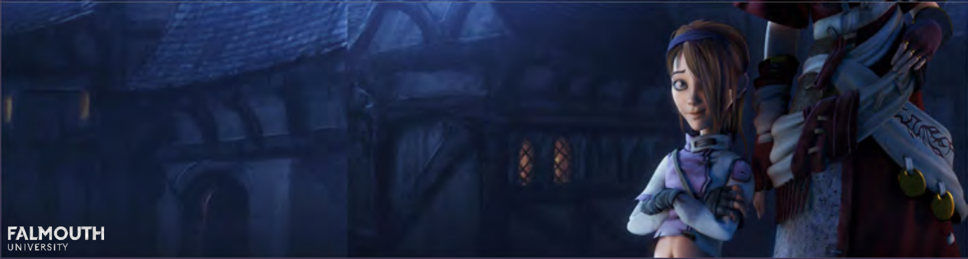

COMP110: Principles of Computing

9: Data Structures II

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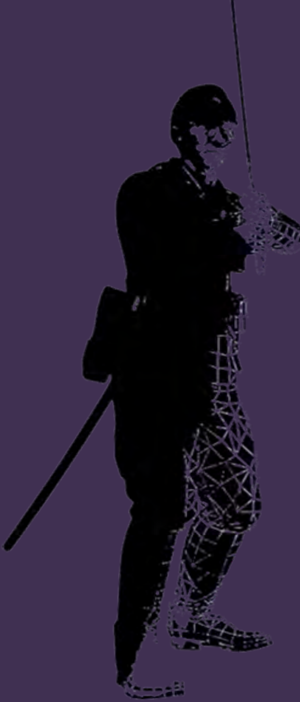

Generics in C#

The problem

- Suppose we want to define a `Pair` class to store two values
- Something like this...

```
class PairOfInts
{
    public int first;
    public int second;

    public PairOfInts(int f, int s)
    {
        first = f;
        second = s;
    }
}
```

The problem

- This is fine if we just want pairs of `int`s
- To store a pair of `string`s we would need another class:

```
class PairOfStrings
{
    public string first;
    public string second;

    public PairOfStrings(string f, string s)
    {
        first = f;
        second = s;
    }
}
```

The problem

- This quickly gets repetitive!
- We could just store a pair of `object`s — in C# `object` can store values of any type

```
class PairOfObjects
{
    public object first;
    public object second;

    public PairOfObjects(object f, object s)
    {
        first = f;
        second = s;
    }
}
```

- However this doesn't let us impose type safety

The solution

- **Generics** are a feature of C# which let us pass types as "parameters"

```
class Pair<ElementType>
{
    public ElementType first;
    public ElementType second;

    public PairOfObjects(ElementType f, ElementType s)
    {
        first = f;
        second = s;
    }
}
```

- `ElementType` can be any type

The solution

- When we instantiate the generic class, we pass in the type in angle brackets:

```
Pair<int> p1 = new Pair<int>(12, 34);
Pair<string> p2 = new Pair<string>("hello", "world");
```

Multiple parameters

- Generics can take multiple parameters:

```
class Pair<Type1, Type2>
{
    public Type1 first;
    public Type2 second;

    public PairOfObjects(Type1 f, Type2 s)
    {
        first = f;
        second = s;
    }
}
```

```
Pair<int, string> x = new Pair<int, string>(123, "hello");
```

Why generics?

- Generics let us write type safe code which can be adapted to data of different types
- Standard libraries in .NET and Unity make use of generics for e.g. collection types
- Similar to **templates** in C++

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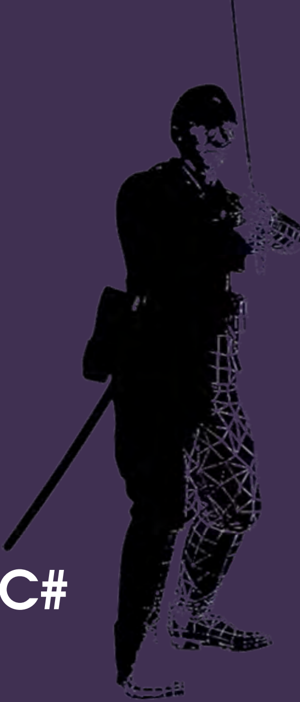

Basic data structures in C#

Classes and interfaces

- A **class** in C# defines constructors, destructor, methods, properties, fields, ...
- An **interface** defines methods and properties which a class can implement
- An interface is a little like a fully abstract class
- A class in C# can only **inherit** from one **class**, but can **implement** several **interfaces**

IEnumerable

- Most collection types in C# implement the `IEnumerable<ElementType>` interface
- This interface allows us to iterate through the elements in the collection, from beginning to end
- C# provides the **`foreach`** loop as a convenient way of using this
- $\implies$ any class which implements `IEnumerable<ElementType>` can be used with a **`foreach`** loop

Arrays

```
int[] myArray = new int[10];
int[] anotherArray = new int[] { 123, 456, 789 };
```

- `int[]` is an array of `int`s
- In general, `ElementType[]` is an array of values of type `ElementType`
- Size of the array is set on initialisation with `new`
- Array **cannot change size** after initialisation
- Use `myArray[i]` to get/set the `i`th element (starting at 0)
- Use `myArray.Length` to get the number of elements

Multi-dimensional arrays

```
int[,] myGrid = new int[20, 15];
```

- `int[,]` is a 2-dimensional array of `int`s
- Use `myArray[x, y]` to get/set elements
- Use `myArray.GetLength(0)`, `myArray.GetLength(1)` to get the “width” and “height”
- Similarly `int[,,]` is a 3-dimensional array, etc.

