COMP 322: Introduction to C++

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Lecture 3
(Variable life cycle & Pointers)

- Function Overloading
- Scope and lifetime of a variable
- Pointers

Function overloading

- **What's the output of the following code?**

```
#include <iostream>

int absValue(int i);


int main()
{
  std::cout << absValue(-4.3);
}

int absValue(int i)
{
    if (i>=0)
        return i;
    else
        return -i;
}
```

Function overloading

- **What's the output of the following code? (answer is 4 because of implicit conversion from double to int)**

```
#include <iostream>

int absValue(int i);


int main()
{
  std::cout << absValue(-4.3);
}

int absValue(int i)
{
    if (i>=0)
        return i;
    else
        return -i;
}
```

Function overloading

- Multiple functions may have the same name but different number of arguments
  - `int max(int i, int j);`
  - `int max(int i, int j, int k);`
- Multiple functions may have the same name and same number of arguments but different types
  - `int max(int i, int j);`
  - `float max(float i, float j);`
- Changing only the return type is not enough

Function overloading

```
int absValue(int i);
double absValue(double i);

int main()
{
  std::cout << absValue(-4.3);
}

int absValue(int i)
{
    if (i>=0)
        return i;
    else
        return -i;
}

double absValue(double i)
{
    if (i>=0)
        return i;
    else
        return -i;
}
```

Quiz

- **Rewrite the absolute value function from previous example using the ternary operator ?:**

Quiz

- **Rewrite the absolute value function from previous example using the ternary operator ?:**

```
int absValue(int i);
double absValue(double i);

int main()
{
  std::cout << absValue(-4.9);
}

int absValue(int i)
{
    return i>=0?i:-i;
}

double absValue(double i)
{
    return i>=0?i:-i;
}
```

More about variables ...

- Variables have:
    - Name
    - Type
    - Address
    - Scope
    - Life span

Scope and lifetime of a variable

- When declaring variables we specify the name and type, but we should also keep in mind their scope and lifetime
- Scope of a variable
  - A section of the program where the variable is visible (accessible)
- Lifetime of a variable
  - The time span where the state of a variable is valid (meaning that the variable has a valid memory)

Scope and lifetime of a variable

- **Local variables (that are non-static) have their lifetime ends at the same time when their scope ends**
  - **Local variables may also be called automatic variables because they are automatically destroyed at the end of their scope**
  - **Scope of local variables is comprised from the moment they are declared until the end of the block or function where they reside (in other terms, until the execution hits a closing bracket })**

Scope and lifetime of a variable

- **Local variables (that are non-static) have their lifetime ends at the same time when their scope ends**

```
int main()
{
    int x;
    x = 5;
    {
        int y;
        y = 9;
        cout << x << endl;
    }
    cout << y << endl; // ERROR:symbol y cannot be resolved
}
```

Scope and lifetime of a variable

- Global variables have their lifetime ends when the execution of the program ends
  - Usually declared at the top of the file outside of any function or block
  - They have global scope

```
int x; // global variable

void someFunction()
{
    // do something with x
}

int main()
{
    // do something with x
}
```

Scope and lifetime of a variable

- **Dynamically allocated variables have their lifetime starts when we explicitly allocate them (operator new, or malloc) and ends when we explicitly deallocate them (operator delete, or free)**
  - **Their lifetime is not decided by their scope (they may live even when they are out of scope)**
  - **We will get back to this in later chapters**
  - **The sample code provided has a memory leak**
  - **and assuming that someFunction() was being called before the cout statement.**

```
#include <iostream>

void someFunction()
{
    int* var = (int*) malloc (sizeof(int));
    *var = 12;
}

int main()
{
  std::cout << *var; // ERROR: var was not
                     // declared in this scope
}
```

Scope and lifetime of a variable (static)

- **Global static variables have their lifetime ends when the execution of the program ends but their scope is limited to the file in which they are declared (file scope)**
  - **Scope is affected (reduced) but not the lifetime**

```
#include <iostream>

static int x; // static global variable

void someFunction()
{
    // do something
}

int main()
{
    // do something
}
```

