

CS202: Programming Systems

Week 7:
Template and metaprogramming

CS202 – What will be discussed?

- ☐ Introduction
- ☐ Function templates
- ☐ Class templates
- ☐ Static class members
- ☐ Metaprogramming

Introduction

- ❑ Frequently, we have to implement the same functions or classes for arguments on different data types
- ❑ The templates enable us to implement the function only once to be used for different argument data types

An example: function template

The same function for different data types:

```
int bigger(int a, int b)
{
    return (a>b) ? a : b;
}
```

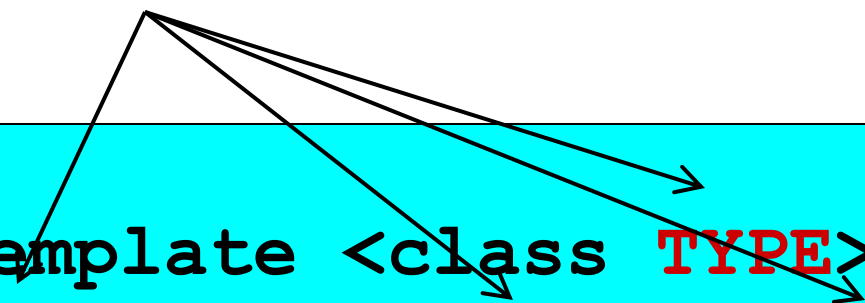
```
float bigger(float a, float b)
{
    return (a>b) ? a : b;
}
```

Templates enable us to write the function once:

```
TYPE bigger(TYPE a, TYPE b)
{
    return (a>b) ? a : b;
}
```

Templates

Name of parameters
representing data types



```
template <class TYPE>  
TYPE bigger(TYPE a, TYPE b)  
{  
    return (a>b) ? a : b;  
}
```

TYPE is chosen
by users and is
not a keyword.

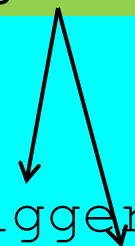
The operator **>**
must be defined
for **TYPE**

Function template

```
template <class TYPE>
TYPE bigger(TYPE a, TYPE b)
{
    return (a>b) ? a : b;
}

int main()
{
    int x=30, y=50;
    Fraction a(2, 3), b(7, 10);
    cout << "The bigger integer " << bigger(x, y);
    cout << "The bigger fraction " << bigger(a, b);
}
```

template instantiation
for given data type



Quiz

- ❑ Write the template function for the **swap** of 2 numbers.

```
template <class TYPE>
void swap(TYPE& a, TYPE& b)
{
    TYPE temp;
    temp = a;
    a = b;
    b = temp;
}
```

Quiz

- ☐ Using templates to implement the `sort()` function for any data type
- ☐ You can implement any sort algorithm that you are familiar with.

Template: how does it work?

Consider **TYPE** `bigger (TYPE a, TYPE b)`

- If we invoke the **bigger** function for 2 variables of **int**. Then:
 - Compiler generate a function, e.g. **bigger_int** and replace all **TYPE** in the function by **int**
 - When the program runs the **bigger_int** will run instead of the generic **bigger**
- Usually the entire template code is located in a header file

Class template

```
template <class TYPE>
class MyArr
{
    public:
        MyArr();
        MyArr(unsigned);
        ~MyArr();
        TYPE& operator[] (unsigned);
        const TYPE& operator[] (unsigned) const;
        MyArr<TYPE>& operator=(const MyArr<TYPE>&);
    private:
        TYPE* pArr;
        unsigned size;
};
```

Class template

- We can use template parameters as data types in class. In the last example, we have
 - TYPE
 - `MyArr<TYPE>`
- They are used as normal data types for variable declaration, function arguments and function return... in the class

Template instantiation

□ From the last example

- **MyArr**: is just a name of the template class
- **MyArr<float>**: name of the class, an array of float

□ Declaring objects

- **MyArr<Fraction> arrFrac(200) ;**
- ➔ Compiler will generate an actual class based on the generic template class

Template class definition

At the point of declaration

```
template <class T>
class MyClass
{
public:
    MyClass () { ... }
};
```

At the point of definition

```
template <class T>
MyClass<T>::MyClass ()
{
    ...
}
```

Template params are not data type

- ❑ Besides the data type params, class can have numbers as params:

```
template <class TYPE, int size>
class List
{
    public:
        ...
    private:
        TYPE arr[size];
};
```

An example

- Then, the list with 100 elements in the example below will be generated at compile time:

```
int main()
{
    List<int, 100> a;
    return 0;
}
```

Static class members

- ❑ Static class members are common (i.e. use the same memory slot) for all instances of that class.
- ❑ Static member functions don't have **this** pointer and are only able to use static members of that class.
- ❑ You can refer to a static member by direct access (i.e. dot) via any object of that class or by scope resolution via class name.

Static class members

- ❑ Static class members have to be defined exactly once in the program.

```
class A
{
    static int x;
    int z;
public:
    static void doSomething();
    int test() { return x+z; }
};
int A::x=5;
```

Implement a Pair template class in C++ that stores two elements of different, generic types. You should be able to access and modify the elements, compare two pairs for equality, and print the pair.

Define a template class Pair that takes two generic types.

Implement the following member functions:

Constructor: Initializes the pair with two values, one of type T1 and the other of type T2.

getFirst: Returns the first element.

getSecond: Returns the second element.

setFirst: Updates the first element.

setSecond: Updates the second element.

operator==: Compares two pairs for equality. Two pairs are equal if both their first and second elements are equal.

print: Prints the pair elements in a readable format.

Test the Pair class with different data types, such as int and std::string, double and char, etc.

Metaprogramming

- ❑ Templates enable C++ compiler work as an interpreter. Programs are interpreted at the compiling time.
- ❑ For example, loops or conditional checking can be replaced by recursive templates

An example

```
template<int N>
class Factorial
{
public:
    static const int val = N*Factorial<N-1>::val;
};

template<>
class Factorial<0> {
public:
    static const int val=1;
};

int main()
{
    cout << Factorial<5>::val << endl; return 0;
}
```

Metaprogramming

- ❑ Those programs have results at the compiling time.
- ❑ This technique becomes very useful and powerful in C++ programming.
- ❑ See **C++ Template Metaprogramming** book by David Abrahams for further information on this

Exercise

- Using **metaprogramming** to write the **bubblesort** for an array of integers