COP3503

Templates

Code Reuse Speeds Up Development

- **Inventing** the wheel is hard, but necessary.
- **Reinventing** the wheel is a waste.
- Some systems are nearly identical, but only differ in the **types** that they use.
- We may have to duplicate code and change the types.

```
void DoSomeStuff(int);
void DoSomeStuff(double);
void DoSomeStuff(unsigned char);
```

```
class DynamicArrayInt{};
class DynamicArrayFloat{};
class DynamicArrayString{};
```

We **could** duplicate code like this… or maybe there's a better way!

Imagine a Simple Input Function…

```
int GetNumericValue(int min, int max)
{
    int value;
    /* Assume proper input code here */
    return value;
}
```

What about other numeric types?

```
float GetNumericValue(float min, float max)
{
    float value;
    /* Assume proper input code here */
    return value;
}
```

```
short GetNumericValue(short min, short max) …
```

```
char GetNumericValue(char min, char max) …
```

```
unsigned long GetNumericValue(unsigned long min, unsigned long max) …
```

That's a lot of repetition!
Copy+paste, change data type…
Copy+paste, change data type…
Copy+paste, change data type…

Templates to the Rescue!

```
template <typename T>
T GetNumericValue(T min, T max)
{
    T value;
    /* Assume proper input code here */
    return value;
}
```

All the data types (that we've seen up to now) are gone!

```
float x = GetNumericValue(3.14f, 29.774f);
double dx = GetNumericValue(3.14, 19.9);
int y = GetNumericValue(-5, 2000000);
char z = GetNumericValue('a', 'z');
```

You write one template, and the compiler uses that to create 4 **specializations** – one for each data type.

- The compiler will create a new version, or **specialization**, of this function, for each data type that it finds

Isn't the Function Overloading?

- In this particular example, it's **very similar**, but not the same as overloading a function.
- Overloading a function is passing different types of parameters (possibly a different number of parameters).

```
// Overloading a function – multiple, DIFFERENT versions
int GetNumericValue(int min);
int GetNumericValue(int min, int max);
int GetNumericValue(int min, int max, string error);
SomeObject* obj = new SomeObject;
delete obj;
```

```
// Template – one function (written by you)
template <typename T>
T GetNumericValue(T min);
```

Multiple **specializations** created (if necessary), by the compiler, from your template.

The specializations are invisible to you and only created on an as-needed basis by the compiler.

Template Breakdown

```
template <typename T>
```

`T`
the newly-defined data type
(T is common, but it can be anything—keep it small, simple)

`template`
defines this as a template (genius!)

`typename`
define whatever follows this as a **usable data type**

```
template <typename T>
T GetNumericValue(T min, T max)
{
    T value; // Make a variable of SOME type
    int inputAttempts = 0;
    return b;
}
```

Depends on the specialization
(how you tried calling the function)

Template Specialization

```
template <typename T>
void TemplateFunction(T min);
```

- For functions, specializations are typically deduced by the compiler, based on parameter types:

```
TemplateFunction(2);      // T == int
TemplateFunction(-27.8);  // T == double
TemplateFunction(3.14f);  // T == float (f means float instead of double)
```

```
// You can explicitly indicate a specialization
char someValue = GetNumericValue<char>(2, 15);
```

Tell your compiler to create or use the **char** specialization.

- Specializations of classes are a little different.
- For template classes, you must provide a type.

Templates and Classes

```
// GenericClass.h
template <typename T>
class GenericClass
{
    T singleObject;
    T* pointerToT;
    T lotsOfT[100];
    int otherVariable;
    char otherStuff[12];
public:
    GenericClass(int someValue);
};
```

Replace all instances of T with the specialization type, then compile that.

Create a specialization of the class.

```
GenericClass<int> intSpecialization;
GenericClass<float> floatSpec;
GenericClass<Widget> widgetSpec;
GenericClass<RandomObject> random;
// Etc…
```

You've already used templates with the `std::vector` class:

```
std::vector<int> numbers;
std::vector<string> words;
```

Templates and Classes

```cpp
// GenericClass.h
template <typename T>
class GenericClass
{
    int singleObject;
    int* pointerToT;
    int lotsOfT[100];
    int otherVariable;
    char otherStuff[12];
public:
    GenericClass(int someValue);
};
```

Create a specialization of the class.

```cpp
GenericClass<int> intSpecialization;
GenericClass<float> floatSpec;
GenericClass<Widget> widgetSpec;
GenericClass<RandomObject> random;
// Etc...
```

Templates and Classes

```
// GenericClass.h
template <typename T>
class GenericClass
{
    float singleObject;
    float* pointerToT;
    float lotsOfT[100];
    int otherVariable;
    char otherStuff[12];
public:
    GenericClass(int someValue);
};
```