Scope and lifetime of a variable (static)

- **Local static variables have their lifetime ends when the execution of the program ends but their scope is limited to the function in which they are declared (function scope)**
  - **Lifetime is affected (extended) but not the scope**

```
#include <iostream>

int someFunction()
{
    static int x = 0;
    return ++x;
}

int main()
{
    std::cout << someFunction() << std::endl;
    std::cout << someFunction() << std::endl;
    std::cout << someFunction() << std::endl;
}
```

Pointers - Introduction

- Regular variables:
  - Are locations in memory
  - When declared, a memory address is automatically assigned
  - We don't care about their physical address
  - Accessible by their names
- Use the address operator & to get the physical address of a variable

```
int var;
cout << &var;
```

Output would be something similar to 0x7ffc8e229ddc

Pointers - Introduction

- To store the address of a memory location in a variable, we need a special type of variables called pointer variable
  - Use the dereference operator * to declare a pointer variable
  - int *ptr = &var;
    - ptr is a pointer variable
    - ptr stores the address of the variable var
    - ptr is pointing to var
    - ptr and &var are exactly the same thing
    - *ptr and var are exactly the same thing
    - The type of a pointer variable should match the type of the variable whose address is being stored: var is of type int, so *ptr should be of type int as well.

Pointers - Introduction

- Spaces don't matter when declaring pointers. The following declarations are all equivalent:
  - int *ptr;
  - int* ptr;
  - int * ptr;
- Be careful when declaring multiple variables on the same line
  - int * ptr1, ptr2;
    - Only one pointer is being declared
    - ptr2 is not a pointer, it is simply an integer variable
  - int *ptr1, *ptr2;
    - Both variables are pointers

Pointers - code example

What's the output of the following code?

```
// main function
int main()
{
	int a = 7, b = 9;
	int *ptr1;
	int *ptr2 = &b;
	ptr1 = &a;

	*ptr1 = 15;
	*ptr2 = *ptr1;

	cout << a << '\n';
	cout << b << '\n';
	return 0;
}
```

Pointer Arithmetics

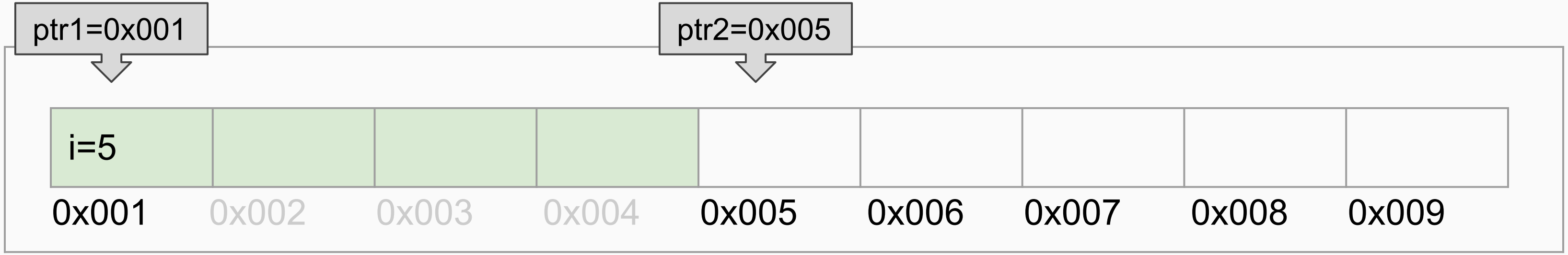
- Used to jump to different memory locations
- Only addition and subtraction (no multiplication and division)
- When you increment a pointer by one, it points to the next memory location
- Result depends on the size of the data type to which the pointer is pointing

Pointer Arithmetics

- Imagine the memory as a table. Each cell is an element
- char *ptr; // ptr is a pointer of type char. Assuming that sizeof(char) = 1 byte
  - ++ptr; // will point to the next byte in the memory table (unless the compiler is applying memory padding or alignment for optimization)
- int *ptr; // ptr is a pointer of type int. Assuming that sizeof(int) = 4 bytes
  - ++ptr; // will point to a location that is 4 bytes away in the memory table

