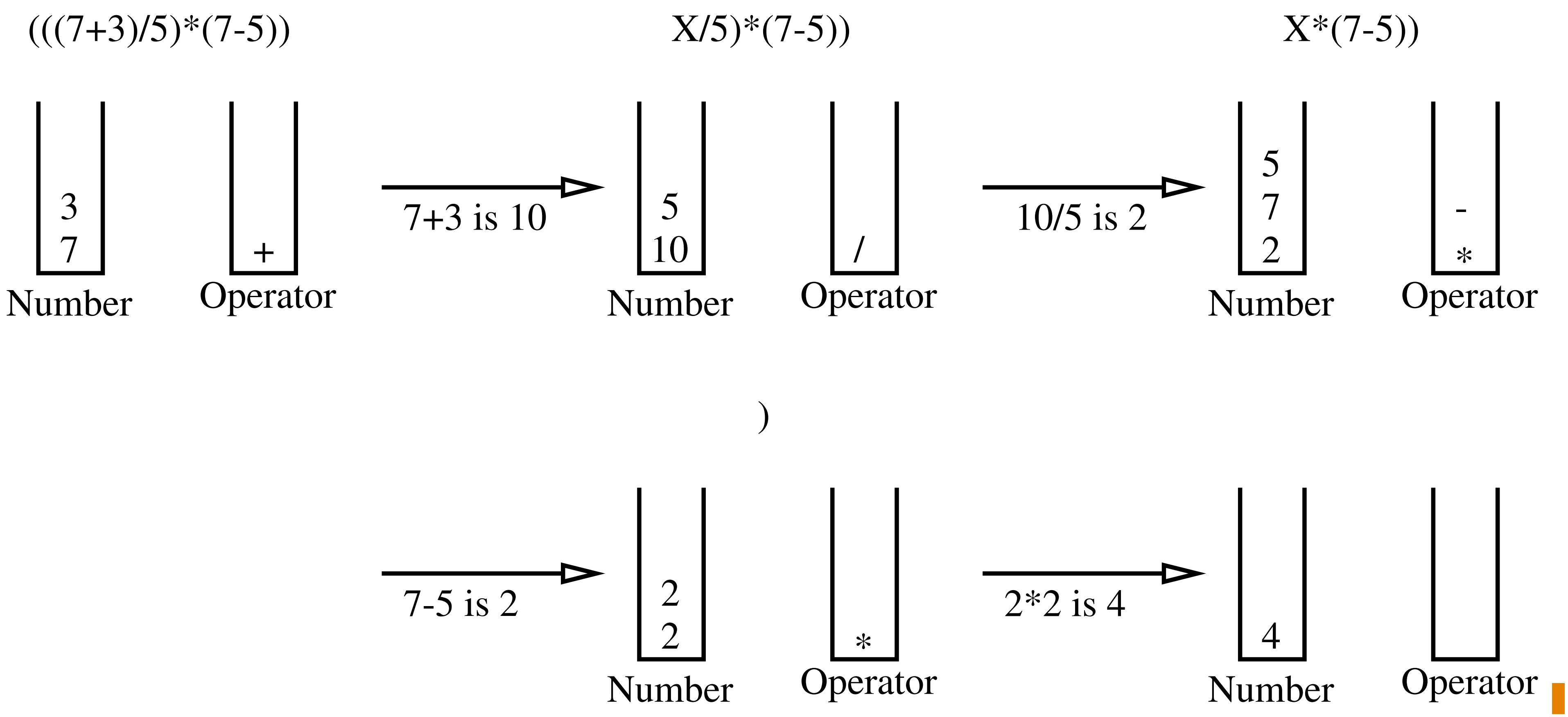
Why Use a Stack?

