



Module 39

Partha Pratim
Das

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition
Instantiation
Partial Template
Instantiation &
Default
Template
Parameters
Inheritance

Summary

Module 39: Programming in C++

Template (Class Template): Part 2

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Module Objectives

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What is a
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Summary

- Understand Templates in C++



Module Outline

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- What is a Template?
- Function Template
 - Function Template Definition
 - Instantiation
 - Template Argument Deduction
 - Example
- `typename`
- Class Template
 - Class Template Definition
 - Instantiation
 - Partial Template Instantiation & Default Template Parameters
 - Inheritance



What is a Template?: RECAP (Module 38)

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Summary

- Templates are specifications of a collection of functions or classes which are parameterized by types
- Examples:
 - Function search, min etc.
 - The basic algorithms in these functions are the same independent of types
 - Yet, we need to write different versions of these functions for strong type checking in C++
 - Classes list, queue etc.
 - The data members and the methods are almost the same for list of numbers, list of objects
 - Yet, we need to define different classes



Function Template:

Code reuse in Algorithms: RECAP (Module 38)

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- We need to compute the maximum of two values that can be of:
 - `int`
 - `double`
 - `char *` (C-String)
 - `Complex` (user-defined class for complex numbers)
 - ...
- We can do this with overloaded Max functions:

```
int Max(int x, int y);  
double Max(double x, double y);  
char *Max(char *x, char *y);  
Complex Max(Complex x, Complex y);
```

With every new type, we need to add an overloaded function in the library!

- **Issues in Max function**
 - **Same algorithm** (compare two value using the appropriate operator of the type and return the larger value)
 - **Different code versions** of these functions for strong type checking in C++



Class Template: Code Reuse in Data Structure

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- Solution of several problems needs stack (LIFO)
 - Reverse string (char)
 - Convert infix expression to postfix (char)
 - Evaluate postfix expression (int / double / Complex ...)
 - Depth-first traversal (Node *)
 - ...
- Solution of several problems needs queue (FIFO)
 - Task Scheduling (Task *)
 - Process Scheduling (Process *)
 - ...
- Solution of several problems needs list (ordered)
 - Implementing stack, queue (int / char / ...)
 - Implementing object collections (UDT)
 - ...
- Solution of several problems needs ...
- **Issues in Data Structure**
 - Data Structures are **generic - same interface, same algorithms**
 - **C++ implementations are different** due to element type



Stack of char and int

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Summary

```
class Stack {
    char data_[100];           // Has type
    int top_;
public:
    Stack() :top_(-1) {}
    ~Stack() {}

    void push(const char& item) // Has type
    { data_[++top_] = item; }

    void pop()
    { --top_; }

    const char& top() const    // Has type
    { return data_[top_]; }

    bool empty() const
    { return top_ == -1; }
};
```

- Stack of char

- Can we combine these Stack codes using a type variable T?

```
class Stack {
    int data_[100];           // Has type
    int top_;
public:
    Stack() :top_(-1) {}
    ~Stack() {}

    void push(const int& item) // Has type
    { data_[++top_] = item; }

    void pop()
    { --top_; }

    const int& top() const    // Has type
    { return data_[top_]; }

    bool empty() const
    { return top_ == -1; }
};
```

- Stack of int



Class Template

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Summary

- A **class template**

- describes how a class should be built
- Supplies the class description and the definition of the member functions using some arbitrary type name, (as a place holder)
- is a:
 - **parameterized** type with
 - **parameterized** member functions
- can be considered the definition for a **unbounded set** of class types
- is identified by the **keyword template**
 - followed by comma-separated list of **parameter** identifiers (each preceded by **keyword class** or **keyword typename**)
 - enclosed between **<** and **>** delimiters
 - followed by the definition of the class
- is often used for **container** classes
- Note that every template parameter is a **built-in type** or **class** – type parameters



Stack as a Class Template:

Stack.h

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Summary

```
template<class T>
class Stack {
    T data_[100];
    int top_;
public:
    Stack() :top_(-1) {}
    ~Stack() {}

    void push(const T& item)
    { data_[++top_] = item; }

    void pop()
    { --top_; }

    const T& top() const
    { return data_[top_]; }

    bool empty() const
    { return top_ == -1; }
};
```

