

Chapter 8. Templates

Programming Concepts in Scientific Computing
EPFL, Master class

October 25, 2023

Some more factorization

Some algorithms are not **type dependent**

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Some algorithms are not **type dependent**

```
int getMaximum(const int &a, const int &b) {  
    if (a > b)  
        return a;  
    return b;  
}
```

Some more factorization

Some algorithms are not **type dependent**

```
int getMaximum(const int &a, const int &b) {  
    if (a > b)  
        return a;  
    return b;  
}
```

```
double getMaximum(const double &a, const double &b) {  
    if (a > b)  
        return a;  
    return b;  
}
```

Some more factorization

Some algorithms are not **type dependent**

```
int getMaximum(const int &a, const int &b) {  
    if (a > b)  
        return a;  
    return b;  
}
```

```
double getMaximum(const double &a, const double &b) {  
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        return a;  
    return b;  
}
```

Can we use **types as parameters** ?

Template Functions

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template<typename T>
T getMaximum(const T & a, const T & b) {
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Type matching !

```
double a,b;
double res_d = getMaximum(a,b);
```

Template Functions

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    if (a > b)
        return a;
    return b;
}
```

Type matching !

```
double a,b;
double res_d = getMaximum(a,b);
```

or

```
int c,d;
int res_i = getMaximum(c,d);
```

Apply templates to **vector** class ?

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Yes

Template Classes

```
template <typename T> class MyVector {  
public:  
    T &operator[](unsigned int dim) { return value[dim]; }  
  
private:  
    T value[3];  
};
```

Template Classes

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MyVector<double> real_vector;
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```
MyVector<int> integer_vector;
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MyVector<double> real_vector;
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- ▶ Will be done during compilation

Template Classes

- ▶ MyVector is a templated class
- ▶ Template parameters included in type definition

```
MyVector<double> real_vector;
```

```
MyVector<int> integer_vector;
```

- ▶ Will be done during compilation
- ▶ Instanciated Template classes/functions:
modified name (`MyVectorInt`, `MyVectorDouble`)

Template Classes

Template parameters can be:

- ▶ Other types (typename)
- ▶ Integers
- ▶ Enum values

Templates: Adding dimension to the vector type

```
template <typename T, int dim = 3> class MyVector {  
    ...  
private:  
    T value[dim];  
};
```

Templates: Adding dimension to the vector type

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};
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Templates: Adding dimension to the vector type

```
template <typename T, int dim = 3> class MyVector {  
    ...  
private:  
    T value[dim];  
};
```

Using it:

```
MyVector<double> vector_3d;  
MyVector<double, 2> vector_2d;
```

Type Matching: scalar product function

```
template <typename T, int dim>
T scalarProduct(const MyVector<T, dim> &v1, /
                 const MyVector<T, dim> &v2 /
) {

    T res;
    for (int d = 0; d < dim; ++d)
        res += v1[d] * v2[d];
    return res;
}
```

Type Matching: scalar product function

```
template <typename T, int dim>
T scalarProduct(const MyVector<T, dim> &v1, /
                 const MyVector<T, dim> &v2 /
) {

    T res;
    for (int d = 0; d < dim; ++d)
        res += v1[d] * v2[d];
    return res;
}
```

Using:

```
MyVector<double> vector1_3d;
MyVector<double> vector2_3d;

double res = scalarProduct(vector1_3d, vector2_3d);
```

Type matching: ostream « operator

```
template <typename T, int dim>
std::ostream &operator<<(std::ostream &stream, const MyVector<T,
    stream << "[";
    for (int d = 0; d < dim; ++d) {
        if (d != 0)
            stream << ", ";
        stream << vect[d];
    }
    stream << "]"";
    return stream;
}
```

Template specialization

```
template <typename T> T getMaximum(const T &a, const T &b) {  
    if (a > b)  
        return a;  
    return b;  
}
```

Template specialization

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template <typename T> T getMaximum(const T &a, const T &b) {  
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```

getMaximum working over vectors ?

Template specialization

```
template <typename T> T getMaximum(const T &a, const T &b) {  
    if (a > b)  
        return a;  
    return b;  
}
```

getMaximum working over vectors ?

```
MyVector<double> v1, v2;  
MyVector<double> res = getMaximum(v1, v2);
```

Template specialization

Exceptions in type matching

Template specialization

Exceptions in type matching

```
template <>
MyVector<double, 3>
getMaximum(MyVector<double, 3>>(const MyVector<double, 3> &v1,
                                const MyVector<double, 3> &v2) {

    MyVector<double, 3> max;
    for (int i = 0; i < 3; ++i) {
        max[i] = getMaximum(v1[i], v2[i]);
    }
    return max;
}
```

Template specialization

Exceptions in type matching

template <> Specialisation comes here, being ignoring the T inside

```
MyVector<double, 3>
getMaximum<MyVector<double, 3>>(const MyVector<double, 3> &v1,
                                const MyVector<double, 3> &v2) {

    MyVector<double, 3> max;
    for (int i = 0; i < 3; ++i) {
        max[i] = getMaximum(v1[i], v2[i]);
    }
    return max;
}
```

Template specialization

Exceptions in type matching

```
template <>
MyVector<double, 3>
getMaximum<MyVector<double, 3>>(const MyV
                                const MyVector<doub

