C++ Template Meta

A basic introduction to basic C++ techniques used in template metaprogramming.

Important reminder

Otherwise identical classes with different template classes are **<u>NOT</u>** the same class!

For example:

- `list<bool> != list<char>`
- `vector<int> != vector<double>`
- `list< list<int> > != list< list<char> >`

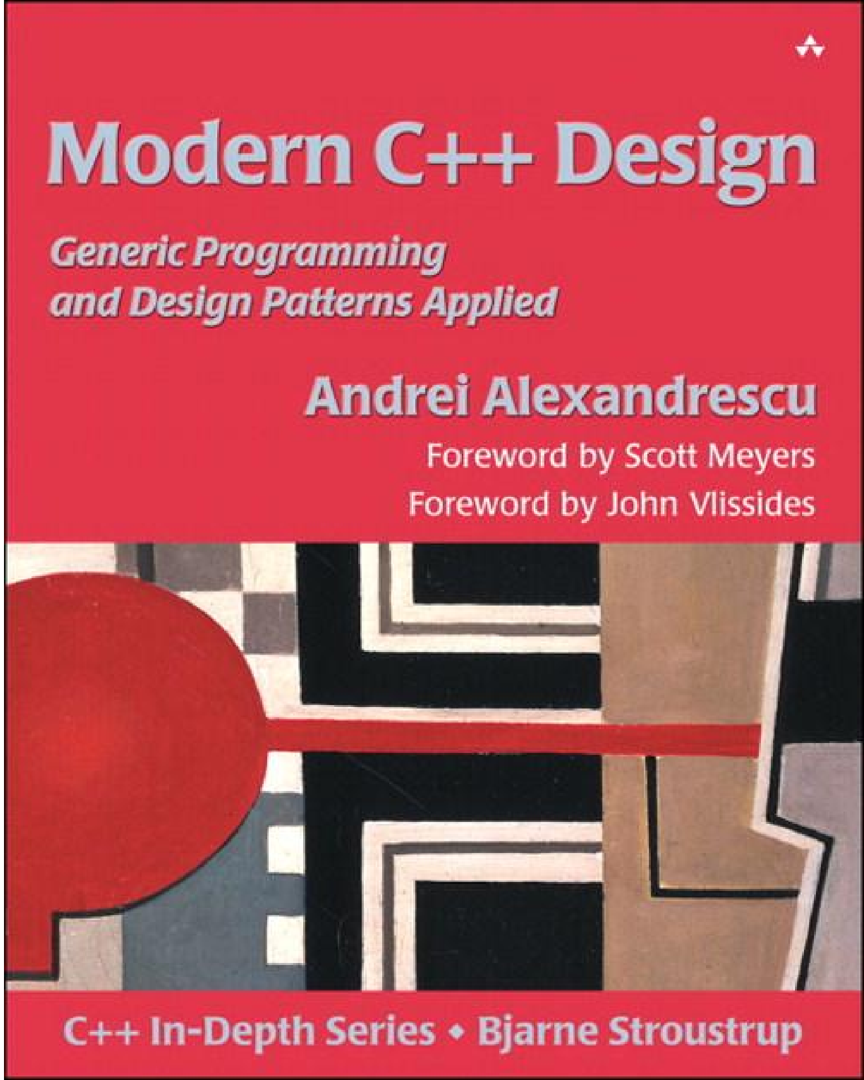
What you will learn

I will be teaching you using this book ->

We will be going over chapter's 2 and 3, techniques and typelists respectively.

If you would rather read it directly than listen to me, the links is here:

https://www.mimuw.edu.pl/~mrp/cpp/SecretCPP/Addison-Wesley%20-%20Modern%20C++%20Design.%20Generic%20Programming%20and%20Design%20Patterns%20Applied.pdf



What is TMP?

What is it?