- Stack of type variable T
- The traits of type variable T include
 - copy assignment operator (T operator=(const T&))
- We do not call our template class as stack because std namespace has a class stack



Reverse String: Using Stack template

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```
#include <iostream>
#include "Stack.h"
using namespace std;

int main() {
    char str[10] = "ABCDE";

    Stack<char> s;          // Instantiated for char

    for (unsigned int i = 0; i < strlen(str); ++i)
        s.push(str[i]);

    cout << "Reversed String: ";
    while (!s.empty()) {
        cout << s.top();
        s.pop();
    }

    return 0;
}
```

- Stack of type char



Postfix Expression Evaluation: Using Stack template

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```
#include <iostream>
#include "Stack.h"
using namespace std;

int main() {
    // Postfix expression: 1 2 3 * + 9 -
    unsigned int postfix[] = { '1', '2', '3', '*', '+', '9', '-' }, ch;

    Stack<int> s;          // Instantiated for int

    for (unsigned int i = 0; i < sizeof(postfix) / sizeof(unsigned int); ++i) {
        ch = postfix[i];
        if (isdigit(ch)) { s.push(ch - '0'); }
        else {
            int op1 = s.top(); s.pop();
            int op2 = s.top(); s.pop();
            switch (ch) {
                case '*': s.push(op2 * op1); break;
                case '/': s.push(op2 / op1); break;
                case '+': s.push(op2 + op1); break;
                case '-': s.push(op2 - op1); break;
            }
        }
    }

    cout << "\nEvaluation " << s.top();

    return 0;
}
```

- [Stack of type int](#)



Template Parameter Traits

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● Parameter Types

- may be of any type (including user defined types)
- may be parameterized types, (that is, templates)
- MUST support the methods used by the template functions:
 - What are the required constructors?
 - The required operator functions?
 - What are the necessary defining operations?



Function Template Instantiation: RECAP (Module 38)

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- Each item in the template parameter list is a template argument
- When a template function is invoked, the values of the template arguments are determined by seeing the types of the function arguments

```
template<class T> T Max(T x, T y);  
template<> char *Max<char *>(char *x, char *y);  
template <class T, int size> Type Max(T x[size]);  
  
int a, b; Max(a, b); // Binds to Max<int>(int, int);  
double c, d; Max(c, d); // Binds to Max<double>(double, double);  
char *s1, *s2; Max(s1, s2); // Binds to Max<char*>(char*, char*);  
  
int pval[9]; Max(pval); //Error!
```

- Three kinds of conversions are allowed
 - L-value transformation (for example, Array-to-pointer conversion)
 - Qualification conversion
 - Conversion to a base class instantiation from a class template
- If the same template parameter are found for more than one function argument, template argument deduction from each function argument must be the same



Class Template Instantiation

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- Class Template is instantiated only when it is required:
 - `template<class T> class Stack;` is a forward declaration
 - `Stack<char> s;` is an error
 - `Stack<char> *ps;` is okay
 - `void ReverseString(Stack<char>& s, char *str);` is okay
- Class template is instantiated before
 - An object is defined with class template instantiation
 - If a pointer or a reference is dereferenced (for example, a method is invoked)
- A template definition can refer to a class template or its instances but a non-template can only refer to template instances



Class Template Instantiation Example

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

template<class T> class Stack;           // Forward declaration

void ReverseString(Stack<char>& s, char *str); // Stack template definition is not needed

template<class T>                       // Definition
class Stack { T data_[100]; int top_;
public: Stack() :top_(-1) {} ~Stack() {}

    void push(const T& item) { data_[++top_] = item; }
    void pop() { --top_; }
    const T& top() const { return data_[top_]; }
    bool empty() const { return top_ == -1; }
};

int main() {
    char str[10] = "ABCDE";
    Stack<char> s;                       // Stack template definition is needed

