COMP 322: Introduction to C++

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Lecture 4
(Pointers & references)

- Pointers
- References
- Passing arguments by reference

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?

```
12 // main function
13 int main()
14 {
15       int a = 7, b = 9;
16       int *ptr1;
17       int *ptr2 = &b;
18       ptr1 = &a;
19
20       *ptr1 = 15;
21       *ptr2 = *ptr1;
22
23       cout << a << '\n';
24       cout << b << '\n';
25       return 0;
26 }
```

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

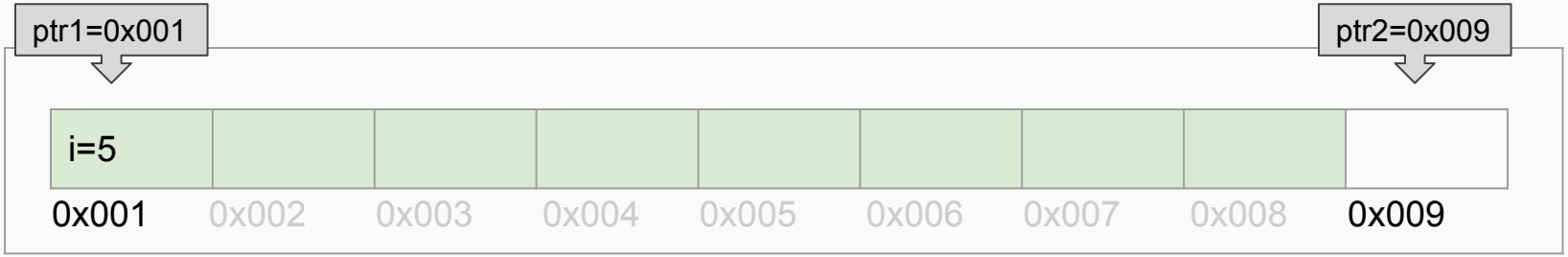
- Imagine the memory as a table. Each cell is an element
- char *ptr; // ptr is a pointer of type char. Assuming that sizeof(char) = 1 byte
  - ptr++; // will point to the next byte in the memory table (unless the compiler is applying memory padding or alignment for optimization)
- int *ptr; // ptr is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

```
1  #include <iostream>
2  using namespace std;
3
4  int getProduct(int x, int y)
5  {
6      return x*y;
7  }
8
9  // main function
10 int main()
11 {
12       int a = 4;
13       int b = 5;
14       int product = getProduct(a, b);
15       cout << product;
16 }
```

By Reference

```
1  #include <iostream>
2  using namespace std;
3
4  int getProduct(int &x, int &y)
5  {
6      return x*y;
7  }
8
9  // main function
10 int main()
11 {
12       int a = 4;
13       int b = 5;
14       int product = getProduct(a, b);
15       cout << product;
16 }
```

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

```
1  #include <iostream>
2  using namespace std;
3
4  int getProduct(int &x, int &y)
5  {
6      return x*y;
7  }
8
9  // main function
10 int main()
11 {
12       int a = 4;
13       int b = 5;
14       int product = getProduct(a, b);
15       cout << product;
16 }
```

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;
    }
}
```

Reading assignment for next week

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