Create a specialization of the class.

```
GenericClass<int> intSpecialization;
GenericClass<float> floatSpec;
GenericClass<Widget> widgetSpec;
GenericClass<RandomObject> random;
// Etc...
```

Templates and Classes

```
// GenericClass.h
template <typename T>
class GenericClass
{
    Widget singleObject;
    Widget* pointerToT;
    Widget lotsOfT[100];
    int otherVariable;
    char otherStuff[12];
public:
    GenericClass(int someValue);
};
```

Create a specialization of the class.

```
GenericClass<int> intSpecialization;
GenericClass<float> floatSpec;
GenericClass<Widget> widgetSpec;
GenericClass<RandomObject> random;
// Etc...
```

Templates and Classes

We can create as many specializations as we want, and we only have to write the class once!

```
// GenericClass.h
template <typename T>
class GenericClass
{
    RandomObject singleObject;
    RandomObject* pointerToT;
    RandomObject lotsOfT[100];
    int otherVariable;
    char otherStuff[12];
public:
    GenericClass(int someValue);
};
```

Create a specialization of the class.

```
GenericClass<int> intSpecialization;
GenericClass<float> floatSpec;
GenericClass<Widget> widgetSpec;
GenericClass<RandomObject> random;
// Etc...
```

What About Multiple Typenames?

```
template <typename Type1, typename Type2>
void Foo(Type1 obj1, Type2 obj2);
```

```
template <typename A, typename B, typename C>
class SomeClass
{
    A object;
    B* pointer;
    C arrayOfThings[20];
};
```

```
string name = "Batman";
// Foo<std::string, const char*>
Foo(name, "Robin");

// Foo<int, float>
Foo(25, -4.6f);

// Foo<int, int>
Foo(0, 10);
```

```
// Create an object with 1 string, pointer to // an integer and an array of 20 float pointers
SomeClass<string, int, float*> myObject;
```

```
// Create an object with 1 int, a pointer to a SomeClass object,
// and an array of 20 chars
SomeClass<int, SomeClass, char> myObject;
```

Whether one template type or multiple, it’s the same concept—just more of it!

Template Class Functions

```
// Still in GenericClass.h...
template <typename T>
class GenericClass
{
    int numberOfThings;
    T* someArray;
public:
    GenericClass(int someValue);
};

template <typename T>
GenericClass<T>::GenericClass(int someValue)
{
    this->numberOfThings = someValue;

    // Allocate an array of... somethings
    this->someArray = new T[someValue];
}
```

`template <typename T>`

This has to be above **every** definition of a class member function, no exceptions.

`<T>`

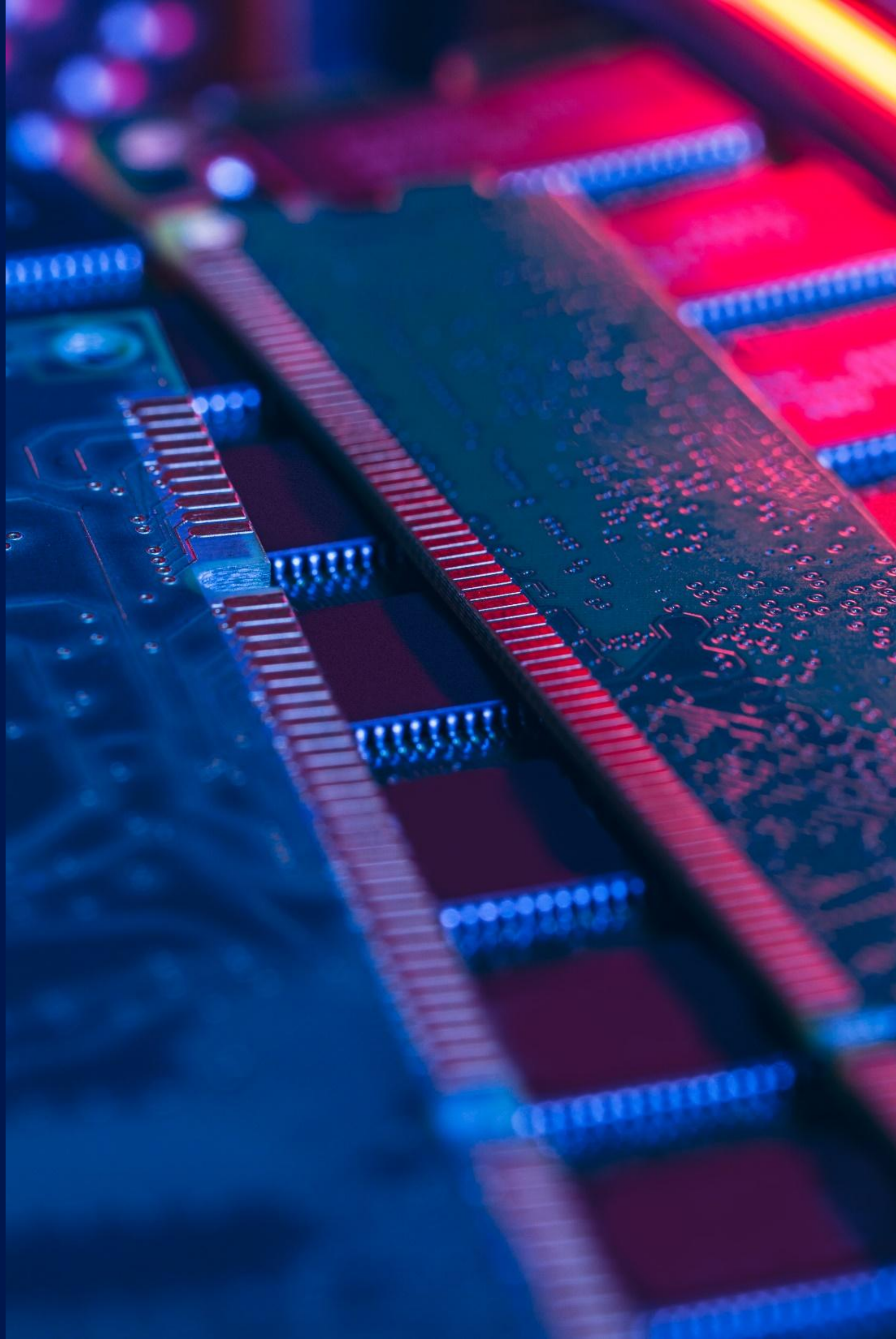
This has to go after the class name, before the scope-resolution operator, in **every** function definition.