- 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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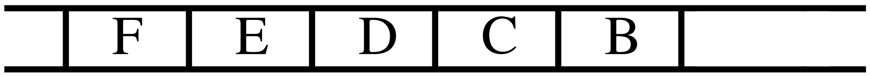
Queues

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

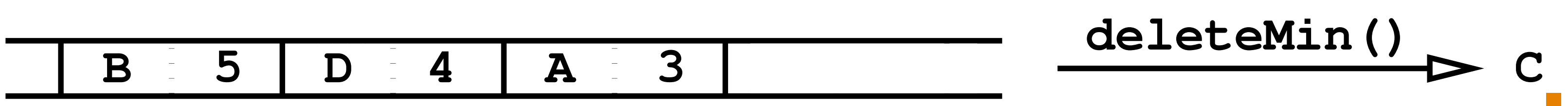


Uses of Queues

- 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 matters
- 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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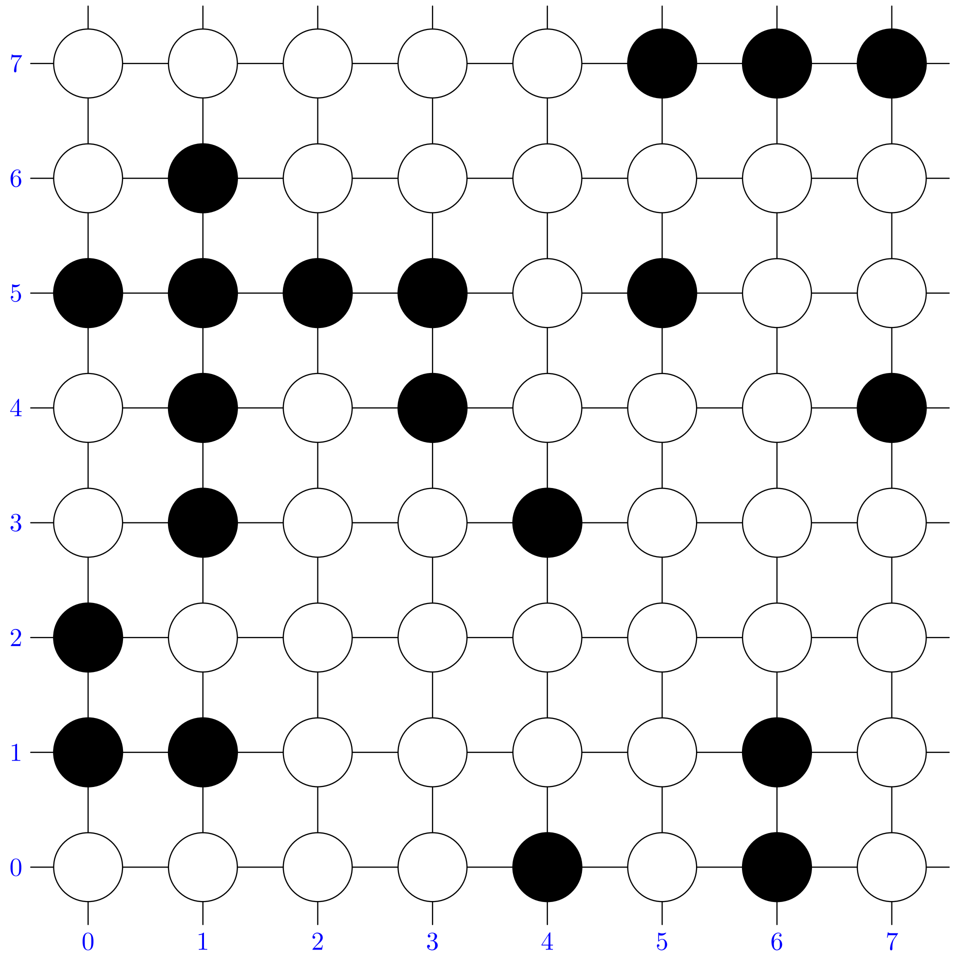
