CSCI-1200 Data Structures — Fall 2009
Lecture 23 — C++ Inheritance and Polymorphism

Review from Lectures 21&22 and Lab 13

- A Priority Queue as a Heap, `percolate_up` and `percolate_down`
- A Heap as a Vector, Building a Heap, Heap Sort
- Merging heaps are the motivation for *leftist heaps*

Today's Class

- Inheritance is a relationship among classes. Examples: bank accounts, polygons, stack & list
- Basic mechanisms of inheritance
- Types of inheritance
- Is-A, Has-A, As-A relationships among classes.
- Polymorphism

23.1 Motivating Example: Bank Accounts

- Consider different types of bank accounts:
  - Savings accounts
  - Checking accounts
  - Time withdrawal accounts (like savings accounts, except that only the interest can be withdrawn)
- If you were designing C++ classes to represent each of these, what member functions might be repeated among the different classes? What member functions would be unique to a given class?
- To avoid repeating common member functions and member variables, we will create a **class hierarchy**, where the common members are placed in a **base class** and specialized members are placed in **derived classes**.

23.2 Accounts Hierarchy

- `Account` is the *base class* of the hierarchy.
- `SavingsAccount` is a *derived* class from `Account`. `SavingsAccount` has inherited member variables & functions and ordinarily-defined member variables & functions.
- The member variable `balance` in base class `Account` is `protected`, which means:
  - `balance` is NOT publicly accessible outside the class, but it is accessible in the derived classes.
  - if `balance` was declared as `private`, then `SavingsAccount` member functions could not access it.
- When using objects of type `SavingsAccount`, the inherited and derived members are treated exactly the same and are not distinguishable.
- `CheckingAccount` is also a derived class from base class `Account`.
- `TimeAccount` is derived from `SavingsAccount`. `SavingsAccount` is its base class and `Account` is its indirect base class.

23.3 Exercise: Draw the Accounts Class Hierarchy

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

// Note we've inlined all the functions (even though some are > 1 line of code)

// ------------------------------------------------------------------------------
class Account {
public:
  Account(double bal = 0.0) : balance(bal) {}
  void deposit(double amt) { balance += amt; }
  double get_balance() const { return balance; }

protected:
  double balance;   // account balance
};

// ------------------------------------------------------------------------------
class SavingsAccount : public Account {
public:
  SavingsAccount(double bal = 0.0, double pct = 5.0) : Account(bal), rate(pct/100.0) {}

  double compound() { // computes and deposits interest
    double interest = balance * rate;
    balance += interest;
    return interest;
  }
  double withdraw(double amt) { // if overdraft ==> return 0, else return amount
    if (amt > balance) {
      return 0.0;
    } else {
      balance -= amt;
      return amt;
    }
  }

protected:
  double rate;  // periodic interest rate
};

// ------------------------------------------------------------------------------
class CheckingAccount :  public Account {
public:
  CheckingAccount(double bal = 0.0, double lim = 500.0, double chg = 0.5) : Account(bal) {
    limit = lim;
    charge = chg;
  }

  double cash_check(double amt) {
    assert (amt > 0);
    if (balance < limit && (amt + charge <= balance)) {
      balance -= amt + charge;
      return amt + charge;
    } else if (balance >= limit && amt <= balance) {
      balance -= amt;
      return amt;
    } else {
      return 0.0;
    }
  }

protected:
  double limit;    // lower limit for free checking
  double charge;   // per check charge
};
```

```
// ------------------------------------------------------------------------------
class TimeAccount : public SavingsAccount {
public:
  TimeAccount(double bal = 0.0, double pct = 5.0) : SavingsAccount(bal, pct) {
    funds_avail = 0.0;
  }

