Technische Universität München

Template Metaprogramming and STL

Tutorial for Advanced Programming

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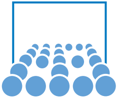

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What is template metaprogramming?

From Wikipedia:

- Metaprogramming is the writing of computer programs that can treat programs (itself or others) as their data
- Template metaprogramming (TMP) is a metaprogramming technique that uses templates to generate temporary code that will be merged and compiled at compile-time

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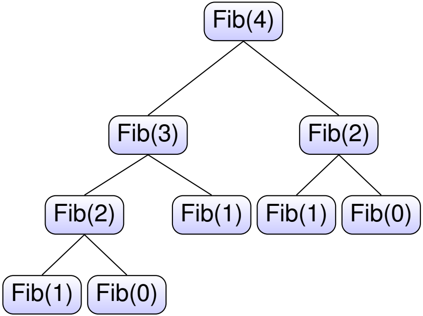
How do we use templates?

- Fibonacci with classical recursion:

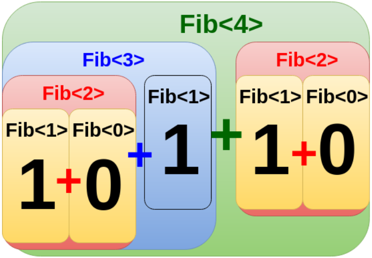
```
size_t Fib(size_t n){
if(n==1) return 1;
if(n==0) return 0;

return Fib(n-1)+Fib(n-2);
}

int main(){
    size_t result = Fib(4);
}
```



How do we use templates?

- Fibonacci with template metaprogramming:

```
template<int n> class Fib{
public:
      static const size_t value =
      Fib<n-1>::value + Fib<n-2>::value;
};
template<> class Fib<1>{
     public:
          static const size_t value = 1;
};
template<> class Fib<0>{
     public:
          static const size_t value = 0;
};
int main(){
     size_t result = Fib<4>::value;
}
```



Template tricks

- Variadic template

```
template<typename... Arguments> class tuple;
tuple<> tupleInstance1;
tuple<int> tupleInstance2;
tuple<int, std::map<bool, std::vector<float>>> tupleInstance3;
template<typename... Params>
void printf(const std::string &str_format, Params... parameters);
```

- Curiously Recurring Template Pattern:

```
    template<class T>
    class Base{
    // methods within Base can use template to access members of Derived
        void interface(){
            static_cast<T*>(this)->implementation();
        }
    };
    class Derived : public Base<Derived>{
        void implementation();
    };
```

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STL

- The Standard Template Library is a software library for the C++ programming language
- Influenced many parts of the C++ standard library
- Provides four components:
  - Algorithms
  - Containers
  - Functional
  - Iterators

Containers and Iterators

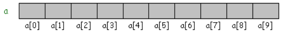
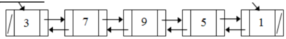
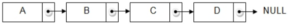
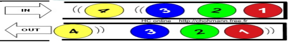
- Iterator:

  Pointer-like object (object, which supports pointer operations) that is able to point to a specific element in a container

- Container:

  Object that represents a group of elements of a certain type, stored in a way that depends on the type of the container

- Most used STL container:

vector	Array	 a a[0] a[1] a[2] a[3] a[4] a[5] a[6] a[7] a[8] a[9]
list	Doubly-linked list	
slist	Singly-linked list	
queue	FIFO structure	
stack	LIFO structure	 IN 4 3 2 1 HC online http://chohmann.free.fr OUT 4 3 2 1
pair	2-tuple	
set	Set of unique elements	

C++ stdlib: Usage examples

- Getting the maximum value of an array:

```cpp
vector<int> values(3,5); //Three ints with value 5
values.push_back(2); // values: 5 5 5 2
values[1] = 1; // values: 5 1 5 2
vector<int>::const_iterator current = values.begin();
vector<int>::const_iterator pos, end = values.end();
int max = *current; current++;
while(current!=values.end()){
    if(*current>max){
        max = *current;
    }
    current++;
}
```

- Finding an element satisfying a constraint:

```cpp
class EqualPred{
 int match;
 EqualPred(int n): match(n){};
 bool operator()(int x){return x==match};
}
...const_iterator pos = std::find_if(start, end, EqualPred(3));
```

Boost C++ Libraries (`boost.org`)

- ”Boost is the most powerful and complicated 3rd part library. However, Boost is so heavy that people and companies may refuse to use it.” (jdxyw.com)
- About 50 major sub-components based on STL:
  - ”Better” smart pointers
  - Maths and Matrices
  - Threads
  - Boost Graph Library
  - many many more... (`http://www.codeproject.com/Articles/4496/An-Introduction-to-Boost`)

Boost Graph Example

```
typedef boost::adjacency_list<boost::vecS, boost::vecS, boost::directedS>
    graph_t;
graph_t g(6);
boost::add_edge(1,2,g);
boost::add_edge(1,5,g);
boost::add_edge(2,2,g);
boost::add_edge(2,0,g);
boost::add_edge(3,4,g);
boost::add_edge(4,3,g);
boost::add_edge(5,0,g);

typedef graph_traits<graph_t>::vertex_iterator
    vertex_iter;
pair<vertex_iter, vertex_iter> vrange=vertices(g);
for(vertex_iter it =vrange.first; it!=vrange.second; ++it)
cout << *it << endl;

typedef graph_traits<graph_t>::edge_iterator
    edge_iter;
pair<edge_iter, edge_iter> erange=edges(g);
for(edge_iter it =erange.first; it!=erange.second; ++it)
cout << source(*it,g) <<"——"<<target(*it,g) << endl;
```

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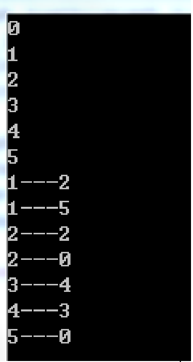

```
0
1
2
3
4
5
1---2
1---5
2---2
2---0
3---4
4---3
5---0
```

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Conclusion

- Template metaprogramming is a powerful C++ tool to generate code at compile-time
- STL is a very useful collection of generic classes and functions (great example of TMP)
- C++ Standard Library $\approx$ STL
- Very powerful Boost libraries ($\Rightarrow$ CSE)
- References:
  - `https://monoinfinito.wordpress.com/series/introduction-to-c-template-metaprogramming/`
  - Scott Meyers, Effective C++
  - Davide di Gennaro, Advanced C++ Template Metaprogramming
  - Dave Abrahams, Aleksey Gurtovoy, C++ Template Metaprogramming