



Module 39

Sourangshu
Bhattacharya

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

Sourangshu Bhattacharya

Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

sourangshu@cse.iitkgp.ac.in

Slides taken from NPTEL course on Programming in C++

by **Prof. Partha Pratim Das**



Module Objectives

Module 39

Sourangshu
Bhattacharya

Objectives & Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

- Understand Templates in C++



Module Outline

Module 39

Sourangshu
Bhattacharya

Objectives & Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

- 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)

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

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)

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

- 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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

- 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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

```
#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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

```
#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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

● 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)

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

- 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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template
Instantiation &
Default Template
Parameters

Inheritance

Summary

- 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

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template
Instantiation &
Default Template
Parameters

Inheritance

Summary

```
#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

Module 39

Sourangshu
Bhattacharya

Objectives & Outline

What is a Template?

Function Template

Class Template

Definition

Instantiation

Partial Template Instantiation & Default Template Parameters

Inheritance

Summary

```
#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)

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

```
#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)

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

```
#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)

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

```
#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)

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template

Instantiation &

Default Template

Parameters

Inheritance

Summary

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

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

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



Module Summary

Module 39

Sourangshu
Bhattacharya

Objectives &
Outline

What is a
Template?

Function
Template

Class
Template

Definition

Instantiation

Partial Template
Instantiation &
Default Template
Parameters

Inheritance

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