

WEEK 2

Foundational Ideas &
Dynamic Memory

AGENDA

- Week 2-1
 - Types
 - Declarations and Definitions
 - Header File Includes Ordering
 - Scope and Function Overloading
 - References and Array of Pointers
- Week 2-2
 - Dynamic Memory, Debugging

WEEK 2-1

Types, Declarations, Scope, Overloading, References, Array of
Pointers

| Reviewing old and new ideas

TYPES

- As C++ is an extension of the C programming language, the types that can be used in C++ are inherited from C with some additions
- These fundamental types include:
 - **char**
 - **int** (**short**, **long**, **long long**)
 - **float** (**double**, **long double**)
 - **bool** – Note **bool** is not available in C

TYPES - BOOL

- The bool type is used to store a logical true/false value. Eg `bool x = true;`
- The value of a bool type can be inverted with the use of the `!` negation operator
 - `!x` – If `x` is true then it is now negated to be false.
- Conversions from bool to int and vice versa generally produce values of 0 and 1. Wherein `false` is equated to 0 and `true` is relegated to 1 (however any non-zero number is considered to be `true`)

TYPES

- Compound types are types that are composed of other (**fundamental**) types
- You may already know these from **C** as **structs**
- In **C++** there are also **classes** which we'll delve into in the following weeks

TYPES - AUTO

- A keyword that was introduced in C++11, the 2011 standard of the language is the auto
- auto is used in place of a type when initializing a variable
 - `int x = 3;` vs `auto x = 3;`

TYPES - AUTO

- The auto keyword is able to determine the type of the variable x through the value given from the right
 - `auto x = 3; // 3 is an integer value so the type of x is also an int`
- auto is useful in that we don't need explicitly specify the type of things if it can be determined by the compiler and if the types we want to use are lengthy to type

DECLARATIONS

- Declaration is the process of assigning a type to an entity (or a name). The entity can be a variable, an object, a function...
- The type we assign to it allow for the C++ compiler to understand what sort of meaning lies with this entity and how it should be interpreted

DECLARATIONS

- An example of a declaration could be this function:
 - `double minus(double a, double b);`
 - This declares a function that perhaps performs subtraction between two double numbers and returns the result
 - Note that it doesn't have a definition yet.

DECLARATIONS

- There is a certain type of declaration called the **forward declaration**
- This sort of declaration is statement to indicate to the C++ compiler of an entity that will be used but is perhaps not yet defined in full.
- The **forward declaration is like a prototype in the header file**

DEFINITIONS

- Definitions are the meanings or implementation of a declared entity such as the contents of a function.
- From our previous minus function its definition could be as follows:

```
double minus(double a, double b) {  
    return a - b;  
}
```
- As perhaps alluded to previously in our stint with namespaces there is the idea of a one definition rule where a definition may only occur once with in a particular scope

DECLARATIONS AND DEFINITIONS

- Declarations aren't necessarily definitions as the former doesn't associate meaning to an entity while the latter does.
- When considering the declaration and definitions of entities in our programs we mainly want to structure them in a way that avoids breaking the one definition rule
- This idea will lead to thinking about how we include header files and perhaps where we should be placing our definitions

HEADER FILE INCLUDE ORDERING

- When including header files in any portion of your code there is a standard ordering that should be adhered to:
 1. Include **system libraries / headers first** – eg `#include <iostream>`
 - System libraries are typically enclosed by the `<>` symbols
 2. Include **other libraries / headers second** – eg `#include "libx"`
 3. Include **your own libraries / headers last** – eg `#include "mylib"`
 4. After all these includes is when you can specify **namespaces** and other **directives** – eg using `namespace ...`

DECLARATIONS – DEFAULT PARAMETER VALUES

- If desired, function parameters can have default values to them if they aren't supplied
- The syntax for it looks like the following:
`double minus(double a, double b = 5.0);`
- The parameters that have default values have to be placed on the most **right side of the parameter list**.
- The function can now then be called without specifying anything for the **b** variable:
 - `double x = minus(4.0) // One parameter; a = 4.0, b = 5.0`
 - `double x = minus(4.0, 1.0) // Two parameters; a = 4.0, b = 1.0`

SCOPE

- The idea of **scope** equates to the portion of code **where a declaration is visible, normally defined by the {} brackets**
- There are a few different levels of scoping:
 - **Global** scope – visible to the **whole program**
 - **File** scope – visible to just the **code within a file**
 - **Function** scope – visible to the **length of a function**
 - **Class** scope – visible to the **functions of the class**
 - **Block** scope – visible to the **code block**
- The scope of a declaration can be said to be **local** to one of the above levels