MyVector<double, 3> max;
for (int i = 0; i < 3; ++i) {
    max[i] = getMaximum(v1[i], v2[i]);
}
return max;
}
```

Template specialization

Exceptions in type matching

```
template <>
MyVector<double, 3>
getMaximum(MyVector<double, 3>>(const MyVector<double, 3> &v1,
                                const MyVector<double, 3> &v2) {

    MyVector<double, 3> max;
    for (int i = 0; i < 3; ++i) {
        max[i] = getMaximum(v1[i], v2[i]);
    }
    return max;
}
```

Template specialization

Exceptions in type matching

```
template <>
MyVector<double, 3>
getMaximum<MyVector<double, 3>>(const MyVector<double, 3> &v1,
                                const MyVector<double, 3> &v2) {

    MyVector<double, 3> max;
    for (int i = 0; i < 3; ++i) {
        max[i] = getMaximum(v1[i], v2[i]);
    }
    return max;
}
```

```
MyVector<double> v1, v2;
MyVector<double> res = getMaximum(v1, v2);
```

Templates specialization

Can we code-factor more ?

Templates specialization

Can we code-factor more ?

```
template <typename T, int dim>
MyVector<T, dim> getMaximum(const MyVector<T, dim> &v1,
                           const MyVector<T, dim> &v2) {

    MyVector<T, dim> max;
    for (int i = 0; i < dim; ++i) {
        max[i] = getMaximum(v1[i], v2[i]);
    }
    return max;
}
```

Templates specialization

Can we code-factor more ?

```
template <typename T, int dim>      Overloading: different signatures here
MyVector<T, dim> getMaximum(const MyVector<T, dim> &v1,
                           const MyVector<T, dim> &v2) {

    MyVector<T, dim> max;
    for (int i = 0; i < dim; ++i) {
        max[i] = getMaximum(v1[i], v2[i]);
    }
    return max;
}
```

This is overloading

Template meta programming

```
int arithmetic(int i) {  
    if (i == 1)  
        return 1;  
    return i + arithmetic(i - 1);  
}
```

Template meta programming

```
int arithmetic(int i) {  
    if (i == 1)  
        return 1;  
    return i + arithmetic(i - 1);  
}
```

Let's call the function

```
int a = 5;  
std::cout << arithmetic(a);
```

Template meta programming

```
template <int i> int arithmetic_template() {  
    return i + arithmetic_template<i - 1>();  
}
```

Template specialisation

```
template <> int arithmetic_template<1>() {  
    // ends recursion  
    return 1;  
}
```

Let's call the function

```
std::cout << arithmetic_template<5>();  
std::cout << std::endl;
```

Template meta programming

Can we do this ?

```
int a = 5;  
std::cout << arithmetic_template<a>();  
std::cout << std::endl;
```

And why ?

Don't get the point ...

Variadic template meta programming

Termination case, if we have only 1 parameter left

```
template <typename T> T adder(T v) { return v; }
```

```
template <typename T, typename... Args>  
// template ...Args is a variadic template  
T adder(T first, Args... args) {  
    return first + adder(args...);  
}
```

Using it:

```
std::cout << adder(1, 2, 3, 4);  
std::cout << adder(1., 2, 3., 4);  
std::cout << adder(std::string("a"), std::string("b"));
```

Variadic template meta programming

```
template <typename T, typename... Args> // variadic  
T adder(T first, Args... args) {  
    T ret = first;  
    ((ret += args), ...);  
    return ret;  
}
```

Using it:

```
std::cout << adder(1., 2, 3., 4);  
std::cout << adder(std::string("a"), std::string("b"));  
std::cout << std::endl;
```


Function returning a pair

Use a struct for that (returning a pair)

```
template <typename T1, typename T2> struct pair {  
    T1 obj1;  
    T2 obj2;  
};
```

```
pair<int, int> foo() {  
    // return two integers together  
    return pair<int, int>{2, 3};  
}
```

Using it:

```
pair<int, int> p = foo();  
// fetching the integers  
int a = p.obj1;  
int b = p.obj2;  
}
```

std::pair

```
std::pair<int, int> foo() {  
    // return two integers together  
    return std::make_pair(2, 3);  
}
```

Using it:

```
std::pair<int, int> p = foo();  
// fetching the integers  
int a = std::get<0>(p);  
int b = std::get<1>(p);
```

std::tuple

```
std::tuple<int, int, double> foo() {  
    // return a tuple with 3 entries  
    return std::make_tuple(2, 3, 3.14);  
}
```

Using it:

```
std::tuple<int, int, double> p = foo();  
// fetching the integers  
int a = std::get<0>(p);  
int b = std::get<1>(p);  
double c = std::get<2>(p);
```

auto magic

```
std::tuple<int, int, double> foo() {  
    // return a tuple with 3 entries  
    return std::make_tuple(2, 3, 3.14);  
}
```

Using it:

```
// magical auto keyword  
auto [a, b, c] = foo();
```

Take away message

- ▶ **Templating** is a mechanism to **substitute** parameters during compilation
- ▶ **Template Classes** create types with parameters included in the type name
- ▶ **Template parameters** are other types, integers, enums
- ▶ Compiler does **type matching** to deduce template parameters
- ▶ **Specializations** allow exceptions
- ▶ **Overloading** or **Template** ? no rule: need programming experience
- ▶ **Meta-programming** allows calculation at compilation
- ▶ **Variadic templates** allow flexible expressions