COMP110: Principles of Computing

8: Data Structures I

Arrays and lists

Memory allocation — recap

- Memory is allocated in **blocks**
- The program specifies the size, in bytes, of the block it wants
- The OS allocates a **contiguous** block of that size
- The program owns that block until it frees it
- Blocks can be allocated and deallocated at will, but can **never grow or shrink**

Collection types

- Memory management is hard and programmers are lazy
- Collections are an **abstraction**
  - Hide the details of memory allocation, and allow the programmer to write simpler code
- Collections are an **encapsulation**
  - Bundle together the data's representation in memory along with the algorithms for accessing it

Arrays

- An **array** is a contiguous block of memory in which objects are stored, equally spaced, one after the other
- Each array element has an **index**, starting from zero
- Given the address of the 0th element, it is easy to find the *i*th element:

$$\text{address}_i = \text{address}_0 + (i \times \text{elementSize})$$

- E.g. if the array starts at address 1000 and each element is 4 bytes, the 3rd element is at address $1000 + 4 \times 3 = 1012$
- Accessing an array element is **constant time** $O(1)$

Lists

- An array is a block of memory, so its size is **fixed** once created
- A **list** is a variable size array
- When the list needs to change size, it **creates** a new array, **copies** the contents of the old array, and **deletes** the old array

Arrays and lists in C#

```
int[] myArray = new int[10];

int[] myOtherArray = new int[] { 2, 3, 5, 7, 11 };

List<int> myList = new List<int>();

List<int> myOtherList = new List<int> { 2, 3, 5, 8, 13 };
```

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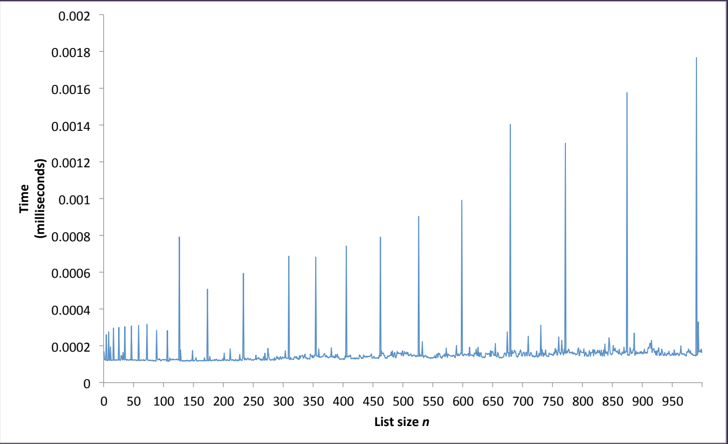
Time taken to append an element to a list of size *n*



Operations on lists

- **Appending** to a list is **amortised constant time**
  - Usually $O(1)$, but can go up to $O(n)$ if the list needs to change size
- **Inserting** anywhere other than the end is **linear time**
  - Can't just insert new bytes into a memory block — need to move all subsequent list elements to make room
- Similarly, **deleting** anything other than the last element is **linear time**

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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

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;
```

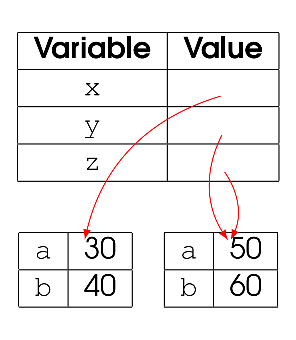
Variable	Value	
x	a	30
	b	40
y	a	50
	b	60
z	a	50
	b	60

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}");
```

Pass by value

Socrative room code: `FALCOMPED`

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

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

int a = 7;
double(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 double(Foo x)
{
    x.value = x.value * 2;
}

Foo a = new Foo(7);
double(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 double(Foo x)
{
    x.value = x.value * 2;
}

Foo a = new Foo(7);
double(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)

Pointers

- Recall that memory is a series of 1-byte locations, each with a numeric **address**
- A **pointer** to something is simply the **address** at which it starts
- When allocating a block of memory, the OS returns a pointer to the start of the block
- When the memory is freed, any pointers into it are said to be **dangling**
- If the memory is subsequently reused for something else, those pointers could end up pointing to random data
- Again this is not really possible in Python/C#, but a common source of bugs in C/C++

Workshop time

Workshop

- Continue working on your **research journal** to prepare for the peer review on Thursday
- Today, pay particular attention to your **bibliography**
- Common pitfalls to watch out for:
  - Do entries have all required fields?
  - Are proper nouns etc in titles correctly capitalised?
  - Are names with accented characters properly formatted?
  - Are there duplicate entries?
- Feel free to use your breakout groups (from previous weeks) to check each other's bibliographies over and help each other fix any issues
- Post in chat here if you have questions or problems!