COMP140: Creative Computing: Codecraft

6: Data Structures, Collections, & Generic Types

Learning outcomes

- **Understand** the various collection classes in C++
- **Compare** the collection classes
- **Implement** an application which uses collection classes

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Common Data Structures

Introduction

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- These can be used in order to build larger systems (e.g. Inventory Systems, AI Navigation etc)
- Most programming languages have these built in
- Before writing any system you should always examine these data structures and pick the appropriate one for your Use Case

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Big-O-Notation

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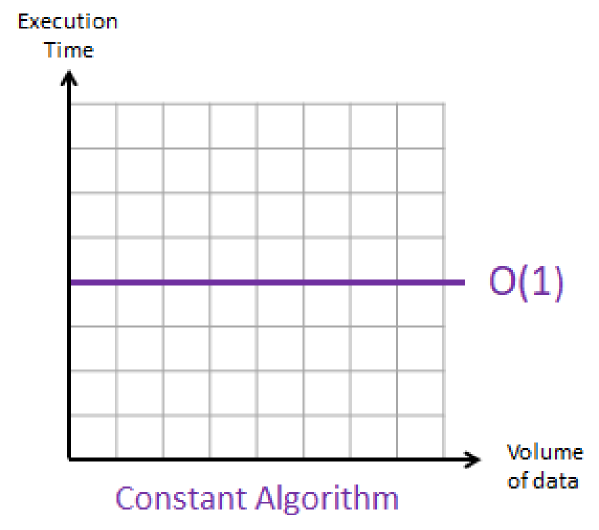
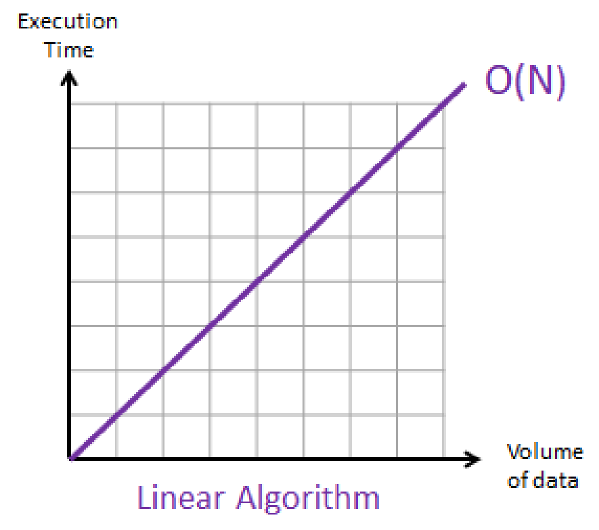
- The efficiency of an algorithm can be gauged by how long it takes
- This is know as **Time Complexity**
- **Big O Notation** is used to describe this

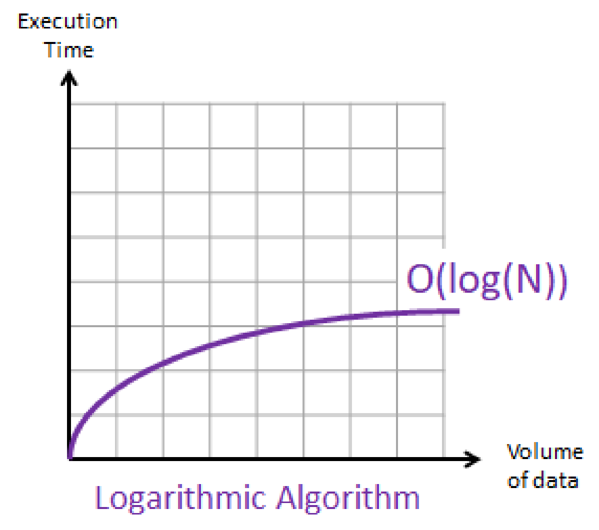
Constant - O(1)



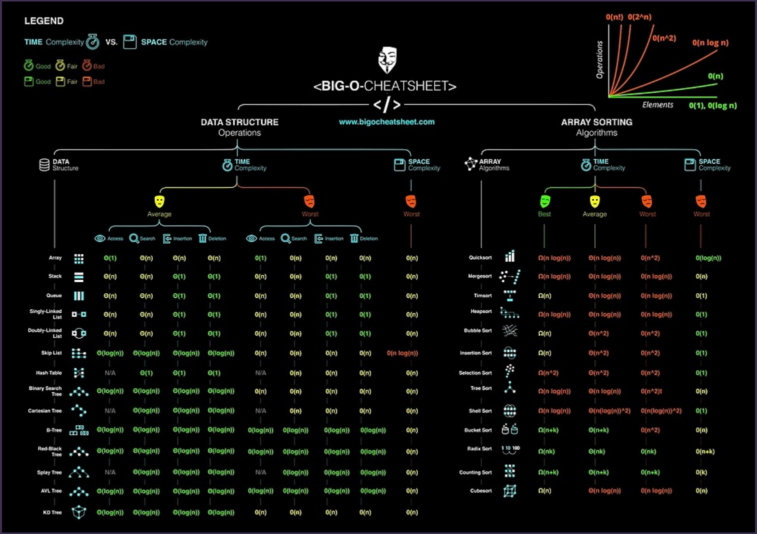
Linear - O(n)



