Programming in C and C++

5. C++: Overloading, Namespaces, and Classes

Dr. Neel Krishnaswami

University of Cambridge

(based on notes from and with thanks to Anil Madhavapeddy, Alan Mycroft,

Alastair Beresford and Andrew Moore)

Michaelmas Term 2016-2017

C++

To quote Bjarne Stroustrup:

"C++ is a general-purpose programming language with a bias towards systems programming that:

- ▶ is a better C
- ▶ supports data abstraction
- ▶ supports object-oriented programming
- ▶ supports generic programming."

Alternatively: C++ is "an (almost upwards-compatible) extension of C with support for: classes and objects (including multiple inheritance), operator overloading, exceptions and templates".
[templates are a generalised form of generics]
Much is familiar from Java, but with many subtle differences.

C++ fundamental types

- ▶ C++ has all the fundamental types C has
  - ▶ character literals (e.g. `'a'`) are now of type `char`
- ▶ In addition, C++ defines a new fundamental type, `bool`
- ▶ A bool has two values: `true` and `false`
- ▶ When cast to an integer, `true`→1 and `false`→0
- ▶ When casting from an integer, non-zero values become `true` and `false` otherwise
- ▶ This is also available in C (since C99) via the `<stdbool.h>` header

C++ enumeration

- ▶ Unlike C, C++ enumerations define a new type; for example
  `enum flag {is_keyword=1, is_static=2, is_extern=4, ... }`
- ▶ When allocating storage for an enumeration, you use its name; for example: `flag f = is_keyword`
- ▶ Implicit type conversion is not allowed:
  `f = 5; //wrong`   `f = flag(5); //right`
- ▶ The maximum valid value of an enumeration is the enumeration's largest value rounded up to the nearest larger binary power minus one
- ▶ The minimum valid value of an enumeration with no negative values is zero
- ▶ The minimum valid value of an enumeration with negative values is the nearest least negative binary power

References

- ▶ C++ supports <u>references</u>, which provide an alternative name for a variable
- ▶ Generally used for specifying parameters to functions and return values as well as overloaded operators (more later)
- ▶ A reference is declared with the `&` operator; for example:
  ```
  int i[] = {1,2}; int &refi = i[0];
  ```
- ▶ A reference must be initialised when it is defined
- ▶ A connection between a reference and what it refers to cannot be changed after initialisation; for example:
  ```
  refi++; //increments value referenced
  ```

References in function arguments

▶ When used as a function parameter, a referenced value is not copied;
for example:
`void inc(int& i) { i++;} //bad style?`

▶ Declare a reference as `const` when no modification takes place

▶ It can be noticeably more efficient to pass a large struct by reference

▶ Implicit type conversion into a temporary takes place for a `const`
reference but results in an error otherwise; for example:

```
1 float fun1(float&);
2 float fun2(const float&);
3 void test() {
4   double v=3.141592654;
5   fun1(v); //Wrong
6   fun2(v);
7 }
```

▶ Cf. Fortran call-by-reference

Overloaded functions

- Functions doing different things should have different names
- It is possible (and sometimes sensible!) to define two functions with the same name
- Functions sharing a name must differ in argument types
- Type conversion is used to find the "best" match
- A best match may not always be possible:

```
1 void f(double);
2 void f(long);
3 void test() {
4   f(1L);  //f(long)
5   f(1.0); //f(double)
6   f(1);   //Wrong: f(long(1)) or f(double(1)) ?
```

Scoping and overloading

- Functions in different scopes are not overloaded; for example:

```
1 void f(int);
2
3 void example() {
4   void f(double);
5   f(1); //calls f(double);
6 }
```

- Rarely happens in practise since crossing scopes like this leads to confusing control flow.

Default function arguments

- A function can have default arguments; for example:
  ```
  double log(double v, double base=10.0);
  ```
- A non-default argument cannot come after a default; for example:
  ```
  double log(double base=10.0, double v); //wrong
  ```
- A declaration does not need to name the variable; for example:
  ```
  double log(double v, double=10.0);
  ```
- Be careful of the lexical interaction between * and =; for example:
  ```
  void f(char*=0); //Wrong '*=' is assignment
  ```

Namespaces

Related data can be grouped together in a namespace:

```
namespace Stack { //header file
void push(char);
char pop();
}
```

```
namespace Stack { //implementation
const int max_size = 100;
char s[max_size];
int top = 0;

void push(char c) { ... }
char pop() { ... }
}
```

```
void f() { //usage
...
Stack::push('c');
...
}
```

Using namespaces

- ▶ A namespace is a <u>scope</u> and expresses logical program structure
- ▶ It provides a way of collecting together related pieces of code
- ▶ A namespace without a name limits the scope of variables, functions and classes within it to the local execution unit
- ▶ The same namespace can be declared in several source files
- ▶ The global function `main()` cannot be inside a namespace
- ▶ The use of a variable or function name from a different namespace must be qualified with the appropriate namespace(s)
  - ▶ The keyword `using` allows this qualification to be stated once, thereby shortening names
  - ▶ Can also be used to generate a hybrid namespace
  - ▶ `typedef` can be used: `typedef Some::Thing thing;`
- ▶ A namespace can be defined more than once
  - ▶ Allows, for example, internal and external library definitions

