GAM160: Further Games Programming

6: Data Structures and Collections

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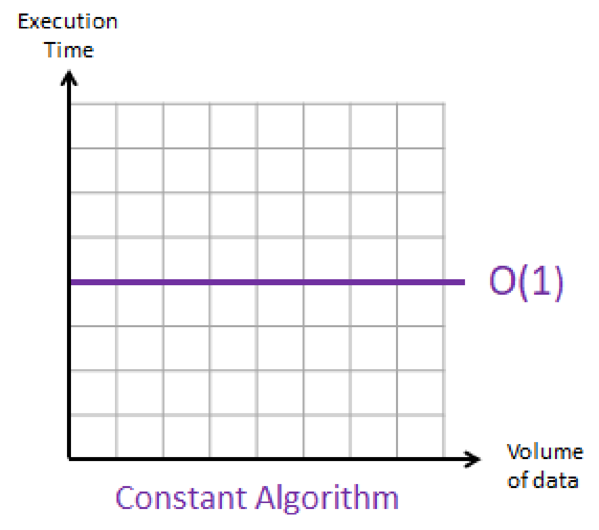
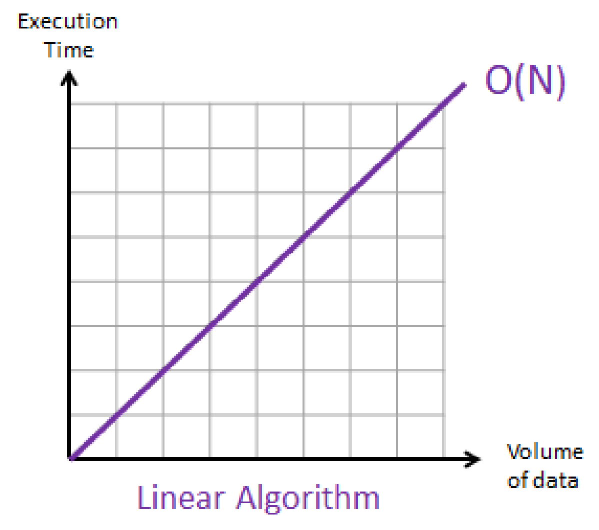
- The efficiency of an algorithm can be gauged by how long it takes
- This is know as **Time Complexity**
- **Big O Notation** is used to describe this

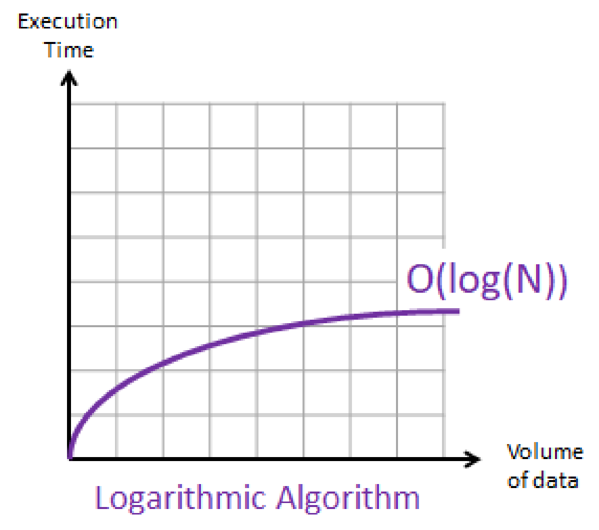
Constant - O(1)



Linear - O(n)



Logarithmic - O(log(n))



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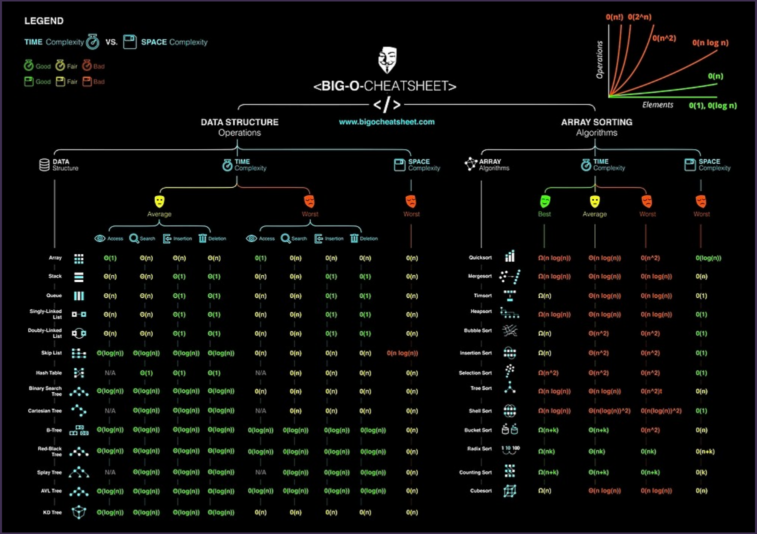
Big O Cheatsheet



