Lecture 12 - Template

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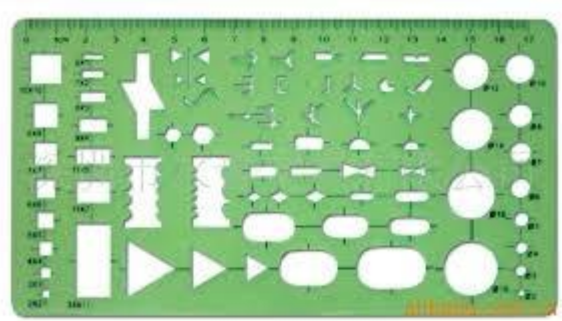

Introduction

- Function templates and class templates enable you to specify, with a single code segment, an entire range of related (overloaded) functions—called function-template specializations—or an entire range of related classes—called class-template specializations.
- This technique is called generic programming.
- Note the distinction between templates and template specializations:
  - Function templates and class templates are like stencils out of which we trace shapes.
  - Function-template specializations and class-template specializations are like the separate tracings that all have the same shape, but could, for example, be drawn in different colors.

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Introduction (cont.)

- Most C++ compilers require the complete definition of a template to appear in the client source-code file that uses the template. For this reason and for reusability, templates are often defined in header files, which are then `#include`d into the appropriate client source-code files. For class templates, this means that the member functions are also defined in the header file.

Function Templates

- Overloaded functions normally perform *similar or identical operations on different types of data.*
- If the operations are *identical for each type, they can be expressed more compactly and conveniently using function templates.*
- Initially, you write a single function-template definition.
- Based on the argument types provided explicitly or inferred from calls to this function, the compiler generates separate source-code functions (i.e., function-template specializations) to handle each function call appropriately.

Function Templates (cont.)

- All function-template definitions begin with keyword `template` followed by a list of template parameters enclosed in angle brackets (`<` and `>`); each template parameter that represents "any fundamental type or user-defined type" must be preceded by either of the interchangeable keywords `class` or `typename`, as in
    - `template<typename T1, typename T2>`
  - Or
    - `template<class T>`
- The type template parameters of a function template are used to specify the types of the arguments to the function, to specify the return type of the function and to declare variables within the function.

Example: *printArray()*

```
#include <iostream>
using namespace std;
template <typename T>
void printArray(const T* const arr, int count)
{
    for(int i=0;i<count;++i)
        cout << arr[i] << " ";
    cout << endl;
}
int main()
{
    const int aCount=5;
    const int bCount=7;
    const int cCount=6;

    int a[aCount] = {1,2,3,4,5};
    double b[bCount] = {1.1,2.2,3.3,4.4,5.5,6.6,7.7};
    char c[cCount] = "HELLO";

    cout << "Array a: ";
    printArray(a, aCount);
    cout << "Array b: ";
    printArray(b, bCount);
    cout << "Array c: ";
    printArray(c, cCount);
}
```

```
Array a: 1 2 3 4 5
Array b: 1.1 2.2 3.3 4.4 5.5 6.6 7.7
Array c: H E L L O
```

- T is referred to as a type template parameter, or type parameter.

Function Templates (cont.)

- When the compiler detects a `printArray` function invocation in the client program (e.g., lines 21, 23 and 25), the compiler uses its overload resolution capabilities to find a definition of function `printArray` that best matches the function call.
- The compiler compares the type of `printArray`'s first argument (`int *` at line 21) to the `printArray` function template's first parameter (`const T * const` at line 4) and deduces that replacing the type parameter `T` with `int` would make the argument consistent with the parameter.
- Then, the compiler substitutes `int` for `T` throughout the template definition and compiles a `printArray` specialization that can display an array of `int` values.

Function Templates (cont.)

- The function-template specialization for type `int` is
  - ```
    void printArray( const int * const array, int count )
    {
       for ( int i = 0; i < count; i++ )
          cout << array[ i ] << " ";

       cout << endl;
    }
    ```
- As with function parameters, the names of template parameters must be unique inside a template definition.
- Template parameter names need not be unique across different function templates.

```
template < typename T>
int func1(T par)  {…}

template < typename T>
double func2(T par)  {…}
```
```

Overloading Function Templates

- Function templates and overloading are intimately related.
- The function-template specializations generated from a function template all have the same name, so the compiler uses overloading resolution to invoke the proper function.
- A function template may be overloaded in several ways.
  - We can provide other function templates that specify the same function name but different function parameters.
  - We can provide nontemplate functions with the same function name but different function arguments.

