

# Templates

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# Overview

- Introduction
- Function Templates
- Class Templates



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# Templates

- C++ supports **code reuse** in different ways
  - Inheritance (is-a) and composition (has-a, nested objects) provide a way to reuse object code
  - The template feature in C++ provides a way to **reuse source code**



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## Function Templates

- Suppose you want to write a function that returns the absolute value of a number
- Ordinarily, this function would be written for a particular data type (e.g., **int**):

```
int abs( int n ) {                // absolute value of ints
    return ( n < 0 ) ? -n : n; } // if n is negative, return -n
```

- Here, the function is defined to take an argument of type **int** and to return a value of this same type
- Now, suppose you want to find the absolute value of a type **long**
- You need to write a completely new function:

```
long abs( long n ) {              // absolute value of longs
    return ( n < 0 ) ? -n : n; }
```

- And again, for type float:

```
float abs( float n ) {           // absolute value of floats
    return ( n < 0 ) ? -n : n; }
```



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# Function Templates

- The body of the function is the same in each case, but they must be separate functions because they handle variables of different types
- It is true that in C++, these functions can all be overloaded to have the same name, but you must nevertheless write a separate definition for each one
- In the C language, which does not support overloading, functions for different types cannot even have the same name
- In the C function library, this leads to families of similarly named functions, such as `abs()`, `fabs()`, `fabsl()`, `labs()`, `cabs()`, and so on



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# Function Templates

- Rewriting the same function body over and over for different types wastes time as well as space in the listing
- Also, if you find you have made an error in one such function, you will need to remember to correct it in each function body
- Failing to do this correctly is a good way to introduce inconsistencies into your program
- It would be nice if there were a way to write such a function just once and have it work for many different data types
- This is exactly what function templates do for you



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# Function Templates: Example

```
// template used for absolute value function
template <class T>          // function template
T abs(T n) {
    return (n < 0) ? -n : n;
}

int main() {
    int int1 = 5;
    int int2 = -6;
    long lon1 = 70000L;
    long lon2 = -80000L;
    double doub1 = 9.95;
    double doub2 = -10.15;
    // calls instantiated functions
    cout << abs( int1 ) << endl; // abs(int)
    cout << abs( int2 ) << endl; // abs(int)
    cout << abs( lon1 ) << endl; // abs(long)
    cout << abs( lon2 ) << endl; // abs(long)
    cout << abs( doub1 ) << endl; // abs(double)
    cout << abs( doub2 ) << endl; // abs(double)
    return 0; }
```

See Example e11\_1.cpp



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## Function Template Syntax

- The key innovation in function templates is to represent the data type used by the function not as a specific type such as `int`, but by a **generic name** that can stand for **any** type
- In the function template above, this name is **T**
- The **template** keyword signals the compiler that we are about to define a function template
- The keyword **class**, within the angle brackets, might just as well be called type
- As we have seen, we can define our own data types using classes, so there is really no distinction between types and classes
- The variable following the keyword class (T in this example) is called the **template argument**



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## What the Compiler Does

- What does the compiler do when it sees the template keyword and the function definition that follows it?
- The function template itself does not cause the compiler to generate any code
- It cannot generate code because it does not know yet what data type the function will be working with
- It simply remembers the template for possible future use
- Code is generated (compiled) according to the function call statement
- This happens in expressions such as `abs(int1)` in the statement:

```
cout << abs(int1);
```



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## What the Compiler Does

- When the compiler sees a function call, it knows that the type to use is `int`
- So, it generates a specific version of the `abs(T n)` function for type `int`, substituting `int` wherever it sees the name `T` in the function template

`int` → `T`

- This is called **instantiating** the function template, and each instantiated version of the function is called a **template function**

See Example e11\_1.cpp



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## With Which Data Types Can a Template Function Work?

