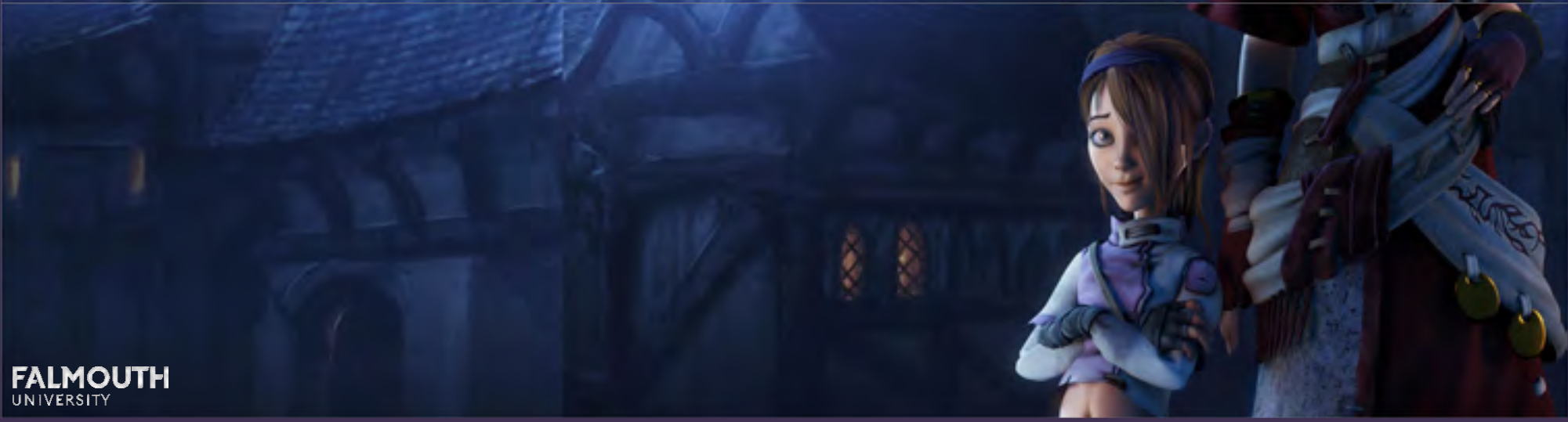

COMP110: Principles of Computing

9: Data Structures II

Worksheets Resume

Worksheet 6 is out now!
Formative deadline: next Friday

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Basic data structures in C# (continued from last time)

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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Pass by reference

References

- Our picture of a variable: a labelled box containing a value
- For "plain old data" (e.g. numbers), this is accurate
- For **objects** (i.e. instances of classes), variables actually hold **references** (a.k.a. **pointers**)
- It is possible (indeed common) to have **multiple references** to the same underlying object

The wrong picture

```
class Thing
{
    public int a, b;

    public Thing(int a_, int b_)
    {
        a = a_; b = b_;
    }
}

Thing x = new Thing(30, 40);
Thing y = new Thing(50, 60);
Thing z = y;
```

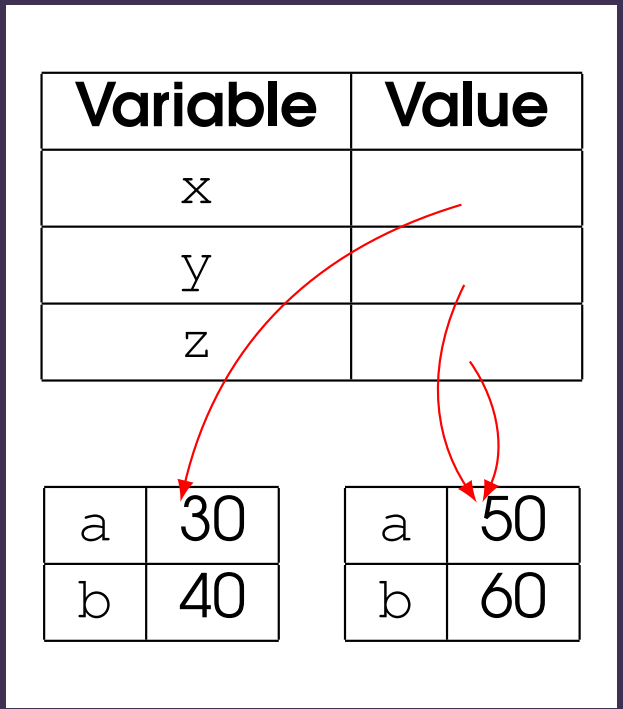
Variable	Value	
x	a	30
	b	40
y	a	50
	b	60
z	a	50
	b	60

The right picture

```
class Thing
{
    public int a, b;

    public Thing(int a_, int b_)
    {
        a = a_; b = b_;
    }
}

Thing x = new Thing(30, 40);
Thing y = new Thing(50, 60);
Thing z = y;
```