Use T, or whatever you called it, as a regular data type, anywhere you need one of those variables.

Template Definition Rule

Only 1 file

- Template classes must be written entirely in a single file.
- Normally it’s “good practice” to split classes into .h/.cpp files.
- Template classes **cannot** be split into two files, **because of the compiler**.
- In order to create specializations, the compiler must know about ALL of the code your class uses.
- To do **that**, the compiler must be able to “see” all of the code in a class, including function definitions.
- Just remember: Templates work differently, and they must exist entirely in a single file.



Still Split Class Declaration and Definition

```
// File: SomeClass.h
template <typename T>
class SomeClass
{
public:
    void Foo(int x);
    int Bar(string s, float xyz);
};
/*====== END CLASS DEFINITION, BEGIN MEMBER FUNCTION DEFINITIONS ======*/

template <typename T>
void SomeClass<T>::Foo(int x)
{

}

template <typename T>
int SomeClass<T>::Bar(string s, float xyz)
{

}
```

(It's good practice.)

Define the class itself at the top of the header file.

You **can** write the functions inside the class—it's just a style choice.

```
template <typename T>
class SomeClass
{
public:
    void Foo(int x)
    {
    }
};
```

What About Nested Classes?

```
template <typename T>
class TemplateClass
{
    T var1, var2;
    T array_Of_T[7];
public:

    class NestedClass
    {
    public:
        T someValue;
        int data1;
        float data2;
        // Etc...
    };
};
```

The nested class will
use
its

```
// Normal instantiation of a nested class
NonTemplateClass::NestedClass nestedObject;
nestedObject.data1 = 50;
```

```
// The T is a float, for the outer AND inner classes
// float is "passed on" to NestedClass
TemplateClass<float>::NestedClass nestedObject;
nestedObject.someValue = 3.14f; // someValue is type float

// The T is a char, for the outer AND inner classes
TemplateClass<char>::NestedClass nested;
nested.someValue = '$'; // someValue is type char
```

Why Write Template Classes?

- One word: **storage**
- A template class is often **like a cardboard box**:
  - Store **something** in it (or remove something from it)
  - Transfer it and its contents from point A to B
- Templates (like boxes) are plain, versatile, **don’t know about their contents**
- They deal with **objects as a whole**, not specific details.
- A template (or a box) is a **bad choice for custom functionality**.

A “template” for storing and shipping things

You Can’t Use Templates for Everything

```
template <typename T>
T GetNumericValue(T min, T max)
{
    T value;
    /* Assume proper input code here */
    return value;
}
```

The compiler will **try** to create a specialization that replaces all instances of `T` with `Dinosaur`.

Given this function, that will likely fail!

There’s no way to stop someone from trying it. Templates are open for all data types

```
Dinosaur trex = GetNumericValue(stegosaurus, triceratops);
```

This probably doesn’t make sense to you (me neither, and I wrote it!)