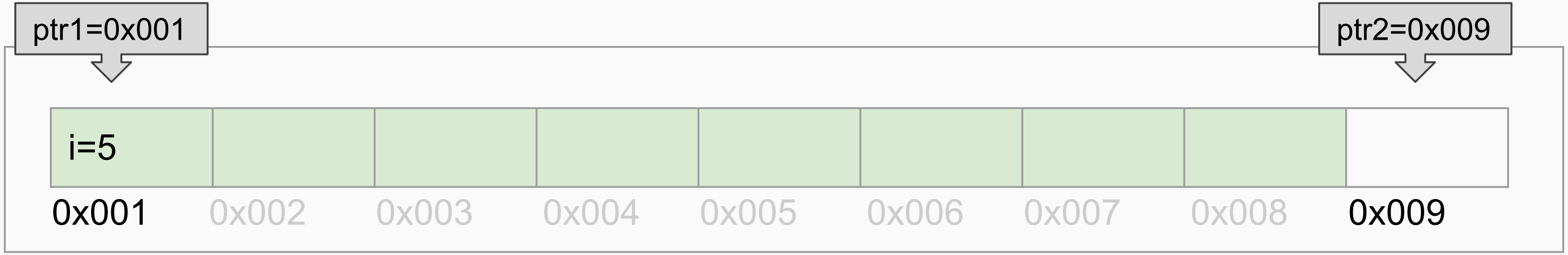
Pointer Arithmetics

- int i = 5;
- int *ptr1 = &i; // ptr1 is a pointer of type int. Assuming that sizeof(int) = 4 bytes
- int *ptr2 = ++ptr1; // will point to a location that is 4 bytes away in the memory table



Pointer Arithmetics

- double i = 5;
- double *ptr1 = &i; // ptr1 is a pointer of type double. Assuming that sizeof(double) = 8 bytes
- double *ptr2 = ++ptr1; // will point to a location that is 8 bytes away in the memory table



Pointers - Example 1

```
int main()
{
    int value = 100;
    int* pValue = &value;
    cout << "Value is equal to: " << *pValue << endl;
    cout << "Address of value = " << pValue << endl;
}
```

The output is:

```
Value is equal to: 100
Address of value = 0x7fff69d9b6b8
```

Pointers - Common mistakes

- Dereferencing invalid pointers
  - Uninitialized pointers point to random memory location

```
int main()
{
    int *ptr; // non-initialized pointer
              // points to random memory location
    *ptr = 12; // memory corruption

}
```

Pointers - Common mistakes

- Good practice to always:
  - assign pointers to NULL (or nullptr since Cx11) when they point to nothing
  - check if the pointer is not null before dereferencing it

```
int main()
{
    int *ptr = NULL;
    if (ptr != NULL)
    {
        cout << *ptr << endl;
    }
    else
    {
        cout << "pointer is NULL" << endl;
    }

}
```

Pointers - Common mistakes

- Mixing operator precedence rules to accidentally apply arithmetics on pointers instead of the value being pointed to
    - *++ptr; vs ++*ptr; // remember that ++ has higher precedence than *

Pointers - Example 2

```
int main()
{
    int value = 100;
    int* pValue = &value;
    cout << "Value is equal to: " << *pValue << endl;
    cout << "Address of value = " << pValue << endl;
    cout << ++*pValue << endl; // dereference the pointer
                               // then increment its value
    cout << *++pValue << endl; // increment the address of value
                               // then dereference the pointer
    cout << ++pValue << endl;  // increment the address of value
                               // to point to next memory location
}
```

The output is:

```
Value is equal to: 100
Address of value = 0x7ffcf1de7f34
101
-237076680
0x7ffcf1de7f3c
```

Pointers - Example 3

- What's wrong with the following function?

```
float *getPricePointer()
{
    float price = 9.99;
    return &price;
}
```