- Code that is ‘run’ and evaluated at compile time
- ‘Compile time programming’
  - Immutable objects
  - Functional programming
- Can create
  - Data Structures
  - Compile time constants
  - Functions
- Takes advantage of templates to do this

Factorial: Run-Time vs. Compile-Time

```
// Run time programming
unsigned int factorial(unsigned int n) {
	return n == 0 ? 1 : n * factorial(n - 1);
}


// Usage examples:
// factorial(0) would yield 1;
// factorial(4) would yield 24.

// Everything is evaluated at run-time
//Slower to run, faster to compile
```

```
// Template Meta
//Recursive case
template <unsigned int n> struct factorial {
	enum { value = n * factorial<n - 1>::value };
};

// Base case
template <> struct factorial<0> {
	enum { value = 1 };
};

// Usage examples:
// factorial<0>::value would yield 1;
// factorial<4>::value would yield 24.

// Everything is evaluated at compile-time
//Faster to run, slower to compile
```

Factorial: Why does it work?

- <u>Remember</u>: factorial<N> is a class!
- factorial<4> != factorial<3>
  - They are <u>***different classes!***</u>
- Enum's are like static const ints
  - Though they are not the same, but that isn't relevant at the moment
- *Enums <u>**must**</u> be evaluated at compile time!*

```
// Template Meta
template <unsigned int N> struct factorial {
        enum { value = N * factorial<N - 1>::value };
};

template <> struct factorial<0> {
        enum { value = 1 };
};

// Usage examples:
// factorial<0>::value would yield 1;
// factorial<4>::value would yield 24.

// Everything is evaluated at compile-time
```

Factorial: Why does it work?

- Remember: factorial<N> is a class!
- factorial<4> != factorial<3>
  - They are ***different classes!***
- Enum's are like static const ints
  - Though they are not the same, but that isn't relevant at the moment
- *Enums **must** be evaluated at compile time!*

Thus, the **class** factorial<4> has a will always have an enum 'value' with a value of N*factorial<N-1>::value that is *defined* at compile time.

```
// Template Meta
template <unsigned int N> struct factorial {
        enum { value = N * factorial<N - 1>::value };
};

template <> struct factorial<0> {
        enum { value = 1 };
};

// Usage examples:
// factorial<0>::value would yield 1;
// factorial<4>::value would yield 24.

// Everything is evaluated at compile-time
```

Weird Notation?

- Why do we have to say `factorial<4>::value?`
- <u>`factorial<4> is a class`</u>

- We want the value of the enum 'value' within the class `factorial<4>`

factorial<4>::value

```
// Template Meta
template <unsigned int N> struct factorial {
        enum { value = N * factorial<N - 1>::value };
};

template <> struct factorial<0> {
        enum { value = 1 };
};

// Usage examples:
// factorial<0>::value would yield 1;
// factorial<4>::value would yield 24.
```

<u>// Everything is evaluated at compile-time</u>

Did I peak your interest?

1. If you just came to see what this was on, hopefully I intrigued you enough to stay.

2. Next I am going to show you a few basic techniques

3. Before I do, questions on what TMP is?

Basic Techniques

Things to note

- I am going to teach you in **C++99**
- Most of what you are about to learn is *now* built into c++11, c++14, c++17, or their stl libraries.
- The rest exists in other libraries such as stl Loki, Blitz++, boost mpl, ipl, and boost::hana

Why Learn LEgacy Techniques?

1. These are fundamental techniques used in TMP
2. Many of these you will use anyway, just with a pretty wrapper around them
3. **To help you learn the TMP way of thinking, and better understand how to program in TMP**

Common Practice in TMP

1. Macros used as wrappers
   - Normally macros should be avoided, but in TMP it is common to have them wrappers
   - Functions can also be used as wrappers, *but they add overhead*
2. Structs with a typedef or enum that stores the result of a computation
   - Structs like this will often replace variables

```
// Template Meta
template <unsigned int N> struct _factorial {
    enum { value = N * _factorial<N - 1>::value };
};

template <> struct _factorial<0> {
    enum { value = 1 };
};

// Factorial Wrapper
#define factorial(x) _factorial<x>::value

// Usage examples:
// factorial(0) would yield 1;
// factorial(4) would yield 24.
```

Static assertions (Compile Time Assertions)

- Now standard in c++11 via static_assert, but we will ignore that

Second point

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Final point

A one-line description of it

“This is a super-important quote”

– From an expert

This is the most important takeaway that everyone has to remember.

Thanks!

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