Logarithmic - O(log(n))



Big O Cheatsheet



Data Structure	Average: Access	Average: Search	Average: Insertion	Average: Deletion	Worst: Access	Worst: Search	Worst: Insertion	Worst: Deletion	Space: Worst
Array	Θ(1)	Θ(n)	Θ(n)	Θ(n)	O(1)	O(n)	O(n)	O(n)	O(n)
Stack	Θ(n)	Θ(n)	Θ(1)	Θ(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Queue	Θ(n)	Θ(n)	Θ(1)	Θ(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Singly-Linked List	Θ(n)	Θ(n)	Θ(1)	Θ(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Doubly-Linked List	Θ(n)	Θ(n)	Θ(1)	Θ(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Skip List	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(n)	O(n)	O(n)	O(n)	O(n log(n))
Hash Table	N/A	Θ(1)	Θ(1)	Θ(1)	N/A	O(n)	O(n)	O(n)	O(n)
Binary Search Tree	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(n)	O(n)	O(n)	O(n)	O(n)
Cartesian Tree	N/A	Θ(log(n))	Θ(log(n))	Θ(log(n))	N/A	O(n)	O(n)	O(n)	O(n)
B-Tree	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)
Red-Black Tree	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)
Splay Tree	N/A	Θ(log(n))	Θ(log(n))	Θ(log(n))	N/A	O(log(n))	O(log(n))	O(log(n))	O(n)
AVL Tree	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)
KD Tree	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(n)	O(n)	O(n)	O(n)	O(n)

Array Algorithm	Time: Best	Time: Average	Time: Worst	Space: Worst
Quicksort	Ω(n log(n))	Θ(n log(n))	O(n^2)	O(log(n))
Mergesort	Ω(n log(n))	Θ(n log(n))	O(n log(n))	O(n)
Timsort	Ω(n)	Θ(n log(n))	O(n log(n))	O(1)
Heapsort	Ω(n log(n))	Θ(n log(n))	O(n log(n))	O(1)
Bubble Sort	Ω(n)	Θ(n^2)	O(n^2)	O(1)
Insertion Sort	Ω(n)	Θ(n^2)	O(n^2)	O(1)
Selection Sort	Ω(n^2)	Θ(n^2)	O(n^2)	O(1)
Tree Sort	Ω(n log(n))	Θ(n log(n))	O(n^2)t	O(n)
Shell Sort	Ω(n log(n))	Θ(n(log(n))^2)	O(n(log(n))^2)	O(1)
Bucket Sort	Ω(n+k)	Θ(n+k)	O(n^2)	O(n)
Radix Sort	Ω(nk)	Θ(nk)	O(nk)	O(n+k)
Counting Sort	Ω(n+k)	Θ(n+k)	O(n+k)	O(k)
Cubesort	Ω(n)	Θ(n log(n))	O(n log(n))	O(n)

Dynamic Array

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  - Create a new array of the appropriate size
  - Copy elements from the old array into this new one
  - Destroy the old array
  - Add in the new element
- The above process can be quite costly

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- You should consider using a Dynamic Array over a normal array
- One caveat, Dynamic Arrays are more expensive

Use Case

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- Keep track of players as they are added into the game

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- Keep track of players as they are added into the game
- Inventory systems

C++ Vector Example

```
vector<int> scores;
scores.push_back(100);
scores.push_back(200);
for (int score : scores)
{
    std::cout<<"Score is "<<score<<std::endl;
}
int player1Score=scores[0];
scores.erase(scores.begin()+1);
```

Additional Notes

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- Searching the collection is linear elements and will increase as more elements are added (O(n))
- insertion/deleting at the end of the collection is constant in performance (O(1))

Generic Types

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- This uses a concept called Templates which act in proxy for the type
- The Compiler then generates the code which uses the actual type

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- These are know as generic parameters and you should insert the data type that the collection will handle (including your own data types aka classes and structs)

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- Word of warning, it is often difficult to write generic code
- If you have errors they are often difficult to isolate as the compiler messages are so cryptic

Linked List

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- You then realise that you are adding/removing elements from the middle of the collection
- You also realise that you don't require random access to elements in the collection

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  - In C++ we have the **list** class
- Linked Lists contain elements (called Nodes) which usually have a reference (or pointer) to the previous and next Node in the list
- This means that there is a slight increase in memory needed when working with lists