Values and references

Socrative room code: `FALCOMPED`

```
int a = 10;
int b = a;
a = 20;
Console.WriteLine($"a: {a}");
Console.WriteLine($"b: {b}");
```

Values and references

Socrative room code: FALCOMPED

```
class Foo
{
    public int value;

    public Foo(int v)
    {
        value = v;
    }
}

Foo a = new Foo(10);
Foo b = a;
a.value = 20;
Console.WriteLine($"a: {a.value}");
Console.WriteLine($"b: {b.value}");
```

Values and references

Socrative room code: FALCOMPED

```
class Foo
{
    public int value;

    public Foo(int v)
    {
        value = v;
    }
}

Foo a = new Foo(10);
Foo b = new Foo(10);
a.value = 20;
Console.WriteLine($"a: {a.value}");
Console.WriteLine($"b: {b.value}");
```

References and values — an analogy

- Suppose you are sending someone a document
- Pass **by value** is like sending a .docx file — the recipient gets their own copy
- Pass **by reference** is like sending a Google Docs link — there is one copy, which the recipient can potentially edit

Pass by value

Socrative room code: `FALCOMPED`

In **function parameters**, "plain old data" is passed by **value**

```
void doubleIt(int x)
{
    x = x * 2;
}

int a = 7;
doubleIt(a);
Console.WriteLine(a);
```

What does it print?

Pass by reference

Socrative room code: FALCOMPED

However, objects (class instances) are passed by **reference**

```
class Foo
{
    public int value;
    public Foo(int v) { value = v; }
}

void doubleIt(Foo x)
{
    x.value = x.value * 2;
}

Foo a = new Foo(7);
doubleIt(a);
Console.WriteLine(a.value);
```

What does it print?

Lists are objects too

```
List<string> a = new List<string>{ "Hello" };
List<string> b = a;
b.Add("world");
foreach (string word in a)
{
    Console.WriteLine(word);
}
// Output:
//   Hello
//   world
```

... which means you should be careful when passing lists into functions, because the function might actually change the list!

Pass by value again

In C#, struct instances are passed by **value**

```
struct Foo
{
    public int value;
    public Foo(int v) { value = v; }
}

void doubleIt(Foo x)
{
    x.value = x.value * 2;
}

Foo a = new Foo(7);
doubleIt(a);
Console.WriteLine(a.value);
```

This prints 7

By reference or value?

- In C#, these function arguments are passed **by value**:
  - Basic data types (`int`, `bool`, `float` etc)
  - Instances of `struct`s
- These function arguments are passed **by reference**:
  - Instances of `class`es — this includes classes built into .NET or Unity etc
  - Arguments with the `ref` keyword attached
- Passing by value implies copying — not a problem for small data values but beware of passing large structs around

References and pointers

- Some languages (e.g. C, C++) use **pointers**
- Pointers are a type of reference, and have the same semantics
- References in other languages (e.g. C#, Python) are implemented using pointers
- C++ also has something called references, which are similar but different (pointers can be **retargeted** whilst references cannot)
- Implementation-wise, a pointer is literally just a memory address (i.e. a number)

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Stacks and queues

Stacks and queues

- A **stack** is a **last-in first-out (LIFO)** data structure
- Items can be **pushed** to the **top** of the stack
- Items can be **popped** from the **top** of the stack

- A **queue** is a **first-in first-out (FIFO)** data structure
- Items can be **enqueued** to the **back** of the queue
- Items can be **dequeued** from the **front** of the queue

Implementing stacks

- Stacks can be implemented efficiently as lists
- Top of stack = end of list
- To push an element, use `Add` — $O(1)$ complexity
- To pop an element we can do something like this:

```
x = myStack[myStack.Count - 1];
myStack.RemoveAt(myStack.Count - 1);
```

- This is also $O(1)$

Implementing queues

- Queues can be implemented as lists, but not efficiently
- End of list = back of queue
- Enqueue using `Add` — $O(1)$ complexity
- Dequeue by retrieving and removing from beginning of list:

```
x = myQueue[0];
myQueue.RemoveAt(0);
```

- This is $O(n)$

Implementing queues

- End of list = front of queue
- Dequeue is like popping from end of list — $O(1)$ complexity
- Enqueue using `Insert(0, x)` — $O(n)$ complexity

Using stacks and queues

- C# has `Stack` and `Queue` classes which you should use instead of trying to use a list
- Python has `deque` (double-ended queue) which can work as either a stack or a list

Stacks and function calls

- Stacks are used to implement **nested function calls**
- Each invocation of a function has a **stack frame**
- This specifies information like **local variable values** and **return address**
- Calling a function **pushes** a new frame onto the stack
- Returning from a function **pops** the top frame off the stack
- Hence the term **stack trace** when using the debugger or looking at error logs
- More on this next week when we look at **recursion**

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Workshop

Workshop

Begin working on Worksheet 6
I am available for the rest of the session if you run into any problems!
(Or if you have any general questions etc.)