C++
Templates, Exceptions, Namespaces
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Templates

Review

- We learned a new relationship between classes: “inheritance”
- public inheritance shows “is a kind of” relationship, Triangle is a kind of Shape
- “derived class” “inherits” data members and member functions from “base class”
  may add more data members and re-define (“override”) inherited member functions
- virtual functions are bound dynamically - to match dynamic type
  Shape * sp = new Triangle();   sp->draw();   // calls Triangle::draw() if draw() is virtual
- dynamic binding works only with pointers and references
- polymorphic functions can be written by calling virtual functions
- useful for building frameworks, like GUI, Java Applets in Browser

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Templates

- C++ is strongly typed
- sometimes it is useful to have type-independent definitions
  - generic containers (lists, stacks, dictionaries)
  - generic algorithms (sort, min, max, reverse, size, copy)
- C++ templates allow such genericity
- EG

```
int min( int a, int b )
{
  return a < b ? a : b;
}
double min( double a, double b )
{
  return a < b ? a : b;
}
```

-

C solution

```
 # define min(a,b) ((a) < (b) ? (a) : (b))
```

- but may have problems with side effects

```
int i = min( j++, k++ );
```

- and you must be careful to fully parenthesize to avoid precedence problems
- templates avoid these problems and allow programmers to specify algorithms once

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Template Functions

- template function definition

```
template
  < typename Type >
Type min( Type a, Type b )
{
  return a < b ? a : b;
}
```

- Type stands for one (consistent) type for the template definition
- template function use

```
int main()
{
```

```
    int x = min( 10, 20 ); // OK: Type is int
    double y = min( 10.5, 20.8 ); // OK: Type is double
    double y = min( 10, 20.8 ); // OK? Yes, 3rd step, check type cast
  }
```

General Template Form

- syntax

```
template
  < templateParameterList >
functionOrMethodOrClassDefinition
```

- templateParameterList is comma separated list of

```
typename identifier // useful for containers of elements
class identifier // same as typename, but deprecated
int value // useful for array sizes or defaults
```

Specializing a Template Function

- templates are typically general for any type
- sometimes this general case is inappropriate (or inefficient) for a special case
- e.g., min for two character strings
- you can specialize by defining the specialized function

```
char * min( char * a, char * b )
{
  return strcmp( a, b ) < 0 ? a : b;
}
```

- this function will be used for arguments of type char *
- template will be used for any other type

Revised Function Resolution Algorithm

- get all non-template functions matching the call
- if more than one, ambiguity error
- if there is exactly one, select it
- if none, examine all template instances
- if more than one, ambiguity error
- if exactly one match, select it (if it is not instantiated, first instantiate it)
- if none, re-examine all non-templates to see if there is a match via type conversion

Parameter Matching

- non-const formal cannot match to a const actual,
  e.g., strcat(“Hello”, “World”);   // ERROR
- const formal can match to const or non-const actual,
  e.g., int len = strlen(“Hello”); char s[]=”Hello”; int len = strlen(s); // BOTH OK
- const & formal can match to either non-const or const
  (it creates anonymous object for literals (e.g., 10 or “hello”))
- & (reference) formal can only match to valid l-value,
  e.g., int x=10, y=20; swap(x, y); but not swap(10, 20)
  <u>const</u> char <u>const</u> * p = “hello”;

Template Classes

- useful for generic containers (and more)
- usually best to start by writing a specialized class first
- then, after testing, convert it into a template
- E.g.,

```
class Stack
{
  int len;
  int top;
  int * buf;
public:
  Stack( int capacity = 100 )
    : len( capacity ), top( 0 ),
      buf( new int [capacity] )
  {
  }
  ~Stack()
  {
    delete[] buf;
  }
  void push( int x )
  {
    buf[top++] = x;
  }
  int pop()
  {
    return buf[--top];
  }
  int size()
  {
    return top;
  }
};
```

- ---

  now make it into a template

```
template
  < typename Type >
class Stack
{
  int len;
  int top;
  Type * buf;
public:
  Stack( int capacity = 100 )
    : len( capacity ), top( 0 ),
      buf( new Type [capacity] )
  {
  }
  ~Stack()
  {
    delete[] buf;
  }
  void push( Type x )
  {
    buf[top++] = x;
  }
  Type pop()
  {
    return buf[--top];
  }
```

```
  int size()
  {
    return top;
  }
};
```

Defining Template Methods

- defining methods outside class can be painful
- we want to move method definitions to a separate .cpp file
- must prefix each method with template parameter specification
- must qualify each name with Stack<Type>::
- ---

  Stack.h file

  ```
  template
    < typename Type >
  class Stack
  {
    int max;
    int len;
    Type * buf; // alternative: Type buf[1024];
  public:
    Stack( int capacity = 100 );
    ~Stack();
    void push( Type x );
    Type pop();
    int size();
  };
  ```
- ---