Error: Ambiguous Definitions

- A compilation error occurs if no matching function definition can be found for a particular function call or if there are multiple matches that the compiler considers ambiguous.


```cpp
 1 #include <iostream>
 2 using namespace std;
 3 template <typename T>
 4 void fun(T t) {cout << t;}
 5 template <typename U>
 6 void fun(U u) {cout << u;}
 7 int main()
 8 {
 9     int x;
10     fun(x);
11     return 0;
12 }
```

```
ambiguous.cpp:6: error: redefinition of
'template<class U> void fun(U)'
ambiguous.cpp:4: error: 'template<class T> void
fun(T)' previously declared here
```

Example: Overloading vs. Templates

```
#include <iostream>
using namespace std;

template <typename T>
int func(T t)  {    cout << t << ": template function" << endl;  }

int func(int Y)
{   cout << Y << ": function overloading with int" << endl;  }

int func(double Z)
{   cout << Z << ": function overloading with double" << endl;  }

int main()
{
    int x = 5;
    func(x);
    return 0;
}
```

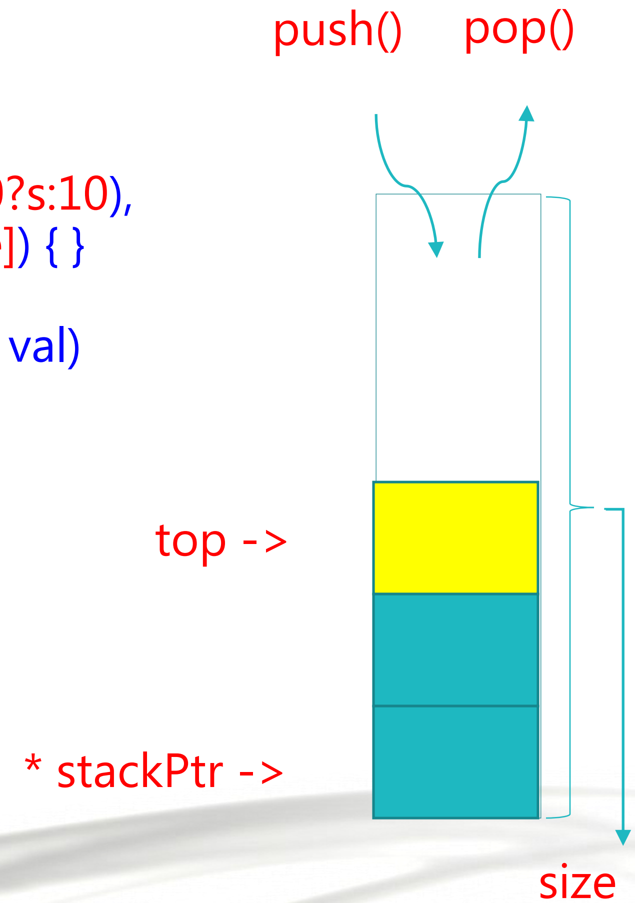
Output:
5: function overloading with int

Class Templates

- It's possible to understand the concept of a "stack" (a data structure into which we insert items at the top and retrieve those items in last-in, first-out order) independent of the type of the items being placed in the stack.
- We need the means for describing the notion of a stack generically and instantiating classes that are type-specific versions of this generic stack class.
- C++ provides this capability through class templates.
- Class templates are called parameterized types, because they require one or more type parameters to specify how to customize a "generic class" template to form a class-template specialization.

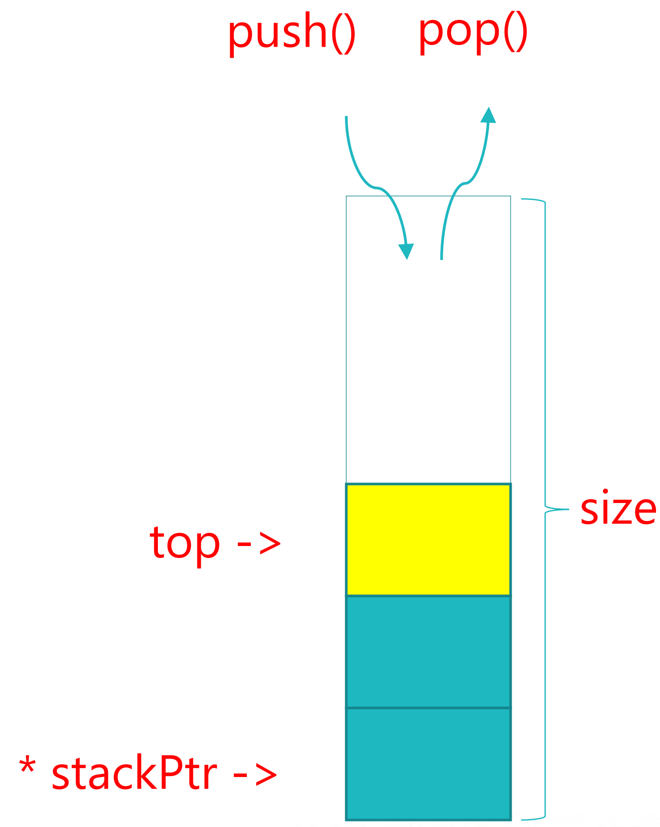
Stack.h

```
#ifndef STACK_H
#define STACK_H
template <typename T>
class Stack {
public:
   Stack(int=10);
   ~Stack()
   {
       delete [] stackPtr;
   }
   bool push(const T&);
   bool pop(T&);
   bool isEmpty() const
   {
       return top == -1;
   }
   bool isFull() const
   {
       return top == size -1;
   }
private:
   int size;
   int top;
   T* stackPtr;
};
template <typename T>
Stack<T>::Stack(int s): size(s>0?s:10),
       top(-1),stackPtr(new T[size]) { }
template <typename T>
bool Stack<T>::push(const T& val)
{
   if(!isFull())
   {
       stackPtr[++top] = val;
       return true;
   }
   return false;
}
```