Data Structure	Time Complexity: Average: Access	Average: Search	Average: Insertion	Average: Deletion	Worst: Access	Worst: Search	Worst: Insertion	Worst: Deletion	Space Complexity: 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 Algorithms	Time Complexity: Best	Average	Worst	Space Complexity: 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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  - 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 slightly 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# List Example

```
List<int> scores=new List<int>();
scores.Add(100);
scores.Add(200);
foreach(int score in scores)
{
    Debug.Log("Score is "+score.ToString());
}
int player1Score=scores[0];
scores.Remove(100);
```

Additional Notes

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

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Generic Types

Quick Aside - Generic Programming

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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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  - List<int>

Look back at List

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  - List<int>
- 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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Generic Programming

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- C# examples - `http://www.tutorialsteacher.com/csharp/csharp-generics`
- 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 **LinkedList** class
- Linked Lists contain elements (called Nodes) which usually have a reference 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

C# Linked List Example

```
LinkedList<Transform> waypoints=new LinkedList<
    Transform>();

waypoints.AddLast(GameObject.Find("Waypoint1").
    Transform);
waypoints.AddLast(GameObject.Find("Waypoint2").
    Transform);
waypoints.AddLast(GameObject.Find("Waypoint3").
    Transform);

foreach(Transfrom t in waypoints)
{
    Debug.Log("Waypoint Locations "+t.position.
        ToString());
}
```

C# Linked List Example

```
waypoints.AddFirst(GameObject.Find("Waypoint0").
    Transform);

LinkedListNode<Transform> waypoint2Node = linked.Find(
    GameObject.Find("Waypoint2"));
waypoints.AddAfter(waypoint2Node,GameObject.Find("
    SpecialQuest"));
```

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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

Use Case

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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<GameObject> unitsToBuild=new Queue<GameObject>()
    ;

unitsToBuild.Enqeue(soliderPrefab);
unitsToBuild.Enqeue(builderPrefab);
unitsToBuild.Enqeue(tankPrefab);

foreach(GameObject go in unitsToBuild)
{
    Debug.Log("Units to build "+go.name);
}
```

C# Queue Example

```
GameObject nextUnitToBuild=unitsToBuild.Peek();

unitsToBuild.Dequeue();
```

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Stack

The Problem

The Problem

- 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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  - In C# we have the **Stack** class
- 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<Command> issuedCommands=new Stack<Command>();

issuedCommands.Push(new Command("Edit"));
issuedCommands.Push(new Command("Create"));
issuedCommands.Push(new Command("Update"));
```

C# Stack Example

```
Command lastCommandIssued=issuedCommands.Peek();

Command lastCommandIssued=issuedCommands.Pop();
```

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Associative Array: Dictionary

The Problem

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- If you need to store one unique copy of an element

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- You want to access an element via a key

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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

The Solution

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  - In C# we have the **Dictionary** class
- These data structures are structured as key-value pair
- 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# Dictionary Example

```
Dictionary<string,int> highScoreTable=new Dictionary< ↩
    string,int>();

highScores.Add("Brian",200);
highScores.Add("Sarah",2000);
highScores[Julia]=4000;

foreach(KeyValuePair<string,int> pair in  ↩
    highScoreTable)
{
    Debug.Log("High Score "+pair.Key+" "+pair.Value);
}
```

C# Dictionary Example

```
if (highScores.ContainsKey("Brian"))
{
    int score=highScores["Brian"];
}

highScores.Remove("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

Sorting

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- In C#, the best sorting algorithm will be picked depending on the size of the collection
- Most of the common data types don't need additional work
- For custom classes, we have to write our own sorting algorithm

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  1. Provide a custom delegate function for the sort
  2. Provide a custom class which inherits from **IComparer**
  3. Your own class has to inherit from **IComparable**
- Often you will use option 3 as the default sort
- Which then be override by option 1

C# Example - Sorting with Delegate

```
struct Character
{
    string name;
    int health;
    int strength;
}

//Adding omitted!
List<Character> characters=new List<Character>();

//Sort by health
characters.Sort(delegate (Character c1, Character c2)
{
    return (c1.health.CompareTo(c2.health));
});
```

C# Example - Sorting with ICompareable

```
struct Character:IComparable<Character>
{
string name;
int health;
int strength;

// sort by name
 public int CompareTo(Character compareCharacter)
 {
     return name.CompareTo(comareCharacter.name);
 }
}

//Adding omitted!
List<Character> characters=new List<Character>();

//Sort will use the CompareTo in the struct or class
characters.Sort()
```

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  - Zero: The objects are in the same order
  - Greater than zero: The instance follows the one passed in

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

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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://unity3d.com/learn/tutorials/modules/intermediate/scripting/lists-and-dictionaries
https://www.101computing.net/big-o-notation/
http://bigocheatsheet.com/