Template Metaprogramming

Group 8

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GROUP 8

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Definition of Template Metaprogramming

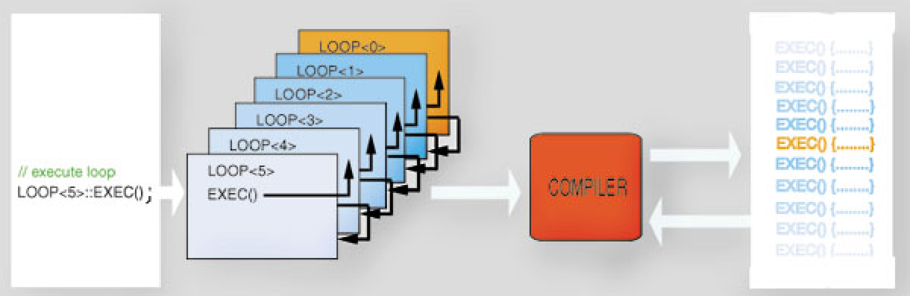
- "Programming a program"
- "Compile-time"

Definition

- Used by compiler to generate temporary source code, which is merged by the compiler and then compiled.
- The output can include compile-time constants, data structures, and complete functions.
- The use can be thought of as compiler-time polymorphism.
- Used by a number of languages, the best-known being C++.

The reason why Template MP was chosen?

- Be used to move computations from run-time to compile-time
- Generate code using compile time computations
- Enable self-modifying code
- Time-saving for a future call



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When TMP should be used?

- A macro is not enough details.
- Using recursive function with predetermined number of loops for significant reduction in run time by avoiding calling the overhead of function as well as setting up stack variables.
- Constant value need calculating.

When TMP should not be used?

- A macro is enough details and small code size which more friendly than TMP
- Program has already had a long-time compilation

How to make TMP more practical for programmers?

- Some facts of TMP:
  - Like other const expressions, values of enumeration constants are evaluated at compile time.
  - When accessing to new argument of a template, compiler creates a new instance of the template.
- Naming appropriately:
  - Not naming at all, which means "don't look at this, it's irrelevant and it's there only for technical reasons".
  - Naming meaningfully to express the function of parameter.
- Stratify abstraction:
  - Stratification prevents code duplication in case programmers need the same technique for checking other expressions at some point.

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Advantages of TMP

- It reduces repetition of the code.
- Executed exactly once at compile time regardless of how many times it is called at runtime.
- Created base on template $->$ better maintainability

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Disadvantages of TMP

- Syntax is quite complex
- Compilation takes long time since code is generated in compile-time
- Cannot print a string during the compilation
- Make difficult debugging
- Not supported by all compilers (even though ISO C++ Standard)

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Preprocessing the code using a macro I

1. **One-line macro preprocessor**

```cpp
// Defining macro
#define MAX(a,b) (((a) > (b)) ? (a) : (b))

// Initializing 2 int variables
int x = 10;
int y = 20;

// Consuming the MAX macro
int z = MAX(x,y);
```

Preprocessing the code using a macro II

2. **Multiline macro preprocessor**

```
// Defining multi line macro
#define SWAP(a,b) { \
(a) ^= (b); \
(b) ^= (a); \
(a) ^= (b); \
}

// Initializing two int variables
int x = 10;
int y = 20;

// Consuming the SWAP macro
SWAP(x,y);
```

Dissecting template metaprogramming in the Standard Library

- An incomplete function contained in the C ++ Standard Library is used to generate complete functions.
- The template metaprogramming is the C++ template to generate C++ types and code in compile time.

```
template<typename T>
class Array
{
    T element;
};
```

Building the template metaprogramming I

- Four factors → template metaprogramming: *type*, *value*, *branch*, and *recursion*.

```
struct ValueDataType
{
    typedef int valueDataType;
};
```

- Similarly, a value can be stored to the variable thanks to *enum* to access the value variable for its value.

```
struct ValuePlaceHolder
{
    enum { value = 1 };
};
```

Building the template metaprogramming II

1. **Mapping a function to the input parameters**

```
template<int A, int B>
struct Multiplexer
{
    enum { result = A * B };
};
```

To access the *result* variable:

```
int i = Multiplexer<2, 3>::result;
// i = 6
```

Building the template metaprogramming III

2. **Choosing the correct process based on the condition**

```
template<typename A, typename B>
struct CheckingType
{
    enum { result = 0 };
};

```

```
template<typename X>
struct CheckingType<X, X>
{
    enum { result = 1 };
};

```

Building the template metaprogramming IV

```
if (CheckingType<UnknownType, int>::result)
{
    // run the function if the UnknownType is int
}

else
{
    // otherwise run any function
}

```

Building the template metaprogramming V

3. **Repeating the process recursively**
   The factorial value can be calculated as below:

```
template <int I>
struct Factorial
{
    enum { value = I * Factorial<I-1>::value };
};
```

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

```
int fact10 = Factorial<10>::value;
// fact10 = 3628800
```