  Stack.cpp file

  ```
  template
    < typename Type >
  Stack<Type>::Stack( int capacity = 100 )
    : max( capacity ), len( 0 ),
      buf( new Type [capacity] )
  {
  }
  template
    < typename Type >
  Stack<Type>::~Stack()
  {
    delete[] buf;
  }
  template
    < typename Type >
  void Stack<Type>::push( Type x )
  {
    buf[len++] = x;
  }
  template
    < typename Type >
  Type Stack<Type>::pop()
  {
    return buf[--len];
  }
  template
  ```

```
  < typename Type >
int Stack<Type>::size()
{
  return len;
}
```

Uses of the Template

- auxiliary definitions

```
 #include <iostream>
 #include "Stack.h"
 #define ArrayLength(a) (sizeof(a) / sizeof(*a))
using namespace std;
typedef Stack<int> intStack;
typedef Stack<char> charStack;
typedef Stack<double> doubleStack;
template
  < typename T >
void fill( Stack<T> & stk, T * a, int len )
{
  for ( int i=0; i < len; ++i )
    stk.push( a[i] );
}
template
  < typename T >
void empty( Stack<T> & stk )
{
  while ( stk.size() > 0 )
    cout << stk.pop() << ' ';
  cout << endl;
}
```

- The main

```
int main()
{
  doubleStack dstack;
  charStack cstack;
  intStack istack;
  static double dlist [] = { 1.5, 2.5, 3.5, 4.5, 6.5, 9.98 };
  static char clist [] = "Hello";
  static int ilist [] = { 0, 1, 2, 3, 4, 6, 7, 8, 9, 10 };
  fill( dstack, dlist, ArrayLength( dlist ) );
  fill( istack, ilist, ArrayLength( ilist ) );
  fill( cstack, clist, ArrayLength( clist ) );
  empty( dstack );
  empty( istack );
  empty( cstack );
}
```

- the output

```
9.98 6.5 4.5 3.5 2.5 1.5
10 9 8 7 6 4 3 2 1 0
o l l e H
```

Template Parameter Defaults

- similar to default function parameters

- hypothetical example

```
template
  < typename charType = char, int capacity = 100 >
class basic_string
{
  // can have a string of wchar_t too,
  // but default is char String
};
```

Member Templates

- member functions (of non-template classes) may be templates
- often used for writing type conversion operators
- **wouldn't it be cool if they had defined the following:**

```
class ostream
{
  ostream & operator << ( const int & item )// for primitive types
  {
    // ...
  }
  // ... rest of specializations for fundamental (built-in) types
  template
    < class T >
  ostream & operator << ( const T & item )
  {
    item.print( *this );
    return *this;
  }
};
```

- then we could just write method print on our new class and get operator << for free

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Non-type Template Parameters

-
```
template
  < size_t Bits > // Bits is an unsigned integer
class bitset
{
  // ...
};
```

- use

```
enum Day { Mon, Tue, Wed, Thu, Fri, Sat, Sun, numDays };
bitset < numDays > workDays;
workDays.set( Mon );
workDays.set( Wed );
workDays.set( Fri );
for ( int d = (int)Mon; d < (int)numDays; ++d )
  if ( workDays[d] )
    cout << "Have to work on << d << "th day of the week\n";
```

Specializing a class Template

- specializations can be defined, usually for improved efficiency
- EG
-

```
template
```

```
  < int, typename valueType >
class map
{
  // implemented as an array for O(1) performance
};
```

Partial Template Instantiation

- you can specialize part or all of the template

```
template
  < typename T, typename U >
class The_Class { .... };
```

- partial template specialization

```
template
  < typename U >
class The_Class<int,U> { ... };
```

- full template specialization

```
template
  <>
class The_Class<int, short> { ... };
```

- pay attention to the empty formal argument list!
- partial template instantiation is used in the STL, EG

```
template
  < typename T, typename Allocator = allocator<T> >
class vector
{
  // lots of stuff here, dynamic array of Ts
};
```

- partial template specialization for bool
- the idea is to use one bit per entry, but it is tricky...

```
template
  < typename Allocator = allocator<T> >
class vector<bool, Allocator>
{
  // lots of stuff here, bits packed in words
};
```

Explicit Template Instantiation

- you can control where a specific template instantiation is created
- classes can be explicitly instantiated

```
template
  < typename T >
class List { ... };
...
template class List<int>; // creates List<int>
```

- template functions can be explicitly instantiated

```
template
  < typename T >
T max( T const & x, T const & y ) { ... }
...
template int max( int const &, int const & );
```

```
    // creates max(int,int)
```

Exceptions

- they are designed to support run-time error handling
- they handle only synchronous exceptions such as array range checks
- they don't handle asynchronous events like GUI events, interrupts, or signals
- they are also a non-local alternative to the return statement, but should be used with care
- Examples

  Stack stk;   stk.pop();   // where stk is empty()

  String s;   s[i] = s[j];   // where index is out of bounds

Exception Specifications

- used to declare which exceptions a function or method may throw

```
void f()
  throw(std::bad_alloc, std::bad_cast)
{
  if (blah)
    throw std::bad_alloc;
  if (blahBla)
    throw std:: bad_cast;
  do_something_else();
}
```