Lists

```
using System.Collections.Generic;

List<int> myList = new List<int>();
List<int> anotherList = new List<int> { 1, 2, 3, 4 };
```

- Like a list in Python, but can only store values of the specified type (here `int`)
- Append elements with `myList.Add()`
- Get the number of elements with `myList.Count`

Strings

```
string myString = "Hello, world!";
```

- `string` can be thought of as a collection
- In particular, it implements `IEnumerable<char>`
- So for example we can iterate over the characters in a string:

```
foreach (char c in myString)
{
    Console.WriteLine(c);
}
```

Strings are immutable

- Strings are **immutable** in C#
- This means that the contents of a string **cannot be changed** once it is created
- But wait... we change strings all the time, don't we?

```
string myString = "Hello ";
myString += "world";
```

- This isn't changing the string, it's creating a new one and throwing the old one away!
- Hence building a long string by appending can be slow (appending strings is $O(n)$)
- C# has a **mutable** string type: `StringBuilder`

Dictionaries

- Dictionaries are **associative maps**
- A dictionary maps **keys** to **values**
- Takes two generic parameters: the **key type** and the **value type**
- A dictionary is implemented as a **hash table**

Using dictionaries

```
var age = new Dictionary<string, int> {
    ["Alice"] = 23,
    ["Bob"] = 36,
    ["Charlie"] = 27
};
```

Access values using `[]`:

```
Console.WriteLine(age["Alice"]);  // prints 23
age["Bob"] = 40;          // overwriting an existing item
age["Denise"] = 21;       // adding a new item
age.Add("Emily", 29);     // adding a new item -- will raise
                          // an error if already present
```

Iterating over dictionaries

- `Dictionary<Key, Value>` implements `IEnumerable<KeyValuePair<Key, Value>>`
- `KeyValuePair<Key, Value>` stores `Key` and `Value`

```
foreach (var keyValue in age)
{
    Console.WriteLine("{0} is {1} years old",
                      kv.Key, kv.Value);
}
```

- (C# tip: the `var` keyword lets the compiler automatically determine the appropriate type to use for a variable)
- Dictionaries are **unordered** — avoid assuming that `foreach` will see the elements in any particular order!

Hash sets

- Sets are **unordered** collections of **unique** elements
  - Sets **cannot** contain **duplicate** elements
  - Attempting to `Add` an element already present in the set does nothing
- `HashSet`s are like `Dictionary`s without the values, just the keys
- As discussed in Week 5, certain operations are much more efficient (constant time) on hash sets than on lists

Using sets

```
var numbers = new HashSet<int>{1, 4, 9, 16, 25};
```

Add and remove members with `Add` and `Remove` methods

```
numbers.Add(36);
numbers.Remove(4);
```

Test membership with `Contains`

```
if (numbers.Contains(9))
    Console.WriteLine("Set contains 9");
```

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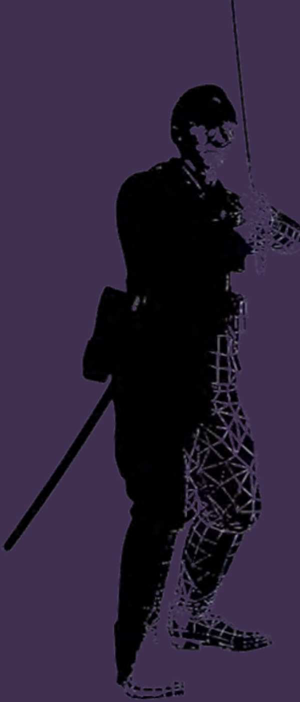
Linked lists



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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 **previous node** in the list (null for the first item)
  - A pointer or reference to the **next node** in the list (null for the last item)
- The nodes are **not necessarily contiguous** in memory, unlike an (array-backed) list

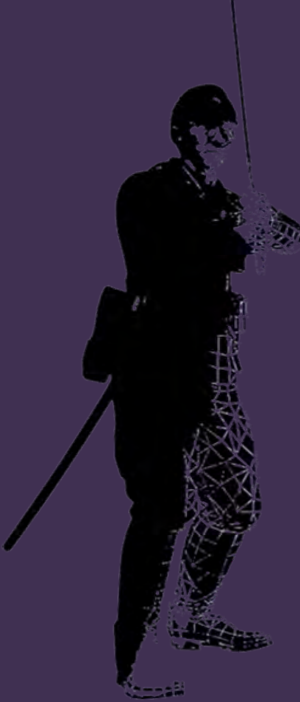
- In C#: `LinkedList<ElementType>`

Operations on linked lists

Linked lists vs array-backed lists

- **Inserting** and **removing** from the middle of an array list requires shuffling the following elements to make or fill space
- This makes these operations $O(n)$
- Linked list doesn't require this shuffling, so inserting and deleting is $O(1)$
- However...
- **Finding the *i*th element** of an array list is simple pointer arithmetic, which is $O(1)$
- In a linked list we have to count along the "next" pointers, which is $O(i)$
- So which data structure is more efficient? It depends what operations we need to do more often

Workshop



Workshop Activity

- **Priority 1**: check you have submitted your research journal!
- Then, in your **breakout groups** (from week 2 on LearningSpace):
- I have put a Word document in your room on Teams (Files tab) — you can edit this collaboratively
- For a variety of C# collection types:
  - What operations are possible?
  - How are they done?
  - What is their time complexity?
  - What is an example scenario where this data structure is appropriate?
- Use the **Microsoft .NET documentation** along with **googling** and **experimentation** to find out!
- Reconvene here at **5:45pm** to compare notes