Use Case

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- Your Player has a number of quests they can try and complete
- If the AI/Player carries an action and a number of systems need to be notified of the event

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C++ List Example

```
list<vec2> waypoints;

waypoints.push_back(vec2(10,10));
waypoints.push_back(vec2(15,15));
waypoints.push_back(vec2(20,20));

for(vec2 position:waypoints)
{
    std::cout<<"Waypoint Locations "<<position.x<< ↩
        " "<<position.y<<std::endl;
}
```

C++ List Example

```
waypoints.push_front(vec2(0,0));

auto iter=std::find(waypoints.begin(),waypoints.
    end(),vec2(15,15));
waypoints.insert(iter, vec3(25,25));
```

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- Also perform better than dynamic arrays for moving elements around the collection
- This feature means that Linked Lists are a good data structure if you need to sort your data
- Main drawback of Linked Lists is that you can't have direct access to elements in the list, it takes linear time (O(n)) to access

Queue

The Problem

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- Examples of this could be waypoints or commands to an AI character

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- You add elements to the end of the queue and you remove elements from the start

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- An RTS where you have a base which produces units
- A spawning system, where you have to defeat enemies in a specific order

C++ Queue Example

```
queue<Command> aiCommands;

aiCommands.push(Command("Attack"));
aiCommands.push(Command("Recharge"));
aiCommands.push(Command("Run"));
```

C++ Queue Example

```
Command nextCommand=aiCommands.front();

aiCommands.pop();
```

Stack

The Problem

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- If you need to manage the state of an AI character

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- If you need to implement a Undo system

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- This is **L**ast-**I**n-**F**irst-**O**ut data structure
- You add elements to the top of the stack and you remove elements from the top

C++ Stack Example

```
stack<AIState> aiStates;

aiStates.push(Command("Attack"));
aiStates.push(Command("Idle"));
aiStates.push(Command("Run"));
```

C++ Stack Example

```
Command lastState=aiStates.top();

aiStates.pop()
```

Associative Array: Map

The Problem

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- If you need to store one unique copy of an element
- You want to access an element via a key
- You are doing lots of searches for an element

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- It allows you to retrieve the items via the key
- This makes it a good choice for looking up large data sets

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- Localisation system, each language is stored in an Associative Array
- Unit Manager, a class to manage units created in the game
- Save Game System

C++ Map Example

```
map<string,int> highScores;

highScores["Brian"]=200;
highScores["Sarah"]=2000;
highScores["Julia"]=4000;

for(auto iter : highScores)
{
    std::cout<<"High Score "+iter.first<<" "<<iter.
        second<<std::endl;
}
```

C++ Map Example

```
auto iter=highScores.find("Brian");
if (iter!=highScores.end())
{
    int score=highScores["Brian];
}

highScores.earse("Sarah");
```

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- Associative Arrays tend to have good performance for retrieval (O (log n))
- If you add an item and its key already exists it may overwrite the value

Operations on collections

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- Most of the common data types don't need additional work
- For custom classes, we have to write our own comparison

Sorting C++

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- Which then be override by option 1
- 2 is probably the more modern way of doing it, but syntax can be confusing
- You have to include the **<algorithm>** header file

C++ Example - Sorting with Function

```cpp
struct Character
{
std::string name;
int health;
int strength;
}

bool sortByHealth(Character a, Character b){return a.health<b.health;}

//Adding omitted!
vector<Character> characters;

//Sort by health
sort(characters.begin(), characters.end(), sortByHealth);
```

C++ Example - Sorting < operator

```cpp
struct Character
{
std::string name;
int health;
int strength;

bool operator <(const Character& other) const {return
    name<other.name;}
}

//Adding omitted!
vector<Character> characters;

//Sort by health
sort(characters.begin(), characters.end());
```

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Exercise

Exercise 1 - Collections

1. Download one of the following projects as a zip file
   - BA Students - `https://github.com/Falmouth-Games-Academy/GAM160-Exercises`
   - BSc Students - `https://github.com/Falmouth-Games-Academy/COMP140-Exercises`
2. Add additional items to the collection
3. Display these to the screen

Exercise 2 - Sorting

1. Write a default sort, so that the items are sorted by name
2. Sort the collection when the **s** key is pressed
3. Write another sort, to sort by score, trigger this off by a key press
4. Write another sort, to sort by age, trigger this off by a key press

Exercise 3 - Searching

1. Investigate how to search for items in collections
2. Add code to search for specific items in the collections
3. Add visual representation to show that the search has completed, this could be a colour change or just displaying the found item elsewhere on the screen

References

https://www.geeksforgeeks.org/the-c-standard-template-library-stl/
https://www.101computing.net/big-o-notation/
http://bigocheatsheet.com/