- default is that function may throw any exception

```
void g()
  // implied throw(...)
{
}
```

- to declare that a method throws no exceptions

```
void h()
  noexcept
{
}
```

- violation of exception specification calls unexpected()
- unexpected() usually calls terminate(), unless std::bad_exception is in the spec, then it re-throws std::bad_exception
- a function never throws an exception not listed in its specification
- you can define unexpected() as a handler

Example definition

- ```
  class BaseException {};
  class RangeException : public BaseException {};
  class SizeException : public BaseException {};
  ```

  class Vector (yet again!)

  ```
  class Vector
  {
    int * buf;
    int size;
  protected:
    bool inbounds(int i)
    {
      return 0 <= i && i < size;
    }
  ```
  ```

```
public:
  static const max = 100;
   Vector( int newSize )
    throw( SizeException )
  {
    if ( newSize < 0 || newSize > max )
      throw SizeException();
    size = newSize;
    buf = new int[newSize];
    for (int i=0; i < newSize; ++i )
      buf[i] = 2 * i;
  }
  int & operator [] ( int i )
    throw( RangeException )
  {
    if ( !inbounds(i) )
      throw RangeException();
    return buf[i];
  }
};
```

- Use of Vector

```
int getInt( char * prompt )
  // implies throw( ... )
{
  cout << prompt << ": ";
  int i;
  cin >> i;
  if ( i < 0 )
    throw "Hello"; // throws a const char *
  return i;
}
```

- Use of Vector (cont.)

```
void testExceptions()
  throw() // says we throw no exceptions
{
  for ( ; ; )
    try {
      int size = getInt( "Enter a size" );
      Vector v1(size);
      int index = getInt( "Enter an index" );
      cout << v1[index];
    }
    catch ( const RangeException & e )
    {
      cout << "Index out of bounds\n";
    }
    catch ( const SizeException & e )
    {
      cout << "Size out of range 0..max\n";
    }
    catch ( ... )
    {
      cout << "Got some unknown exception\n";
```

```
      throw; // rethrows the current exception
    }
  // calls unexpected() which calls terminate()
}
```

-

Use of Vector (cont.)

```
int main()
{
  while (true)
    try {
      testExceptions();
    }
    catch ( const BaseException & e )
    {
      cout << "Got some kind of BaseException\n";
    }
}
```

- **Another Exception Example (with various type exceptions)**

```
#include <iostream>
using namespace std;
void f(int i)
   throw(int, string, char)
{
  cout << "Entering f, i = " << i << endl;
  switch (i)
  {
     case 0:
        break;
     case 1:
        throw 10;
     case 2:
        throw string("hello");
     default:
        throw 'A';
  }
  cout << "Leaving f, i = " << i << endl;
}

int main()
{
  for (int i=0; i<4; i++)
     try {
        cout << "before call to f i = " << i << endl;
        f(i);
        cout << "after call to f i = " << i << endl;
     }
     catch (int i)
```

```
    {
        cout << "caught int exception i = " << i << endl;
    }
    catch (char c)
    {
        cout << "caught char exception c = " << c << endl;
    }
    catch (string s)
    {
        cout << "caught string exception s = " << s << endl;
    }
  cout << "Leaving main"<< endl;
}
/* output of this program:
before call to f i = 0
Entering f, i = 0
Leaving f, i = 0
after call to f i = 0
before call to f i = 1
Entering f, i = 1
caught int exception i = 10
before call to f i = 2
Entering f, i = 2
caught string exception s = hello
before call to f i = 3
Entering f, i = 3
caught char exception c = A
Leaving main
*/
```

Visualize

Namespaces

- allows organization of the global name space (scope)
- necessary support for development of many standard libraries
- EG

```
namespace mySpace
{
  class Stack;
  ostream & operator << ( ostream & out, const Stack & stk );
  void myStackFunction( Stack s );
}
```

- a namespace may be split across files - they are cumulative

```
namespace mySpace
{
  void myTopLevelFunction(); // adds to mySpace
}
```

- all C++ standard library identifiers are in namespace **std**

Using Namespaces

- qualified use of entities in a namespace

```
mySpace::Stack stk;
mySpace::myTopLevelFunction();
myStackFunction( stk ); // OK: argument is a mySpace::stk
std::cout << stk; // OK: stk is of type mySpace::stk
```

- un-qualified use of entities in a namespace

```
using mySpace::Stack;
using std::cout;
Stack stk;
myStackFunction( stk ); // OK: argument is a mySpace::stk
cout << stk; // OK: both arguments are directly visible
```

- open up a namespace (everything is directly visible)

```
using namespace std;
using namespace mySpace;
Stack stk;
myTopLevelFunction();
myStackFunction( stk );
cout << stk;
```

- never use “using” when the context isn't clear
  - in a .h file
  - or in another namespace (makes them part of that namespace)