- The data type must support operations performed in the function
- For example, in the abs function two operators are used:  $(n < 0)$  and  $-n$
- Any data type that supports these operators can be used with the abs function



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## Advantage of Using Templates

- Notice that the amount of RAM used by the program is the same whether we use the template approach or write three separate functions
- What we have saved is having to type three separate functions into the source file
- This makes the listing shorter and easier to understand
- Also, if we want to change the way the function works, we need make the change in only one place in the listing instead of three



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## Template Arguments May Be Objects

- For example, a template function MAX can find the maximum of two integers, floating point numbers, or complex numbers
- Integers and floats are built-in types; complex is a user-defined type (class)

```
class ComplexT {           // a class to define complex numbers
    float re, im;
public:
    : // other member functions
    bool operator>(const ComplexT&) const ; // header for >
};

/* body of the function for operator > */
bool ComplexT::operator>(const ComplexT& z) const
{
    float f1 = re * re + im * im;
    float f2 = z.re * z.re + z.im * z.im;
    return f1 > f2;
}
```



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## Template Arguments May Be Objects

```
// template function
template <class type>
const type & MAX( const type &v1, const type &v2 )
{
    if (v1 > v2) return v1;
    else return v2;
}

int main()
{
    int i1 = 5, i2 = -3;
    char c1 = 'D', c2 = 'N';
    float f1 = 3.05, f2 = 12.47;
    ComplexT z1( 1.4, 0.6 ), z2( 4.6, -3.8 );
    cout << MAX( i1, i2 ) << endl;
    cout << MAX( c1, c2 ) << endl;
    cout << MAX( f1, f2 ) << endl;
    // operator << must be overloaded to print ComplexT
    cout << MAX( z1, z2 ) << endl;
    return 0;
}
```

See Example e11\_2.cpp



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## Function Templates with Multiple Arguments

- **Example:** takes three arguments: two template arguments and one basic type
- The purpose of this function is to search an array for a specific value
- The function returns the array index for that value if it finds it, or -1 if it cannot find it
- The arguments are a pointer to the array, the value to search for, and the size of the array

```
// function returns index number of item, or -1 if not found
template <class atype>
int find( const atype* array, atype value, int size ) {
    for ( int j = 0; j < size; j++ )
        if ( array[ j ] == value ) return j;
    return -1;
}

char chrArr[ ] = { 'a', 'c', 'f', 's', 'u', 'z' }; // array
char ch = 'f'; // value to find
int intArr[ ] = { 1, 3, 5, 9, 11, 13 };
int in = 6;
double dubArr[ ] = { 1.0, 3.0, 5.0, 9.0, 11.0, 13.0 };
double db = 4.0;
```



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## Function Templates with Multiple Arguments

```
int main() {
    cout << "\n 'f' in chrArray: index=" << find(chrArr, ch, 6);
    cout << "\n 6 in intArray: index=" << find(intArr, in, 6);
    cout << "\n 4 in dubArray: index=" << find(dubArr, db, 6);
    return 0;
}
```

- Here, the name of the template argument is **atype**
- The compiler generates three versions of the function, one for each type used to call it



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# Template Arguments Must Match

- When a template function is invoked, all instances of the same template argument must be of the same type
- For example, in `find()`, if the array name is of type `int`, the value to search for must also be of type `int`
- We cannot write

```
int intarray[ ] = {1, 3, 5, 7};           // int array
float f1 = 5.0;                          // float value
int value = find(intarray, f1, 4);        // ERROR!
```

because the compiler expects all instances of `atype` to be the same type

- It can generate a function `find(int*, int, int);`
- However, it cannot generate `find(int*, float, int);`  
(because the first and second arguments must be the same type)



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# More Than One Template Argument

- You can use more than one template argument in a function template
- For example, suppose you like the idea of the `find()` function template, but you are not sure how large an array it might be applied to
- If the array is too large, then type `long` would be necessary for the array size instead of type `int`
- On the other hand, you do not want to use type `long` if you do not need to
- You want to select the type of the array size, as well as the type of data stored, when you call the function

```
template <class atype, class btype>
btype find(const atype* array, atype value, btype size) {
    for ( btype j = 0; j < size; j++ ) // note use of btype
        if ( array[j] == value ) return j;
    return static_cast<btype>(-1);
}
```



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## More Than One Template Argument