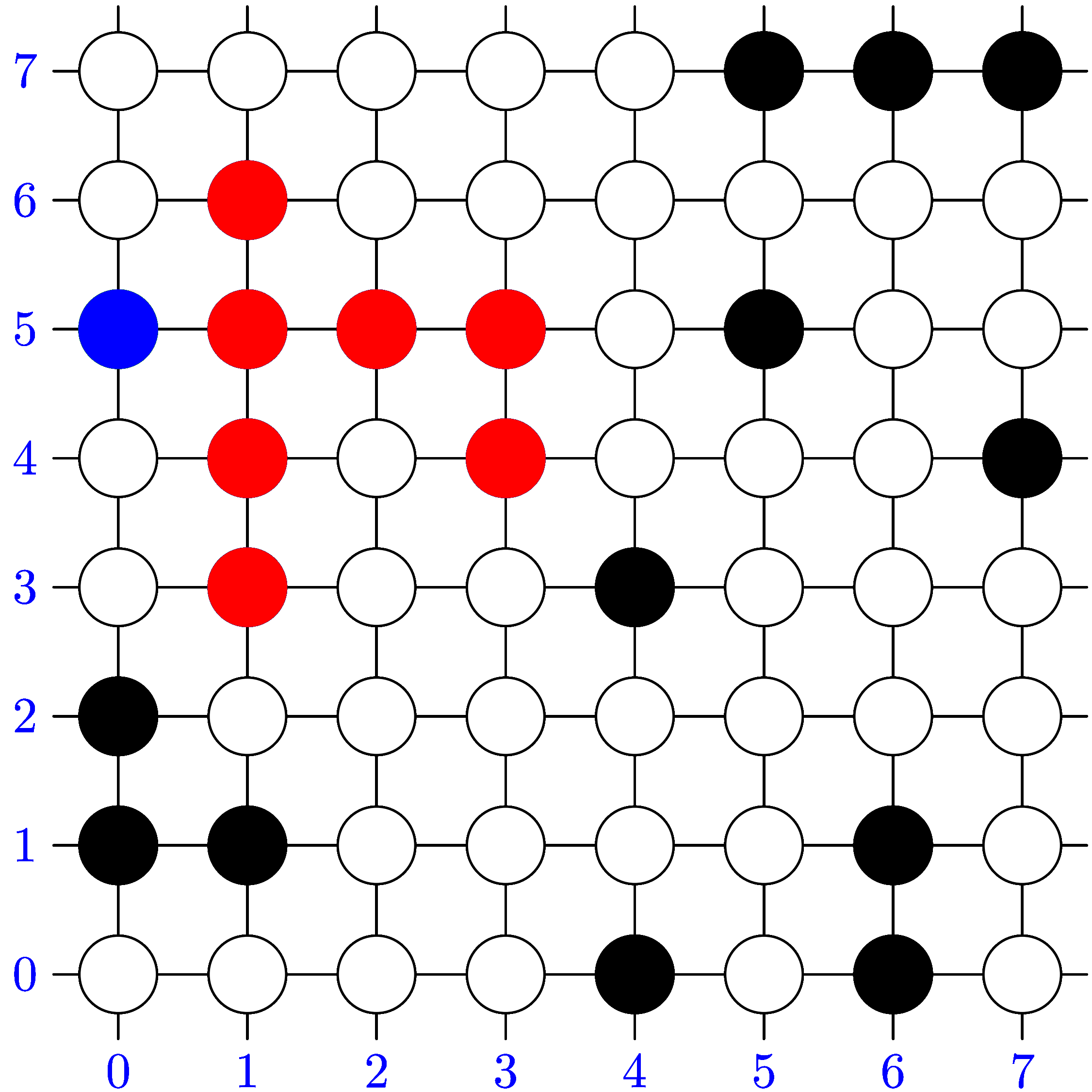
Connected Nodes



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

Connected Nodes



startNode = (2,5)

next = (0, 5)

`uncheckedNodes` =

(1, 6)
(3, 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;
  set<Node> clusterNodes;

  uncheckedNodes.push(startNode);
  clusterNodes.insert(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