Stack.h (cont.)

```
template <typename T>
bool Stack<T>::pop(T& val)
{
   if(!isEmpty())
   {
      val = stackPtr[top--];
      return true;
   }
   return false;
}
#endif
```



use_stack.cpp

```cpp
#include <iostream>
#include "Stack.h"
using namespace std;
int main()
{
   Stack <double> dStk(5);
   double dVal = 1.1;
   cout << "push elements: ";
   while(dStk.push(dVal))
   {
      cout << dVal << ' ';
      dVal += 1.1;
   }
   cout << "\nStack is full, cannot push "
        << dVal;
   cout << "\npop elements: ";
   while(dStk.pop(dVal))
      cout << dVal << ' ';
   cout << "\nStack is empty\n";
   Stack<int> iStk;
   int iVal = 1;
   cout << "push elements: ";
   while(iStk.push(iVal))
      cout << iVal++ << ' ';
   cout << "\nStack is full, cannot push "
        << iVal;
   cout << "\npop elements: ";
   while(iStk.pop(iVal))
      cout << iVal << ' ';
   cout << "\nStack is empty\n";
}
```

```
push elements: 1.1 2.2 3.3 4.4 5.5
Stack is full, cannot push 6.6
pop elements: 5.5 4.4 3.3 2.2 1.1
Stack is empty
push elements: 1 2 3 4 5 6 7 8 9 10
Stack is full, cannot push 11
pop elements: 10 9 8 7 6 5 4 3 2 1
Stack is empty
```

Class Templates (cont.)

- The `Stack` class-template definition looks like a conventional class definition, except that it's preceded by the header (line 3)
  - `template< typename T >`

  to specify a class-template definition with type parameter `T` which acts as a placeholder for the type of the `Stack` class to be created.
- The type of element to be stored on this `Stack` is mentioned generically as `T` throughout the `Stack` class header and member-function definitions.
- Due to the way this class template is designed, there are two constraints for non-fundamental data types used with this `Stack`
  - they must have a default constructor
  - their assignment operators must properly copy objects into the `Stack`

Class Templates (cont.)

- The member-function definitions of a class template are function templates.
- The member-function definitions that appear outside the class template definition each begin with the header
  - `template< typename T >`
- Thus, each definition resembles a conventional function definition, except that the `Stack` element type always is listed generically as type parameter `T`.
- The binary scope resolution operator is used with the class-template name to tie each member-function definition to the class template's scope.

Class Templates (cont.)

- The program begins by instantiating object `dStk` of size `5`.
- This object is declared to be of class `Stack< double >` (pronounced "`Stack` of `double`").
- The compiler associates type `double` with type parameter `T` in the class template to produce the source code for a `Stack` class of type `double`.
- Although templates offer software-reusability benefits, remember that multiple class-template specializations are instantiated in a program (at compile time), even though the template is written only once.

Class Templates (cont.)

- Notice that the code in function `main` is almost identical for both the `dStk` manipulations in lines 6–18 and the `iStk` manipulations in lines 19–28.
- This presents another opportunity to use a function template.
- In the next example, we define function template `testStack` (lines 5–19) to `push` a series of values onto a `Stack< T >` and `pop` the values off a `Stack< T >`.
- Function template `testStack` uses template parameter `T` (specified at line 5) to represent the data type stored in the `Stack< T >`.

test_stack.cpp

```cpp
#include <iostream>
#include <string>
#include "Stack.h"
using namespace std;
template <typename T>
void testStack(Stack<T> &theStack,
    T value, T increment,
    const string stackName)
{
  cout <<"push elements from "
        <<stackName<<":\n";
  while(theStack.push(value))
  {
    cout << value << ' ';
    value += increment;
  }
  cout << "\nStack is full. Cannot push "
         << value << "\npop elements from "
         << stackName << ":\n";
  while(theStack.pop(value))
    cout << value << ' ';

  cout << "\nStack is empty.\n";
}
int main()
{
  Stack<double> dStk(5);
  Stack<int> iStk;
  testStack(dStk, 1.1, 1.1, "dStk");
  testStack(iStk, 1, 1, "iStk");
  return 0;
}
```

```
push elements from dStk:
1.1 2.2 3.3 4.4 5.5
Stack is full. Cannot push 6.6
pop elements from dStk:
5.5 4.4 3.3 2.2 1.1
Stack is empty.
push elements from iStk:
1 2 3 4 5 6 7 8 9 10
Stack is full. Cannot push 11
pop elements from iStk:
10 9 8 7 6 5 4 3 2 1
Stack is empty.
```