- Now, we can use type `int` or type `long` (or even a user-defined type) for the size, whichever is appropriate
- The compiler will generate different functions based not only on the type of the array and the value to be searched for, but also on the type of the array size

```
short int result , si = 100;  
int invalue = 5;  
result = find(intArr, invalue, si)
```

```
long lonresult, li = 100000;  
float fvalue = 5.2;  
lonresult = find(floatArr, fvalue, li)
```



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## More Than One Template Argument

- Note that multiple template arguments can lead to many functions being instantiated from a single template
- Two such arguments, if there were six basic types that could reasonably be used for each one, would allow the creation of up to 36 functions
- This can take up a lot of memory if the functions are large
- On the other hand, you do not instantiate a version of the function unless you actually call it



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## Why Not Macros?

- Old-time C programmers may wonder why we do not use macros to create different versions of a function for different data types
- For example, the `abs()` function could be defined as

```
#define abs(n) ( ( n < 0 ) ? (-n) : (n) )
```
- This has a similar effect to the function template because it performs a simple text substitution and can thus work with any type
- However, macros are not used much in C++
- There are several problems with them



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## Problems With Macros

- They do not perform any **type checking**
- There may be several arguments to the macro that should be of the same type, but the compiler will not check whether or not they are
- Also, the type of the **value returned is not specified**, so the compiler cannot tell if you are assigning it to an incompatible variable
- In any case, macros are confined to functions that can be expressed **in a single statement**
- There are also other, subtler problems with macros

**On the whole, it is best to avoid macros**



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# Class Templates

- The template concept can be applied to classes as well as to functions
- Class templates are generally used for data storage (container) classes
- Stacks and linked lists are examples of data storage classes
- The previous examples of these classes could store data of only a single basic type



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# Class Templates

- The Stack class in the program that is presented below could store data only of type int:

```
class Stack {  
    int st[MAX];           // array of ints  
    int top;               // index number of top of stack  
public:  
    Stack();               // constructor  
    void push( int var );  // takes int as argument  
    int pop();             // returns int value  
};
```

- If we wanted to store data of type long in a stack, we would need to define a completely new class:

```
class LongStack {  
    long st[MAX];          // array of longs  
    int top;               // index number of top of stack  
public:  
    LongStack();           // constructor  
    void push( long var ); // takes long as argument  
    long pop();            // returns long value  
};
```



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## Solution with a Class Template

```
template <class Type>
class Stack {
    enum {MAX = 100};
    Type st[MAX];           // stack: array of any type
    int top;                // number of top of stack
public:
    Stack(){ top = 0; }     // constructor
    void push( Type );     // put number on stack
    Type pop();            // take number off stack
};

template<class Type>
void Stack<Type>::push( Type var ) // put number on stack
{
    if ( top > MAX - 1 )     // if stack full,
        throw "Stack is full!"; // throw exception
    st[ top++ ] = var;
}
```



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## Solution with a Class Template

```
template<class Type>
Type Stack<Type>::pop()      // take number off stack
{
    if ( top <= 0 )          // if stack empty,
        throw "Stack is empty!"; // throw exception
    return st[--top];
}

int main()                  // s2 is object of class Stack<long>
{
    Stack<float> s1;         Stack<long> s2;
    // push 2 floats, pop 2 floats // push 2 longs, pop 2 longs
    try {
        s1.push( 1111.1 );
        s1.push( 2222.2 );
        cout << "1: " << s1.pop() << endl;
        cout << "2: " << s1.pop() << endl;
    }
    // exception handler
    catch( const char * msg ) {
        cout << msg << endl;
    }

    try {
        s2.push( 123123123L );
        s2.push( 234234234L );
        cout << "1: " << s2.pop() << endl;
        cout << "2: " << s2.pop() << endl;
    }
    // exception handler
    catch( const char * msg ) {
        cout << msg << endl;
    }

    return 0;
} // End of program
```

See Example e11\_3.cpp

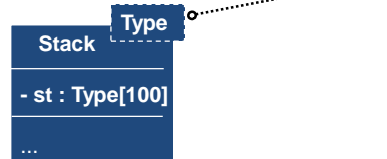


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# UML Notation for Template Classes and Objects

A template class:



An object of template Stack.  
In this example, intStack object is an integer Stack .



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