SCOPE EX 1

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

int main(){

    int x = 3;
    cout << "What is x1: " << x << endl;

    { // This starts a 'block'
        int x = 5;
        cout << "What is x2: " << x << endl;
    } // This ends a 'block'

    cout << "What is x3: " << x << endl;
}
```

What is x during these print outs? 

SCOPE EX 2

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

int main(){

    for (int x = 0; x < 10; x++){
        cout << x;
    } // x goes out of scope here at the end of the block

    cout << x << endl; // x can no longer be accessed here
    return 0;
}
```



SCOPE EX 3 - SHADOWING

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

int main(){

    int x = 22;
    for (int x = 0; x < 10; x++){
        cout << x << endl; // this x local to the scope of the loop ‘shadows’ the other x
    } // This inner x goes out of scope here at the end of the block

    cout << x << endl; // prints 22 here at the end
    return 0;
}
```

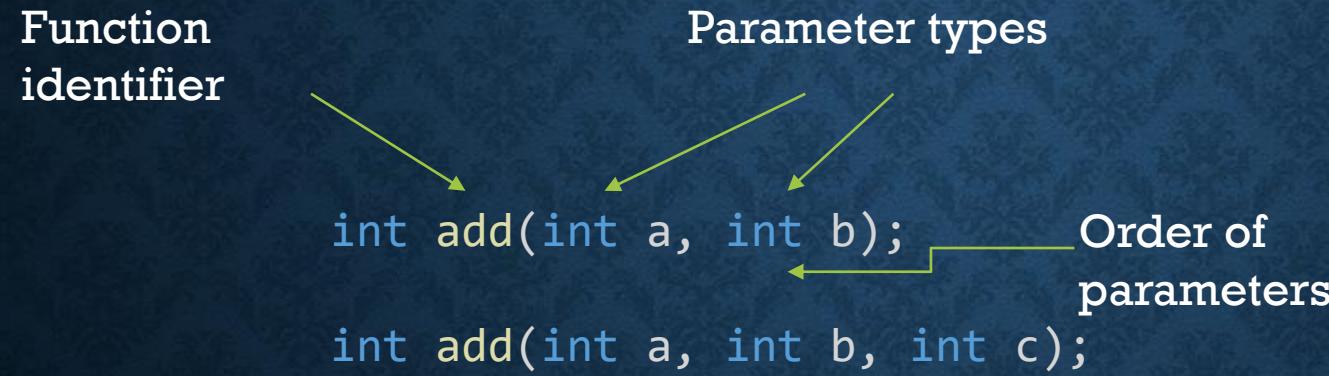
FUNCTION OVERLOADING

- Having already encountered the issue of conflicting identifiers and the **one definition rule**, we would like to avoid it as much as possible
- However what if we wanted to reuse the same function names but have slightly different definitions for them
- C++ offers the feature of overloading these functions, functions with multiple definitions/meanings are thus called **overloaded functions**.

FUNCTION OVERLOADING

- A function **declaration** is comprised of a few different parts and the formation of these parts can be called the function's **signature**.
- The function's signature is made of the following:
 - The function's identifier or name
 - The parameter types
 - The order of the parameters
- Functions with the **same identifier or name** but a **different signature** will identify them as overloaded functions.
- A function's **return type** and **parameter names** are not considered part of its signature

FUNCTION OVERLOADING



These two are overloaded functions.

REFERENCES

- In C++ a **reference** is an **alias** to the variable or object.
- It's similar to a pointer in that it refers to something but it has a few big differences:
 - Pointers can be made to point to something, nothing and can switch what it refers to, references will only refer to the original entity and can not be changed after initialization
 - References can't be **null**
 - References **must be initialized when created.**
 - References are declared using the **&** symbol eg. `int & x = y // x is a reference to y`

REFERENCES

- We'll be mainly looking at references in a context of **passing a variable into a function call**
- Passing variables by reference serves as an alternative to passing them by address/pointers.