    ReverseString(s, str);

    return 0;
}

void ReverseString(Stack<char>& s, char *str) { // Stack template definition is needed
    for (unsigned int i = 0; i < strlen(str); ++i) s.push(str[i]);

    cout << "Reversed String: ";
    while (!s.empty()) { cout << s.top(); s.pop(); }
}
```



Partial Template Instantiation and Default Template Parameters

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

template<class T1 = int, class T2 = string> // Version 1 with default parameters
class Student { T1 roll_; T2 name_;
public: Student(T1 r, T2 n) : roll_(r), name_(n) {}
    void Print() const { cout << "Version 1: (" << name_ << ", " << roll_ << ")" << endl; }
};

template<class T1> // Version 2: Partial Template Specialization
class Student<T1, char *> { T1 roll_; char *name_;
public: Student(T1 r, char *n) : roll_(r), name_(strcpy(new char[strlen(n) + 1], n)) {}
    void Print() const { cout << "Version 2: (" << name_ << ", " << roll_ << ")" << endl; }
};

int main() {
    Student<int, string> s1(2, "Ramesh");    // Version 1: T1 = int, T2 = string
    Student<int> s2(11, "Shampa");          // Version 1: T1 = int, defa T2 = string
    Student<> s3(7, "Gagan");                // Version 1: defa T1 = int, defa T2 = string
    Student<string> s4("X9", "Lalita");      // Version 1: T1 = string, defa T2 = string
    Student<int, char*> s5(3, "Gouri");      // Version 2: T1 = int, T2 = char*

    s1.Print(); s2.Print(); s3.Print(); s4.Print(); s5.Print();

    return 0;
}

-----
Version 1: (Ramesh, 2)
Version 1: (Shampa, 11)
Version 1: (Gagan, 7)
Version 1: (Lalita, X9)
Version 2: (Gouri, 3)
```




Templates and Inheritance:

Example (List.h)

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```
#ifndef __LIST_H
#define __LIST_H

#include <vector>
using namespace std;

template<class T>
class List {
public:
    void put(const T &val) { items.push_back(val); }
    int length() { return items.size(); }
    bool find(const T &val) {
        for (unsigned int i = 0; i < items.size(); ++i)
            if (items[i] == val) return true;
        return false;
    }
private:
    vector<T> items;
};

#endif // __LIST_H
```

- List is basic container class



Templates and Inheritance: Example (Set.h)

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```
#ifndef __SET_H
#define __SET_H

#include "List.h"

template<class T>
class Set {
public:
    Set()    { };
    virtual void add(const T &val);
    int length();
    bool find(const T &val);
private:
    List<T> items;
};

template<class T>
void Set<T> :: add(const T &val)
{
    if (items.find(val)) return;
    items.put(val);
}

template<class T> int Set<T> :: length() { return items.length(); }
template<class T> bool Set<T> :: find(const T &val) { return items.find(val); }
#endif // __SET_H
```

- Set is a base class for a set
- Set uses List for container



Templates and Inheritance:

Example (BoundSet.h)

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```
#ifndef __BOUND_SET_H
#define __BOUND_SET_H

#include "Set.h"

template<class T>
class BoundSet : public Set<T> {
public:
    BoundSet(const T &lower, const T &upper);
    void add(const T &val);
private:
    T min;
    T max;
};

template<class T> BoundSet<T>::BoundSet(const T &lower, const T &upper)
    : min(lower), max(upper) { }

template<class T> void BoundSet<T>::add(const T &val) {
    if (find(val)) return;
    if ((val <= max) && (val >= min))
        Set<T>::add(val);
}

#endif // __BOUND_SET_H
```

- BoundSet is a specialization of Set
- BoundSet is a set of bounded items



Templates and Inheritance:

Example (Bounded Set Application)

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```
#include <iostream>
using namespace std;
#include "BoundSet.h"

int main() {
    int i;
    BoundSet<int> bsi(3, 21);
    Set<int> *setpnr = &bsi;

    for (i = 0; i < 25; i++) setpnr->add(i);

    if (bsi.find(4))
        cout << "We found an expected value\n";

    if (bsi.find(0) || bsi.find(25)) {
        cout << "We found an Unexpected value\n";
        return -1;
    }
    else
        cout << "We found NO unexpected value\n";

    return 0;
}
-----
We found an expected value
We found NO unexpected value
```

- Uses BoundSet to maintain and search elements



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Summary

- Introduced the templates in C++
- Discussed class templates as generic solution for data structure reuse
- Explained partial template instantiation and default template parameters
- Demonstrated templates on inheritance hierarchy
- Illustrated with examples



Instructor and TAs

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