Pointers - Example 3

- What's wrong with the following function?
  - getPricePointer is returning the address of a local variable.
  - Local variables have limited scope and lifetime
  - price will be automatically destroyed as soon as the function returns
  - Its address will be pointing to an invalid memory location

```
float *getPricePointer()
{
    float price = 9.99;
    return &price;
}
```

Reference variables

- Reference variable is a C++ concept that doesn't exist in C
- Reference permits to assign multiple names to the same variable
- To declare a reference variable we use the address & operator
- int x;
- int &y = x; // be careful not to confuse with int *y = &x;
  - y is a reference to x
  - y is considered to be an alias for x
  - y and x are the same thing
  - y and x are two names for the same memory location

Reference variables - Example

```
int main()
{
    int a = 100;
    int &b = a;
    cout << "a = " << a << endl;
    cout << "b = " << b << endl;
    b = 12;
    cout << "a = " << a << endl;
    cout << "b = " << b << endl;

}
```

The output is:

```
a = 100
b = 100
a = 12
b = 12
```

Passing arguments by reference

By Value

```
#include <iostream>
using namespace std;

int getProduct(int x, int y)
{
	return x*y;
}

// main function
int main()
{
		int a = 4;
		int b = 5;
		int product = getProduct(a, b);
		cout << product;
}
```

By Reference

```
#include <iostream>
using namespace std;

int getProduct(int &x, int &y)
{
	return x*y;
}

// main function
int main()
{
		int a = 4;
		int b = 5;
		int product = getProduct(a, b);
		cout << product;
}
```

Passing arguments by reference

By Pointer

```
#include <iostream>
using namespace std;

int getProduct(int* x, int* y)
{
    return (*x)*(*y);
}

// main function
int main()
{
    int a = 4;
    int b = 5;
    int product = getProduct(&a, &b);
    cout << product;
}
```

By Reference

```
#include <iostream>
using namespace std;

int getProduct(int &x, int &y)
{
    return x*y;
}

// main function
int main()
{
        int a = 4;
        int b = 5;
        int product = getProduct(a, b);
        cout << product;
}
```

Reference variables vs pointers

- Reference variables must be initialized
  - `int &x = var;`
- Reference variable cannot be changed to reference another variable
  - Similar to constant pointers
- Unlike pointers, references cannot be NULL
- Pointer has its own memory address whereas a reference shares the same memory address with the variable it is referencing
- Reference variables are very commonly used as function parameters
  - Better performance by avoiding copying values
- References are safer than pointers so they are preferred to pointers whenever you have the choice (if there is no need for dynamic allocation)

Pointers - are they worth the headache?

- Pointers are used for
  - Efficiency (no need to statically reserve a huge array in advance)
  - Implementation of complex data structures
  - Dynamic allocation of memory
  - Passing functions as parameters
  - Many advanced C++ techniques
- Misusing pointers is the mother of all software bugs
  - Memory leaks
  - Dangling pointers
  - Buffer overflow
  - Abduction by aliens … :)

Pointers - confusing the cat (C++ interview question)

- **What's the output of the following code:**

```
int main()
{
    int *ptr = NULL;
    int i = 7;  i++;
    for(int j=0; j<=2; j++) {
        i = j;
    }
    ptr = &i;
    if (ptr != NULL) {
        (*ptr) *= (*ptr);
    }

    if (ptr != NULL) {
        cout << (*ptr)++ << endl;
        cout << i << endl;
    }
    else {
        cout << "pointer is NULL" << endl;
    }
}
```

Pointers - confusing the cat (C++ interview question)

- **What's the output of the following code: 4, 5**

```
int main()
{
    int *ptr = NULL;
    int i = 7;  i++;
    for(int j=0; j<=2; j++) {
        i = j;
    }
    ptr = &i;
    if (ptr != NULL) {
        (*ptr) *= (*ptr);
    }

    if (ptr != NULL) {
        cout << (*ptr)++ << endl;
        cout << i << endl;
    }
    else {
        cout << "pointer is NULL" << endl;
    }
}
```

Research the following topics for next week

- Const pointers
- Null pointers
- Pointers to pointers
- Relationship between pointers and arrays