Keep Templates Generic

- Don’t use unique functionality of objects inside a template.

```
template <typename T>
void GenericClass<T>::Foo()
{
    T someVariable;
    someVariable.Bar();
}
```

Every type you use to create a specialization of this class **must** have a `Bar()` function.

```
GenericClass<int> intSpec;
// Won’t work, compiler error.
// *int* isn’t a class, doesn’t have a
// Bar() function (or any functions)
```

- Templates should deal with generic, reusable functionality.
- Storing some data, not operating on it.

Can You Have a Template That Doesn't Work With Everything?

- You **could** write template code that expects a specific interface.
- May be a style you (or your team) develop
- C++ cannot limit types you use with a template—it's up to you to do things properly.

```
class Good
{
public:
    void DoStuff();
};
```

```
class Bad
{
public:
    void Nope();
};
```

```
// Won't compile, no Bad::DoStuff()
// function exists
GenericClass<Bad> nonConforming;

// In main()…
// No problem, Good::DoStuff() exists
GenericClass<Good> someTemplate;
```

```
template <typename T>
void GenericClass<T>::Foo(T& other)
{
    // As long as T has DoStuff() overloaded, it's okay
    other.DoStuff();
}
```

You **can** assume this function exists as part of your program design…as long as others know this is a choice you've made

What About Templates Within Templates?

- `std::vector<T>` is a general purpose, go-to storage container.
- It can store any type of data, even `std::vector<T>`.

Even in “simple” terms this could be a confusing concept.

```
vector<int> numbers;  // specialization: int
vector<string> words; // specialization: string

vector<vector<int>> numberGroups; // Specialization: vector<int>
```

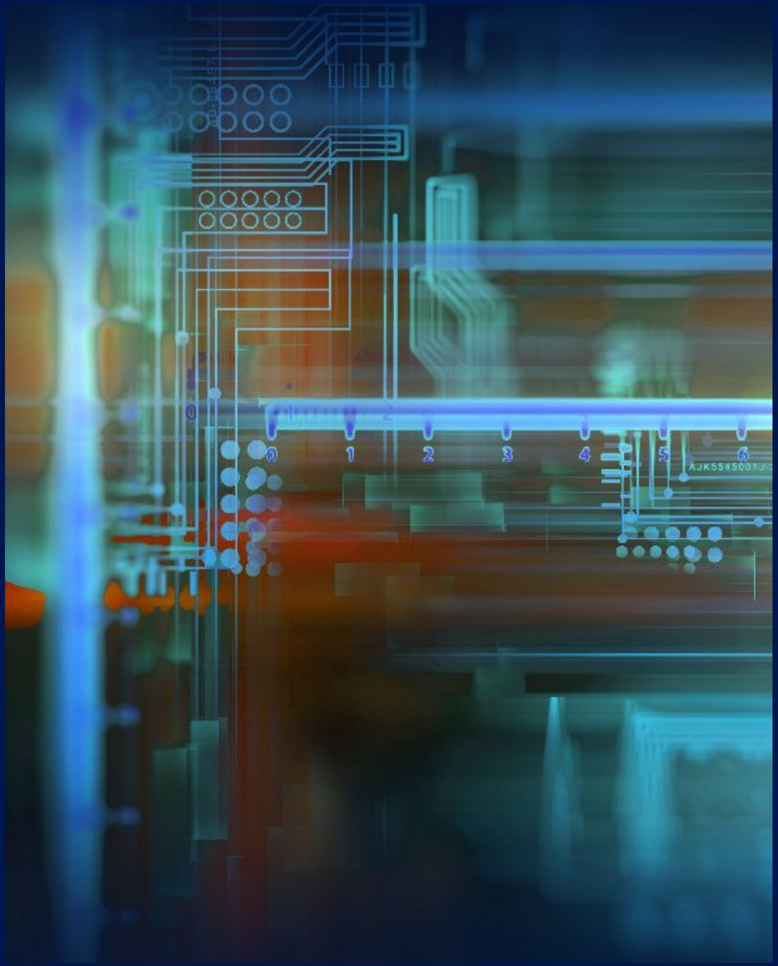
```
// May look scary or intimidating, but works just fine
vector<vector<vector<int>>> this_is_scary;
```

This is: A vector of... vectors of... vectors of integers
Or: A box containing boxes containing boxes of numbers

Recap

- Templates let you reuse **functions** and **classes** with **different data types**.
- Templates define new types, often named **T** or other simple names.
- The compiler creates **specializations** of a template with the type(s) specified.
- Template classes make excellent **storage containers**.
- Template classes must be **completely defined in a single file**—typically a header file.
- Template code can sometimes look confusing, but is very powerful and versatile.

Conclusion



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Thank you for watching.