  // redefines 2 member functions from SavingsAccount
  double compound() {
    double interest = SavingsAccout::compound();
    funds_avail += interest;
    return interest;
  }
  double withdraw(double amt) {
    if (amt <= funds_avail) {
      funds_avail -= amt;
      balance -= amt;
      return amt;
    } else {
      return 0.0;
    }
  }
  double get_avail() const { return funds_avail; };

protected:
  double funds_avail;  // amount available for withdrawal
};
```

23.4 Constructors and Destructors

- Constructors of a derived class *call the base class constructor* immediately, before doing ANYTHING else. The only thing you can control is which constructor is called and what the arguments will be. Thus when a `TimeAccount` is created 3 constructors are called: the `Account` constructor, then the `SavingsAccount` constructor, and then finally the `TimeAccount` constructor.
- The reverse is true for destructors: derived class constructors do their jobs first and then base class destructors are called at the, automatically. *Note: destructors for classes which have derived classes must be marked virtual for this chain of calls to happen.*

23.5 Overriding Member Functions in Derived Classes

- A derived class can redefine member functions in the base class. The function prototype must be identical, not even the use of `const` can be different (otherwise both functions will be accessible).
- For example, see `TimeAccount::compound` and `TimeAccount::withdraw`.
- Once a function is redefined it is not possible to call the base class function, unless it is explicitly called as in `SavingsAccount::compound`.

23.6 Public, Private and Protected Inheritance

- Notice the line

  ```
  class Savings_Account : public Account {
  ```

  This specifies that the member functions and variables from `Account` do not change their *public*, *protected* or *private* status in `SavingsAccount`. This is called *public* inheritance.
- *protected* and *private* inheritance are other options:
  - With protected inheritance, public members becomes protected and other members are unchanged
  - With private inheritance, all members become private.

23.7 Stack Inheriting from List

- For another example of inheritance, let's re-implement the `stack` class as a derived class of `std::list`:

```
template <class T>
class stack : private std::list<T> {
public:
  stack() {}
  stack(stack<T> const& other) : std::list<T>(other) {}
  virtual ~stack() {}
  void push(T const& value) { this->push_back(value); }
  void pop() { this->pop_back(); }
  T const& top() const { return this->back(); }
  int size() { return std::list<T>::size(); }
  bool empty() { return std::list<T>::empty(); }
};
```

- Private inheritance hides the `std::list<T>` member functions from the outside world. However, these member functions are still available to the member functions of the `stack<T>` class.
- Note: no member variables are defined — the only member variables needed are in the list class.
- When the stack member function uses the same name as the base class (list) member function, the name of the base class followed by `::` must be provided to indicate that the base class member function is to be used.
- The copy constructor just uses the copy constructor of the base class, without any special designation because the stack object is a list object as well.

23.8 Is-A, Has-A, As-A Relationships Among Classes

- When trying to determine the relationship between (hypothetical) classes C1 and C2, try to think of a logical relationship between them that can be written:
  - C1 is a C2,
  - C1 has a C2, or
  - C1 is implemented as a C2
- If writing "C1 is-a C2" is best, for example: "a savings account is an account", then C1 should be a derived class (a subclass) of C2.
- If writing "C1 has-a C2" is best, for example: "a cylinder has a circle as its base", then class C1 should have a member variable of type C2.
- In the case of "C1 is implemented as-a C2", for example: "the stack is implemented as a list", then C1 should be derived from C2, but with private inheritance. This is by far the least common case!

23.9 Exercise: 2D Geometric Primitives

Create a class hierarchy of geometric objects, such as: triangle, isosceles triangle, right triangle, quadrilateral, square, rhombus, kite, trapezoid, circle, ellipse, etc. How should this hierarchy be arranged? What member variables and member functions should be in each class?

23.10 Note: Multiple Inheritance

- When sketching a class hierarchy for geometric objects, your may have wanted to specify relationships that were more complex... in particular some objects may wish to inherit from *more than one base class*.
- This is called *multiple inheritance* and can make many implementation details significantly more hairy. Different programming languages offer different variations of multiple inheritance.

23.11 Introduction to Polymorphism

- Let's consider a small class hierarchy version of polygonal objects:

```
class Polygon {
public:
  Polygon() {}
  virtual ~Polygon() {}
  int NumVerts() { return verts.size(); }
  virtual double Area() = 0;
  virtual bool IsSquare() { return false; }
protected:
  vector<Point> verts;
};

class Triangle : public Polygon {
public:
  Triangle(Point pts[3]) {
    for (int i = 0; i < 3; i++) verts.push_back(pts[i]); }
  double Area();
};

class Quadrilateral : public Polygon {
public:
  Quadrilateral(Point pts[4]) {
    for (int i = 0; i < 4; i++) verts.push_back(pts[i]); }
  double Area();
  double LongerDiagonal();
  bool IsSquare() { return (SidesEqual() && AnglesEqual()); }
private:
  bool SidesEqual();
  bool AnglesEqual();
};
```

- Functions that are common, at least have a common interface, are in `Polygon`.
- Some of these functions are marked `virtual`, which means that when they are redefined by a derived class, this new definition will be used, even for pointers to base class objects.
- Some of these virtual functions, those whose declarations are followed by `= 0` are *pure virtual*, which means they must be redefined in a derived class.
  - Any class that has pure virtual functions is called "abstract".
  - Objects of abstract types may not be created — only pointers to these objects may be created.
- Functions that are specific to a particular object type are declared in the derived class prototype.

23.12 A Polymorphic List of Polygon Objects

- Now instead of two separate lists of polygon objects, we can create one "polymorphic" list:

```
std::list<Polygon*> polygons;
```

- Objects are constructed using `new` and inserted into the list:

```
Polygon *p_ptr = new Triangle( .... );
polygons.push_back(p_ptr);
p_ptr = new Quadrilateral( ... );
polygons.push_back(p_ptr);
Triangle *t_ptr = new Triangle( .... );
polygons.push_back(t_ptr);
```

  Note: We've used the same pointer variable (`p_ptr`) to point to objects of two different types.

23.13 Accessing Objects Through a Polymorphic List of Pointers

- Let's sum the areas of all the polygons:

```
double area = 0;
for (std::list<Polygon*>::iterator i = polygons.begin(); i!=polygons.end(); ++i)
   area += (*i)->Area();
```

  Which `Area` function is called? If `*i` points to a `Triangle` object then the function defined in the `Triangle` class would be called. If `*i` points to a `Quadrilateral` object then `Quadrilateral::Area` will be called.

- Here's code to count the number of squares in the list:

```
int count = 0;
for (std::list<Polygon*>::iterator i = polygons.begin(); i!=polygons.end(); ++i)
   count += (*i)->IsSquare();
```

  If `Polygon::IsSquare` had not been declared `virtual` then the function defined in `Polygon` would always be called! In general, given a pointer to type `T` we start at `T` and look "up" the hierarchy for the closest function definition (this can be done at compile time). If that function has been declared `virtual`, we will start this search instead at the actual type of the object (this requires additional work at runtime) in case it has been redefined in a derived class of type `T`.

- To use a function in `Quadrilateral` that is not declared in `Polygon`, you must "cast" the pointer. The pointer `*q` will be NULL if `*i` is not a `Quadrilateral` object.

```
for (std::list<Polygon*>::iterator i = polygons.begin(); i!=polygons.end(); ++i) {
   Quadrilateral *q = dynamic_cast<Quadrilateral*> (*i);
   if (q) std::cout << "diagonal: " <<  q->LongerDiagonal() << std::endl;
}
```

23.14 Exercise

What is the output of the following program?

```
class Base {
 public:
  Base() {}
  virtual void A() { cout << "Base A\n"; }
  void B() { cout << "Base B\n"; }
};

class One : public Base {
public:
  One() {}
  void A() { cout << "One A\n"; }
  void B() { cout << "One B\n"; }
};
class Two : public Base {
public:
  Two() {}
  void A() { cout << "Two A\n"; }
  void B() { cout << "Two B\n"; }
};

int main() {
  Base* a[3];
  a[0] = new Base;
  a[1] = new One;
  a[2] = new Two;
  for (unsigned int i=0; i<3; ++i) {
    a[i]->A();
    a[i]->B();
  }
  return 0;
}
```