```
// Swapping values by address
// swap1.cpp
#include <iostream>
using namespace std;
void swap ( int *a, int *b ); // Diff declar

int main ( ) {
int left = 0;
int right = 1;

cout << "left is " << left << endl;
cout << "right is " << right << endl;

swap(left, right);

cout << "After swap, left is " << left << "\n"
<< "right is " << right << endl;
}

void swap ( int *a, int *b ) {
int c;
c = *a; // Note the differences here
*a = *b;
*b = c;
}
```

```
// Swapping values by reference
// swap2.cpp
#include <iostream>
using namespace std;
void swap ( int &a, int &b ); // Diff declar

int main ( ) {
int left = 0;
int right = 1;

cout << "left is " << left << endl;
cout << "right is " << right << endl;

swap(left, right);

cout << "After swap, left is " << left << "\n"
<< "right is " << right << endl;
}

void swap ( int &a, int &b ) {
int c;
c = a; // Note the differences here
a = b;
b = c;
}
```

ARRAY OF POINTERS

- An **array of pointers** is a common data structure that is similar to an array except in each index of the array is a **pointer** instead of a **fundamental** type so they contain addresses instead of values.
- This style of storing items in an array will be quite useful when we approach the topic of **polymorphism**.
- In preparation for that later topic of study try to familiarize yourselves with this kind of array.

NULLPTR

- When initializing pointers, in C typically we would use the keyword **NULL**
- In C++, it is more typical to use the keyword **nullptr**. In the 2011 C++ standard it was a new keyword that was created to better differentiate that it was a **null value for a pointer versus being a ‘zero’ value**
- When creating a pointer in order to have it be defined as null:

```
int* myptr = nullptr;
```

- You will need to build with **-std=c++11** to have access to the keyword **nullptr**.
- **Avoid undefined pointers in all cases if possible. Just like in C.**

WEEK 2-2

Dynamic Memory

| Getting more resources as needed

MEMORY



STATIC MEMORY

- Static memory refers to the amount of memory allocated for a program at load time.
- This amount of memory is determined at compile time
 - In other words of the memory given to a program is already set by the time it's run
- Memory that's used by a program needs to be returned to the system when that program has finished its execution. Memory that's statically allocated is done so automatically when the program exits / its code paths go out of scope.
- In our example of playdoh, perhaps we are given one jar of it every play time and that same jar is collected at the end of play time.

STATIC MEMORY

Playdoh Supply and Children

Playdoh Jar 1

Child 1

Playdoh Jar 2

Child 2

Playdoh Jar 3

Child 3

Playdoh On Loan

Child 1 – Has Jar 1

Child 2 - Has Jar 2

Child 3 - Has Jar 3

Static memory has the notion that what you defined and allocated at compile time is all the memory you have access to. In this example we have one child attached to one playdoh jar. **This is fine if you always know how much you need ahead of time.**

STATIC MEMORY

Playdoh On Loan

Child 1 – Has Jar 1

Child 2 - Has Jar 2

Child 3 - Has Jar 3

Playdoh Returned after Play time

Playdoh Jar 1

Playdoh Jar 2

Playdoh Jar 3

Child 1

Child 2

Child 3

After play time is concluded every child returns their playdoh. So during the next play time they can be used again.

DYNAMIC MEMORY

- In the case where we perhaps **don't know how much memory we need** for our program's needs until runtime (**if for example we require a user's input to decide**), how are we able to request more resources at that time?
- This is where the notion of **dynamically allocated memory** comes into play. The ability to on demand request more memory from the system during run time.

DYNAMIC MEMORY

Playdoh Supply and Children

Playdoh Jar 1

Child 1

Playdoh Jar 2

Child 2

Playdoh Jar 3

Child 3

Playdoh On Loan

Child 1 – Has Jar 1

Child 2 - Has Jar 2

Child 3 - Has Jar 3

Child 4

A temporary child enters our daycare just for today after all the playdoh has been assigned. Will they not have any to play with?



DYNAMIC MEMORY

Other Daycare

Playdoh Supply and Children

Playdoh Jar 1

Child 1

Playdoh Jar 2

Child 2

Playdoh Jar 3

Child 3

Playdoh On Loan

Child 1 – Has Jar 1

Child 2 - Has Jar 2

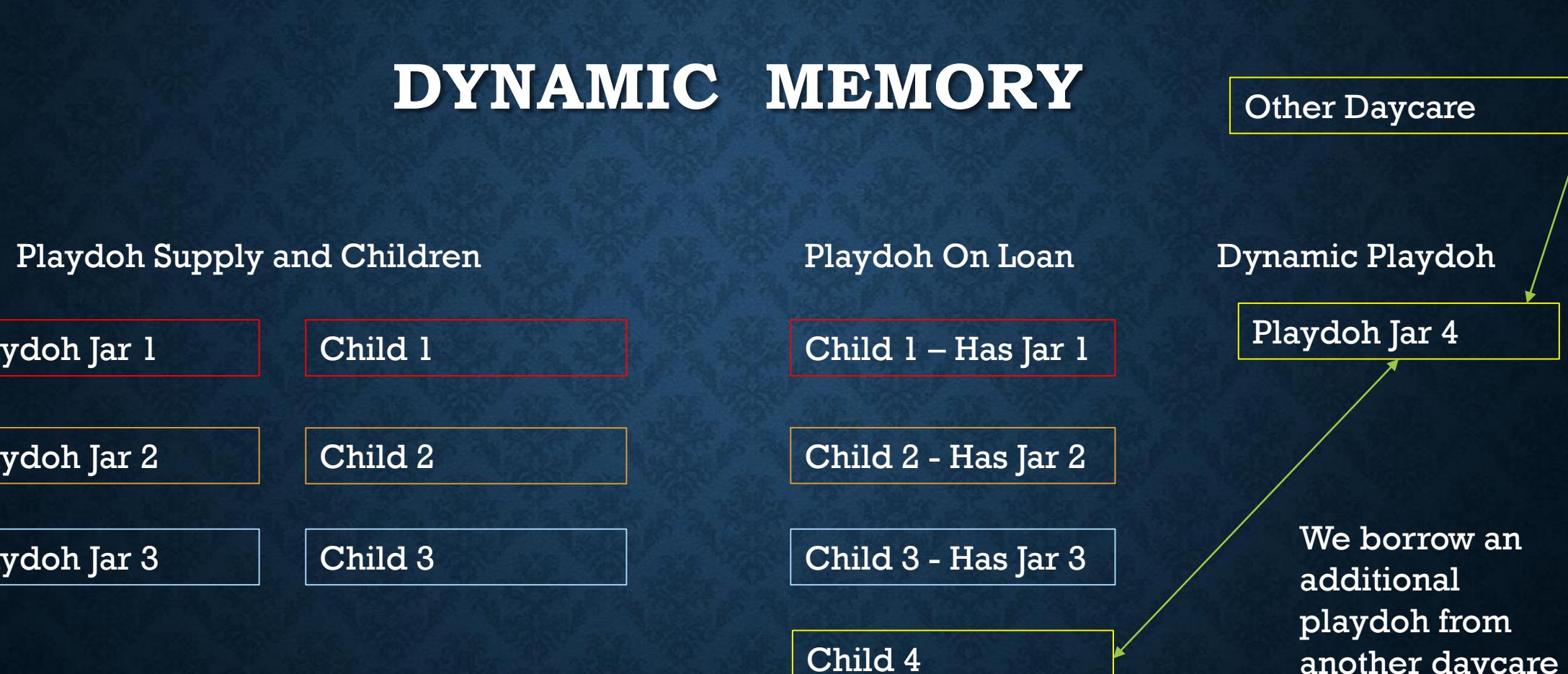
Child 3 - Has Jar 3

Child 4

Dynamic Playdoh

Playdoh Jar 4

We borrow an additional playdoh from another daycare



DYNAMIC MEMORY

- The main key word in C++ that allows for dynamic memory allocation is **new**
- The typical syntax for this process makes use of pointers:
 - *pointer = new Type [size]*
- Eg. `myStruct* s = new myStruct [5]; // allocating an array of myStructs`
- Eg. `myStruct* myint = new myStruct; // allocating a single instance`

DYNAMIC MEMORY

- Going back to the playdoh example. We've borrowed/allocated one additional dynamic playdoh for use just for today. What happens to it after the day is done? Do we keep it with us?
- If we keep it with ourselves then the place, we borrowed it from will be one short. We only needed it for this one instance so we should return it back.
 - It is our responsibility to return this ourselves. We borrowed it after all.
 - If we don't no one else will be able to access that jar and we reduce the amount of playdoh everyone can use/share with one another

DYNAMIC MEMORY

Playdoh On Loan

Child 1 – Has Jar 1

Child 2 - Has Jar 2

Child 3 - Has Jar 3

Child 4

Dynamic Playdoh

Playdoh Jar 4

Other Daycare

We return Jar 4
back to the
other daycare

DYNAMIC MEMORY

Playdoh On Loan

Child 1 – Has Jar 1

Child 2 - Has Jar 2

Child 3 - Has Jar 3

Child 4

Playdoh Supply and Children

Playdoh Jar 1

Child 1

Playdoh Jar 2

Child 2

Playdoh Jar 3

Child 3

Returns back to their
own daycare after
today



DYNAMIC MEMORY

- Compared to the `new` keyword when dealing with **allocating dynamic memory** there is also the `delete` keyword for **deallocating memory** when we are done with it.
- The issue of not returning memory to the system is that we reduce the amount of memory that's available to the system overall
- The act of never returning this memory is considered a `memory leak`
- Similar to the `new` keyword the syntax for deallocating is:
 - `delete [] pointer;`
 - Eg. `delete [] myint; // the [] specifies we are deallocating an array`
 - Eg. `delete myint; // without the [], we are deallocating a single instance`

DYNAMIC MEMORY

- For every instance of the **new** keyword being used, there should be an accompanying **delete** at some point in the program.
- Many issues in creating memory leaks is usually the presence of **new** and the lack of **delete**
- Always deallocate any memory you allocate

COMMON MEMORY ISSUES

- Generally there are three common memory issues that you will encounter as you start to work with dynamic memory:
 - **Double deletions** – Attempting to deallocate the same memory twice
 - **Attempting to access memory that isn't allocated**
 - **Memory Leaks** – Failure to deallocate memory and possibly the loss of allocated memory

COMMON MEMORY ISSUES - DOUBLE DELETIONS

Consider the following code:

```
int* x = new int[10];
delete [] x; // attempt to delete undefined pointer
delete [] x; // attempt to delete undefined pointer again??
```

What do you think will occur?

COMMON MEMORY ISSUES - DOUBLE DELETIONS

Consider the following code:

```
int* x = new int[10];
delete [] x; // attempt to delete undefined pointer
delete [] x; // attempt to delete undefined pointer again??
```

On [Linux/Matrix](#) you will get an error message like as you run the program. The double 'free' means you've attempted to free the same memory twice.

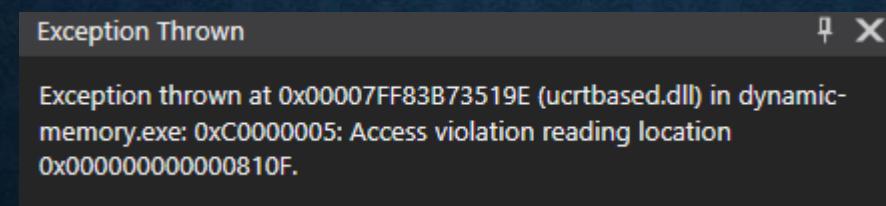
```
*** Error in `./me': double free or corruption (fasttop): 0x00000000018d7010 ***
===== Backtrace: =====
/lib64/libc.so.6(+0x81679)[0x7fe250ad4679]
```

COMMON MEMORY ISSUES - DOUBLE DELETIONS

Consider the following code:

```
int* x = new int[10];
delete [] x; // attempt to delete undefined pointer
delete [] x; // attempt to delete undefined pointer again??
```

On **Visual Studio** you will get a similar kind of error message when debugging. The 'access violation' refers to **attempting to delete memory that is not longer there**.



COMMON MEMORY ISSUES – ACCESSING MEMORY WE HAVEN'T ALLOCATED

- The opposite spectrum of the double deletion error is when we try to access memory that isn't allocated. Here we have an uninitialized integer pointer.

```
int* y;  
cout << "val of y: " << *y << endl;
```

In this case we usually get a **build error** in VS2019 regarding uninitialized variables. However in Matrix/Linux you might end up with a random value.

COMMON MEMORY ISSUES – ACCESSING MEMORY WE HAVEN'T ALLOCATED

- The opposite spectrum of the double deletion error is when we try to access memory that isn't allocated. Here we have a `nullptr`.

```
int* y = nullptr;  
cout << "val of y: " << *y << endl;
```

In this case we usually get an `access violation` error in VS2019 (similar to before). In Matrix we would get a `segmentation fault`.

COMMON MEMORY ISSUES – MEMORY LEAKS

- Memory leaks occur when we don't deallocate dynamic memory that we had allocated earlier. Consider:

```
char* y = nullptr;
for (int i = 0; i < 10; ++i){
    y = new char[100000]; // allocate new memory over and over
    strcpy(y, "HELLO");
}

delete[] y;
```

Is there any issue here?

COMMON MEMORY ISSUES – MEMORY LEAKS

```
char* y = nullptr;
for (int i = 0; i < 10; ++i){
    y = new char[100000]; // allocate new memory over and over
    strcpy(y, "HELLO");
}
delete[] y;
```



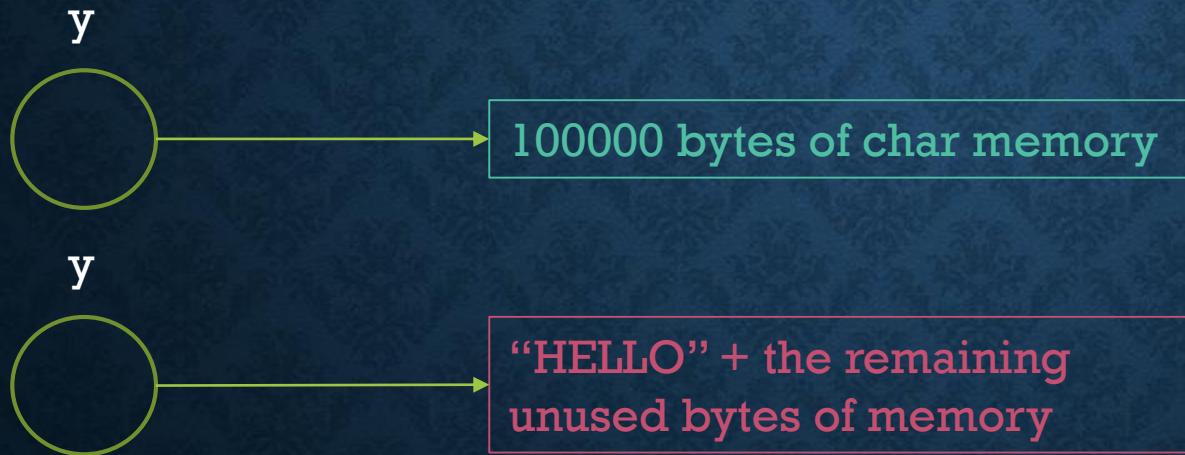
This delete only ends up deleting the most recently allocated memory



Every time we allocate memory here we lose the previous memory

COMMON MEMORY ISSUES – MEMORY LEAKS

When i = 0;



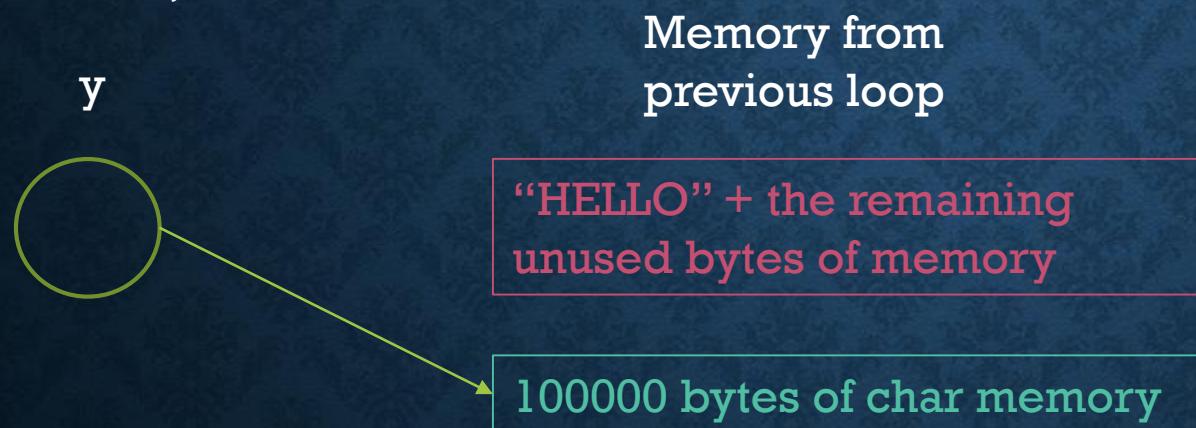
```
y = new char[100000];
```

Allocate memory

```
strcpy(y, "HELLO");
```

COMMON MEMORY ISSUES – MEMORY LEAKS

When i = 1;



This memory is now LOST,
we have a leak

Allocate memory

```
y = new char[100000];
```



```
strcpy(y, "HELLO");
```

COMMON MEMORY ISSUES – **MEMORY LEAKS**

- So how do we deal with these kinds of issues?
- On Visual Studio there are **built-in Memory Diagnostic tools** to monitor how memory has been used in your program while debugging.
- For a reference on how to use these tools refer to:
<https://docs.microsoft.com/en-us/visualstudio/profiling/memory-usage?view=vs-2019>