Example

```
1 namespace Module1 {int x;}
2
3 namespace Module2 {
4   inline int sqr(const int& i) {return i*i;}
5   inline int halve(const int& i) {return i/2;}
6 }
7
8 using namespace Module1; //"import" everything
9
10 int main() {
11   using Module2::halve;  //"import" the halve function
12   x = halve(x);
13   sqr(x);                //Wrong
14 }
```

Linking C and C++ code

- The directive `extern "C"` specifies that the following declaration or definition should be linked as C, not C++ code:
  `extern "C" int f();`

- Multiple declarations and definitions can be grouped in curly brackets:

```
1 extern "C" {
2   int globalvar; //definition
3   int f();
4   void g(int);
5 }
```

- Why do we need this? E.g. 'Name mangling' for overloaded functions.

User-defined types

- ▶ C++ provides a means of defining classes and instantiating objects
- ▶ Classes contain both data storage and functions which operate on storage
- ▶ Classes have access control: `private`, `protected` and `public`
- ▶ Classes are created with `class` or `struct` keywords
    - ▶ `struct` members default to `public` access; `class` to `private`
- ▶ The <u>constructor</u> syntax is a member function with the same name as the class
- ▶ The <u>destructor</u> syntax is a member function with the same name as the class, prefixed with a tilde (`~`)
- ▶ A constructor can be overloaded to provide multiple instantiation methods
- ▶ Can create `static` (i.e. per <u>class</u>) member variables

Example

```
1 class Complex {
2   double re,im;
3  public:
4   Complex(double r=0.0L, double i=0.0L);
5 };
6
7 Complex::Complex(double r,double i) {
8   re=r,im=i;  // deprecated initialisation-by-assignment
9 }
10
11 int main() {
12   Complex c(2.0), d(), e(1,5.0L);
13   return 0;
14 }
```

Constructors and destructors

- ► A default constructor is a function with no arguments (or only default arguments)
- ► If no constructor is specified, the compiler will generate one
- ► The programmer can specify one or more constructors
- ► Only one constructor is called when an object is created
- ► There can only be one destructor
  - ► This is called when a stack-allocated object goes out of scope or when a heap-allocated object is deallocated with `delete`; this also occurs for stack-allocated objects deallocated during exception handling (more later).
  - ► Stack-allocated objects with destructors are a useful way to release resources on scope exit (similar effect as Java try-finally) – "RAII: Resource Allocation is Initialisation".

Copy constructor

- ▶ A new class instance can defined by assignment; for example;
  ```
  Complex c(1,2);
  Complex d = c;
  ```
- ▶ In this case, the new class instance is initialised with copies of all the existing class' non-static member variables; no constructor is called
- ▶ This behaviour may not always be desirable (e.g. consider a class with a pointer as a member variable)
  - ▶ In which case, define an alternative <u>copy constructor</u>:
    ```
    Complex::Complex(const Complex&) { ... }
    ```
- ▶ If a copy constructor is not wanted, make the copy constructor a private member function, or in C++11 use `delete`.

Assignment operator

▶ By default an object is copied on assignment by overwriting all non-static member variables; for example:

```
1 Complex c(), d(1.0,2.3);
2 c = d; //assignment
```

▶ This behaviour may also not be desirable

▶ The assignment operator (operator=) can be defined explicitly:

```
1 Complex& Complex::operator=(const Complex& c) {
2   ...
3 }
```

Constant member functions

- Member functions can be declared `const`
- Prevents object members being modified by the function:

```
1 double Complex::real() const {
2   return re;
3 }
```

- Logically gives `const Complex *this` instead of `Complex *this`

Arrays and the free store

▶ An array of class objects can be defined if a class has a default constructor

▶ C++ has a `new` operator to place items on the heap:
`Complex* c = new Complex(3.4);`

▶ Items on the heap exist until they are explicitly deleted:
`delete c;`

▶ Since C++ (like C) doesn't distinguish between a pointer to a single object and a pointer to an the first element of an array of objects, array deletion needs different syntax:

```
1 Complex* c = new Complex[5];
2   ...
3 delete[] c; // Cannot use "delete" here, only "delete[]"
```

▶ When an object is deleted, the object destructor is invoked. When an array is deleted, the object destructor is invoked on each element

▶ The C++ standard library provides `std::vector` or `std::array`, so raw arrays are rarely used

Exercises

1. Write an implementation of a class `LinkList` which stores zero or more positive integers internally as a linked list <u>on the heap</u>. The class should provide appropriate constructors and destructors and a method `pop()` to remove items from the head of the list. The method `pop()` should return -1 if there are no remaining items. Your implementation should override the copy constructor and assignment operator to copy the linked-list structure between class instances. You might like to test your implementation with the following:

```
1 int main() {
2   int test[] = {1,2,3,4,5};
3   LinkList l1(test+1,4), l2(test,5);
4   LinkList l3=l2, l4;
5   l4=l1;
6   printf("%d %d %d\n",l1.pop(),l3.pop(),l4.pop());
7   return 0;
8 }
```

Hint: heap allocation & deallocation should occur exactly once!