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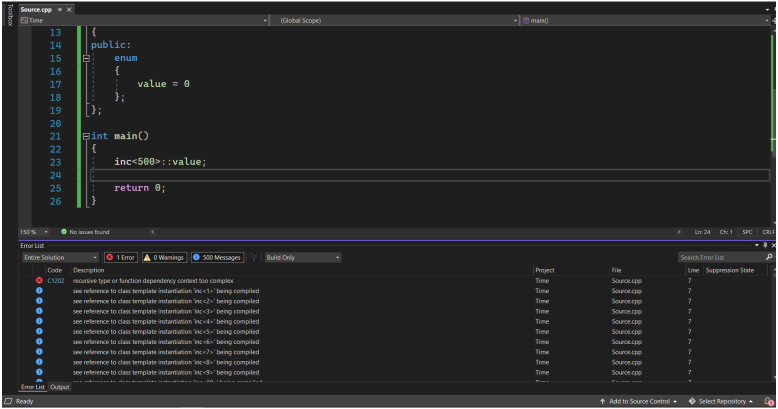
Demonstrate the power of metaprogramming

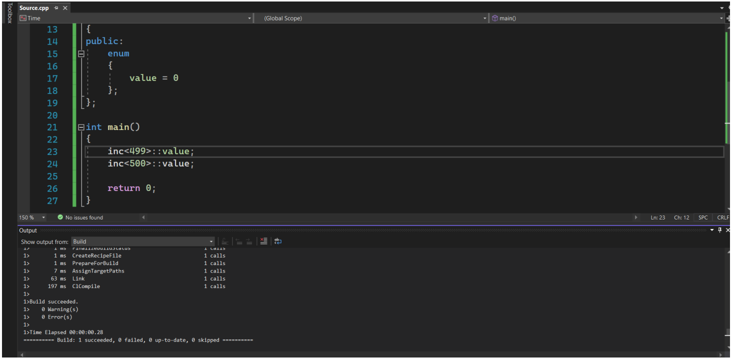
- Tasks that have been done since the last compilation would not need to be repeated or re-initialized.
- Demonstrate via *inc* $<$*int N*$>$ *function*: increase by 1 at time
- The evidence was done by comparing the compilation time and the number of recursive iterators.

First issue: The limitation of number of recursive iterators



Solution: "set a thief to catch a thief"

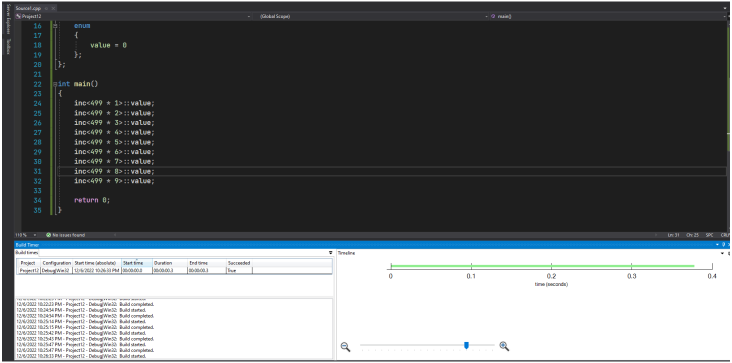
- Use smaller → larger



- Proof that the previous value will be save, no need to re-initialized.

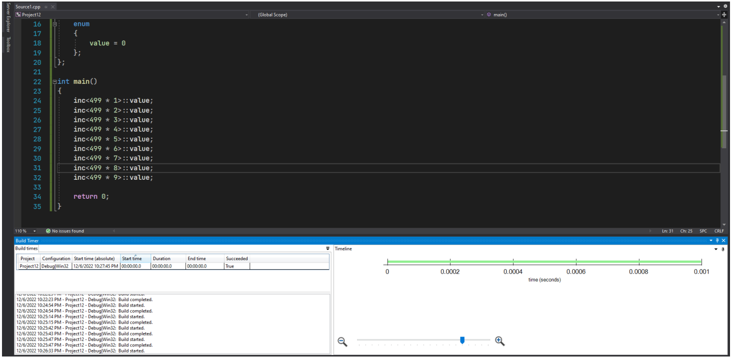
Second: Use build timer extension to measure compilation time

First calling,



Second: Use build timer extension to measure compilation time

Second calling,



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Metaprogramming library I

1. These are some typical funtions of metaprogramming library:
   - std::is_pointer
   - std::is_union
   - std::is_class
   - std::is_floating_point
   - std::is_enum
   - std::is_integral
2. Usage: Check whether the given type is the appropriate type or not.
3. Parameter: The single parameter *T (Trait class)* and check if T is the right type.
4. Return value: A boolean (true if it is the right type and reverse).

Metaprogramming library II

5. Syntax:

```
template <class T> struct is_"function name"

```

6. Return type:
   - **True:** if the type is "function name" type
   - **False:** if the type is not "function name" type

Metaprogramming library III

7. Illustration:

```
class GFG {};
int main()
{
  cout << boolalpha;
  cout << "is_pointer:"
    << endl;
  cout << "GFG: "
    << is_pointer<GFG>::value << '\n';
  cout << "GFG*: "
    << is_pointer<GFG*>::value << '\n';
  cout << "GFG&: "
    << is_pointer<GFG&>::value << '\n';
  cout << "nullptr_t: "
    << is_pointer<nullptr_t>::value << '\n';

  return 0;
}

```

Output:

```
is_pointer:
GFG: false
GFG*: true
GFG&: false
nullptr_t: false

```

Thank you

We apprepriate your attention!